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LIGHT METALS

MAY
1945

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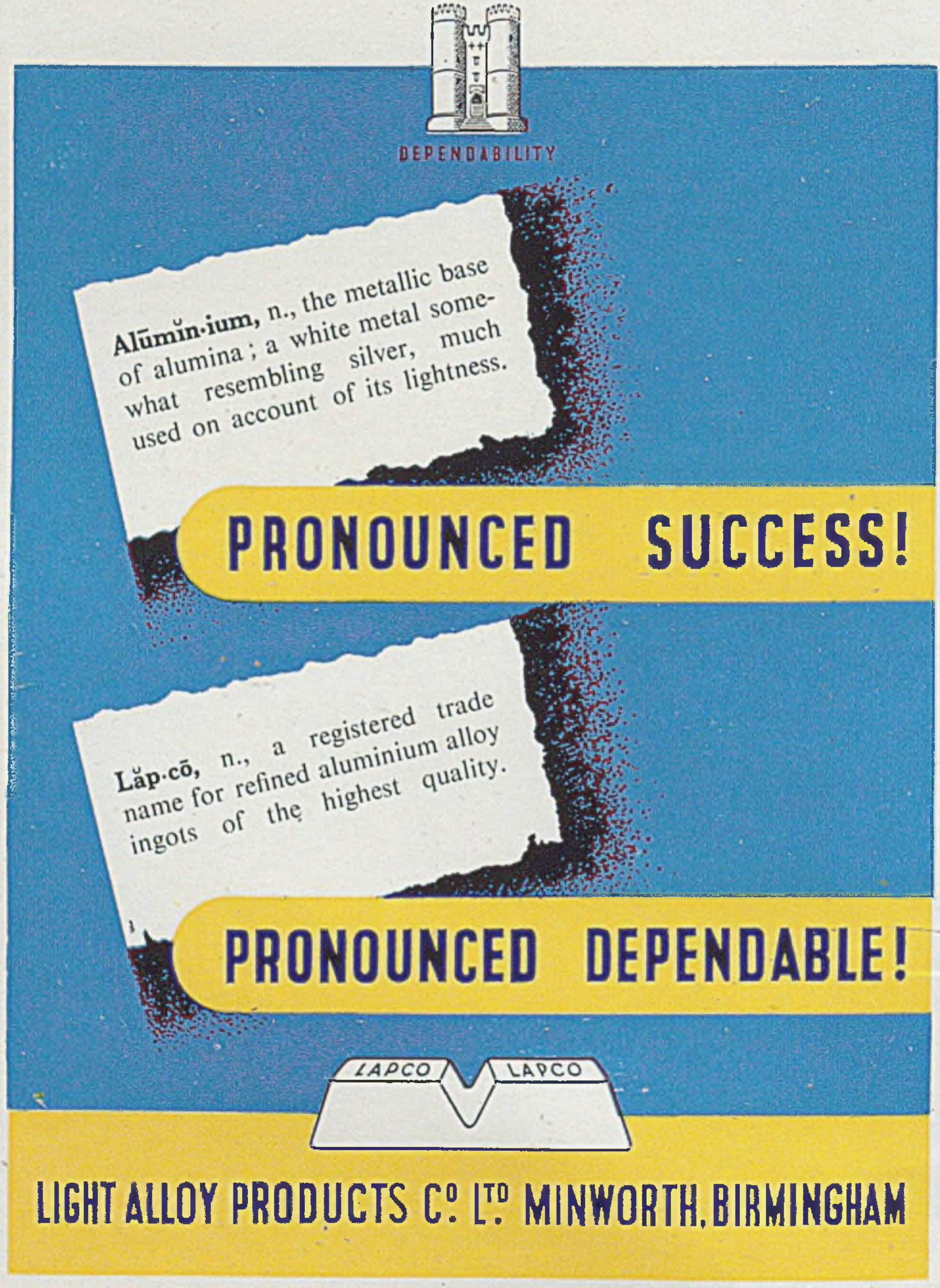


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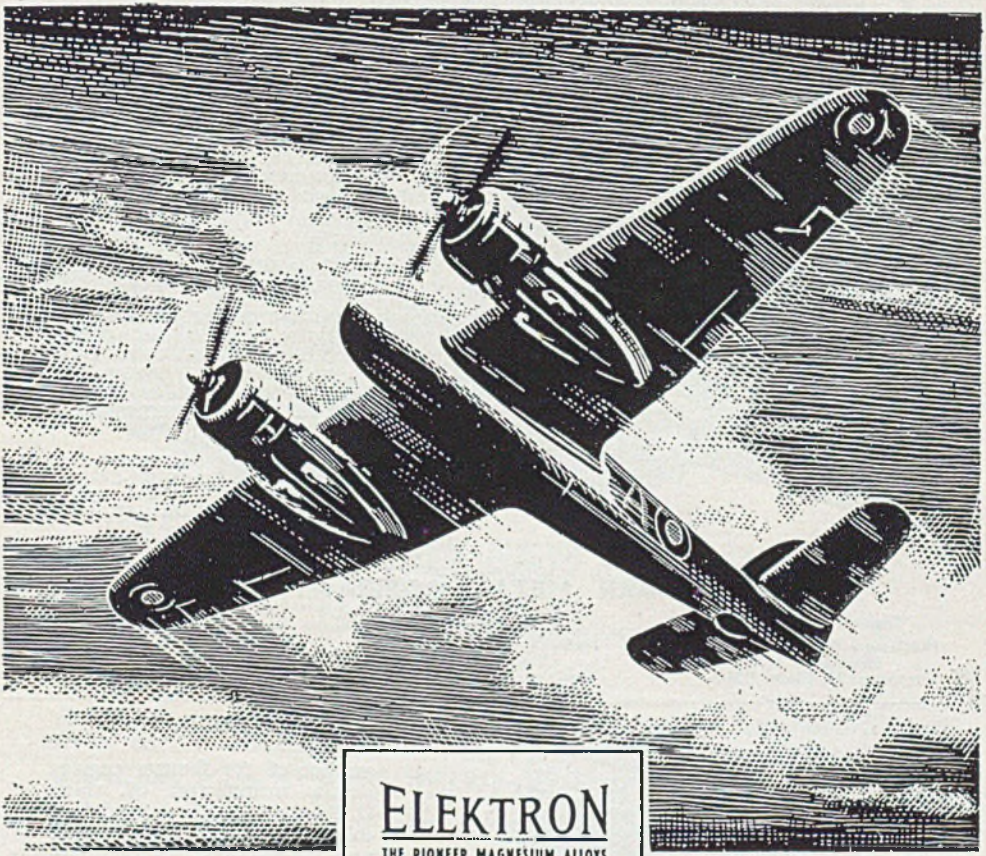


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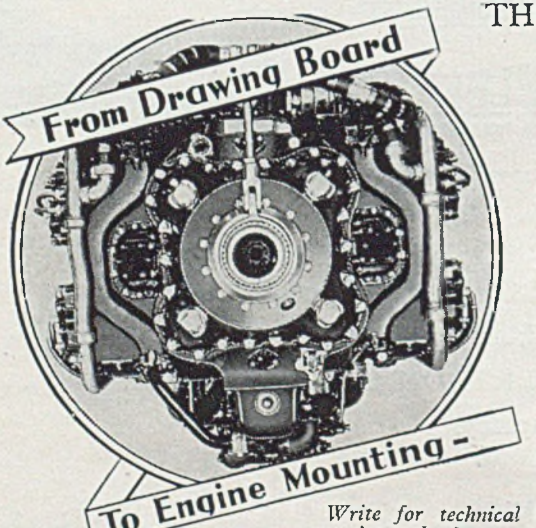
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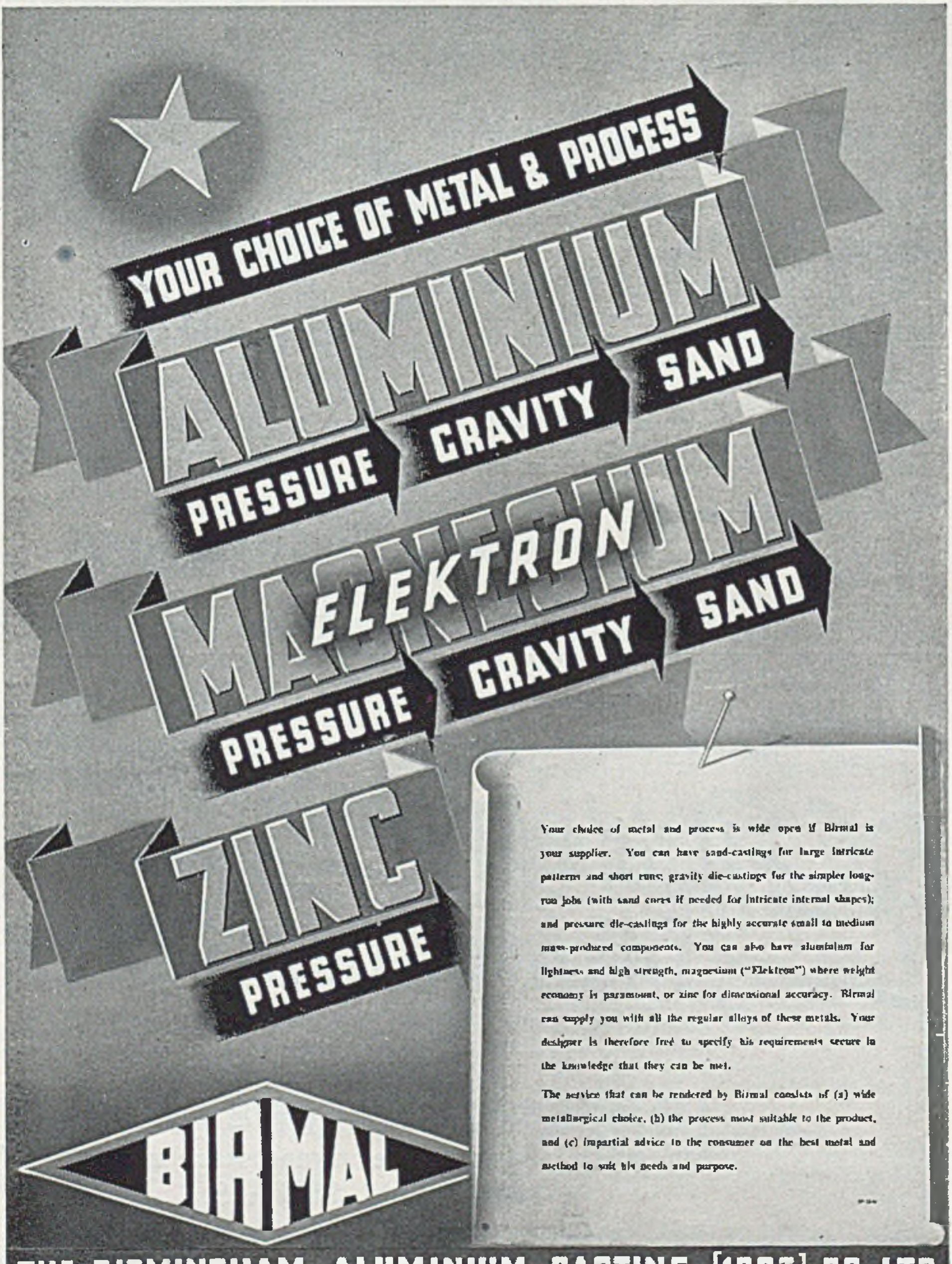

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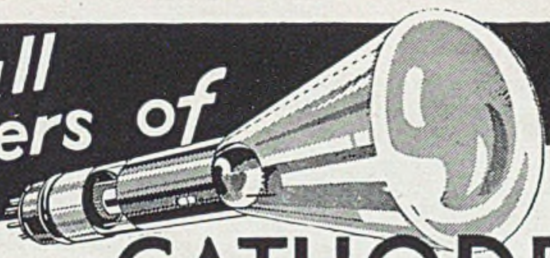

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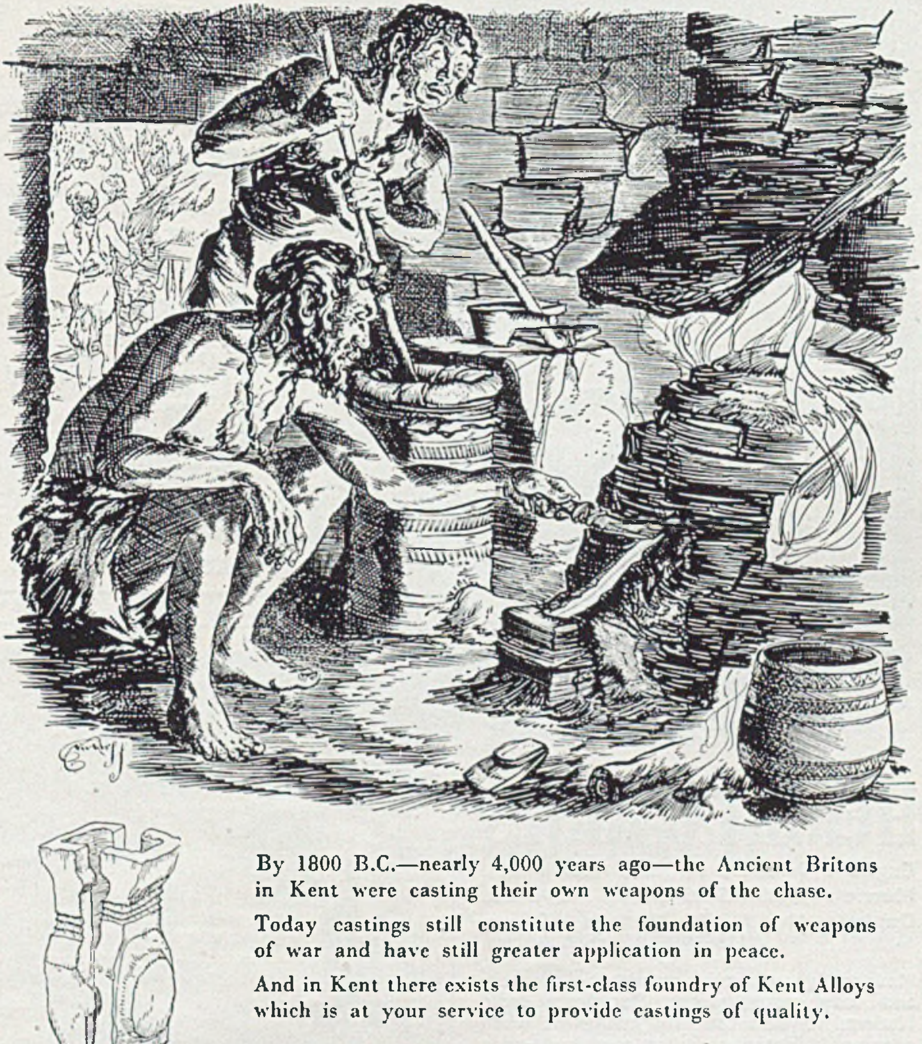

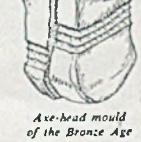

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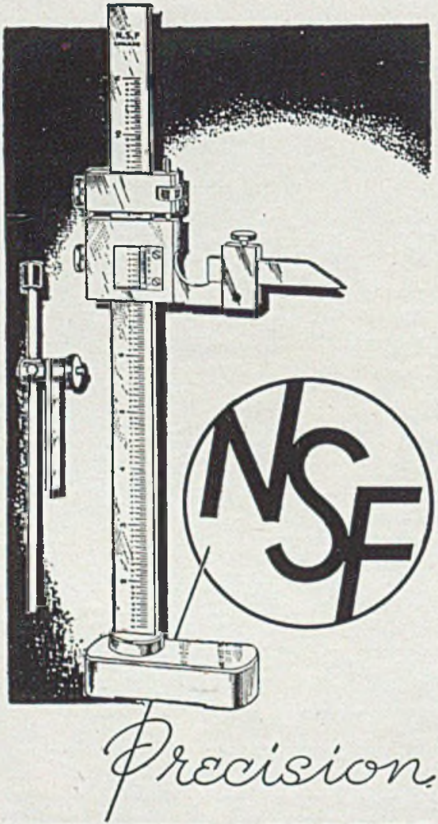
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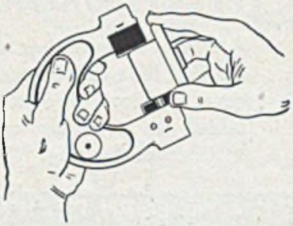

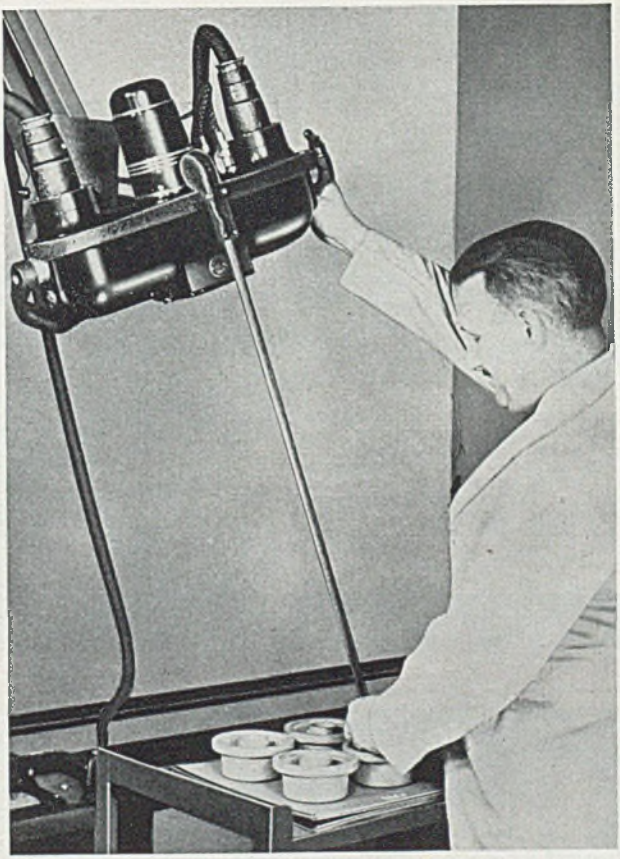


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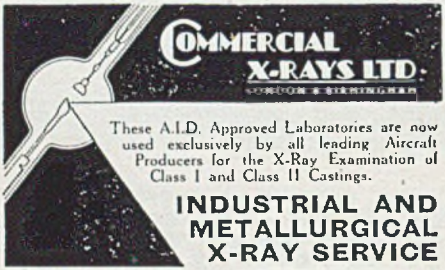
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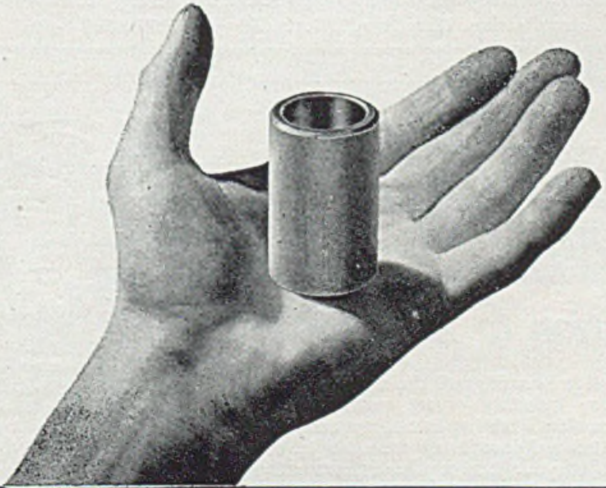

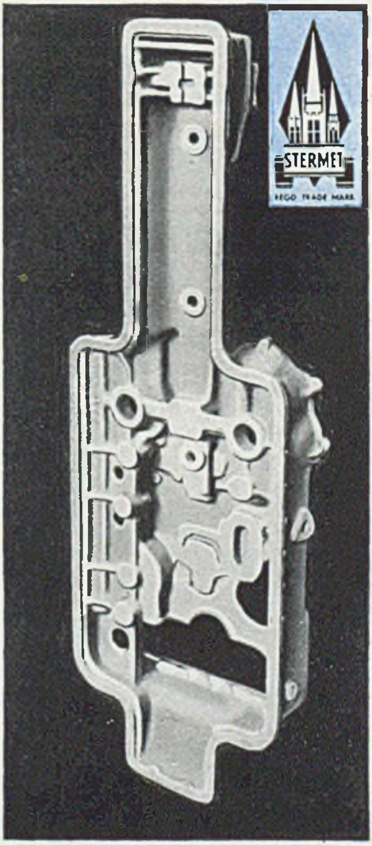

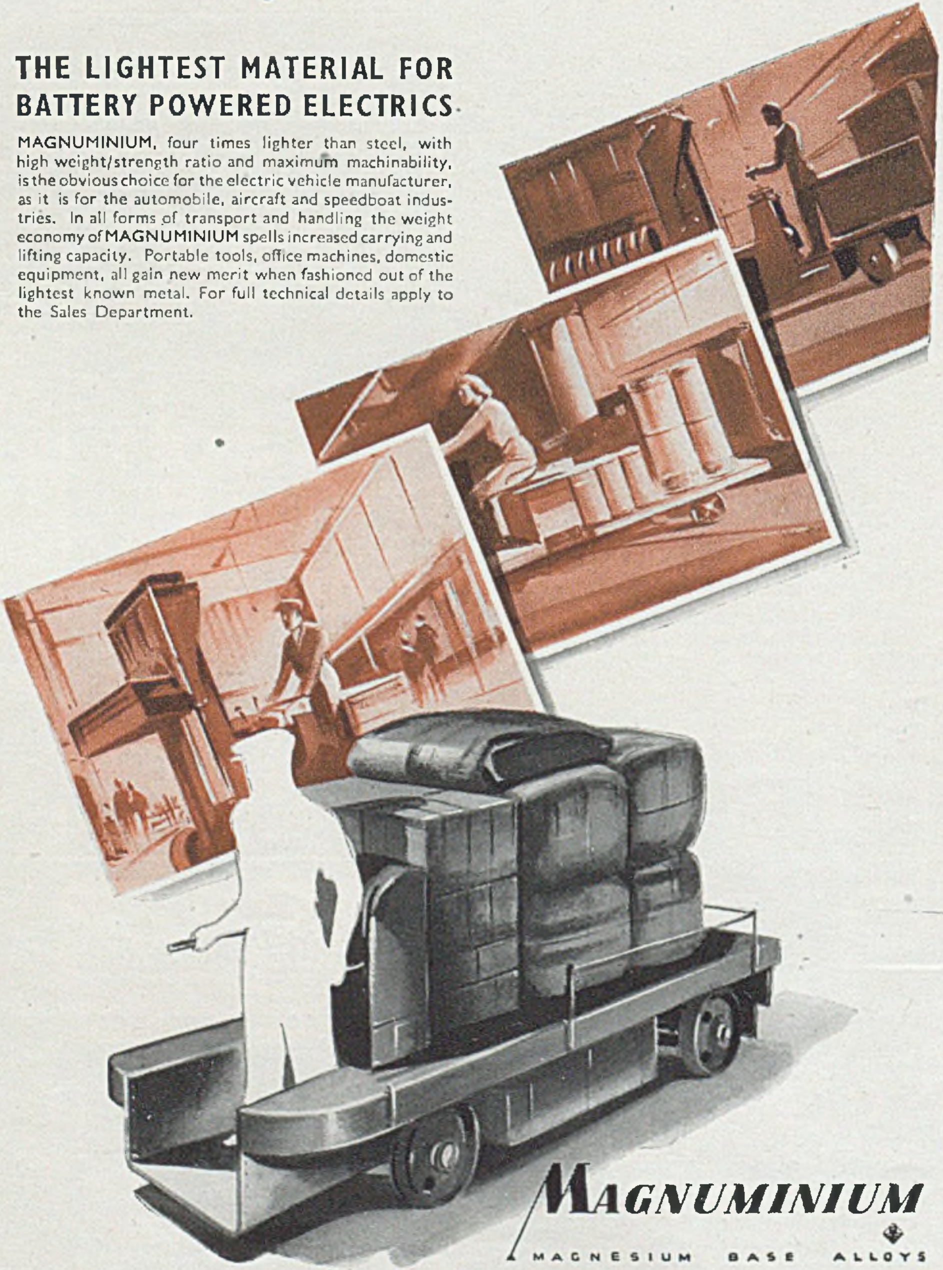

VOL. VIII. No. 88 MAY, 1945

LIGHT METALS

Proprietors:
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ROLAND E. DANGERFIELD

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

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

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

EDITORIAL OPINION

You'll Keep It Quiet, Won't You?

LISTENERS to wireless news in the early days of the war contrived to extract quantities of unsuspected fun from those unfortunate spokesmen in Cairo, whose extension and compression of the truth frequently proved excessive, even for the then very elastic front in the Western Desert. That phase of history is finished with, but Ministries, and subordinates who mismanage their news, flourish still, like the green bay tree. Their methods of handling information are, too often, as primitive and questionable as were those of the inspired amateurs in Egypt.

Particularly may this charge be levelled against those concerned with publicity for the so-called " temporary " aluminium house. Details were apparently supplied to the Sunday Press and, in part at least, to the daily Press: in the case of the latter, the public notice received was, in the main, ignored; favourable reviews appeared in certain representatives of the former, but in one case, at least, the project received a most damaging and uncritical write-up.

This mishandling of the situation has, we feel, done harm, first to the general cause of post-war housing and, secondly, to the aluminium industry. Let us examine the systematic qualification applied to these newer types of proposed post-war buildings—" temporary " houses. The use of this adjective can here be justified only with the greatest of difficulty. Examination of the numerous types of prefabricated or unit-constructed house at the Tate Gallery site, will show that, materially, the bulk will still be in perfect order even in 25 years' time, whilst from the design standpoint, their survival is certainly to be commended, whatever the opposition from " brick boxes " of the sort which disfigured our countryside after the 1914-1918 war.

To probe into this matter a little more deeply, what is the public's verdict on the prefabricated house? Few have had opportunity personally to inspect the different forms in which it is available, and fewer still have, as yet, been given the chance to test out the structures by actually living in them. Invariably, where the house has been seen, it has made a convert in its favour. In Stepney, for example, certain prefabricated units (of the most primitive type, we consider) have been made available—no bathroom, outside sanitation, hopelessly inadequate cupboard space, and no means of confining and isolating the smell of cooking and the odours of washday. Yet these hutments, which have little to recommend them beyond their cosiness and warmth, are most highly praised by those living in them. Recently we explained that the disadvantages cited were uncommon to the bulk of " temporary " houses; that, in fact, there were almost a dozen types differing in no wise in their internal appointments from what we are pleased to consider the ordinary house. We added that in most cases the " temporary " house had more to offer than the majority of older cottages in rural areas. Of them all, the aluminium house, without doubt, presents the greatest attractions.

