MAGNESIUM ALLOYS—HIGH PURITY *versus* HIGH Mn

LIGHT METALS

OCTOBER
1945

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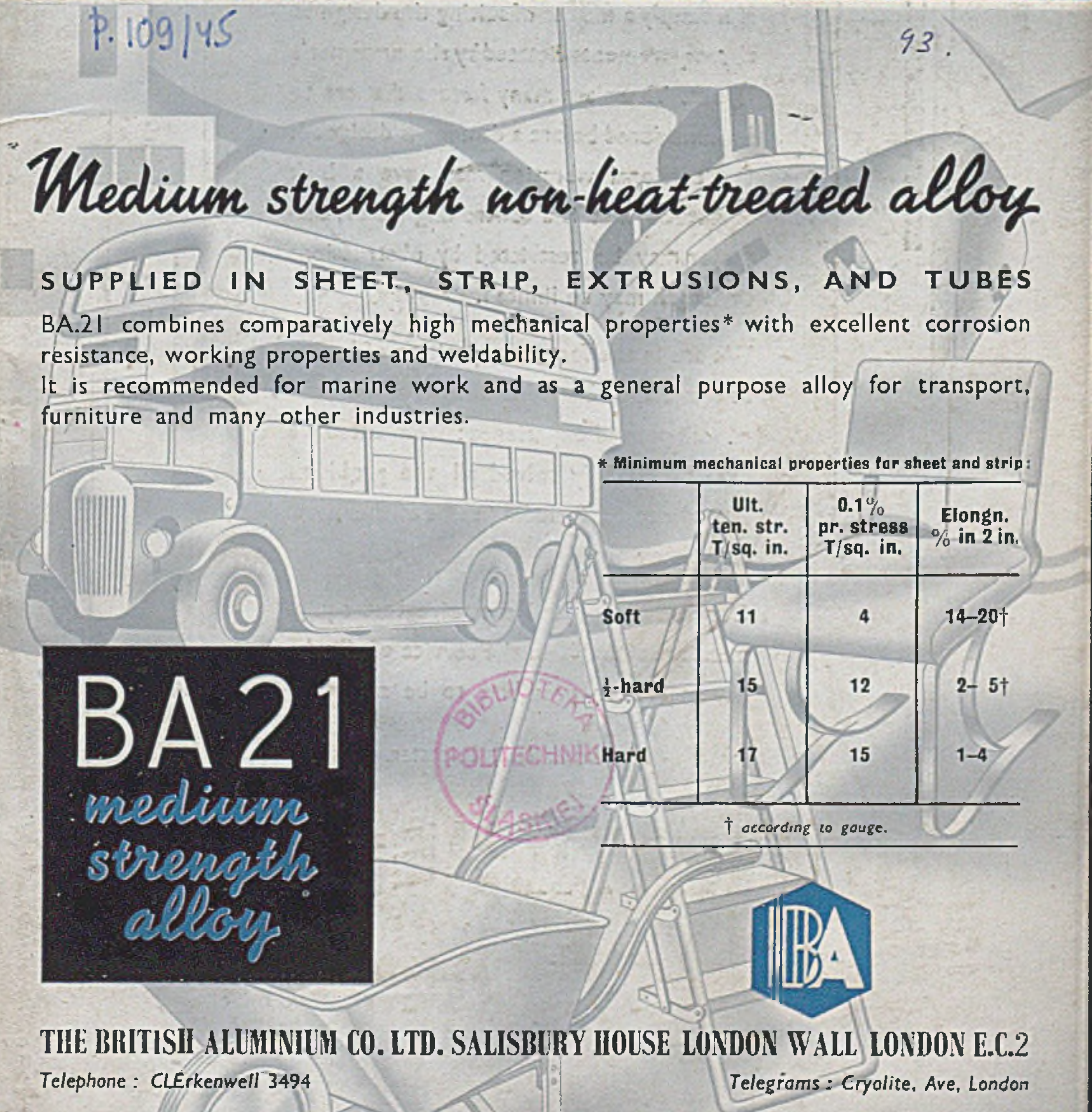

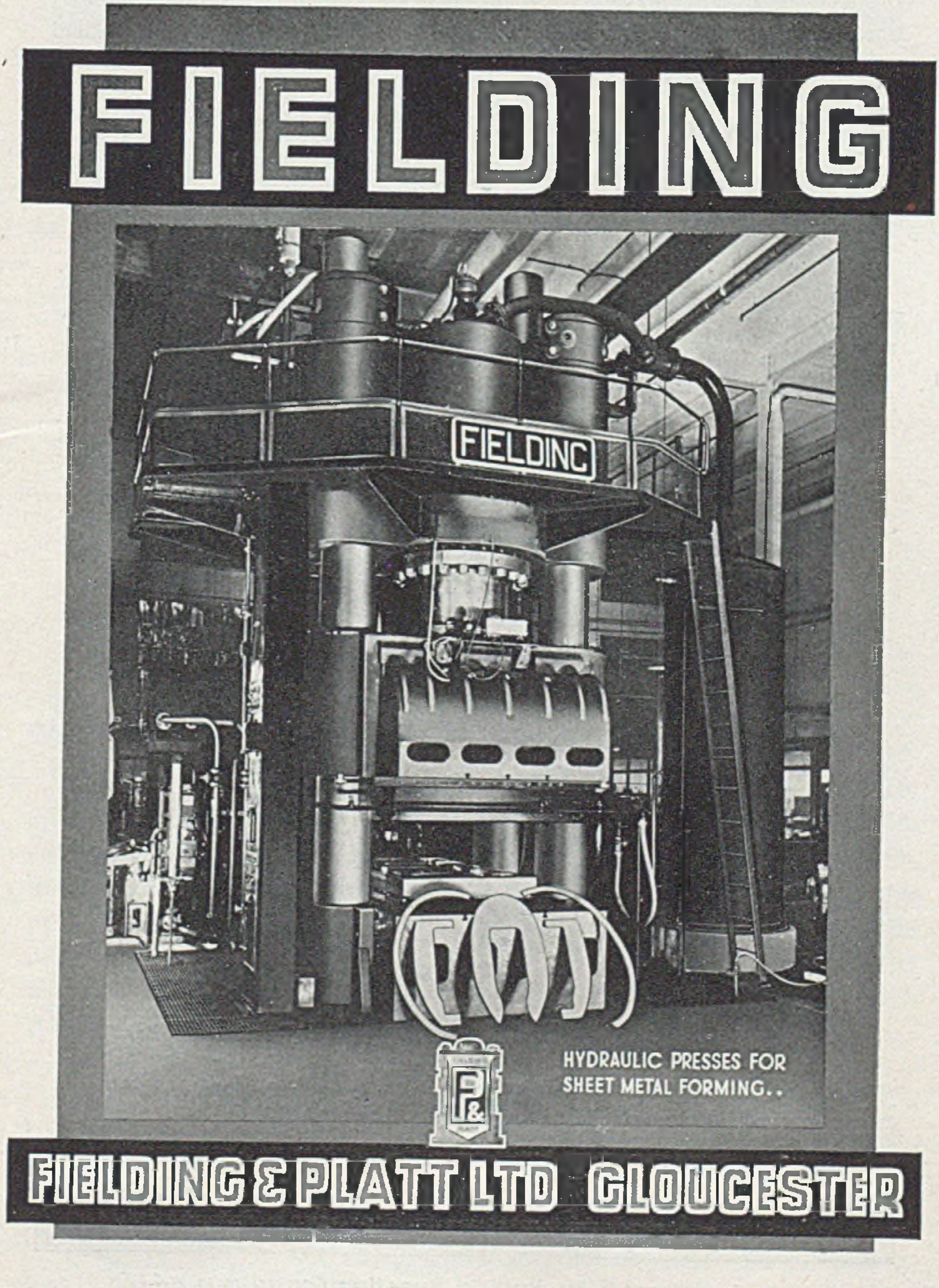


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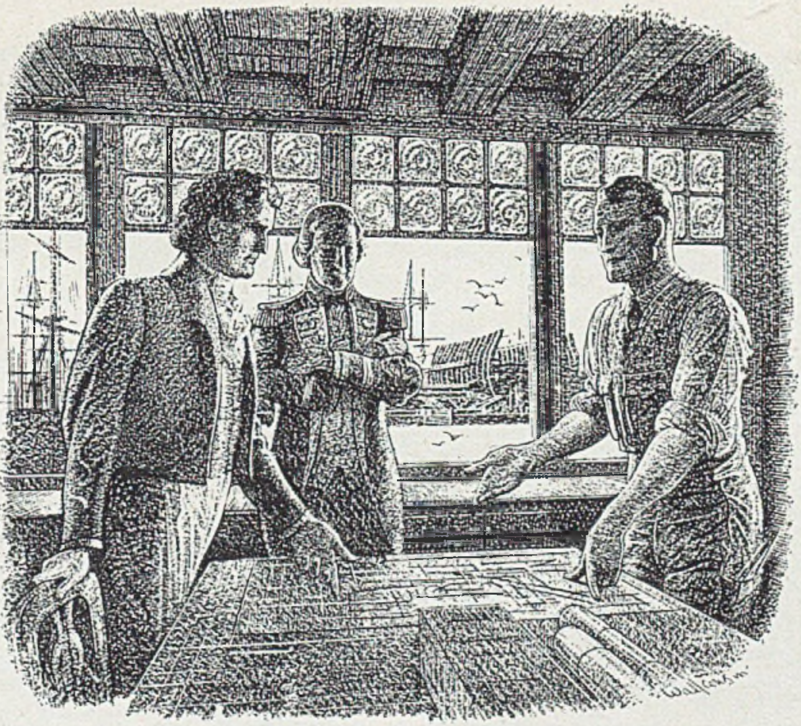


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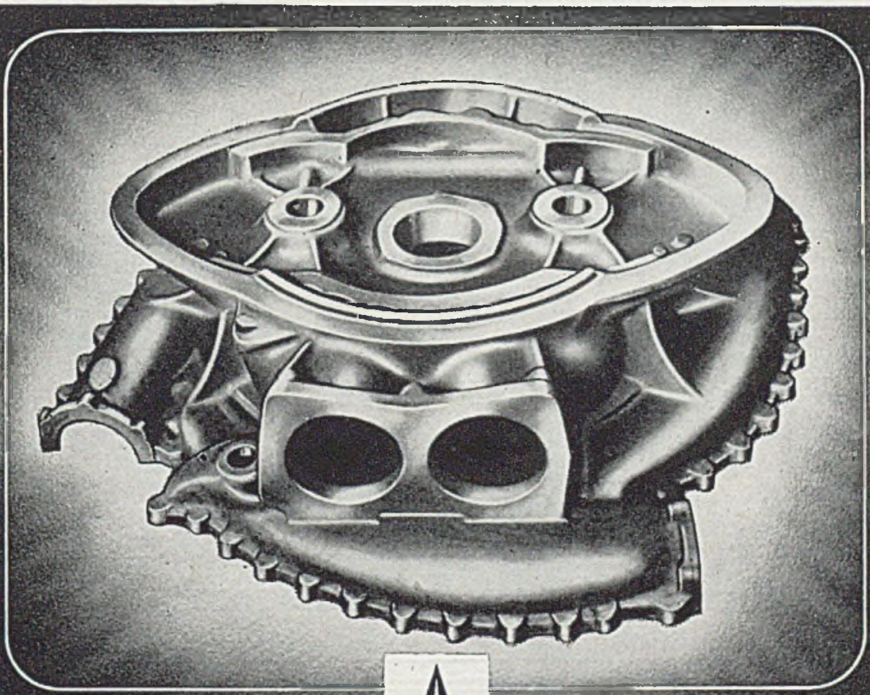

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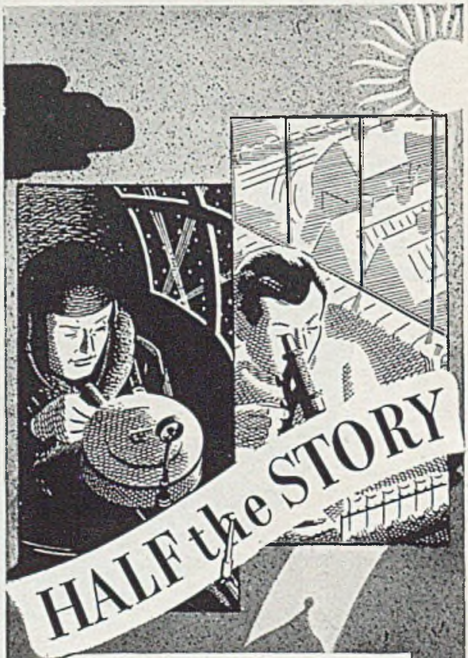

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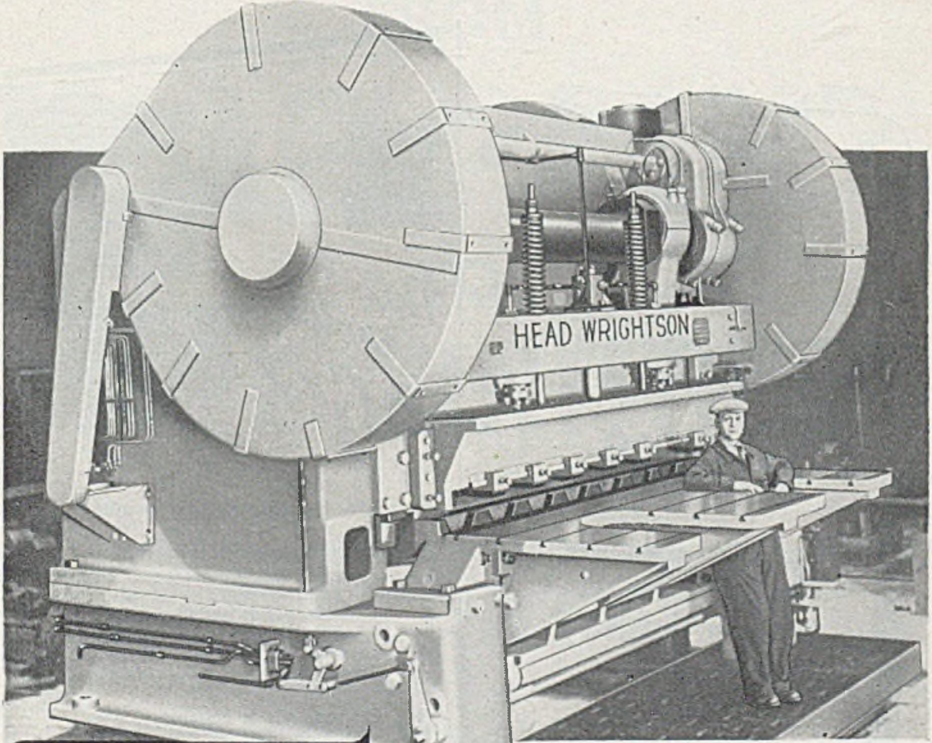

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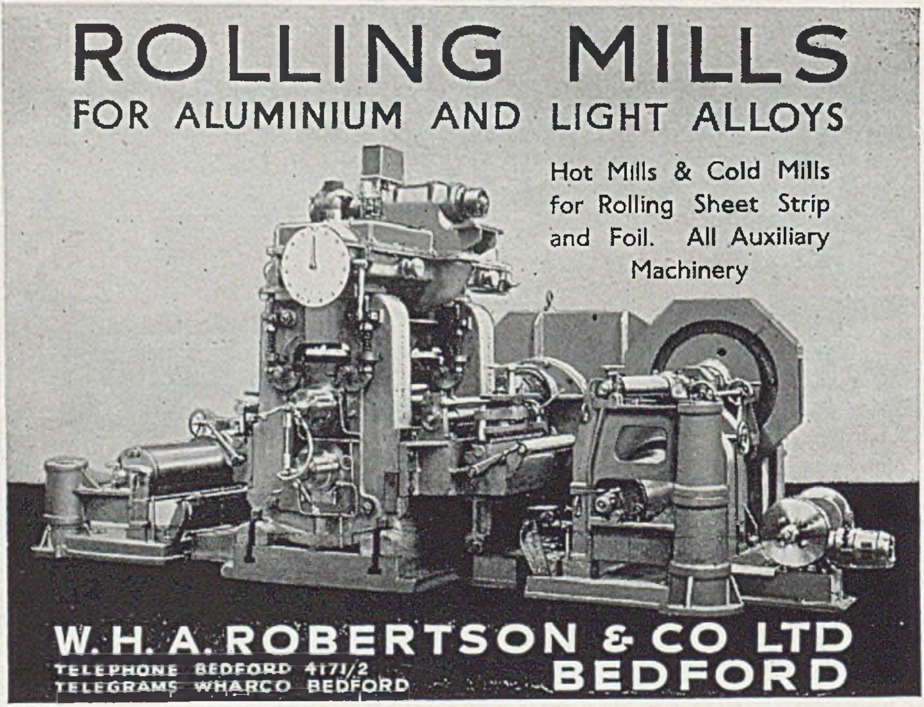

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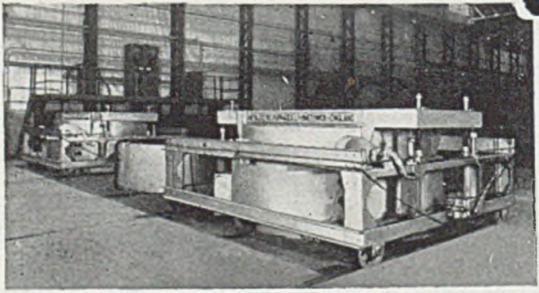

