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LIGHT METALS

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

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EDITORIAL OPINION

Roll Up! Roll Up!

FESTIVITIES during Bank Holidays on Hampstead Heath were, in pre-war days, enlivened by the cries of the hoopla and coconut-shie men enjoining merry-makers to pay their money and try their skill at winning for nothing those shiny new watches or milky nuts that no amount of money can purchase nowadays. During the period which began on May **30**, however, and will end on July 14, Messrs. Selfridge, Ltd., need no such whippers-in to attract sightseers to the Aluminium Exhibition, for, in all, these average some 11,000 per day.

Possibly we may be considered as prejudiced witnesses, for the subject matter of the display is very near to our hearts, and care was taken from the very first to ensure that presentation should be as faultless as humanly possible. Nevertheless, we believe it is true to say that every one of those responsible for the organization of "Aluminium—from War to Peace" has been more than gratified by the reception accorded to it by the public.

No secret formula or magic spell is responsible for the success achieved: continuity of presentation and singleness of aim are the factors to which this must be attributed, and the Exhibition Committee and the Management and staff of Messrs. Selfridge are to be congratulated on their insistence in maintaining the rigid standard first laid down during initial discussions on the project. In "Aluminium—from War to Peace," a very great service has been rendered to aluminium users throughout this country, to export interests, and to buyers from the Dominions and abroad. When its allotted time in London has elapsed, it is hoped that those in the provinces may have an opportunity of visiting the exhibition and of expressing in turn, as they will, the enthusiasm aroused at the initial showing, for, truly, it may be seen a dozen times, and yet not lose in novelty.

All at Sea

AT this late date in the history of metals (and of light and ultra-light metals in particular), need no longer exists to refer again to the essential fallibility of pure laboratory tests for determining resistance to corrosion in service. On factory roofs and laboratory window-sills, in the chief chemist's bathroom, and in selected spots at less-popular seaside resorts, we invariably find a neat array of metal strips or panels suitably arranged to obtain maximum benefit from the sporadic bursts of sunshine experienced in these islands; from fumes produced by laboratory assistants in a hasty attempt to remove excess acid with ammonia, from steam arising from the statutory "five inches" in the morning tub, or from corrosive media invariably present in inshore waters. Railway tunnels, domestic geysers, even the common chimney, too, are all apt to be found carrying these mysterious tablets: the country is plastered with such specimens, in every conceivable metal and alloy, treated at its surface with every known concoction or by every known process devised by man or ordained by providence.

Simultaneously, at selected centres, alternating dip apparatus or the conventional humidity chamber or salt spray will be found in full blast; yet the grievous fact must be admitted, these combined operations, in very rare instances only, achieve more than mediocre success, for an alloy which appears to stand up satisfactorily to the ozone and salt-laden air of Southend is quite likely to fail if exposed to the effluent from the Yellow River, whilst the specimen which corrodes like fun in the flue of the household geyser withstands most creditably the worse onslaughts to which it may be subjected in the gasworks. High-purity magnesium ingot can be stockpiled in the open air for months on end in the pure dry air of Central Canada. Similar metal behaves remarkably well even in our own moisture-laden, smoky atmosphere, but few magnesium founders would agree to take this fact at its face value and leave their metal lying for long in a nearby field.

It is because of this that, nowadays, final judgment as to the suitability of a material for a given purpose is invariably based on an actual service test. Wrong conclusions, however, must not be drawn: laboratory tests, as we all

BRITISH AIRCRAFT EXHIBITION

WE would direct readers' attention to the comprehensive display of British aircraft which is being exhibited on the John Lewis site in Oxford Street, London, under the auspices of the Ministry of Aircraft Production, with the assistance of the Ministry of Information.

ALUMINIUM—FROM WAR TO PEACE

IN response to numerous requests from public, commercial and industrial interests, Messrs. Selfridge have arranged that the exhibition "Aluminium—from War to Peace," now being held at their store in Oxford Street, will continue until Saturday, July 14.

know, have, in the past, yielded data of infinite value to the pure research man and to the industrialist. What might be termed "general" exposure tests, again, have yielded further information confirming, or sometimes conflicting with, the results of experiments *in vitro*: as is well known, the final service test is frequently assessed in the light of these preliminary investigations.

In connection with the use of light and ultra-light alloys under marine conditions, corrosion phenomena have frequently given rise to grave doubts, or even to violent controversy. The truth of this statement may be proved by reference to certain experiences recorded in the Pacific war zone.

It is against this general background that we draw attention to the opening account in this issue of "Light Metals." Here is described how a ship set sail, gaily festooned with some **150** castings of various types in different aluminium and magnesium alloys; all had been variously treated, and distribution and controls were so arranged that some true opinion, it was hoped, could be formed of the behaviour of the alloys on re-examination after the vessel had returned to port.

It so happened, however, that the voyage was a little more protracted than had been expected, and many months elapsed before the trial castings were seen again. They had been exposed to almost every type of hazard that every sea and ocean could summon up.

It is not our purpose here to attempt a detailed analysis of the results; these will be found, summarized rather briefly, it is true, in the record to which we have referred. We would point out, however, that photographs of all the surviving specimens (and some, unfortunately, were lost in transit) have been reproduced in order to demonstrate quite conclusively that all too much of the loose talk regarding vulnerability of aluminium and magnesium to sea-water attack is based on very insecure grounds. Certainly, some specimens have been markedly corroded; however, we are left wondering what would have happened, say, to mild-steel test pieces exposed under similar conditions in the same sites.

To those who still doubt the wisdom of exposing light alloys to the perils of the sea (and some such doubters still roam abroad), we recommend at least a close study of these illustrations. The original photographs may, if necessary, be consulted in the files of the Aluminium Development Association.

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"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 ALLOYS UNDER MARINE CONDITIONS

Brief Note Summarizing Results of Exposure Tests on a Range of Small Castings in Light and Ultra-Light Alloys, Subjected to Different Protective Treatments, During a Prolonged Voyage with Wide Variations of Climate and Corrosion Hazard

PERHAPS the most frequent objection put forward by engineers and designers who should be interested in the structural potentialities of light metals is that "they corrode." One is tempted to reply that steel rusts, and that its effective use often depends upon suitable protective treatment such as plating, or, more simply, red-lead painting. It is, indeed, not far from the truth to say that there is some corrosion problem associated with the use of all commercial metals. Why, then, should the light alloys of aluminium, and the ultra-light alloys of magnesium be picked out for special condemnation?

It has been pointed out that a history of the engineering uses of aluminium would be of great interest—a history detailing the failures as well as the successes; in the absence of such an account, one may only suspect that amongst the failures would be found ill-conceived attempts to use untreated aluminium in situations incompatible with its chemical properties. During what might be described as the aluminium peace years—that is, from 1919 to 1939—developments in corrosion-resistant treatments and in the alloys themselves took place that should have negatived active opposition to their use. Perhaps the best example of such development in each case is the anodic oxidation process and the magnesium - aluminium alloys respectively. Anodic oxidation is accepted by the engineering world as being the surest protection scheme to be specified, whilst the name "Birmabright," and those of alloys like it, are synonymous with corrosion resistance. This is all well known, of course, to aeronautical engineers, but still the tradition of extreme corrodibility persists in the engineering world at large.

Magnesium-base alloys, however, have not achieved their coming-of-age in this respect. Not only have they been used too often

(Continued on page 314)

Plate I

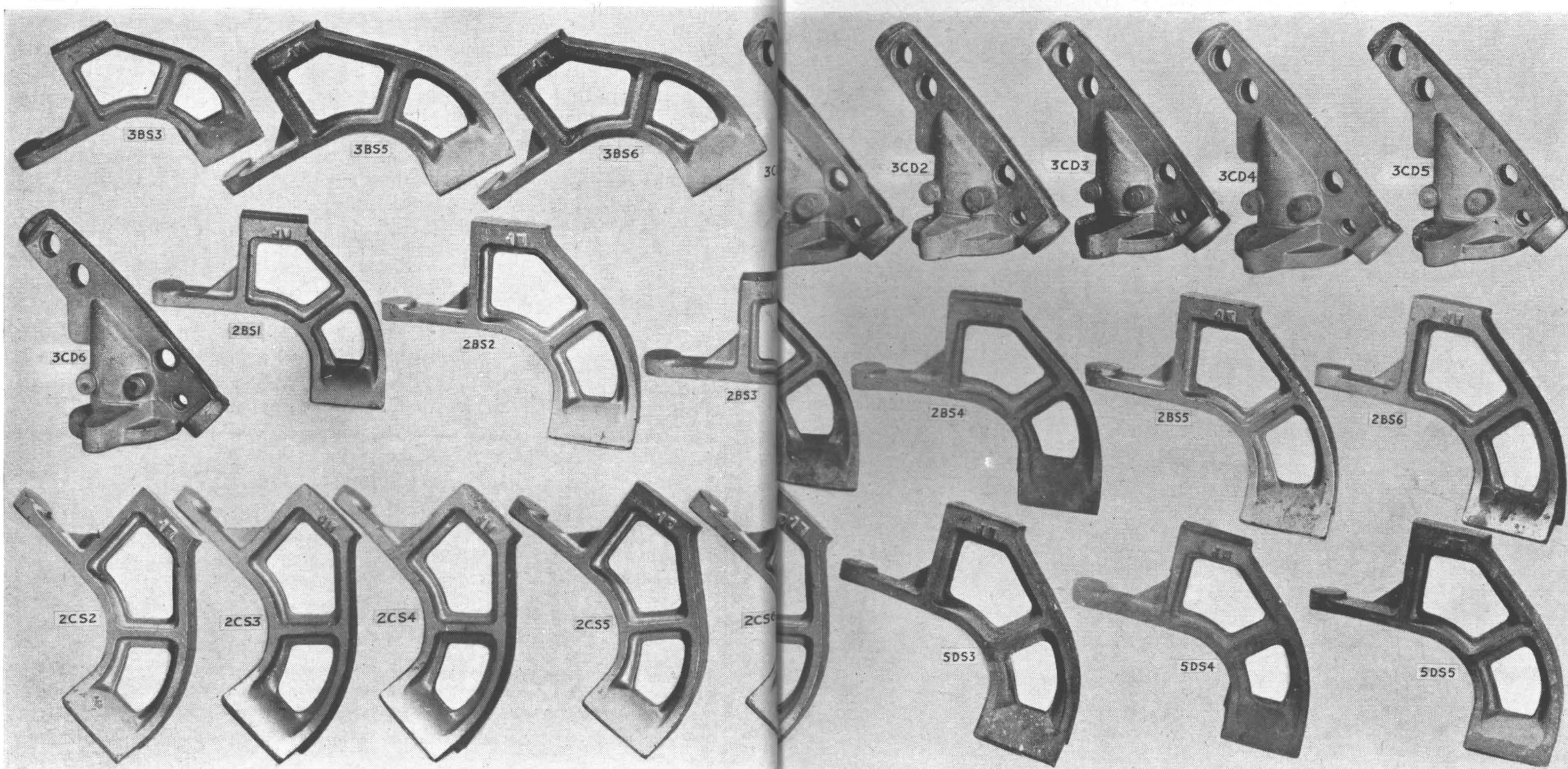
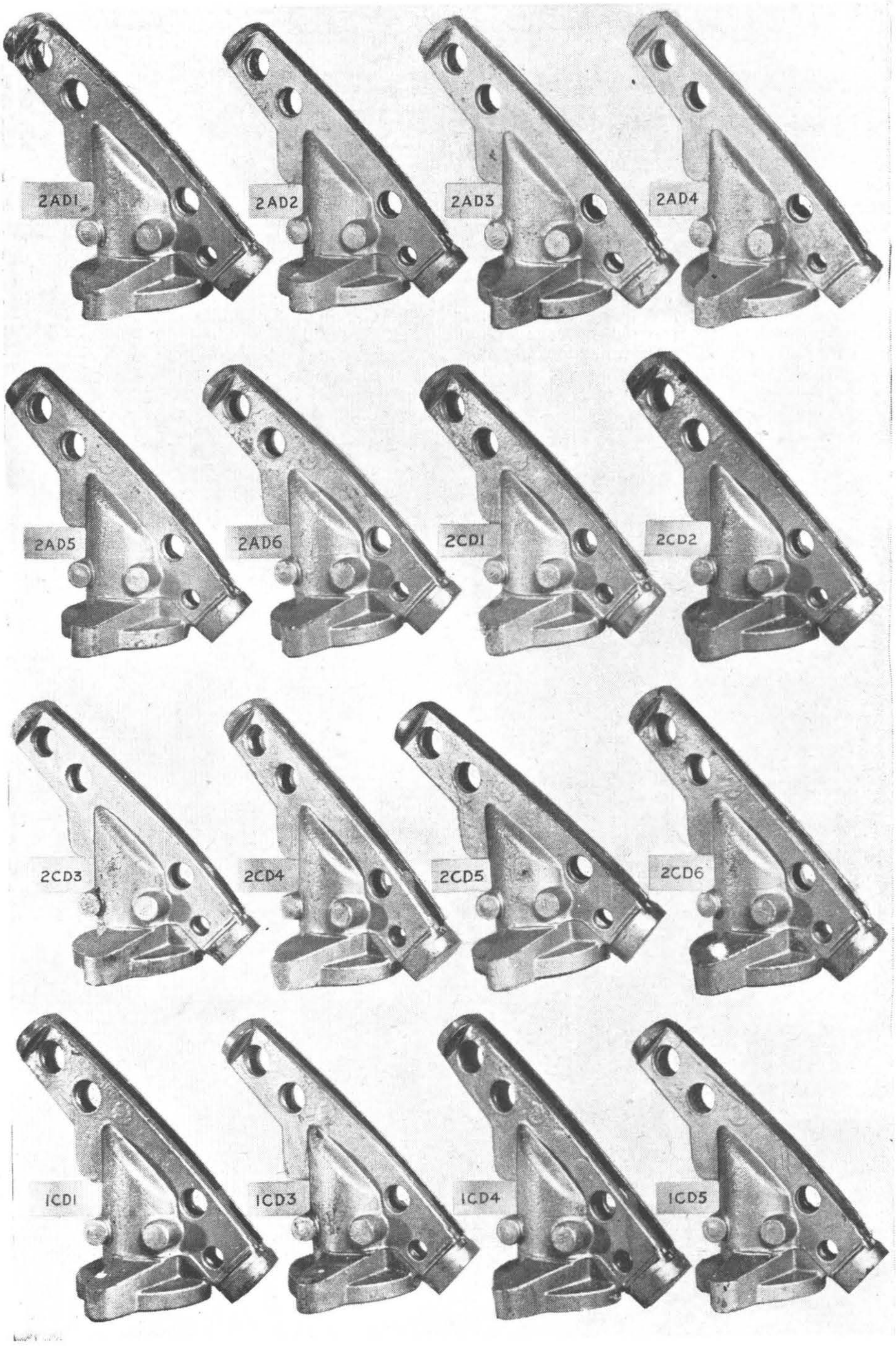


Plate I

Plate 2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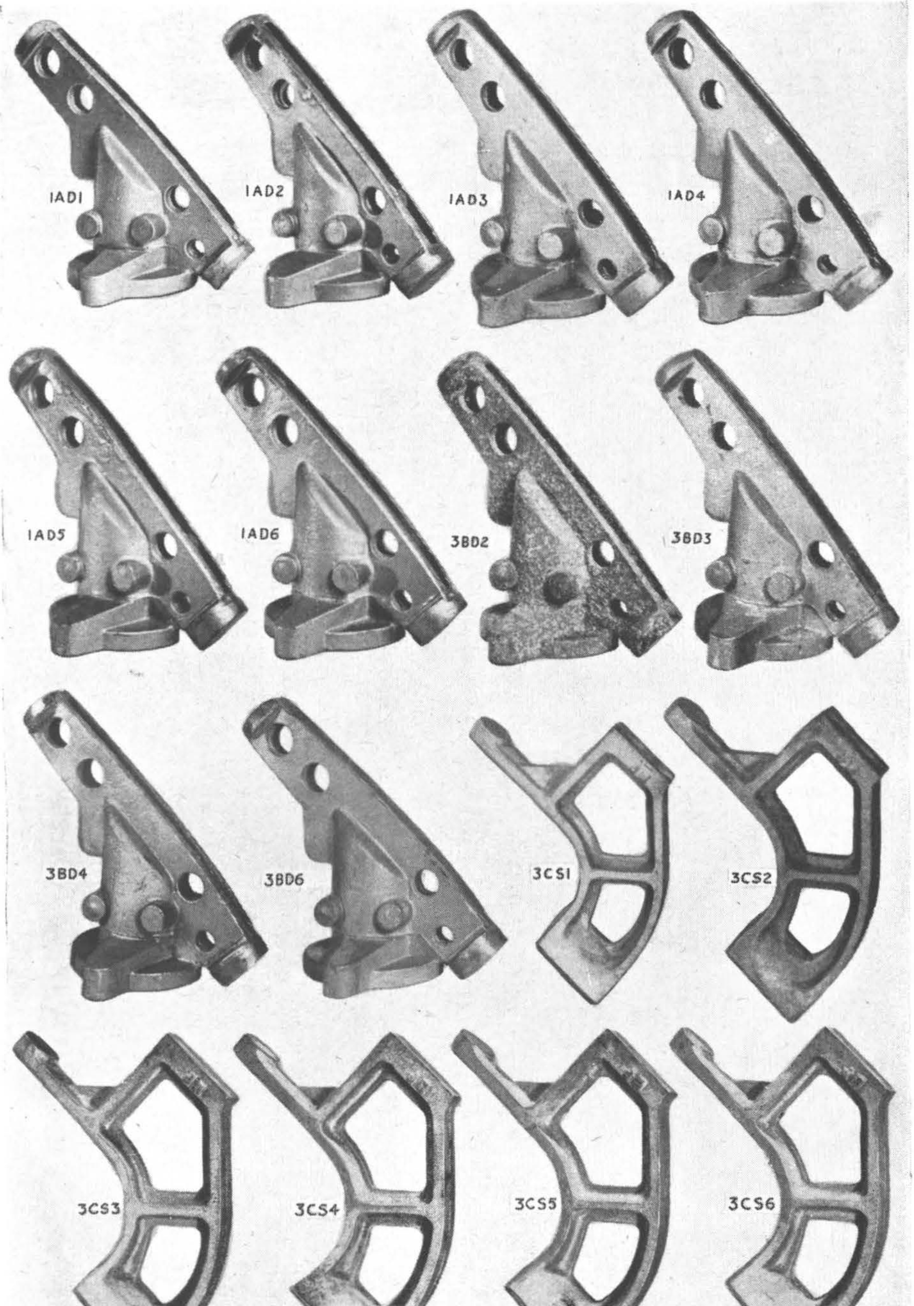
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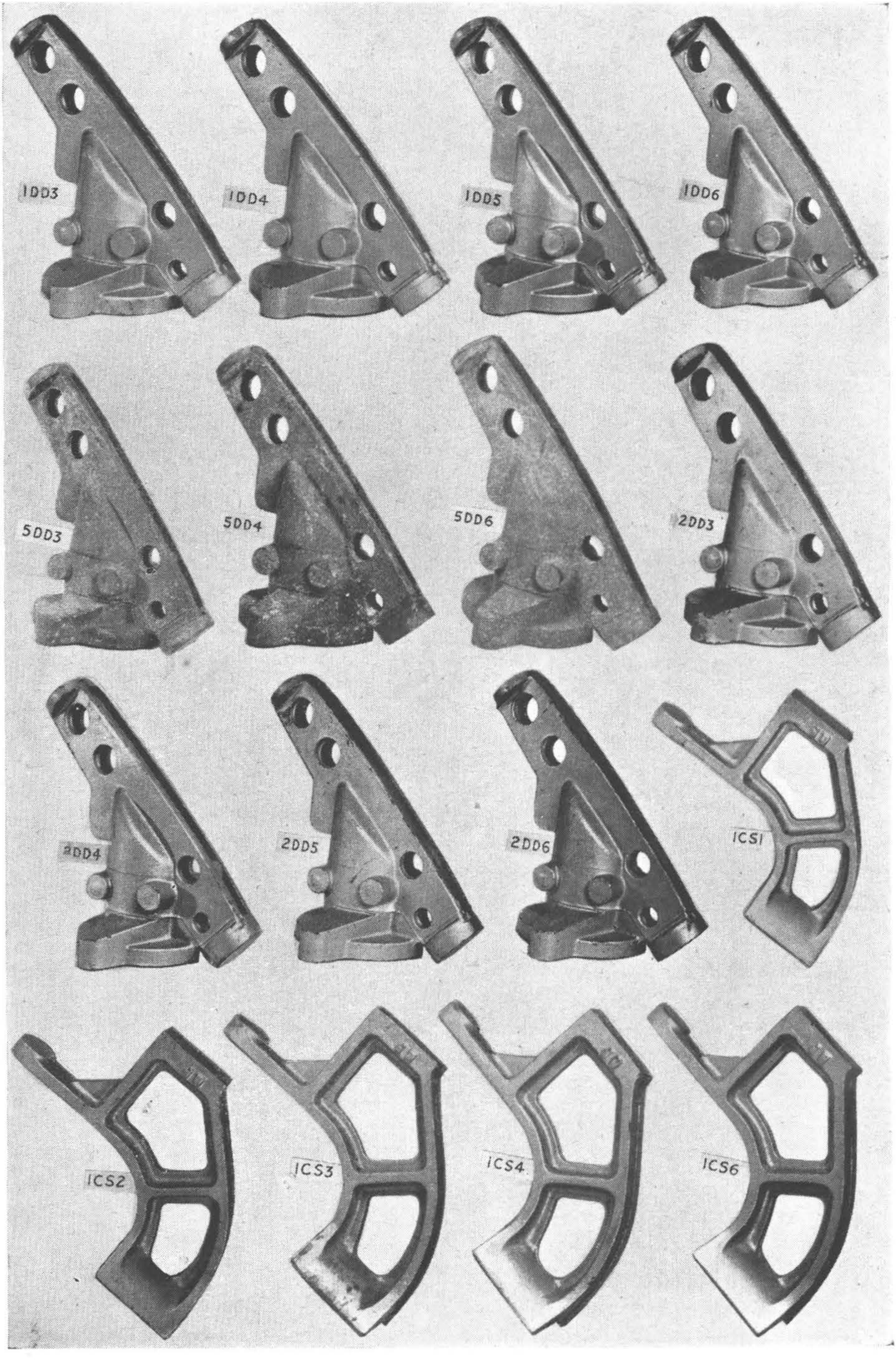
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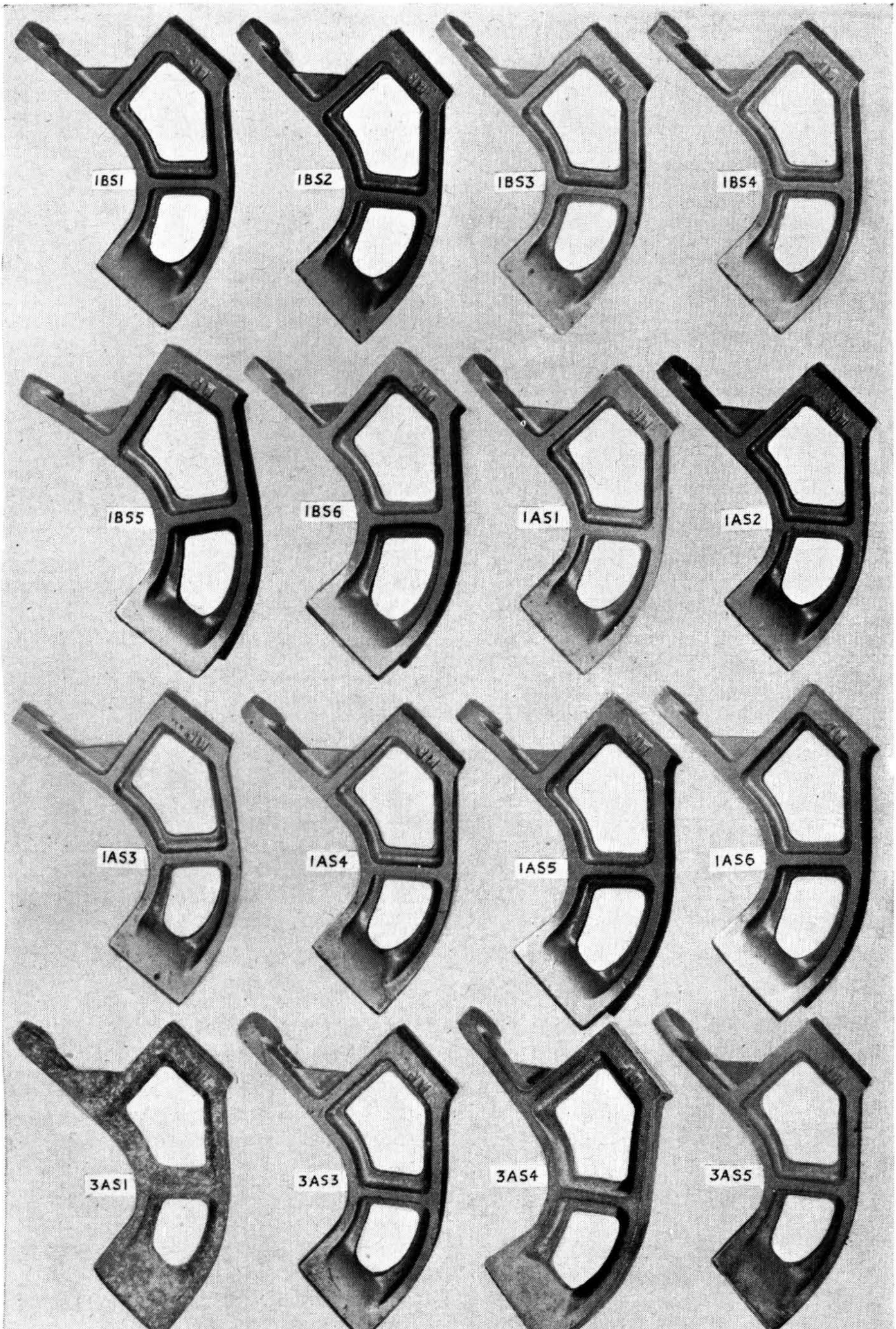
Plate 5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solely (and often unwillingly) because of low specific gravity, and in spite of alleged poor corrosion resistance, but they are often frankly thought of as being purely aircraft materials having meagre post-war commercial potentialities.