Perhaps the public, to which appeal should be made, is not interested in the fundamentals of design; the ingenious devices to which resort has been made for assembling the sections cannot be seen and, probably, in any case, will gratify only the engineer. In contrast, however, eternal truths, such as ample cupboard space, ready accessibility, modern conveniences, and planned orderliness; are factors which automatically draw the buyer.

On the question of price, out of which so much capital was made in a censorious paragraph in a certain Sunday newspaper, it is difficult to avoid this comment, that the sum quoted was that resulting from the valuation, on a current basis, of a prototype, and cannot be considered as representing the ultimate mass-production figure.

Along with the rest of the models created in a worthy effort to solve the housing problem which will face this island and most of the European mainland after the war, the aluminium house has been made, we fear, the plaything of the political juggler. The ultimate success or failure of the scheme will not seriously affect the well-being either of Members of Parliament or Ministers; an alarming percentage of the population, however, will suffer if the general project be not materialized. Let this public, therefore, see the aluminium house and be the first and final arbiter of its merits. We are convinced that its verdict will be overwhelmingly favourable.

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

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

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

Aluminium and Magnesium in the Electrical Industries

The Author Continues his Account from "Light Metals," 1945/8/136, Dealing With the Mechanical Properties, More Especially in the Heated State, of Aluminium in Relationship to its Use as a Conductor

By

B. J. BRAJNIKOFF

IN the light of present-day knowledge, differences between material bodies are to be explained, first, by the nature of the elementary particles (the molecules), and, secondly, by molecular arrangement. The latter factor is of special significance in the solid state, and, in recent years, the introduction of new experimental methods has made possible a much more profound investigation of it.

From both the theoretical and practical standpoints, studies of matter with the aid of X-ray interference technique have proved very fruitful.

Table 1.—Breaking Strength and Elongation of Aluminium at Elevated Temperatures. (After Bengough.)

Heating Temperature, °C.	Resistance to rupture, kg./mm.^{2}	Elongation, %	Contraction % in cross-sectional area
20	13.6	11.5	75
200	9.9	15.0	78
275	7.8	17.2	79
330	5.4	20.3	88
375	2.7	25.0	88
396	1.55	56.0	90
450	1.1	65.0	96
520	0.7	68.5	Nearly 100
560	0.39	70.3	Nearly 100
610	0.33	75.0	Nearly 100
625	0.31	39.0	92

Since its development by Laue in 1912 it has been instrumental in corroborating by direct experiment many assumptions regarding the crystalline state.

Physical and Chemical Characteristics of Metals

The properties of a body with respect to strength depend very much on the condition of the material. The internal structure of metals is particularly important from this point of view. Metals, as a rule, are aggregates of crystalline units disposed in a haphazard manner; but by means of special techniques large single crystals can be produced.

Single crystals of many metals can sustain extensions up to some hundreds per cent. and a rod, for instance, becomes flattened into the shape of a band or strap before it finally breaks. With the help of theories of the structure of crystals we can calculate their strength, the theoretical value of which is usually several hundred times greater than that actually observed. This again points to the fact that there are weak places within the crystal. By taking certain precautionary measures, however, it is now possible to attain nearly theoretical limits.

Table 2.—Breaking Strength of Aluminium at Elevated Temperatures. (After Ludwik.)

Heating temperature °C.	Breaking strength of aluminium, kg./mm.^{2}
20	11.6
75	10.6
135	7.65
310	2.6
403	1.25
510	0.55
600	0.35
	Specimen annealed at 350°C.

The physical characteristics of metals may be altered by mechanical treatment. Thus, the specific gravity and the electrical conductivity of aluminium (as those of copper) in the shape of a cold-drawn wire, are somewhat lower, and the specific volume greater than the corresponding properties of both metals in the massive annealed form; this fact is conditioned by changes in crystalline

Table 3.—Mechanical Properties of Aluminium at Elevated Temperatures (after Martin).

Heating temperature, °C. ..	16	100	200	300	350	400	500	600	Nature of aluminium specimens
Resistance to rupture, kg./mm.²	8.2	6.4	4.35	2.50	1.63	1.10	0.54	0.28	Test piece subjected to annealing treatment
Elongation, %	51.2	62.3	83.9	90.4	124.0	127.9	121.4	150.0	Specimen subjected to annealing treatment
Breaking strength, kg./mm.²	11.7	10.3	7.7	4.65	2.10	1.44	0.64	—	Cold-rolled test piece

structure associated with cold-working. Although cold-working (e.g., cold-rolling) decreases the electrical conductivity of aluminium, the effect is small compared with the increase of strength achieved. Specific volume conductivity of hot-rolled aluminium was found to be between 60.5 and 61.5 per cent. of that of copper, whilst that of the hard-drawn material varied between 56.2 and 60.7 per cent. of that of copper, according to purity and other conditions; for annealed high-purity aluminium the value is 64.6 per cent. of that of copper.

Table 4.—Mechanical Properties of Aluminium at Elevated Temperatures (after le Chatelier).

Heating temperature, °C.	Breaking strength of aluminium, kg./mm.²
15	18.7
100	15.3
150	12.9
200	10.1
250	7.7
300	5.7
350	3.3
400	2.4
460	1.6

Moreover, electrical conductivity, as well as heat conductivity are also affected—almost always in the direction of diminution—by the presence of various admixtures in the metal, for which reason, in special fields of applications (viz., electrolytic condensers, high-grade foil, etc.), the purity of aluminium should be of the highest degree possible.

On the other hand, possibilities, opened up by electrically suitable alloys based on super-purity aluminium, are just as great, and their sphere of utility is bound to expand.

The great practical importance of high-purity aluminium and aluminium-base alloys in electrical technology has led of late to their intensive study, particularly with respect to problems associated with further refining, improvements of methods of production, and the perfection of techniques for the examination of their properties.

Modern physico-chemical analysis, together with achievements of metallography, have enabled us to a fuller extent

Table 5.—Results of Tensile Tests on Aluminium Bus-bars in the Heated State.

No. of aluminium specimens	Heating temperature, °C.	Resistance to rupture, kg./mm.²	Elongation, %	Average breaking strength, kg./mm.²	Mean elongation %
1	No heating	14.8	7	14.9	5.75
2	No heating	15.0	4.5	—	—
11	50	14.7	5	14.5	5
12	50	14.3	5	—	—
13	100	14.1	8	13.55	7
14	100	13.0	6	—	—
15	150	12.3	6	12.35	7.25
16	150	12.4	3.5	—	—
17	200	10.5	5	10.5	5.75
18	200	10.5	6.5	—	—
19	250	9.4	5.5	9.08	5.5
20	250	8.75	5.5	—	—
21	300	7.45	6	7.14	6.25
22	300	6.85	6.5	—	—
23	350	4.5	6.5	4.75	7.0
24	350	5.0	7.5	—	—

to appreciate, at least in part, the processes taking place in aluminium under various conditions of mechanical treatment, to study the effects of alloying it with various metals and non-metals, and to establish the precise relationships between the constituent parts of the alloys as revealed by equilibrium diagrams.

Table 6.—Results of Tensile Tests on Aluminium Bus-bars Before and After Subjection to Heating.

No. of specimens	Temperature of annealing treatment of aluminium, °C.	Breaking strength, kg./mm.^{2}	Elongation, per cent.
1	Prior to annealing treatment	Average 14.9	5.75
2	50	14.8	6.0
3	100	14.5	5.0
4	150	14.8	6.0
5	200	13.8	5.0
6	250	13.3	6.0
7	300	11.3	10.0
8	350	8.6	35.0
9	375	8.0	35.0

Kurnakoff and Zhemchujny have shown that physical properties of solid solutions vary successively parallel with the content of the component-metals: thus, the hardness of every pure metal increases as the content of a second metal added to it rises to a maximum, whereas, on the contrary, its electrical conductivity decreases up to a certain minimum limit.

Table 7.—Brinell Hardness and Impact Strength of Aluminium at Low and High Temperature.

Temperature, °C.	Brinell hardness	Resistance to impact, kg./cm.^{2}
−80	From 35 to 40	From 5.2 to 6.2
0	From 32 to 38	From 4.0 to 4.2
+200	From 22 to 18	From 2.8 to 3.0

Mechanical Behaviour of Aluminium

One of the shortcomings of aluminium as a material for conductors and bus-bars is that, in comparison with copper, it has lower mechanical properties. Thus, for example, whereas the tensile strength of copper, in the annealed state, is on the average 24 kg./mm.^{2}, that of aluminium is only about 10 kg./mm.^{2} With the object of improving the mechanical characteristics of aluminium it is subjected to cold drawing or rolling, in consequence of which its tensile strength can be raised from 15 to 28 kg./mm.^{2}, depending on the degree of work hardness resulting from the treatment. However, such hardness is retained by the metal only up to a certain temperature level, beyond which its strength properties drastically fall due to recrystallization. The temperature at which bus-bars usually operate is higher than that of the surrounding atmosphere. According to normal practice, the electrical load of bus-bars is calculated to allow for their overheating to the extent of approximately 40 degrees C. above the ambient temperature. If the maximum temperature of the air be taken to be equal to 40 degrees C., then in this case the bus-bars have to work under heating up to 80 degrees C. In the event of a short-circuit, they may experience local overheating up to 200 degrees C. or more. As to the cables of overhead transmission lines, they, too, according to Zeerleder and Bourgeois, can be heated by the action of current and by the sun up to 90 degrees C.

The mechanical strength of annealed pure metals, provided that they do not undergo allotropic modifications, gradually decreases as the temperature rises; on cooling to the initial temperature, the mechanical strength is restored to the original value. However, in the case of a metal acquiring the work hardness, such recovery is possible only after its heating up to the range of temperatures below the temperature of recrystallization, as heating above the level of the latter leads to the disappearance of working effects and, consequently, to the loss of improved mechanical strength inherent to the cold-working process.

Table 8.—Hardness of Aluminium Bus-bars During the Processes of Heating and Cooling.

Heating temperature, °C.	Average diameter of three indentations, mm.	Brinell hardness
Prior to heating	1.41	39.6
50	1.42	39.6
100	1.54	33.0
150	1.64	28.5
200	1.90	21.0
250	2.18	15.9
300	3.00	8.0
350	3.36	6.1
300	3.18	7.0
250	2.72	9.9
200	2.43	12.6
150	2.25	15.0
100	2.05	18.2
50	1.9	19.0
20	1.96	19.4

Although aluminium selected for use as a conductor material is of the highest marketable purity, yet it always contains iron as $FeAl^3$, which is incapable of passing into solid solution, and silicon which, on the contrary, is readily soluble at high temperatures, but on slow cooling of the alloy to the ordinary temperature, is almost completely released in a free state. Zeerleder and Bosshard consider that, in the event of the simultaneous presence of silicon and iron, there is formed a triple compound possessing limited solubility.

Hence it is seen that commercial aluminium employed as a conductor material is not a pure metal in the strict sense of the term, but must be regarded as an alloy, and, consequently, the nature of changes occurring in its mechanical properties during heating is still more complicated by modifications in physical composition.

Table 9.—Indentation Diameter and Brinell Hardness of Aluminium Bus-bars after Heating to Temperatures between 50 and 350°C.

Annealing of aluminium bus-bars, temperature °C.	Diameter of indentation, mm.	Brinell hardness
Prior to annealing treatment	1.35	42
50	1.35	42
100	1.42	39.6
150	1.40	39.8
200	1.42	39.6
250	1.45	38.0
300	1.63	28.5
350	1.89	21.5

Table 10.—Effect of Resistance Heating on Mechanical Properties.

No. of aluminium specimens	Temperature of heating by the electric current, °C.	Strength of current, A.	Period of heating, hours	Elongation, %	Brinell hardness	Breaking strength, kg./mm.^{2}
1	Prior to heating	—	—	8.0	40.0	12.69
2	From 90 to 100	900	162	8.0	37.0	12.77
3	From 200 to 230	1,500	16	15.0	30.5	8.80

Experimental Studies and Tests

From the considerations as put forward it should be quite obvious that a knowledge of the mechanical performance of aluminium, both when heated to a high temperature level and after it has been recooled, is of the utmost importance for a great variety of problems in electrical engineering; such knowledge is necessary, above all, as a basis for development work on the utilization of aluminium alloys as conductor materials.

Amongst notable contributions in this direction are the results of the systematic researches conducted by Usoff at the Russian Electrotechnical Institute. These comprise an extensive series of mechanical tests on aluminium bus-bars heated to different temperature levels within the range from 50 degrees to 350 degrees C., as well as after recooling. The tests included:—

(1) Measurements of hardness at the temperatures: 20, 50, 100, 150, 200, 250, 300, 350 degrees C.

(2) Determinations of the ultimate stress, or breaking stress, at the same temperature levels, with simultaneous evaluations of the tensile strength and elongation of the specimens at the moment of rupture.

(3) Measurements of hardness after heating for 15 minutes at 50, 100, 150, 200, 250, 300, 350 degrees C. and cooling to room temperature.

(4) Determination of breaking load under the same conditions.

The specimens of aluminium bus-bars used for the determination of hardness and ultimate stress had a cross-section of 40 by 4 mm.; the reason for selecting this size was due to the fact that bus-bars of a small cross-sectional area possess a greater degree of work hardness, in consequence of which, alterations in properties, associated with the disappearance of this hardness on heating, should be revealed much more markedly.

Table 11.—Influence of Section on Mechanical Properties.

Cross-sectional area of aluminium bus-bars, mm.	Brinell hardness	Resistance to rupture kg./mm.^{2}
40 × 4	42	14.9
40 × 8	40	12.69
60 × 8	30.2	10.8
80 × 10	28.5	10.0

Ultimate Strength of Aluminium in Hot and Cold State

Tests for breaking strength of aluminium during heating have been conducted by various workers, but the results obtained are rather discordant, particularly within the temperature range from 50 to 350 degrees C. This may be explained as due to differences in purity of aluminium, as well as in the degree of work-hardness of the specimen employed. The following data, given in Tables 1, 2, 3 and 4, summarize the results derived by Bengough,[1] Ludwik,[2] Martin,[3] and Le Chatelier,[4] respectively.

Test results for breaking strength and elongation of aluminium undergoing heating, as obtained by different investigators, are presented in Fig. 1.

Experimental Part

The specimens as adopted at the Russian Electrotechnical Institute for the testing of the breaking strength were fashioned from hard-drawn aluminium bus-bar in accordance with the shape and dimensions as indicated in Fig. 2, from which it will be noted that the gauge length for estimating elongation was taken equal to 200 mm. The heating of specimens was conducted in an electric tube furnace 600 mm. in diameter and 200 mm. long, fitted with nickeline-wound heating units. Measurement of the temperature of the specimens was performed with aid of a copper-nickeline thermocouple, the hot junction of which was attached to the centre of the test piece by tying with asbestos cord in such a manner that it was in contact with the specimen. The time period required for annealing was 15 minutes, and that for the testing of specimens in the heated state 10 minutes.

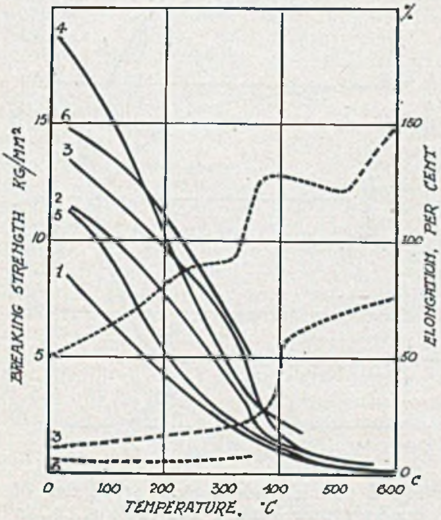


Fig. 1 (above).—Curves showing temperature relationships between breaking strength and elongation of aluminium: 1, annealed aluminium, Martin; 2, cold-drawn aluminium, Martin; 3, Bengough; 4, le Chatelier; 5, annealed at 350°C., Ludwik; 6, cold-drawn aluminium bus-bar, 40 × 4 mm. cross-section, Russian Electrotechnical Institute.

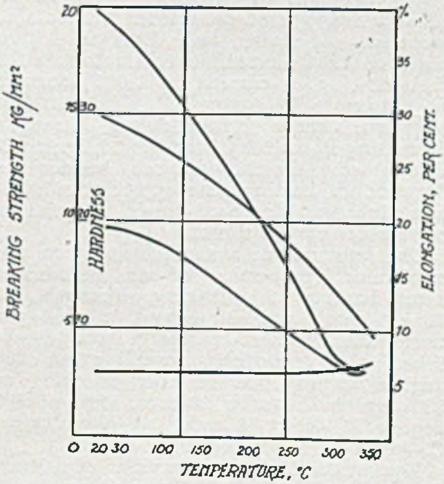
Fig. 2 (right).—Mechanical properties of aluminium bus-bars. Curves, reading from top show: hardness on heating; hardness after cooling; breaking strength; elongation.

The testing operations for determining the breaking strength of aluminium was carried out in a Moor and Federhaff press of two tons capacity.

Test results relating to studies of the ultimate strength of aluminium in the course of its heating, and also after recooling to room temperature, are given in Tables 5 and 6, respectively. Further results of the examination of the mechanical performance of aluminium under the action of heat and after cooling are presented in graphic form in Figs. 4 and 5.

Published information on the measurement of hardness of aluminium under the influence of heat is scanty. Of the existing works mention should be made of the investigation of hardness and resistance to impact within the range −80 degrees to +200 degrees C., conducted by Schwinning and Fischer.[5] The results obtained by these workers on sheets, specimens 8 mm. thick, are recorded in Table 7.

The relationships between the hardness values and other mechanical characteristics of aluminium during heating and after cooling are most readily compared with the help of the curves in Figs. 4 and 5, as derived by the Russian Electrotechnical Institute.



The tests were carried out in a Shopper press using a steel ball 5 mm. diameter under a load of 62.5 kg., the specimen, consisting of a hard-drawn bus-bar of 40 by 4 mm. cross-section and 880 mm. long, was polished. Heating was effected by the ends, resistance of the specimen being connected to the leads of a current transformer. Temperature measurements were made with the same copper-nickeline thermo-couple as used in the testing of the breaking strength, the hot junction of the thermo-couple being inserted sidewise into an aperture drilled in the middle of the bus-bar.

On attaining the required temperature, the specimen was indented at three points, care being taken to produce the impressions, as far as possible, near the middle part of the bus-bar, in order to ensure that the temperature levels of the segments tested corresponded perfectly to the temperature registered by the pyrometer. Tests were conducted both during the heating of the specimen and in the course of its cooling. The determinations of the hardness of aluminium in annealed state were carried out on the corresponding specimens used in testing for breaking strength.

As has already been stated, under actual service conditions, overhead conductors and bus-bars may be heated sometimes up to a temperature of 80 or 100 degrees C. The total duration of such periodic heatings in the course of service life may reach, in the aggregate, some thousands of hours. On the other hand, in the event of a short-circuit, the temperature may rise to 200 degrees C. and over, but its duration in such cases will not be greater than a few seconds. Zeerleder and Bosshard have observed that aluminium conductors, after their heating by current for 1,000 hours at 70 degrees to 90 degrees C., were partially annealed, their breaking strength decreasing from 15 kg./mm.^{2} to 10 kg./mm.^{2} Undoubtedly, in this instance, besides the duration of heating, the appreciable hardness inherent to hard-drawn aluminium conductors played a part.

The influence of a short heating on the mechanical properties of an aluminium wire having a breaking strength of 21 kg./mm.^{2} and an elongation of 4 per cent., was studied by Siebe, who established that complete annealing at 260 degrees C. was reached after 60 secs., at 350 degress C.—after 10 secs., and at 400 degress C.—after 4 secs., at 500 degrees C.—after 1 sec. of heating

Examination of the behaviour of a hard-drawn aluminium wire, of breaking strength 22.3 kg./mm.^{2}, under the action of momentary heatings by means of the electric current, which correspond to the effects produced by the occurrence of short-circuits, has been carried out by Schmitt.[7] This worker found that the wire begins to lose its mechanical strength at 160-180 degrees C. After heating to 180 degrees C. for 0.1 sec. its resistance to rupture was 99.8 per cent., and after 10 secs.—87 per cent. of the original value. After heating to 200 degress C., the breaking strength of the wire for the same periods was found to be equal to 93 per cent. and 81 per cent.; after heating to 250 degrees C., 78 per cent. and 68 per cent., and after heating up to 300 degress C.—was 63 per cent. and 55 per cent., respectively.

From these data it is seen that, as a conductor material, an aluminium wire, possessing marked hardness owing to cold-working is very sensitive to both long heating up to 100 degrees C. and momentary heating within the range 200-300 degrees C.

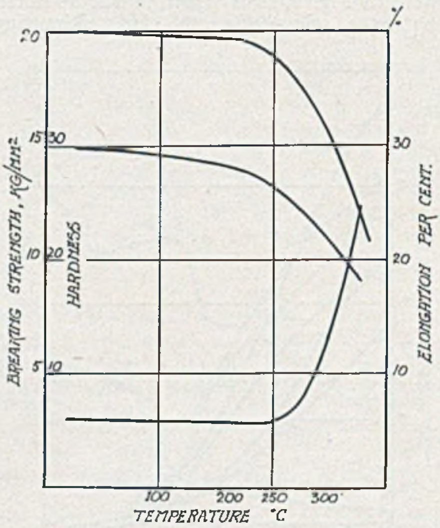


Fig. 3 (above).—Mechanical properties of bus-bars after heating and cooling, i.e., in the annealed state: top curve, hardness values; centre curve, breaking load; bottom curve, elongation.

With a view to ascertaining the influence of heating by electric current upon the mechanical characteristics of an aluminium conductor, Usoff took a bus-bar of 40 by 8 mm. cross-sectional area and 1,600 mm. long, and subjected it to electric heating to a temperature of 90 to 100 degrees C. for 162 hours. Subsequently, the temperature was raised to 200-230 degrees C. for 16 hours. Prior to the application of heat, and after both periods of heating, determinations were made of the hardness, breaking strength, and elongation on specimens cut from the bus-bar. The results of these tests are presented in Table 10.

Evaluation of Test Results

Variation of the Resistance to Rupture

Heating even to 50 degrees C. reduces the breaking strength of aluminium; and, on further heating, the value begins to fall rapidly; the higher the initial resistance to rupture of the metal, the more appreciable the drop. As may be seen from Fig. 1, all the curves approach one another and tend to converge at a single point in the neighbourhood of 600 degrees C.

The tests have demonstrated the following values for the loss of original mechanical strength of aluminium bus-bars owing to heating:—

50 degrees C.— 2.5 per cent.
100 degrees C.— 9.2 per cent.
200 degrees C.—30 per cent.

As regards bus-bars having a larger cross-sectional area, it should be remembered that the degree of hardness due to cold-working diminishes as cross-section increases. Thus, the measurements of hardness and breaking strength of bars tested in the cold condition yielded the values as indicated in Table 11.

The character of the alteration in the mechanical properties of aluminium bus-bars possessing various degrees of work hardness during the heating should conform to the loci of the curves of Fig. 1. As the intensity of heating increases, resistance to rupture will fall steeply from its original value at room temperature right up to 400 degrees C., where all the curves meet at almost one point, registering a breaking load of 1.5 kg./mm.^{2} Thus, when the initial resistance to rupture of an aluminium bus-bar in the cold condition be known, it is possible to determine, approximately, its breaking strength at other temperatures.

Analysis of the curve in Fig. 4 reveals that on cooling the metal after heating it within the range 50 degrees to 150 degrees C., the original resistance to rupture is practically restored. Heating to higher temperature levels leads to a gradual loss of mechanical strength in the cold state. Thus, for example, the loss of strength in aluminium through heating at 200 degrees C. is equal to 7.5 per cent. Drastic reduction of resistance to rupture also occurs after annealing aluminium at 250 degrees C., due to the onset of recrystallization.

Elongation at Moment of Rupture

Tests on bus-bars heated up to 250 degrees C. have revealed that the value of elongation at the moment of rupture does not alter. In Bengough's experiments, similar behaviour was displayed, elongation showing a relatively small change within the same temperature range. This fact indicates that, in the hot state, aluminium, whilst losing its mechanical strength, does not, apparently, suffer any marked increase in plasticity prior to the onset of recrystallization. After annealing, below 250 degrees C., the elongaton of aluminium is unaffected, its value remaining the same as that of unannealed metal. From 250 degrees C. and above, however, elongation rapidly increases.

Variation of Hardness

The hardness of aluminium bus-bars varies during heating in a manner analogous to the resistance of the metal to rupture. At 50 degrees C. the diminution of hardness is negligible, but, on heating at higher temperature levels, the value quickly falls. Thus, from the curve in Fig. 4 it can be observed that during the heating of the metal at 50 degrees C., the loss of hardness is about 4 per cent.; at 100 degrees C. it is 16.5 per cent., and at 200 degrees C. the drop is 47 per cent. The hardness of aluminium is practically unaffected by subjecting the metal to annealing within the temperature range 50-150 degrees C., but annealing above 150 degrees C. causes a marked fall.

On the basis of the foregoing experimental data and other available information, it is possible to draw the following general conclusions with regard to the variations of the mechanical properties of aluminium conductors in the shape of wires and bus-bars at operating temperatures and short-circuit overheating.

The heating of aluminium bus-bars up to 80 degrees C. results in relatively little reduction in mechanical strength in the hot state (the decrease is about 10 per cent.) and, practically, does not affect strength properties on their return to the ordinary temperature.

Aluminium conductors consisting of hard-drawn wires, lose on heating up to 80 degrees C., an appreciable amount of their mechanical strength, in consequence of their possessing a greater degree of initial hardness due to cold-working; the loss may reach, after long heating, 25 per cent. of the original strength.

The heating of aluminium conductors and bus-bars up to 200 degrees C. entails a considerable loss (from 30 per cent. to 50 per cent.) of the mechanical strength in the hot condition, but this can, to a great extent, be recovered, provided that the period of heating be short. In the case of bus-bars the loss may be 10 per cent. maximum, but, in conductors made of hard-drawn wire, the drop is appreciably larger, namely, from 10 per cent. to 20 per cent. of the original strength. Finally, the heating of aluminium conductors at higher temperatures owing to short-circuits may lead to their complete annealing. In the case of a flash-over it may be presumed, of course, that local temperatures of such high orders will be reached, that complete fusion of the metal will occur.

(To be continued.)

NEWS—General, Technical and Commercial

Light-alloy Castings

WE have received a reply from E. Carrington in answer to a letter from F. N. Smith reproduced on page 170 of "Light Metals" for April. The latter commented upon certain details in an article by Carrington featured in the March issue of "Light Metals" (page 103), and the author of the original account here gives, at length, reasons for certain of his statements.

"I was very interested to read in 'Light Metals' for April (p. 170) Mr. Smith's comments on my article which appeared in your March issue.