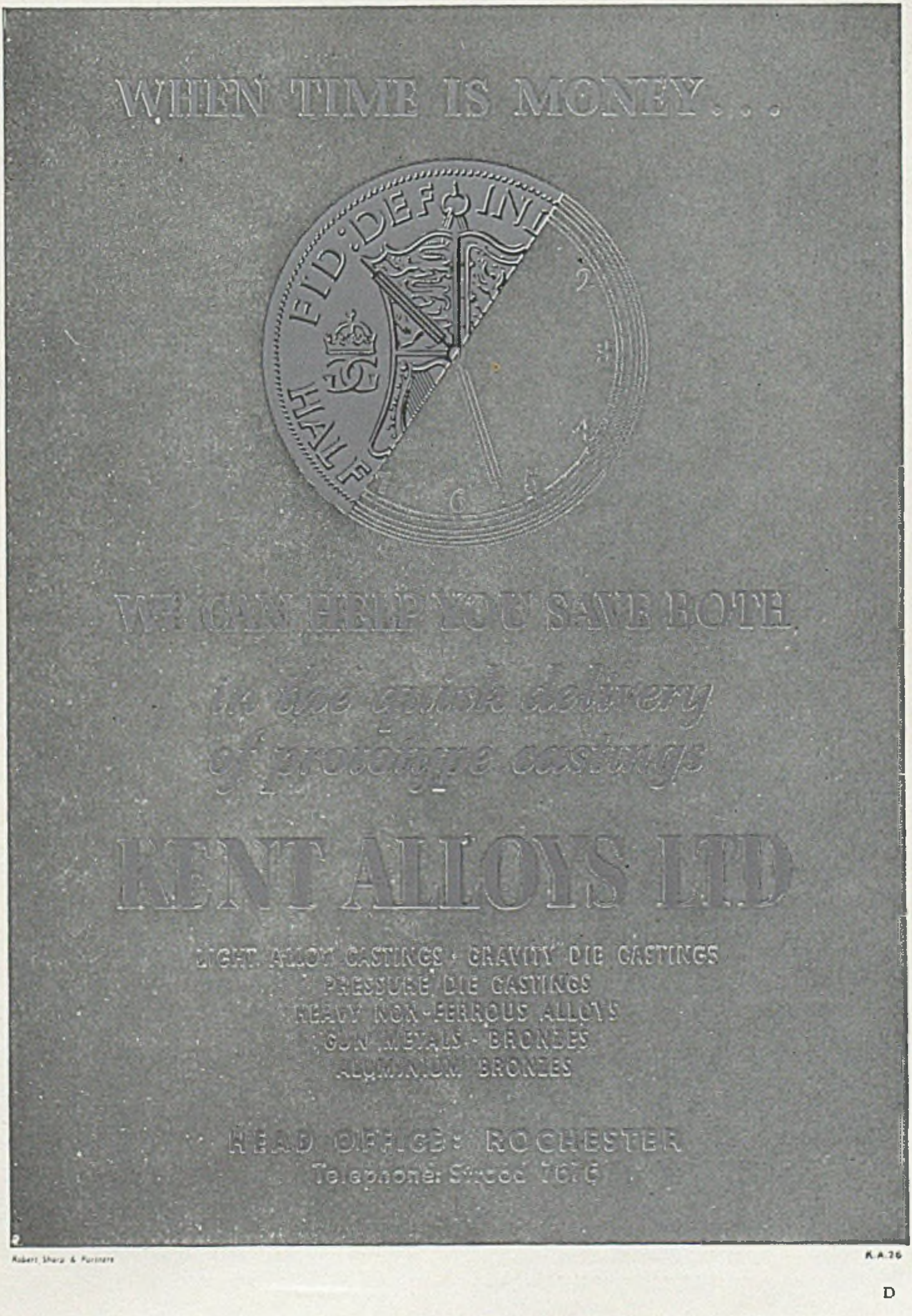
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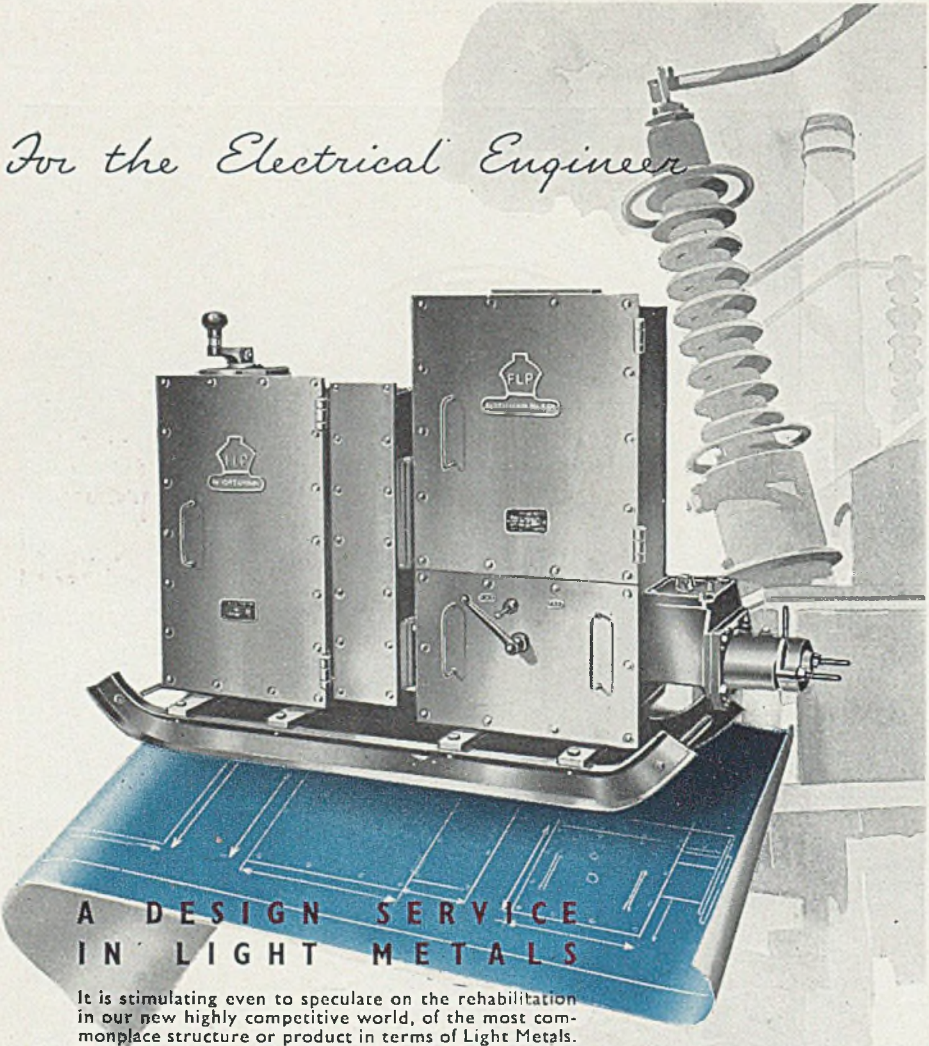

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VOL. VIII. No. 93 OCTOBER, 1945

LIGHT METALS

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Editor:
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LONDON, E.C.1

EDITORIAL OPINION

Another Nail in the Coffin

CONTROVERSY still rages around the merits of high-purity base metal and high manganese as specifics for immunizing magnesium alloys against untimely destruction by corrosive agents. On balance, supporters of the high-purity school seem, at the moment to be leading, and Hanawalt and Nelson are to be congratulated on the convincing manner in which, in this issue of "Light Metals," they have presented their case.

Nevertheless, the evidence recently put forward by Fox and Bushrod in support of the high-manganese practice is not to be rejected out of hand, despite obvious shortcomings in the authors' experimental technique. For, prior to the advent of super-purity magnesium, such notable advances had been made in the application of the ultra-light alloys, that no doubt existed as to the fact that the corrosion menace, once so dreaded, had been, in a measure, overcome. This was achieved by the use of high manganese contents, as we know, coupled with technological progress in the art of extraction which enabled an inherently purer metal to be obtained in the first place.

In assessing the results obtained by the U.S. investigators and comparing them with those derived from work in this country, it is essential that the true perspective of the problem be preserved. Maximum corrosion resistance is justifiably assumed to be bound up with high purity (ample evidence is available in other fields of metallurgy to support this statement) and this, in turn, makes for greater ease of control in the final composition of an alloy. If, however, Fox and Bushrod erred in the conclusions they drew from their research, it is certainly not to be inferred that their high-manganese alloys have a low resistance to corrosion, though this may be inferior to that of the metal of Hanawalt and Nelson.

Again, if it be necessary to guard against the misinterpretation of salt-spray data, so, equally, is it needful to be wary of generalizing on the basis of individual field tests. The magnesium-alloy boat, for instance, so outstandingly successful in prolonged fresh-water trials in U.S.A., would have to be put to the test on our own lakes and rivers before it could be judged as a satisfactory proposition for use in Great Britain. Hanawalt himself recently made this point quite clear.

However much argument may centre around relative degree of attack, development of the magnesium-base alloys has now reached that point when it may safely be said that, high-purity base or high manganese, in either case corrosion resistance to normal atmospheres and fresh water is good—better, in fact, than that of the mild steels. The fact having been accepted that surface attack does take place, whether the material we are using be steel or magnesium, its significance is, as a rule, tacitly judged in the light of the section thickness concerned. Steel sheet of the subtance normally used for tinplate manufacture has a relatively short life on exposure to urban atmospheres; 10-gauge steel will rust equally heavily, but has a life of many years even in the entirely unprotected state. Similarly, an ultra-light-alloy casting exposed to the normal hazards of our climate is found to be attacked with extraordinary slowness, and will probably last for years without any serious deterioration in its strength properties.

Such being the case, there would appear to be every reason for adapting here the procedure current in U.S.A., namely, the stipulation of alloys on a super-purity base where forgings or rolled or extruded products are called for, whilst castings and less critical forms (usually of heavier section) could safely be cared for by the high-manganese compositions. A "bi-metallic" system of this sort would provide a ready made means for coping with the "secondary magnesium" problem, should it ever arise in this country.

It is refreshing to find that the "prejudice of ignorance," so commonly exhibited here in less-well-informed circles regarding the corrosion stability of ultra-light metal, is not confined solely to this island: visitors to the U.S. exposure stations, we learn, are frequently surprised to find "how well magnesium stands up to the atmosphere"! Tradition dies hard. We look forward to the inauguration, one day, of an intensive campaign to drive home the final nail into the coffin of the corrosion bogy; maybe the ghost of "inflammability" could be finally laid at the same time. Both still tend to pop up in the most unexpected quarters, as even Dr. Dow himself, we believe, once admitted.

Contents

SPECIAL FEATURES

REGULAR FEATURES

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

PRESSURE DIE CASTING

Answering Criticisms of his Investigations (and the Conclusions Drawn From These) by E. Carrington, J. L. Erickson in This Reply Enlarges on his Own Explanation of the Mechanism of Metal Flow and Gas Entrapment in Pressure Dies. Carrington's Interpretation of the Results Obtained by Certain Continental Workers is Also Questioned

UNDER the title " Commentary on Pressure Die-casting," Carrington in " Light Metals " 1945/8/342 presents certain observations on my paper " Pressure Die-casting," which appeared in " Light Metals " 1945/8/173.

Carrington states that he read, and carefully re-read, my account, yet, despite this effort on his part, he has failed to comprehend the purpose of the experiments I described. Even more inexcusable is the fact that he misinterprets the work of other researchers such as Fromer, Brandt and Köster and Göhring, whom he cites in an effort to refute my conclusions.

It is my candid opinion that Carrington should have confined his commentary merely to calling attention to the presence of typing errors in my original paper.*

He, Carrington, criticizes the experimental procedure described, and asserts that there is no justification for my having drawn the conclusions recorded. In particular he questions:—

(1) The fact that the die cavity CDE filled with molten metal in the manner stated in the article.†

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* (1) " Light Metals," April, 1945, p. 182, column 1. The sentence, " The type A testbar thus made is similar to the standard commercial pressure die castings where all of the air is trapped as it is made with a small gate," should read: " The type A testbar thus made is similar to the standard commercial pressure die casting where all of the air is trapped and it is made with a small gate."

(2) " Light Metals," April, 1945, p. 184, column 1. The sentence, " These two testbars were sectioned *one* in the gauge length and *one* in each grip section," should have read: " These two testbars were sectioned *once* in the gauge length and *once* in each grip section."

(3) " Light Metals," April, 1945, p. 185, column 2. The sentence, " The results of this type of shot showed that when the air is forced out of one cavity CDE, into the other cavity GHI, the testbars B′ made in cavity *GHI* . . . " should have read: " The results of this type of shot showed that when the air is forced out of one cavity CDE, into the other cavity GHI, the testbars B′ made in cavity *CDE* . . ."

(4) " Light Metals," April, 1945, p. 186, column 1. The sentence, " The results of the type shots B-B′, C-C′, and D′ raised the question as to whether the superior qualities of the B′, C′, and D′ testbars resulted solely from the fact that the metal which composed them solidified in a pre-heated die cavity, i.e., due to a *more* pronounced temperature gradient . . . " should have read: " The results of the type shots B-B′, C-C′, and D′ raised the question as to whether the superior qualities of the B′, C′, and D′ testbars resulted solely from the fact that the metal which composed them solidified in a preheated die cavity, i.e., due to a *less* pronounced temperature gradient . . ."

† Carrington writes:—

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

(b) " . . . but it would appear that too much is taken for granted as to the way in which the metal will fill it."

(c) " Another point connected with the die shape which Erickson has ignored is the butt, and the runner between the butt and the first testbar. Before the metal is actually injected by the piston there is quite a lot of air between it and the mould proper. If there are corners and changes of direction in this part of the die, turbulence will take place before the metal enters the testbar cavities."

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

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

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

(g) " . . . in none of the shots was the air able to escape, and in view of the photographs of Köster and Göhring all would contain some air."

(h) " How can it be said that any of the bars was cast ' in the absence of air ' when in every case the mould was full of air and there were no vents ?"

(i) " Here again the assumption is made that all the air is compressed in the runner F, and that the bar is presumably free from air."

(j) " While the B′ bar might contain air because of the action of centrifugal force on the metal between the butt and the first testbar cavity, causing it to run on the outside of the curve only, and thus to allow air to remain on the inside, with the E bar the air would be left in the first mould [CDE] because of the flow of the metal through a small gate as shown in Figs. 5 and 6.

---

(2) The sensibleness of discarding all of the testbars which were shown to possess unsoundness in the gauge length*

---

* Carrington writes: —

(a) " This is most surprising. Testbars were made by different methods in order to see what kind of bars were obtained, and then all the doubtful bars were discarded. This defeats the whole object of the experiments."

(b) " Surely all the bars should have been tested, and their conditions reported on, in order to obtain a general idea as to the castings to be expected under each set of conditions."

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

---

(3) The sensibleness of not employing vents in the making of some testbars.†

---

† Carrington writes:—

(a) " One of the ways in which attempts are made to obtain castings free from porosity is said to be the use of ' heavy and abundant straight vents,' and yet, although these are very often used in practice, no attempt is made to use them in these experiments."

(b) " Later, Erickson explains defects obtained on heat treatment with castings made by high pressure, and castings with overflow, but does not mention those made with good venting. This omission seems really important."

(c) " In describing the types of possible testbars, under types A′ and A, type A′ is said to have no escape for air, and to be quite similar to those made commercially in general practice."

---

(4) The fact that testbars which were shown upon heating to contain gas were called radiographically sound.‡

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‡ Carrington writes:—

(a) " Frankly, if castings which we know to contain gas appear radiographically sound, it is time that we either changed our radiographic technique or stopped using radiography."

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

---

(1) *Mechanism of Die Fill*

Carrington is correct in believing that certain of my conclusions would be open to question provided the cavity CDE had not filled in the manner stated in my article. He has, however, failed to demonstrate that the description in my article of the manner in which cavity CDE filled is not an accurate description of how the die actually did fill in use.

My article contends that the die cavity CDE was filled by a ray of molten metal having a front whose cross-sectional area is equal to the cross-sectional area of the cavity CDE, and that in filling cavity CDE the metal forced the air present in the cavity CDE and the air present in the runner ahead of it leaving no air behind. (See Fig. 2.)

Carrington does not believe this to be the way in which the cavity CDE filled. It is his opinion that this manner of fill did not occur. To support his belief he presents: (1) a diagram illustrating the manner in which Frommer states a given

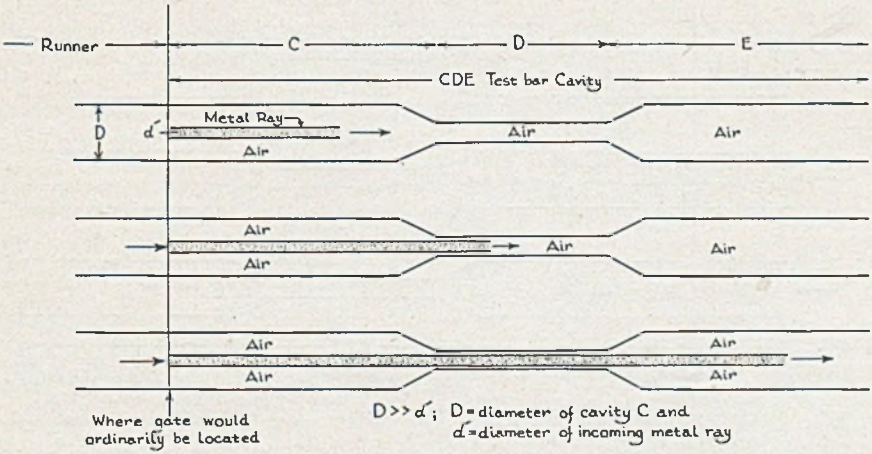

Fig. 1.—Interpretation by Carrington of mechanism of entry into the CDE cavity by the incoming stream of molten metal.

die cavity is filled, (2) a mention of Brandt's researches, and (3) a series of photographs taken by Köster and Göhring illustrating the manner in which Wood's metal under pressure filled glass dies. Carrington calls attention especially to the findings of Köster and Göhring, adding that I assumed "that the metal acts like a liquid piston and pushes *all* the air before it," while "Köster and Göhring have shown quite conclusively that this is not so. . . ." An attempt is made by Carrington to support his belief that the cavity CDE was not filled in the manner pictured in Fig. 2, but was filled in a manner similar to that shown in the illustrations of Köster and Göhring, namely by a narrow metal ray which shot through the die cavity CDE, a ray having a cross-sectional diameter less than the cross-sectional area of the die cavity CDE. (See Fig. 1.)