It can be agreed that magnesium is chemically active, but its position at the active end of the electro-chemical series has influenced too much, it is suggested, the thoughts of many writers on magnesium. Again, the adversely critical views of engineers on magnesium alloys are too often based on what they remember of their schoolboy's elementary chemistry. Magnesium is almost impossible to use, they argue, for even boiling water is decomposed by it (forgetting that such knowledge is based upon the reaction of pure metallic magnesium in the form of powder or thin ribbon, which is obviously a very different matter from the oxidation reactions of comparatively massive magnesium alloy castings or forgings).

It is, of course, true that early productions of magnesium castings were often contaminated by flux inclusions, but the trouble can now be said to have been eliminated. Such teething troubles are unfortunately, and, it may be suggested, unreasonably, remembered now the child has grown up. Let them be forgotten, from now on.

Authorities vary considerably in the emphasis they put on the corrodibility of magnesium alloys. Carpenter and Robertson in "Metals" (Oxford University Press, 1939) list amongst "the most notable characteristics of magnesium . . . its chemical activity which gives it a low resistance to corrosion"; while, on the other hand, Haughton and Prytherch: "Magnesium and its Alloys" (H.M.S.O., 1937), although stating that the reactive nature of the metal causes it to corrode very readily, record the interesting fact "that a piece of magnesium alloy and a piece of steel were left exposed on a window-sill for about a year. At the end of this period the magnesium alloy was only lightly coated with corrosion product, while steel was covered with a thick layer of rust."

Laboratory corrosion tests often seem merely to confirm the fact that magnesium alloys corrode, whilst, indeed, it is doubtful if any correlation exists between the results of salt spray, intermittent immersion, constant immersion and service conditions. Laboratory tests may serve to make comparisons between the resistance of differently treated test samples, the resultant order of merit finding reflection in the gradation of practical results to be expected when the same finishes are used under service conditions. It is felt, however, that, too often, the experimental results appear to be so poor that it is not likely that the material would ever get as far as practical applications.

Now whatever be the truth of the corrodibility of light alloys under suitable service conditions, it may be repeated once more that, in the application of both aluminium-base and magnesium-base alloys, there is a minimum protection scheme to be specified. Anodic oxidation has been mentioned in the case of aluminium alloys, whilst the standard treatment for magnesium alloys is the one known as R.A.E. 30-min. chromate treatment. Although these treatments are protective to some extent, their chief value is in the fact that they act as key films for subsequent painting.

Many paint schemes have been proposed, and, indeed, some are sufficiently standardized to be included in the D.T.D. series of Ministry of Aircraft Production specifications. Great interest centres around lacquers based upon synthetic resins at the present time, as is

Table 1.—Details of Samples Tested.

No.	Plate	Alloy	Type of Casting	Treatment	Lacquer Scheme
1AS 1–6	5	D.T.D. 133b	Sand	Anodized	Stoving
2AS 1–6	7	D.T.D. 133b	Sand	Anodized	Air-drying
3AS 1–6	5	D.T.D. 133b	Sand	Nil	Nil
1AD 1–6	3	D.T.D. 133b	Die	Anodized	Stoving
2AD 1–6	2	D.T.D. 133b	Die	Anodized	Air-drying
3AD 1–6	6	D.T.D. 133b	Die	Nil	Nil
1BS 1–6	5	D.T.D. 424	Sand	Anodized	Stoving
2BS 1–6	1	D.T.D. 424	Sand	Anodized	Air-drying
3BS 1–6	1	D.T.D. 424	Sand	Nil	Nil
1BD 1–6	6	D.T.D. 424	Die	Anodized	Stoving
2BD 1–6	7	D.T.D. 424	Die	Anodized	Air-drying
3BD 1–6	3	D.T.D. 424	Die	Nil	Nil
1CS 1–6	4	D.T.D. 165	Sand	Anodized	Stoving
2CS 1–6	1	D.T.D. 165	Sand	Anodized	Air-drying
3CS 1–6	3	D.T.D. 165	Sand	Nil	Nil
1CD 1–6	2	D.T.D. 165	Die	Anodized	Stoving
2CD 1–6	2	D.T.D. 165	Die	Anodized	Air-drying
3CD 1–6	1	D.T.D. 165	Die	Nil	Nil
1DS 1–6	6	D.T.D. 136a	Sand	Chromated	Stoving
2DS 1–6	7	D.T.D. 136a	Sand	(R.A.E. 30-minutes)	Air-drying
5DS 1–6	1	D.T.D. 136a	Sand	Nil	Nil
1DD 1–6	4	D.T.D. 136a	Die	Chromated	Stoving
2DD 1–6	4	D.T.D. 136a	Die	(R.A.E. 30-minutes)	Air-drying
5DD 1–6	4	D.T.D. 136a	Die	Nil	Nil

Plate 6

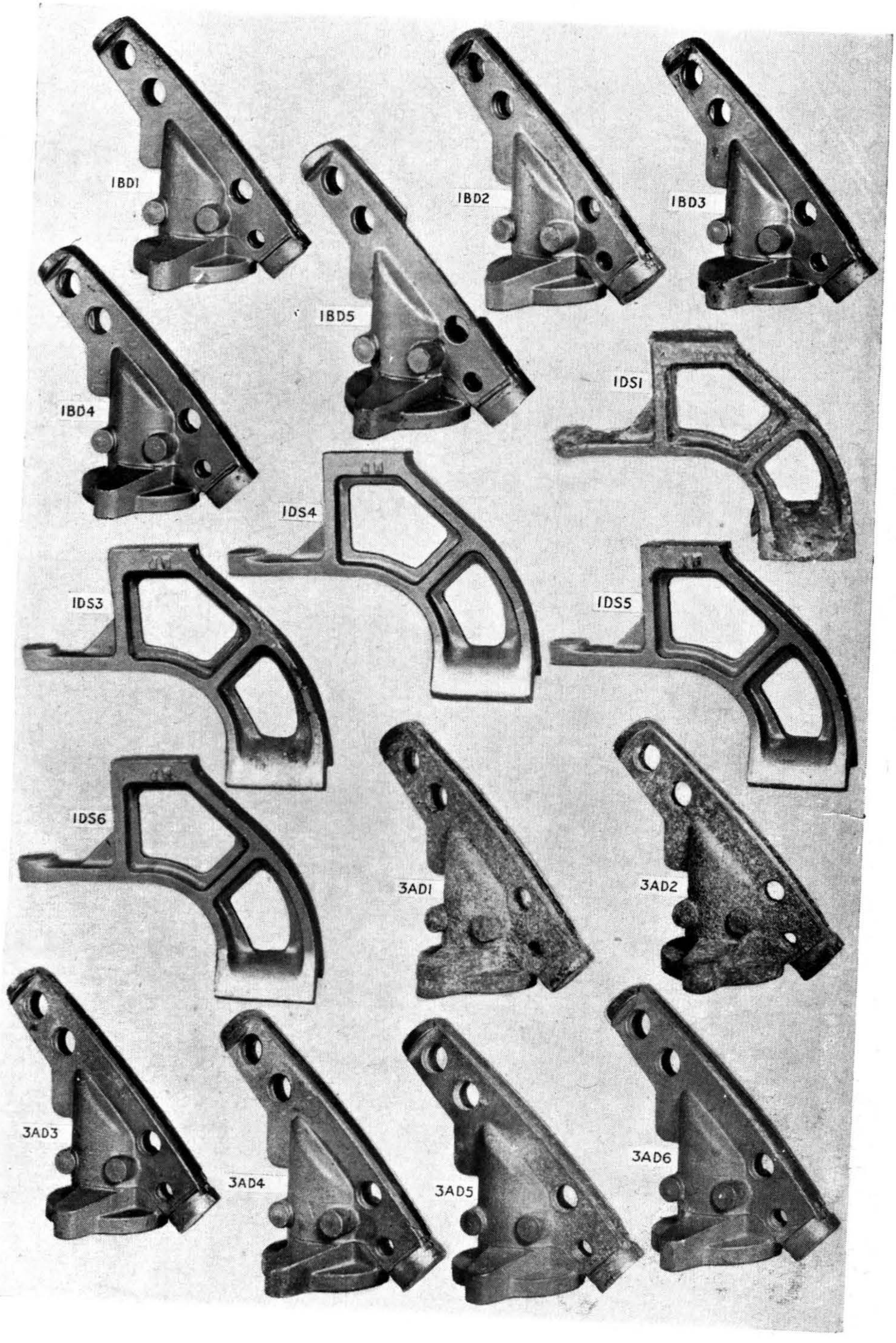
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Plate 7

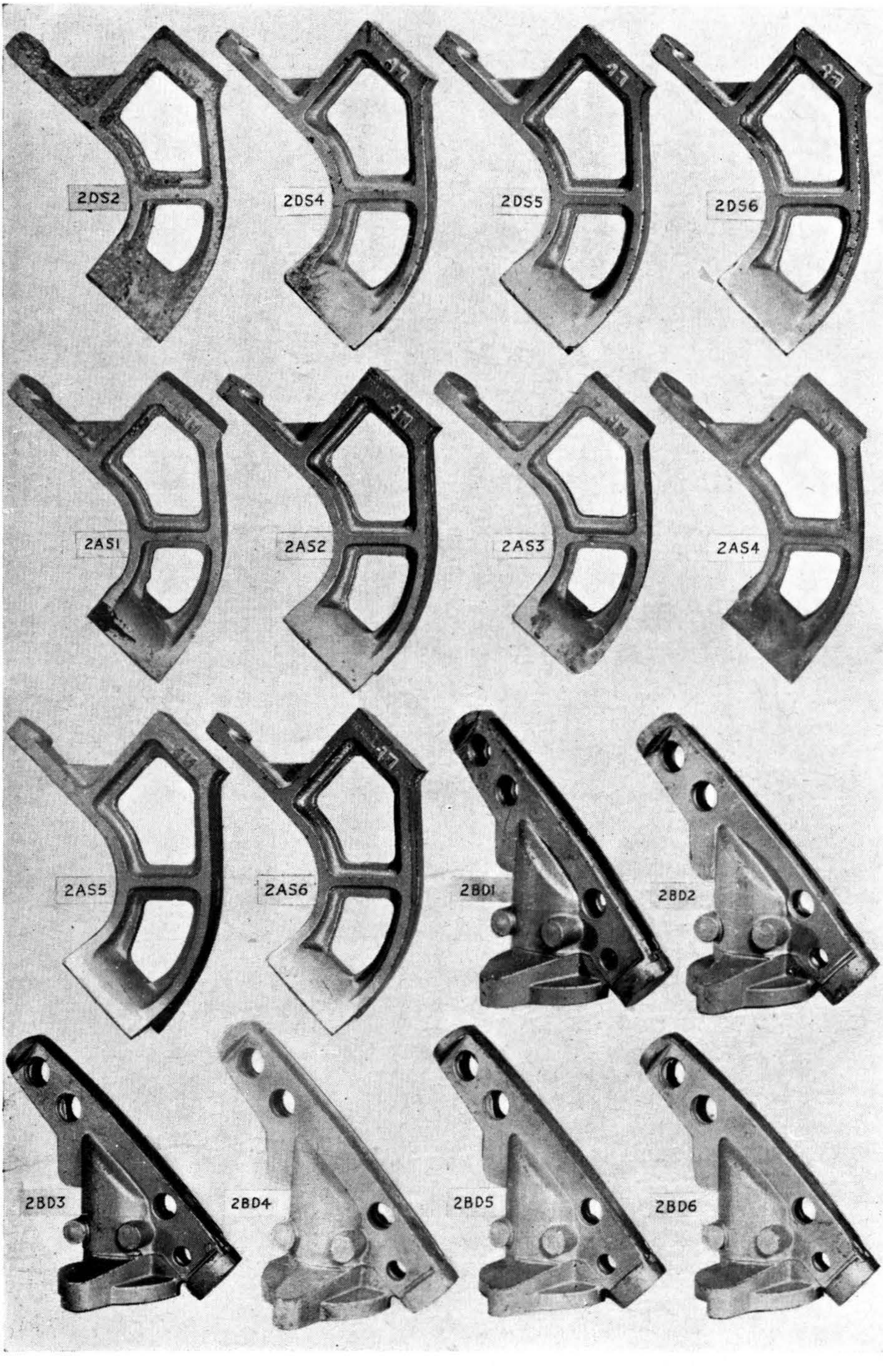
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Table 2.—Distribution of Specimens.

Exposed				Sheltered Deck				Sheltered			
Stoving	Plate	Air-drying	Plate	Stoving	Plate	Air-drying	Plate	Stoving	Plate	Air-drying	Plate
Sand cast		Sand cast		Sand cast		Sand cast		Sand cast		Sand cast	
1AS 1 and 2	5	2AS 1 and 2	7	1AS 3 and 4	5	2AS 3 and 4	7	1AS 5 and 6	5	2AS 5 and 6	7
1BS 1 and 2	5	2BS 1 and 2	1	1BS 3 and 4	5	2BS 3 and 4	1	1BS 5 and 6	5	2BS 5 and 6	1
1CS 1 and 2	4	2CS 1 and 2	1	1CS 3 and 4	4	2CS 3 and 4	1	1CS 5 and 6	4	2CS 5 and 6	1
1DS 1 and 2	6	2DS 1 and 2	7	1DS 3 and 4	6	2DS 3 and 4	7	1DS 5 and 6	6	2DS 5 and 6	7
Die cast		Die cast		Die cast		Die cast		Die cast		Die cast	
1AD 1 and 2	3	2AD 1 and 2	2	1AD 3 and 4	3	2AD 3 and 4	2	1AD 5 and 6	3	2AD 5 and 6	2
1BD 1 and 2	6	2BD 1 and 2	7	1BD 3 and 4	6	2BD 3 and 4	7	1BD 5 and 6	6	2BD 5 and 6	7
1CD 1 and 2	2	2CD 1 and 2	2	1CD 3 and 4	2	2CD 3 and 4	2	1CD 5 and 6	2	2CD 5 and 6	2
1DD 1 and 2	4	2DD 1 and 2	4	1DD 3 and 4	4	2DD 3 and 4	4	1DD 5 and 6	4	2DD 5 and 6	4

somewhat natural. Both stoving and air-drying schemes are in use.

An interesting field test in which representative light alloys, both aluminium-base and magnesium-base, were submitted to exposure on board ship has recently been carried out by Magnal Products Limited, in the course of tests on lacquers developed by that company for the protection of light alloys.

Sand and die-castings in the following specifications, R.R. 50 (D.T.D. 133b), D.T.D. 424, "Birmabright" (D.T.D. 165), and "Elektron A.Z. 91" (D.T.D. 136a), were exposed in various locations on board a tanker. Each set, except one, of aluminium alloy castings in each alloy group were anodized, and further protected with one coat of zinc chrome air-drying or stoving primer having a synthetic resin base followed by one coat of aluminium pigmented synthetic resin base air-drying or stoving top coat; similarly, the magnesium alloy castings were chromated, and followed by one of the schemes detailed above. A complete set of castings in each alloy group were allowed to remain in the "as-cast" condition, partly in order to act as a control set, and partly to determine the inherent corrosion resistance of the alloys under test.

Table 1 gives particulars of samples treated together with reference numbers serving as index to the illustrations.

Table 2 shows the ship positions in which the samples were exposed. Two specimens of each alloy group were tested on the deck (exposed position), and in the chief engineer's office (sheltered deck position), and in the engine room (sheltered position).

The samples were subjected to extremes of temperature during the 13 months they were at sea, for the journey was as follows: England—New York—Panama—Pacific Ocean—Falkland Isles — Antarctic — South Africa — Persia — Australia—Panama—Curaçao—England.

The samples after test were examined visually, which is perhaps not a very satisfactory method of assessing corrosion test results in general, but serves to show gradation of results of casting protection in an extended test as this. The full value of the test was probably lost in so far as some of the samples were really tested to destruction and no information was obtained on the length of useful life, for obvious reasons. Many criticisms may no doubt be made of the test, but the fact remains that interesting and instructive results were obtained. The illustrations should be carefully studied.

General conclusions may be summarized: Birmabright was far and away the best alloy for corrosion resistance. The alloys RR 50 and D.T.D. 424 were approximately equal, whilst the magnesium alloy came last. But even although the samples fell in this expected order there were many surprises, and it is suggested that a false impression would be obtained if this statement were accepted at its face value. For, with reference to location, protected magnesium alloy stood up surprisingly well in the sheltered deck position and protection was adequate for use in sheltered positions. It may be concluded that lacquered Birmabright, RR 50 and D.T.D. 424 are suitable for exterior and interior use, whilst non-lacquered aluminium alloys, but especially

Table 3.—Distribution of Control "As-cast" Specimens.

Exposed				Sheltered deck				Sheltered			
Sand cast	Plate	Die cast	Plate	Sand cast	Plate	Die cast	Plate	Sand cast	Plate	Die cast	Plate
3 AS 1 and 2	5	3 AD 1 and 2	6	3 AS 3 and 4	5	3 AD 3 and 4	6	3 AS 5 and 6	5	3 AD 5 and 6	6
3 BS 1 and 2	1	3 BD 1 and 2	3	3 BS 3 and 4	1	3 BD 3 and 4	3	3 BS 5 and 6	1	3 BD 5 and 6	3
3 CS 1 and 2	3	3 CD 1 and 2	1	3 CS 3 and 4	3	3 CD 3 and 4	1	3 CS 5 and 6	3	3 CD 5 and 6	1
5 DS 1 and 2	1	5 DD 1 and 2	4	5 DS 3 and 4	1	5 DD 3 and 4	4	5 DS 5 and 6	1	5 DD 5 and 6	4

Note.—It will be observed from the illustrations that unfortunately some of the specimens are missing; perhaps this is only to be expected considering the nature of the test.

Birmabright, and lacquered magnesium alloy are suitable for interior fittings.

The results showed one further unexpected property of lacquer films. It is broadly accepted that air-drying lacquers are markedly inferior to stoving lacquers, and yet the tests show under these conditions that an air-drying lacquer exhibited but a slight tendency to flake, and hence showed better adhesion and corrosion resistance.

The practical lesson may be gathered from this extensive field test that light alloys should be tested out under actual service conditions, for until that is done, suitability for purpose and choice of protective scheme cannot be forecast. Who would have said that magnesium-alloy castings even protected with the best protective methods known at present would be adequate for use in the marine atmosphere of a ship's engine-room?

Heat Treatment of MAGNESIUM-ALLOY CASTINGS

Concluding from "Light Metals," 1945/8/172, a Comprehensive Survey of the Founding of Magnesium Alloys. The Technique and Plant Requirements for the Heat-treating of Ultra-light-alloy Castings are Discussed, and Reference is Made to the Use of Inert Atmospheres

IT will have been inferred from preceding articles that the usual magnesium alloys are those which contain about 8 to 11 per cent. of aluminium and small amounts of zinc in the order of about 1 per cent. In addition, normal alloys contain a small percentage of manganese to improve corrosion resistance, but this constituent does not appear to take part in the structural changes due to heat treatment.

The principle of heat treatment of magnesium alloys is to obtain a solution of an intermetallic constituent, which, separating out during solidification and natural cooling, is taken into solid solution by means of thermal treatment at a temperature a little below that at which the constituent is actually molten. It is not necessary, for our purpose, to review the various estimates that appear in the literature on the actual percentage solubility of the aluminium-magnesium compound at room temperature and at temperature of complete solidification. These estimates are, in fact, widely different.

The effect of the heat treatment described, more accurately termed "solution treatment," is to improve the mechanical properties, an appreciable enhancement of tensile strength and ductility being obtained. The 0.1 per cent. proof stress and Brinell hardness are but slightly affected. As indicated, the temperature of solution treatment is about 430 degrees C., as the melting point of the constituent which is to be dissolved to 435 degrees C.

The physical form and size of the eutectic constituent is such that comparatively long periods at treatment temperature are required to produce adequate solution. In practice complete solution is seldom achieved. Castings so treated may be further heated at a temperature of 250 degrees C. to give a further improvement in tensile strength. This condition is known as "fully heat treated," or is described as being "solution treated and aged"; in this condition the 0.1 per cent. proof stress and Brinell hardness are increased; the elongation, however, is decreased.

British aircraft designers usually specify magnesium-alloy castings to be either in the as-cast or solution-treated condition, in sharp distinction to American requirements which, almost without exception, are for fully heat-treated castings; no explanation can be offered for this difference in viewpoint.