"As regards the elongation obtained on D.T.D. 298 test bars, I quite agree that figures better than that given (11 per cent.) are often obtained, but I am confident that such results are not obtained in the majority of foundries using this alloy. Mr. Smith will no doubt agree that good results can only be obtained if the whole of the casting and heat treatment processes are carefully controlled by the laboratory. I can assure him that even under such conditions, up to quite recently, some foundries were having difficulty in even getting bars to pass specification, and I myself had quite a lot of trouble when the alloy first came into use. An interesting point was that I always had much greater difficulty in obtaining satisfactory results with D.T.D. 304 than with D.T.D. 298, but the representative of one of the firms, which was very closely connected with this alloy, told me that they could easily get D.T.D. 304 and D.T.D. 361 figures, but had difficulty in getting D.T.D. 298 figures. It seems that with this alloy the foundry and heat-treatment conditions are somewhat critical, and that when the correct conditions have been found for any individual foundry, the laboratory must see that they are adhered to. Amongst other things, casting temperature certainly has a material effect upon physical properties and a high casting temperature can itself easily be the cause of low results.

"Very slight adulteration may also have a serious effect upon tensile figures, and because of this customers would be well advised to order D.T.D. 299. 304 and 300, from firms which specialize in these alloys rather than from jobbing foundries which will supply castings from any alloy, but which may not have facilities for the careful control of these rather special alloys.

"The figure of 11 per cent. is that which I believe any well-conducted foundry should be able to attain. I do not think that many foundries will be able to average 16.4 per cent., and I heartily congratulate Mr. Smith and Messrs. Kent Alloys on these excellent figures, and on those obtained with D.T.D. 300.

"Regarding the use of aluminium dies for die casting, Mr. Smith says that my statement that 'as these have the same thermal expansion as the castings the danger of cracking is practically eliminated' is, of course, fallacious. He says: 'From considerations of die-casting practice it is obvious that the thermal expansion of the die material is almost a negligible factor in determining the constraint to the contraction of the casting in the die providing the thermal conductivity of the die material is of a relatively high order; this, of course, is true in the case of an aluminium alloy die.'

"I do not think that this is at all 'obvious,' and if Mr. Smith can be prevailed upon to enlarge upon this statement in an article in "Light Metals," I am sure it will be read with great interest.

"Messrs. Kent Alloys have no doubt made very many die castings in D.T.D. 298, and know that only simply shaped castings can be made, and that even with these production is by no means easy. Now the thermal conductivity of any material depends upon the temperature gradient between the two faces. Would Mr. Smith say that if he used iron dies, but increased the conductivity by blowing cold air on the outside or spraying them with water cracking would be eliminated?

"The higher conductivity permits aluminium dies to be used at a much lower average temperature than is used with iron dies (about 300 degrees C. instead of 400 degrees C.), and this may help to produce a sound casting, but I am still of the opinion that the similarity in thermal expansion helps materially. It should be pointed out that these aluminium dies are anodized and while the coating is thin, the fact still remains that it has heat-insulating properties and will lower the conductivity of the die.

"The main point in Mr. Smith's last paragraph, however, is that he lays down a condition for a die which will have no constraint on the casting, and then says that aluminium dies satisfy that condition. This, then, confirms my opinion that the aluminium die is 'one of the biggest steps forward in the industry for some time.' Mr. Smith quotes this sentence but does not comment upon it. I can only hope that he agrees with it. I ought, perhaps, to say that I am in no way financially interested in aluminium dies.

"Whatever the theory of the matter may be, the fact does remain that alloys which have hitherto been looked upon as impossible die-casting alloys, and also pure aluminium are successfully cast in aluminium dies.

"I should like to thank Mr. Smith for his interest in the article and for his comments."—E. CARRINGTON.

Light Metals in Post-war U.S.A.

FROM a correspondent, Betty Frank, in U.S.A., comes the following picture of plans in that country for reorganizing the light-metal industries for coping with peacetime problems. Schemes in hand promise to see aluminium and magnesium contributing to the creation of 60,000 new small businesses at the close of hostilities.

The war has revealed some startling facts about light metal production in U.S.A. Whereas before the war 160,000 tons, or 15 lb. for each American, was produced annually, wartime capacity of 1,250,000 tons, or an increase of from six to eight times in capacity, has been recorded. Equally revealing are the figures with respect to magnesium production, which increased from an annual figure of 3,000 tons before the war to 300,000 tons at the present time.

Post-war markets, crying for aluminium products which have long been denied the consumer public, will create the incentives for even greater production of the metal. Not only will aluminium be used extensively by itself, but new and exciting ways of combining it with other materials, such as steel and wood, are foreseen.

Richard S. Reynolds, of Reynolds Metals, speaking at the recent Senate Committee hearings, spoke of aluminium boxcars, aluminium-clad steel for roofs, aluminium doors and hoods for automobiles, as well as improved kitchenware and other household goods. He presented samples of a new building material, composed of two layers of aluminium enclosing a layer of wood, which he predicts will be widely used for housing, for its outer surface will be capable of reflecting 96 per cent. of the sun's heat.

The expansion of magnesium uses is not as clear-cut as in the case of aluminium. In spite of this, producers are looking ahead to the post-war market, convinced that further uses will be found. Some of these applications are already being pointed out. Dr. Willard Dow recently spoke of magnesium wheels which are now standard aircraft equipment. That the automobile industry will use them similarly is a foregone conclusion.

Forest S. Baster, engineering vice-president of the White Motor Company, Cleveland, Ohio, in writing about increased power production by internal-combustion engines at lower cost as the result of wartime progress, in the March issue of the Society of Automotive Engineers' Journal, states that top-efficiency engines can be built from alloys of aluminium and magnesium, priced competitively with cast iron.

The post-war market for aluminium can now anticipate a demand for only 450,000 tons of the virgin metal, plus 300,000 tons of the secondary or re-used supplies. How to bridge the gap between this estimate and the possible supply of 1,250,000 tons is the problem which producers must solve if the industry is to expand as the Senate Committee hopes it will.

Handbook of Industrial Radiography

THE publication of a "Handbook of Industrial Radiography"* has filled a gap in the industrial radiologist's bookshelf. It has been compiled from a series of lectures given by members of the Industrial Radiology Group of the Institute of Physics, and edited by J. A. Crowther, M.A., Sc.D., F.Inst.P. As the editor points out in his preface, each chapter is written by an expert actually engaged on the work which he describes. This fact alone will immediately commend the book to such an intensely practical technician as the industrial radiologist. The handbook is primarily concerned with the production of radiographs, and is therefore complementary to Dr. Pullin's book,† with the latter's emphasis on interpretation.

The physical principles of industrial radiology are outlined in the first chapter, which, assuming only a rudimentary knowledge of physics, will therefore be of considerable assistance to those who have become interested in the industrial use of X-rays during the war period, but whose previous training has been confined to the photographic field. Such workers find it extremely difficult to master the ordinary text books which deal with the theory of X-rays, and this chapter, whilst providing the essential theoretical background, will also serve as an introduction to a more complete study of atomic physics and radiation. The following two chapters deal with the design of industrial X-ray equipment and the quantitative measurements involved in its efficient utilization, followed by an adequate account of the physical aspects of X-ray photography. The absence of any reference to the chemistry of photographic processes, however, is a notable omission from this section.

Practical industrial radiography forms the

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* London: Edward Arnold and Co. Price 21s. net.

† Engineering Radiography, V. E. Pullin, C.B.E. G. Bell and Sons, Ltd., 1934.

subject matter of four chapters, referring to heavy metals, light metals, gamma radiography, and miscellaneous industrial applications respectively. This last will be found to be particularly interesting and should provide some useful hints as to possible applications of X-ray methods to inspection problems not normally attacked in this way.

The final chapter is devoted to the protection of X-ray workers from the physical and biological effects of X-radiation. Name and subject indexes to the complete book are included, and bibliographies to five of the nine chapters are provided by the respective authors. The omission of any hints for further reading from the remaining chapters is perhaps unfortunate, particularly in the case of those dealing with the radiography of the heavy and light metals.

The various authors are to be complimented for their share in the compilation of this extremely useful handbook, especially as it is understood that they have refused to accept any fee or honorarium for their services in this connection. Any royalties accruing from the sale of the book will be passed to the Benevolent Fund of the Institute of Physics.

Pressure Test Specifications

THE American Society of Automotive Engineers publishes an interesting series of Aeronautical Material Specifications (AMS 2601-2607) dealing with the pressure testing of castings and other parts. The conditions and methods of testing are laid down, special reference being made to magnesium-alloy castings. Standards of acceptance are given, based on the leakage from a 2-in. dia. area per min. Impregnation of magnesium-alloy castings is specified, subject to customer's approval, where the amount of leakage is, within a definite range, in excess of the acceptance figure.

Aluminium in American Transportation

LATEST addition to the many applications of aluminium in the transport industry is reported from the Great Northern Railway. This company has collaborated with Alcoa to produce America's first experimental aluminium box-car, using 3,722 lb. of the light metal to effect a weight saving of 4,057 lb.

An aluminium shovel dipper, used in the coalfields near Wilmington, Illinois, for stripping the overburden from outcrop coal, has moved 90,000,000 tons to date.

Aluminium drums for the transport of aviation fuel via the skyway from Calcutta to Chungking are now being produced by The Aluminium Cooking Utensil Company. The use of aluminium for this job reduces the weight from 52 lb. to 21 lb., enables painting and proofing to be omitted, and provides a container which has no effect on the quality of the spirit.

Special Adhesives

THE plastic-synthetic rubber adhesive "Metlbond" was developed by Vultee Aircraft primarily for bonding aluminium alloys, but tests were carried out on a variety of materials, all of which bonded well. These included aluminium and its alloys, magnesium, steel, zinc, cadmium, fibrous glass, rayon, cotton, other celluloses, woods, natural and synthetic rubbers and several plastics. Use of the new adhesive, it is pointed out, has simplified the problem of bimetallic corrosion.

"Redux" adhesive forms the subject of a booklet recently issued by Aero Research, Ltd. Technical and Physical data are presented regarding this system of joining, which, incidentally, was one of the first of its kind to be adopted in engineering and general structural practice.

ALUMINIUM DEVELOPMENT ASSOCIATION

THE formation of the Aluminium Development Association by the leading British elements in the aluminium alloy production and fabricating industry is timed to throw the full weight of the industry into the problems which must arise in transition from war to peace.

During the war, vast expansion and great improvements in technique have taken place. Almost the whole of this effort has, however, been directed towards the production of aluminium alloys for aircraft.

The Association's main objective is to develop new and extended uses for aluminium alloys by initiating or assisting in the production of prototypes, encouraging research of all kinds and by undertaking propaganda designed better to inform the public of the many uses to which this versatile metal should be put.

Membership is open to users of the metal, who should apply to the Association's Offices at Union Chambers, 63, Temple Row, Birmingham, 2. Those familiar with the work of the Wrought Light Alloys Development Association will recognize the address and will note with satisfaction that this Association, which has already done so much useful work, is to be absorbed at a later date within the more comprehensive body, the activities of which will embrace both the plastic-working and casting techniques.

For the greater convenience of those making use of the facilities to be offered it is intended, as soon as possible, to open offices in London.

The members of the first Council of the Association are: The Hon. Geoffrey Cunliffe, President; Mr. Horace W. Clarke, Vice-president; Mr. D. Cannon Brookes, Mr. W. C. Devereux, Mr. H. E. Jackson, Mr. E. Player, Mr. Austyn Reynolds, Mr. G. A. Woodruffe.

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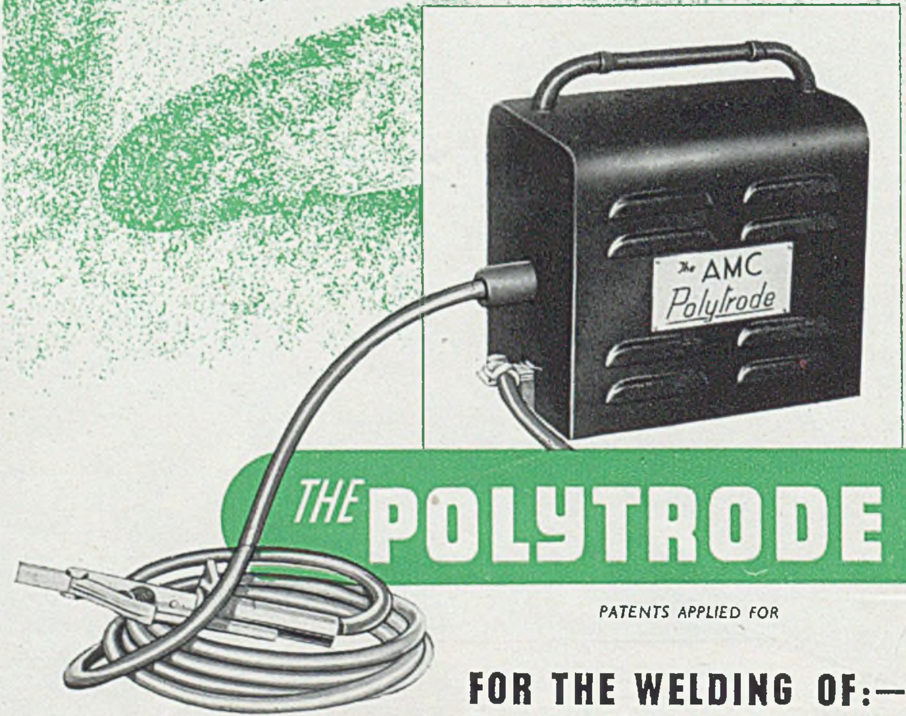

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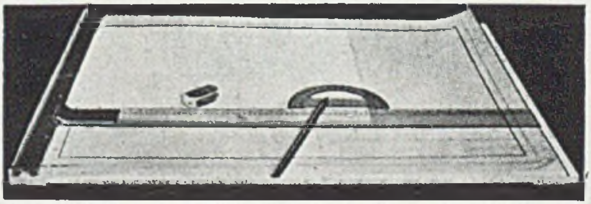
Aluminium and Magnesium Alloys in LIGHT ENGINEERING

Continuing from "Light Metals" 1945/8/168, a Survey of the Use of Aluminium and Magnesium Alloys in the Construction of Smaller Machine Tools and Allied Equipment. In Some Instances, the Applications are of a Highly Specific Nature



LIGHT metal drawing board. This construction presents many advantages over the more conventional wooden type: It is lighter and dimensionally more stable; in addition, it is less likely to be damaged by ill use. The board features an integral scale.

THE concluding paragraph of the first part of this account drew attention to the specialized use of aluminium in small engineering hand tools, where the use of light alloys is dictated either by specific operating factors or by reason of the fact that, in precision work, minimum deadweight is highly advantageous.

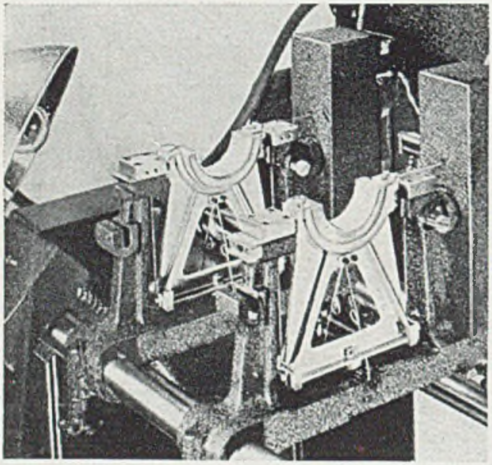
Other hand-lapping tools of this type are so designed that the plastic-impregnated block may be exchanged or turned, as it is usually found by experience that heavy wear occurs only on the front portion of the lap, restriction in the size of which ensures that economy can be effected in expensive diamond dust. Thus, in use, when the front of the lap is worn, it may be reversed. The moulded impregnated block fits into dovetail grooves in the aluminium support, any sliding movement being prevented by means of a small leaf spring.

Rather different, but still undoubtedly a portable tool or instrument, is the Avery wheel weigher used for checking the total loaded weight of aircraft. Essentially a weighbridge in miniature, the wheel weigher is of mixed steel and aluminium construction and is capable of weighing 7 tons although its own weight is only 54 lb. Light weight is essential here as the apparatus has to be taken by hand over comparatively rough and sometimes boggy ground and then manœuvred into position under the wheel.

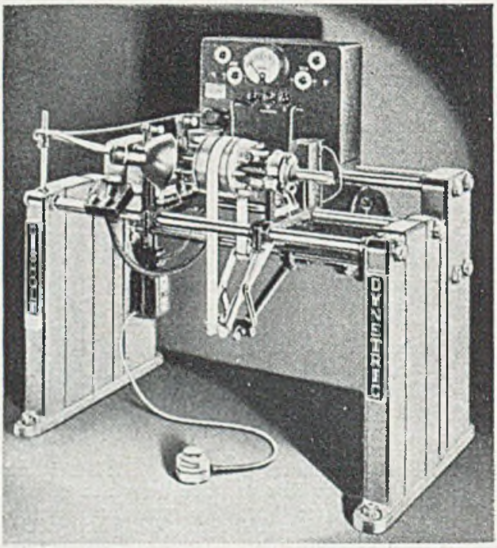
No more need be said about the role of light alloys in portable tools, but it will be understood that the examples quoted above are only a very few from among many which can be seen in use in factories and workshops to-day all over the world. The extent to which such tools will remain popular after the war depends to some extent on the psychological approach made to the public by the tool fabricators. The incorporation of aluminium and magnesium alloys may put up the price a little, but by only a small amount, as these alloys, although still somewhat more expensive in comparison with ferrous and copper-base metals, are easy to fabricate and lend themselves to mass production methods. The saving in weight which may be effected by their use yields advantages which are readily recognized by responsible authorities in larger concerns, but the possibly slightly increased cost renders such equipment more difficult to sell to small garage or repair shop operators to whom such benefits may have little direct appeal or who may not be aware of the ultimate good resulting from the reduction of deadweight.

The executives of large automobile and repair shops are impressed with the possibility of reducing fatigue and so promoting production and decreasing faulty work, which commonly tends to be found in increasing quantity towards the end of the day; the individual user in a small shop, on the other hand, is likely to see in weight reduction nothing more than the luxury for which he is most likely unwilling to pay, unless he be enlightened through the medium of suitable educational publicity.

It should also be emphasized that reduction in weight is not necessarily the



At the left and below. The Gisholt dynamic balancing machine. The use of aluminium for the legs of this apparatus is specific, as the high damping capacity of the metal, its flexibility, and low inertia, facilitate response to frequencies of a low order.



only advantage to be derived from the use of light metals. Freedom from corrosion is often important and always welcome, and the absence of magnetic properties may be an additional advantage on occasion.

Applications Depending on Specific Properties of the Light Alloys

We have previously referred to the value of light alloys in improving the balance of rotating parts. Complicated and highly specialized apparatus has been devised for investigating the balance properties of parts destined to be rotated at high speeds, and it is interesting to note that, in some of these machines, light alloys have themselves been employed in vital positions. Such a machine is the Gisholt dynamic balancing machine illustrated, which is of particular importance in checking up precise parts required to rotate at high speeds, the claim being made that it is capable of detecting and measuring out-of-balance defects in about 30 secs. Rotating parts are subjected to both static and dynamic tests and vibrations resulting from either type of loading are quickly discovered. Centrifugal effects are indicated and located by an electrical unit, no optical or mechanical devices being used. Vibrations from outside sources are tuned out automatically.

To permit the test piece to vibrate freely and with maximum amplitude, it is supported on strong, light-weight aluminium bearing legs which ensure that no appreciable proportion of the vibration from the part under test is absorbed by the inertia of the bearing supports. The high flexibility and low inertia of these legs permit the machine to work at a low natural rate of vibration without picking up external disturbances. The use of aluminium is, in this instance, highly specific. Definite advantage is taken of the low frequency of vibration of aluminium as compared with, say, steel, in order to achieve high accuracy and to widen the working range of the instrument.

Hacksaw Blades

In the U.S., aluminium paint has been used on hacksaw blades primarily to distinguish blades of one alloy from another. An incidental advantage was said to be that the coating of aluminium acted as a lubricant and reduced both binding of the blade in the cut and the amount of heat generated, resulting in cooler running and better retention of a sharp cutting edge.

Light Metal Drawing Board

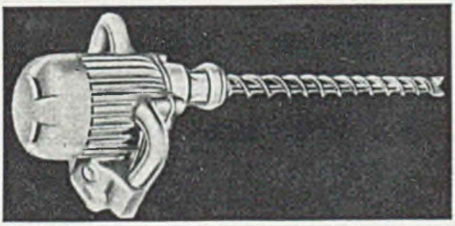
Illustrated is a light-metal drawing board which is lighter, dimensionally more stable and less likely to be damaged than the wooden type. It was constructed of sheet duralumin 1/16-in. thick, suitably stiffened along two edges, and mounted on it were two celluloid scales which added further to its usefulness by enabling horizontal and vertical lines of exact dimensions to be drawn with the minimum of trouble.

Permanent Magnets and Magnet Assemblies

Aluminium itself is only very slightly paramagnetic and, consequently, it has proved to be a useful material in the construction of magnet assemblies. Thus, for example, at the Stanley works in New Britain, Connecticut, an assembly of electromagnets held in an aluminium ring was installed in 1934 to pick up the bolts needed for the assembly of the various tools and to deposit them on to a gravity slide from whence they proceeded to the assembly point at which they were required.

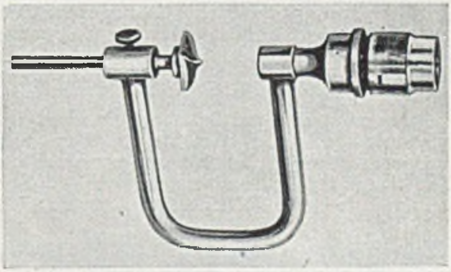
As an ingredient in certain alloys, however, it has the surprising effect of raising the magnetic susceptibility to an amazing degree, frequently to a ferro-magnetic order. Heusler alloys of copper, manganese and aluminium have been known and used for some considerable time, but in recent years, alloys of nickel, iron and aluminium have been introduced, which possess even better magnetic properties.

Such alloys contain nickel (24-30 per cent.), aluminium (9-16 per cent.) and remainder iron; cobalt is sometimes included. The alloys are characterized by a high coercivity, combined with good remanence. They have, for certain purposes, largely superseded the ordinary magnetic steels. These aluminium-containing alloys, however, cannot be worked either hot or cold and, in consequence, can be used only in the cast form. Where intricate shapes are essential, a somewhat expensive grinding operation may be employed or, alternatively, the alloy can be pulverized and incorporated with a plastic material such as bakelite and pressed into the desired shape. This degrading of the alloy, however, results in a slight falling-off in magnetic properties.



ELECTRIC drill due to Siemens-Schuckert (Great Britain), Ltd. To achieve maximum weight reduction, main components of the body of this unit are in the form of magnesium-alloy castings.

Recent research has shown that improved alloys may be obtained by the further addition of titanium. If the cobalt, nickel and titanium contents be kept within narrow limits and if the aluminium content just exceeds half that of the titanium, then an alloy is produced which, after separation tempering, has magnetic properties of a higher order than those possessed by the earlier compositions.

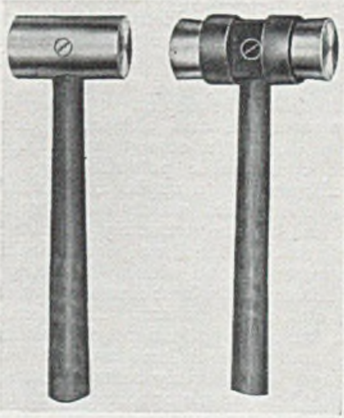


BRACE designed for hand use, or for fixing in a stand. It is very rigid, but weight has been reduced to a minimum by virtually all-aluminium construction.

In view of these facts, it is not surprising to find that aluminium-containing magnet alloys have been employed very satisfactorily for the construction of magnetic chucks where coercivity and remanence of a high degree are required, and it is probable that the future will see an increasing interest in this direction.

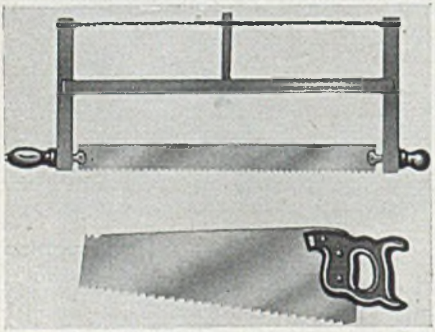
Indicating Instruments and Instrument Panels

Light alloys have been employed for certain moving parts of instruments of various types with the main object of increasing sensitivity by reducing the mass and inertia of the component. Aluminium



TWO types of special hammer featuring aluminium-alloy heads. Special compositions of light metal were evolved for this purpose, and the service life was claimed to be superior to that of heavy non-ferrous metals formerly used.

has been used as the material of construction for instrument dials. Here, the main advantages are freedom from corrosion and attractive appearance, although light weight is not altogether unwelcome, as many instruments are portable or attached to portable tools or machinery. For this purpose, however, aluminium possesses an added attraction, resulting from the ability to finish it easily in contrasting styles with a smooth or matt surface, uni- or multicoloured or in the natural silvery colour of aluminium. It thus becomes possible to mark the graduations on an aluminium dial by making use of contrasted smooth and matt areas or by colouring and, provided, in the latter case, that care is taken in the choice of dyestuff, the result is considerably more legible and decidedly more permanent than graduated dials produced by ordinary lacquer-printing on metal or by similar processes.

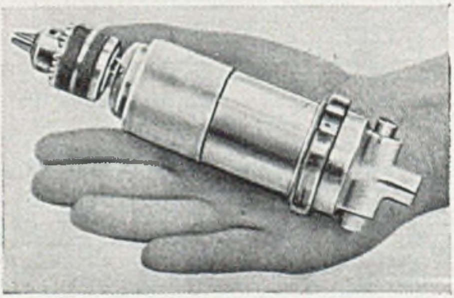


CROSS-CUT and bow saws for wood. In both cases, grips are in light alloy to ensure durability.

Such dials have also an extremely attractive appearance and aluminium for this purpose would, in consequence, appear to possess considerable potentialities. It is, after all, simply an application to industry of the aluminium watch and clock dials which had become extremely popular before the war because of their permanent attractive appearance and which were being fitted as standard by the best English and foreign watch and clock makers. This is certainly not a recent application, for aluminium clock faces were in existence at least 20 years ago, and possibly before that, so that there has been ample opportunity to confirm their satisfaction by the acid test of service under all kinds of conditions. Practically all flat dials on British aircraft instruments are of light-alloy sheet, the circles being stamped out in bulk, engraved, anodized, spray-painted and finally filled and luminized.

Before the war, aluminium had become an extremely popular material for the construction of wireless chassis, particularly of the non-mass-produced variety, because it could be drilled and formed so easily with the minimum of special tools and because it possessed an attractive appearance which was retained except under exceptionally corrosive conditions (experimental chassis have also been produced in magnesium-base alloys). For exactly similar reasons, aluminium has proved very satisfactory for the fabrication of instrument panels, particularly for those of complicated design holding a number of instruments of different types. Although the light-engineering field does not often call for the installation of complicated instrument panels, excepting, of course, the field of aircraft engineering, nevertheless there are a number of instances in which the use of a durable and easily fabricated material would be an advantage.