It is unfortunate that Carrington's "careful reading" of my article did not reveal to him the fact that the gate I was of a cross-sectional area equal to the cross-sectional area of the grip end of the testbar cavity CDE, for had he noted this fact he might not have been so quick to assume a similarity existed between the filling of the cavity CDE and the cavities shown in the pictures of Köster and Göhring.

In the case of the filling of the die cavity CDE, the metal flowed through the runner into the grip end and on up the gauge length without passing through a *gate* in the true sense of the word. Whilst in the case of the filling of the cavities shown in Köster and Göhring's illustrations, the metal entered the cavity through an orifice having a cross-sectional diameter much less than the cross-sectional area of the cavity. Naturally where the orifice diameter, d, is smaller than the diameter, D, of the cavity and the velocity of injection is high the metal will shoot into the cavity as shown in Fig. 3, diagram A. In my experiment when a small gate was employed at III the cavity GHI filled in a manner consistent with the findings of Köster and Göhring and the predictions of elementary hydrodynamics.

Where d = D, as in the filling of the cavity CDE, the cross-sectional area of the incoming metal ray d^1 equals D, therefore the die cavity fills as illustrated in Fig. 2 and Fig. 3, diagram B, and Carrington is in error in assuming the cavity CDE filled as illustrated in Fig. 1. Therefore much of his refutation of my conclusions is without substantiation.

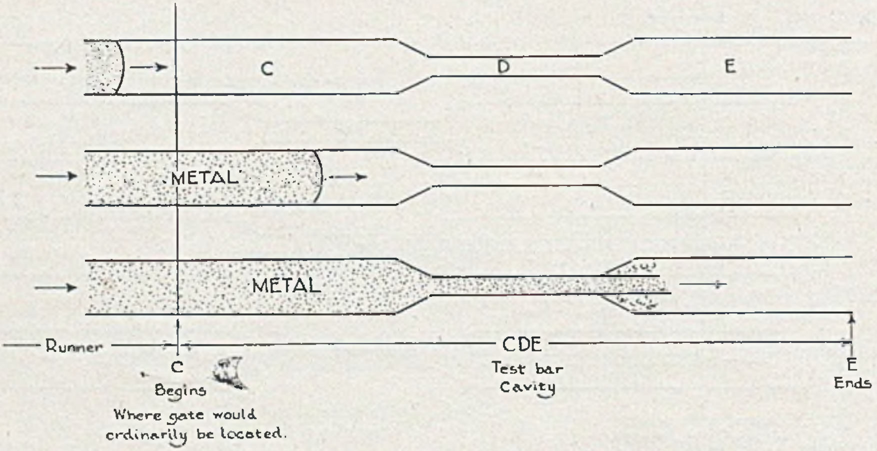

Fig. 2.—Interpretation by Erickson of mechanism of entry into the CDE cavity by the incoming stream of molten metal.

(2) Discarding Defective Testbars

Carrington is very definite in his denunciation of the fact that " . . . all the doubtful bars were discarded." Indeed he emphatically states, " This defeats the whole object of the experiments." Had he read just once more* my sub-title or my opening paragraph, or the section of my article entitled " Purpose of the Experiment," I feel certain he would not have made so careless a statement.

In the first place the purpose of the experiment was to determine whether or not certain *die-casting alloys*, when cast into a sealed die cavity containing confined air, would exhibit *physical properties* different from those exhibited by the same alloys cast in a similar die cavity containing no air.

It was after a mathematical consideration of the value of vents in aiding air to escape from commercial die-casting dies of several kinds that I concluded vents to be of little value in many instances. Also, I was convinced that frequently in the operation of many commercial dies the vents became sealed before they could properly affect the escape of the air. The following question then seemed in need of an answer: Does trapped air in any way *affect the solidification of the molten metal* within the die cavity? The experiment described in my article was an attempt to answer this particular question.

Still another question seemed to need an answer: Might it be the case that castings made by injecting molten metal into a die cavity filled with confined air—castings which on radiographic examination failed to evidence trapped gas porosity—were of a quality inferior to castings made by injecting the molten metal into an evacuated die cavity? This question I thought needed to be answered as it is the case that many commercial die castings are made in a similar fashion, i.e., the air is trapped within the die cavity and subsequently compressed to such a degree that it either occupies a very small volume locally or it is compressed and dispersed throughout the whole metal mass. Indeed the ideal conditions of the so-called pre-fill injection system (where the air is completely forced out of the die cavity) are seldom realized in commercial practice.

It was obvious from what was stated in my article that I was *not* interested in discovering a new way to gate a testbar or a new way to produce porosity-free testbars. I was interested simply in learning the *comparative physical properties*

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* Carrington says he gained his impressions of my paper after " careful reading and re-reading."

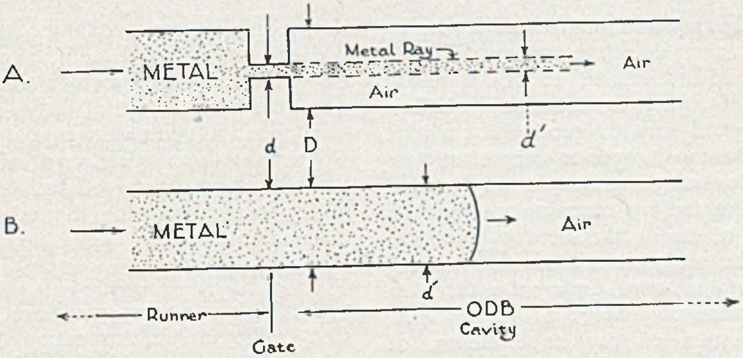

Fig.3.—Diagram A shows the mechanism of filling of cavity ODB when incoming metal is forced to pass through a small gate. Here the diameter of the gate is less than the diameter of the CDE cavity. Diagram B shows mechanism of filling of the CAB cavity when incoming metal is forced into the CDE cavity without having to pass through gate. Here the diameter of the gate is equal to the diameter of the ODE cavity. In Erickson's experiments the cavity CDE is similar to the cavity ODB, as shown in diagram B in this illustration. It is not similar to cavity ODB, shown in diagram A, as ODB in diagram A is provided with a small gate.

of metal cast in the presence of trapped air and metal cast in the absence of air.

In the course af performing the experiment many testbars were made which displayed porosity when inspected by the ordinary radiographic methods prescribed by government specifications.

Those testbars which contained "detectable" gas porosity, or other detectable defects, were discarded, for had they been used to obtain data, as Carrington states they should have been,* a meaningful comparison between the testbars cast in one way and the testbars cast in another way could not have been obtained.

To illustrate this point let us take a hypothetical example. Suppose we have two groups of testbars, both groups are of the same alloy and both groups have been cast in the same manner, except that one group was cast in a sand mould and one in a chill mould. We desire to learn which type of mould produces the most desirable type of micro-structure as regards strength properties. To do this we must compare the strength of testbars from each group. However, we must make certain first that the testbars we use to obtain our data are not host to defects, else we will get a false picture of the strength properties of the metal making up the testbars. All testbars host to defects must not be used, else that particular group to which they belong will seem to be made up of testbars whose *microstructures* are more inferior as regards physical properties than they actually are. If we merely wanted to determine which group, that made up of chill-cast bars or that made up of sand-cast bars, contained the most superior *testbars* we would use all the testbars to obtain our data. In so doing we might discover that the sand-cast testbars were superior in strength properties to the chill-cast testbars; however, this result would not be an indication of which type of microstructure was the better as regards strength properties, due to the fact that our results might have been influenced by reason of the chill-cast bars becoming host to excessive porosity whilst the sand-cast bars were non-porous. To obtain a fair comparison of the true strength properties of the metal itself comprising the testbars it is necessary to test only porosity-free testbars.

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* He states: "Surely all the bars should have been tested, and their conditions reported on, in order to obtain a general idea as to the castings to be expected under each set of conditions."

This illustration should explain why in my experiment defective testbars were discarded and not tested to obtain data. Instead of trying to determine whether chill or sand moulds produced castings having the most superior microstructures as regards strength properties, my experiment attempted to determine whether the presence of air in the die cavity or the absence of air produced castings having *the most superior microstructure as regards strength properties.*

The results of my experiments, of course, showed clearly that there was a pronounced difference in the strength properties of the microstructure of testbars cast into die cavities containing confined air and the microstructure of testbars cast into die cavities containing no air. It is unfortunate that Carrington failed to realize that the admission of the results of defective testbars would have defeated " the whole object of the experiments."

(3) The Failure to Employ Vents

Carrington displayed regret that I did not employ vents in making the testbars used to obtain my data.*

No vents were employed because none was needed. Vents are employed commercially to effect the escape of air confined in the die cavity, runner, butt, etc. In the experiment I described, the air was purposely confined and not permitted to escape. To vent the cavity GHI would have been to " defeat the object of the experiment," which was, of course, to determine the effect of confined air on the metal cast in its presence under pressure.

Carrington remarks, " Later, Erickson explains defects obtained on heat treatment with castings made by high pressure, and castings with overflow, but does not mention those made with good venting." I fail to perceive why Carrington should be so concerned. Does he believe that I indicated that good venting *would not* have made possible successful heat treatment? If so, let me state that in my opinion good venting of the cavity GHI would have tended to produce a more heat-treatable testbar than it produced without the aid of vents, provided, of course, the vents were properly placed. No testbars employing vents were made because the purpose of the experiment was not to determine the effect of the presence of vents.

(4) Radiographic Inspection

Carrington is concerned over the fact that radiographic inspection failed to reveal the presence of gas in testbars which were later shown to contain gas as evidenced from the fact that they developed internal and surface blisters during heat treatment. He calls attention to the fact that I said " that castings made with a very high pressure but with neither overflows nor venting, were 'radiographically sound,' " and adds a statement I don't believe he would seriously hold to, namely, " Frankly, if castings which we know to contain gas appear radiographically sound, it is time that we either changed our radiographic technique or stopped using radiography." The purpose of radiography has never been to detect the presence of *gas* in cast metals—it has been rather to detect the presence of *porosity*. Radiography is at a loss to detect the presence of a gas in a metal. Radiography can, however, detect a pore, but never a gas. Radiography in my experiment was employed solely to detect porosity, never the presence of a gas. A dissolved gas in cast aluminium is not revealed on radiographic inspection. Nor can radiography reveal the presence of adsorbed gases.

I thought it important to call attention in my article to the fact that a testbar may evidence no porosity when inspected by ordinary radiography, and yet when it is heated blisters may form on its surface and in its interior—important because often an attempt is made in commercial die casting to compress and disperse the trapped gases with the aid of high pressures. The absence of microscopic porosity is, however, no guarantee that a casting is heat treatable. At first I thought that such blisters were caused by

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* He states: " No attempt is made to use [vents] in these experiments."

the evolution of dissolved gas at elevated temperatures. X-ray diffraction studies showed, however, that no dissolved gas was present. *Micro-radiography*, on the other hand, revealed the presence of ultra-fine, evenly distributed micro-porosity.

I must apologize for not making it clearer in my article that what I meant by a testbar being "*absolutely free*" from porosity was: a testbar absolutely free of any macroscopic porosity detectable by the ordinary radiographic procedures called for in standard X-ray inspection practice.

Carrington suggests "that a bar be prepared from wrought material and radiographed with each batch of experimental bars in order to provide a standard." This indicates that he was left with the impression that no standard was employed in the radiographic inspection. Permit me to assure Carrington that the entire radiographic procedure was conducted in accordance with government specifications employing the recommended *penetrameters*.

A Reply to Other Remarks

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

First, let me assure Carrington that in America Class I* pressure die castings are to-day commonplace.

Microscopic porosity-free aluminium-alloy die castings are no longer a goal in U.S.A.—they're a fact! It was true in America for a long time that die castings were considered unsuitable for stress parts. To-day, however, as a result of the demand for large numbers of light-weight stress parts, Class I aluminium-alloy die castings are a fact. The die-casting industry rose to the need with the required quality product.

Carrington goes on to state that he "would certainly like to see pore-free pressure castings," and that "all those which he has examined were porous in the middle, although the pores in castings made by a cold-chamber machine can generally only be seen under a microscope." Hundreds of thousands of aluminium-alloy porous-free castings have been made in America. It seems odd that none can be found in England for Carrington to examine!

As regards Carrington's statement, "A large gate is used [in the pre-fill injection method of die casting] in order to allow this pressure to be applied," let me say that I have always considered the reason for the use of a large gate to be that it decreases the velocity of the incoming metal ray and thereby decreases its impact on the cavity wall thus decreasing splashing and turbulence and consequently reducing the chance that splashing metal will seal off any vents if employed.

Carrington intimates that I advocate the employment of "building machines with mounting injection pressures." The fact is that I said nothing about what I believe is the best pressure die-casting procedure.

For Carrington's information the various gases employed in an earlier experiment of mine were all free of water vapour. It is not stated that the gases were not dried prior to use as Carrington suggests. ("It would be instructive to try 'air' with increased oxygen, and pure nitrogen. One important point regarding these gases appears to have been missed: that is their moisture content.")

Carrington asks, ". . . how is it possible to know that there were no cold shuts present in either of the bars?" I never said it was possible.† If a cold shut had

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* Specification AAF-No. 11347.

† Although it is. See X-ray Micrography as a Tool for Foundry Control, Leslie W. Ball, Trans. A.F.A., June, 1945.

showed up in the fracture of a tested bar the result of that particular bar would have been discarded.*

Carrington writes in reply to my remark (namely, "the presence of trapped air within the die cavity affects the metal which is forced to soldify in its presence in such a way that heat treatment of the cast metal is not feasible") that it is "hardly possible to draw such a conclusion when a non-heat-treatable alloy was used." Now it was clearly stated in my article that "no testbars were heat treated for the purpose of improving their physical properties." Heat treating was merely done to determine the effect of various casting conditions on the formation of surface blisters, internal porosity, and dimensional distortion. When I stated that certain test bars were not heat treatable, that is, they did not lend themselves to successful heat treatment, I simply meant that they blistered, etc., when heated. It is obvious that, regardless of the nature of the alloy employed to make a casting, if a casting blisters upon heating it does not lend itself to heat treatment, that is, it isn't heat treatable. I'm inclined to believe that the blister formation is independent of the alloy employed.

I thought it would be interesting to learn whether this waiting period had any effect on the ultimate properties of the metal when it was die cast. As to the validity of your statement, "Under such conditions, when neither oxidation nor gas absorption can take place . . ." I have yet to see that hypothesis conclusively verified.†

I am indebted to Carrington for calling the attention of the readers of "Light Metals" to certain typing errors in my paper and for his hope that I can continue my investigations in the field of pressure die casting.

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* Less than 0.1 of 1 per cent. contained cold shuts.

† I refer you to the papers listed in my bibliography which followed my paper in the "Light Metals," April, 1945, issue under the headings: Diffusion, Gases Present in Al, Adsorption and Sorption, and Origin in Al.

REFERENCES

(1) *Barton, H. K.; The Injection of Metal into Die-Casting Dies, "Machinery (Lond.),"* 1944, 64, (1642), 357-359; (1650), 581-583; (1655), 721-723. **(2)** *Brandt, W. R.; The Flow of Aluminium During Die Casting, "Techn. Zentr. prakt. Metallbearbeitung,"* 1937, 47; (19/20) 751-4; (21/22) 824-9; (23/24) 893-9; *"Die Casting" (Suppt. to Machinery)*, 1938, *August* 11, 87-90; *(Nov. 3)*, 1-7; *"Metals Abs.,"* 1938 5, 840. **(3)** *Frommer, Leopold; "Spritzgusstechnik," Berlin, Verlag von Julius Springer*, 1933, *pp.* 11-41 *and appendix.* **(4)** *Koster, Werner and Karl Göhring; The Shape of the Incoming Metal Stream and the Process of Filling the Mould During Pressure Die Casting as Shown by the Cinematograph, "Giesserei,"* 1941, 28, (26), 521-528.

For Carrington's reply to the above discussion see p. 515.*)*

CORRESPONDENCE

REPRODUCED below will be found correspondence on Erickson's paper.

"I have just finished Mr. Erickson's article in the April, 1945, issue of 'Light Metals,' entitled 'Pressure Die-casting,' and take the liberty of writing you with the request for clarification of a certain item.

"356 alloy with very low iron was used in the tests, but no information is given as to whether these test-bars were tested as cast, how soon after casting, or artificially aged. This material is very highly susceptible to air ageing and hardens considerably during the process. We found that ageing die-cast 356 alloy test-bars and castings at about 155 degrees C. for a couple of hours increased the tensile properties and decreased the elongation. Can you shed some light? 356 with very low iron seems to be rather unpopular amongst the die-casters on account of the tendency of the metal to stick to the die. What has been Mr. Erickson's experience?

"Mr. Erickson's article is extremely interesting and it is particularly pleasing to me, because it furnishes some additional proof for some of the claims that I have made for quite some time in the face of very strong but gradually diminishing opposition that the best physical and structural properties of die-castings are possible only with large gate and relatively slow injection speed, so as to prevent splashing of the metal and air absorption.

"I would like to see the article enlarged to take in the effect of large gate and modern injection speed on properties and structure of castings themselves, especially where the section is changing from heavy to thin and where the metal has to traverse relatively long distances between narrow metal walls."—D. Basch (G.E.C., U.S.A.).

In reply, the author writes as follows:—

"The test-bars were all cast and the tensile tests performed within 24 hours after the time of casting, without expansion.

"Concerning the tendency of 356 alloy of low iron content to stick to the mould, I can only say that in preparing the test-bars I noticed no such tendency. Whether this alloy would have been likely to stick if cast in some other shape than that of the test-bar I employed I cannot say, as Western Die-Casting Co. seldom received orders requiring the 356 alloy. Where this material was called for, the grade employed had a much higher alloy content."—J. L. Erickson.