The thermal treatment known as "annealing" is sometimes practised to relieve casting stresses, but in this case, in which a low temperature treatment is given to as-cast material, no improvement in mechanical properties is obtained. The chief advantage of annealing lies in the fact that castings of thin section are not so likely to distort during subsequent machining operations during which the cast skin is removed. It should be mentioned that the DTD specifications covering solution-treated magnesium-alloy castings and fully heat-treated magnesium-alloy castings are numbered **281**, **289** and **285** respectively. The alloys to the specification DTD **59A** and **136A** are the as-cast forms of these heat-treated alloys. For the purpose of comparison the following table is given to show the specification requirements:—

As cast			Solution treated			Solution treated and aged		
	U.T.S. tons/sq. in.	Elong. %		U.T.S. tons/sq. in.	Elong. %		U.T.S. tons/sq. in.	Elong. %
DTD 59A	9	2	DTD 289	13	6	—	—	—
DTD 136A	8	—	DTD 281	13	4	DTD 285	13	1

The method by which heat treatment is performed will now be described.

The simplest method of heating magnesium-alloy castings to the solution-treatment temperature is by the use of the fused-chromate salt bath, in which a mixture of potassium dichromate and sodium dichromate is heated to cause melting. The design of equipment is, of course, similar to that used for the treatment of aluminium alloys in normalizing. It should be emphasized as strongly as possible, however, that the *salts used for aluminium treatment react explosively with magnesium alloys, and must not on any account therefore be used in conjunction with the ultra-light alloys*. The salt bath may be heated by gas, oil, electricity or solid fuel, the furnace design and flue arrangements being such that there is no appreciable temperature gradient within the bath. The chromate salt bath is, further, extremely efficient in heat exchange.

It should be noted that magnesium-alloy castings are of lower specific gravity than the molten salt and, therefore, they float. To overcome this difficulty, castings to be treated are loaded into a perforated metal basket, the castings being, in the simplest cases, secured by iron wire.

It is often found, however, that other means of sinking have to be adopted, for at the temperature of treatment the material has little mechanical strength and is easily distorted. In such cases it is necessary to make use of jigs designed to support those sections of a casting which might warp on accidental stressing during the period of immersion in the salt. Iron jigs may be used on the ground of cheapness, but, as they will materially increase the weight of charge to be loaded, it is preferable to use aluminium jigs. The specific gravity of aluminium jigs is sufficiently higher to effect sinking. The salt-bath method, then, is simple, thermally efficient, and comparatively inexpensive in equipment costs. Practical disadvantages are that the castings, when removed from the bath, are, of course, covered with a film of solidified chromate salts which have to be removed by washing. The drag-out loss is, therefore, considerable, but above all there is the danger of the incidence of dermatitis associated with chrome compounds. The method is covered by British patents.

It was long thought that the salt-bath method provided the only satisfactory means of heat treating magnesium alloys, for, as they were treated virtually in absence of air, no oxidation could take place. This oxidation was feared to be an ever present possibility if air-circulating ovens were used. It was found, however, that provided a suitably controlled temperature was maintained within the oven, standard equipment could be used. The principles of inert atmospheres—that is, inert as far as magnesium is concerned—present two satisfactory alternatives. First, an atmosphere may be used from which oxygen and moisture have been removed, and second, an atmosphere in which sulphur dioxide or carbon dioxide is present in sufficient quantities to restrain oxidation. To make use of the first principle it is necessary to use gas-burning apparatus giving a mixture of gases resulting from the incomplete combustion of town gas, the gases being nitrogen, carbon monoxide and carbon dioxide. The water present in this gas is removed by passing through some dehydrating substance. This method is in production use, but requires constant analytical checks to ensure absence of free oxygen. The presence of even 1 or 2 per cent. of this element is sufficient to cause violent oxidation with consequent scrapping of the work. The use of incompletely burnt gas has been applied both to electric and gas-fired ovens.

The second method, consisting of the introduction of carbon dioxide or sulphur dioxide, necessitates the use of a cylinder supply of these gases, although a supply of sulphur dioxide may be obtained ***in situ*** by the introduction to the charge of iron pyrites decomposing on heating to give sulphur dioxide. These methods may again be applied to normal equipment fired by electricity or gas. There is need for practical investigation to ascertain just how far these atmospheres are really essential; American work has shown that, at least for some alloys, no atmosphere requirements need be observed; it has to be remembered that the surface characteristics of the components may have a bearing on this subject. In those cases where a corrosion-resistant, tough cast surface is present, inert atmospheres may not be necessary, and, as a matter of fact, an American proposal to pre-treat magnesium with hydrofluoric acid in order to produce a protective film, has been found to be satisfactory on experimental heat-treatment batches.

The technical implications of this innovation are such that no apology need be made here for a short digression. Somewhat unfortunately, as we have pointed out in earlier sections of this account, there is a tendency in certain quarters to regard magnesium and magnesium-base alloys as quite special phenomena in the metallurgical world. To a lesser extent, the same comment applies to aluminium and aluminium-base alloys. The difficulties which have arisen as a result of this false attitude are many and serious in the engineering world; somewhat luckily, however, they do not exert any material influence for harm in connection with process operations.

To emphasize the ordinary nature of magnesium it should be remembered at once, that the use of protective atmospheres to guard against surface damage or metal loss during heat treatment is not confined to the ultra-light alloys; on the contrary, where economy and practice permit, or where the value of the material being treated is sufficiently great, inert atmospheres are used in conjunction with the heavy metals and the alloy steels. The only difference between the two main groups lies in the nature of the gaseous protective medium used.

It is hardly to be expected that magnesium-base alloys exhibiting the resistance to attack at high temperature characteristic of the true heat-resisting materials will be developed. The theory of these, it will be recalled, is, in general, based either on the presence of a permanently resistant surface film unaltered by heating within the normal working range, or, more commonly, upon the ability of the alloy in question to produce, continually, a new film as the old is destroyed or removed. This is usually achieved by combining with the alloy an element giving rise, usually to an oxide, which diffuses preferentially and continually to the surface. It is essential, incidentally, that such films should, of course, be "continuous" in structure and here the fundamental difference between the physical properties of the magnesium-oxide film and the aluminium-oxide film emerges. The resistance to surface attack of aluminium in the heated state by air is due to the impermeable nature of the alumina film always present; the magnesium-oxide film is quite porous to air.

The use of the fluoride coating referred to prompts an interesting comparison with a recently developed technique for the maintenance in a clean condition of steel surfaces designed particularly for hot galvanizing or other surface finishing. The metal, cleaned initially by mechanical means, is coated with a glass, the effect of which is virtually that of an extremely high-viscosity, inert covering flux. The material may be heat treated, the glass film remaining intact. When it is desired to operate on the metallic surface itself, the component is subjected to some suitable thermal or mechanical shock which causes the glass "cover" to shatter and drop off, if necessary in situ, leaving probably a clean metallic surface in contact with the zinc bath, etc.

In defence of this digression it can only be said that it has been made in order to drive home the essential fact, which must be realized once and for all, that magnesium-base alloys are not freaks in the world of metals.

To revert once more to our main subject of discussion, the methods and equipment described are primarily with reference to solution treatment; if the second ageing treatment is required, the castings may be treated in any type of oven provided the temperature is uniform, for at this comparatively mild heat no question of oxidation arises. It should be noted, however, that the salt bath cannot be used for this purpose as the salt mixture is solid at the temperature of treatment.

DTD specifications state that castings and test samples are to be treated at a temperature not exceeding **435** degrees C. for a period of not less than **16** hours and cooled in air or quenched in oil or water. Three observations may be made on this statement. It is dangerous, in practice, to use a temperature approaching **435** degrees C., for if this temperature is exceeded, within a very short time the castings are spoilt due to fusion of eutectic. In addition there is no safeguard against oven temperature irregularities and for this reason in practice the temperature of treatment should not exceed **430** degrees C., and only that provided the oven temperature does not at any point rise above **435** degrees C. Complete solution of the eutectic requires an extremely long period and is, in fact, seldom achieved in practice. The period of **16** hours appears therefore to be short and it may be found necessary to increase the time to as much as **30** hours to obtain a sufficient degree of solution to give satisfactory test results. Finally, castings are usually allowed to cool in air, but an air blast is preferable since it lessens the possibilities of precipitation during cooling. Precipitation, if it does occur, will result in loss of ductility.

The ageing treatment consists of reheating the castings to a temperature not greater than **210** degrees C. for a period of not less than eight hours.

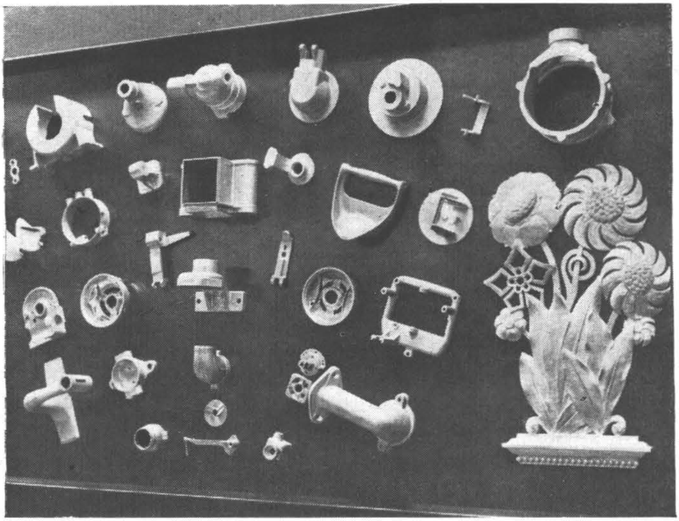
ALUMINIUM—
from WAR TO PEACE

THE Rt. Hon. Ernest Brown, the new Minister for Aircraft Production, inaugurating the Exhibition. Seated at the right are the Mayor and Mayoress of Marylebone and the Hon. Geoffrey Cunliffe, whilst seated at the speaker's left is Mr. Holmes, Chairman of Selfridges.

THE exhibition " Aluminium from War to Peace " is designed to tell the story of aluminium and to show in broad outline how light metals, which have, for the past five years, been reserved almost entirely for wartime needs are being re-adapted once again to the services of a world at peace.

To date, the number of visitors daily passing through the Exhibition Hall in Selfridge's has averaged 8,000, whilst the aluminium house on a nearby site continues to draw some 3,000 sightseers per day. It will not be surprising, therefore, if the reader of the account which is to follow finds his curiosity only half satisfied or his questions answered but in part. For amongst this large number are included not only the general public, the chief interest of which is in consumer goods for domestic and allied purposes, but also a large body representing diverse professions, trades and industries from Great Britain, the Empire and foreign lands.

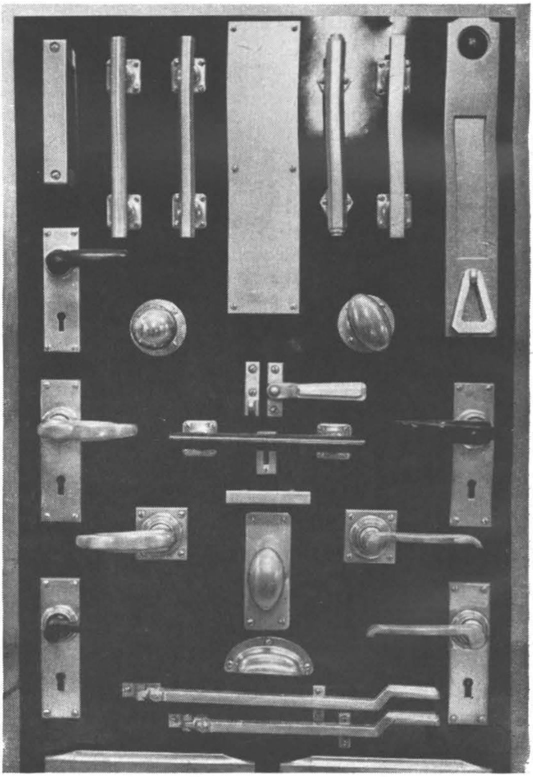
In many instances such visitors are already well acquainted with the uses of aluminium and queries are inspired by the sight of novel designs or novel applications of the metal. In other cases, however, the use of aluminium is contemplated for the first time. Clearly it has not been possible to show anything more than a fraction of the vast field already served or capable of being served by light metal, and certain well-established applications are, by reasons of limitations of time and space, unrepresented.



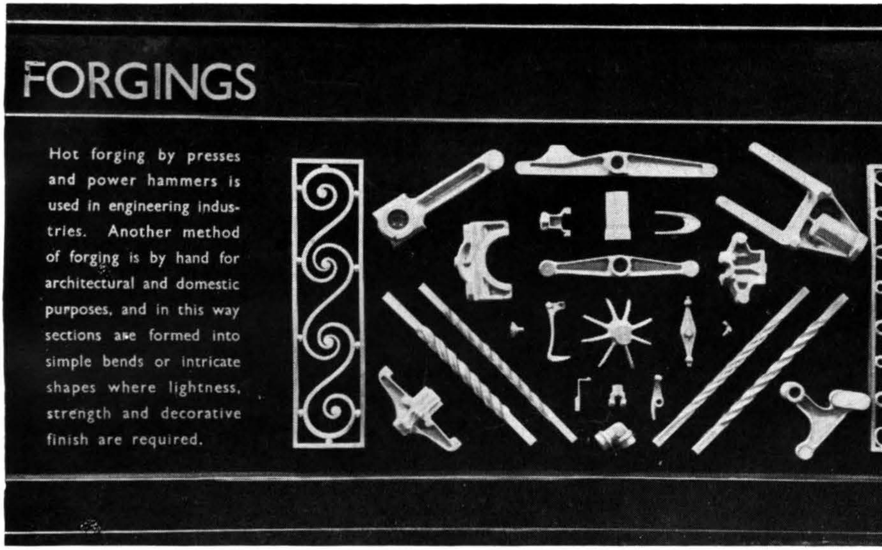
PANEL illustrating possibilities of production of small castings of varying intricacies of design in aluminium alloys.

On all matters of doubt, therefore, for answers to problems concerning the use of aluminium in fields not touched upon in the exhibition, upon questions as to the suitability of aluminium with respect to existing designs, or the modification of designs in order to facilitate the replacement of heavy metal by aluminium, the visitor is enjoined to consult the Information Officer in the Exhibition Hall. Alternatively, inquiries may be addressed to the Information Officer, Aluminium Development Association, Union Chambers, 63, Temple Row, Birmingham, 2. Telephone, Midland 0847.

Particular interest attaches to the entrance screen and tableau of murals which form the approach to the exhibition. These works, designed by Ralph Lavers and executed by Starkie Gardner and Co., Ltd., were originally conceived to tell the story of aluminium, and, at the same time, to express in themselves the personality of the metal. Originally the whole of the screen was to be anodized and dyed light grey, medium grey and dark grey, the murals being left in the natural aluminium colour. Subsequently, these suggestions were amended, anodizing to be in light



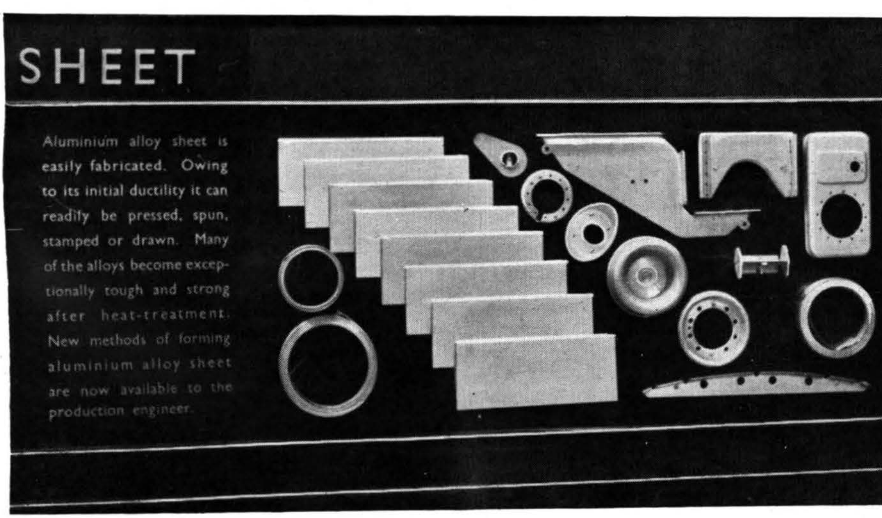
GROUP of light-alloy door furniture of conventional designs.

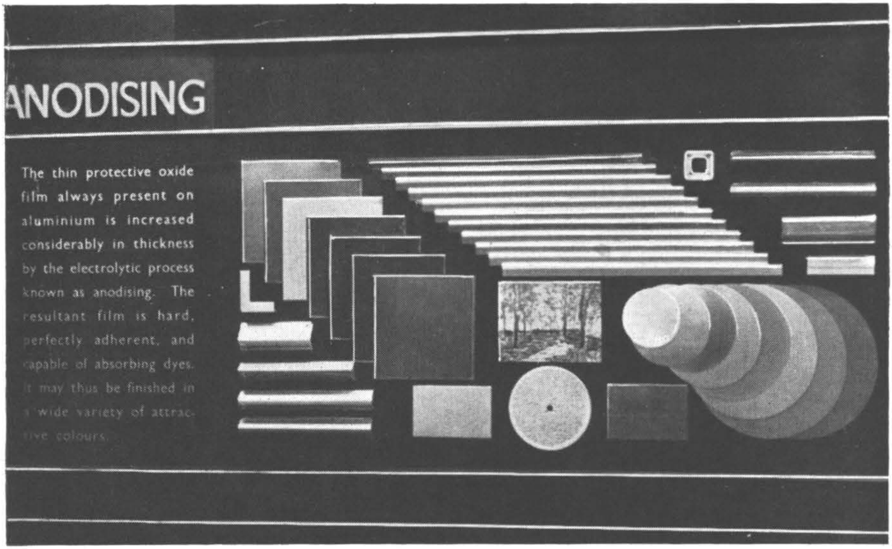


REPRODUCED above is the panel setting out details of the forging technique for light alloys, together with representative examples. At the foot of the page is the panel dealing with the properties and uses of aluminium sheet.

grey, dark grey and black to suit the artist and to fit in with the anodizing technique.

After early experiments it was decided to abandon any attempt to show perspective as the thickness of the materials being used already possessed a third dimensional value. Time was short and the utmost simplification was essential; for this reason all details not absolutely necessary were discarded. After consultation with the artist it was agreed that the murals were to be a combination of drawing and

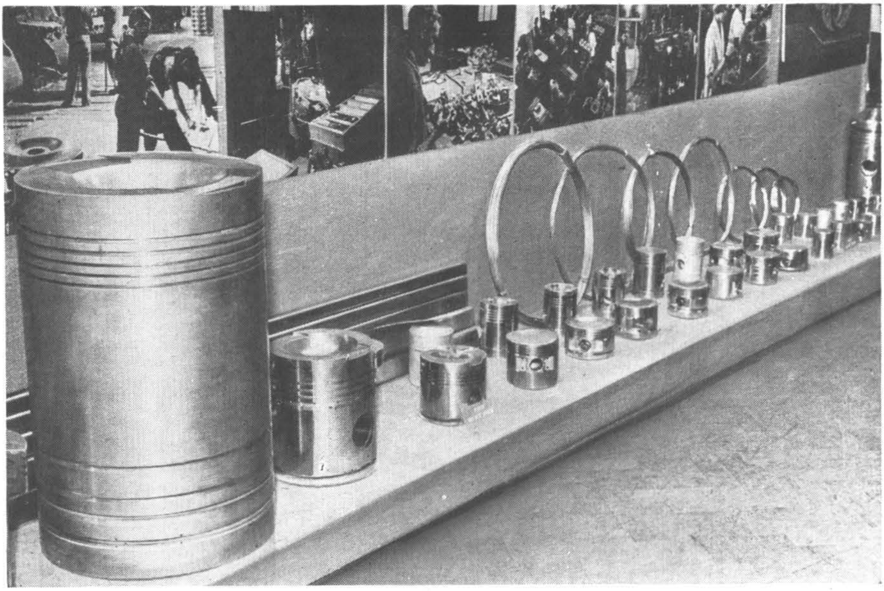




SET out on the panel illustrated here is a series of examples showing the range of possibilities presented by the anodizing and dyeing technique for aluminium. At the foot of the page is an illustration showing part of the piston exhibit.

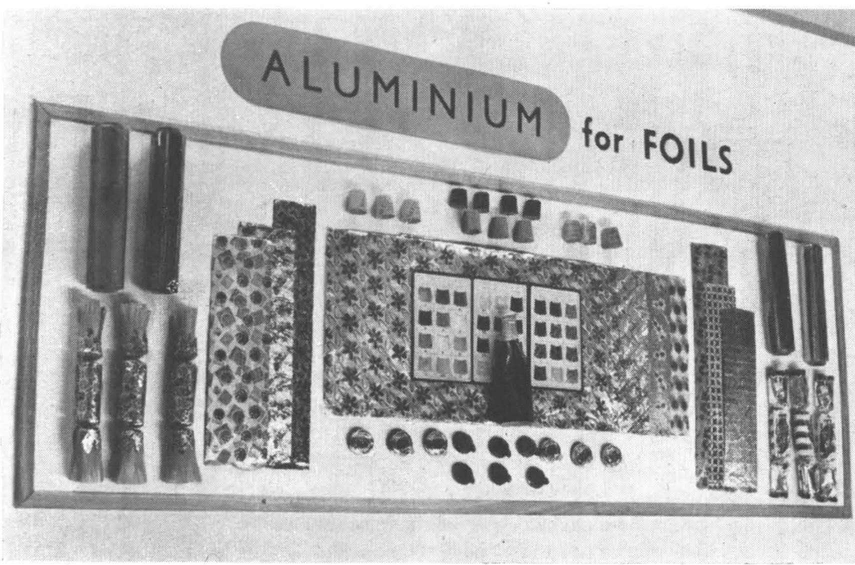
modelling and to be produced as cut-outs from sheet of various thicknesses, the required effects being achieved by suitably engraving, texturing and chasing.

The " Foreword " and the text embodied in the screen and approach are printed



in Gill sans, the lettering being left in the natural colour of the metal on a black, anodized ground, thus matching the murals themselves.

In the murals around the " foreword " panel the attempt is made to show how aluminium takes its place alongside traditional materials such as bronze. In this regard, a useful service is done to light metals and for those who contemplate their use, for, in the minds of many, there tends to exist, consciously or unconsciously, a suspicion that the newness of aluminium implies a degree of social inferiority in comparison with the established and traditional materials, such as iron and bronze. In symbolic sequence, the " foreword " panel depicts " Genesis," the Stone Age, the Bronze Age, the Iron Age, and the new-born spirit of " Aluminium," which is



PANEL illustrating a variety of plain, coloured, and embossed aluminium foils for packaging and other purposes.

thus depicted as a lineal descendent of a great line and not as a newcomer and a stranger to the ideals of the past.

The symbols of stone, bronze and iron are duplicated and positioned on both sides of the " foreword " panel, with " Genesis " on the underside and " Aluminium " on the top side, fitted between circular disc features, the murals themselves running between the two exits and depicting in sequence the winning of bauxite, reduction, alloying, pouring, extruding, rolling, forging and casting.