As an example from aircraft engineering practice, we would cite the blind-flying instrument panel which has been described in detail in previous pages of this journal.[8] This instrument panel, standardized by the R.A.F. on the advice of their Technical Equipment Committee, consisted of a spring-mounted duralumin panel carrying six blind-flying instruments, in the construction of which light-alloy components were largely employed. The illustration shows the capsule incorporated in the Smith air-speed indicator, consisting of two corrugated aluminium diaphragms soldered together and partially exhausted to give sensitivity to changes of pressure. The production of this component was made possible only through the ductility of the light alloy of which it was made. Formerly, instruments such as the air-speed indicator, altimeter and vertical-speed indicator were constructed in such a way as to incorporate a diaphragm, which could be made of very



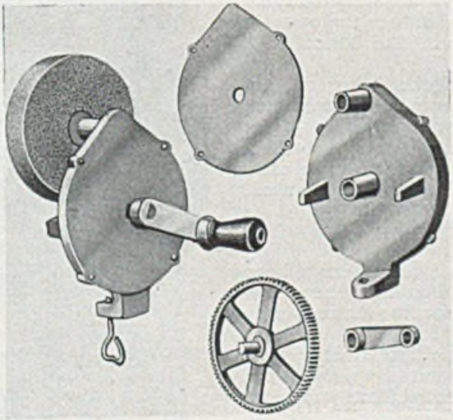
PNEUMATIC drill featuring aluminium-alloy main casing and light-alloy cage to epicyclic gearing. The weight of the drill is 24 oz.

thin sheet metal but which was more often of oiled silk. With the use of aluminium it became possible to make a diaphragm so thin as to respond sufficiently to a difference in pressure on each side without the use of high gearing. This single diaphragm, corrugated for greater strength and stability, is still used in certain simple instruments. In more accurate instruments, however, a capsule of the type shown has superseded the diaphragm. The components of the capsule are produced by means of a press tool working on a rubber bed.

Also pictured are the components of the Reid and Sigrist turn indicator. The dial shown at the right of the illustration is planished upon the reverse side to provide an airtight fit for the small triangular box, shown in the centre of the illustration, which carries the inclinometer. When this box is airtight, transference of air from one side of the box to the other must occur through very small orifices, and there is, consequently, a considerable damping action upon the swing of the small pendulum shown.

Included is an illustration of a group of cast light-alloy components of compasses, automatic pilots and sights used in aircraft, in which, at the left, is shown the anti-vibration mounting from the R.A.F. panel.

Light-alloy cast components of aircraft instruments of various types are depicted, and, at the right of the illustration, are shown (above) a compass grid ring and (below) a compass corrector standard. Components such as these are generally made by processes of stamping, pressing, spinning, sand-casting and die-casting, all of which lend themselves readily to mass-production methods, by means of which production levels have been achieved which would have been quite out of the question with other materials. The blind-flying panel itself was of 16-gauge duralumin, and all the instrument holes were pressed out. The same method was applied to practically all those smaller holes which did not require to be tapped as, for example, in those cases where a fixing screw is passed through the panel and is screwed into the instrument case.



SMALL table or bench grinder. Apart from the wheel, the spindle and the smaller pinion in this assembly, the remainder is constructed entirely in light alloys.

Sand castings were used for the cases of certain instruments; the bezel ring of the Reid and Sigrist turn indicator was sand-cast. The corresponding bezel was spun from aluminium-alloy sheet. This combination of spun bezel and cast-bezel ring has proved to be very satisfactory, although combined bezel and window can be produced as a single component in transparent moulding material, which permits more light to reach the dial. However, plastics are softer than glass and, in Service use, particularly in the Tropics, they are subject to abrasions and scratches which render them less efficient than the light-alloy combination detailed above.

Die casting was employed for all small components to minimize the amount of machining required. Instrument components offer an excellent field for the development of high-quality die castings; although gravity die casting is generally employed, there is an increasing tendency towards the use of pressure die castings. Both gravity and pressure die casting result in high-speed production with good surface finish and close dimensional tolerances, whilst, in addition, a fine grained structure with good mechanical properties results from the chilling effect of the metal mould. The small triangular box in the centre of the group of dismantled units of the Reid and Sigrist turn indicator illustrated is a good example of a component which can be produced simply and reliably by the pressure die-casting process. The fret or spider seen at the right-hand side of the illustration was also produced by die casting.

The previous article in this journal referred to,[8] stresses the importance of the utmost saving in weight in aircraft instruments and their mountings since, in warplanes, weight reduction may allow the fitting of an additional instrument on which the pilot's life may depend in an emergency, whilst, in civil aircraft, it can be reckoned that the carrying of one unnecessary pound costs the operating company not less than £10 per annum.

It is interesting, therefore, to note the application of light metals in certain other of the instruments normally fitted on an aircraft. Thus, the supply of air to the free gyro instruments is ensured by the use of a venturi tube mounted on the outside of the fuselage, this tube consisting of an aluminium spinning mounted on a die casting. The pitot head, consisting of one open pressure tube and a closed or static tube, is also made in light alloy. In the blind-flying instrument panel illustrated, all-metal piping connects the air-speed indicator to the pressure head, and a lead from the static side of this head is connected also to the altimeter and the vertical speed indicator. Initially, the gimbal in which the gyro is mounted was made of steel tube, but improved instruments of this type incorporate a light-alloy die casting, this being found to be more satisfactory not only from the weight-saving point of view, but also because there was a considerable reduction in the amount of machining required.

A high proportion of the bulky components of aircraft compasses are constructed of light alloys. Corrector boxes, for instance, were, for many years, manufactured in brass or bronze, but now die castings of aluminium alloys are invariably used.

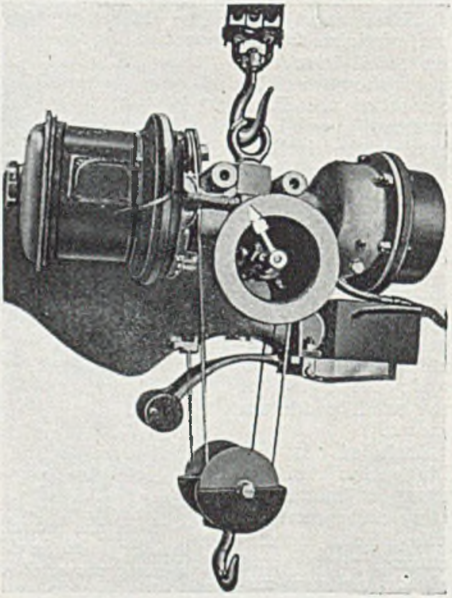
Finishing Soldering Iron Bits by Aluminium Spray

Although a number of alloys have been proposed for soldering iron bits, nevertheless, copper is still by far the most widely used material for the purpose. Whatever the method of heating the iron, wear by corrosion and by erosion occurs, rapidly in the case of gas or furnace-heated irons and more slowly in the case of electric internally heated instruments. Even with electric irons, it is a useful economy to localize the deterioration to the surface solely concerned with the soldering operation, so that when the bit is shaped back, a sound face is produced with minimum cut-away.

The methods which have been evolved for the protection of copper-soldering iron bits fall naturally in three groups:—

1. Chemical treatments, such as the production of a black "oxidized" coating produced by immersion of the bit in an aqueous solution of potassium sulphide and ammonia, thereby producing a coating of copper sulphide. Steel bits may be given a thin coating of electro-deposited copper before immersion. Treatments of this kind are of very little practical value.

2. Electro-deposition of chromium, generally, but not necessarily, as a two-stage process in which nickel is first deposited to a thickness of about 0.001 in., followed by a flash coating of chromium only about 0.00001 in. thick. Recent research has made possible the electro-deposition of considerable thicknesses of chromium direct on to steel but, nevertheless, the nickel-chromium combination is still preferred because chromium alone is very porous and attack of the underlying metal may take place as oxidizing gases and corrosive fumes permeate the system of fine cracks which constitute this particular type of porosity. Incipient corrosion of the base metal and the formation of relatively voluminous corrosion products (oxides and sulphides generally) result in a lifting of the deposit around the corroded areas, followed by stripping of the chromium and rapid deterioration of the bit. Nickel, in thicknesses exceeding 0.0005 in., is practically non-porous, thus eliminating the danger of penetration attack, and it provides a good base on which to deposit the chromium, only a thin film of the latter being sufficient protection over the nickel.



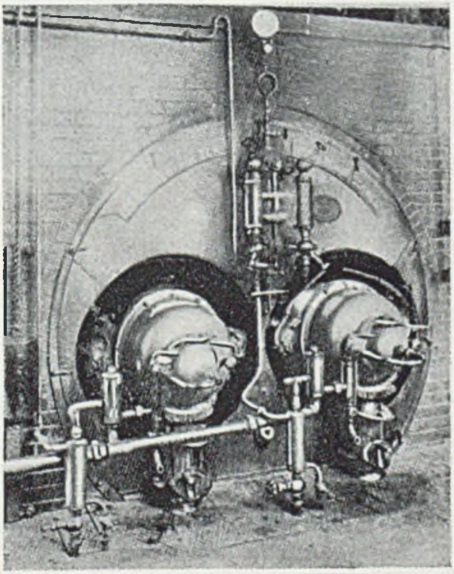
ELECTRIC hoists produced by the Usine Montfiore. The entire body of this apparatus consists of an Alpax casting.

This kind of protection is quite useful. The number of solderings between reshapings is increased many times and the number of shapings.

3. A coating of aluminium sprayed on to a copper bit and heat-treated to cause diffusion and partial alloying of the two metals. This is the most satisfactory form of protection yet devised. It possesses all the advantages of electro-deposited chromium with the additional advantage that, as the heat-treated coating is integral with the bit, failure due to the deterioration of the coating occurs to a much smaller extent.

The economy made possible is very appreciable, first, because the bit may be reshaped a greater number of times, four to 10 shapings being generally practicable, and, secondly, because it is often possible to use the iron longer between reshapings.

In general, the wire pistol method is employed for applying the coat of aluminium. The bits are abrasive blasted, generally with sand or shot, and thoroughly degreased in order to ensure proper adhesion of the aluminium. The light metal is then applied without delay. It may be as thin as possible provided it is continuous. A thickness of 0.004 in. to 0.005 in. is the normal minimum coating by double spray for general-purpose work, but it may quite satisfactorily go down to 0.002 in.; in fact, the thinner layer is preferable, if continuous. The wire employed is commercially pure aluminium 1 mm. diameter, and can be sprayed by the usual gases, namely, oxygen with acetylene, hydrogen, coal gas or propane. Thus, with oxy-hydrogen, the hydrogen is used at a pressure of 22 lb./sq. in., whilst the oxygen pressure is 21 lb./sq. in. Obviously, this method of treatment necessitates the availability in the factory of a metal-spraying equipment, but, with present-day demands, such plant is essential even in most general engineering factories.



OIL-FIRED furnace in which the more massive parts of the fuel-injection apparatus are principally light alloy, the use of which is here dictated, partly by reason of high natural corrosion resistance, and partly by good heat-dissipating qualities.

After spraying, the bit is heat treated in an electric muffle furnace, the aluminium being protected from oxidation during the period of temperature rise by brushing a coat of black spirit varnish or a black shellac solution over the job before putting it in the furnace. The temperature of heat treatment needs to be just above the melting point of aluminium (680 to 750 degrees C.) and the time period at this temperature is short, being about 15 mins. The object is to bring the work temperature up as rapidly as possible, so as to prevent oxidation of the relatively porous spray coat.

The surface finish of treated work may be mottled where the aluminium has irregularly penetrated the metal but, when burnished, it shows a characteristic yellow colour and, if sectioned, the copper shows a penetration of aluminium to form an outer layer of aluminium bronze. The bit is then ready for shaping, an operation which removes the aluminium bronze from the area that is actually to be used for soldering.

Protection of the working face of the bit, which must not be aluminized, can be obtained by the use of a mild steel insertion brazed into the copper bit and tinned. These two features of mild-steel insertion and aluminium protective spray form a really valuable combination.

Few, if any, published data are available as to the extent to which light alloys, more especially in the form of castings, have been employed in hand tools for cabinet-makers' use. It is well known, for example, that the bodies of various types of planes, particularly shoulder planes, are produced as massive iron castings; more expensive equipment of this kind employs bronze. In the construction of these tools, adequate correlation between weight and balance is of the highest importance; this is very necessary in the case of a relatively intricate type of plane such as the "plough." Recently, a number of tools of this type have been brought to our attention in which the body has been produced as a light-alloy casting. We have handled these tools and have found them eminently satisfactory both from the standpoint of weight and balance, and we are assured that, in use, no undue wear of working faces is experienced. This development represents, we believe, an important avenue for exploitation in the near future.

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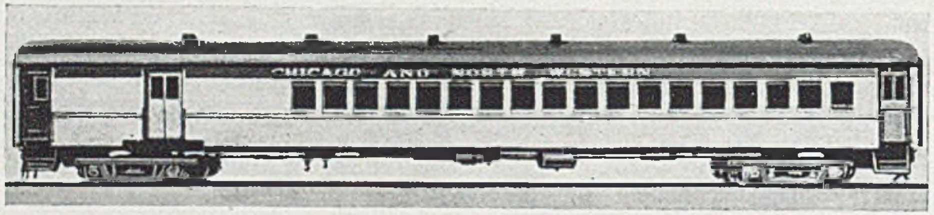
LIGHT-ALLOY ROLLING-STOCK

A Review of World Practice During the Period 1910-1940, After Hug, "Aluminium," 1942, p. 307; 1943, pp. 30, 331 and 394



COACH constructed in 1927 for the "Chicago and North Western" Railroad. Designed for a payload of 120 passengers and with accommodation for luggage and goods traffic, the bodywork of this coach was fabricated in light-alloy sheet.

THE purpose of this account is not to describe in detail every use which has been made of light alloys in rolling-stock, tramcars, and the like, but rather to deal somewhat fully with those examples in which total structure, or at least the main frame, ribbing or other significant items in the assembly have been produced in light metals. In compiling this review the author has made a world survey of the subject and considers therefore that no instances of importance have been omitted.

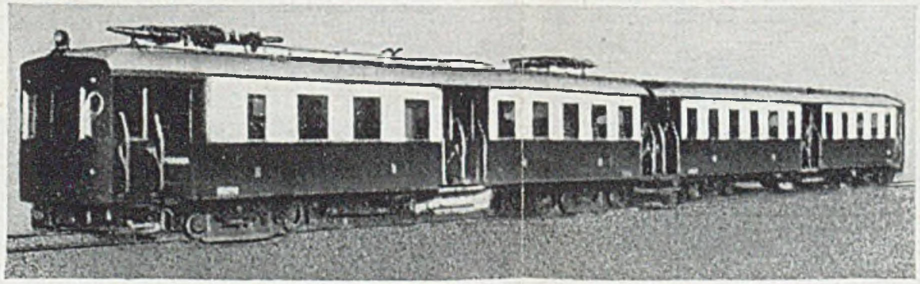
It should be remarked that, in dealing with the various examples of light-metal work examined here, not only will each assembly be described in greater or less detail, but, furthermore, the reasons which led to the adoption of light metal will also be examined. The manner in which the components were assembled, for example, why in the first case they were riveted, and why, later, welded construction was chosen; practical difficulties experienced during production; the behaviour of the finished assembly in service; general remarks regarding structural methods and applications of light alloys, will also be covered.

Needless to say, it is not possible, even in a review of this length, fully to describe every single example of light-metal structure that has been tried out in railway engineering. Should it be desired to enter into greater detail in connection with any one aspect, the bibliography appended to this article should be consulted. In concluding this foreword the author wishes to make it quite clear that he is not indulging in any uncritical propaganda on behalf of light metals, but is merely recapitulating projects already realized. This he does in the hope that his work will prove of use to further the study and development of light-alloy rolling-stock engineering. Already the emergency conditions on the mainland of Europe as regards shortage of heavy metals has done much to stimulate progress in this direction.

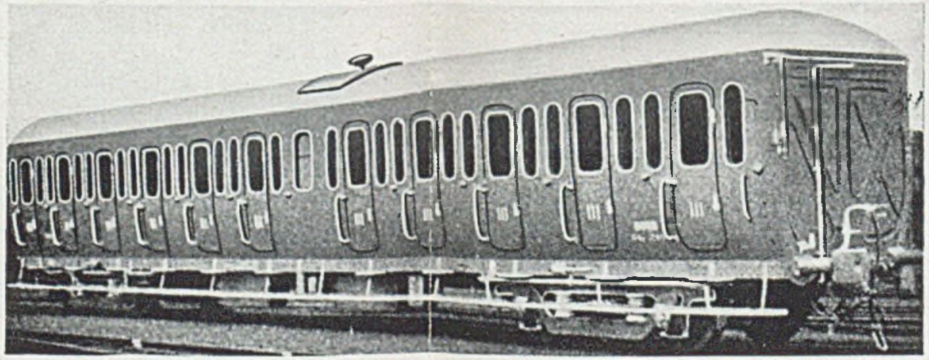
Introduction

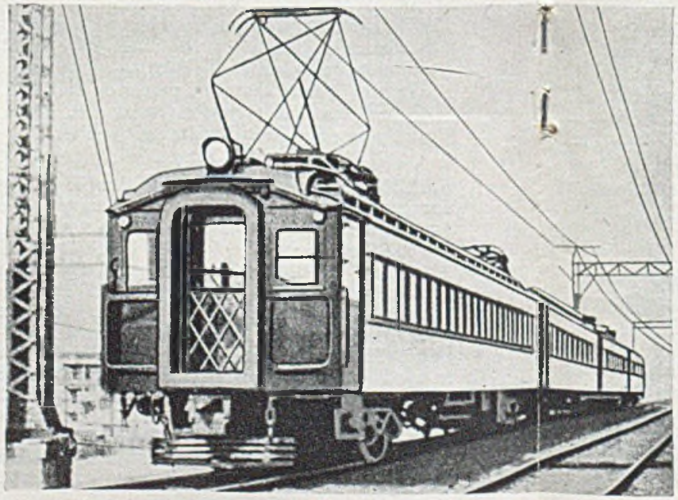
The use of light metals for rolling-stock construction seems, on examination, to have had its beginnings far back at a time when those industries specializing in the production of semi-manufactured forms in aluminium had progressed little beyond the embryo stage. The earliest applications (of which a few details are still available) date back to the year 1904. During 1910, the first considerable use of the metal was made in England when electric locomotives for the Liverpool-Southport Branch Railway were sheeted with aluminium. Actually, even the beginning of this application dates as far back as 1905, when the Chief Engineer of the Locomotive Section, George Hughes, showed that, by using light metal in this way, considerable running economies could be effected in service, on the one hand directly due to a reduction in deadweight, and, secondly, as a result of decreased current consumption. These considerations do not take into account secondary economies due to decreased wear and tear on the permanent way.

The light-alloy sheet used in this particular instance had a tensile strength of about 15 kg./mm.^{2} Apart from a few examples of lesser importance, the next major advances were made after the 1914-1918 war. These developments, in fact, contributed not a little to the successful growth



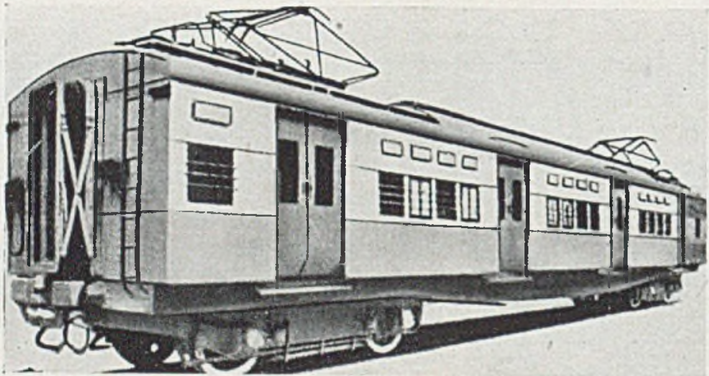
(Top, centre) The bodywork of this suburban electric train, running on the Northern Spanish Railway in 1927, was sheeted in aluminium.





ABOVE is shown the first light-metal suburban coach built for the Northern French Railroad system in 1923. At the left is illustrated the lightweight electric traction unit operated in 1926 by the "Illinois Central System," Chicago.

SHOWN on the right is an interior view, during the course of construction, of the partly covered framework of the "Chicago and North Western" coach pictured at the head of this account.



ELECTRIC traction unit, with light-alloy doors and aluminium - covered bodywork, built for the B.B. and C.I.R. for suburban operation in Bombay in 1926.

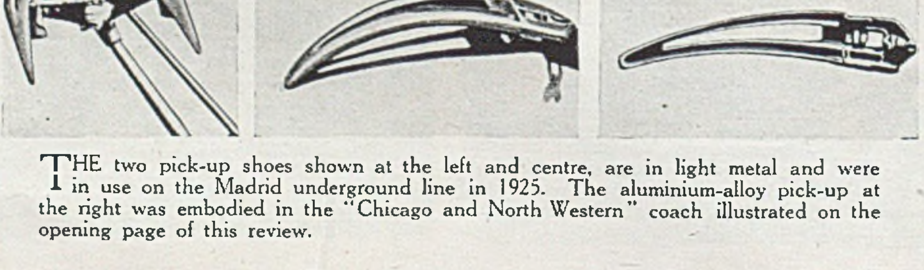
of the aluminium industry generally in the countries concerned. Considerable pioneer work in the development of light-metal structure for railway rolling-stock must be credited to the Compagnie du Chemin de Fer du Nord, which, in 1923, introduced an aluminium coach for passenger use on suburban lines. After this, development proceeded very rapidly, and in the following year the same company built 12 coaches, each embodying 2.9 metric tons of aluminium; these gave very good service.

At the same time, in 1923, important developments began in U.S.A. In this year the Illinois Central System had built (by the Pullman Car and Manufacturing Corp. of Chicago) 25 trailer coaches. The use of light metals in these gave an immediate deadweight reduction of more than 5 per cent. In 1926 this particular line had 215 coaches, all of which embodied large amounts of light metal, the number being increased to 225 in the period 1928-1929. Of these, 140 were electric locomotives. In all of these cases, round about 2 tons of light metal were used in each instance; thus the so-called " coach unit," consisting of one locomotive and one coach proper, was reduced in weight by about 7 tons. As these coaches formed, in all, no small part of the total rolling-stock of the Company, the percentage saving was considerable.

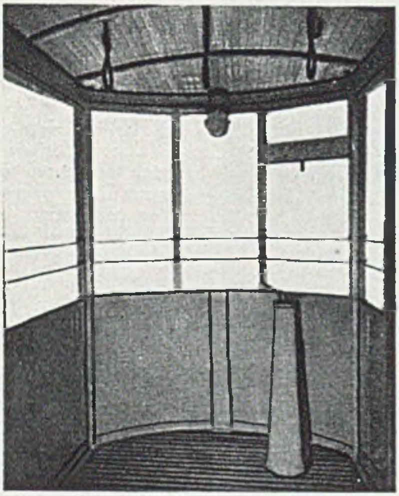
During these years, other railway networks also began to adopt light-metal practice. Thus, in 1927, the Chicago and North Western Railway Company put 34 suburban coaches into service, following this up with 31 more in 1929. The total skin work of these was all in light metal, and 2 tons of aluminium were employed in each instance.

Although, broadly, these developments appear of quite a minor order, they were, in fact, of the highest significance; the use of light metals made it possible with any given locomotive to increase the number of coaches in the train from 9 to 10. In 1933 the Chicago and North Western Railway Company had in service more than 120 light-metal suburban coaches. The railway serving the Ford Works, the Detroit-Toledo and Ironton line, also constructed a series of electric locomotives with light metal, and the practice was later followed by the North Western Pacific Railroute Company; both of these last-mentioned concerns built 10 electric locos and coaches.

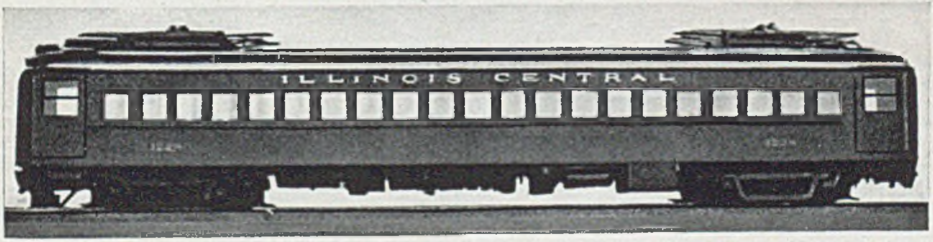
Street railways were also responsible for notable developments. The first aluminium tram in Cleveland, in 1926, showed, as a result of the use of light metal, a weight reduction of 30 per cent., compared with the previous models. During 1926-27, too, developments also made headway in Europe.



THE two pick-up shoes shown at the left and centre, are in light metal and were in use on the Madrid underground line in 1925. The aluminium-alloy pick-up at the right was embodied in the "Chicago and North Western" coach illustrated on the opening page of this review.



TRAILER platform on Zürich tram-car, 1927. This constitutes an early example of all-light-alloy construction.



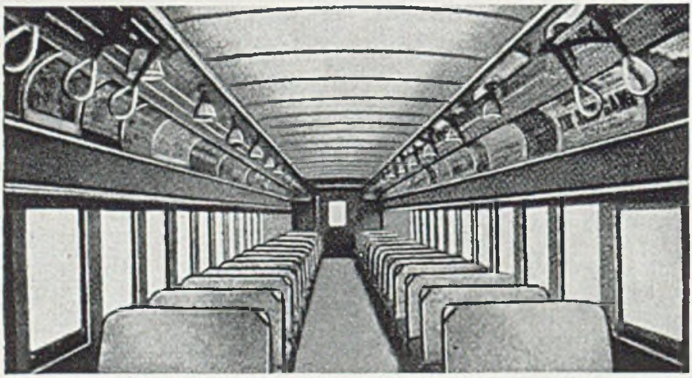
ELECTRIC traction unit, "series 1,201," for suburban use on the Illinois Central System, Chicago, 1926. (See further illustration with regard to Illinois Central System, on the opening pages of this account.)

A Spanish concern, Compañia de los Caminos de Hierro del Norte de España, constructed electric locomotives for the Barcelona-Manresa and the San Sebastien-Irun suburban lines, the outer and inner skins of which were in light-metal sheet. These locomotives were built in the Desierto works of the Sociedad Española de Construccion Naval at Bilbao. In 1927, also, were published the results in investigations of the Metallgesellschaft Frankfurt a. M. Here was suggested the construction of all-aluminium electric locomotives for the suburban network in Berlin.