Light Alloys in Rectifiers, Photocells and Condensers

Continuing from "Light Metals," 1945/8/462, a Discussion on Impregnating Media for Fixed Paper Condensers. Attention is Directed to Chemical Properties in Relationship to Metal with Which They Come into Contact

THE ready-compounded mixture of paraffin and carnauba waxes can be purchased to specification commercially. Three samples from different sources are characterized in Table 65.

Table 65.—Characteristics of Condenser Impregnating Wax Mixture Comprising Paraffin Wax of Melting Point 55°C. with Addition of 2-3% of Carnauba Wax.

Source	A	B	C
Sample No.	1	2	3
Ash on incineration, % ..	0.01	0.01	0.02
Acid value, mgms. KOH/gm.	0.02	0.20	0.75
Saponification value, mgms. KOH/gm.	2.1	1.4	1.7
Melting range, °C.	54–59	54–59	54-60
Softening point, °C.	54	54	54
Melting point, °C.	58	57	57
Flowing point, °C.	60	60	59
Colour	Cream	Cream	Cream
Structure	Finely crystalline	Finely crystalline	Finely crystalline

An American specification for paraffin wax for the impregnation of paper condensers calls for a material of nominal melting point 133/136 degrees F. with the following quality characteristics:—

(a) The wax to be free from low melting - point fractions.

(b) The melting point to be 130 degrees F. minimum when determined by the cooling method as follows. The melted wax is placed in a 1-in. diameter boiling tube to a depth of 2 ins. The tube is fitted with a cork carrying a thermometer, which extends centrally into the wax, and a stirrer. The tube is carried in a conical flask to serve as an air jacket. Cooling is recorded by temperature readings (to 0.1 degree F.) at half-minute intervals until well below the melting point of the wax. The melting point is interpreted as that temperature at which the readings remained constant for at least three readings.

(c) Neutrality limited by acidity maximum 0.05, expressed in terms of mgms.KOH/gm., or alkalinity max. 0.10 expressed in terms of mgms. H_2SO_4 per gm. of wax. The values are determined on a water extract using N/100 sodium hydroxide or N/100 sulphuric acid for the titration for acidity and alkalinity respectively. The water extract is obtained by weighing from 5 to 10 gms. of wax and boiling with 250 ml. of neutral distilled water for two hours in an Erlenmeyer flask under reflux. The titrations are performed hot, above 80 degrees C., using phenol phthalein as indicator, shaking continuously and reheating, if necessary, to keep above 80 degrees C.

(d) Specific gravity to be approximately 0.90 at 20 degrees C.

(e) The wax to be free from water.

The following clauses are typical of specifications used in this country:—

(a) The material required to be a refined petroleum wax, free from liquid hydrocarbons, unsaturated hydrocarbons, and all extraneous matter.

(b) The melting point to be 55-58 degrees C., determined by the cooling curve method.

Table 66.—Laboratory Characteristics of Refined Beeswax, Yellow and White.

Sample No. ..	1	2	3	4	5	6	7	8	9
Grade	White	White	White	White	White	White	Yellow	Yellow	Yellow
Colour	White	Lemon yellow	Pale yellow	Pale yellow	Cream	White	Orange brown	Brownish	Reddish orange
Acid value, mgms. KOH/gm.	8.9	13.2	12.4	13.2	10.0	8.2	17.8	22.2	20.4
Ester value, mgms. KOH/gm.	77.9	84.8	94.5	78.8	85.5	83.2	79.7	67.8	74.9
Saponification value, mgms. KOH/gm.	86.8	98.0	106.9	92.0	95.5	91.4	97.5	90.0	95.3
Specific gravity at 15.5°C.	0.964	0.965	0.970	0.968	0.962	0.958	0.964	0.970	0.969
Melting point, °C.	61	65.5	62	64	62.5	64.5	64	61	62
Ash on incineration, %	0.01	0.01	0.01	0.01	Trace	Trace	0.02	0.04	0.01
Refractive index at 75°C.	1.440	—	—	—	—	—	1.442	—	—

(c) Ash on incineration to be less than 0.001 per cent.

(d) The wax to be free from alkalinity and free from inorganic acid. The total acidity not to exceed 0.0030, expressed in terms of mgms.KOH/gm.

(e) Saponification value to be 0.0030 max. expressed as mgms.KOH/gm.

(f) Volatility, determined by heating a 10 gm. sample in a 3-in. dia. aluminium dish for four hours at 135 degrees C., not to exceed 1.0 per cent.

(g) Total sulphur content not to exceed 0.05 per cent.

(h) Specific gravity at 15.5 degrees C. to be between 0.880 and 0.900.

(i) Flash point (close) not to be less than 200 degrees C., and fire point not to be less than 220 degrees C.

(j) When 3 gm. of wax is heated with 3 ml. of concentrated sulphuric acid on a water bath at 100 degrees C. for six hours, the degree of darkening in colour shall not exceed a light brown or straw.

(k) When heated on a water bath at 100 degrees C. for six hours with a strip of clean polished copper, half-immersed, no staining, discoloration

Table 67.—Effect of Heating Beeswax with Metal in Open Glass Vessels for 14 Days at 110°C.

Type of beeswax	Metal	Acid value after 14 days at 110°C. mgms. KOH/gm.	Other effects
Brown	None	13.0	Wax rather more brown
Brown	Copper turnings	11.6	Colour of wax dark green due to copper compounds
Brown	Copper strip	9.3	Colour of wax dark green due to copper compounds
Brown	Iron powder	19.0	Colour of wax dark brown
Brown	Steel turnings	10.0	Colour of wax almost black
Brown ..	Aluminium-alloy turnings (Al 90%, Cu 4%, Ni 6%)	18.0	Colour yellow, rather lighter
Brown	Nickel turnings	17.0	Colour yellow, rather lighter
Brown	Zinc powder	14.8	Colour unchanged
Brown	Lead strip	13.0	Colour unchanged
Brown	Tin turnings	7.0	Colour of wax darker brown
Bleached ..	None	19.0	Colour of wax brownish yellow
Bleached ..	Copper strip	11.3	Colour of wax dark green due to copper compounds

Table 68.—Laboratory Characteristics of Refined Ceresin Waxes of Electrical Quality.

Sample No.	1	2	3	4	5	6	7
Colour	White	Cream	Light yellow	Brownish yellow	Yellowish brown	Greenish yellow	Brown
Acidity, mgms. KOH/gm.	0.060	0.055	0.040	0.071	0.095	0.044	0.058
Saponification value	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Volatility (loss in weight on heating 4 hours at 135°C. in 3-in. dia. aluminium dish), per cent.	1.65	1.64	2.18	2.25	1.60	2.42	1.08
Ash on incineration, %	Nil	Nil	Nil	0.008	0.007	0.003	0.010
Specific gravity at 15.5°C.	0.894	0.892	0.900	0.902	0.904	0.906	0.916
Melting point, °C.	58	59	60	61	65	71	76

or corrosive attack on the copper shall occur.

(l) When heated on a water bath at 100 degrees C. for six hours with a piece of clean, bright aluminium foil, half-immersed, no staining, discoloration or corrosive attack on the aluminium shall occur.

(m) The material shall be supplied in cakes, free from water, straw and extraneous dirt, and protected in transport by packaging, packages to consist of wooden cases lined with heavy waxed paper.

When double refined or special refined material is stipulated, specifications cannot be much more arduous than the above. In them, sulphur content is sometimes stressed and required to be nil, but this requires defining, and rarely can regular deliveries be assured below 0.03 per cent.

If the paraffin-wax mixture is purchased, that is containing additional agent such as jelly or carnauba wax, then the specification can be along exactly the same lines, with the following additions or modifications:—

(a) Composition—the percentage and nature of addition agent to be stated, limits suggested 2.5 per cent. min., 3.5 per cent. max.

(b) If carnauba wax is permitted, acid value to be increased to 0.12 max. (mgms. KOH/gm.), and saponification value to 0.30 max. (mgms. KOH/gm.).

Regular inspection of consignments of

Table 69.—Characteristics of High Melting Point Hydrocarbon Waxes of Petroleum Origin.

Source	A	B	C
Sample No.	1	2	3
Colour	Brownish orange	Yellow	Yellow
Structure	All finely micro-crystalline and slightly tacky		
Ash on incineration, %	Nil	Nil	Traces
Acid value mgms. KOH/gm.	0.005	0.02	0.03
Saponification value mgms. KOH/gm.	Nil	Traces	Traces
Benzene insoluble matter, %	0.03	0.05	0.06
Loss on heating 4 hrs. at 135°C. in open aluminium dish of 3 ins. dia., %	0.04	0.08	0.06
Melting point, °C.	73	72	70
Specific gravity at 15.5°C.	1.07	1.03	1.05
Specific electrical conductivity at 120°C. in micro-microhms.:			
(a) initial	0.1	0.5	0.1
(b) after 21 days in open vessel at 110-120°C.	0.4	2.0	0.6
Power factor tan δ at 20°C. after vacuum drying at 100-110°C. for 2 hrs.:			
at 50 cycles	0.0001	0.0001	0.0001
at 1,000,000 cycles	0.0001	0.0001	0.0001
Permittivity at 20°C. after vacuum drying at 100 to 110°C. for 2 hrs.:			
at 50 cycles	2.32	2.32	2.35
at 1,000,000 cycles	2.32	2.33	2.35

these waxes is essential, but is simple, and no difficulty is encountered in maintaining the desired quality when the supplier appreciates that the material is required for condenser impregnation.

Similar specifications can cover the higher melting point paraffin waxes with, of course, the limits of melting temperature adjusted accordingly.

For many years paraffin wax was the only really satisfactory wax freely available in quantity for condenser manufacture, but the position has changed appreciably in the past 10 to 20 years. Beeswax was the chief electrical wax available to compete with paraffin. However, this has never been regarded as a suitable condenser wax on account of its lower insulation resistance, and poor power factor. It is very expensive and difficult to obtain in constant quality. It is seasonal, obtained from many sources in grades of varying characteristics; frequently in short supply, and often adulterated with cheaper waxes and with farinous material. Refined grades are yellowish or white, and they can be controlled by close specifications with respect to acid, ester and saponification values, gravity, refractive index, melting point and ash value. Test results on different varieties of pure refined wax are given in Table 66. It will be seen that beeswax is a fatty wax of high acid value. It is not so stable as paraffin wax, has some corrosive action on metals under process conditions, and will rapidly green copper in the presence of moisture.

One simple investigation, originated because of the marked discoloration of beeswax in the processing tanks, studied two grades of beeswax and their reaction with metals under heat at 110 degrees C. for 14 days. The results are of interest. Both brown and bleached waxes were used, these having the following average characteristics:—

	Brown wax.	Bleached wax.
Colour	Orange brown	Cream
Melting point °C. ...	62	65
Acid value, mgms. KOH/gm.	14.2	20.2
Saponification value, mgms. KOH/gm. ...	83.2	92.3
Ester value, mgms. KOH/gm.	69.0	72.1
Acid/Ester ratio ...	4.9	3.5

The waxes, heated in glass vessels for 14 days at 110 degrees C., became somewhat darker in colour, and acidity decreased a little (to 13.0 and 19.0 for the brown and bleached waxes respectively), indicating slight decompositional change. Heated with various metals, however, colour changes are markedly increased, acidity changes becoming either more pronounced or decreased as shown in Table 67. The best metals for plant linings indicated by these tests are zinc and lead. In practice the latter is satisfactory, so is zinc if overheating be avoided. Otherwise the zinc coating flakes. Actually, iron or steel are extensively used, but may promote much darkening.

The ozokerite type of wax has always been available for condenser manufacture. It is a naturally occurring earth wax, probably of petroleum origin, and in its ordinary refined state is marketed in various forms, usually black or greenish black, and not of very high

Table 70.—Physical Characteristics of Micro-crystalline High Melting Point Mineral Waxes compared with Beeswax.

Type	Micro-crystalline high melting point mineral waxes							Beeswax
Sample No.	1	2	3	4	5	6	7	8
Micro structure, crystallinity	Very fine	Very fine	Very fine	Very fine	Fine	Very fine	Fine	Fine
Ubbeholde drip point, °C. ..	85	83	84	88	85	110	75	67
Melting point, capillary tube, °C.	84	81	83	86	83	105	72	62
Viscosity 10°C. above melting point, centipoises	14	20	12	60	15	16	18	20
Specific gravity at 15.5°C. ..	0.915	—	—	—	—	0.918	1.05	0.965

Table 71.—Chemical Test Values of Micro-crystalline High Melting Point Mineral Waxes compared with Beeswax.

Type	Micro-crystalline high melting point mineral waxes							Beeswax
Sample No.	1	2	3	4	5	6	7	8
Acid value, mgms. KOH/gm...	0.50	0.03	0.05	0.5	0.5	0.4	0.05	18.5
Saponification value, mgms. KOH/gm.	1.2	Traces	Traces	1.8	2.0	1.5	Nil	93.5
Ash on incineration, per cent.	0.04	Traces	Traces	0.10	0.08	0.10	Nil	0.01
Effect on copper (bright strip, half immersed at 100–110°C. for 8 hours)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Greening
Thermal oxidation, extended heat test at 110–120°C. in open vessel, progress of deterioration recorded by specific electrical conductivity measurements on samples withdrawn at intervals. Values in micro-micro-mhos after :—								
Initial value	28	0.3	0.4	50	50	1.0	0.5	90
3 days	35	0.7	0.7	59	64	10	0.8	96
7 days	50	1.0	0.7	85	93	40	1.2	115
10 days	56	1.2	0.9	94	104	110	1.5	120
14 days	65	1.3	1.0	109	120	250	1.7	122
17 days	72	1.4	1.0	120	132	600	1.9	125
21 days	85	1.6	1.1	140	155	1,200	2.0	127

purity. In more highly refined grades, it is referred to as ceresin. The ceresins are very good waxes, varying from white, through various shades of yellow, to brown in colour. They are free from saponifiable matter and quite low in acidity, although not usually as low as the paraffin waxes in this respect. Contamination with mineral matter, as shown by ash value, is very low. Volatility is a little higher than for the paraffins, and specific gravity likewise slightly higher. Higher melting points are practicable, but melting is not quite so sharp because even in the highest melting grades, low melting solid hydrocarbons are included. Detailed characteristics of a number of these ceresin waxes are given in Table 68 to illustrate these features. Contraction during solidification is almost as high as with the paraffins, as can be seen from Table 62 ("Light Metals," Sept., p. 460).

The ceresins have never been seriously adopted for condenser manufacture, presumably because they are appreciably more costly than the paraffin waxes, and no benefit is derived in electrical characteristics, nor from serviceability of the resultant condensers. Lower temperature coefficients for capacity, power factor and insulation resistance would be expected at first sight from the higher melting point, but in point of fact this improvement does not materialize. At the same time these waxes are quite suitable chemically and physically, they are free from crystallinity, are hard and dense without being brittle, and are slightly tacky. However, it is difficult to ensure continuity of supply of a constant grade of material in sufficient quantity.

A high melting point hydrocarbon wax showing much improvement over the paraffin waxes was made available about 15 years ago, and to-day similar materials are available in quantity. The first of these waxes produced was of petroleum origin, and said to be produced by refinement from wax residues trapped in petroleum oil pipe lines at the oil wells and refineries. This wax was micro-crystalline in nature, pale yellow to orange in colour, although "white" grades could be produced. Table 69 gives the characteristics on some of these early waxes. Ash values are satisfactorily low, acidity of low order (although not so good as with the paraffins), and saponification value negligible. They are almost completely soluble in benzene, indicating freedom from non-waxy non-hydrocarbons. Volatility is very low.

Melting point is sharp and between 70 and 75 degrees C. This apparently is the cause of their particular attribute, viz., low temperature coefficient of electrical characteristics. Specific gravity is naturally higher than with the paraffins, namely, about unity. Contraction during solidification (see Table 62) is still high, approaching that of the paraffins.

Some electrical values are also included in the table. Specific conductivity of these waxes is very low, and does not increase materially during use in condenser processing. This is confirmed by the low values after heating for 21 days at 110 to 120 degrees C. Power factor is low at the normal frequencies of 50 cycles and at radio frequencies of 1 megacycle. Permittivity (dielectric constant or specific inductive capacity) is the same at both these frequencies and of similar order to that for paraffin wax. This signifies that the wax can be used in place of paraffin without change in design of the condenser (i.e., distance between foils and area of foils can remain the same).

A wide range of high melting point, micro-crystalline waxes, is available to-day, although it is not always obvious from suppliers' descriptions whether they are of petroleum or ceresin origin, or a mixture of the two. Consequently it is necessary to make a selection on the basis of tests and practical trials. Table 70 shows the physical characteristics of some of these waxes against beeswax for comparison. It will be seen that melting points range from 72 degrees C., which is comparable with that of the early waxes of this class, to 105 degrees C. Table 71 gives the chemical characteristics for the same samples. Samples Nos. 2, 3 and 7 are equal to the original type of material. The others show higher acid values and some saponifiable matter, as well as some measurable ash, but still no discoloration of copper. Further, they show measurable deterioration under heat. Beeswax, as representative of the natural fatty waxes, shows up adversely, especially with respect to the corrosion of copper under heat. Table 72 gives electrical characteristics at low frequencies (50 cycles), power factors for Nos. 2, 3 and 7 are outstandingly good, with No. 7 still excellent at audio frequencies (e.g., 1,000 cycles) and higher. Nos. 2 and 3 are still reasonable at these higher frequencies, and so are Nos. 1 and 6, but the other waxes run comparatively high. Permittivities of all of them are of similar order, this holding good for all the frequencies at which tested. Beeswax, as before indicated, shows up adversely.

If best stability and electrical characteristics are required, choice is restricted. If exceptionally high melting point is specifically required, something has to be sacrificed in these other directions. However, a melting point of 72 degrees C. is

Table 72.—Electrical Tests for Power Loss at 20°C. on Samples, After Conditioning Under Vacuum at 100–110°C. for 2 Hrs., Micro-crystalline High Melting Point Mineral Waxes, with Beeswax for Comparison.