In achieving designs of the highest artistic merit, sight has not been lost of necessity for representing with diagrammatic accuracy the processes entailed in the production of aluminium metal in its various semi-manufactured forms. From these murals the visitor may obtain a tolerably accurate idea of aluminium production from the ingot stage to casting, sheet or extrusion.

For the last three murals, symbolizing transport by land, sea and air, traditional subjects were deliberately chosen by the artist to break the customary link between light metals and such modern conceptions as the aeroplane and speedboat. Furthermore, these panels were designed to emphasize and to relieve the great simplicity of the treatment accorded to the industrial symbols.

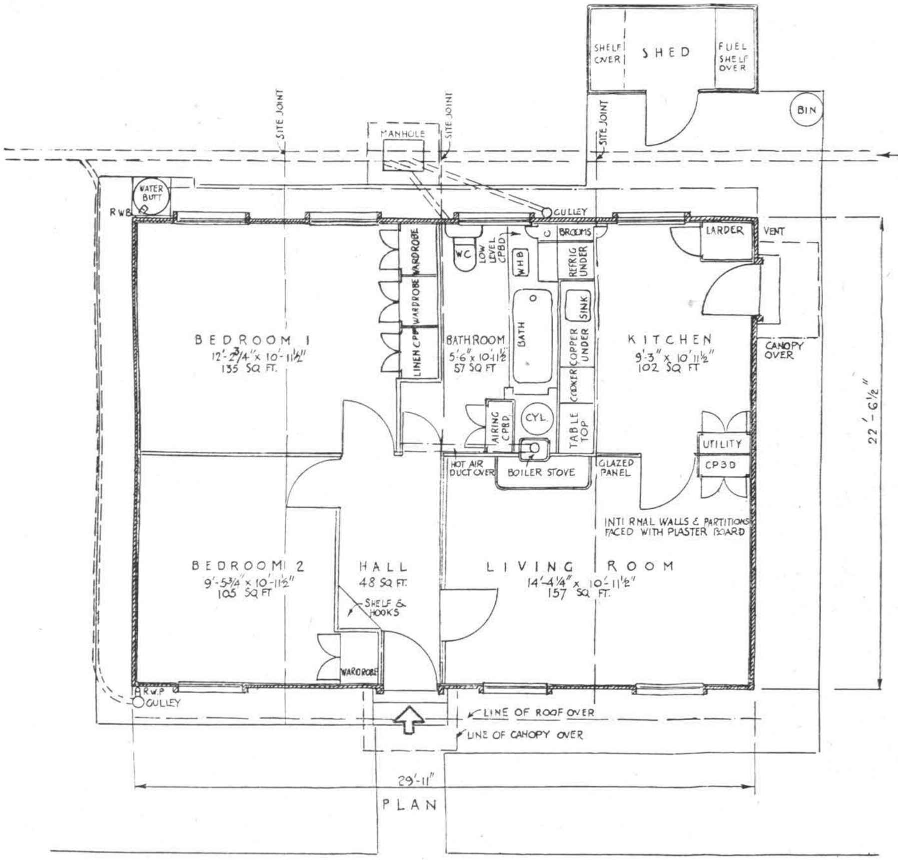
It must be pointed out that on this type of work, unless a designer has the full sympathy and help of a team of competent craftsmen, success is jeopardized.

In the murals, the prospective user of aluminium is presented with a synopsis of the forms in which the metal and its alloys can be obtained, namely, castings and various semi-manufactured and manufactured forms, such as sheet, extrusions and forgings. Elsewhere in the exhibition will be found panels depicting the range of possibilities in each of those fields; these should be studied in comparison with the various manufactured articles comprising the body of the display. Particular attention is directed to the use which is made of semi-manufactured forms, more especially complex sections, from which, often by simple manipulation (bending, for instance), finished articles can be produced with a minimum of machining. Other exhibits serve to show how such forms can be combined with castings to give assemblies requiring minimum time and plant for production. Above all other metals and alloys, aluminium possesses the greatest capacity for adapting itself in this way to the needs of modern industry and art, whether for purely decorative features, the murals for instance, or strictly utilitarian items.

CURVED bay window and accessory furniture. The metalwork here is in anodized and dyed aluminium, the windows, desk top, handles and armrests of chair being in Perspex.

For sand castings there is virtually no size limit. To some extent, however, thinness of sections obtainable will depend both on the size and the design of the casting, as well as upon the alloy in which it is executed. Gravity die-castings, again, are obtainable in all sizes, the upper size limit being governed principally by

(Text continued on p. 333)

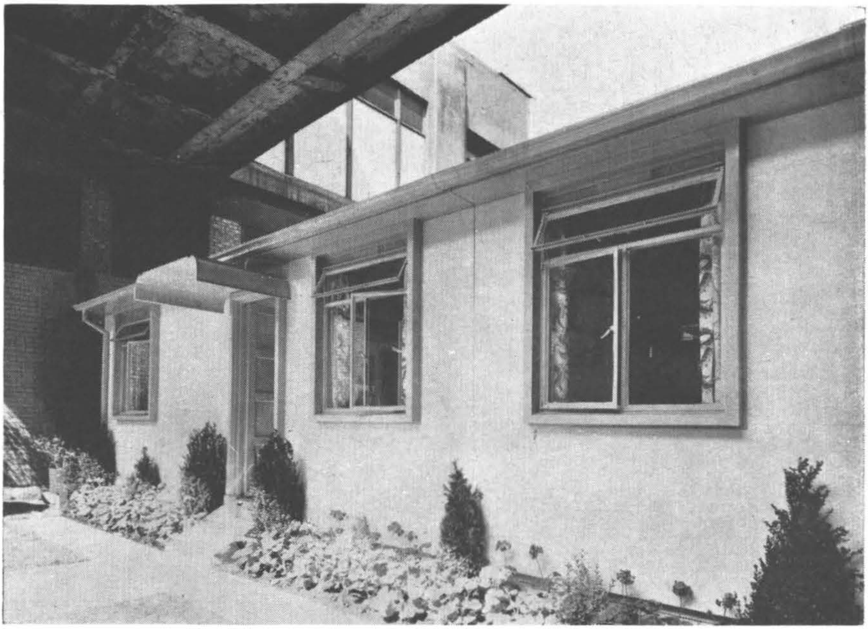


PLAN AND DESIGN DETAILS OF ALUMINIUM HOUSE. The house is rectangular in plan, 29 ft. 11 ins. by 22 ft. 6½ ins., with central entrance.

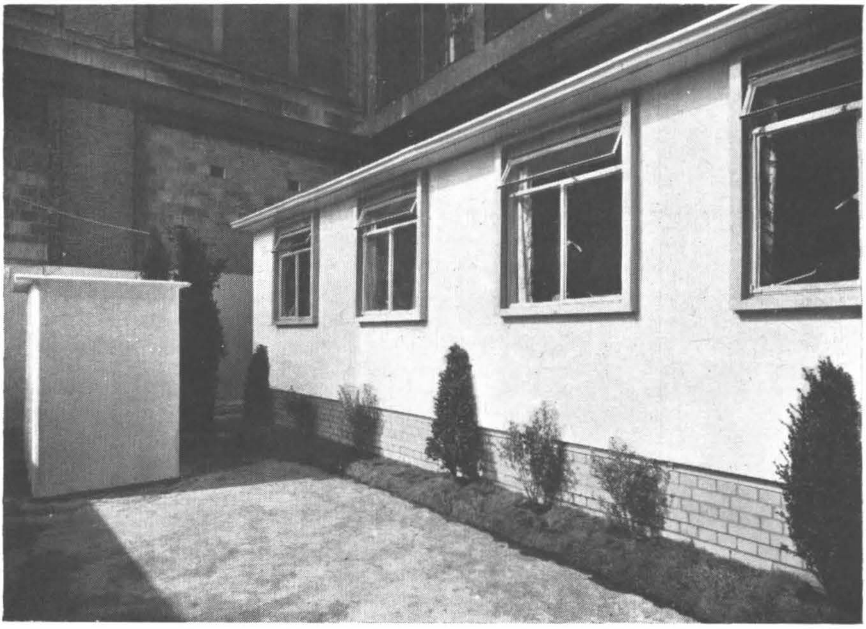
Floor area :—House	..	630 sq. ft.
Shed	..	32 sq. ft.
		662 sq. ft.

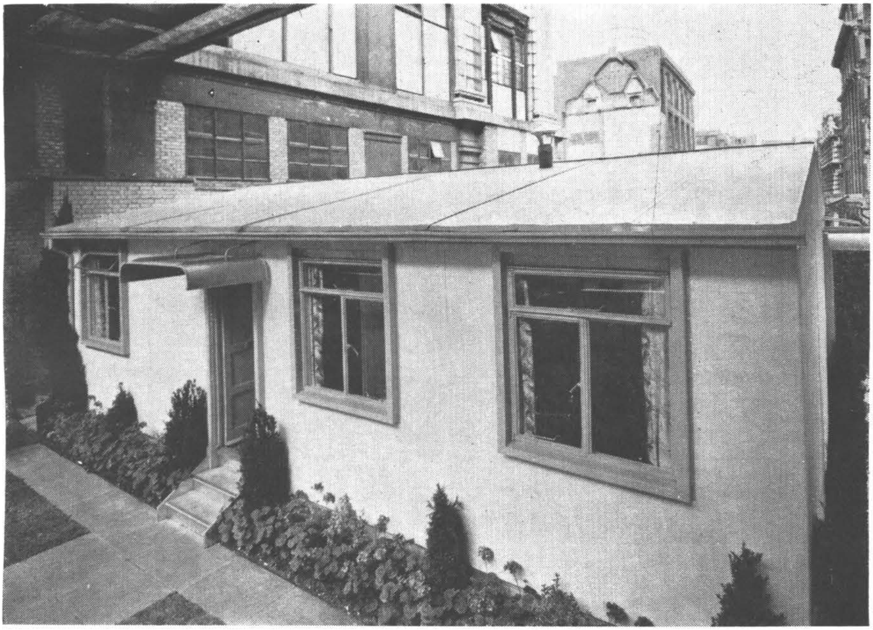
Ceiling height .. 7 ft. 6 ins.

Accommodation	Size		Floor area
Living room	14 ft. 4¼ ins.	× 10 ft. 11½ ins.	157 sq. ft.
Bedroom No. 1	12 ft. 2¾ ins.	× 10 ft. 11½ ins.	135 sq. ft.
Bedroom No. 2	9 ft. 5¾ ins.	× 10 ft. 11½ ins.	105 sq. ft.
Kitchen	9 ft. 3 ins.	× 10 ft. 11½ ins.	102 sq. ft.
Bathroom and w.c. combined	5 ft. 6 ins.	× 10 ft. 11½ ins.	57 sq. ft.
Hall	4 ft. 10 ins.	× 10 ft. 11½ ins.	48 sq. ft.
Outside shed	8 ft. 0 in.	× 4 ft. 0 in.	32 sq. ft.



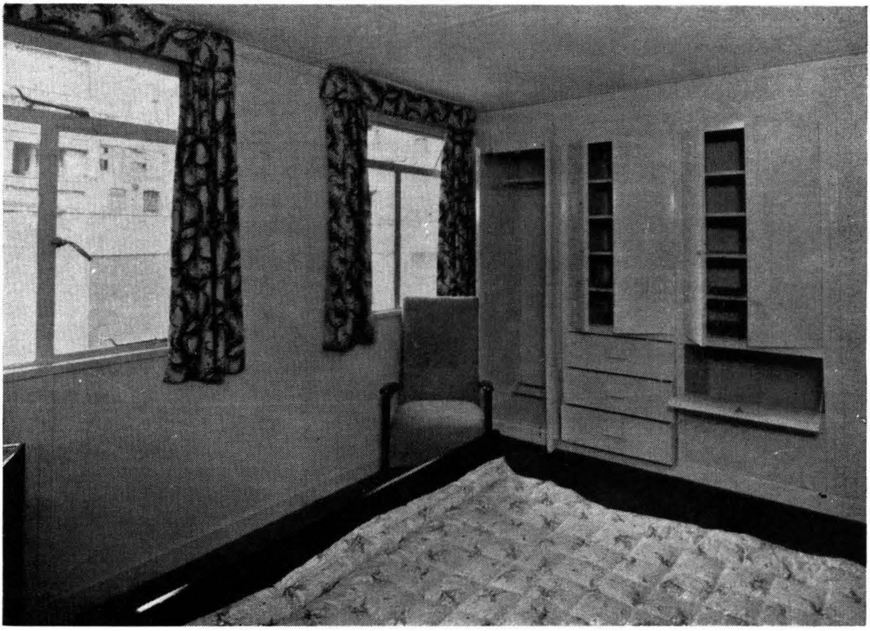
SHOWN above is a front view of the aluminium house, whilst below is shown the rear view.



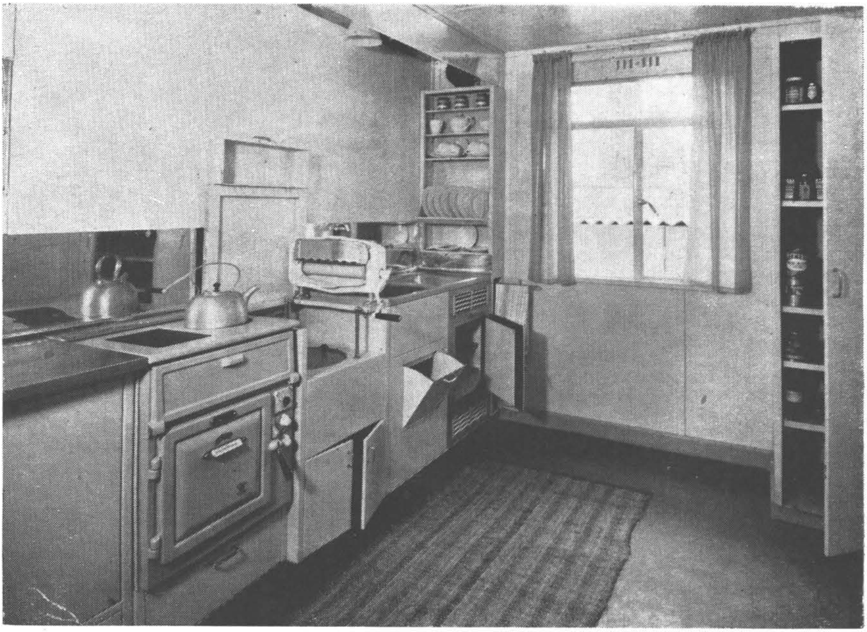


VIEW of the aluminium house illustrated above shows the light-metal roof. Below is seen the lounge, looking towards the fireplace.

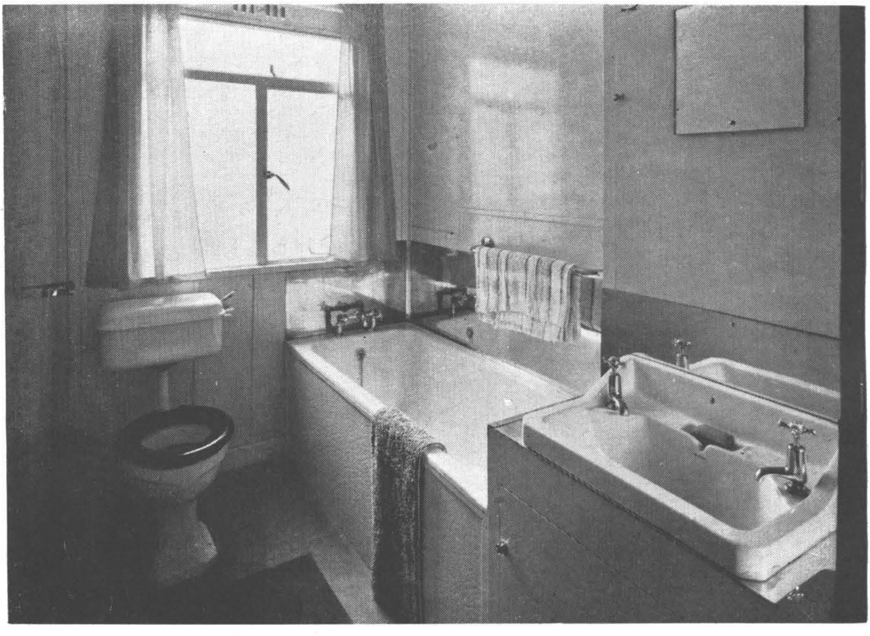
ABOVE is shown another view of the lounge and, below, is illustrated the best bedroom.

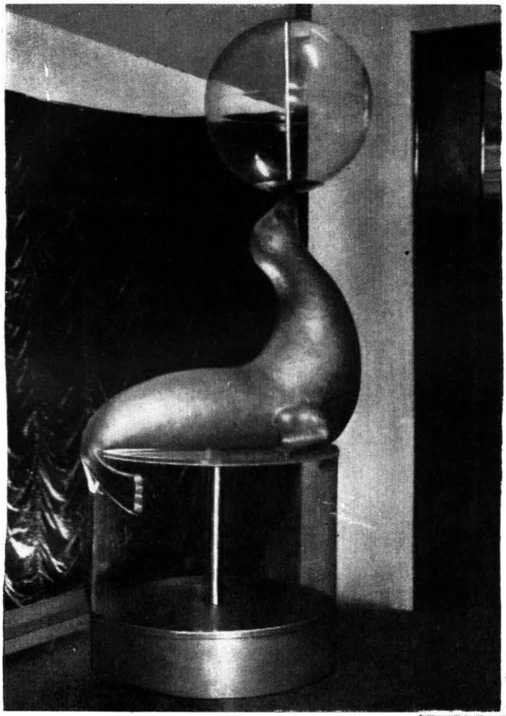


PICTURED above is the guest bedroom in the aluminium house and, below, may be seen the kitchen, the door at the left being open to show the lounge.



A FURTHER view of the kitchen in the aluminium house is illustrated above, whilst below is shown the bathroom.





be produced in aluminium and its alloys to designs and dimensions possible in any other metal.

From these general data it will be seen that the designer is not limited in his scope by the use of light alloys. Intricacies of design and service requirements will, as in the case of heavy metals,

LEFT. Designed by R. Lavers, the seal shown here is beaten from aluminium sheet and is mounted on a Perspex pedestal and is balancing a large blown Perspex ball.

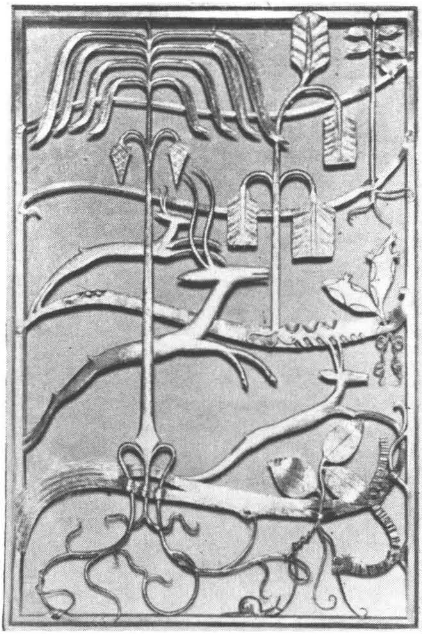
BELOW. Designed for casting in aluminium, the figurette "Spirit of Aluminium" by J. Woodford, R.A., stands on an aluminium plinth, on the facets of which are engraved Perspex plaques illustrating symbolically the fields of science and art where light metals find application. The ball in the hands of the figure is in Perspex and the whole is covered with a Perspex shade.

the cost of producing the necessary permanent mould. Minimum section thicknesses will, in this case, once more be governed by design and choice of alloy.

Pressure die-castings must in the main still be considered as catering principally for smaller castings, maximum dimensions being strictly limited by the expense and technical difficulty involved in the production of very large dies. Numerous examples of all types of castings will be found exhibited.

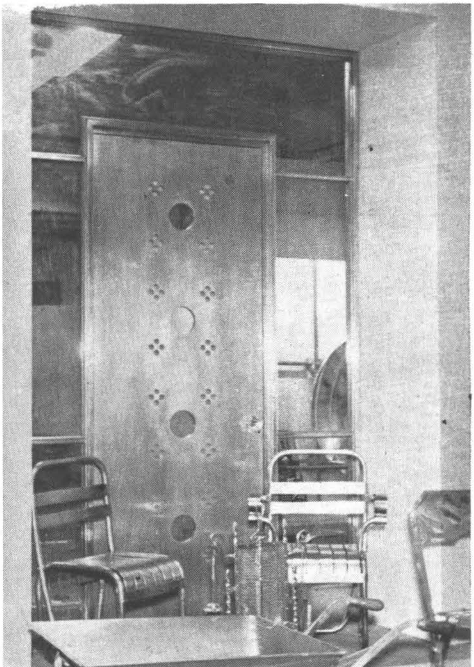
In the rolled form, light alloys may be obtained in all thicknesses, ranging from an inch or more down to less than .002 in.; the maximum dimensions of a sheet or strip being governed by its final thickness. Extrusions include tubes of all thicknesses and bores, and sections up to a size included within a 16-in. circle. Forgings and pressings may

RIGHT. Decorative wall screen wrought in aluminium, antique finish.



influence the possibility of economic production and, furthermore, will determine the particular light alloy to be used.

Two extreme cases might be quoted to illustrate this point; the large plane mirror in the bathroom exhibit, and the



ALUMINIUM door and frame. The door itself is machined from a 1-in. aluminium plate. Lights and windows are in Perspex.

equally large concave naval searchlight mirror shown nearby, are machined from massive aluminium sheet of high purity in order that they may be satisfactorily treated by an anodic process to give a permanent surface of maximum reflectivity. At the opposite end of the scale the casings of the small hand tools, shown

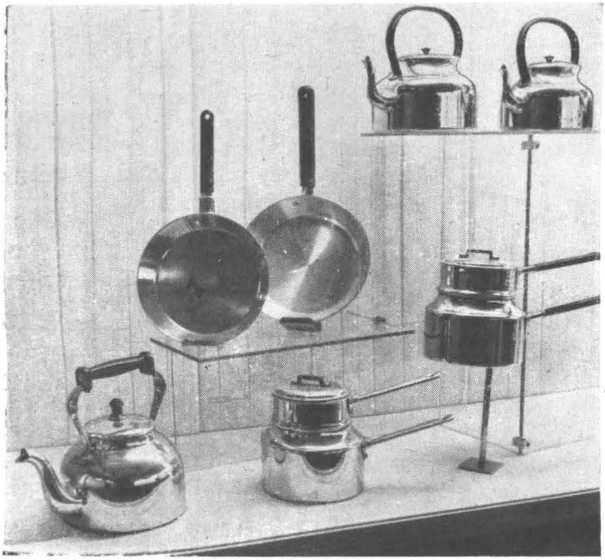
LARGE decorative panel with anodized design in five colours.

VIEW of kitchen of the future showing electric oven and hot plate. In all the units here, extensive use is made of light metals.