Successful attempts were made during the years 1925-26 to employ aluminium in the component parts of electrical apparatus. Thus a number of trams in Istanbul and in Buenos Aires were fitted with motors featuring aluminium rotor windings in place of those in copper. Although the weight saved in this way was of a comparatively minor order, it was, nevertheless, in so far as it represented a reduction in unsprung load, quite welcome. In the same period, aluminium began to be introduced in the suburban trains in the Tropics; thus the electric locomotives on the Bombay-Baroda and Central India Railway were provided with doors cast in Alpax. These doors, by the way, had an effective width of 1,676 mm. as did also those used on the coaches of the Northern Spanish railway previously referred to. An application of a different type, but concerning also a moving part, refers to the use of aluminium in collector arms for electric locomotives supplied by means of overhead wires.

Finally, it might also be noted that, even many years before the outbreak of the first World War, the majority of trams in Zürich and in such German towns as Stuttgart were provided with aluminium-sheet-covered bodywork. Where such bodywork was correctly carried out, it proved itself eminently satisfactory. In 1927-28, in Zürich, the

SHOWN in course of construction here is the light-metal roofing for the coaches of the Illinois Central System.

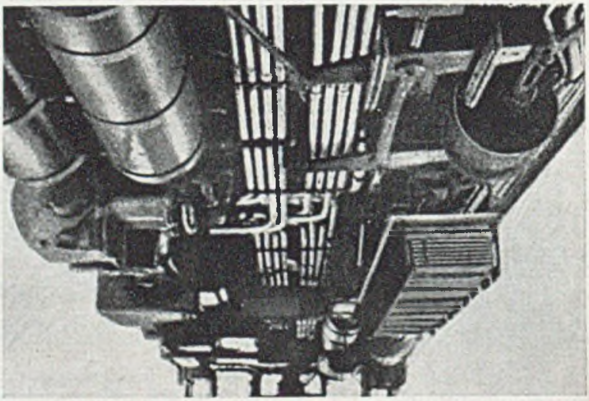


INTERIOR view of "Illinois Central" coach (illustrated on preceding pages) after completion of roof, upholstery, etc.

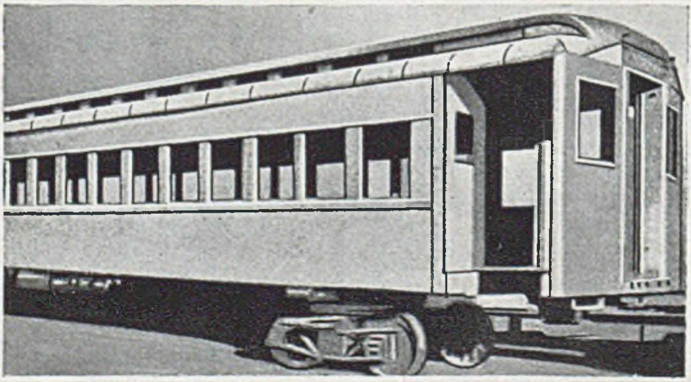
framework of tramway-trailer platforms was also constructed in light metal.

The greater number of the applications so far described, together with others, have already been referred to in the opening paragraphs. In addition, such components as framework for seats, luggage racks, ventilators, grab rails, doors, and so on, were also produced in aluminium alloy.

We will now consider in greater detail the use of aluminium construction for the 215 electric locomotives and passenger vehicles made for the Illinois Central system, Chicago, in 1924-26. Incidentally, it should be mentioned in the first place that the structures to be described were not entirely in light metal. According to a report issued in 1928 by the Vice-President of the Illinois Central Railroad Company, the use of light-metal rolling-stock had proved necessary in order to achieve economic running. A train unit consisting of one locomotive and one coach was designed for a normal running speed of 90 kiloms. per hour, with an acceleration of



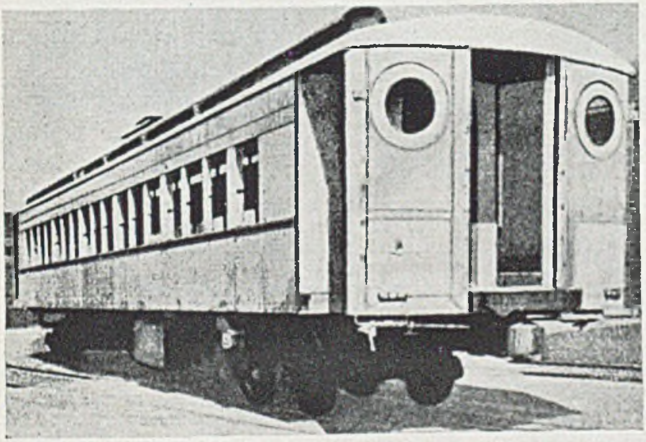
VIEW, from below, of electric traction unit, showing components of braking system and light - alloy conduit for electric cables.



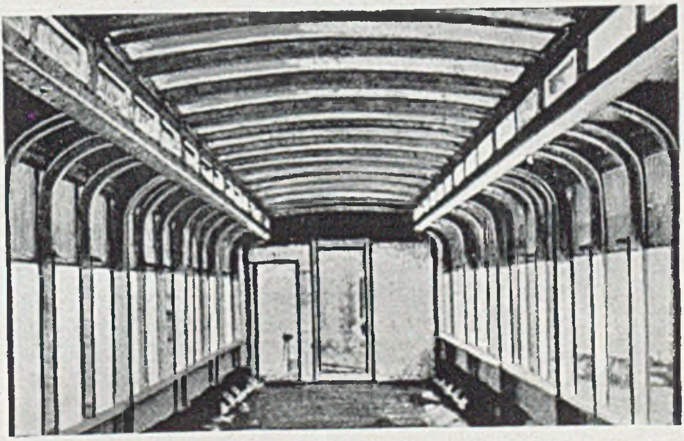
PICTURED here is the partly sheeted bodywork of the coach, an interior view of which is presented at the head of this page.

0.67 metre per second per second, and a deceleration on braking of 0.78 metre per second per second.

In 1922, before the introduction of electric locomotives, 20 coaches were built in all-steel construction, each coach weighing 43 tons. In the period 1923-24, a further 25 coaches were built, in which, by the use of aluminium, a weight of 40 tons per coach was achieved, this representing a weight-saving of 6.7 per cent. When the system was electrified, further improvements were effected and 25 coaches were built according to the new system; of these, the following parts were produced in light alloy: The complete roof structure in sheet and section in 17ST; all internal panelling and fittings; all doors (22 per unit); conduit for the electrical system; telescopic intercoach connection; and miscellaneous components such as chair frames, window fittings, window fastenings, and the like.



ABOVE is one of the first eight coaches for passenger traffic constructed entirely in light alloys for the Pennsylvania Railroad in 1926. The bodywork is here shown in partly finished state.



BELOW. A further view of partly finished structure (interior) of the coach illustrated at the head of the preceding page of this account.

Careful calculations made in subsequent years showed an annual saving in running costs of 190.3 dollars per coach unit (i.e., one coach, plus one locomotive). Had all of these coaches been built of steel, electricity cost alone would have increased by 260.62 dollars per year, this corresponding to more than two-thirds of the normal amortization consequent upon the somewhat higher first cost of the aluminium used. Apart from this, the increased corrosion resistance of the light alloys resulted in a longer service life for the coaches, which are still giving satisfactory service under normal conditions.

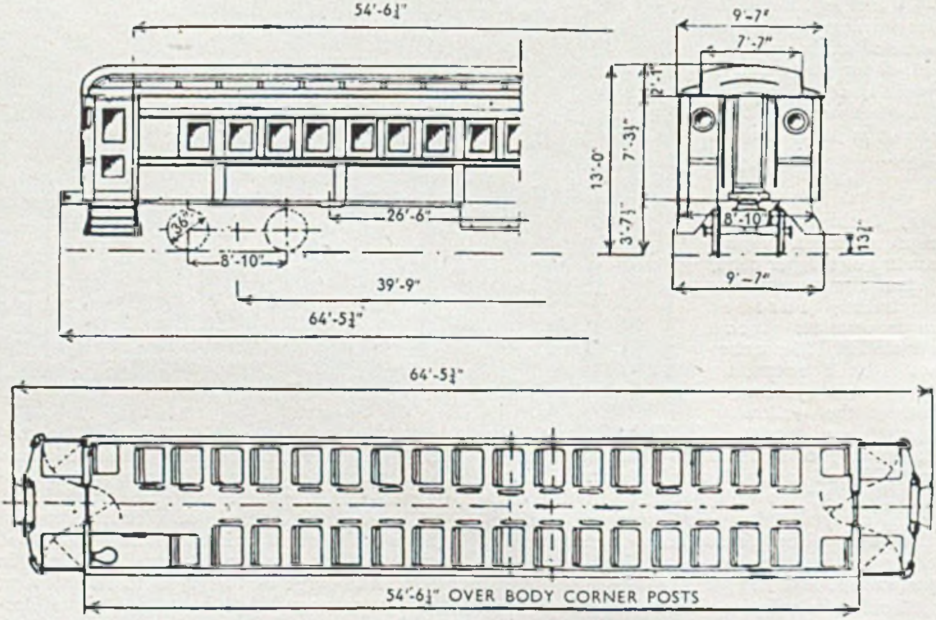
The introduction of light metals in this connection was partly the result of close co-operation with Alcoa, which was responsible for the development of the necessary prefabricated metal. The first aluminium coach, No. 1,334, built for the Illinois Central in 1924 was repainted in May, 1928, having been used for the intervening period in connection with a steam locomotive. It was exhibited for the R.S.M.A. Convention at the terminus of the Philadelphia-Reading line.

The earliest example of a coach showing entire aluminium construction is furnished by the Pennsylvania Railroad, which, in 1926, had eight of this type in the service; these were intended to be hauled by an electric locomotive. Coaches were built in the company's own shops, and each entailed the use of about 9 tons of light metal, this representing a reduction in deadweight of 10.5 per cent., as compared with steel construction. Only the bogies of these coaches consisted of the ordinary steel assemblies. The framework was entirely in 17ST heat-treated. Prolonged investigation had shown that no bad effects were to be anticipated as a result of exposure to weather, and in operation the results of the investigation were fully borne out.

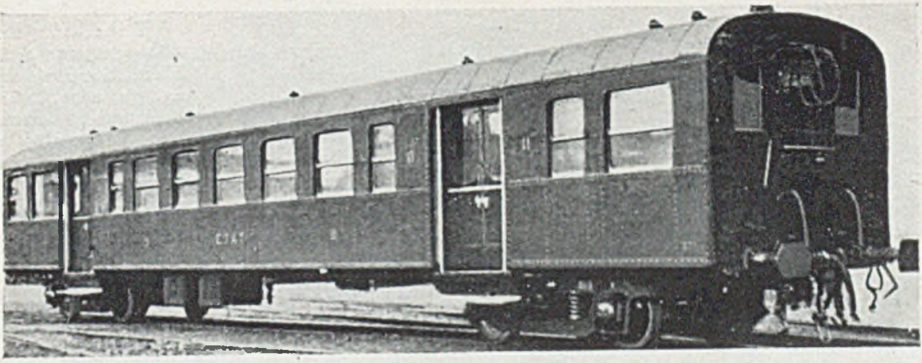
Later, the Pennsylvania Railroad used aluminium in other connections, including electric locomotives and trucks for ore. In 1930, the Delaware-Lackawanna and Western Railroad Company installed 141 electric locomotives, which were constructed by the Pullman Car and Manufacturing Company. In these the roof structure, doors, and inner linings were all in aluminium alloys, as in the case of the Illinois Railroad coaches. In construction and appearance they were similar to the Illinois locomotives, and weighed 66.75 tons each, or approximately 10 per cent. more than the corresponding Illinois locomotives, in spite of the fact that the latter were somewhat longer.

In 1929, the Chicago and North-Western Railroad installed 25 passenger coaches in light-alloy construction for operation with a steam locomotive. The weight of each coach was about 45 tons. It will be observed that American rolling-stock, even when constructed with light metals, is still so designed as to be comparatively heavy when compared with European standards.

In the summer of 1929, the French State Railways had under construction 300 passenger coaches for suburban operation; in these, very considerable use was made of aluminium. They were required for the electrified system operating from Paris westwards. All-aluminium construction was not used, light metal being confined to the inner and outer coverings of the bodywork and to the roof. A net saving of 2.2 tons in deadweight was achieved per coach, 1,500 kg. of light alloy being used to replace 3,700 kg. of steel. In all-steel construction, each coach had a weight of 40,370 kg. One hundred and twenty of the coaches belonged to the C_3 type with three third-class sections and 80 to the C_3E type, third-class with luggage van. These coaches were designed to travel in either direction and were provided at each end with accommodation for a guard. In France other stock capable of running in either direction found extensive use for suburban service. Bearing in mind the inferior manœuvring capacity of steam locomotives as compared with the high flexibility of the electric type, the deadweight reduction of 5.5 per cent. achieved by light-metal construction contributed in no small degree to improving



PARTIALLY dimensioned sketch of the electric traction unit built in 1926 for the Pennsylvania railroad. This constitutes one of the earliest examples of the really extensive use of light metals in rolling-stock construction.

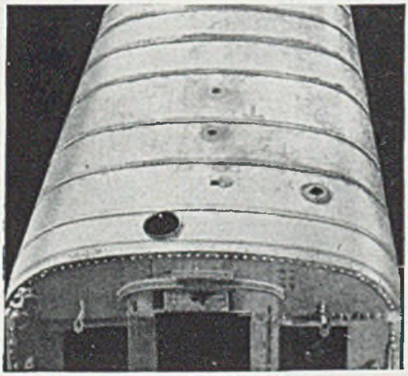


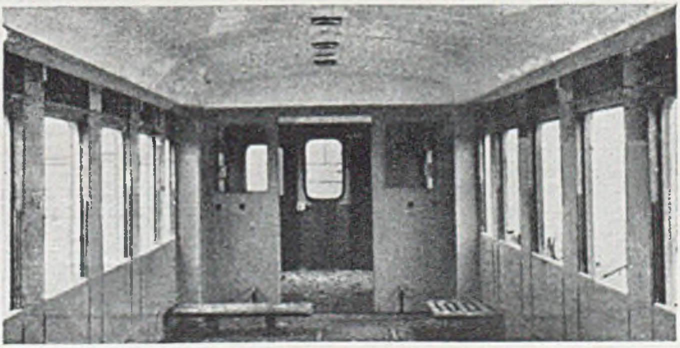
AUXILIARY coach with light-metal clad bodywork and light-metal roof built in 1929 for the French State Railways.

the operation of the steam type. Incidentally, the coaches were so constructed that they would be able, at a later date, to be used in conjunction with the all-electric system.

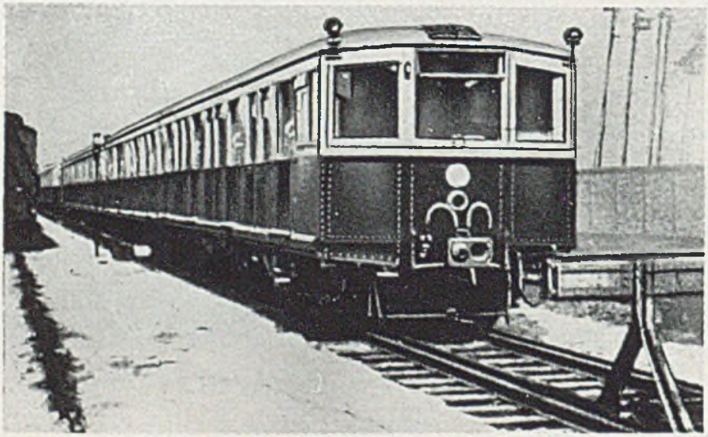
The materials used in the coaches consisted principally of an aluminium-copper-magnesium alloy to the extent of 1,040 kg. per coach, unalloyed aluminium to the extent of 450 kg. per coach, and varying amounts of aluminium silicon and other alloys. Some details in connection with the sheet material used are of interest. For the inner linings 1.3 mm. aluminium-copper-magnesium sheet was employed in place of 1 mm. steel sheet. Internally, the roof was lined with half-hard aluminium sheet 1.3 mm. thick, whilst the outer roof covering consisted of 2 mm. aluminium-copper-magnesium in place of the 2 mm. steel formerly employed. All doors were cast in aluminium silicon, the weight of the doors being about two-thirds that of those of former construction, that is, 49 kg. instead of 69 kg. Amongst the concerns responsible for the construction of the coaches were Talbot Aachen, Entreprises Industrielles Charentaises, Ateliers de Construction du Nord de la France (Blanc-Misseron), Carel and Fouche.

The German State Railways had, for some 15 years prior to 1931, been investigating the serviceability of light-metal rolling-stock on suburban lines in and around Berlin. Four units consisting each of a locomotive and a coach had been constructed, two by the Waggonfabrik Wegmann and Co., of



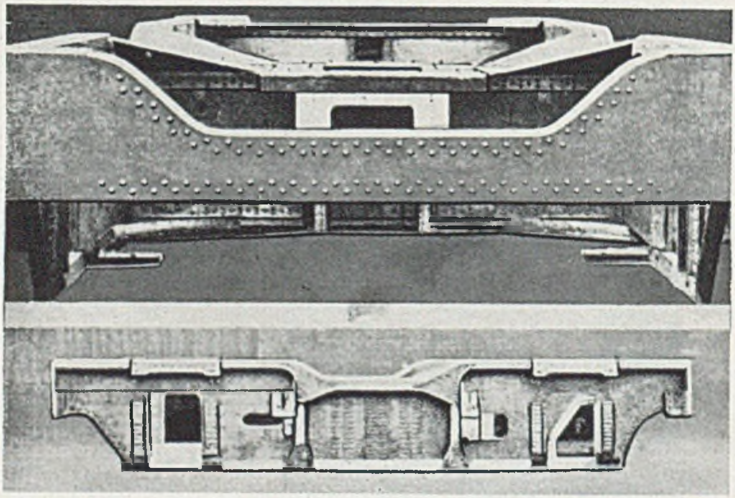


ILLUSTRATED above is the partially finished roof structure of the French coach pictured at the head of this page, whilst at the right is shown an interior view of the same unit in course of construction.



At the left. Experimental combined traction unit and passenger coach built for the Berlin State Railway. The structure makes extensive use of light metals.

Below. Two views of the frame of the experimental light-metal bogie constructed in Berlin in 1926. It weighs 750 kg.



Kassel, and two by the Linke-Hofmann-Busch concern of Bautzen. However, the State Railways had decided in 1927 that the use of aluminium alloys in place of steel for heavy railway engineering structures could not be considered as desirable, in spite of the fact that, in the U.S.A., coaches of entire light-metal construction were already in operation at this date; but they had not been long enough in service to enable their running qualities fully to be assessed.

In the four experimental coaches referred to, therefore, it was decided to employ steel for the under-frame cross-members, for the principal longitudinal members, and the principal cross-members as well as for the bogie assemblies. Experimental bogies, nevertheless were, previously, actually designed and made in light alloy.

This attitude necessitated many important modifications in the plan as originally conceived, and considerable delay in the realization of the scheme resulted, more particularly as little experience was available regarding light-alloy structures. The first unit was ready in 1931 and made its trial run in March of that year. At both ends of each unit on these models was provided a guard's compartment. The normal operating unit on the sytsem consisted of two coaches coupled together in the usual way, the units themselves being then coupled together with a Scharfenberg coupling. For both locomotive and coach bogie construction was similar, the only difference being that the locomotive bogies carried the motors and driving gear. Sub-divisions in the coaches were all similar. Certain coaches, normally used as additions to trains of ordinary make-up, were not provided with guard's compartments; in such cases, seating accommodation was the same at both ends.

In the following will be presented a comparison between these experimental coaches and locomotives (Type B), and those of normal steel construction (Type A). Further, again for comparison, details will be given of the proposed all-light-metal type (Type C). In considering the motive power required for Type C, it should be borne in mind that the masses required to


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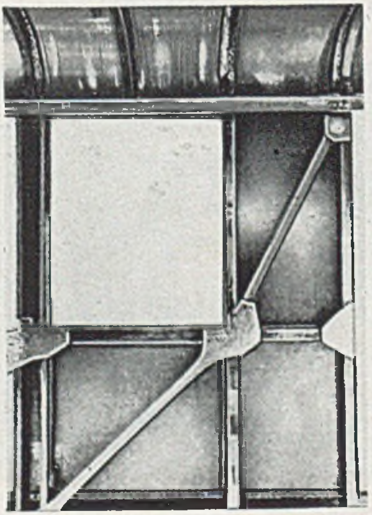
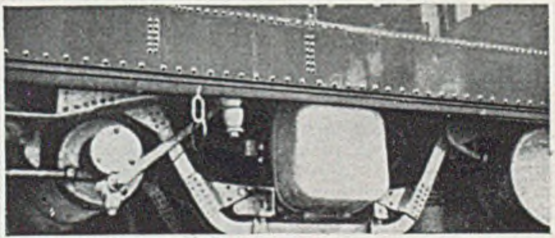
Table 1.

Constructional details	Type A	Type B	Type C
Motors	4 motors each 100 kW. 800 r.p.m.	4 motors each 100 kW. 800 r.p.m.	4 motors each 70 kW.
Drive ratio	1 : 4.25	1 : 4.25	—
Maximum speed	80 km./hr.	80 km./hr.	80 km./hr.
Compressed-air brakes	Knorr system 14-in. cylinder self-acting load regulator operator after each application of brake		
Weight per unit			
Coach body, without electric fittings	32.8 tons	26.3 tons	17.0 tons
Bogie, without transmission	21.2 tons	21.2 tons	15.0 tons
Electrical equipment, including motors and gearing	10.6 tons	10.6 tons	8.8 tons
Total unladen weight	64.6 tons	58.1 tons	40.8 tons
Weight per passenger	214 kg.	193 kg.	133 kg.

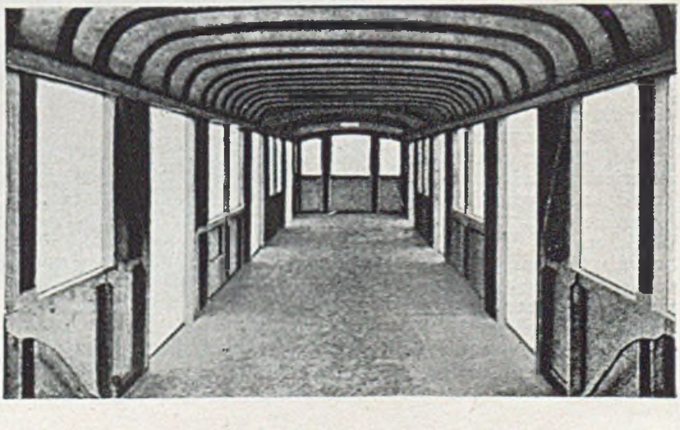
undergo acceleration are considerably smaller than in Types A and B. In the case of Type B it was not considered sound economy to install lower power motors and a generally lighter assembly, for this group was, after all, constructed for purely experimental purposes. However, whilst Class A in steel had a deadweight of 64.6 tons, Class B gave a corresponding figure of only 58.1 tons, this representing a saving of 6.5 tons per unit, which is noteworthy in view of the large amount of steel retained in the assembly. Saving in deadweight, amounted to 10 per cent.

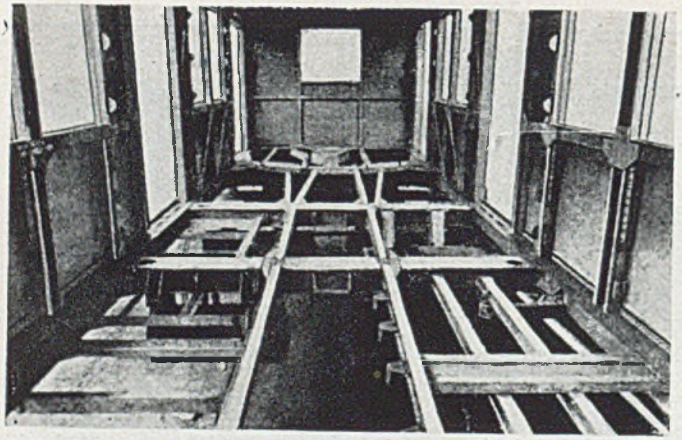
In point of fact, as only the coach framework was entirely redesigned, a comparison of weights should really be effected from this standpoint alone; upon this basis deadweight is reduced from a figure of 32.8 tons





SHOWN above is the light-metal support for the air-brake compressor and auxiliary apparatus attached to the experimental electric traction unit constructed for the Berlin State Railways. At the left is an interior view showing the system of stiffeners for the coach side walls and also part of the roof structure on the same experimental coach. Below is shown an interior view of the experimental coach during the course of construction.





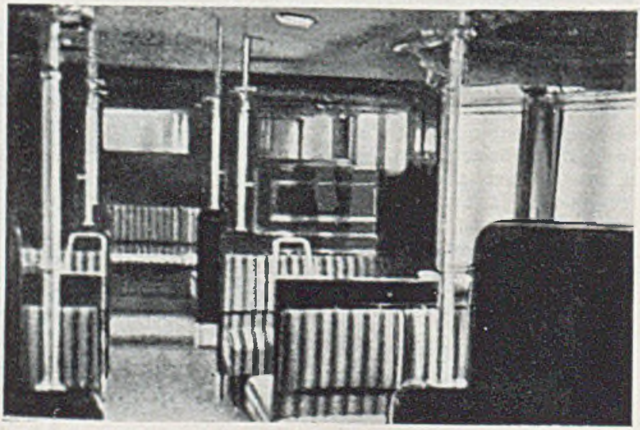
ABOVE. Frame supports and side walls of the auxiliary coach previously illustrated.

This was necessary in order to interpret most economically the statics of the structure and to enable the mechanical and physical properties of the light alloys to be utilized in the best possible manner. Due consideration must be given to the fact that diminution in mass has a considerable effect on the static and dynamic forces to which a moving vehicle is subject; for this reason certain fundamental principles had to be investigated.

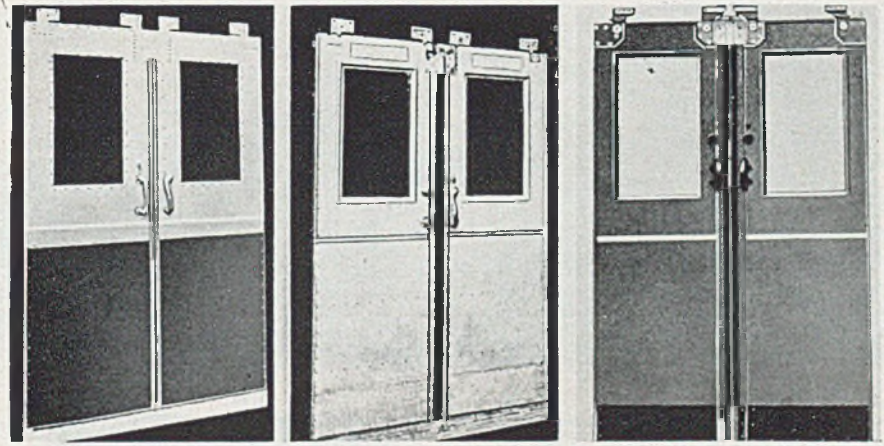
In the construction

to one of 26.3 tons, or, in other words, by 20 per cent.