Type	Micro-crystalline high melting point mineral waxes							Beeswax
Sample No...	1	2	3	4	5	6	7	8
Power factor, tan δ, at 20°C.:								
At 50 cycles	0.0003	0.0001	0.0001	0.0004	0.0005	0.0006	0.0001	0.0025
At 1,000 cycles	0.0004	0.0006	0.0007	0.0005	0.0006	0.0008	0.0001	0.0070
At 10,000 cycles	0.0005	0.0007	0.0006	0.0008	0.0009	0.0010	0.0001	0.033
At 100,000 cycles	0.0007	0.0005	0.0004	0.0011	0.0015	0.0009	0.0001	0.027
At 1,000,000 cycles ..	0.0007	0.0006	0.0003	0.0012	0.0045	0.0006	0.0001	0.015
Permittivity at 20°C. :								
At 50 cycles	2.32	2.35	2.40	2.40	2.44	2.38	2.32	—
At 1,000 cycles	2.33	2.36	2.41	2.40	2.43	2.38	2.33	—
At 10,000 cycles	2.34	2.37	2.41	2.42	2.43	2.37	2.32	—
At 100,000 cycles	2.32	2.36	2.42	2.42	2.42	2.37	2.32	—
At 1,000,000 cycles ..	2.33	2.34	2.40	2.41	2.42	2.42	2.32	—

Table 73.—Physical Properties of Some Chlorinated Naphthalenes.

Derivative	Position of chlorine	Melting point °C.	Boiling point °C at 760 mm.	Boiling point	
				At pressure mm.	°C.
Mono chlor.	α	17	259	14	126
Mono chlor.	β	56	252	12	122
Di chlor.	1, 2	35	281	19	152
Di chlor.	1, 3	61	291	—	—
Di chlor	1, 4	68	284	12	147
Di chlor.	1, 5	107 (sub)	—	—	—
Di chlor.	1, 6	48	—	—	—
Di chlor.	1, 7	63	286	—	—
Di chlor.	1, 8	83	—	—	—
Di chlor.	2, 3	120	—	—	—
Di chlor.	2, 6	140	285	—	—
Di chlor.	2, 7	114	—	—	—
Tri chlor.	1, 2, 3	81	—	—	—
Tri chlor.	1, 2, 4	92	—	—	—
Tri chlor.	1, 2, 5	78.5	—	—	—
Tri chlor.	1, 2, 6	92	—	—	—
Tri chlor.	1, 2, 7	88	—	—	—
Tri chlor.	1, 2, 8	83.5	—	—	—
Tri chlor.	1, 3, 5	103	—	—	—
Tri chlor.	1, 3, 6	80.5	—	—	—
Tri chlor.	1, 3, 7	113	—	—	—
Tri chlor.	1, 3, 8	85/90	—	—	—
Tri chlor.	1, 4, 5	131	—	—	—
Tri chlor.	1, 4, 6	56/66	—	—	—
Tri chlor.	2, 3, 5	109	—	—	—
Tri chlor.	2, 3, 6	91	—	—	—
Tetra chlor.	1, 2, 3, 4	198	—	—	—
Penta chlor.	1, 2, 3, 4, 5	168	—	—	—
Hepta chlor.	1, 2, 3, 4, 5, 6, 8	194	—	—	—
Octo chlor.	1, 2, 3, 4, 5, 6, 7, 8	203	403	—	—
Naphthalene tetra chloride, $C_{10}H_8Cl_4$	1, 2, 3, 4	182	—	—	—

probably satisfactory for most purposes, if not all of them, provided the condenser is mounted in the equipment away from other components dissipating much heat.

Apparently, many of these waxes are specially processed and anti-oxidants included to minimize the development of acidity during condenser processing. The range of tests covered by the characteristics tabulated is sufficiently discriminating to detect any inclusion of this kind that may be damaging. It should be pointed out, however, that there are numerous high melting point "hydrocarbon" waxes on the market, intended for purposes other than electrical insulation, in which the apparent melting point of the paraffins or ceresins is raised by including metallic stearates such as those of zinc or lead. These are quite unsuitable but readily detected by test. Thus, one such wax showed a melting point of 94 degrees C. but insipient fusion at 77 degrees C. and an ash value of 4.5 per cent. The ash consisted of zinc oxide, which was present in the wax as oleate or stearate.

An American specification for high melting point mineral wax for the impregnation of paper condensers stipulates a material refined from crude petroleum oils of Salt Creek origin, and one having the following properties:—

(a) To be free from dirt and foreign matter, and of uniform colour.

(b) Melting point to be not less than 163 degrees F. (72 degrees C.).

(c) Flash point to be not less than 500 degrees F. (260 degrees C.).

(d) Matter insoluble in benzene not to exceed 0.20 per cent., when determined on a 10 gm. sample, dissolved by heating with 500 ml. of benzene, and filtering through a prepared Gooch crucible. The residue on the crucible is washed thoroughly with hot benzene, dried at 100 degrees C. and weighed.

(e) Saponification value not to exceed 0.2 mgms. KOH/gm. when determined on a 20 gm. sample, saponified by refluxing with 50 ml. of decinormal alcoholic potash and 25 ml. of benzene. Decinormal sulphuric acid is used for back titration and phenol phthalein as indicator.

(f) The wax to be free from alkali or acid, as shown by testing a water extract. The water extract to be prepared by boiling 5 gms. of wax with 10 ml. of distilled water for five minutes, shaking periodically. Reaction to be determined by change in colour of red and blue litmus paper in contact with separate portions of the water extract for 15 minutes. No colour change to be evident.

(g) The wax to produce no more than slight bronzing of clean copper foil when heated together for 30 minutes at 375 degrees F. (190 degrees C.).

(h) Material to be supplied in cakes, properly packed in wooden cases to avoid damage in transit.

It will be noted that the foregoing clauses for high melting point wax are not particularly searching, and no mention is made of specific electrical properties. Presumably, reliance is upon ensuring source of supply and a prior knowledge of material from that source. Typical of a specification for the same material in this country are the following requirements:—

(a) Material to be an all-hydrocarbon wax of petroleum origin.

(b) Colour to be uniform, yellow or yellowish orange, and not darker than an approved sample.

(c) The wax to be free from earthy matter, dirt, water and all extraneous matter.

(d) Melting point to be minimum 72 degrees C.

(e) Open flash point to be minimum 250 degrees C.

(f) Matter insoluble in benzene not to exceed 0.20 per cent.

(g) Acid value not to exceed 0.05, expressed in terms of mgms. KOH/gm. of wax, but inorganic acid and alkali to be entirely absent.

(h) Saponification value not to exceed 0.05, expressed in terms of mgms. KOH/gm.

(i) Ash on complete incineration not to exceed 0.01 per cent.

(j) No corrosion or tarnishing of copper to occur when a piece of clean, bright copper foil is heated, half-immersed, in the wax at 100-110 degrees C. for six hours.

(k) Temperature coefficient of electrostatic capacity to be very low. When testing by impregnating paper/aluminium foil condensers by established

Table 74.—Typical Laboratory Characteristics of Synthetic Waxes of Chlorinated Naphthalene Type.

Sample No.	1	2	3	4	5	6
Commercial description	Double refined, M.Pt. 88/95°C.	Refined, M.Pt. 120/125°C.	Refined, M.Pt. 90/95°C.	Refined, M.Pt. 130/140°C.	Refined, M.Pt. 100/115°C.	Crude, M.Pt. 90/95°C.
Colour	Pale yellow	Pale yellow	Pale yellow	Brownish white	Pale yellow	Black
Melting point, °C.	94	122	92	137	111	95
Acidity, mgms. KOH/gm.	0.004	0.10	0.11	0.012	0.11	—
Acidity, expressed as hydrochloric acid, %	0.00025	0.0062	0.0070	0.0008	0.0070	—
Alkalinity, expressed as KOH, % ..	—	—	—	—	—	1.6
Ash, %	Nil	0.004	0.008	Traces	0.009	2.8
Volatility, loss in weight 4 hours at 135°C. in 3-in. dia. aluminium dish, %	13.5	11.2	12.5	7.0	11.8	7.2
Iodine value	Nil	Nil	Nil	Nil	Nil	Nil
Specific gravity at 15.5°C.	1.53	1.65	1.54	1.55	1.57	1.70
S.I.C. at 1,000 pps., approx.	4.5	5.5	5.0	4.5	5.0	—

Table 75.—Results of Stability Tests on Chlorinated Naphthalene Wax, Double Refined, Melting Point 94°C.

Test No.	Object	Test conditions	Summary of results
1	Effect of heat just above melting point.	Heated in open vessel for 48 hours at 115 to 120°C.	No measurable development of acidity or change of colour; loss in weight due to volatilization.
2	Effect of heat in contact with copper.	As in (1) with clean copper strip half immersed.	As in (1) and no attack on copper.
3	Effect of heat in contact with metals.	Heated for 7 days at 115 to 120°C. with clean metals half immersed. Mixture contained in flasks protected from atmosphere by guard tubes. Iron, zinc, copper and brass tested.	Iron became tarnished to slight brown colour and some iron entered the wax. No effect upon the other metals.
4	Effect of overheating in contact with copper.	Heated in open vessel for 12 hours at 220°C. with clean copper foil half immersed.	Wax darkened and ionizable chlorine was produced. Copper became blackish brown in colour, and upon exposure to a humid atmosphere developed patches of green copper chloride within 24 hours.
5	Effect of overheating in presence of moisture and in contact with copper.	As in test No. 4, but with 0.5% water added.	As in test No. 4, only deterioration more rapid, two hours' heating being sufficient to produce same effect.
6	As in (5), only using higher melting wax, melting point 125°C.	As in (5 .	As in (5).
7	Effect of air just above the melting point.	Wax maintained thermostatically at 115 to 120°C., and clean, dry air slowly bubbled through the wax and then through distilled water.	Unaffected. No ionizable chlorine or acidity developed in the wax in 21 days, nor trapped in the water.
8	Effect of air and moisture just above melting point.	Wax maintained thermostatically at 115 to 120°C. Clean, dry air passed first through distilled water to saturate it, then through the molten wax, and finally through distilled water to collect volatiles.	Definite, but very slight development of ionizable chlorine and acidity in the wax after prolonged treatment. Expressed in the terms of hydrochloric acid per cent., the amount of this was as under:— Initially, and in 2 days Less than 0.00020% In 7 days .. .. .. 0.00020% In 14 days .. .. .. 0.00050% In 21 days 0.00090%

production methods, the capacity of such condensers, at any temperature when subjected to a heat cycle from 20 degrees to 40 degrees C. and back to 20 degrees C., shall not differ from the initial capacity at 20 degrees C. by more than 0.5 per cent. Similarly, for a cycle from 20 degrees to 60 degrees C. and back to 20 degrees C., the capacity measured at any temperature during this cycle shall not differ by more than 3 per cent. of the initial capacity at 20 degrees C.

(l) The wax to be supplied in cakes, securely packed in wax-paper lined wooden cases.

For the waxes of rather higher melting point but not quite such good electrical properties, typical specification requirements are as under:—

(a) Material to be a high melting point hydrocarbon wax processed to give minimum of oxidation during use in impregnation process.

(b) Colour to be uniform, maximum darkness of shade to be a brown not exceeding that of an approved sample.

(c) To be free from mineral acids and alkalies, and organic acidity not to exceed 0.50, expressed in terms of mgms. of KOH/gm.

(d) Saponification value not to exceed 2.0, expressed in terms of mgms. of KOH/gm.

(e) Ash on complete incineration not to exceed 0.01 per cent.

Table 76.—Continental Compounds Having a Chlorinated Naphthalene Base.

Sample No.	1	2	3
Application	Condenser impregnation	Condenser. Sealing and filling.	Condenser. Sealing and filling.
Nature	Chlorinated naphthalene/ paraffin wax mixture	Chlorinated naphthalene/ coal tar pitch mixture	Chlorinated naphthalene/ colophony resin/coal tar pitch mixture
Colour	Translucent white	Glossy black	Glossy black
Melting point, °C.	94	97	120
Acid value, mgms. KOH/gm. ..	0.0045	0.48	4.1

(f) Melting point not to be less than 82 degrees C.

(g) Flash point (open) not to be less than 275 degrees C.

(h) No corrosion or staining whatsoever of copper to occur when clean, bright copper foil is heated, half immersed in the wax, at 100 to 110 degrees C. for six hours.

(i) To be packed in wax-paper-lined wooden cases, to give complete protection from deterioration in transit or storage.

Much advance has been made in this class of wax in recent years, and for satisfying the ever-increasing range of service temperatures, such inert, high-melting hydrocarbon waxes are indispensable. When full value can be had from industrial research in recent years, and when first priority can be given to highest quality, further advancement is to be expected.

Another class of wax, including many grades, must not be overlooked. These are the synthetic waxes obtained from chlorination of naphthalene. They have specific advantages over any other waxes, and also their shortcomings, and they have already been extensively employed for the impregnation of fixed paper condensers, not only in America and on the Continent but also in this country. The waxes are recognized under proprietary or registered names, such as Halowax, Nibren wax and Seekay wax. A consideration of their properties in some detail is justified.

The chlorinated naphthalene can claim properly to belong to the realm of synthetic plastics. Naphthalene itself is a pure hydrocarbon, chemically having a double-ring structure, colourless, crystalline, melting point 87 degrees C., inert in character. From its empirical formula, $C_{10}H_8$, it can be seen that there are eight hydrogen atoms that can be replaced by chlorine, and that many different compounds, mono-chlor, di-chlor, tri-chlor, etc., can be produced. Details of the well-estabished chlorine derivatives are given in Table 73, which gives data appertaining to melting points and boiling points. It can be seen that some of these compounds are liquid and low-melting solids; others are solid, including some having melting points as high as 200 degrees C. They are all stable, inert chemicals in the ordinary sense of these terms.

Commercially, the chlorinated naphthalenes are produced from the direct chlorination of naphthalene, degree of chlorination being determined by the time and temperature of the reaction. Obviously, the hydrochloric acid has to be removed subsequently by washing processes. The products obtained are mixtures of chloronaphthalenes, and they can be graded into wax-like materials on a basis of melting point. Crude materials are black and generally strongly alkaline. By refinement, pale yellow waxes having marked crystallinity are obtained, but such waxes are slightly acidic with hydrochloric acid. By double refinement, waxes of negligible acid value are procured, and it is these that are used for condenser manufacture.

Table 77.—Depreciation of Condenser Impregnating Wax in Continuous Use. Type of Wax-chlorinated Naphthalene (Double Refined), Melting Point 94°C.

	Comparative test results on representative batches	
	During first few days of use	After 6 weeks' operation
Electrical tests on condensers:		
Insulation resistance, megohms per microfarad at 300 volts, D.C., 68°F.	8,200	2,500
	8,000	2,200
	8,000	1,700
	8,000	1,650
	7,800	1,450
	7,500	1,350
	7,500	1,350
	7,000	1,100
	6,900	1,100
	6,500	900
	Mean 7,500	Mean 1,500
Power factor (phase angle in minutes) at 900 p.p.s., 68°F.	Min. 25	38
	Max. 30	45
	Mean 27	41
Chemical tests on wax:		
Acidity, mgms. KOH/gm. ..	0.005	0.070
Ash on incineration, % ..	Nil	0.11
Comparative insulation resistance values on wax, megohms	320	28

Table 74 shows the chief characteristics of the commercial chlorinated waxes. Melting points from about 70 degrees C. to 150 degrees C. are possible, although the tabulated data do not extend over the full range. It is material similar to sample No. 1 that is most generally used for condensers. This is a double-refined wax of melting point 90 to 95 degrees C. Any of the other melting-point grades can similarly be produced in the double-refined condition. It will be seen that the double-refined grade has an exceedingly low acid value and low ash value compared with the corresponding figures for the other grades. Volatility is high with all of them, a distinct drawback, because losses and clogging of pipe-lines during vacuum impregnation are appreciable. Specific gravities are high, 50 per cent. greater than those of the high melting point mineral waxes, and very nearly double those of the paraffin waxes. This has to be borne in mind when considering the cost aspect. At the same time, the high specific inductive capacities should be noted. These figures are double those of the paraffin and high melting petroleum waxes, which signifies that smaller condensers can be made with the chlorinated waxes, viz., about half the area of metal foil, with the same thickness of dielectric as when using hydrocarbon waxes. This is one of the major advantages of the chlorinated naphthalene. Another is small shrinkage during cooling, this being almost negligible compared with that of the other waxes, as can be seen from the figures in Table 62. Further, they do not burn and, incidentally, they are mould- and pest-proof.

Apart from the disadvantage of high volatility, the chlorine element renders it necessary to take precautions in using the waxes to safeguard operators from health hazards. Toxity and possibilities of dermatitis are not unduly severe, but all safeguards must be taken to exhaust fumes from open tanks, and to prevent contact between fume or wax and operators' skin. The other shortcoming is the natural tendency under conditions of prolonged heating or overheating, or in the presence of moisture, for hydrochloric acid to form. Although this is only to a very small degree, it is sufficient to be disturbing, and to result in low insulation values if such wax is used for condensers. The shortcomings cannot be prevented,

Table 78.—Depreciation of Condenser Impregnating Wax in Continuous Use. Type of Wax—Paraffin (Refined), Melting Point 58°C.

	Comparative test results on representative batches	
	During first few days of use	After 6 weeks' operation
Electrical tests on condensers:		
Insulation resistance, megohms per microfarad at 300 volts, D.C., 68°F.	11,500	4,000
	11,000	3,800
	10,500	3,600
	10,100	3,500
	10,000	3,200
	9,800	3,000
	9,800	2,800
	9,500	2,600
	9,200	2,000
	8,500	1,500
	Mean 10,000	Mean 3,200
Chemical tests on wax:		
Acidity, mgms. KOH/gm. ..	0.0023	0.22
Ash on incineration, % ..	Nil	0.013
Comparative insulation resistance values on wax, megohms	Infinity	2,200

although ultimately inhibitors will be found which will prevent and minimize the trouble. Consequently it has to be taken care of by process design and control. The extent to which the wax is, and has been, satisfactorily employed over the past 10 or 20 years shows that it can be safely used for condensers.