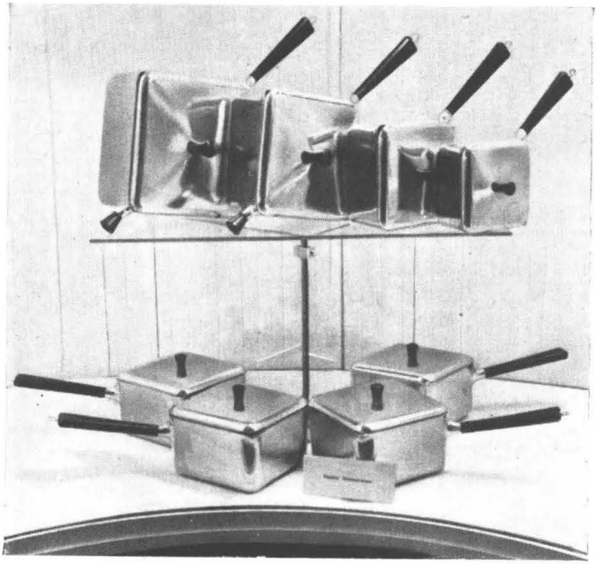
elsewhere, are die-cast in easy-running alloys in order to facilitate the obtaining of the somewhat complicated forms required, and, furthermore, to enable reasonably thin sections to be achieved. The hydroplane and the light-alloy dinghy are both built up from a magnesium-aluminium alloy of the intrinsically high corrosion - resistance required for marine applications such as this.

From the murals, the panels illustrating the possibilities of dyed anodic finishes, and numerous exhibits throughout the hall, a general picture may be obtained not only of the range of finishes which it is possible to impart to aluminium surfaces, but also of the scope offered to the designer on the one hand, and the user requiring specific effects on the other.

Whilst on this subject, opportunity might be taken to refer to the joint use of light metals with other materials in engineering and decorative structures. In practice the use of a single material, however general its applicability, is rarely possible, and really satisfactory results can be achieved only by using each material in its correct form and in its correct place. Here we



GROUP of kitchen utensils in heavy-gauge aluminium.



GROUP of aluminium saucepans of modern design.

would direct attention to the two very different exhibits, namely, that showing a cycle embodying light-alloy components used in conjunction with steel, and to the very novel curved bay window featuring dyed and anodized aluminium, together with transparent plastics. A fuller description of this last item is warranted.

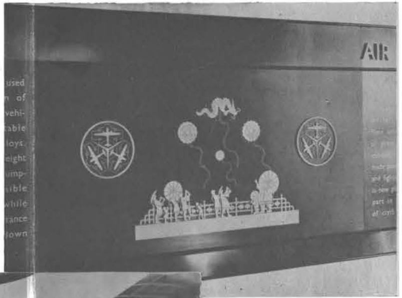
The interior colour scheme is based on anodized aluminium dyed pale blue and terra cotta, the exterior being aluminium in natural finish. The whole of the structure is in light metal, the dado being built up of thick bent plates and extruded sections anodized and dyed. The sill is in thick Perspex with aluminium-plate backing; behind the sill an illuminated trough is provided with a Perspex cover plate housing continuous strip lighting to illuminate curtains from below; supporting columns on both sides are constructed in thick aluminium sheet with timber backing, the " interior " columns being built up from solid-drawn aluminium tube. Artificial-silk curtains processed with a plastic facing are hung on a sliding track of entirely new design.

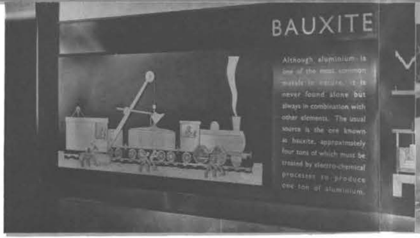
The curved windows are in thick Perspex, two being arranged to open by means of a continuous window lift; these are counterbalanced. The circular light fitting in the ceiling supports a Perspex reflecting plate, the prismatic sections of which are machined. The writing desk is entirely of aluminium anodized and dyed, the top being Perspex laid over stretched

ALUMINIUM coffee pot, teapot, muffin dishes and cocktail set.

THE LIGHT METAL STORY—A MURAL STUDY

BELOW, at the left, is presented a close-up view of the mural depicting the mining of bauxite, together with the associated descriptive matter. From this study may be gained some general idea of the finishing technique evolved for the panels. Shown clearly, also, is the "perspective" effect educed by the superimposition of the variously surfaced sheets; close inspection will enable some details of the textures to be obtained. Below, at the right, is shown a closer view of the terminal sweep of the mural series, the figurette, "Spirit of Aluminium," by J. Woodford, R.A., being seen in the foreground. From this illustration and from that immediately adjacent, at the left, may be obtained a good impression of the platform at the foot of the murals; on this is mounted a number of exhibits illustrative of the make-up of aluminium alloys.





THE works illustrated on this sheet were designed by R. Lavers and executed by J. Starkie Gardner & Co., Ltd. In every case they are built up from massive aluminium sheets superimposed one on the other and textured and cut out to give third-dimensional effects. The design itself so produced is mounted again on massive aluminium sheet, anodized and dyed black. The descriptive matter is reproduced by a special process on the black anodized surface, the lettering itself being left in the natural aluminium colour. In the "Foreword" panel shown above (left), attention is directed especially to the left-hand side of the panel mounting where, it will be noticed, a full rounded design has been adopted. Above, at the right, is presented a general view of the murals. These cover the history of aluminium from the mining of the bauxite through reduction, remelting and alloying to the final production of manufactured forms, such as extrusions and sheet and castings. The terminal sweep of the murals embraces conceptions of transport by land, sea and air, in all of which light metals are destined to play an ever-increasing part.

PICTURED above is a close-up view of the panel representative of transport by air. As explained in the text, the artist has chosen deliberately a symbolism designed to break the commonplace link between light metals and the modern aircraft, thus emphasizing the place of aluminium alongside the metals of tradition, and, at the same time, enhancing the simplicity of the opening panels of the series. The circular devices on each side of the main motif do, however, reassert the place of current design, and light metals, in the present-day scheme of things.

crushed Vaumol grain hide. The drawers are of hardwood faced with Perspex and hide, and fitted with Perspex handles. The revolving chair is formed from a curved aluminium plate supported on a light-alloy pedestal, a plastic roller bearing and spindle being provided for the rotary movement. It is upholstered in hide to match the desk, whilst the arm rests are of Perspex overlaid on hide. The various furnishings, such as book ends, table lamp and standard lamp, are all in aluminium; the standard lamp incorporating Perspex in its design. The inkstand and pen are also in Perspex.

The items shown in the exhibition cover the requirements of users in every field, ranging from the aluminium sauce-

ABOVE. Fireside companion set in aluminium.

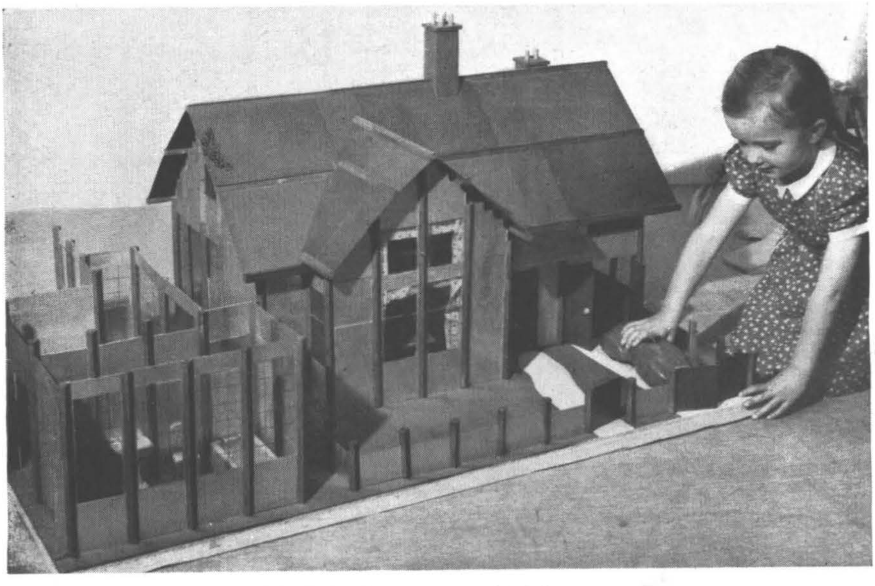
RIGHT. Chair, trolley and table lamp, assembled from aluminium tube and sections.

BELOW. The lines and appearance of a super-sports model are presented by this toy motorcar built up from aluminium sheet and pressings.

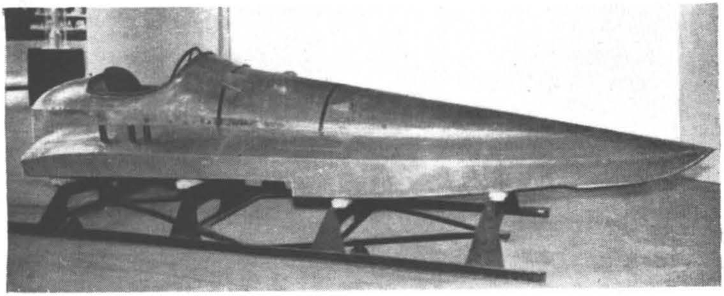
pans of modern design to the latest type of operating table executed in aluminium. One general lesson may be drawn:—whilst, broadly, there are few structural or engineering assemblies which cannot be built in light alloys, there is, nevertheless, a trend to the development of designs specifically adapted to these materials. This is dictated partly by the intrinsic mechanical properties of light metals, which differ as much from those of heavy metals as do those of the heavy metals

GROUP of children's toys, nursery furniture and perambulator. Light alloys here meet the demands of minimum deadweight, ease of production and attractiveness in appearance and finish.

and the steels amongst themselves. It is governed partly, however, by the need and desirability for profiting by the unique properties of aluminium—its light weight, its high corrosion resistance, the ease with which it may be fabricated, and the wide variety of surface finishes which may be imparted to it. It is, indeed, on account of this latter group of considerations that aluminium has found so extensive a field of application. Transference of design directly from another material to light metal is, in most cases, technically and economically unsound and will frequently result in full use not being made of the possibilities which its use presents.



DOLL'S house assembled from toy structural units in aluminium.



LEFT. Hydroplane, the body of which is assembled from corrosion-resistant light-alloy sheet. This boat suffered prolonged immersion in water, but when recovered exhibited no serious corrosion whatsoever.

For this reason many novel designs in household furniture, for example, will be seen which would be quite incapable of realization in wood or plastics, and esthetically unsatisfactory if produced in steel or heavy metal. Nevertheless, where the need exists for the duplication of conventional exterior forms then this is possible, as shown, for example, by the chest of drawers and writing desk (both finished in stoved cream enamel), designed for use on board ship. In these two cases a degree of lightness and durability has been achieved quite impossible with timber, and, furthermore, as comparatively light-gauge sheet has been employed, no space has been lost in the form of heavy drawer fronts and rebated drawer bottoms.

ABOVE. The rocking-horse shown here features a cast aluminium base, giving rigidity without excessive weight.

LEFT. In the foreground is a light-alloy dinghy, whilst in the background may be seen chairs of various designs with light-alloy frames, a small wrought screen in aluminium together with cabinet and table lamp.

Visitors will appreciate that, to use light alloys to advantage, the engineer must design for these materials, whilst the producer of non-engineering structures will obviously be advised to take advantage of the school of industrial designers versed in the use of aluminium and capable of utilizing to the full its many unique qualities.

To quote concrete examples, we would commend particular attention, on the one hand, to the light-alloy extending ladder, and, on the other, to the " door and frame " exhibit. The lightness and rigidity of the ladder should be noted in conjunction with the hollow-section structure of the sides. The door is, in many respects, quite unique. In spite of its ease of movement and light appearance, it is actually machined from 1-in. solid aluminium plate, the design being formed by simple drilling and reamering of holes, into the larger of which are fitted flush Perspex discs, whilst in the case of the small holes coloured vinylite plastic inserts are faced on each side with thinner Perspex discs. The door, which is hung on top and bottom pivots, is provided with Perspex handles, the surrounding screen being glazed with thick Perspex. The main frame is constructed of extruded rectangular-section tube. The whole assembly is in natural aluminium colour, satin finished and lacquered.

Perhaps of more general interest may be quoted the light-alloy barrow and hay rake, these two items representing a field of application at present but little exploited. Maximum lightness and balance are here combined with the high corrosion resistance necessary for equipment and appliances undoubtedly to be called on to face in use quite severe weathering conditions. Again, it will be noticed that exterior design, whilst conforming closely to convention, has, nevertheless, been modified to suit all-aluminium construction and to take full advantage of the possibilities offered.

From such severe exhibits as the operating table and the artificial limbs, and from architectural conceptions, such as the murals and the curved bay window, we may pass to another field, that of children's toys. Specialized properties are called for in materials which cater for the toy-making industry, and these are fully met by aluminium. Economy in first cost, ease of working, availability in light gauges and amenability to the reception of the widest possible range of finishes; all these requirements are automatically met. The toy motorcar and the doll's house serve to illustrate this point.

In the domestic field the scope of light metal is illustrated by an attractive range of cooking utensils, to some of which, incidentally, colour and enhanced comfort are added by the simultaneous use of plastics. A small cocktail set indicates how advanced designs may be achieved in the metal. Gas stoves and water heaters may be rendered more attractive, lighter and thermally more efficient by the judicious incorporation of aluminium components. Aluminium has been shown to be able to stand up eminently satisfactorily to prolonged heat and moisture deposition.

In the aluminium kitchen may be seen an assembly embodying the latest designs in light metal. Washing machine, wringer, dish washer and sink are all executed in light alloy which provides the necessary combination of stainlessness and intrinsic attractiveness in colour.

The aluminium house which was opened to public exhibition by Mr. Duncan Sandys, Minister of Works, on Tuesday, June 5, has, of all the individual exhibits, proved the main popular attraction. A plan of the house and various exterior and interior views are reproduced elsewhere in this account. In concluding this review of the exhibition " Aluminium—from War to Peace," we cannot do better than present the official synopsis giving details of its construction and erection.

The house was originally conceived by the Aircraft Industry's Research Organization for Housing. This organization employed Hiduminium Applications, Ltd., as designers under the supervision of A. Goldberg, the architect being A. F. Hare. The house is now sponsored by M.A.P., which has retained Hiduminium Applications and the architect as consultants on design and process development.

The house on view at the exhibition is one of seven temporary types to be supplied to local authorities under the Housing (Temporary Accommodation) Act, 1944. Under this Act, the temporary houses will be provided and owned by the Government. The local authorities will choose the tenants, fix and receive the rent, manage the houses and keep them in repair. An order for 50,000 aluminium houses has been placed by the Minister of Works, the Ministry of Aircraft Production acting as agents for production. This order is being treated on lines similar to the manufacture of aircraft. Production will take place at five centres: Bristol Aeroplane Co., at Weston-super-Mare; Hawksleys, Ltd., at Hucclecote; Vickers-Armstrongs, Ltd., at Chester and Blackpool; Blackburn Aircraft, Ltd., at Dumbarton.

The Bristol Aeroplane Co. act as the parent firm of the group, and High Duty Alloys, Ltd., are technical advisers to them. The exhibition house was produced at the Bristol Aeroplane Co. with Hiduminium Applications as design consultants.

Production will begin on a small scale this month at the parent factory and will be followed shortly at the other works, and will eventually build up to a peak production of 5,000 houses a month.

CONSTRUCTION

General.—The house is completely prefabricated in four separate units, each unit approximate size 22 ft. 6½ ins. long by 7 ft. 6 ins. wide. Each unit is assembled in the factory, where all fitments are installed and final decoration is carried out.

Site Erection.—Consists of hoisting the units on to brick dwarf-wall foundations and then connecting the four units together at floor, walls and roof with tapered pins. Unit A.—Consists of kitchen and half living room. Unit B.—Consists of bathroom, w.c., service unit, all piping and drains, boiler fire and half living room. Unit C.—Consists of part bedrooms, hall and wardrobe cupboards. Unit D.—Consists of part bedrooms Nos. 1 and 2.

Floor.—Aluminium alloy extruded section framed panels with T. and G. boarding.

Walls.—Frames of aluminium alloy extruded and rolled strip sections riveted together, clad externally with 20-gauge aluminium-alloy sheet riveted to frames. The frames are filled solid with lightweight aerated concrete providing thermal insulation. The external sheet cladding is stuck to the infilling with bitumen adhesives. The panels are faced internally with plaster board or building board fixed to ply battens screwed to aluminium-alloy frame and stuck to infill with bitumen adhesives. Site joints are made with aluminium-alloy spring clips forming a double capillary groove.

Internal Partitions.—Aluminium-alloy frames filled with aerated concrete and faced each side with plaster board or building board stuck to infill.

Ceilings.—Plaster board or building board supported by aluminium-alloy channel-sections spanning between roof trusses, with layer of insulation material fixed to top of ceiling boards.

Roof.—Formed of two trusses and two trussed purlins constructed of aluminium alloy extruded and rolled sections bolted to walls and spinal partition. Covered with aluminium-alloy panels 2 ft. 6 ins. wide, formed with a Boughing section covered with layer of insulation and faced internally with aluminium-alloy sheet. The panels are formed at sides and ridge with an upstand which is covered with an aluminium-alloy rolled strip cloak with capillary groove. The eave overhang, complete with gutter, is constructed of aluminium alloy.

Windows.—Windows, internal and external surrounds, are in aluminium alloy.

Doors.—Doors and frames are in timber.

Fittings.—Kitchen and bathroom unit and cupboard units similar to the M.O.W. standard units are constructed in aluminium alloy.

Protective Treatment.—Aluminium alloy is naturally highly resistant to atmospheric corrosion, but, as an additional precaution, structural sections and wall facings undergo a special anti-corrosive treatment.

Commentary on PRESSURE DIE CASTING

Observations on a Paper by J. L. Erickson, Which Appeared in "Light Metals," 1945/8/173.

By E. CARRINGTON

An attempt has been made in the following notes to comment upon Erickson's very interesting paper, both from the theoretical and practical point of view.

In his introduction, Erickson says that porosity " is indirectly responsible for (1) the almost universal opinion of engineers that pressure die castings are inferior to sand and gravity die castings as regards uniformity of tensile and fatigue strength properties, and (3) high rejection rates in cases where the pressure die castings must be absolutely radiographically sound." As regards (1) it is obvious from his own article that not only engineers, but metallurgists and die casters realize that pressure die castings are not universally sound. He himself has shown this by rejecting a large proportion of bars because of unsoundness, often more than **50** per cent. being discarded.

This is most surprising. Test bars were made by different methods in order to see what kind of bars were obtained, and then all the doubtful bars were discarded. This defeats the whole object of the experiments. In some cases only **30** per cent. were radiographically sound. It may therefore be said that those tested were " accidentally " good, and that the discarded bars were really representative of the kind of castings obtained under those particular conditions. If Erickson had cast **100** bars, and only one had been sound, would he have tested that one and said it represented the type of bar made under those conditions? Surely all the bars should have been tested, and their conditions reported on, in order to obtain a general idea as to the castings to be expected under each set of conditions.

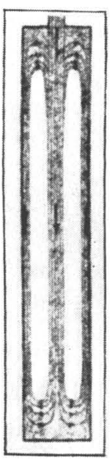


Fig. 1.—Ideal flow according to Frommer.

As regards (3), it is again surprising to find that pressure die castings " must be absolutely radiographically sound." In this country the Air Ministry classifies all pressure castings as Class III, and none need be radiographed, because they would not be expected to appear radiographically sound. They are, of course, quite suitable for the purpose for which they are used, as a little rough work with a hammer will soon show.

One of the ways in which attempts are made to obtain castings free from porosity is said to be the use of " heavy and abundant straight vents," and yet, although these are very often used in practice, no attempt is made to use them in these experiments. The function of vents is not merely to allow air to escape, but to control the speed of escape. If the air escapes comparatively slowly, it has a cushioning effect and prevents excessive turbulence. When the metal reaches the end of the vent the vent has done its job, and if there is still air in the interior of the casting, solidification will be so quick that it will be unable to escape. The writer would certainly like to see pore-free pressure castings. All those which he has examined were porous in the middle, although the pores in castings made by a cold chamber machine can generally only be seen under a microscope. Manufacturers may advertise " that high pressures will produce pore-free castings " in America, but they do not do so in England.

There is another possible way in which porosity in pressure castings may be minimized, which has not been mentioned by Erickson. Ziesenheim[1] calls this method " Prefill Injection." He suggests that the gravity die-casting process points the way to better pressure die castings. In this process the metal is poured into a heated die and fills the die slowly from bottom to top, thus driving all the air before it. " Aluminium castings so made were superior to those made at high injection velocity in

[1] "Metal Industry," 1944/65/219.

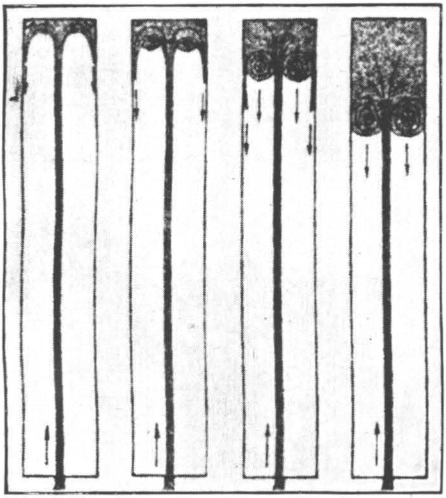


Fig. 2.—Actual flow according to Frommer.

pressure-die-casting machines. It became evident that if the virtue of slow movement of metal could be combined with high final pressure on the metal as it chills . . . a great forward step would be made." The prefill injection system works on this principle. The metal is injected comparatively slowly so as to allow the air to escape, and then pressure is immediately applied hydraulically, in order to compress any gas which has been trapped. A large gate is used in order to allow this pressure to be applied. It is claimed that in addition to giving sound castings, such a system of injection gives a long die life.

This method seems more likely to give a sound casting than building machines with mounting injection pressures which must give greater turbulence and higher gas content.

Later, Erickson explains defects obtained on heat treatment with castings made by high pressure, and castings with overflow, but does not mention those made with good venting. This omission seems really important. He then says that castings made with a very high pressure but with neither overflows nor venting, were "radiographically sound." Frankly, if castings which we know to contain gas appear radiographically sound, it is time that we either changed our radiographic technique or stopped using radiography. The question arises as to whether a casting of the test-bar type, which contained evenly distributed microscopic gas cavities, would simply give a somewhat darker but uniform X-ray negative, and whether such darkness might be looked upon as due to dark-room technique.

It is suggested that a bar be prepared from wrought material and radiographed with each batch of experimental bars in order to provide a standard.

The work previously carried out by Erickson, showing the different effects of different gases, is very interesting. It would be instructive to try "air" with increased oxygen, and pure nitrogen.

One important point regarding these gases appears to have been missed: that is their moisture content. In view of the readiness of aluminium to split up water, to form aluminium oxide and hydrogen gas which readily dissolves in molten aluminium, all gases used for these experiments should be thoroughly dried by passing them through several feet of silica gel.

The die used for these experiments is also interesting, but it would appear that too much is taken for granted as to the way in which the metal will fill it. Frommer[2] has suggested that the ideal direction of flow to fill a parallel-sided mould would be as shown in Fig. 1, but that the actual flow is as shown in Fig. 2. According to this, metal would be entering the second bar cavity of Erickson's mould before it had filled the first, and thus both bars would contain air, relative amounts probably depending upon the size of the interconnecting gate.

Koster and Jöhring[2] have carried out experiments in which Wood's metal was pressure cast into a glass mould, the process being photographed by ultra-rapid cinematography (3,600 pictures per sec.). Fig. 3 shows the pictures obtained when filling a test-bar mould, and it will be seen that the

[2] "Die Gresserei," 1941/26/521.