The constructors were greatly hindered in their application of light metals by numerous limitations which circumstances had imposed on them. In spite of this, the assembly according to Type C indicated a deadweight reduction of about 48 per cent. for the coach body, 28 per cent. for the bogies, 18 per cent. for electrical equipment, and a total reduction of 37 per cent. for the complete unit. Naturally enough, these figures could not be attained merely by the simple replacement of steel by aluminium; they required the evolution of designs of entirely new bases.



SHOWN in the upper and lower illustrations at the right are interior views of the first- and second-class passenger compartments in the auxiliary coach previously referred to.



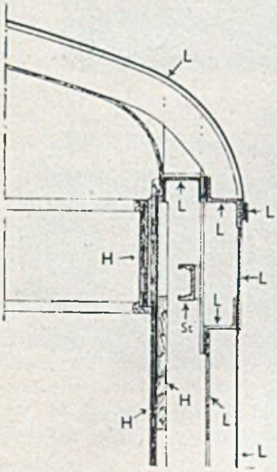
THREE views of the two-door types used in the Berlin experimental coach, the illustrations left and centre showing each partially constructed, that at the right showing a finished door.

of this experimental lightweight rolling-stock, alloys used included Aeron (Lautal) for the frame and sheet covering. Components consisted partly of rolled products and partly of forgings. They were heat-treated to a tensile strength of 30-33 kg./mm.^{2}, the thin sheet used having a strength of up to 42 kg./mm.^{2}, with an elongation of about 20 per cent. Other forging alloys used were Scleron and VLW.14.B. Amongst the casting alloys employed were those of the aluminium-silicon group.

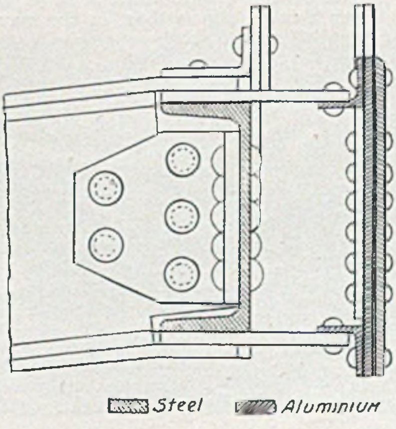
Actual choice of material for specific components was difficult, as experience in this field was, at the time, limited, particularly as regards the resistance of massive aluminium components to impact, oscillation, and, of course, to crash conditions. However, lessons learnt in the sphere of aircraft construction were of considerable value. Here it was known that, with suitable alloys, no danger was to be apprehended from impact or vibrational stresses.

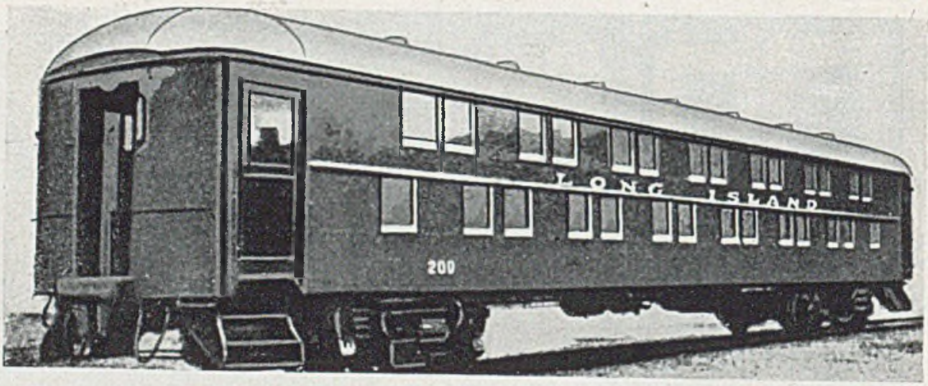
The sheets used ranged in thickness from 2 mm. to 6 mm. In special structural units, rolled sections of **Z**, **U** and **L** form were produced, together with other profiles of circular and rectangular section. Rivets and coach screws were in light metal, whilst bolts joining the various metallic sections together were in steel.

Aluminium alloys betray marked differences one from the other in their reaction to the Brinell hardness test. The light alloys do not change in their mechanical properties at low temperature, whilst the



AT the left.—Construction of the upper main member of the coach framework: L, Lautal; H, wood; St, steel (guides for sliding doors). At the right.—Diagram showing method of joining main cross-members to the exterior longitudinal members in the Berlin State Railways' experimental coach.





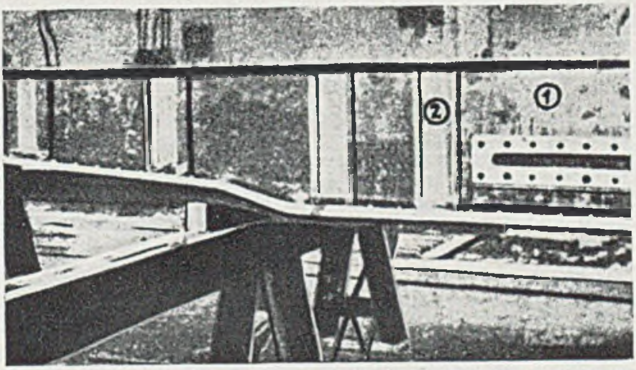
ABOVE. Double-deck suburban coach (No. 200) of the Long Island railroad constructed in 1932. Light-alloy frame and bodywork were employed.

AT the right. An interior view of the coach illustrated above. Note that this design is not the true double-deck construction as commonly understood in European practice.

steels on the contrary are, in general, unfavourably influenced. The somewhat lower structural strength of light metal is often grossly exaggerated, in spite of the fact that it is known that, in winter, at low temperatures, steel will lose almost entirely all the advantages it possesses over the former. The low elastic modulus (T) of light metals as compared with that of steel results, for stresses up to the elastic limit, in a greater capacity for withstanding deformation (A), thus: $A = \frac{\sigma^2 . V}{2\ T}$, where σ = stress of the elastic limit and V volume. From this it follows that, in the event of a

DOUBLE-DECK traction unit and coach for the Long Island railroad constructed in 1937. Maximum use was made of light alloys in this assembly in order to achieve minimum deadweight.

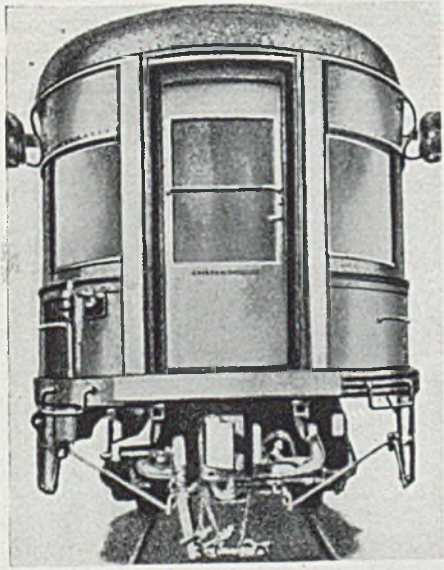
collision, damage remains more localized than in the case of steel and, in addition, that the mass involved, and hence the impact forces concerned, is reduced to a much lower level. The aim of the constructors was to produce coaches assuring the same operational safety as those in steel, whilst, at the same time, using the minimum amount of light alloys, which at the time, volume for volume, cost 7 to 10 times as much as the ferrous materials.



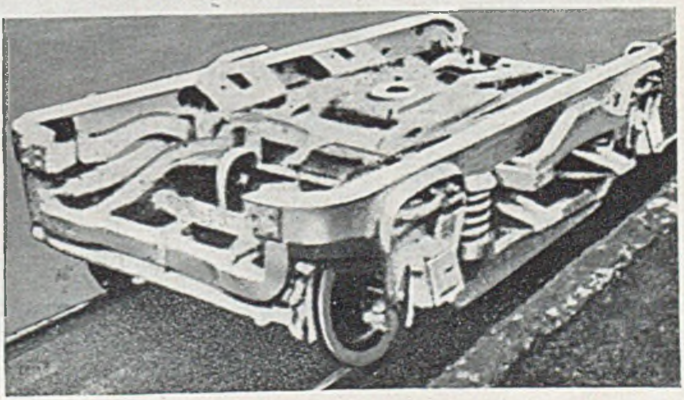
ABOVE. End portion of main longitudinal members of the Pullman Sleeper, a view of which is shown below at the left. This element is cold-formed from A.17 ST: 1, additional stiffener; 2, lower sheet member of the longitudinal component of the frame.

Economical construction can only be achieved as a result of the most prolonged and careful calculations, taking into account every possible stress involved. In these calculations, it appears desirable that stressing should not exceed a value of 80 per cent. of the maximum possible figure, the remaining 20 per cent. being considered as a safety factor necessary in order that any incalculable differences be automatically eliminated. Such non-uniformity may arise as a result of various components being worked to different degrees, or from variations in the joining technique.

The determinations involved in the structures I am describing were by no means easy to elucidate. The side walls of the coaches were, for the purpose, considered in general as load-bearing members, in spite of the fact that the covering sheet was of such form and gauge that it could



ABOVE. Head-on view of the aluminium sleeper constructed by the Pullman Company in 1933.



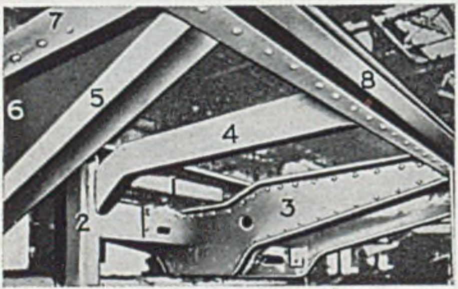
AT the right is shown the "Commonwealth"-type bogie constructed in light metal for the Pullman sleeper illustrated above.

sustain only tensile stresses and was not capable of loading in compression.

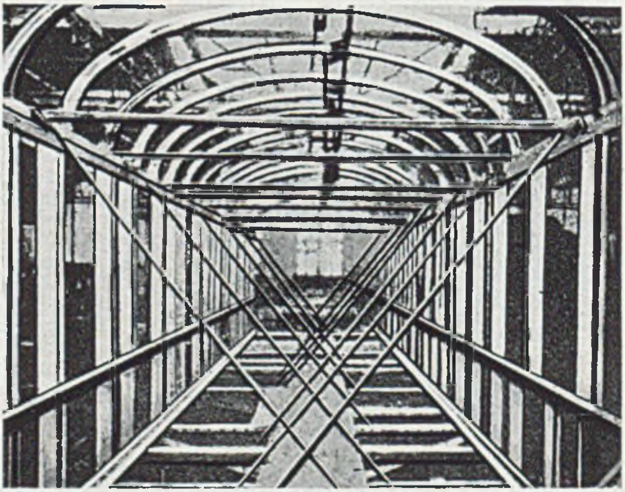
Fundamentally the side walls form a triangular frame broken by door cavities and windows. Additional stress arising from variously distributed floor loadings had to be considered in the calculations, and careful stress analyses were made of all jointing systems involved; here, incidentally, the relatively low elastic modulus of light alloys is a factor of the highest importance.

For those elements of the structure subjected to tensile stresses, no special designs were elaborated. For the components stressed in compression, however, moments of inertia of the greatest possible order were selected, as the modulus of elasticity of light alloys is only about one-third that of steel. Thus, simple U sections 80 by 60 mm. are not always sufficiently rigid, even with the addition of uniformly spaced longitudinal stiffeners along the side wall of the structure. For this reason, the upper frame member used was made of a girder consisting of two U sections firmly joined together with the necessary interval between each. This system of construction was also employed for those load-bearing members undergoing bending or torsion stresses in two directions.

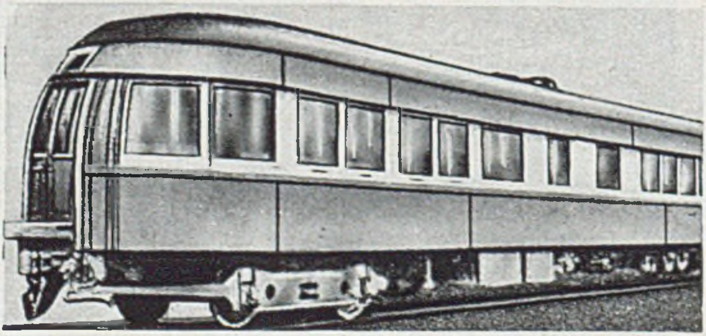
Jointing was mostly carried out by means of rivets. As compared to the corresponding structure in steel, the number of rivets used was very large, the diameter of the rivets, however, being comparatively small. This was done in order to ensure the adequate mating of the contact faces of each



ABOVE. Details of the main frame elements of the Pullman sleeper previously illustrated: 1, main roof beam; 2, junction unit; 3, cross-member riding on bogie; 4, floor bearers; 5, cross-member corner pieces; 6, wall; 7, upper corner of cross-member; 8, longitudinal member. Numbers 1-4 inclusive are in cold-formed A 17 ST; Nos. 5 and 6 are in 17 ST; Nos. 7 and 8 are in drawn A 17 ST.

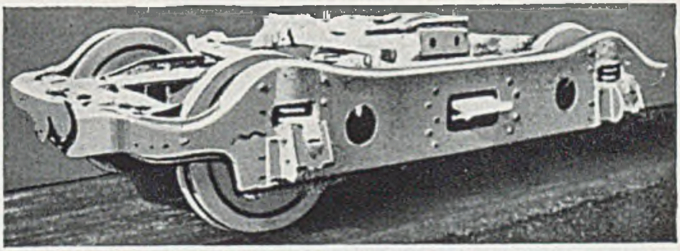


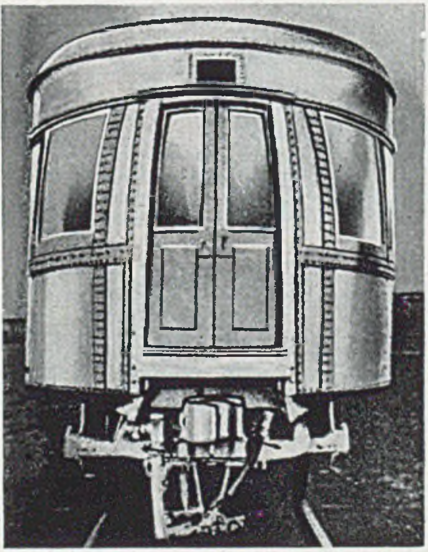
ASSEMBLING the light-metal frame of the Pullman sleeper.

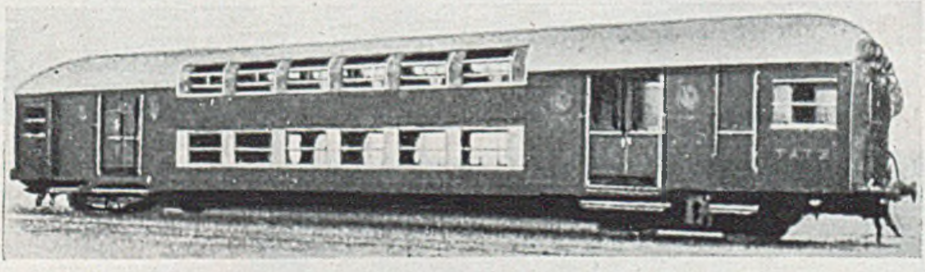


THE Pullman de Luxe saloon constructed entirely in light alloys (see also two succeeding illustrations).

RIGHT. Light-alloy bogie of riveted construction for the Pullman saloon pictured at the foot of the preceding page. (Below) Head-on view of the Pullman saloon previously referred to. Note particularly the novel door design.







DOUBLE-DECKER suburban coach constructed in 1933 for the French State Railways. Light steel structures were principally used in this assembly, but all fittings and sheeting were in light alloys.

joint, and to assure that such contact faces were of adequate dimensions. Rivet intervals (which depend upon the magnitude of the forces to be borne) range from 2½ to 3 times rivet diameter, the distance of the row of rivets from the edge of the sheet being 1.6 to 1.8 times rivet diameter, as dictated by the greater deformability of light alloys as compared with steel.

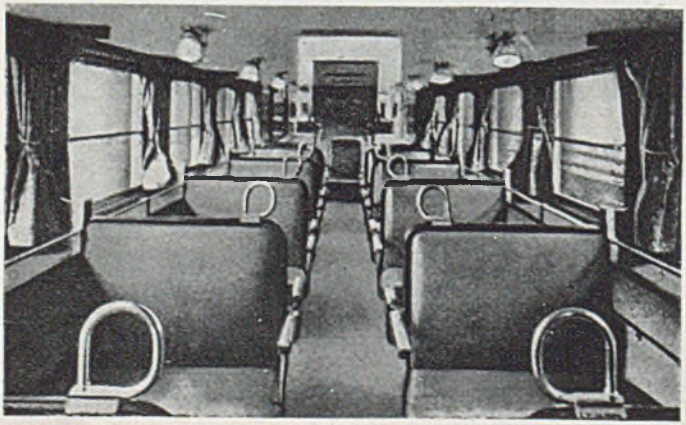
At the time this work was carried out, the usual welding technique could not be employed, as the mechanical strength and corrosion resistance of the joints was not considered satisfactory. Jointing of sheet by seaming could be used only for the roof, as this system needs the use of fully annealed material, the strength of which is comparatively low. Jointing by means of bolts was used, amongst other things, for attaching brake brackets. Direct screwing was only used in exceptional cases. Arc and gas welding were not used, as experience had shown that, at the time, such welds were not satisfactory under conditions of alternating stress, unless they had been hammered. Doors were produced partly from cast sections and partly from riveted sheet.

The framework of the coach is subjected to static stress in three directions. The side walls with the longitudinal stiffeners, and the upper frame member, served to take perpendicular forces arising as a result of loads on the bogie bearings through the main cross-members. To take up horizontal forces acting along the longitudinal axes of the frame, the side walls were stiffened at their ends, this being achieved by means of end pieces which were also used to stiffen the structure in the neighbourhood of doors. In view of the fact that the position of doors and electrical equipment was more or less predetermined, it was not possible to provide a one-plane system of cross-members.

The maximum forces to which the main longitudinal members were subjected occurred at the extremes in the neighbourhood of door cavities, where additional strength due to side wall structure was not available, considerable compression and shear stress also occurred at such points.

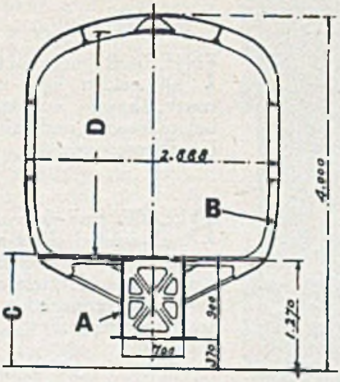
Buffer impact was absorbed by buffer blocks attached to the main longitudinal members, and, through these, was distributed over the entire structure. Joints between the buffer blocks and the longitudinal members were so constructed that, for stresses other than those along the normal, shear would occur in the rivets, thus limiting the damaging effect of the impact on the remainder of the structure. So far as the author is aware, the assemblies which have been described proved quite satisfactory during their subsequent years of service life.

ABOVE. A further view of the double-deck suburban coach constructed for the French State Railways in 1933 (see preceding illustration). At the right is shown an interior view looking along the length of the coach whilst in course of construction. Below is shown an interior view of the lower deck of the same coach, entrance to the upper deck being visible in the background.

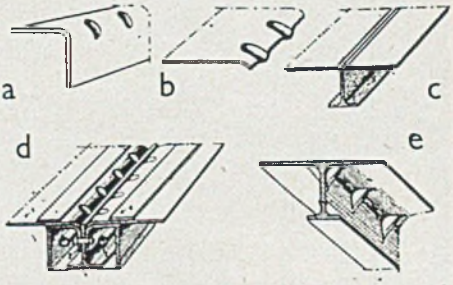


Double-deck Suburban Coach for Long Island Railroad (New York), 1932

The Long Island Railroad forms part of the Pennsylvania system and the double-deck coach about to be described was con-



PARTIALLY dimensioned cross-section of the coachwork of the first all-welded light-metal coach structure built for the French State Railways.

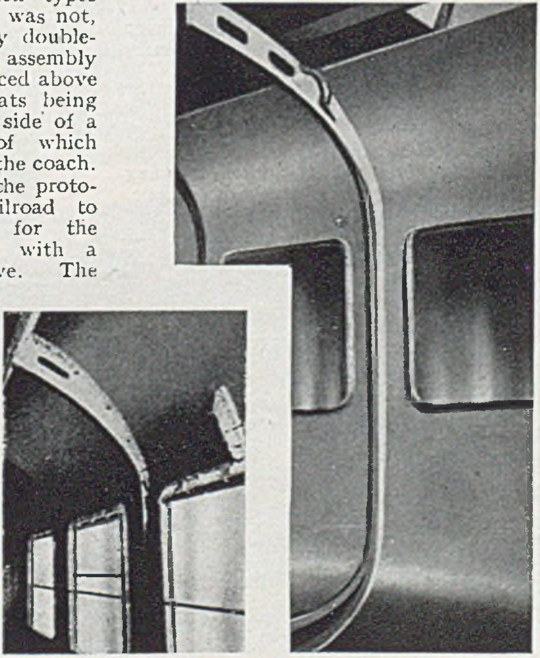


WELDING system used for the fabrication of girders from sheet for the all-welded French railway coach illustrated in section at the left: a, bent corner sections; b, bent sheet ready for welding; c, stiffening member built up from sheet and tacked ready for welding; d, girder structure completely assembled for welding; e, section of finished girder.

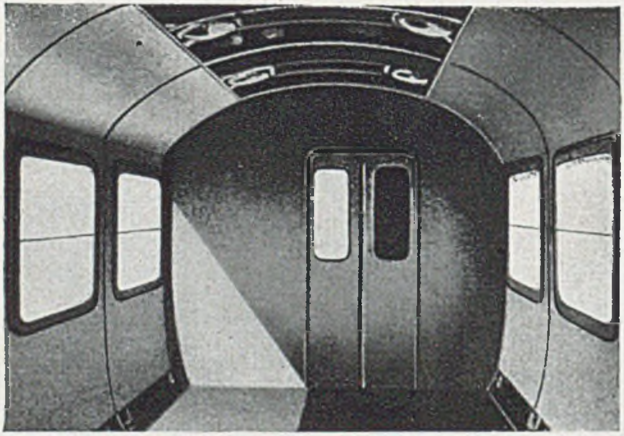
structed in the neighbouring Pennsylvania workshops at Altoona. From the outset it was designed ultimately to form part of an electrified system. The framework of the coach was entirely constructed of aluminium alloys, including the main frame, bodywork frame, outer covering and internal fittings. It had seating accommodation for 120 passengers and weighed 32.5 tons.

In contrast to analogous coach types constructed in Europe, this coach was not, strictly speaking, of the ordinary double-deck type; rather it consisted of an assembly in which one lot of seating was placed above the other, the upper row of seats being reached by steps placed on each side of a centre gangway, the height of which corresponds to the total height of the coach.

Valuable results achieved with the prototype led the Pennsylvania Railroad to construct two further coaches for the Long Island network, together with a corresponding electric locomotive. The train was designed to run over the route between Port Washington, Hemstead and Montauk. The new coaches had a total length of 24 metres and seating accommodation for 136 passengers; they were thus about three metres longer than the prototype and carried 16 more seats. In spite of this, however, experience gained with the first model enabled the two new coaches constructed in light metal to be reduced



TWO views of the all-welded light-metal coach, showing stiffening members welded into position to side-wall components forming the covering of the complete unit.



INTERIOR view of the all-welded light-metal coach, showing appearance before location and fixing of interior components.

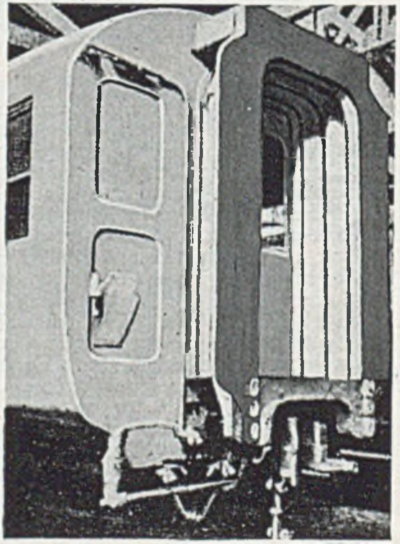
BELOW. End view of the all-welded light-metal coach, showing completed structure with telescopic inter-coach connection and auxiliary fittings.

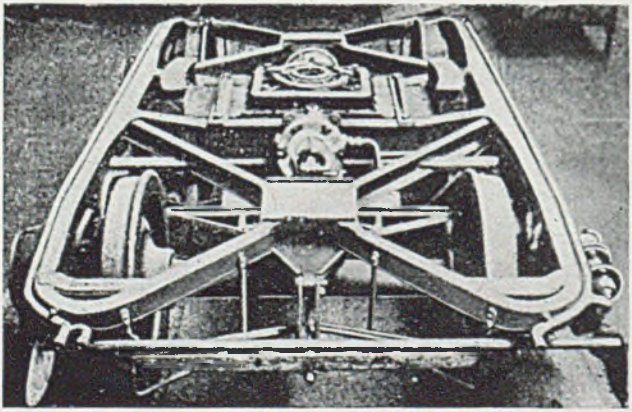
still further in weight as compared with the prototype.

The new construction, with the motor cab attached, weighed 40.8 tons, the trailer coach weighing 36.3 tons. Constructed entirely in steel, the passenger coach with motor cab, which was some 19.5 metres long, seated 80 passengers and weighed 52 tons. There is no doubt that this double-deck design provided a means for increasing passenger accommodation without increasing the length of the coach. The use of aluminium, furthermore, made it possible to produce a passenger coach with integral motor cab weighing only 60 per cent. of that of the all-steel-type passenger coach; in other words, pay-load was nearly doubled.