Table 75 summarizes test results, showing the extent of instability of the chlorinated naphthalene waxes. The tests and results are self-explanatory, and they establish that the waxes, strictly speaking, are, under certain conditions, unstable, and that the degree of decomposition is exceedingly minute. They lead to the conclusion that, if the condenser units are fully dried before immersion in the wax, no trouble from acidity formation should be encountered, a fact borne out in practice.

Table 76 gives some data on Continental products having a chlorinated naphthalene base, sample No. 1 being the condenser impregnant, and the other two filling or sealing compounds. This material is practically free from crystallinity, presumably due to the paraffin-wax admixture.

Table 77 gives interesting information upon the deterioration in chlorinated naphthalene wax during six weeks of condenser processing. The insulation resistance values of the condenser units fall to about 20 per cent. of the original value. Power factor rises 50 per cent. Regarding the wax itself, acidity increases by 14 times; some extraneous dirt is included, and insulation resistance falls to less than one-tenth of the original value.

Table 78 gives similar data for paraffin wax. Insulation resistance of the condenser unit falls to 30 per cent. of the original values. The acidity of the wax increases one hundredfold, and the wax itself shows a marked fall in insulation resistance.

With both types of wax, therefore, marked deterioration occurs, and must be taken care of, either by periodic scrapping of the reservoir of wax, or by designing the plant so that the major portion of the reservoir of wax is consumed by the load of units, and a major quantity of new wax is added for each new load.

Table 78 compares the electric strength of the chlorinated naphthalene wax with that of paraffin wax by breakdown tests on condensers. It is self-explanatory, and the conclusion to be drawn is that the electric strengths of the two types of wax are identical.

The contraction during solidification is considered an important feature of condenser waxes.

For this reason well-defined methods have been developed for the assessment of this quality. The process, in general, involves the determination of total contraction of the wax in cooling from 100 degrees C. to room temperature, but variations are possible should it be

Table 79.—Influence of Type of Impregnating Wax upon Breakdown Voltage of Paper Condensers. (Double Refined Chlorinated Naphthalene Wax, M.Pt. 94°C. versus Refined Paraffin Wax, M.Pt. 58°C.—otherwise all processing conditions constant.)

Test No.	Paper interleaving, linen stock, 2 × 0.0005 ins.		Paper interleaving, wood stock, 2 × 0.0005 ins.	
	Chlor-naphthalene	Paraffin	Chlor-naphthalene	Paraffin
1	3,500	3,500	3,500	3,250
2	3,500	3,500	2,500	3,000
3	3,000	3,250	3,500	3,000
4	3,000	3,000	3,250	3,000
5	3,000	3,000	3,250	3,000
6	2,750	2,750	3,000	3,000
7	2,750	2,750	2,750	2,750
8	2,750	2,500	2,750	2,750
9	2,250	2,500	2,500	2,750
10	2,250	2,250	2,500	1,750
Average	2,875	2,900	3,100	2,925

desired to measure contraction from any other temperature above the melting point of the wax, if necessary down to sub-zero temperatures. Operating conditions, the design of the assembly into which the condenser is embodied, and other like factors will govern the choice.

In purchasing and using the chloronaphthalene waxes, attention must be given to hydrochloric acidity; this applies to the wax as purchased and continuously in processing. If this is kept to the low values indicated for good waxes in the foregoing, no undue trouble is to be anticipated.

The nature of the requirement clauses for chloronapthalene wax for condenser manufacture, typical of American specifications, is shown by the following items:—

(a) The chlorinated naphthalene wax to be pale yellow in colour.

(b) To be free from naphthalene, as indicated by odour.

(c) To be free from monochloronapthalene as indicated by the absence of any signs of wetness to the crystals in the fracture of a freshly broken sample.

(d) To be free from tarry matter, dirt and all extraneous matter.

(e) Acidity not to exceed 0.04, expressed in terms of mgms. KOH/gm. of wax when tested as follows:—

> A 10 gm. sample of the grated wax is weighted, and it is then refluxed for 15 mins. with 50 ml. of neutralized alcohol. Fifty ml. of hot distilled water is added, and thoroughly mixed, and 5 ml. of a 1 per cent. solution of phenolphthalein is added as indicator. Titration is effected hot with N/50 potassium hydroxide solution, end point being a pink coloration persistent for 30 secs.

(f) Volatility. Not to exceed 1.5 per cent. when heated in an air-circulated oven for 3 hours at 105 degrees C.

(g) Melting point to be 90 degrees C. min., 98 degrees C. max., when determined as follows:—

> Wax to a depth of about 2 ins. is placed in a 1-in. dia. test tube, and a thermometer is centrally fitted. The tube is surrounded by a beaker of water and temperature raised to 100 degrees C. Then, when equilibrium has been attained, the heat is removed. The wax is kept under observation as it cools until the first crystal of chlorinated naphthalene appears. This is taken as the melting point. Three determinations are made and averaged.

(h) Specific gravity to be 1.39 min., 1.42 max., at a temperature of 150 degrees C.

With advantage, the specification could be more rigid without excluding suitable commercial waxes, and the following clauses are advocated.

(a) Material to be a chlorinated naphthalene wax, free from naphthalene, monochloronaphthalene, tarry matter, water, dirt and all extraneous material.

(b) Acidity not to exceed 0.005, expressed in terms of mgms. KOH/gms. of wax, or 0.00031 per cent. expressed as hydrochloric acid.

(c) Ash on complete incineration not to exceed 0.001 per cent.

(d) Volatility, 4 hours at 135 degrees C. in 3-in. dia. aluminium dish, not to exceed 14.0 per cent. by weight.

(e) Specific gravity at 20 degrees C. ± 5 degrees C. to be 1.50 to 1.55.

(f) Melting point to be 90 to 98 degrees C., determined by cooling curve.

(g) No corrosion or tarnishing of clean, bright copper foil, half immersed, heated on a water bath at 100 degrees C. for 6 hours.

(h) No corrosion or tarnishing of aluminium foil, half immersed, heated on a water bath at 100 degrees C. for six hours.

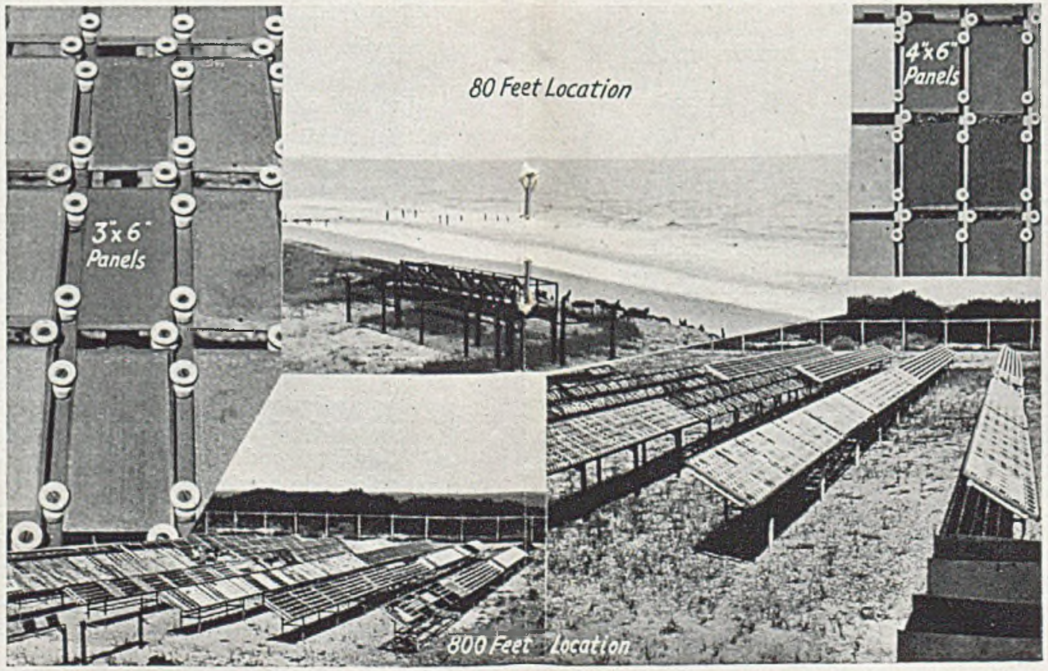
(i) To be supplied in cakes, packed in wax-paper-lined wooden cases to give full protection against damage in transit or storage.

(To be continued)

CORROSION STABILITY OF MAGNESIUM ALLOYS

J. D. Hanawalt and C. E. Nelson* Present a Discussion on the Corrosion Resistance of the Ultra-light Alloys in Terms of a High Purity Magnesium Base Versus one of Normal—Purity Coupled with High Manganese. The Authors Draw Particular Attention to the Care Needed in Interpreting Salt-spray Test Results as Guides to Performance in Service*

Fig. 1 (above).—Shown here is a magnesium-alloy canoe after ten years' service. It should be noted that, in spite of the fact that the alloy used in this case was not of high purity, and despite the fact that the canoe was not repainted during this period, no corrosion has occurred. Fig. 2 (below).—View of part of the exposure station at Wilmington, N.C.



THIS paper is written primarily in reply to the paper by Fox and Bushrod[1] on "Protective Influence of Mn in the Corrosion of Mg-Al Alloys." A second purpose is to discuss the question of the correlation between the salt-water corrosion and the atmospheric stability of common Mg alloys.

Fox and Bushrod[1] have stated that their results do not check those of Hanawalt, Nelson, and Peloubet,[2] and, more particularly, that a high Mn content in a Mg-Al alloy will counteract the effect of high Fe content and give the same low corrosion rate in salt solution as is given by the low Fe alloys defined by Hanawalt, Nelson, and Peloubet. This idea in the Fox and Bushrod paper has been restated by various reviewers of that paper in the abbreviated form that "it is not the Fe content which is important, but rather the Mn to Fe ratio."

The conclusion of Fox and Bushrod is contrary to the results of the work of Hanawalt, Nelson and Peloubet, and further is not, in the judgment of the present authors, supported by the data published by Fox and Bushrod. Fig. 3 reproduces unretouched photographs of low Fe alloy after 5½ years in 3 per cent. NaCl solution. In contrast, high Mn-high Fe alloys of the composition claimed by Fox and Bushrod to have equivalent salt-water corrosion resistance would be completely disintegrated under the same conditions within a few months. The beneficial effect of Mn has been well known for many years and was restudied in detail by Hanawalt, Nelson and Peloubet. Bakken,[3] in a patent on Mg-Al-Mn alloys in 1926, said: "Proportions from 0.2 to 1.0 per cent. of manganese have been found effective in increasing the resistance to corrosion." However, Mn additions to Mg-Al alloys do not accomplish the same results in increasing the salt-water corrosion resistance as does a lowering of Fe to the tolerance limit. It seems clear that the reason Fox and Bushrod did not come to this conclusion is primarily because they limited their observations to a two- to four-day duration for their salt-water test, and then assumed that their test was comparable to the tests of much longer duration used by Hanawalt, Nelson and Peloubet. Actually, whilst low Fe and high Fe-high Mn specimens, at least in the as-cast state, do have somewhat the same corrosion rate after four days in salt water, for continuing exposure, the corrosion rate of the high purity alloy decreases whilst the corrosion rate of the high Fe-high Mn alloy increases until the specimen is completely disintegrated. As can be seen in Fig. 5, there is a great difference in the corrosion behaviour of the high and low Fe alloys, and they only appear to be somewhat similar if one looks at the four-day rates. Even at four days, visual examination will show considerable superiority for the low Fe alloys. Another reason for the differences in interpretation of the Fox and Bushrod data would seem to be that they disregard the difference between 0.005 per cent. Fe and Fe below the tolerance limit.

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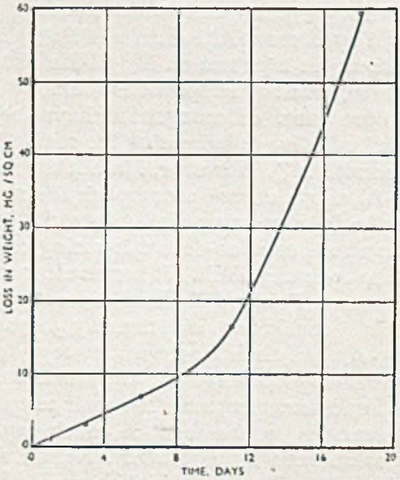
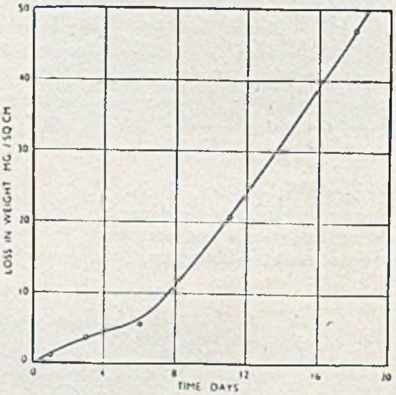
In a more recent paper by Fox and Bushrod[13] Figures 1* and 2† purport to show that low iron (.001 per cent. or less) gives the same corrosion rates as .023 per cent. Fe even when tested for about 18 days. It is obvious from examining their analysis as given in Table 2‡ that nickel is above the tolerance limit shown by Figure 10§ in the paper by Hanawalt, Nelson and Peloubet, and that other elements have not been reported within sufficiently narrow limits to be certain that they had no deleterious effects. Comparison of the appearance of samples shown in their Figure 7|| to those in Fig. 3 of the present discussion, clearly indicates that Fox and Bushrod were not working with controlled quality material. The present authors found by sad experience that it was not possible to get adequate fundamental information on the salt-water corrosion effect of impurities by testing samples taken from random batches of production material.





Type of Test.	Condition of Material.	Ingot No.	Composition.				
			Al, %.	Zn, %.	Mn, %.	Ni, %.	Fe, %.
Immersion in 3% NaCl solution.	As-cast.	1	7·9	0·52	0·28	0·0016	0·023
		2	7·8	0·51	0·27	0·0021	0·019
		3	7·7	0·49	0·25	0·0018	0·005
		4	7·7	0·50	0·21	0·0016	0·001
	Solution-treated: 24 hr. at 420° C.	5	7·9	0·51	0·27	0·0015	0·023
		6	7·9	0·49	0·25	0·0021	0·016
		7	7·9	0·49	0·24	0·0020	0·006
		8	7·9	0·50	0·21	0·0019	0·002
	Fully heat-treated: 24 hr. at 420° C. followed by 18 hr. at 200° C.	9	8·3	0·49	0·28	0·0020	0·018
		10	8·2	0·51	0·26	0·0019	0·013
		11	8·1	0·47	0·25	0·0018	0·007
		12	7·9	0·46	0·24	0·0015	0·002
Atmospheric.	As-cast.	13	7·9	0·52	0·28	0·0019	0·020
		14	7·9	0·50	0·26	0·0020	0·012
		15	7·7	0·51	0·25	0·0017	0·004
		16	7·7	0·53	0·23	0·0021	0·002
	Solution-treated: 24 hr. at 420° C.	17	8·1	0·55	0·23	0·0022	0·024
		18	7·9	0·53	0·23	0·0021	0·013
		19	8·0	0·49	0·22	0·0013	0·006
		20	7·8	0·56	0·20	0·0021	0·004
	Fully heat-treated: 24 hr. at 420° C. followed by 18 hr. at 200° C.	21	7·9	0·50	0·28	0·0016	0·022
		22	8·0	0·49	0·27	0·0015	0·015
		23	7·9	0·51	0·26	0·0018	0·008
		24	8·1	0·50	0·24	0·0019	0·003

* Above, left:—Figure 1, after Fox and Bushrod, in "Protective Influence of Manganese in Corrosion of Magnesium Alloys" ("J. Inst. Met.," 1945/71/258); authors' caption reads—"Loss-in-weight / time curve for alloy conforming to D.T.D. specification 59A (0.023 per cent. iron) in immersion tests in 3 per cent. NaCl solution."

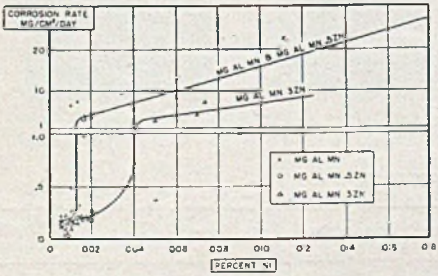
† Above, right:—Figure 2, after Fox and Bushrod, *ibid.* (*loc. cit.*, p. 259); authors' caption reads—"Loss-in-weight / time curve for alloy conforming to D.T.D. specification 59A (0.001 per cent. iron) in immersion tests in 3 per cent. NaCl solution."

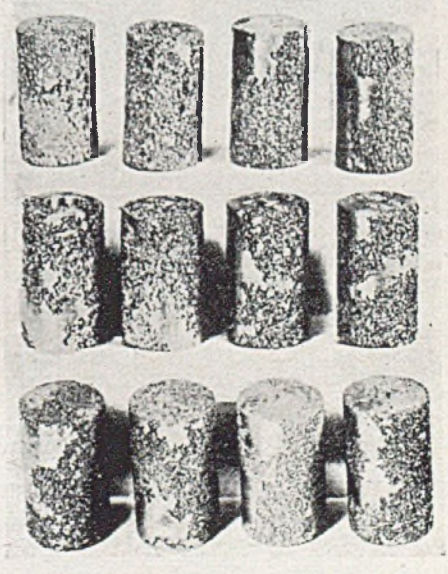
‡ Adjacent, left:—Table 2, after Fox and Bushrod, *ibid.* (*loc. cit.*, p. 257).