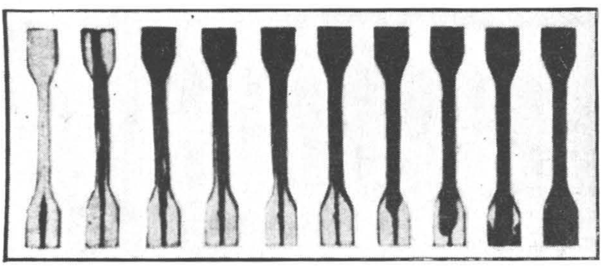


Fig. 3.—Filling of a test-bar mould. Reading from left to right, the illustration at the extreme left shows the mould 4×10^{-3} secs. after pouring had commenced. The succeeding illustrations show the appearance of the mould at intervals of 12×10^{-3}, 20×10^{-3}, 34×10^{-3}, 43×10^{-3}, 57×10^{-3}, 62×10^{-3}, 67×10^{-3}, 74×10^{-3}, and 82×10^{-3} secs., the last representing the mould in its completely filled state.

flow of metal is similar to that suggested by Frommer.

Brandt[3] carried out experiments which suggested that the metal does not flow in a parallel-sided stream, as suggested by Frommer. He says that the direction of flow is essentially maintained, but the metal spreads until it contacts the walls and keeps on flowing until it reaches the farthest part of the die. The rate of flow is reduced, due to the spreading and the resistance of trapped air. This method of flow would also leave a pocket of air at the entrance to Erickson's first bar.

The shape of the runner F may have a good deal of effect upon the type of bar produced in the second half of the mould. Koster and Jöhring[2] used two U tubes, one semi-circular in shape and the other rectangular, as shown in Fig. 4. The flow of metal in these moulds is shown in Figs. 5 and 6, and it will be noticed that although there must be much more turbulence in the rectangular mould than in the semi-circular one, the former gives a more gas-free casting, because the metal in the semi-circular mould is thrown by centrifugal force in a thin stream round the outside of the mould and thus traps a good deal of air when it gets to the far end. Even when the mould is " full " there is still an air pocket at the entrance. In view of the curvature of the runner F in Erickson's mould it is quite possible that air is similarly trapped.

Another point connected with the die shape which Erickson has ignored is the butt, and the runner between the butt and the first test bar. Before the metal is actually injected by the piston there is quite a lot of air between it and the mould proper. If there are corners and changes of direction in this part of the die, turbulence will take place before the metal enters the test-bar cavities. Examination of the photograph of the casting shows that there are changes of direction. Moreover, at the entrance of the first test-bar cavity there is a curve somewhat resembling that of the U mould used by Koster and Jöhring[2], and it may therefore be reasonably expected that in addition to turbulence in the butt there will be gas at the entrance to the first bar cavity because of the metal running round the outside of the curve between the butt and the mould.

In describing the types of possible test bars, under types A[1] and A, type A[1] is said to have no escape for air, and to be quite similar to those made commercially in general practice. The question immediately arises, why are no vents used in general practice? In the case of the experimental mould there is obviously a desire to try the effect of entrapping as much air as possible, but why is the air not allowed to escape from a commercial test-bar mould? If runs had been carried out using vents in the experimental die, some light might have been thrown on this question. Again, type A test bar is said to be similar to the standard commercial pressure die casting " where all the air is trapped as it is made with a small gate." How does the amount of air trapped depend upon the gate? Metal enters the mould through the gate at a very high pressure, and solidifies under that pressure, so that no air can escape through the gate. Hence, if there are neither overflows nor vents, all the air is trapped, whatever the size of gate.

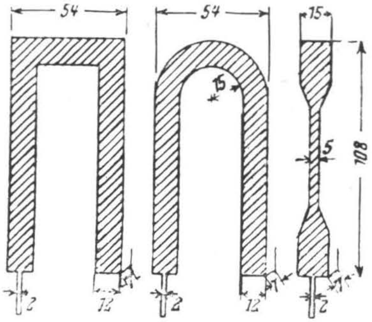


Fig. 4.—Shape of moulds used by Koster and Jöhring.

Type BB[1]. Here it is stated that the first bar, B[1], is cast after the main air mass, which fills the cavity CDE before the metal enters, has been compressed into the second cavity GHI. This assumes that the metal acts like a liquid piston and pushes all the air before it. Koster and Jöhring have shown quite conclusively that this is not so, and while most of the air will have been pushed forward, it is probably incorrect to say that the metal in the cavity CDE solidifies with *much* less chance of coming in contact with air than does the metal which makes bar B.

Type D. Here again the assumption is made that all the air is compressed in the runner F, and that the bar is presumably free from air. A glance at Fig. 5 shows that if the second leg of the rounded U mould were cut off or stopped up at the finish of the curve as shown by the line on the fifth picture, there would be a very considerable amount of air in the straight portion (i.e., the test bar) when the rounded portion was filled.

Type E. While the B[1] bar might contain air because of the action of centrifugal force on the metal between the butt and the first test-bar cavity, causing it to run on the

[3] "Techn. Zentralbl. prakt. Metallarbeit," 1937/47/751; 819; 893.

outside of the curve only, and thus to allow air to remain on the inside, with the E bar the air would be left in the first mould because of the flow of the metal through a small gate as shown in Figs. 5 and 6.

Type F. In this type of shot the metal is said to compress the air into the cavity F. Why, then, 40 per cent. scrap? (Table 2, "Light Metals," April, p. 183.)

Type G. If part CDEF is "filled solid" before the casting process is complete, how is it possible to know that there are no cold shuts in either of the bars?

B tests performed on test bars. 1. Radiographic inspection. Criticism has already been made on the scrapping of all bars which were not "absolutely free from even the slightest porosity," both as regards the actual scrapping of the bars and the possibility of obtaining bars without porosity.

2. Tensile test. Here again we have a large proportion (sometimes a very large proportion) of the bars scrapped. Surely the object of any experiment is to see what happens, but if we deliberately close our eyes to a large proportion of what happens, it is not much use reporting on the other part. The object of the work is "to determine specifically the effect which trapped air (necessarily confined within the die cavity of the steel die moulds used in the manufacture of pressure die castings) has upon the solidification of the molten metal which is forced into the die cavity under high pressure," but the bars which show this trapped air are scrapped, and those which do not are retained!

3. Metallographic inspection. The best and the worst bar, as regards physical tests, were examined under the microscope, but instead of examining comparable sections, one was sectioned in the gauge length and the other in the grip portions. It is a pity that the worst part of each bar was not photographed. That is the part which would interest all foundrymen.

6. Heat treatment. Here again, only bars which appeared sound were heat treated. (Incidentally, 525 degrees C. is not "close to the solidus temperature." The solidus

Table 1.—Effect of Heating.

		Type C	Type C1
Radiographically sound after heating (%)		0	100
Yield (lb./ins.^{2})	Before heating ..	21,000	31,000
	After heating ..	12,500	11,500
	% loss	40.5	62.9
Max. stress (lb./ins.^{2})	Before heating ..	41,000	51,000
	After heating ..	19,000	21,000
	% loss	53.7	58.8
Elongation %	Before heating ..	4.0	8.0
	After heating ..	21.0	23.0
	Increase	525	287
Yield / Max. stress	Before heating ..	51.2	60.8
	After heating ..	65.8	54.8
	% difference ..	+ 28.5	− 9.8

for unmodified 13 per cent. silicon alloy is 578 degrees C., and for the modified alloy 564 degrees C.). If sound and unsound bars had been heated it might have been possible to see some connection between the amount of visible trapped air and the degree of blistering.

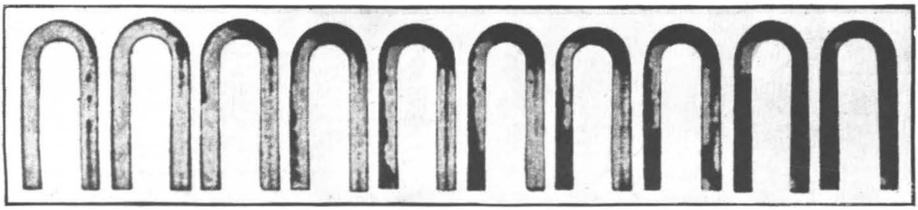


Fig. 5.—Progress of filling for a rounded U-type mould. Reading from left to right, the illustration at the extreme left shows the mould 6 x 10^{-3} secs. after pouring has commenced. Succeeding illustrations show the mould at intervals of 8.5 x 10^{-3}, 17 x 10^{-3}, 24 x 10^{-3}, 34 x 10^{-3}, 38 x 10^{-3}, 54 x 10^{-3}, 58 x 10^{-3}, 72 x 10^{-3} and 86 x 10^{-3} secs., the last illustration showing the mould completely filled.

Now let us turn to the results obtained from the heated bars. In the conclusions it is stated that "the presence of trapped air within the die cavity affects the metal which is forced to solidify in its presence in such a way that heat treatment of the cast metal is not feasible." In the first place it is hardly possible to draw such a conclusion when a non-heat-treatable alloy was used. In the second place, examination of the tensile results after heating (Table 6, "Light Metals," April, p. 186) shows that—

1. We have two kinds of bar, one of which (C) was unsound after being heated, while the other kind (C1) was sound. Presumably, then, the C bars have more trapped air and are therefore "not heat treatable." After heating for 60 minutes, however, the tensile strength of the C bar has dropped by 53.7 per cent., but that of the "sound" C1 bar has dropped by 58.8 per cent. The yield point of the C bar has dropped by 40.5 per cent.

against 62.9 per cent. for the C^1 bar. The elongation has increased by 525 per cent. for the C bar against only 287 per cent. for the "sound" C^1 bar. The ratio $\frac{\text{yield}}{\text{max. stress}}$ has increased by 28.5 per cent. for the C bar, but has dropped by 9.8 per cent. for the C^1 bar.

From this it would appear that the more "heat treatable" bars show much more depreciation in properties than the bars which proved to be radiographically unsound after being heated. The conclusion quoted above cannot therefore be justified. This conclusion continues: "By pressure die casting aluminium alloy in steel dies from which air has been forced, heat treatability of the metal so cast is assured." This method has not been tried, however, as in none of the shots was the air able to escape, and in view of the photographs of Koster and Jöhring all would contain some air.

Phase I, Table 2, Alloy No. 47. Shot type A-A^1. The physical properties of both A and A^1 bars were inferior to those of the test bars cast similarly, i.e., with the same size gate, but cast "in the absence of air," namely, E and C^1 test bars respectively. How can it be said that any of the bars was cast "in the absence of air" when in every case the mould was full of air and there were no vents? Moreover, one of the two classes of "superior" bars (E) had 20 per cent. of its number rejected as radiographically unsound; gas appears to have been picked up, then!

Shot Type B-B^1. It is presumed that "the test bars B^1 made in cavity GHI" should read "made in cavity CDE."

Shot Type C-C^1. It is interesting to see here that Erickson agrees with Koster and Jöhring that the metal which enters the cavity through a small gate fills the cavity from the end farthest from the gate.

Shot Type D^1. In explaining the superiority of B^1, C^1 and D^1 bars the writer says that this may be due to the fact that the metal "solidified in a preheated die cavity, i.e., due to a more pronounced temperature gradient between the die wall and the solidifying metal in the cavity." . . . "As the farthest part of the die filled up, new hot metal entered the die. Directly this metal came to rest there was a definite temperature gradient set up between the die wall and the centre of the test bar die cavity just filled with metal." The fact is, of course, that the temperature gradient becomes less. As new metal at 1,250 degrees F. (675 degrees C.) was pushed through the die, held at 400 degrees F. (200 degrees C.) the die was warmed up and the metal cooled. When the injection was complete there was new hot metal in contact with warmed-up die walls in cavity CDE, and cooler metal in contact with cooler die walls in cavity GHI. It appears probable that there would be less chilling effect in cavity CDE than in cavity GHI, and that one might therefore expect a modified structure in cavity GHI rather than in CDE. As Erickson says, the fact that this was not so may be due to the effect of a larger gas content in the metal in the second cavity.

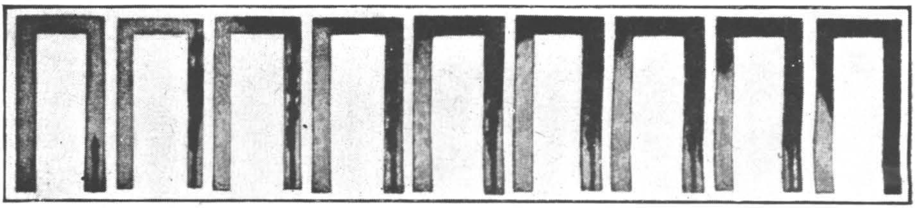


Fig. 6.—Filling process for U-type mould of rectangular form. Reading from left to right, the illustration at the extreme left shows the mould 4 x 10^{-3} secs. after pouring had commenced Succeeding illustrations show the mould at intervals of 8.5 x 10^{-3}, 16 x 10^{-3}, 21 x 10^{-3}, 31 x 10^{-3}, 41 x 10^{-3}, 55 x 10^{-3}, 63 x 10^{-3} and 85 x 10^{-3}. The illustration at the extreme right shows the mould at the termination of pouring.

Shot Type E-E^1. See the rounded U tube. The second bar should be at least as sound as the first. Erickson says: "Radiographs of all of the E-E^1 type shots showed that the region of maximum porosity existed within the cavity F." There was, therefore, porosity elsewhere, but 80 per cent. of the E bars and 40 per cent. of the E^1 bars were looked upon as radiographically sound (Table 2, "Light Metals," April, p. 183).

Shot Type F. It is said that the addition of an overflow produces a better bar. This is shown by comparing F bars (with overflow) with A bars (same gate but no overflow). It should be pointed out, however, that only 60 per cent. of the F bars were sound, against 70 per cent. of the A bars (Table 2, "Light Metals," April, p. 183).

Phase II. C-C^1 shots were made at increasing temperatures. It is stated that the properties of C^1 bars improved, and that those of C bars were unaffected. A few lines farther down, however, "as the temperature increased, the percentage of C test bars rejected due to the presence of porosity increased." How, then, can it be said that the properties of C bars were unaffected?

Phase III. It is not easy to see the object of these experiments. The metal was held at quite low temperatures, even the highest used (700 degrees C.) being less than is often required for making a pressure die casting. Moreover, instead of imitating die-casting practice by agitating the melt frequently, or taking some metal out and throwing it back, the melt is allowed to remain in the pot with its protective film of oxide unbroken. Under such conditions, when neither oxidation nor gas absorption can take place, and where " stewing " cannot cause reversion to the unmodified condition, because the metal is already unmodified, it is difficult to see how the properties of the bars could be materially affected.

Phase V. The scrapping of unsound bars and the conclusions to be drawn from a study of the tensile results obtained on tested bars have already been dealt with.

In view of the objection which may be found to the assumption that any bars have been cast " in the absence of air," and to the way in which bars have been tested as if they represented the results obtained under certain conditions when actually 60 per cent. may have been scrapped because of porosity, it is impossible to agree with the conclusions drawn.

1. The presence of trapped air does appear to affect the metal, but it is not clear what is meant by the heat treatment being feasible as no attempt was made to heat treat a heat-treatable alloy. It cannot be logically stated that " by pressure die casting aluminium alloys into steel dies from which the air has been forced heat treatability of the metal so cast is assured," because in no case has the air been forced from the die. When two substances with such low viscosities as liquid aluminium and air are thrown together at a high speed and under a high pressure it is impossible to keep them apart. Some intermixture must take place. Admittedly there is a great probability that the gas content of the metal in different parts of the die will vary, but that is very different from all the gas being in one part and none of it in another.

2. In view of the difficulty of judging the photomicrographs, and even of saying which is the best type for a casting made under conditions which do not allow normal crystallization, it is preferable not to comment on this conclusion, but to accept Mr. Erickson's statement.

3. In view of the fact that modification is carried out precisely to give better physical properties, it would have been very surprising if in these experiments the modified structure had not given better test-bar results.

4. This is practically the same as No. 2, as the adverse effect on the microstructure mentioned in No. 2 is probably caused by the internal porosity mentioned in No. 4. The reading of both these conclusions, however, suggests that turbulence alone can give porosity. How does this occur? The only way in which turbulence itself can occur is by metal being projected across some part of the mould where there is no wall to confine it. If this happens the metal must be in the presence of air, and therefore both air and turbulence have their effect upon the casting. It may be said that the metal coming along later would take the place of that pushed forward, and would therefore not be in contact with air, but this is not so. Turbulence can only be caused by a change of direction, and this means the presence of corners. It is most difficult to remove any gas from an enclosed space with corners, and it is therefore suggested that in no case have test bars been subjected to turbulence in the absence of air.

5. The conclusion that the presence of air in the die cavity " tends to prevent the normal eutectic aluminium-silicon alloy from developing the modified structure " is very interesting, and it would appear well worth while to carry out further work.

The impression gained, then, after careful reading and re-reading of Erickson's paper, is that, whilst the information obtained is useful it is impossible to draw such definite conclusions from it as Mr. Erickson has done. The reasons for this are:—

1. In his four classifications of conditions, only one can definitely be said to have existed, namely, confined air and turbulence. When injecting metal into an irregularly shaped cavity at about 11 tons/sq. in. there must always be turbulence. Also if one starts with a cavity full of air, and injects metal without releasing the air, there must always be air, and while it will be unevenly distributed it is impossible to imagine all of it being in one part of the die and none in another.

2. The scrapping of poor bars is a most serious matter and may have given an entirely wrong impression of the whole of the experiments.

3. Table 6 (" Light Metals," April, p. 186) does not in any way justify the assumption that the bars with higher gas content are " not heat treatable."

4. There is no justification for the assumption that the metal will enter the gate at I as a wide, even stream, and will act like a liquid piston.

In spite of the above the account of this work is very interesting, and it is hoped that Mr. Erickson will carry out a great deal more research work on the same subject. It is suggested that in view of the difficulty in anodizing pressure die castings, anodizing tests might also be carried out in addition to tensile tests.

Light Alloys in
Photocells, Rectifiers and Condensers

The Properties of Interleaving Papers are Critical, and, Physically and Chemically, are Related to the Electrode Metals. (Account continued from "Light Metals," 1945/8/292)

THE previous section of this article concluded a brief presentation of the characteristics of the metal-electrode materials (tin-coated paper, metallic tinfoils and aluminium foils). Before passing on to the dielectric materials, it is of interest to illustrate with figures some of the statements made concerning the lower electrical values exhibited by condensers having tin-coated paper electrodes. These are summarized in Table 43, and some explanation of them is necessary. For the comparison, the condensers were produced under conditions as closely identical as practicable. The need for this precaution becomes more and more apparent as one goes more deeply into the subject of condenser materials and processes.

Considering first batch Nos. 1, 2 and 3, the only material difference concerned the electrode materials, which are clearly recorded in the table. The paper employed was the same throughout, the same making from one source of supply. The impregnant, paraffin wax, was the same. Processing conditions were identical, the batches being made under production conditions at the same time in order that the influence, if any, of temperature and humidity would be equal. The only variation in processing from normal was extended pre-drying, this being decided by experience as desirable to ensure the best electrical results from the tin-coated electrode condensers. The electrical test results are average values, insulation resistance being determined on all condensers in each batch, and breakdown to destruction on a percentage. It will be seen that using tin-coated paper electrodes the characteristics are only 50 per cent. of the values obtained when aluminium foil is employed. Prior sparking of the tin-coated paper made no significant difference.

The remaining data in the Table, batches Nos. 4, 5 and 6, refer to similar trials using a different impregnant. This was a high-melting-point petroleum-hydrocarbon wax, the use of which gives a better temperature characteristic to the condenser, i.e., more stable capacity, power factor and insulation values between 20 and 60 degrees C. The results lead to the same conclusions, viz., insulation resistance is actually less than 50 per cent. of that for aluminium foil condensers, and electric strength about 60 per cent.

When tinfoil is used instead of aluminium foil, electrical values are obtained closely identical with those derived from the latter, and still about 100 per cent. higher than those from condensers having tin-coated paper electrodes. Electrically, therefore, the tin and aluminium foils are equivalent, and tin-coated paper inferior.

FIXED PAPER CONDENSERS

Paper Interleaving

The paper interleaving of a fixed paper condenser is the rigid medium that keeps the metal foil electrodes spaced at a predetermined distance apart from one another. It provides the means of carrying the

Table 43.—Comparison of Electrical Test Results on Condensers having Metal Foil and Metal-coated Paper Electrodes, measured at 60°F.

Batch No.	Type of foil	Number of foils	Number of papers	Type of impregnant	Insulation resistance, megohms/microfarad	Breakdown voltage, volts A.C.
1	Aluminium metal	2	4	Paraffin wax	9,500	1,050
2	Tin-coated paper	2	2	Paraffin wax	5,000	550
3	Tin-coated paper previously sparked	2	2	Paraffin wax	5,000	570
4	Aluminium metal	2	4	High melting mineral wax	10,500	1,100
5	Tin-coated paper	2	2	High melting mineral wax	4,500	700
6	Tin-coated paper previously sparked	2	2	High melting mineral wax	4,400	710

Table 44.—Summary of Types of Cc ndenser Paper Covered by Tests in Tables Nos.

Sample No.	Origin	Supplier	Composition	Appearance
1	American	A	Linen	Brownish, unbleached
2	American	B	Linen	Brownish, unbleached
3	French	C	Linen	White, bleached
4	French	C	Linen	White, bleached
5	French	D	Linen	White, bleached
6	German	E	Linen	White, bleached
7	German	F	Linen	White, bleached
8	German	E	Linen	White, bleached
9	British	G	Linen	Brownish, unbleached
10	British	H	Linen	White, bleached
11	British	H	Linen	Brownish, unbleached
12	British	H	Linen	Brownish, unbleached
13	British	H	Linen	Brownish. unbleached
14	British	H	Linen	Brownish, unbleached

dielectric impregnant of wax, jelly, oil or other fluid and, therefore, itself must, willy nilly, constitute a part of this dielectric. Bearing these features in mind as fundamentals, together with the service functioning requirements of the condenser, as well as the needs for satisfactory continuous production of the units, the salient quality characteristics of a paper tissue for the purpose can be enumerated. These are briefly listed as requirements below:—

(1) A thin tissue paper, as uniform in thickness as possible throughout its length and across its width.

(2) Availability in continuous length on reels.

(3) Uniformly wound with even tension and free from creases and tears.

(4) High mechanical strength, including tensile, bursting and tear strengths.

(5) High propensities for oil or wax absorption.

(6) Uniformity of fibrous texture and freedom from patches of matted fibre or extraneous inclusions that might lead to areas of lower wax or oil absorption.

(7) A paper of uniform compressibility and extensibility.

Table 45.—Physical Test Results on Condenser Papers.

Sample No.	Substance, weight basis, grams per sq. metre	Thickness, inches × 1,000	Density, grams per c.c.
1	13.0	0.50	1.02
2	12.2	0.49	0.97
3	12.8	0.46	1.11
4	10.1	0.37	1.10
5	13.0	0.49	1.08
6	12.8	0.41	1.24
7	12.0	0.50	0 95
8	12.5	0.40	1.24
9	11.8	0.47	0.99
10	11.6	0.49	1.01
11	12.0	0.43	1.10
12	12.1	0.49	0.95
13	14.1	0.50	1.13
14	10.5	0.40	1.01

(8) Freedom from chemicals or from any non-fibrous ingredients that impart low electrical insulation or electric strength, or which, in the presence of moisture, might ionise to yield electrically or electrochemically conducting products, or which may be soluble in the impregnating medium and thereby lower its electric strength and insulation, or impoverish its power factor or permittivity values.