Electric Locomotives for the Reading Company, 1932

In 1932, the Reading Company built 30 electric locomotives, which, whilst featuring no aluminium in the structure proper, employed light metal in the electrical

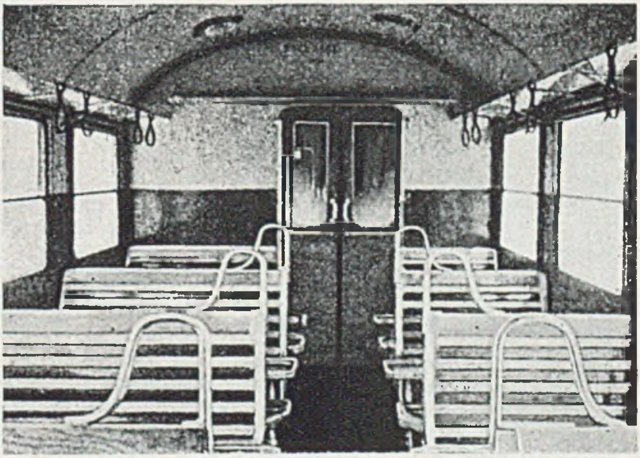


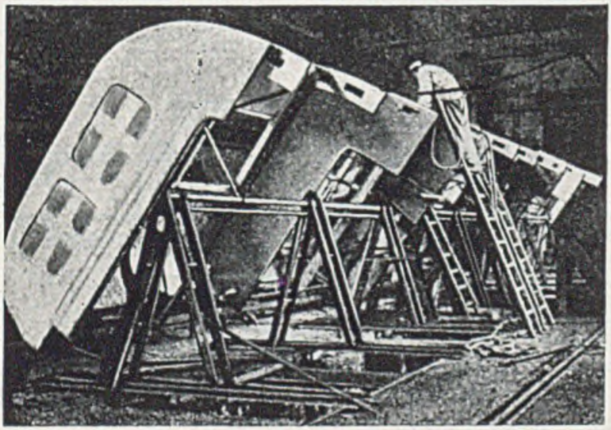


COMPLETED bogie for the all-welded coach as seen from above. Here the frame, equalizing lever and cradle are fabricated from light sections in steel.

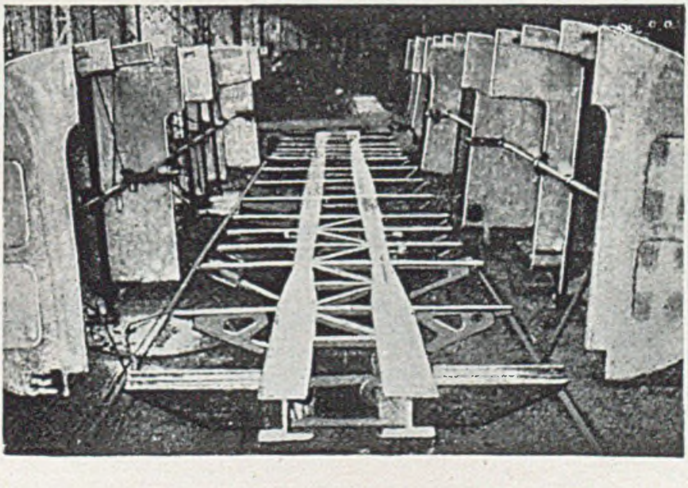
equipment and controls, the weight reduction obtained in this way being found necessary in order that the train length might be increased. These locomotives weighed 57 tons each, a figure not considered excessive in U.S.A.

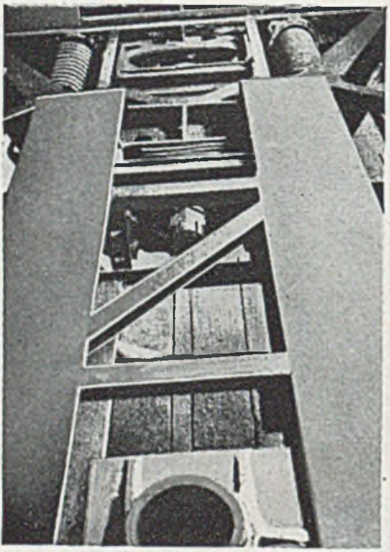
The earliest example of all-light-alloy coach construction is exemplified by two saloon and sleeping cars constructed in 1933 by the Pullman Company of U.S.A. These were designed for main - line operation. Erected in Chicago, they were shown publicly at the "Century of Progress" Exhibition in that year. They are particularly noteworthy in so far as they were, at the time, entirely novel in design, and because they were completely in aluminium alloy; thus, underframe, superstructure, bogies, couplings and buffers, as well as part of the electrical equipment, were in light metal. The only parts in which



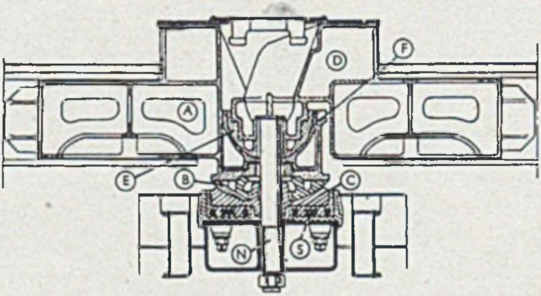


ABOVE. Interior view of the all-welded light-metal coach (third class) showing appearance of the unit complete with seats and interior fixtures. At the left is shown a vertical longitudinal section of the welded coach during course of construction; it is mounted on a special swinging jig. Below is shown the underframe of the welded coach with the two longitudinal halves positioned ready for location.





ABOVE. Steel main member of the articulated coach referred to in the text, ready for imposition of the aluminium bodywork.

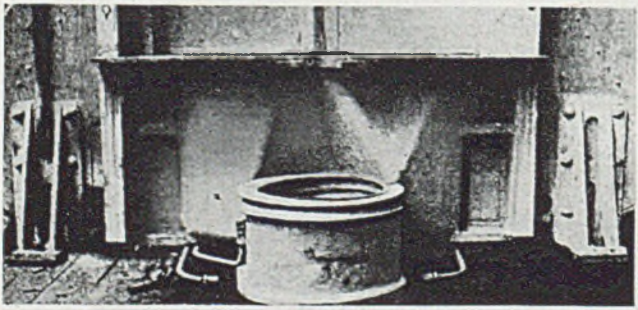


RIGHT. Location of junction pins of the units of the articulated coach on bogies (vertical section through longitudinal axis of coach): AD, steel end-pieces on end frame of coach ; BC, pins and bearing plates of the bogie ; EF, pins and bearing plates of coach units ; S, Spencer rubber damper ; N, securing pin.

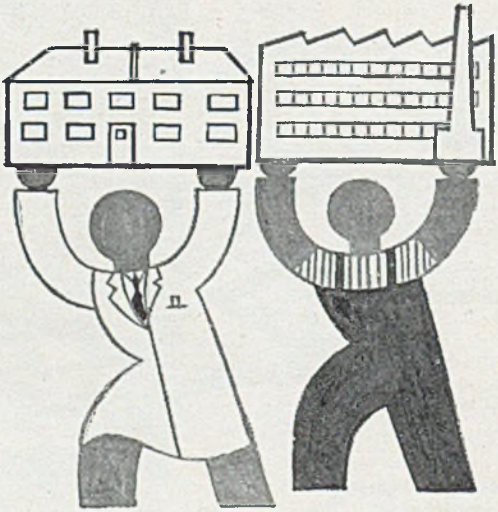
steel was featured (other than a few odd fittings) were the tyres, axles, springs, couplings, and so on.

The first of the two coaches, christened "Pullman Car," was a sleeper to which was attached an observation car and a dining car. The length of the coach framework was 25.7 metres and its total weight 44 tons. Constructed in steel, this type would normally weigh 82 tons; thus, by the use of aluminium, deadweight had been practically halved. Even so, according to current European standards, 44 tons would still be considered moderately heavy. It must not be forgotten, however, that according to American standards a coach of this type must be capable of standing a load up to 180 tons, a figure demanding, naturally, very heavy construction, particularly for platforms and the like. The Commonwealth-type bogie used on this coach made use of a one-piece frame cast in 220 T4 alloy (aluminium-magnesium). Castings in this same alloy were used for cradle mountings, wheel discs, axle bogies and guides. Equalizing lever and brake cross-members were in 25 ST forgings (aluminium-copper-magnesium). The total weight of a four-wheeled bogie of this construction was about 6.1 tons, a figure representing a deadweight reduction of about 46 per cent. as compared with the normal American six-wheeled bogie required by the all-steel coach.

Practically all components in the coach were cold stampings in A-17 ST (aluminium-copper-magnesium with 5 per cent. copper). Corner pieces and other protective features were in 17 ST (aluminium-copper-mag-



SHOWN here is the steel casting referred to under "A" in the previous illustration. It is ready for location on the coach structure.



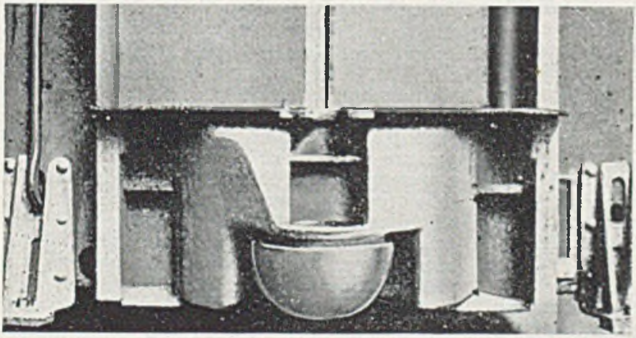
nesium). The longitudinal frame member was worked up from rolled section and was 28 metres long.

The saloon coach, christened the "Pullman De Luxe Coach," embodying observation car and dining car, was constructed on a frame 24 metres long and weighed 33.5 tons, this representing a reduction in deadweight of 50 per cent. as compared with steel construction. The bogies were constructed from hot-formed 17 ST sheet assembly by riveting, and heat-treated. The bogies were of the four-wheeled type and weighed 4.1 tons each.

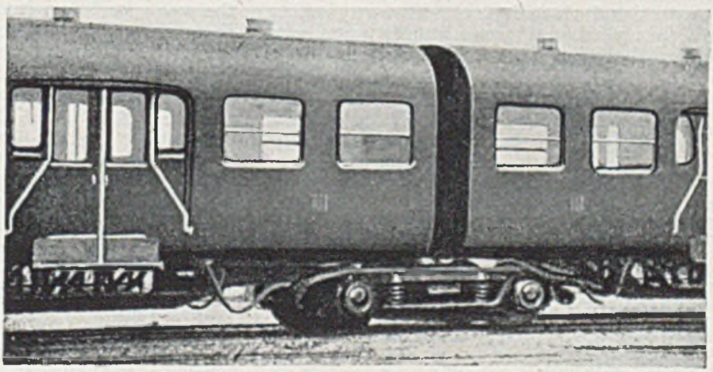
The general lines followed in the construction of these coaches was such as assured, immediately, an assembly equally as serviceable as the normal steel structures. It might be pointed out that the requirements of the Pullman Company are more stringent than those demanded for rolling-stock in general. The coaches described were not only required to withstand a load of 180 tons, but also a tensile load of 70 tons. If it be borne in mind that, as a result of the low modulus of elasticity of aluminium, it is necessary, for a given deflection and for equal thickness of material, to employ girders with webs three times the height of those demanded for steel, it will become obvious that the construction of the coaches entailed many problems. Nor is the higher thermal expansivity of aluminium (about double that of steel) to be neglected. In contrast to usual American practice, unalloyed aluminium rivets were used throughout the structure.

The reasons which led the Pullman Company to construct these experimental coaches were as follow: With lightweight rolling stock of this type it is possible to avoid, on long journeys, the replacement of locomotives which, on very hard runs, must often be done twice; thus, immediately, considerable economy in time and money is effected. Obviously, too, the use of lighter rolling-stock results in lower consumption of electrical energy, fuel oil, water and lubricant, and in a general decrease of maintenance costs for rolling-stock, permanent way, and bridges. Finally, on inclines, increased speed can be obtained without resort to the use of additional engines.

In 1933, 10 double-deck coaches were built for the French State Railways. In this instance the main framework of the chassis was not constructed in light metal, light steel assemblies being used for both sub-



CORRESPONDING to the illustration at the bottom of the preceding page is pictured here the steel casting referred to under "D" in the cross-sectional diagram. It is ready for location on the coach structure.



EXTERIOR view of the junction between two units in the articulated coach. Note position of bogie.

structure and superstructure frameworks. Inner and outer covering, cross-supports for the roof, dividing partitions, floors, doors and inner fittings were, however, all in aluminium alloys, 5 tons of light metal replacing 13.5 tons of steel. This meant that, for the bodywork alone, a saving was effected of some 8,630 kg. in deadweight. Only by the achievement of a light structure of this type was it possible to introduce double-deck coaches on the French railroads. The weight of an all-steel structure of suitable design would have been so great that it must have resulted in permissible axle loading being exceeded; thus it might have been necessary to replace four-wheeled bogies by six-wheeled bogies, the dimensions of which were too great to allow of their satisfactory use on existing chassis. The tare weight of the coaches was 47 tons, and an eight-wagon train could carry 2,040 passengers. It is interesting to note that the nine-wagon train of 1930 had a total payload of only 1,508 passengers. By 1935, 50 of these double-deckers were in service.

In 1935 the French Northern System constructed three-unit articulated suburban coaches in light metal, assembly being by means of welding. The replacement of the conventional riveting by the newer system of joining aroused great interest, and was due to the Chief Engineer, M. Leroy, of the Compagnie du Chemin de Fer du Nord. Several years' normal running service have disclosed no weakness in the welded structure and, as a result, assembly by riveting is fast becoming obsolete. The design concerned comprised an articulated unit made up of three sections with four bogies. The framework consisted of a principal member fabricated from steel-sheet pressings; on this the coach superstructure was erected, the latter being entirely in welded light-metal sheet. The exclusive use of rolled sheet in this design was based on the principle of stressed-skin theory, which, ultimately, yields the lightest possible unit with the best possible mechanical properties. As a result of the almost exclusive use of welding, the coach may be considered to exhibit maximum stiffness and strength.

As high-strength heat-treatable alloy sheet cannot be fabricated by welding (principally because subsequent heat-treatment of massive assemblies of this type is impracticable), it is necessary in work of this type to select an alloy of sufficient strength which is amenable to the welding process and, at the same time, is mechanically suitable for rolling-stock construction; thus, in this instance MG. 7 was chosen, an alloy giving an average breaking strength of 20-25 kg./mm.^{2} if the mechanical properties at the welds be taken into account—hence the sheet and other structural elements entering into the assembly were of comparatively

Table 2.

Component	End section A	Centre section	End section B	Total weight
	Kg.	Kg.	Kg.	Kg.
Steel main member	7,000	5,600	7,000	19,600
Bodywork tare	3,550	3,330	3,550	10,430
Coach floor	814	687	814	2,315
Linoleum covering	188	159	188	535
Window fixtures	884	729	884	2,497
Seats	563	447	563	1,573
Surface treatment (siccolin spray)	1,628	679	262	2,569
Internal fittings, panelling, shelving for luggage, snatch bars, etc.	690	582	690	1,962
Sliding doors	584	584	584	1,752
Ventilation equipment	33	33	33	99
Pneumatic brake lines	103	88	102	293
Lighting, telephones	258	207	258	723
Door fastenings, conduit, cable, bellow	230	179	231	640
Intercoach connectors, emergency signalling equipment	748	398	748	1,894
Drawbars and buffer equipment	613	—	613	1,226
Heating	553	343	547	1,443
Lubrication	8	5	2	15
Internal and external painting	449	479	449	1,377
Braking equipment (including bogies)	668	1,205	667	2,540
Total weight	19,618	15,776	18,239	53,633
Bogies (1 X 2 X 1 X)	5,338	10,772	5,338	21,448

Total weight, approximately 75 tons.

Bogie components—	Kg.
Frames (4)	780
Compensating lever (8)	380
Cradle beam (4)	340
Bearing housings (8) with light-metal axle boxes (16)	2,680
All spring mountings	950
Other components	200
Total weight	5,330

heavy section. Yet, in spite of this, the total unit had a deadweight of only 75 tons, a figure representing a 37 per cent. decrease in comparison with a similar unit fabricated in steel. The total length of this articulated coach was 58 metres, with seating accommodation for 274 and 260 standing.

Of the total weight of materials used, 17 tons consisted of light metal, that is, about 23 per cent. of the whole weight. Aluminium construction resulted in a 16 per cent. saving in weight on the framework of the coach, 12 per cent. on bogies, 6 per cent. for the telescopic inter-coach connection, drawbar and buffer equipment, and 3.5 per cent. for internal fittings, making, in all, a 37.5 per cent. decrease in deadweight as compared with an all-steel structure. These coaches have been in daily use on the suburban line from Paris since March, 1936, and have proved eminently satisfactory. Running properties, tested at 140 kiloms. per hour, proved excellent, but normal operating speed is fixed at 120 kiloms. per hour.

The welding system developed for use in this assembly was of an entirely new type. By means of arc-welded seams, girders of various types were built up from sheet. The design of the girders, which is shown in an accompanying illustration, is such as to achieve great rigidity. The material used, MG 7, is eminently suited to joining by welding and, furthermore, may readily be formed to the desired shape. All material prior to welding was preheated to 280 degrees C.

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Light Alloys in Rectifiers, Photocells and Condensers

The Author Concludes, from "Light Metals," 1945/8/202, His Discussion on Wet and Dry Electrolytic Condensers and Proceeds to a Detailed Consideration of Fixed Paper Condensers

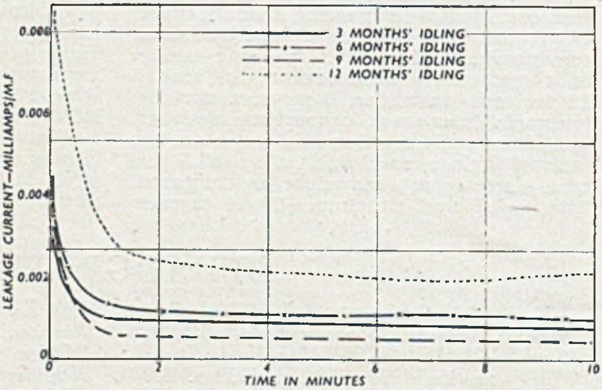


Fig. 166.—Re-forming characteristics of low voltage (25 v.) dry electrolytic condenser after various periods of shelf idling.

THE concluding paragraph of the previous part of this account ("Light Metals," April, p. 202) dealt with factors affecting the life of electrolytic condensers. It was pointed out that the life of the electrolyte itself constituted a principal limitation. High temperature, too, due to heavy leakage current, is also capable of shortening the useful life of such condensers.

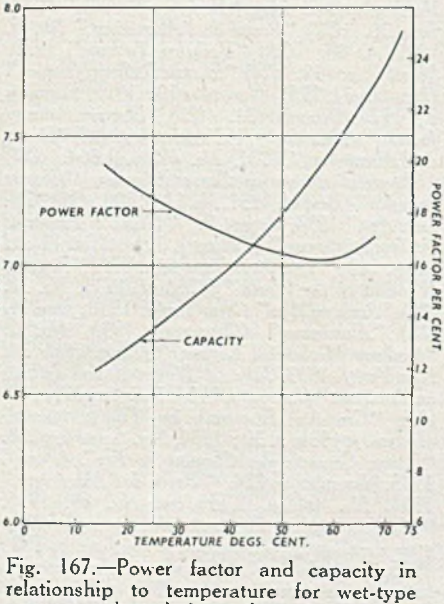


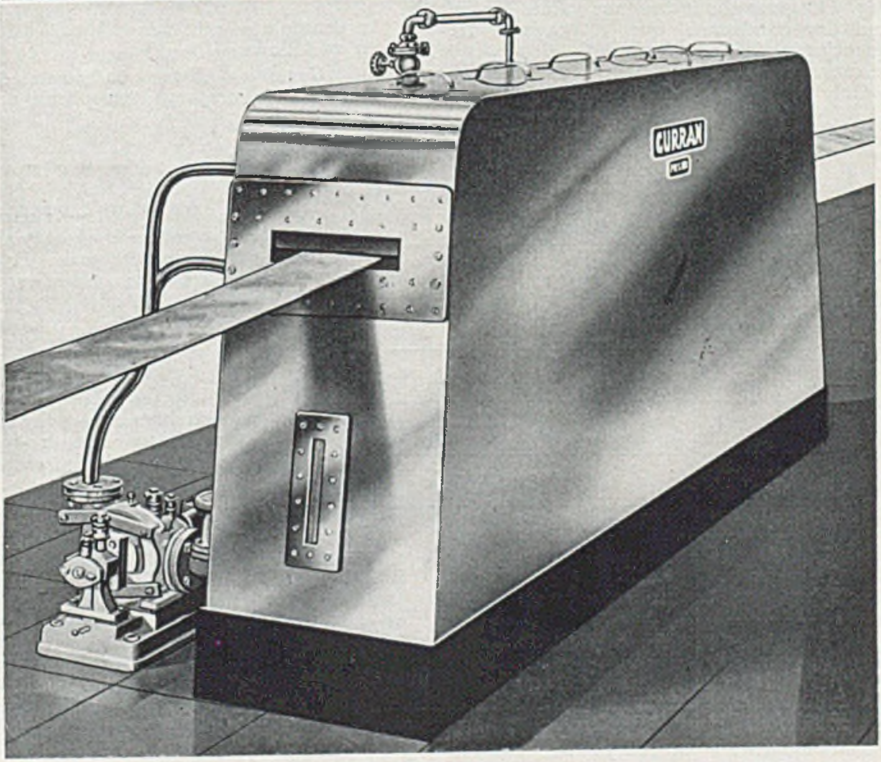
Fig. 167.—Power factor and capacity in relationship to temperature for wet-type electrolytic condensers.

Clogging of the porous film, either by deposit of crystals or of precipitate from the electrolyte, or of aluminium salts in the colloidal state, can also cause loss of capacity. Cathodic oxidation in condensers carrying a ripple can likewise cause deterioration.

In some wet condensers copper has been employed for the containing can, but it is suggested that this copper contaminates the electrolyte and promotes deterioration. A modern suggestion is to use aluminium plated with chromium inside, but in this case a severe a.c. ripple overload will cause the plating to strip and to spoil the electrolyte. Another procedure is to roughen the cathode, mechanically or chemically, in order to increase its area and so reduce the loss of capacity due to any film formation.

6. Practical Applications

Large-capacity condensers with minimum physical dimensions are required in radio receivers and amplifiers for smoothing rectified a.c. current. Two classes are used. Low-voltage types represent one category, having capacity values from 6 to 50 mf., and suitable for operation at voltages from 6 to 100 v. These are used, for example, for passing undesired low frequencies on grid bias circuits. High-voltage types cover capacities from 3 to 24 mf. and voltages from 200 to 550 v. These are used chiefly for smoothing rectified a.c. supplies on the anode circuits to valves.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For by-passing audio frequencies only, the behaviour of the condensers at higher frequencies is of interest. The curve in Fig. 171 shows the equivalent series of resistance value over a range of frequencies for a 6 mf. 500 v. dry-type condenser. Fig. 172 gives the impedance values for wet and dry condensers over a range of frequencies, and Fig. 173 gives the dependence of capacity upon frequency.

Only a general guide can be given upon the choice of a particular condenser, namely:—

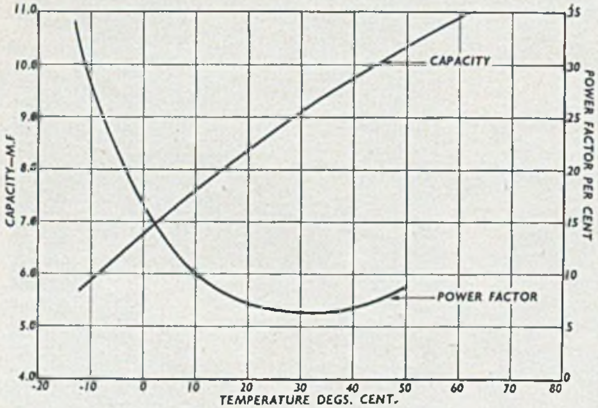
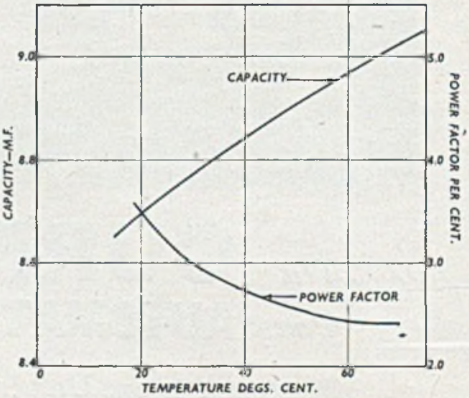


Fig. 168 (left). — Thermal characteristics of capacity and power factor for semi-dry type electrolytic condensers.

Fig. 169 (below). — Thermal characteristics of capacity and power factor for dry-type electrolytic condensers.



(i) If a low power factor is required the dry and semi-dry types are preferred to the wet type.

(ii) To cater for a wide range of working temperatures, the wet type in general will give lower stability and characteristics especially at extreme temperatures.

(iii) To function as a voltage limiter by drawing a large leakage current, while the rest of the load is inoperative, as with slow heating valves, a wet electrolytic condenser should be chosen on the grounds of reliability and length of service.

(iv) A wet electrolytic condenser must be mounted vertically with the vent above the level of the electrolyte. A dry condenser can be fixed in any position and, therefore, must be used when the foregoing requirements cannot be maintained.

(v) The dry type is preferable where long idling periods are entailed. This is because they are effectively sealed and have greater film stability.

Electrolytic condensers are used on alternating current circuits principally for split-phase motors. They are also used as regulating condensers for limiting the voltage rise in a rectifier circuit before regulation. Wet condensers are used for this purpose and they depend for their operation upon the fact that the d.c. leakage current rises as the voltage is raised above the normal operating point.

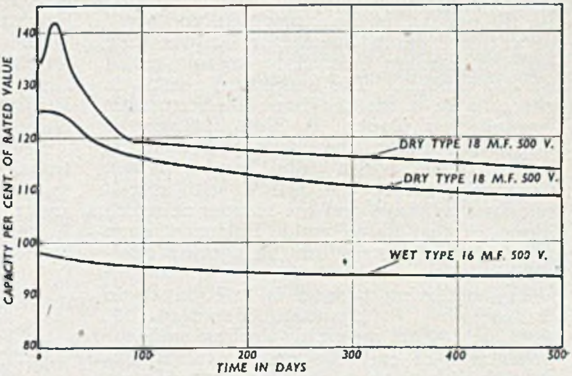
Standard Specification for Performance and Acceptance Test

An example of a standard specification is given as follows:—

(i) *General*.—All tests to be carried out in normal laboratory atmospheric conditions, between 15 and 20 degrees C. All condensers to be held in their normal working positions for all tests, wet-type condensers being upright.

(ii) *Re-forming*.—Condensers shall be subjected to an initial re-forming treatment by the application of a steady d.c. voltage equal to their rated working voltage in the correct direction indicated by the terminal marking. The duration shall be as shown in Table 31. The leakage current shall then be measured by a milliammeter and shall not exceed 0.15

Fig. 170.—Time characteristics or life curves for dry and wet electrolytic condensers at 50°C. and 500 Volts d.c.



milliamps per mf. per volt for dry types and 0.35 milliamps for wet types. In no case need the leakage be less than 0.1 milliamps.

(iii) *Capacity.* — Capacity shall be measured at 50 cycles per second, using the impedence method, a bridge circuit or equivalent network. For this test the condenser shall be subjected to a d.c. polarizing voltage of 75 per cent. of the rated peak working voltage of the condenser and the a.c. ripple voltage (R.M.S.) superimposed shall not exceed 10 per cent. of the rated peak working voltage. Maximum permissible tolerances from the normal capacity value are given in Table 32.