The present paper gives the results of experimental work which was undertaken to duplicate as closely as possible the technique described in the Fox and Bushrod paper, and compare it with the technique used by Hanawalt, Nelson and Peloubet. To this end, four types of Mg-Al-Mn-Fe alloys were studied: (1) high Fe, high Mn; (2) high Fe, low Mn; (3) low Fe, high Mn; (4) low Fe, low Mn. These alloys were cast in (a) iron chill moulds of the design and dimensions given by Fox and Bushrod, and (b) in sand moulds. The alloys were tested in salt water in the following states: as-cast, HT, HT followed by ageing. The salt-water tests were carried out by (a) a four-day continuous immersion in 3 per cent. NaCl (pH = 10.2 by adding MgO); (b) a four-day continuous immersion in 3 per cent. NaCl; (c) a four-day alternate immersion in 3 per cent. NaCl; (d) a 14-day alternate immersion in 3 per cent. NaCl; (e) a 28-day alternate immersion in 3 per cent. NaCl. Other pertinent experimental data are also given in this paper. However, before proceeding with the presentation of the experimental data, it is desired to discuss the subject of corrosion of magnesium more generally. Such a discussion may serve to take away some of the emphasis on salt-water corrosion and provide a better perspective for the person not familiar with magnesium.

Comparison of Atmospheric Stability of Magnesium with Salt-water Tests

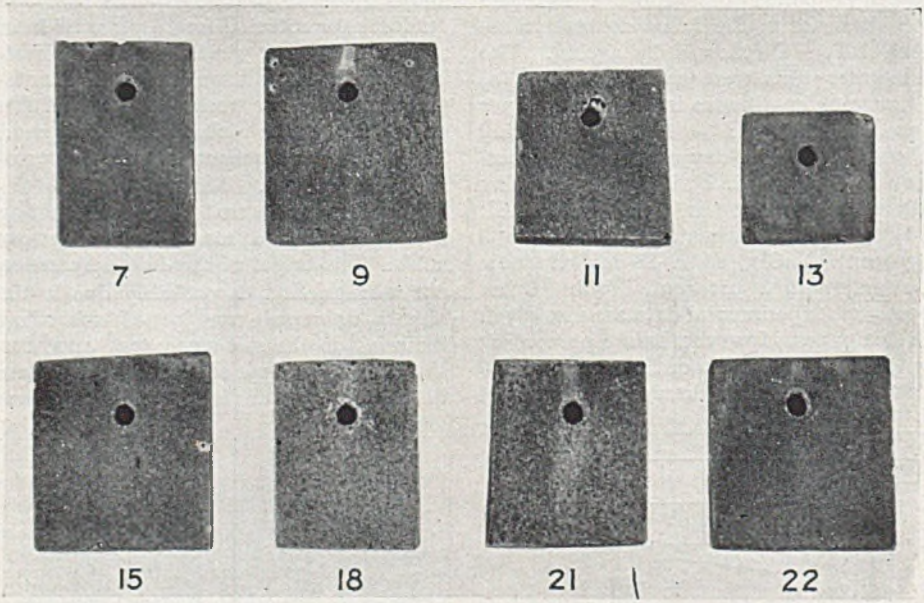
There is a great difference in degree between the action of salt water on magnesium alloys and the action of ordinary atmospheres. Those familiar with magnesium know that castings of magnesium alloys made 15 years ago have been left outdoors unprotected for 15 years without serious detriment; whereas, the same castings placed in salt water would disintegrate within a few weeks. In spite of this good atmospheric stability, a widespread feeling that magnesium is poor in corrosion has existed. This feeling has undoubtedly been a great factor in inhibiting the utilization of magnesium in many fields. The origin of this false impression about magnesium is probably due to the almost universal practice of subjecting materials to the salt spray test, and, further, to early experience with magnesium in the days when foundry practice was





§Above: Figure 10, after Hanawalt, Nelson and Peloubet "Corrosion Studies of Magnesium and its Alloys" ("Metals Technology," Sept., 1941, "Am. Inst. Min. Met. Eng." Tech. Pub. No. 1353, p. 13): author's caption reads: "Effect of nickel on magnesium-aluminium-manganese and magnesium-aluminium-manganese-zinc." || Adjacent, right: Figure 7, after Fox and Bushrod, "Protective Influences of Manganese in Corrosion of Magnesium Alloys" ("J. Inst. Met.," 1945/71/Plate XXXII, facing p. 260): author's caption reads: "Typical specimens after testing by immersion in 3 per cent. sodium chloride solution: top row, specimen from ingots 1, 2, 3 and 4, from left to right, after 18 days exposure: middle row, specimens from ingots 5, 6, 7 and 8, from left to right, after 8 days exposure; bottom row, specimens from ingots 9, 10, 11 and 12, from left to right, after 12 days exposure. In all cases iron contents decrease from left to right.

not well established, and occasional flux inclusions turned what would otherwise have been an ordinary atmospheric exposure into salt-water corrosion. A general lack of appreciation, at least in the United States,* of the good atmospheric stability of magnesium has been indicated by the reactions of visitors to the exposure station at Wilmington, N.C. One location is at 80 ft. from the ocean and the other at 800 ft. Within the past year or two, several hundred persons representing many U.S. industries have visited this station, which has on exposure, side by side, thousands of specimens of metal of many types, including magnesium, aluminium, zinc and steels. The visitors always return home surprised and impressed by the outstandingly good appearance of the magnesium alloys. Whilst set up purely as a technical testing ground, the discovery of how a visit to



Alternate immersion, 3% NaCl, 95°F.

Spec. No.	Alloy No.	Al	Ca	Cd	Cu	Fe	Mn	Ni	Pb	Si	Sn	Zn	Analysis	Months on test
*7	*8518	6.4	<0.001	Nil	0.0001	0.0001	0.10	Nil	Nil	0.003	Nil	0.70	Spect.	67
*9	*8565	4.9	<0.001	0.013	0.0001	0.0025 0.0006	0.23	Nil	0.16	0.002	Nil	0.70	Spect.	67
*11	*8567-2	Pure 6.0	—	—	—	—	0.05	Pure Mg					Nominal	67
*13	*8644-1	6.2	<0.001	Nil	0.0001	0.0005	0.038	Nil	Nil	0.001	Nil	Nil	Spect.	66
*15	*8652-2	5.9	<0.001	Nil	0.0001	0.0001	0.005	Nil	Nil	<0.001	Nil	Nil	Spect.	66
*18	*8655-2	6.0	—	—	—	—	0.20	Pure Mg					Nominal	66
*21	*9030	6.4	0.001	Nil	0.01	0.00015	0.10	Nil	0.004	0.14	Nil	Nil	Spect.	64
*22	*8644-3	6.0	<0.001	Nil	0.0001	0.0003 0.0028	0.038	Nil	Nil	0.001	Nil	Nil	Spect.	66

Fig. 3.—Showing the appearance of low-iron magnesium-base alloys after 5½ years' exposure to 3 per cent. salt solution. Data regarding the composition of these specimens are tabulated immediately below the illustrations. (Compare with corrosion test pieces of Fox and Bushrod reproduced in footnote on preceding page.)

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* And in England, as evinced by the reactions of visitors to similar exposure tests here.—Ed.

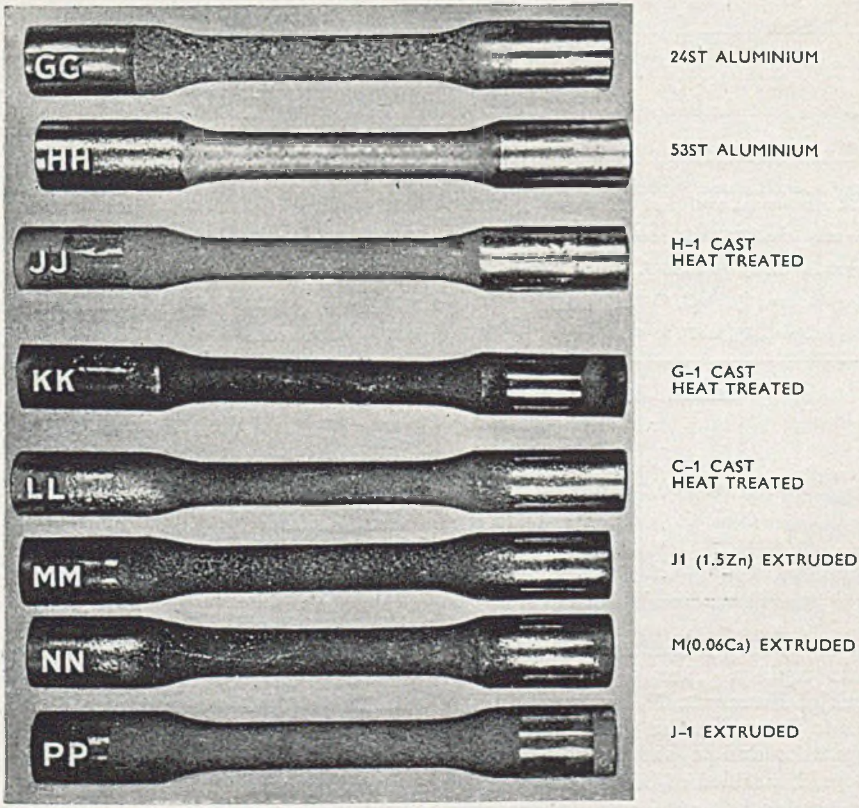


Fig. 4.—Tensile test bars (cleaned) after four years' coastal exposure at Wilmington, N.C. (experimental panel No. 61. Exterior station I, 80 ft. from sea).

this station changes people's conceptions of the corrosion resistance of magnesium has brought the station into considerable use as a place to take the person doubtful about the serviceability of magnesium. Fig. 2 gives a view of part of the station and Fig. 4 shows some magnesium specimens after four years' exposure 80 ft. from the sea. A further discussion on this corrosion station is to be found in an article by J. A. Peloubet.[4]

Thus, whilst the salt-water corrosion test can be used as an accelerated test for laboratory studies, and whilst, for some metals, it may bear some correlation with atmospheric exposure, even for common magnesium alloys containing normal amounts of impurities, the salt-water corrosion compared to atmospheric exposure is relatively much more severe than for most other metals and the degree of correlation is much lower. The comparison is particularly misleading in the case of magnesium, because of the dominating effect of the large potential differences caused by the impurities in common magnesium alloys when placed in salt water. In salt water, magnesium stands removed by 0.7 volt or more from the other common metals in the electrochemical series. The electrolytic currents thus generated are sufficient to prevent the formation of protective films which would be formed in media less conducting electrically. In fact, a potential of the magnitude of that between Fe and Mg if applied to Al in salt solution will prevent the formation of the otherwise naturally occurring protective

Table 1.—Corrosion Rate vs. Mn : Fe Ratio vs. Time of Testing.

Test	44976 Mg, 6Al, 0.3 Mn, $<$0.001 Fe						44761 Mg, 6Al, 0.3 Mn, 0.020 Fe						44762 Mg, 6Al, 0.06 Mn, $<$0.001 Fe						44763 Mg, 6Al, 0.06 Mn, 0.020 Fe					
	Chill cast			Sand cast			Chill cast			Sand cast			Chill cast			Sand cast			Chill cast			Sand cast		
	AC	HT	HT-A	AC	HT	HT-A	AC	HT	HT-A	AC	HT	HT-A	AC	HT	HT-A	AC	HT	HT-A	AC	HT	HT-A	AC	HT	HT-A
4-day Fox and Bushrod, 3% NaCl + MgO, pH 10.2, room temp., total imm.	2.02	0.31	0.32	1.42	0.48	0.31	1.89	6.48	3.98	1.30	1.07	1.67	0.27	0.123	0.086	0.61	0.135	0.080	69.1	51.2	71.1^{3}	90.1	93.6^{3}	86.9^{3}
4-day total imm., 3% NaCl, room temp. ..	1.32	0.48	0.76	1.32	1.33	2.37	0.63	5.20	4.36	1.15	6.52	4.80	0.167	0.351	0.44	0.19	0.41	0.37	58.0	53.1	53.2	$82.6^{3.5}$	92.8^{3}	117.7^{3}
4-day alt. imm., 3% NaCl, 95°F.	1.06	0.97	0.91	0.80	1.07	0.99	4.47	23.3	17.2	4.41	8.06	7.25	0.54	0.56	0.75	0.55	0.46	0.47	$64.6^{3.5}$	74.4^{3}	88.4^{3}	100.7^{3}	129.3^{3}	114.8^{3}
14-day alt. imm., 3% NaCl, 95°F...	0.49	0.50	0.50	0.50	0.32	0.33	10.4	21.7	30.2	6.0	17.6	24.1	0.32	0.33	0.35	0.37	0.16	0.29	$69.4^{4.5}$	71.2^{4}	46.7^{6}	103.3^{4}	$49.5^{5.5}$	53.9^{5}
28-day alt. imm., 3% NaCl, 95°F...	0.59	0.29	0.23	0.53	0.17	0.28	12.4	26.7^{13}	22.1^{13}	13.2	21.7^{15}	18.5^{14}	0.21	0.35	0.49	0.24	0.28	0.25	—	—	—	—	—	—

		44976	44761	44762	44763
Av. analysis ..	Al ..	6.2	6.0	6.3	6.4
	Cd ..	0.001	$<$0.01	$<$0.01	$<$0.01
	Cu ..	0.01	$<$0.01	$<$0.01	0.006
	Fe ..	$<$0.001	0.023	$<$0.001	0.022
	Mn ..	0.36	0.27	0.057	0.072
	Ni ..	0.001	$<$0.001	$<$0.001	0.002
	Pb ..	0.018	0.021	0.023	0.001
	Si ..	0.01	$<$0.01	$<$0.01	0.006
	Sn ..	0.001	$<$0.001	$<$0.001	0.002
	Zn ..	0.01	$<$0.10	$<$0.01	$<$0.01

Small numerals are actual (average) days sample lasted if less than the nominal test period.

Alloy compositions given at head of columns are nominal, and average analyses are found at foot of table.

coating, and will cause the Al to disintegrate rapidly. The significance of the work of Hanawalt, Nelson and Peloubet[2] was to determine the tolerance limits for impurities and to show that magnesium alloys, if purified of certain elements, are very stable in 3 per cent. NaCl solution. The statement has been made that there is very little correlation between the salt-water tests and the atmospheric exposure. This statement must be taken to apply only within the limits of the experiments to date. Magnesium alloys of ordinary and of controlled purity are on exposure at the 80- and 800-ft. racks at Wilmington, and in industrial and rural Michigan. The present status of the results is indicated by some data presented in Table 2 in terms of loss in mechanical properties. It can be seen that the atmosphere at the 80-ft. station is severe enough to show the greater resistance of the controlled purity alloys after a few years, whilst at the more mild exposure stations a significant difference has not as yet been observed. It will be interesting (to someone) to make the comparison after 50 years of unprotected exposure to the milder atmospheres. A more general comparison of various alloys after four years' exposure at the 80-ft. Wilmington location is shown in Table 3. These are the specimens pictured in Fig. 4. All of the magnesium alloys shown, except the " M " plus Ca, are of controlled purity.

In the United States, controlled purity has been introduced only for wrought metal, which, because of thin sections, is more sensitive to property losses due to surface attack than are heavier sectioned castings. Present A.S.T.M. specifications give a maximum of 0.005 per cent. for iron and nickel. Actually, iron and nickel in U.S. wrought alloys will be less than the tolerance limits in practically all cases. Probably not a little of the value of this controlled purity grade of alloy lies simply in the better impression it makes when evaluated by the salt-water test. After magnesium is better known and utilized, and the corrosion fear has been allayed by its good service records, there will be many fields of application for which controlled purity is unnecessary.

About ten years ago, more than 100 magnesium-alloy canoes were made and sold for service in the United States, Canada and Alaska. Except for some cases of stress cracking of the gunwales, due to a particular method of fabrication which resulted in high residual stresses, there have been no corrosion failures reported. One canoe which had been in use in Michigan every year for ten years was examined recently. It showed no corrosion in spite of the fact that it had never been repainted and the original paint had been chipped at various places. (See Fig. 1.) The alloy used for these canoes made ten years ago was Mg-4 per cent., Al 3 per cent. Mn, and was not of high purity. The rivets were 2S aluminium. Samples of 0.051-in. sheet cut from this canoe completely disintegrated in less than one day in a 3 per cent. NaCl solution, yet similar samples cut from an area from which the paint had been gone for a long time, showed tensile strength losses when tested of less than 3 per cent. This illustrates that service experience provides information which no amount of accelerated laboratory test data can take away.

Another illustration of the good serviceability of commercial grade magnesium alloys is that of the generator cap parts on the Ford car. Millions of these magnesium die castings have been in service since 1939 with no record of corrosion to date. When enough of such illustrations of good serviceability have been established, the control of purity of magnesium alloys will probably be based purely upon the economics of the matter, high-purity being reserved for those applications involving more severe salt atmospheres.

Experimental Procedure and Results

Table 1 presents the mean corrosion rates for five different laboratory corrosion testing procedures for a group of four alloys specially alloyed, cast and heat treated to present the following variables:

(a) Low iron—high manganese (44976).

(b) High iron—high manganese (44761).

(c) Low iron—low manganese (44762).

(d) High iron—low manganese (44763).

(e) Sand versus chill casting in each alloy.

(f) As cast (AC), solution heat treated (HT), and solution heat treated and aged (HTA) states for each alloy and casting method.

The chill mould used was made to be identical to that described by Fox and Bushrod, and the sand mould had the same approximate shape, but without the taper. Melting practice conformed to that described by Fox and Bushrod, with the substitution of the appropriate Dow flux (310). Sixteen castings were made in each mould (chill and sand), 32 in all, for each alloy. Each casting was analysed completely, in duplicate. The average analyses are shown at the foot of Table I. Detailed analyses and corrosion data are available from the authors upon request.