(9) Freedom from any chemicals or other ingredients that may cause corrosion of the metal foil electrodes (aluminium or tin), during the process of manufacture of the condenser units, during shelf life or in service.

(10) Freedom from conducting particles, whether these be inclusions of metal or carbon, or whether they be slime spots.

(11) Freedom from pin-holes or porous patches.

(12) An electrical quality of paper, with high dielectric strength, high insulation resistance, low power factor, and high permittivity or dielectric constant.

(13) Constancy of quality in all these respects from roll to roll in the same batch, and from batch to batch.

The papers employed range in thickness from 0.0003 to 0.0005 in. for general purposes, with thicker gauges in much smaller quantity for a few special applications. These papers are extraordinarily pure in the chemical sense, mechanically strong and uniform both physically and electrically. After all is said and done, this raw material is only paper, and it must be stressed at the outset that it reflects much credit upon the effort, both research and industrial, of the producers, for the success they have achieved in maintaining control for the production of such an ordinary type of raw material in such high grade and to such a degree of precision.

The natural water supply in the district in which the paper is made has some bearing upon quality, for it is evident that this has to be used for preparing the pulp and for all washing purposes. Thus, in a peaty district where water is somewhat acidic, a paper may be slightly on the acid side of neutral, whereas in a chalky or limestone area, it will result in a slightly alkaline product. The paper is manufactured in the principal countries of the world, Great Britain, France, Germany, Japan, U.S.A., etc. It is usually found that paper mills specialize in this class of high purity, high strength, thin tissue paper, which has outlets for purposes other than for electrical insulation. Thus, similar material is used for transfers, such as employed for pottery, for cigarettes and for carbons. The manufacture of the actual carbons, or even of transfers, of course, needs to be segregated from insulation papers.

Up to about 15 years ago the lowest thickness of condenser paper generally available was 0.0005 in., and practically the whole of it was a linen rag tissue. Subsequent to that period, 0.0004 in. and 0.0003 in. thicknesses have become regularly available, and much wood stock paper has been used and established as satisfactory.

To convey some impression of the problems that are involved in the manufacture of condenser tissue, the following brief notes are given, outlining the procedure for the usual 0.0005-in. linen rag stock paper. The starting point is flax waste in the form of short ends from the carding machines, and it is hand picked to remove extraneous matter before it is passed forward for processing. The selected material is washed and then, to remove non-cellulosic, resinous or acid-forming components, it is heated with a suspension of milk of lime in steam-heated revolving drums. The time period for treating is something of the order of 12 hours. Alkali, soda or potash is not used for these treatments, because of its absorption and retention of the fibre. The liquor is then strained off and the fibrous residue pressed and passed through a mechanical operation in a machine known as a " devil," which pulls the fibres apart. Short ends are removed by sieving operations. Bleaching and washing operations follow, these being carried out in mixing machines. The pulp is then beaten in heated mixers. This is followed by a centrifugal operation for the removal of heavy impurities. It is stored as a concentrated slip in tanks provided with stirrers, and drawn from these and diluted with water for passing to the paper-making machines. On the way to the latter, a further centrifuging process is included in order to remove final traces of dirt or heavy particles. The usual felting, drying and calendering operations follow. Air conditioning of the buildings in which the open processes of the paper machine, during the drying and calendering, seem to be essential, at least with respect to dirt and other impurities. Carbon spots, due to soot in the atmosphere, are a common source of trouble, giving points of low electrical breakdown on test. Nevertheless, air conditioning does not seem to be generally practised, which is an evident weakness.

Apart from self-apparent factors of fibre composition, quality, with special reference to chemical impurities, and thickness, the electrical properties of the paper may be dependent upon the degree of beating to which the pulp is subjected, and are affected by the degree of calendering and the density and porosity of the finished product. Reference will be made to these factors later, but they are mentioned at this stage because it cannot be too strongly stressed that, in comparing the merits of various metal foils, for example, aluminium versus tin foil, by means of various electrical tests upon similar condensers made with them, the papers in these condensers must be identical. It is not sufficient to use papers that are the same on chemical tests and

Table 46.—Chemical Test Results on Condenser Papers.

Sample No.	Reaction	pH value colourmetric	pH value after 72 hrs. at 125° C.	Ash %	Moisture %	Alcohol soluble %	Water soluble %
1	Neutral	7.2	5.5	0.22	7.6	0.23	0.50
2	Neutral	7.2	5.4	0.16	6.7	0.58	1.57
3	Alkaline	9.0	8.6	0.92	6.8	0.42	0.58
4	Alkaline	8.6	8.5	1.27	7.0	0.57	0.62
5	Neutral	8.4	8.4	1.15	6.9	0.55	0.60
6	Neutral	6.8	5.5	0.60	6.5	0.42	2.50
7	Neutral	8.2	8.0	0.46	6.6	0.30	1.05
8	Alkaline	9.4	9.2	2.45	6.9	1.25	1.10
9	Alkaline	8.6	8.4	0.90	6.8	0.45	1.43
10	Neutral	8.4	8.3	0.18	7.9	0.28	0.73
11	Neutral	6.1	5.7	0.08	6.9	0.24	1.16
12	Neutral	8.0	7.8	0.25	8.0	0.40	1.15
13	Neutral	7.8	7.6	0.29	6.7	0.57	0.33
14	Neutral	7.9	7.8	0.28	6.5	0.75	0.45

Table 47.—Mechanical Test Results on Condenser Papers Before and After Dry Heat Test.

Sample No.	As received		After 72 hours at 125°C.	
	Tensile strength oz. on ¼" strip	Elongation %	Tensile strength oz. on ¼" strip	Elongation %
1	20.5	2.4	20.0	2.2
2	21.5	1.9	22.0	1.8
3	28.0	1.9	29.5	1.8
4	26.5	1.8	25.5	1.7
5	27.0	2.0	27.5	2.0
6	22.0	2.0	21.0	2.0
7	28.0	2.0	25.0	1.8
8	27.2	2.0	27.0	2.0
9	26.0	1.9	27.4	1.9
10	24.3	2.2	24.5	2.2
11	23.0	2.0	23.0	2.0
12	27.0	2.1	27.8	2.0
13	32.5	2.4	36.0	2.7
14	20.8	1.9	21.5	2.0

thickness. The condensers in each batch should be made from the same rolls of paper to ensure as closely as possible that paper, which has had the same degree of beating and calendering, is used throughout. This is just as essential as ensuring the same processing conditions. Otherwise, misleading results may be obtained and the wrong conclusions drawn.

Excessive beating is said to cause a tendency towards greater hydration which means better absorbency and, in consequence, a greater retention of undesirable chemicals during washing operations. The more hydrated the paper the greater is the difficulty in removing moisture from condenser units in the drying operations. The trend is thus towards lower insulation resistance values in the final condensers.

Experience, too, seems to indicate that the greater the calendering, the lower is the insulation resistance. On the other hand, as this should increase density and reduce porosity, one would expect better electric strength. This is not borne out in practice, although high density and low porosity are essential to high electrical strength. In short, these two qualities must be achieved by means other than by heavy calendering, i.e., such factors as fibre size and control of the paper-making operation itself have to be closely studied and controlled to provide for them.

These thin electrical papers present a different problem from the thicker ones employed in cable and coil insulation. These range from 0.00175 to 0.010 in. in thickness. Studies upon them have indicated that low density, highly porous types are to be preferred provided a high ratio of impregnant to paper is maintained. With the thin materials used for condensers, however, heavier beating of the fibre is entailed in order to get down to the thickness values, especially with wood stock papers and thicknesses as low as 0.003 in. If a high quality density paper can be secured without excessive beating, or with beating that only cuts the fibres rather than pounding and macerating them, then a low impregnation ratio should be tolerable, but as soon as much hydration of the fibre is permitted, a higher impregnation ratio is desirable in order to offset the impoverishment of insulation by the greater retention of moisture and of chemicals. In practice, however, the impregnation ratio is largely determined by process conditions, with special reference to the pressures imposed upon the units, the method of applying this pressure and the conditions obtaining when this is applied. It will be seen later when process is dealt with that the most favourable factors for these conditions, and for producing condensers of uniform quality to close capacity limits, do tend to a low impregnation ratio. Therefore, much reliance has to be placed upon the paper manufacturer, controlling both the beating and the calendering conditions very closely.

Much work has been done by condenser manufacturers upon condenser tissues with a view to establishing qualities most suited to their needs. Electrical testing has not yielded as much information as would be expected. The reasons for this are that it is very difficult, if not impossible, to test the material for insulation resistance, electric strength, power factor and permittivity, in the perfectly dry condition, and tests made under controlled humidities are not very informative because in a condenser the paper is in a thoroughly dry and impregnated condition. Chemical tests have proved more helpful, and it is largely upon the results of the intensive work by chemists that the modern methods of evaluation of condenser papers are founded. These researches have included simple physical tests which, too, have been found very useful in evaluation.

All this laboratory work has been carried out alongside closely controlled production, much of it with the use of pilot plants in which conditions could be varied, while still maintaining close control, so that the chemical and physical tests could be correlated with condenser quality; the latter included all the essential electrical values of capacity, electric strength, insulation resistance, power factor and permittivity.

Of the variety of tests used for this evaluation of condenser paper, the following gives brief details of some of the most useful.

Chemical quality is given major attention. Freedom, or degree of freedom from retained chemicals, is covered by reaction to indicator papers, pH value estimations on water extracts, amount of impurity extractable with water, or with alcohol, total ash on incineration, and, in more recent years, by taking water extracts and determining electrical conductivity and pH value electrometrically.

Physical quality is assessed from the substance, namely, weight basis, thickness and density, and, nowadays, by porosity. Mechanical properties are covered by tensile strength and elongation measurements, and sometimes additionally with bursting strength tests. Electrical tests are usually confined to breakdown values with alternating current on the material in the " as received " condition.

Ageing characteristics and resistance to heat are examined by subjecting specimens to a period of dry heat and then repeating the mechanical and electrical tests.

General features covered include the following:—

Fibre composition, which is determined by pulping the paper and examining microscopically. A small sample of the paper is torn into small pieces and boiled gently with diluted caustic potash (0.5 per cent. by weight) for a few minutes to remove non-cellulosic material. The paper is then thoroughly washed by shaking several times with distilled water till free from alkali. It is then pulped by shaking with water. The pulp is diluted with water and a small sample of the suspension is dried on a microscope slide for examination and assessment in the usual way.

Visual examination is made for pin-holes crossed fibres, slime spots, carbon spots metal particles and the like. Coloı generally shows whether the material bleached or unbleached.

The briefly mentioned list of tests req a little more amplification, on accou their importance, and, therefore, practical details are presented below.

The reaction test is usually carried ou indicated previously under the section dea ing with the electrode foils. Samples of the paper in contact with red and blue bibulous litmus paper, moistened with distilled water, are pressed between glass plates for a period of 10 minutes. The test pieces are examined carefully at the end of this time, when no signs of acidity should be evident, and not more than the slightest evidence of alkalinity. No double reaction or white spots on the litmus paper should be visible, as this indicates local contamination as with carbon or metal particles.

The pH value can be quickly determined colorimetrically. A 2 gm. sample in small pieces is placed in an Erlenmeyer flask; 100 ml. of hot, pure distilled water is added and the mixture simmered for 10 minutes. The liquid is decanted and made up to 100 ml. with the same water (to compensate evaporation losses). It is rapidly cooled and pH value determined colorimetrically with the standard B.D.H. indicators or their equivalent.

Ash is determined by complete incineration, carrying out the test slowly and carefully to avoid losses.

Table 48.—Electric Strength Test Results (Mean Values) on Condenser Papers Before and After Heat Test.

Sample No.	Electric strength volts A.C.			Electric strength volts A.C. after 72 hours at 125°C.		
	One thickness	Two thicknesses	Three thicknesses	One thickness	Two thicknesses	Three thicknesses
1	350	620	960	300	590	960
2	370	680	950	350	650	950
3	380	770	1,260	360	660	960
4	300	620	760	300	620	810
5	310	630	770	310	630	800
6	350	700	1,020	350	710	1,040
7	350	760	1,080	350	760	1,080
8	350	800	1,100	350	810	1,050
9	280	640	900	290	640	940
10	330	580	940	300	600	870
11	300	560	900	250	500	840
12	310	610	950	320	600	940
13	300	700	950	300	680	980
14	300	520	850	310	550	970

Table 49.—Average Values for Insulation Resistance of Condensers Made with Various Linen Base Papers.

Sample No.	Insulation resistance values, megohms/microfarad.	
	Average value	Remarks
1	6,500	—
2	14,500	—
3	3,000	Very high pH and ash values
4	9,500	—
5	5,500	—
6	1,000	High ash, very high water soluble values
7	400	Rather high water soluble, low density
8	1,000	Very high ash, pH and soluble matters
9	3,000	High ash and water soluble
10	3,500	—
11	10,000	—
12	3,000	High water soluble, low density
13	2,500	—
14	3,600	—

The water and alcohol extracts are standardized to six hours' period of hot Soxhlet extraction, syphoning approximately once in 15 minutes. The extracts are carefully evaporated to dryness, and dried to constant weight at 105 to 110 degrees C.

Total moisture content is sometimes determined, more as a value-for-money reason than for quality evaluation. It is determined by heating a sample to constant weight at 105 to 110 degrees C. and expressing the loss in weight as a percentage of the original weight.

Acidity or alkalinity are sometimes actually made on samples by extraction tests, followed by titration with N/100 alkali or acid respectively.

Substance is usually expressed in terms of grams per sq. metre, computed from the weight of an appropriate length of the paper. Several tests are made from samples taken at intervals along the roll, and from various rolls, and averaged.

Thickness is measured by micrometer measurement. It is usually taken on 10 superimposed thicknesses of the paper and taking the average of 10 readings.

Density is calculated from the weight and thickness values, from the relationship:—

$$\text{Density gms./c.c.} = \frac{\text{(Wt. basis in gms./sq. m.)}}{\text{(Thickness in inches)} \times 10000 \times 2.54}$$

Tensile strength and elongation are measured on a paper-testing machine, using a 7-in. acting length. Bursting strength is measured on an Ashcroft tester. The electric strength tests are instantaneous values with the A.C. voltage gradually raised to breakdown.

Typical heat test conditions for ageing include 72 hours at 120 to 125 degrees C., with the samples freely exposed in a hot-air oven.

In illustration of some of these points, test values have been briefly summarized in Tables 44 to 49 inclusive. The papers concerned were all linen base tissues from widely separated but reputable sources. Table 44 summarizes them, showing that both bleached and unbleached papers were included. Table 45 gives physical data, showing thicknesses from 0.00037 to 0.00050 ins., and calculated densities (on material in the condition " as received ") from 0.95 to 1.24.

Table 46 shows chemical results. PH values range from 6.1 to 9.4, ash from 0.08 to the very high figure of 2.48 per cent., alcohol soluble matter from 0.23 to 1.25 per cent., and water soluble matter from 0.33 to 2.50 per cent.

Table 47 deals with mechanical tests before and after conditioning by the severe heat test. No deteriorating effect of the latter is revealed. Table 48 covers electric strength tests on single, double and treble thicknesses, before and after heat test. It shows that this does not provide a discriminatory method of evaluation.

Table 49 gives average insulation resistance values from condensers made with these papers, all process conditions being

Table 50.—Dielectric Strength of Condenser Papers and of Corresponding Condensers.

	Breakdown voltage of 0.0004-in. condenser paper, volts (alternating current)											Average breakdown value of 1-mfd. condensers, using two sheets of paper between tinfoils; volts (alternating current)
	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4	Sample No. 5	Sample No. 6	Sample No. 7	Sample No. 8	Sample No. 9	Sample No. 10	Average	
Lot No. 4T ..	500	425	500	500	490	490	515	520	515	505	496	655
Lot No. 2T ..	490	490	290	275	500	490	485	495	500	500	451	679
Lot No. 7T ..	500	500	515	515	515	515	520	520	505	505	511	954
Lot No. 5T ..	520	520	535	525	530	520	525	525	535	520	525	1,024
Lot No. 1620T	590	570	590	780	560	630	560	730	630	620	626	1,603

Table 51.—Test Data on 0.0004-in. Condenser Paper.

Paper	Porosity of paper, cc.			Density of paper as received	Conducting paths per square feet			Average breakdown value of 1 mfd. condensers using two sheets of paper between tinfoils; volts (alternating current)
	Maximum	Minimum	Average		Maximum	Minimum	Average	
Lot No. 4T ..	18.9	6.7	9.7	0.980	7	2	4	655
Lot No. 2T ..	21.7	5.3	12.8	0.955	5	3	4	680
Lot No. 8D ..	10.9	0.9	4.4	1.020	8	5	6	945
Lot No. 7T ..	9.0	4.4	6.0	0.947	8	2	5	954
Lot No. 5T ..	4.5	1.7	2.6	1.014	5	4	4	1,024
Lot No. 3T ..	4.8	2.7	3.7	0.968	13	4	8	1,032
Lot No. 9D ..	13.4	2.5	6.2	0.980	15	10	12	1,060
Lot No. 1D ..	3.2	1.0	1.9	1.020	17	10	13	1,138
Lot No. 12P ..	3.1	0.7	1.4	1.160	18	11	13	1,275
Lot No. 13P ..	2.8	0.6	0.9	1.180	24	10	16	1,340
Lot No. 2D ..	8.9	1.6	3.6	1.000	10	5	7	1,430
Lot No. 162OT	2.9	2.7	2.9	0.956	19	16	17	1,603

the same as far as controllable over a period of time. In the remarks column, comments are made to explain low insulation values from the test results on the papers themselves. Nevertheless, they are not full explanations, nor can all electrical peculiarities be accounted for in this way. Thus, the explanation for the exceptionally low insulation value on sample No. 7 is not convincingly covered. On the contrary, the poor performance of No. 8 would be fully anticipated from the chemical characteristics of the paper.

In America, apparently the breakdown voltage of a condenser is regarded as a more discerning characteristic than is insulation resistance. From this angle they tend to disprove the importance of density and pay full attention to porosity in the condenser paper. Under equal conditions it may be, of course, that the production of higher density in a paper gives the low porosity value, but it is dangerous to assume this. The low porosity should be achieved by processing to give the right texture and uniformity, even if this gives higher density, but not by higher calendering which may introduce other undesirable features.

The question of porosity is both intriguing and important, and in view of this, together with the fact that control of porosity seems to be fundamentally a correct line of attack, a précis of Roman's original work will be given.

The Importance of Porosity in the Testing of Condenser Paper

The importance of the "porosity" of condenser paper and of having a uniform degree of porosity, was first pointed out by F. L. Roman in a paper to the American Society for Testing Materials, in June, 1930. The paper discussed the relationship between several characteristics of condenser paper manufactured from linen stock and the dielectric strength or breakdown voltage of condensers produced using this paper. The condenser tissues investigated were of 0.0004-in. and 0.0005-in. thicknesses and originated from American and foreign sources.

The conclusions drawn by Roman from the investigation included the fact that variations in density of paper exert no noticeable effect upon the breakdown voltage of the corresponding condensers. Conducting paths through the paper, when present in small numbers, were shown to have no important effect on the breakdown voltage of condensers having two sheets of

Table 52.—Test Data on 0.0005-in. Condenser Paper.

Paper	Porosity of paper, etc.			Average breakdown valve of 1 mfd. condensers, using two sheets of paper between tinfoils; volts (alternating current)
	Maximum	Minimum	Average	
Lot No. S_1	25.2	4.8	14.1	712
Lot No. D_1	22.0	2.9	11.6	747
Lot No. D_2	9.6	1.2	4.8	955
Lot No. S_2	6.4	1.6	3.1	1,280
Lot No. D_3	2.4	0.7	1.5	1,418
Lot No. S_3	3.8	1.5	2.3	1,671
Lot No. H_1	0.8	0.4	0.5	1,679
Lot No. H_2	0.6	0.2	0.4	1,712

Table 53.—Porosity Tests of Uniform and Non-uniform Condenser Papers.

0.0004-in. condenser paper, uniform in porosity—Lot No. 1620-T					0.0005-in. condenser paper, non-uniform in porosity—Lot No. 889-S				
Porosity, cc. (15 samples)	Ultimate dielectric strength of corresponding condensers, volts (alternating current) (50 units)				Porosity, cc. (15 samples)	Ultimate dielectric strength of corresponding condensers, volts (alternating current) (50 units)			
2.7	1,320	1,750	1,950	2,100	4.5	700	250	800	1,330
2.7	1,400	1,740	1,050	1,950	3.9	1,240	830	1,750	1,450
2.9	2,020	1,460	1.280	1,520	5.1	510	1,240	640	1,440
2.9	2,400	1,380	1,040	1,540	5.5	690	1,080	800	610
2.9	1,460	1,660	2,160	1,550	4.2	660	1,350	1,190	710
2.9	1,640	1,760	1,800	1,150	5.0	520	580	1,120	850
2.9	1,800	1,750	1,500	1,190	16.0	660	1,070	810	1,440
2.9	1,150	1,320	1,250	1,920	15.4	660	400	1,330	250
2.9	1,020	1,750	1,940	1,460	18.4	550	560	480	420
2.9	1,220	1,950	1,860	1,440	16.2	860	1,220	720	1,240
2.7	1,850	1,580	1,720	1,960	14.9	650	1,720	1,220	970
2.9	1,380	2,120	2,000	—	14.9	700	1,230	700	—
2.9	1,480	1,400	1,440	—	3.9	1,170	580	500	—
2.9					4.1				
2.9					4.0				
Average .. 2.9	Average 1,603				Average 9.1	Average.. 889			
Maximum 2.9					Maximum 18.4				
Minimum 2.7					Minimum 3.9				

paper between the metallic foils. However, the percentage of short-circuit condensers or of those failing at low voltages is expected to increase approximately as the square of the number of conducting paths

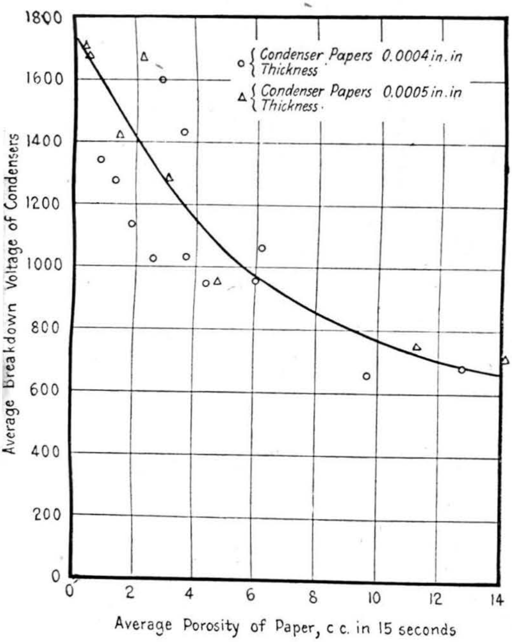


Fig. 181.—Relationship between porosity of condenser paper to breakdown voltage of condensers, using two sheets of paper between metallic foils. (See Tables 51 and 52.)

per unit area of the paper. On the other hand, variations in porosity of the paper were shown to have a marked influence on the breakdown strength of the corresponding condensers and, from the work carried out, Roman put forward recommendations on the porosity requirements for papers for use in low-voltage condensers and for those employed in high-voltage condensers.