(iv) *Power Factor.*—Determined by a bridge method at 50 cycles power factor shall satisfy the limits given in Table 33.

(v) *Insulation.*—Condensers in insulating cases or in metal cases, but insulated therefrom, shall be subject to an insulation test applied between the condenser sections and the case or the sections and a metal plate on which the metal case is laid. The test shall also be applied between any separate condenser sections which are intended to be completely insulated from one another. It shall not be applied between the terminals of any condenser sections which have any common connections between them. The insulation resistance measured at 1,000 v. d.c. shall exceed 100 megohms.

(vi) *Extra Tests.*—When desired the tests may be amplified by the inclusion of tests for re-forming characteristic and voltage characteristic, both taken after the application of the rated working voltage for 100 hours, followed by 100 hours idling.

Coursey and Ray's paper is very comprehensive, as can be readily seen from the above brief abstract. Many of the practical features of electrode design, etc., are patented, and the paper gives a long list of patent information in addition to a comprehensive bibliography of scientific references.

It is apt to close the section on rectifiers and electrolytic condensers with reference to two recent production plants introduced in America in industrial finishing shops. The first of these is popularly termed the

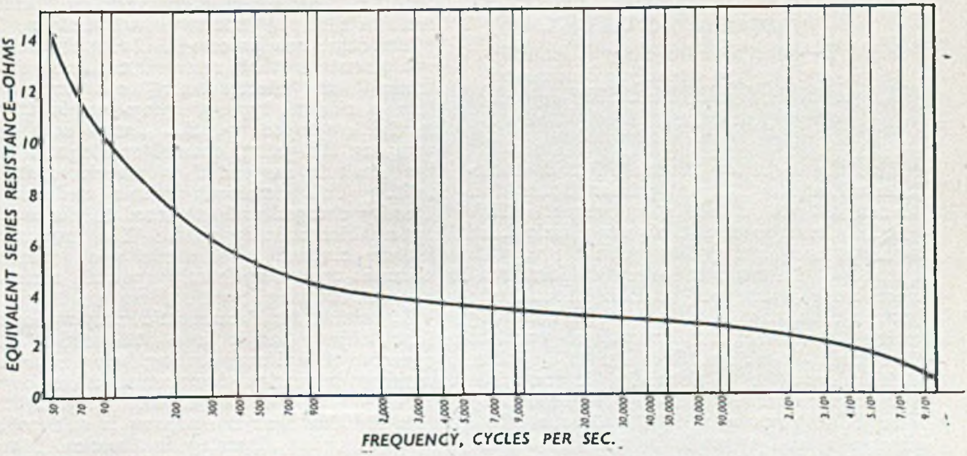


Fig. 171.—Curve showing dependence upon frequency of the equivalent series resistance of a dry-type electrolytic condenser, capacity 6 mF., 500 V.

"detearing unit," an equipment employed for the removal of the excess "drain-down" of varnish, paint, enamel or lacquer from articles that are finished in organic media by dip process. The equipment seems, in effect to be a modification of electrostatic precipitation plant. A high potential is imposed between the work and a metal screen over which the work passes. Obviously, the type of article, with special reference to shape and the manner in which dipped, must have some influence upon whether the process can be applied effectively.

The detearing process is referred to in "Machinery" (London), February 17, 1944, p. 180, in an article dealing with the production of cartridge cases. It explains that the cases are thoroughly cleaned, rust-proofed by successive dips in phosphoric acid solution, water and aqueous chromate solution, and dried. This sequence of processes occupies 30 seconds and ensures cleanliness prior to varnishing. For the latter, the cases are suspended from hooks inserted through their primer holes and transferred to a chain conveyor. This carries them to the tank of plastic base varnish, and as they leave this the varnish runs down the cases to leave a uniform coat except for a ring of varnish around the mouth of the case. The duty of the detearing unit is to remove this drain-down varnish. The unit is shown in Fig. 175 (after "Machinery"). Essentially, it comprises two copper screens which are electrically charged to a potential of 80,000 volts. This charge is said to pull the varnish off the ends of the cases in the form of spray before they actually reach the screens; the second screen removes any varnish that may drain down the cases after passing the first screen. Rather than make the screens messy with varnish, they are covered, in practice, with heavy wrapping paper, which absorbs the varnish; this avoids the labour of repeated cleaning of the screens.

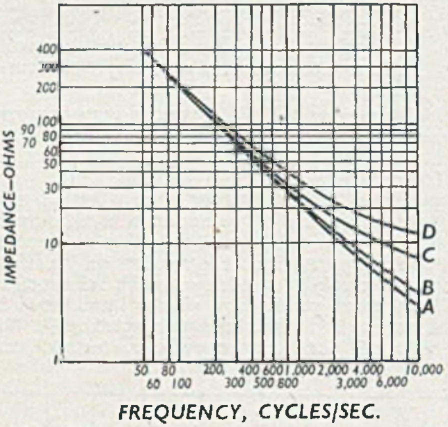


Fig. 172.—Impedance/frequency relationship of wet- and dry-type electrolytic condensers: A, 8 mf. 525V dry; B, 8 mf. 500V dry; C, 8 mf. 460V dry; D, 8 mf. 475V wet.

From the detearing outfit, the cases are transferred to a baking oven, conveyorized so that they first enter a preheating zone and then the baking section at 475 degrees F, and, finally, a cooling section. The baking-zone period is 20 minutes.

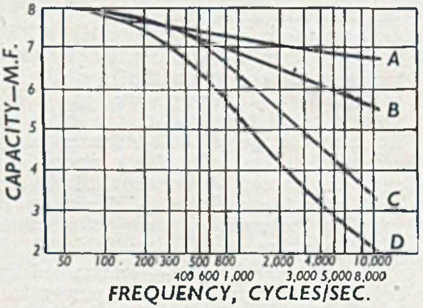


Fig. 173.—Capacity/frequency relationship of wet- and dry-type condensers: A, B, C and D as in Fig. 172.

Sufficient has been said of detearing to show its significance, and technologists concerned with industrial finishing are fully aware of its importance in dip-finishing processes and their extension to a larger variety of work. Obviously, insufficient is yet known of the process over here to be over-optimistic, and what suits war production may not be so favourable to peace-time outputs. However, the significant fact remains that the process is in operation.

The other new process involving electronic equipment is that referred to as "electronic" or "electrostatic" spraying. In this, a normal type of spray-gun is apparently employed in the usual way for spraying the paint, enamel or lacquer, but the work is suspended in an electrostatic field. The atomized organic medium is thereby charged and attracted to the work, upon which it is deposited. The important feature claimed is that the work thereby becomes coated uniformly upon all surfaces without rotating it.

The claims for electrostatic spraying sound far-reaching, but it is a little difficult to conceive of uniform coating being achieved without having a demonstration to overcome various obvious doubts. Again, the fact remains that the process is said to be operating with advantage in America. Moreover, equipment is being advertised in this country.

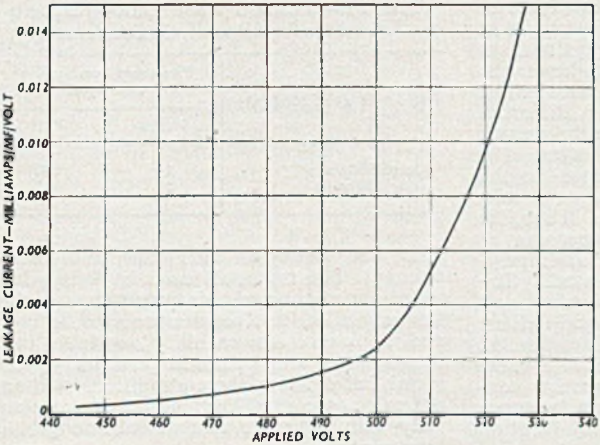


Fig. 174.—Curve for "regulating" type condenser, showing leakage currents for applied voltages between 440 and 540.

These illustrations are brought in to bring the application side of rectifiers and electrolyte condensers up to date. Many industries will be interested in them as soon as facilities are made available. At the same time, an ever-widening field of application will inevitably create further development and progress in the design and production of rectifiers and electrolytic condensers, of rectifiers of greater output per unit area without loss of efficiency, and of condensers of greater efficiency and longer service life. This does not signify anything appertaining to a vicious circle, but normal healthy progress from the slow but sound application of scientific knowledge to industrial practice.

Fixed Paper Condensers

Fixed paper condensers are produced in a very wide range of forms and sizes. Primarily they comprise two metal plates in parallel position separated by a dielectric. The electrodes consist of very thin metal foil and the dielectric insulation in general consists of high-grade paper impregnated with a suitable medium, which, in turn, may be wax, oil, jelly or other appropriate material. The paper thus plays the fundamental role of carrier for the impregnant, enabling the two metal electrodes to be held at a distance apart which is virtually constant throughout the condenser. However, its quality in other respects is very critical and must conform to very strict standards.

The metal foil used for the electrodes at one time consisted of tin-lead, tin-lead-antimony, or tin-antimony-alloy, or pure tin itself, or it consisted of high-grade paper (of composition and quality similar to that used for the separating insulation itself) coated on one side with tin, chemically precipitated and secured in position with suitable adhesive to give a continuous metal conducting coating. During the past 20 or 30 years, these materials have been gradually replaced by aluminium foil, so that to-day the latter material represents practically the whole of the metal condenser foil consumed, if not the whole of it. The adoption of aluminium was both earlier and quicker on the Continent and in America than in this country. Availability was one reason for this; but a number of factors had to be examined and tested by field trial before aluminium could be accepted. To-day, the eminent suitability of aluminium for the purpose, established by years of use, and regarded from the viewpoint of chemists, metallurgists and engineers better equipped technically, creates surprise at all the early doubts concerning its soundness for the purpose and at the struggle that existed in introducing it.

Perhaps the characterizing feature of a condenser is its electrostatic capacity. This

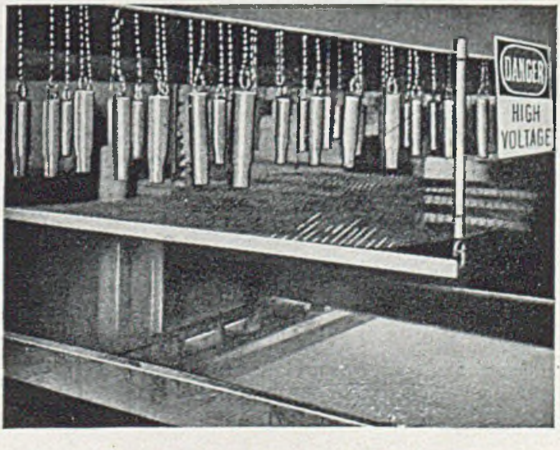


Fig. 175.—Copper screens electrically charged to a high voltage are employed, as illustrated here, to remove excess varnish from cartridge cases.

is proportional to the surface area of one of the electrode plates (assuming them to be of equal size), and inversely proportional to their distance apart. That is, the larger the area of foil in the electrode, the greater the capacity, and the thinner the dielectric insulation between them likewise the greater the capacity, other things being equal. The capacity is also directly proportional to the specific inductive capacity (S.I.C.) or permittivity of the dielectric insulation. Thus, for the same construction, a condenser can be made having a higher capacity if an impregnant of higher S.I.C. can be used. The hydrocarbon waxes such as paraffin and ceresin, and the mineral oils and jellies, have closely the same S.I.C. value, but the chlorinated naphthalene waxes have a value about twice as high. Consequently, condensers of the same capacity can be made smaller, about half the size, by substituting the chlorinated naphthalene waxes for paraffin wax, an aspect that will be referred to again.

Table 31.—Standard Specification Re-forming Requirements for Wet and Dry Electrolytic Condensers.

Condensers tested	Duration of Treatment	
	Dry type	Wet type
Within 1 month of manufacture	10 minutes	2 hours
After 6 months' shelf "idling"	30 minutes	6 hours
After 12 months' shelf "idling"	60 minutes	12 hours

In order to produce condensers of suitable capacity in a compact form, the units are manufactured in rolls. To this end, the two foils with the requisite number of papers separating them are wound together on a mandrel. Thus, if two separating papers are required, the various materials are fed to a mandrel together in the order two papers, one foil, two papers and one foil. The papers extend beyond the ends of the foils to prevent short-circuiting, and the foils are a little narrower than the papers and arranged centrally to prevent flash over at the edge. The roll is then wound on an automatic or hand machine to the required length. The metal foils are cut short of the papers, again to prevent flash over. The ends of the papers are secured with adhesive to prevent unrolling in handling through the next operations. Conducting tapes are slipped in during winding to make mechanical contact with the metal foils, and it is these tapes which are subsequently taken out to the condenser terminals.

The rolls pass through operations of pressing to shape in order to fit their final containers, drying, impregnating, assembling and sealing in their cans, and finally testing. The materials used have to withstand the rigours of this processing, enable the inspection test requirements to be met, and to ensure serviceability as stable condensers for long periods. Actually, the metal foil satisfies these conditions without difficulty, provided that its nature, particularly with regard to mechanical strength, is appreciated.

Table 32.—Standard Specification Capacity Tolerances for Electrolytic Condensers.

Rated voltage of condenser	Maximum permissible tolerances	
	Minus	Plus
Up to 100 volts	10	100
Over 100 volts	10	50

A few brief notes upon the quality requirements will explain clearly how far raw material, process, method and design are each responsible, and how each can be manipulated to best meet the requirements imposed.

Specified capacities have to be met generally within a limit of plus or minus 5 per cent. In some cases closer tolerances are required, while in others a wider limit suffices, or may be necessary for reasons of practical difficulties in meeting a particular design. In all cases accuracy of production is essential. The width of metal foil must be accurate and thickness uniform. If only a short length of foil is needed to give the capacity, a longer length of narrower foil can be considered in order to give greater accuracy in winding. It should be pointed out that in winding the length is controlled by the number of turns. The diameter of the mandrel upon which the foil is wound gives another variable assisting in attaining accuracy, dependent upon the length involved. However, capacity is still more affected by the thickness of the interleaving paper, upon which such close thickness tolerances, and uniformity throughout its length, cannot be maintained as with metal foil. Grading of the rolls of paper, and segregating into groups,

Table 33.—Standard Specification Requirements for Wet and Dry Electrolytic Condensers.

Rated working voltage in volts of the condenser	Maximum power factor per cent. for :—	
	Wet type	Dry type
Below 50	—	20
Between 50 and 100 ..	—	15
Between 100 and 450 ..	20	10
Over 450	25	10

is of assistance in this direction. Again, strict control of process and methods is essential if limits are to be maintained.

The degree of constancy of capacity with temperature changes is important and may be specified. This is governed to some degree by process and in particular by the nature of the impregnating medium. Where the latter is a wax, not only is it necessary to use one of suitably high melting point, but its physical and chemical nature must be correct. Further, the physical shape and size of the condenser unit must be stable, with no tendency for the turns to "spring" apart, if capacity is to remain constant when the condenser is subjected to a temperature gradient.

The insulation resistance of the condenser unit must be high and must not deteriorate with time. It is determined by the quality of the raw materials employed in the first instance, a maximum purity of paper and of impregnant, and cleanliness of the metal foil. However, in the second place it is determined by correct processing with special reference to the expulsion of all moisture and sealing to prevent the ingress of moisture.

Given correct raw materials and processing, the electrical strength of a condenser in terms of "breakdown voltage" is a function of the nature and thickness of the dielectric, and therefore a value that is relatively simple to cater for in design.

Power factor or loss factor is another characteristic that often has to meet stipulated limits, as it represents the energy loss in the dielectric. It has to be dissipated through the condenser as heat and therefore if excessive it may be destructive. The variation of power factor with temperature is likewise of importance.

It is proposed to discuss in some detail the various raw materials employed in the production of fixed paper condensers, and the processes employed. The latter will be dealt with in the critical sense to demonstrate the precautions required to ensure the production of sound condensers and the obvious pitfalls to avoid. Condenser quality in relation to materials will be illustrated on the basis of the electrical characteristics mentioned above. Finally, design will be referred to in so far as it reflects upon the features discussed and upon the uses of aluminium and its alloys for other component parts of the condenser.

The raw materials involved in the manufacture of fixed paper condensers are metal foil of thin gauge for the electrodes, or thin metallized paper, thin high-purity, high-grade paper as insulation and dielectric, and the impregnating medium which may be oil, wax, jelly or similar substance such as chlorinated diphenyl. These will be dealt with in some detail separately.

Tin-foil Paper

Practically the only metallized paper that has been employed for the electrodes of fixed paper condensers is tin-foil paper. It is a product specially produced for the purpose, consisting of a thin high-grade tissue paper of the same grade as that used for the insulation, coated on one side with chemically precipitated tin. The paper thickness is of the order of 0.0004 in. to 0.00045 in., and the overall thickness about 0.0005 in. The paper generally is a linen rag stock material, very close to neutral in reaction and, in the ideal case, free from retained chemicals or other injurious constituents. The tin is chemically precipitated from aqueous solution by means of zinc, and it is separated from the resultant suspension by filtration. It is then thoroughly washed to remove chemicals and mixed with an aqueous adhesive, such as one of starch base, and spread over the paper. The latter is dried and the tin coating is burnished in order to spread the tin into a continuous, electrically conducting film, having a smooth, bright appearance.

The thickness of paper insulation in a condenser is determined by the electrical breakdown voltage that it has to withstand, and it is provided by the requisite number of layers of thin tissue. The majority of small condensers use two thicknesses between the metal foils; in fact, a single layer is never used because of the strong probability of electrical breakdown through weak spots in the paper. Using metallized paper, however, only one additional paper between foils is used for condensers that are approximately the equivalent of those just referred to. Nevertheless, such condensers having metallized paper foils are not so good as those having metal foils. The characteristics of electrical breakdown strength and of insulation resistance are poorer. A little consideration shows that the reason for this lower quality is obvious. The tin powder, chemically precipitated, is certain to retain some ionizable chemicals, however thoroughly it be washed. Again, the adhesive employed for securing the tin powder to the paper will contain some ionizable chemicals from those employed in preparation of the starch or dextrin used as its base. Further, this type of adhesive is not as stable to heat and, therefore, to the heat of processing encountered during condenser manufacture, as can be desired, and decomposition to acidic products is probable. These features lead to lower insulation resistance values than would otherwise be anticipated.

Regarding breakdown strength, it will be realized that during the tin coating of the condenser tissue, some tin particles will contaminate the side of the paper that should be free from metal. More serious still, during the rolling and burnishing of the tin coating, some tin particles become forced through weaker spots in the paper, while others are pushed partially through. Thus, it is for these reasons that lower electric strength values are recorded on condensers having metallized paper electrodes than are exhibited by those using metal foils.

At one time it was the practice to subject all metallized paper to a brush discharge before use by passing between a metal roller and a metal comb. The object was to burn out all the metal particles that appeared on the wrong side of the paper, or those partially through. Clearance of short circuits or of potentially weak spots by this means, however, was not really achieved, and other difficulties were produced. Many of the "burn spots" still proved to be conducting, and even passing the paper through the discharge machine several times did not succeed in clearing the weak points. Again, a separate room was found to be necessary for the operation, isolated from the condenser-winding shop. This was on account of the metallic fume produced by the discharge process, this fume contaminating the condenser paper insulation during winding. Consequently, this breakdown discharge operation has been abandoned by most users of metallized paper.

Tin-coated paper is still used for some purposes, despite its disadvantages. In fact, it has peculiar merits in certain applications. These concern condensers for spark-quench circuits, where the material exhibits self-healing properties, i.e., a condenser breaks down and leaks, but recovers itself.

Tin-foil-coated paper is popularly referred to as "Mansbridge" paper, and condensers in which it is embodied as "Mansbridge condensers," after the patentee, C. F. Mansbridge (B.P. No. 19451, 1900). At that time, it was not practicable to obtain commercially metal foils in thin gauges and continuous lengths sufficiently long for economic winding operations. Therefore, tin-coated paper made the production of fixed paper condensers commercially feasible. When tin foil itself became available, the coated paper still held the field on account of economic considerations. The appearance of aluminium foil changed the situation because of its markedly higher covering capacity (i.e., surface area per unit weight), and from that time the tin-foil paper material has gradually declined and become relegated to uses for which specifically advantageous.

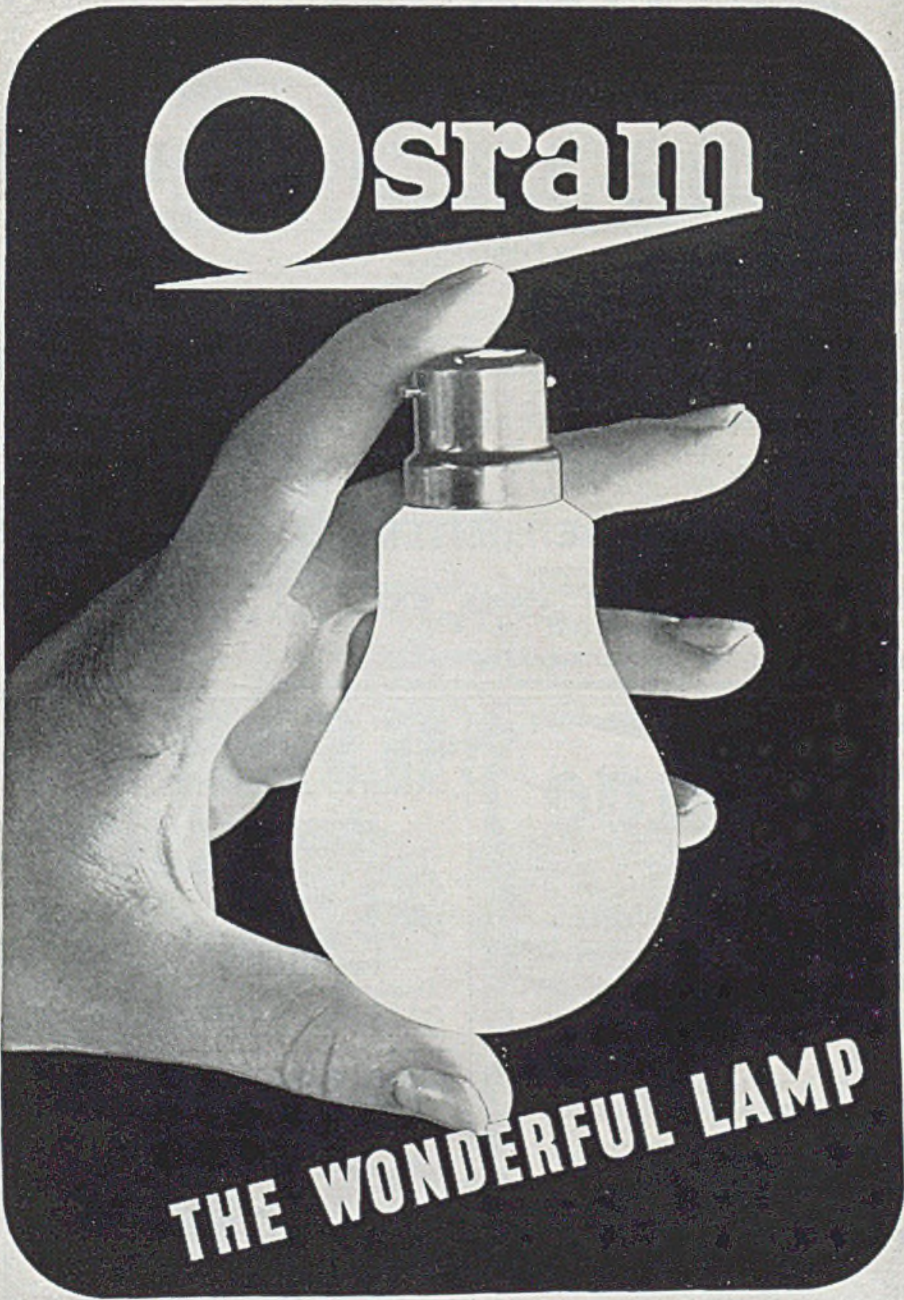
It might be as well to point out here that, in studying this comparative presentation of various techniques and materials for condenser manufacture, the mistake should not be made of assuming, out of hand, that any one material is so far superior to another, or of such universal applicability, that it may entirely displace the other. In any sphere of industry, in fact, 100 per cent. displacement of this type is exceedingly uncommon, but, at the same time, changes in requirements, alterations and developments in production procedures, and economic disturbances, all tend strongly to alter the balance of power between raw materials.

At the moment, for example, tin (which, in any case, is not too abundant a material) is in very short supply, hence its use is restricted to fields of the highest priority. From this same economic standpoint, emergency conditions have rendered aluminium more abundant than ever before, and now, when immediate calls on the metal for aircraft purposes have eased, it is likely to find its field of use extending, and even trespassing on that still retained by tin, in so far as condenser manufacture is concerned.

Technical and economic considerations of this sort exert a vital directing course on the lines which progress takes. It may, for example, be accepted as certain that the paper dielectric itself is, to a greater or lesser extent, being made the subject of intensive research, a state of affairs promoted, in part, by the development of modern impregnating techniques using the newer plastics, some of which have electrical properties far superior to any other media hitherto developed. Somewhat less likely, but a possibility, nevertheless, not to be ruled out, is the development of suitable papers based, say, principally on bentonite, or indeed, of course, the use of plastic foils, the mechanical properties of which are in many ways allied, but, in certain respects, superior to those of paper.

Tin-coated paper is supplied to a reasonable degree of uniformity in characteristics, in continuous lengths, slit to a close degree of accuracy to any width desired. Troubles from "burred-over" edges, which cause difficulties in unwinding when occurring in metal foils, are not encountered. However, the material must be tightly wound with even tension, and when reeled at the time and slit to width, it must be neither too dry nor too wet. If too wet, drying during storage or transit occurs, with shrinkage and tightening of the outer layers and edges. The material then takes a cockled or bowed form, when used in winding condenser sections. This is detrimental because speed of winding is reduced, as well as the accuracy and tightness of the condenser sections being below standard. Again the material is usually provided on card or wooden centres, which shrink during storage and give difficulties in chucking, the tin-coated paper tending to slip on its former. Wood is preferred because it can be expanded and split by the expanding chuck and thus tin-foil paper is held firmly.

(To be continued.)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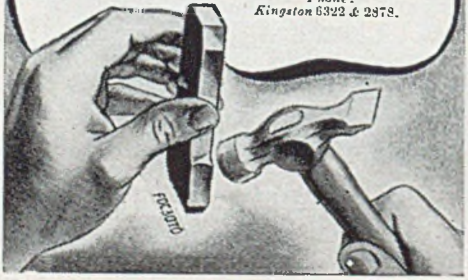

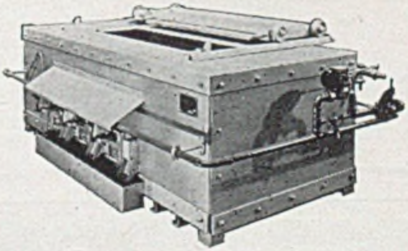

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