The fundamental reason for the work arose from the fact that with the increase in production requirements for condensers, the quantity of condenser tissue employed became very large and yet no adequate test methods had been applied to ensure that satisfactory paper could be evaluated at the inspection stage, in order to guarantee the manufacture of condensers to meet specified electrical requirements. Production trials by actually making batches of condensers were necessary and it could not be assured that by this means the influence of paper quality could be interpreted due to the influence of processing technique or variations in it under manufacturing conditions. The work entailed, therefore, a study of the characteristics of condenser papers and an attempt to correlate them with electrical characteristics in the product produced under controlled conditions.

The investigation studied properties of electrical strength, conducting paths, density, and porosity, all measured on the papers, and correlated these with electric strength in the finished condensers. Each of these items is dealt with briefly below.

Electric Strength of the Paper

In Table 50 are given Roman's results on electric strength of condenser papers and the average values for the corresponding condensers of 1 mf. capacity, manufactured with two sheets of paper between the tinfoil electrodes. From this can be seen the influence of papers of low breakdown voltage and of high breakdown voltage. For making the measurements on the papers, the various samples were all conditioned together for one hour at 105-110 degrees C. and kept in the desiccator until required for breakdown test. In the actual test two sheets of paper were removed together from the desiccator and placed between two sheets of tinfoil; this pile-up was tested immediately between brass electrodes with flat polished contact surfaces in accordance with A.S.T.M. methods. The electrodes were cylindrical rods, 2 ins. in diameter, and had the contact surfaces rounded to a radius of one-eighth the diameter of the electrodes and they were arranged to transmit a constant pressure of 15 lb./sq. in. to the pile-up. The condensers themselves for test were all made together under as nearly as possible the same conditions and were impregnated with the same material.

Tests were also made on condenser papers conditioned for 24 hours at 65 per cent. humidity and 21 degrees C. immediately prior to testing. The electric strength values obtained were found to be in the same relative order as for the dried papers. The electric strength tests, however, were not considered entirely satisfactory because check tests showed that slight differences in the methods of sampling or in the test determination itself, could easily cause greater variation than shown by the papers themselves as revealed by the test results given in Table 50. It was concluded that comparative electric strength tests give a slight indication of the comparative dielectric strength of condensers produced with them, but that the method of testing is not suitable for routine testing and for showing whether a paper is capable of producing a condenser of specified breakdown voltage.

Relation between Conducting Paths in the Paper and the Electric Strength of Condensers

Consideration of the number of conducting paths per unit area of the paper is logical and Roman points out that paper manufacturers have directed their main attention towards reducing these conducting particles. In commercial papers, he gives 30 per sq. ft. as the limit rarely exceeded, the A.S.T.M. test method being employed. On the assumption that the average conducting path is effective over an area of 1-32 in. diameter, and that a total of 12 sq. ft. of paper are required in a 1-mfd. condenser, having two papers between metal foils, the probability that two conducting paths will come in contact when each paper has 30 such paths per sq. ft. is approximately derived from the following formula:—

$$\frac{\text{Area of conducting path in sq. ins.} \times \text{No. of sq. ft. of paired paper in condenser} \times \text{Sq. of No. of conducting paths per sq. ft.}}{144} =$$

$$\frac{\frac{\pi}{4}(1/32)^2 \times 6 \times (30)^2}{144} = \frac{4.142}{144} = 2.88 \text{ per cent.}$$

With 10 conducting paths per sq. ft. the probability would only be 0.32 per cent., or about 1 in 300.

The assumptions made in deriving the formula are only approximately correct and, further, a portion of the paper extends beyond the metallic foils. Again, it has to be assumed that the conducting paths still exist after the impregnation of the condenser unit. Nevertheless, the formula serves to show the number of condensers that may be expected to fail at very low voltages due to conducting paths in the paper, and that this number is small if the number of conducting paths per sq. ft. is kept within the usual range.

The influence of conducting paths on the electric strength of the corresponding condensers, when the conducting paths do not meet in the paired papers, is not so well known. In Table 51 data is given which shows that condensers having high dielectric strength can be produced using paper in which the number of conducting paths is within the usual range. Thus, papers of lot Nos. 1620T and 2D showed the best dielectric strength in condensers and had 17 and 7 conducting paths respectively, whereas papers in condensers which broke down at lower voltages had fewer conducting paths. Roman points out that it would be absurd to assume that an increase in the number of conducting paths would be beneficial to the dielectric strength of the condensers and it is evident that the better electric strength of condensers made from paper, having the higher number of conducting paths, is due to the paper concerned being of better quality in some other respects.

Relation between Density of Paper and Electric Strength of Condensers

The data in Table 51 also indicates that the average apparent density of the condenser paper has no important effect upon the electric strength of the corresponding condenser. For example, papers lot Nos. 2T and 1620T have approximately the same density, whereas the condensers made from them showed average breakdown voltages

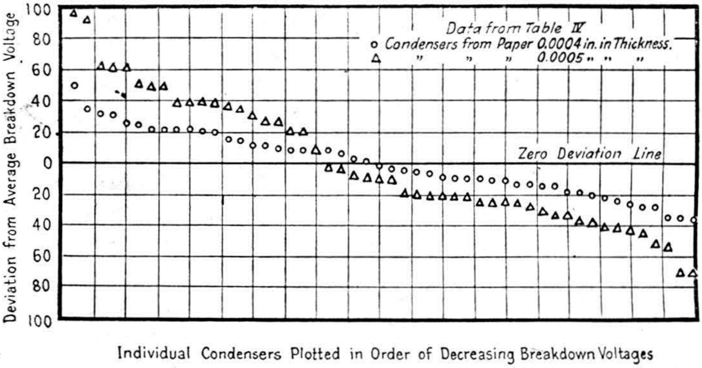


Fig. 182.—Percentage deviation of the breakdown voltage of the individual condensers from the average breakdown voltage of the corresponding lot.

of 680 and 1603 respectively. Again, paper No. 1620T was among those of lowest density and highest area per lb. and yet it gave condensers having the highest electric strength.

Roman points out that these findings are contrary to the usual understanding on other insulating papers and suggests that changes in density and in other characteristics of the paper, such as degree of hydration, affect the degree of penetration of the impregnating material. It may also tend to prevent thorough drying and complete impregnation. Consequently it is possible that an increase in density would be detrimental rather than beneficial, under production conditions, even though high density were found to be advantageous for unimpregnated or thoroughly impregnated papers.

Relation between Porosity of Paper and Electric Strength of Condensers

The influence of porosity is shown in the data in Table 51 and more completely by that given in Table 52 and represented graphically in Fig. 181. These definitely indicate that, in general, condensers of low dielectric strength are produced from paper of high porosity and condensers of high dielectric strength are produced when paper of low porosity is employed. Fig. 181 shows the average relation between porosity of the paper and the breakdown voltage of condensers under the particular conditions of manufacture encountered. It is known that variations in manufacturing process of the condensers account for some of the apparent discrepancies in breakdown voltages obtained on condensers made with papers of about the same porosity. It is also to be expected that the electric strength of condensers produced under manufacturing conditions will be lower than those produced under ideal laboratory circumstances.

Using papers of American and other sources, Roman records that over a period when several million condensers were produced, no instance occurred in which condensers of high breakdown value could not be produced from paper of uniform low porosity or in which high electric strength condensers could be produced from papers of high porosity. All these condensers were wound from paper having apparent density from 0.9 to 1.2 and conducting paths from 2-25 per sq. ft. and used two papers between metallic foils.

Not only is low porosity necessary, but reasonable uniformity of the paper from the point of view of porosity is desirable. Non-uniformity in porosity corresponds to lack of uniformity in the formation of the paper sheet. When the paper only shows a small percentage of its area with high porosity spots there is little danger of the spots coming in contact when the paper is paired. If the percentage of the area of the paper which is of high porosity is large, a considerable portion of the paper will break down at low voltages.

This is shown by the information in Table 53. Paper lot No. 1620T of thickness 0.0004 in. is of low porosity and exceptionally uniform. Paper No. 889S, which is 0.0005 in. in thickness, is non-uniform in porosity. The condensers made with the first of these papers are all of high electric strength and the breakdown voltage of the best unit from this lot is less than 2½ times that of the poorest unit. The condensers made from the second paper range from very poor to very good with the breakdown voltage of the best unit seven times that of the poorest.

The percentage deviation of the breakdown voltage of each individual condenser from the average breakdown voltage of the corresponding lot is shown graphically in Fig. 182. The condensers made from the 0.0004-in. paper of uniform porosity are grouped much more closely along the zero deviation line than the condensers made from the 0.0005-in. paper of non-uniform porosity. This close grouping to the zero line is an important characteristic if condensers are to be used close to their rated value because it is evident that condensers with the closest grouping must show the smallest number of failures.

The data presented indicates that thickness does not improve breakdown voltage of the condenser unless the increased thickness of paper is from a material of low porosity. It would be expected that it would be less difficult to make thicker paper of lower porosity, but papers of 0.0005 in. in thickness have not been appreciably better than those of 0.0004 in. from the viewpoint of porosity. Further, in general, condensers made from 0.0004-in. material have shown approximately the same average electric strength as those made from 0.0005-in. material.

Method of Determining Porosity

Roman's apparatus for determining porosity is a modification of one previously designed by the Westinghouse Electric and Manufacturing Company, and has the advantage that, except for the clamping device, it can readily be assembled from components obtained from the normal apparatus suppliers. The clamping device itself is simple and easily made. Any adjustments that are necessary are made in the connections to maintain the air space from the 0 cc. reading of the burette to the paper in the clamp at approximately 11 cc.

The apparatus is used as follows:—

The stop-cock is opened, approximately 250 cc. of water are poured into the aspirator bottle and the height of the bottle is adjusted to give a reading of 0 cc. in burette with the water in the burette and aspirator at the same level. Holder is fixed to hold the aspirator in this position. The aspirator bottle is then removed from this holder and with the stop-cock still open it is lowered until the burette reading is 88.7 cc., again with the water level the same in the burette and in the aspirator. The ring holder is fixed to hold the aspirator bottle in this position. The apparatus is then ready for operation.

With the aspirator in the upper position and the water in the burette reading 0 cc., the sample of paper to be tested is inserted between the jaws of clamps and the wing lever is tightened. The stop-cock is closed and the aspirator placed in the lower holder. The stop-cock is then opened for 15 secs. and re-closed. The aspirator bottle is raised until the water in the bottle and in the burette are on the same level and a reading of the number of ccs. of air which have been drawn through the paper is recorded. This is the porosity value of the sample.

Routine tests for porosity are made of paper held under ordinary room conditions, but for close checks tests are made immediately after conditioning for 24 hours at 65 per cent. humidity and 70 degrees F. For the inspection of large batches of paper of reasonably uniform quality, three samples from each of five rolls taken from each 2,000 lb. of paper are considered a sufficient check. For non-uniform papers, or those from unknown sources, the number of samples should be from 5-10 times more numerous.

Control of Porosity of Condenser Paper

The porosity limits naturally depend upon service requirements of the condensers. Most condensers having two papers between foils are used in service at low voltages and for such condensers a reasonably uniform paper with a maximum average porosity of 6 cc. is expected to yield condensers of adequate electric strength. Higher porosity can be tolerated for very low voltages, but there are very few instances where such paper can be used with advantage.

It has already been stressed that not only must maximum porosity be controlled, but also average porosity, and it is suggested that in stipulating a maximum average porosity of 6 cc. this can be qualified by specifying not more than one reading in 15 to exceed 8 cc.

For condensers for use at high voltages it is advantageous to select papers of lower porosity. For example, maximum average porosity of 3 cc. with not more than one single reading in 15 greater than 5 cc. is suggested as adequate safeguard. Stricter requirements do not seem justified, nor could they be generally met by paper manufacturers.

Conclusion

Roman's conclusions from his investigations are to the effect that variations in density of condenser paper have no noticeable effect upon the electric strength of corresponding condensers. Specification requirements for minimum apparent density seem, therefore, to be unnecessary. Conducting paths in small numbers, likewise have no important effect when the condensers consist of two papers between the metallic foils. Nevertheless it is desirable to ensure that the number of conducting paths is small. Variation in porosity is important in relation to electric strength and reasonable uniformity in this respect, together with a low porosity value, is advantageous.

Roman's work is very convincing and further consideration will be given to this aspect in the next section. Nevertheless, it is stressed that the porosity characteristic does not cover all quality aspects of condenser tissue, and of these the chemical features can by no means be neglected!

(To be continued)

LIGHT-ALLOY BICYCLES

An Account is Given of the Early History of the Aluminium-alloy Bicycle, Together with a Discussion on the Theory and Practice of More Recently Developed Models

THE problem of satisfactory bicycle design is not an easy one to discuss. It is simple to ask what constitutes a good bicycle, but much more difficult to provide a satisfactory answer. An explanation in general terms, such as performance, reliability, response and finish can readily be framed to meet the approval of the

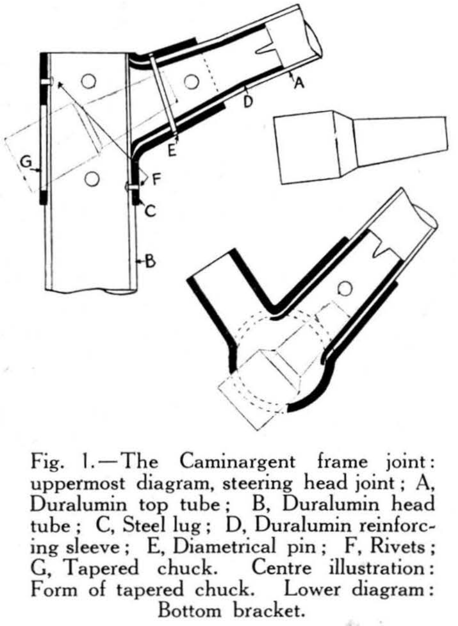


Fig. 1.—The Caminargent frame joint: uppermost diagram, steering head joint; A, Duralumin top tube; B, Duralumin head tube; C, Steel lug; D, Duralumin reinforcing sleeve; E, Diametrical pin; F, Rivets; G, Tapered chuck. Centre illustration: Form of tapered chuck. Lower diagram: Bottom bracket.

majority of cyclists or would-be cyclists, but 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, or, if so, it must clearly be reposing in some confidential file, since no such analysis appears to have been published.

However, in the absence of any better basis of discussion, let us examine these requirements, as typified in general terms, and see how light metals fit into the picture. First, let us consider performance. In any machine economy of effort is always a desirable factor. In the case of the bicycle, its importance is magnified many times by virtue of the limited motive power available. Human effort will obviously vary

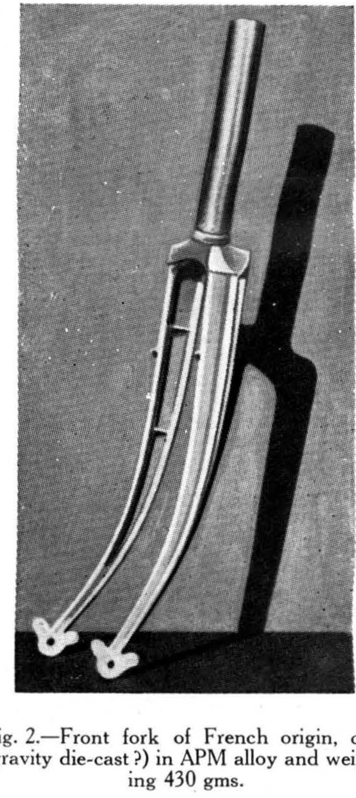


Fig. 2.—Front fork of French origin, cast (gravity die-cast?) in APM alloy and weighing 430 gms.

from one person to another, but in all cases it is desirable to approach as closely as possible to a condition of effortless riding. The effort which has to be made to propel

Note.—Textural references to the illustrations contained in this part of the account will be found in the concluding sections which will appear in the August issue of "Light Metals."

a bicycle at a given speed along a level surface depends on a number of factors, some of them extremely complex to define. The type and condition of the tyres, the gear ratio employed, friction in the bearings, the road surface itself and wind resistance are important factors not all of which can be influenced by the use of light-alloy construction.

It is probable that reduction in weight does reduce frictional resistance both in the bearings and between the tyres and the road; it may also enable the use of narrower tyres, with an inherent reduced frictional resistance. It is interesting to note that, in one case, weight was saved by the use of light-alloy construction to enable an aluminium-alloy wind shield to be fitted over the whole of the front of the bicycle, thus reducing wind resistance.

But it is when we come to consider the influence of weight on effort in cycling up an inclined surface that the value of lightness becomes most apparent. Few roads are level for more than a few yards, and only a small incline is required to increase the cyclist's effort to a marked extent. The increased effort required to maintain a uniform speed is actually W Sin α where α is the angle of inclination of the road surface to the horizontal and W is the weight of the machine, plus the rider. The increased effort is, therefore, directly proportional to W, so that the weight of the machine becomes a significant factor in determining performance on the road. Other advantages which accrue from weight reduction in a bicycle are more rapid acceleration for the same human exertion, and better braking, or, alternatively, lighter brakes may be fitted, lessening still further the weight of the machine. It is important to note that the time lost by a reduction of average speed by, say, 2 m.p.h. on an up-hill stretch of road cannot be regained by a 2 m.p.h. increase of average speed on a downhill stretch of equal length, so that, on an undulating road, lightweight construction results in an increased average speed of travel. It also reduces fatigue, as it is an established fact that effort steadily applied is less tiring than one which has to be varied according to the road conditions encountered.

It is obvious, therefore, that lightweight construction in a bicycle is advantageous, and it is not surprising to find that light alloys and, to a smaller extent, the ultra-light alloys, have been employed for this purpose. The different methods which have been employed, and the extent to which aluminization has been successful, will be reviewed later.

Let us now consider the remaining general factors; first, response. Presumably, response means the mental interpretation of the mechanical link between the feet, transmitting the brain's stimulus of effort required, and the immediately subsequent sensation of movement. Presumably, rapid acceleration, easy running characteristics, and small drag on inclines are important factors leading to what might be called good or ready response characteristics in a lively mount. As has already been shown, lightweight construction is advantageous in promoting these characteristics and, therefore, it may be implied that, from some points of view at least, the lightweight bicycle would be a more responsive mount than a heavier and more sluggish steel machine.

In practice, however, the light-alloy bicycle has sometimes been criticized on the very grounds of poor response. Light-alloy cranks have been said to deflect to a greater extent than steel cranks under the pressure applied by the feet and to give rise to a feeling of sluggishness and insecurity. This is only what would be expected of light-alloy replicas of steel cranks, and points directly to poor design. Both the aluminium- and the magnesium-base alloys are possessed of lower moduli of elasticity than steel, and, in consequence, it becomes necessary to increase the section of light-alloy components in order to retain the rigidity associated with their steel prototypes. It is important to note at this juncture that the densities of the light and ultra-light alloys on the one hand and of the various commercial steels on the other hand differ to a greater extent than the moduli of elasticity, so that it is possible to design light-alloy components with a rigidity equal to that of the corresponding steel member, but still with considerably less weight.

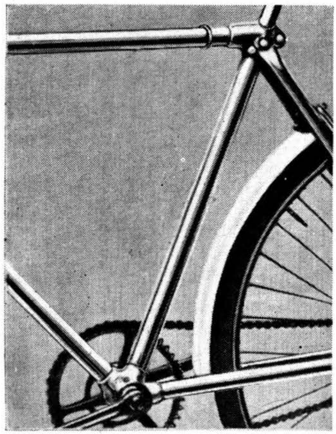


Fig. 3.—Part view of the Delage cycle frame (1930), showing novel method of overcoming assembly difficulties by means of special lugs.

Another objection, also resulting from the low modulus of elasticity of the light alloys, has been raised regarding the " whip " of the aluminium-alloy frames. Some whip is always desirable, if only to absorb road shocks, but complaints have been made that aluminium alloys carry this property too far. Here, again, the problem would seem to be largely bound up with design and method of fabrication. The fact that satisfactory frames have been built in small quantities would lead one to anticipate that this problem, even in the case of mass-produced frames, is by no means insoluble.

With regard to reliability, light alloys are at some disadvantage in view of their relatively low fatigue strength, but where the highest stresses are involved, as in the frame, designs have taken this factor into account with such success that the drawback of fatigue can be eliminated from the present discussion. On the road now are bicycles incorporating light-alloy components which have been ridden hard for 10 years or more without any other troubles and breakdowns than are normally encountered with conventional " all-steel " machines. From the point of view of corrosion resistance, the light alloys are infinitely superior to the ferrous metals. As for finishing, apart from dyed anodic coatings, satisfactory methods of chromium plating have now been evolved; light alloys can be painted and enamelled like steel components and they can be celluloid covered when required, as for handlebars. From these points of view, aluminium-base alloys are certainly not inferior to steel and brass in regard to quality and attractiveness of finish possible. Their inherent corrosion resistance and attractive silvery appearance, on the other hand, allows both the aluminium- and the magnesium-base alloys to be used in the polished but unpainted and unplated condition, while the appearance of dyed anodized aluminium is something which cannot be matched in any other material.

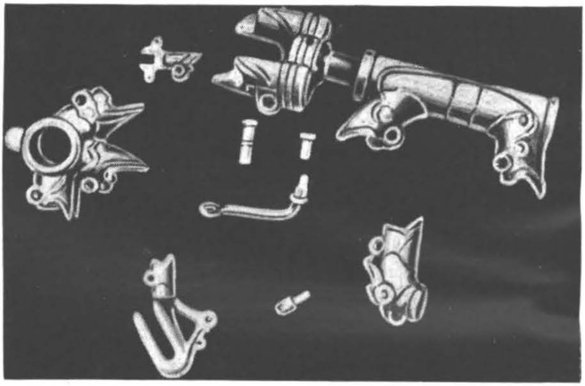


Fig. 4.—Component parts of the all-light-alloy Caminargent bicycle.

Historical

The history of the aluminization of bicycles begins concurrent with the commercialization of aluminium. In **1893**, Clement, in Paris, exhibited racing models with hubs of unalloyed aluminium, whilst, even before **1896**, aluminium frames were in use on some French machines. A cycle manufactured by MM. Cycles San Soudures En Lu-mi-Num, Paris, and introduced into this country in **1896**, will be illustrated. Excluding the front fork, the frame of this machine was cast in one piece in light alloy. Only recently has the casting technique again attracted attention.

About the year **1904**, extensive experiments began to be made on the use of aluminium alloys in the form of sheet and castings. At that time, bicycle manufacturers had not been established for many years, and they were definitely interested in methods of reducing the weight of their manufactures, a procedure which they recognized to be distinctly advantageous. As a result, gearcases, wheel rims, mudguards, chain guards, seat castings, lamps, locks and parcel carriers were all fabricated in pure aluminium or in aluminium alloys for use on the heavy and cumbersome machines which, however, were considered to be the last word in design in those days. Even aluminium frames and gearcases were produced, cast in one piece in heated iron moulds, with front and rear forks, handlebars and seat pillars as separate castings. However, light alloys in **1904** had by no means reached the same stage of development as they have to-day. Casting technique was poor and, in any case, castings are not always the best form in which to use light metals. It is not surprising, therefore, to find that interest in the light alloys died out as improvements began to be effected in the steel tubing available, which made the advantages of aluminization less apparent with the somewhat primitive fabrication techniques employed at that time.

(To be concluded)