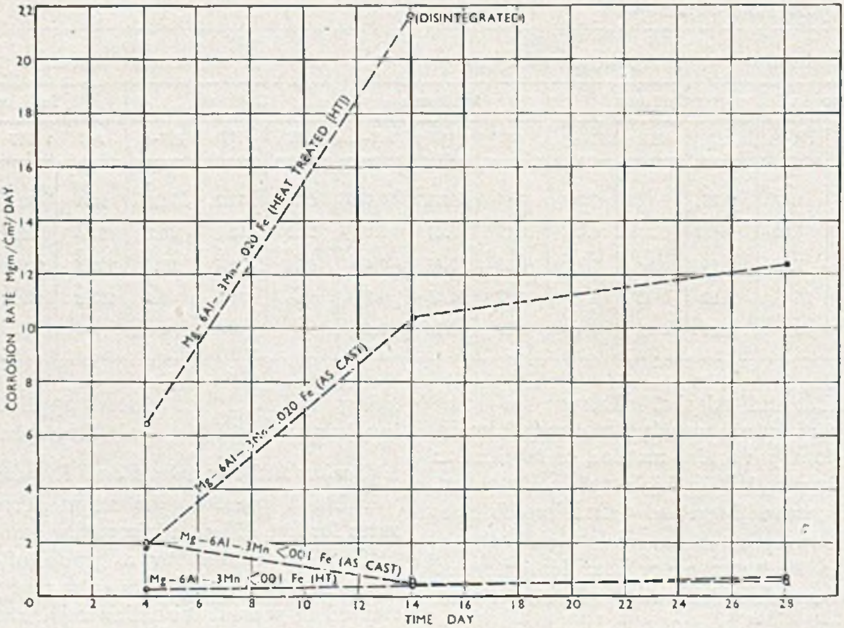


Fig. 5.—Corrosion rates of chill-cast magnesium-base alloys containing 6 per cent. of aluminium and 0.3 per cent. manganese in relationship to iron content. Four-day rates are by the method of Fox and Bushrod, whilst the 14-and 28-day rates are by alternate immersion in 3 per cent. sodium-chloride solution.

The heat treatment given these alloys (HT) consisted in loading the samples into a furnace set at 670 degrees F., raising the temperature to 730 degrees F. over a two-hour period, holding at 730 degrees F. for 16 hours, and then removing from the furnace and allowing them to air cool. The ageing (HTA) consisted in following the above treatment with 16 hours at 350 degrees F.

The samples were surface scalped and ground with Aloxite cloth to prepare them for the corrosion test.

The so-called Fox and Bushrod total immersion test using salt solution with pH adjusted to 10.2 (with MgO) and a similar check test without the pH adjustment were run in large containers so that the same equivalent volume of salt solution (2 litres per sample) was used as in the Fox and Bushrod test. Moreover, high and low purity samples were placed in the same trays at random.

The alternate immersion tests of 4 to 28 days were run on the standard Dow machines with each specimen in an individual container as described in the earlier paper.

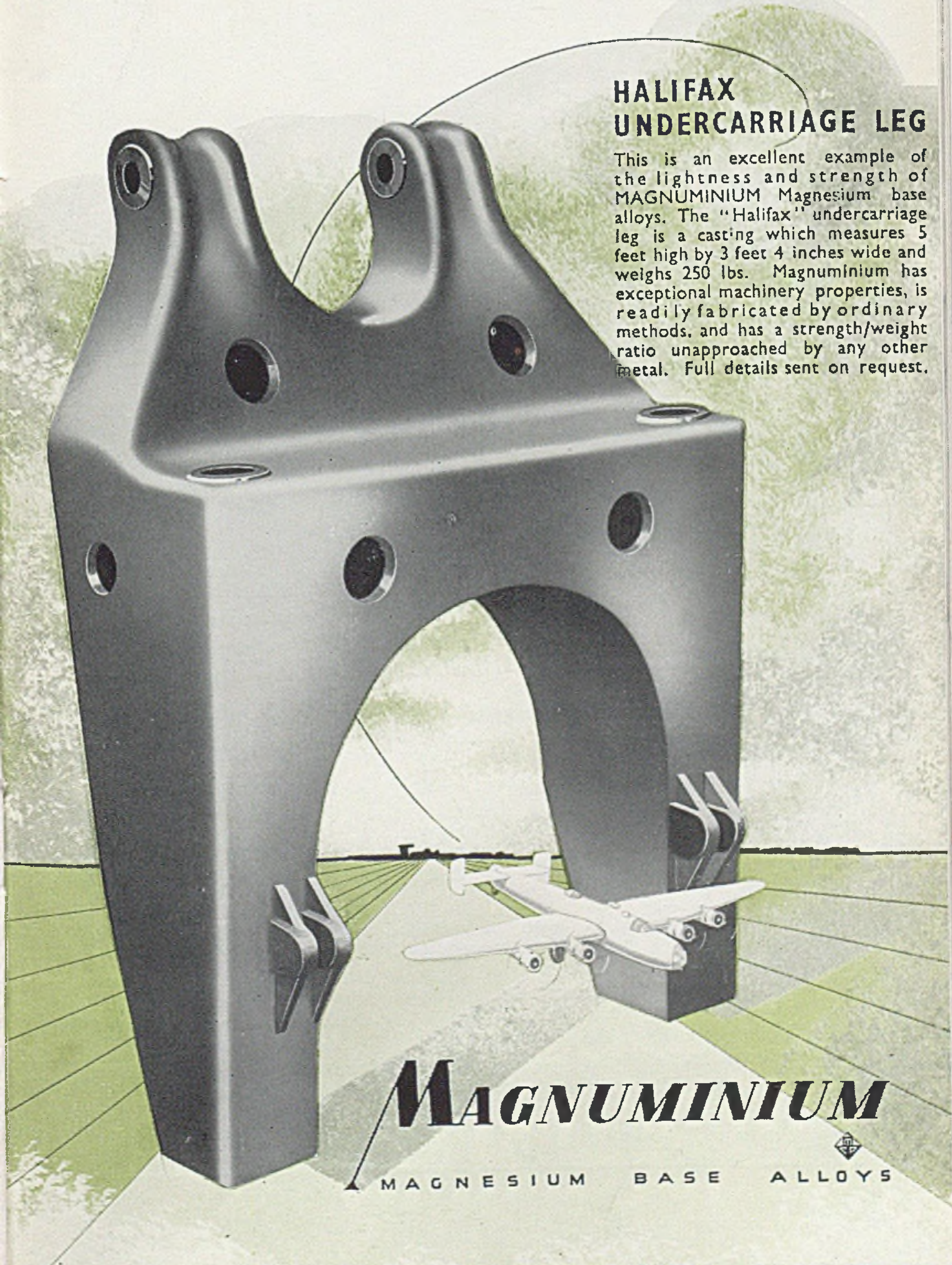
The following conclusions may be drawn from examination of Table 1 :—

(a) The high iron-low manganese alloy (44763) is very poor.

(b) There are no large differences between the remaining alloys (high Mn-low Fe (44976), high Mn-high Fe (44761), and low Mn-low Fe (44762) *in the four-day tests*, with the possible exception of the alternate immersion test on the high Mn-high Fe alloy (44761), which shows up significantly worse than the others in this group.

(c) In the longer tests, 14 to 28 days, the superiority of the high purity alloys is clearly indicated in comparing alloys 44976 and 44762 with 44761 and 44763: 0.3 per cent.

The Lightest Structural Metal



HALIFAX UNDERCARRIAGE LEG

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MAGNUMINIUM

MAGNESIUM BASE ALLOYS

MAGNESIUM CASTINGS & PRODUCTS LTD SLOUGH

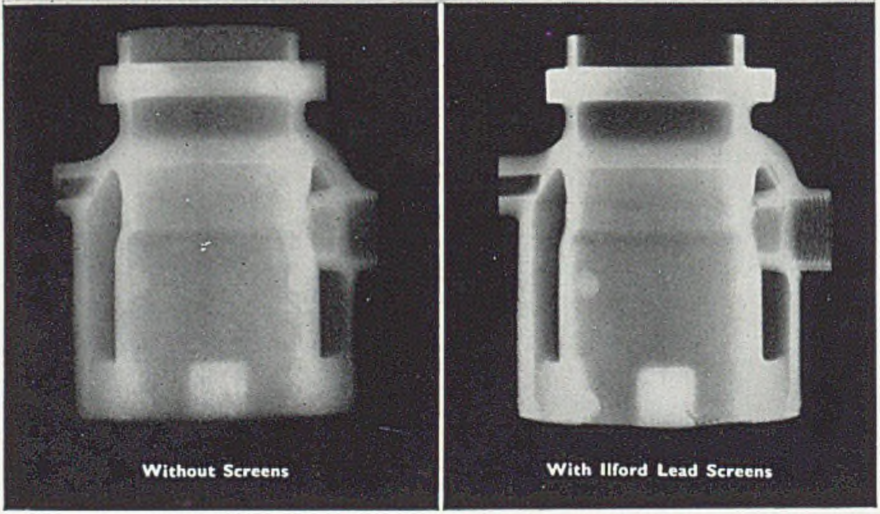
Without Screens
With Ilford Lead Screens

Table 2.—Atmospheric Corrosion Tests, Magnesium Alloys—Effect of Controlled Purity.

Alloy						Condition	Industrial*				Sea Coast†				3% NaCl Immersion	
							1 Year		4 Years		1 Year		4 Years			
Al	Mn	Zn	Fe	Ni	Cu	—	WT. Loss	% Loss T.S.	WT. Loss	% Loss T.S.	WT. Loss	% Loss T.S.	WT. Loss	% Loss T.S.	Time	% Loss T.S.
8.0	0.16	Nil	> 0.01	< 0.001	< 0.01	Cast HT	—	3.8	—	4.6	—	16.5	—	45.0	7 Days	100
10.3	0.31	Nil	0.001	0.001	< 0.01	Cast HT	—	(2 Yr.) 3.5	0.007	6.0	—	0	—	0	1 Year	25.0
6.0	0.20	3.0	> 0.01	< 0.001	< 0.01	Cast HT	—	0	—	0	—	0	—	11.8	30 Days	60.0
6.1	0.56	2.8	< 0.001	< 0.001	0.016	Cast HT	—	(2 Yr.) 4.1	0.010	6.6	0.010	0	0.02	3.9	1 Year	25.0
9.2	0.30	2.2	< 0.001	0.001	< 0.01	Cast HT	—	(2 Yr.) 0	—	0	—	0	—	3.2	1 Year	14.2
6.0	0.25	1.1	> 0.01	< 0.001	< 0.01	As Extruded	—	1.5	—	4.2	—	21.4	—	68.6	14 Days	76.5
6.0	0.58	1.5	< 0.001	0.001	< 0.01	As Extruded	—	(2 Yr.) 4.8	0.011	3.5	—	0	0.012	9.5	—	—
6.0	0.28	0.71	< 0.001	< 0.001	< 0.01	Sheet	—	—	—	—	—	4.3	—	7.1	—	—
6.0	0.50	1.5	< 0.001	< 0.001	< 0.01	Sheet	—	—	—	—	—	6.4	—	2.2	—	—

* Industrial Atmosphere: Midland, Michigan. † 80-ft. Sea Coast Station: Wilmington, N. Carolina.

Table 3.—4-Year Exposure—80-ft. Station, Wilmington, N.C.*

4 Years, 5.1.40 to 6.1.44.

	G-Cast H.T.	J-I Ext. 1.5 Zn	H-Cast H.T.	C-Cast H.T.	M+Ca Ext.	J-I Ex.	24 ST Al	53 ST Al
Symbols	KK	MM	JJ	LL	NN	PP	GG	HH
Al	9.1	5.4	5.2	7.7	0.004	5.7	—	—
Zn	< 0.10	1.6	2.8	2.2 2.3	< 0.10	0.80	—	—
Mn	0.32	0.73	0.64	0.33	1.9	0.37	—	—
Ca	—	—	—	—	0.065	—	—	—
Fe	0.001	< 0.001	< 0.001	< 0.001	0.024	< 0.001	—	Si 0.7
Ni	0.001	< 0.001	< 0.001	0.001	< 0.001	< 0.001	—	Cr 0.25
Cu	< 0.01	< 0.01	0.022	< 0.01	< 0.01	< 0.01	—	—
Mg	—	—	—	—	—	—	—	1.3
mcd corr. rate	0.008	0.012	0.02	0.008	0.009	0.012	0.012	0.0009
Surface	Mach.	Mach.	Mach.	Mach.	Mach.	Mach.	Mach.	Mach.

	G-Cast H.T.			J-I Ext. 1.5 Zn			H-Cast H.T.			C-Cast H.T.			M+Ca Ext.			J-I Ex.			24 ST Al			53 ST Al		
Original properties—																								
%E	9.1	—	—	13.4	—	—	9.6	—	—	8.5	—	—	6.0	—	—	12.6	—	—	16.9	—	—	21.8	—	—
Y.S.	—	14.6	—	—	34.9	—	—	13.4	—	—	14.3	—	—	38.5	—	—	33.2	—	—	50.0	—	—	30.8	—
T.S.	—	—	36.7	—	—	48.0	—	—	36.3	—	—	37.9	—	—	43.4	—	—	46.4	—	—	72.0	—	—	39.2
Final properties—																								
%E	9.7	—	—	9.1	—	—	9.7	—	—	9.2	—	—	1.8	—	—	9.9	—	—	14.0	—	—	20.1	—	—
Y.S.	—	16.1	—	—	33.3	—	—	14.5	—	—	15.6	—	—	34.9	—	—	32.2	—	—	49.5	—	—	30.4	—
T.S.	—	—	36.7	—	—	43.5	—	—	34.9	—	—	36.7	—	—	38.9	—	—	43.6	—	—	69.2	—	—	38.2

* Pictures of these specimens are shown in Fig. 4.

Table 4.—Composition and Corrosion Rates—Mg Alloys taken from German Aircraft[5]

Alloy	Condition	Al	Cu	Fe	Mn	Ni	Si	Zn		Corr. Rate Med.*
					Castings					
AZG	—	6.4 5.8 6.1	0.32 0.02 0.12	0.023 0.003 0.009	0.36 0.10 0.20	0.003 <0.001 0.0013	0.23 <0.01 0.12	3.1 2.3 2.7		29.0 0.3 3.7
A9	—	8.6 7.9 8.2	0.36 0.07 0.15	0.022 0.003 0.009	0.41 0.17 0.27	0.004 <0.001 0.0012	0.14 0.03 0.09	1.0 0.35 0.61		25.2 2.0 10.2
A9V	—	8.7 7.7 8.2	0.10 0.02 0.06	0.022 0.001 0.013	0.27 0.11 0.19	0.002 0.001 0.001	0.27 0.03 0.13	1.10 0.43 0.55		48.6 0.5 23.5
A9h	—	8.7	0.06	0.023	0.24	0.001	0.09	0.68		2.7
A10	—	10.5 9.1 9.7	0.16 0.04 0.10	0.015 0.001 0.007	3.32 0.19 0.25	0.001 0.001 0.001	0.18 0.04 0.11	0.75 0.49 0.64		34.2 0.4 15.9
AZ31	—	3.3 2.9 3.1	0.05 0.01 0.03	0.024 0.001 0.009	0.35 0.19 0.27	0.002 <0.001 0.001	0.07 <0.01 0.03	1.10 0.75 0.89		29.5 0.1 9.4
AZF	—	4.4 4.3	0.24 0.10	0.042 0.011	0.32 0.27	<0.001 <0.001	0.20 0.13	2.9 2.5		1.1 0.8
AZ91	—	10.2 8.6 9.4	0.32 0.08 0.21	0.014 0.001 0.005	0.35 0.18 0.26	0.004 0.001 0.002	0.60 0.04 0.20	0.84 0.63 0.72		17.8 0.8 5.4
					Wrought Products					
AZM	Forgings	7.5 6.0 6.5	0.12 0.01 0.04	0.026 0.005 0.011	0.27 0.08 0.13	0.006 <0.01 0.0015	0.10 <0.01 0.03	1.10 0.76 0.84		44.5 1.0 16.4
AZ855	Forgings	8.5 7.1 7.7	0.01 <0.01 0.01	0.016 0.001 0.011	0.21 0.11 0.15	0.001 <0.001 0.001	0.01 0.01 0.01	0.31 0.30 0.31		32.0 0.3 14.1
AZM	Extrusion	6.1 5.6 5.9	0.07 0.01 0.03	0.014 0.006 0.010	0.35 0.10 0.19	— <0.001 <0.001	0.06 0.02 0.03	0:95 0.76 0.91		7.3 0.2 2.2

* 1 to 4 Weeks Test depending on Corrosion Behaviour. Alternate immersion 3% NaCl

Mn did not counteract the effect of 0.02 per cent. iron as contended by Fox and Bushrod, since corrosion rates for this alloy (44761) are 10 to 100 times as high as the controlled purity alloys, even when the latter alloys contained Mn as low as 0.06 per cent. as in alloy 44762.

Table 4 presents the analyses and corrosion rates of a series of cast and wrought magnesium alloys which were taken from a German Messerschmitt Me 110 and a Junkers Ju 88 aeroplane and examined and tested in the laboratories of the Dow Chemical Co.[5] Only the data on Mg-Al base alloys have been included. These samples are of interest, as they illustrate a variety of alloys with low and high manganese and iron content. It is also very significant that, although they show in many cases high iron, copper or nickel, and high salt-water corrosion rates, none of these parts appeared to be significantly corroded after their normal usage and exposure.

They further illustrate the main point of this discussion—that if the impurities (iron, copper and nickel) be low, then salt-water corrosion rates are good regardless of the manganese content, and, conversely, if the impurities be high, then the salt-water corrosion rates are relatively high even if the manganese is also high.

Many of these alloys are particularly

poor in corrosion due to high copper content. In this connection, the action of 3 per cent. zinc to modify both high iron and high copper is well illustrated.

Conclusions

In so far as Fox and Bushrod and Hanawalt, Nelson and Peloubet cover the same ground, there does not appear to be any difference in experimental results. The differences come about in the interpretation of the data. From the data and discussion presented, we draw the following conclusions:—

1. The *salt-water corrosion resistance* of common magnesium alloys is primarily determined by the presence of impurities, particularly iron, nickel, copper and silicon, in amounts in excess of or less than the tolerance limits for each impurity in the particular alloy, as outlined in the earlier paper of Hanawalt, Nelson and Peloubet. If the impurities are less than their respective tolerance limits, the corrosion rate after a one- to four-month test in 3 per cent NaCl will be of the order of 0.2 mg./cm^2/day or less. If any of the impurities substantially exceed the tolerance limits, then the corrosion rates will be from 10 to 100 times that of the controlled purity alloys, depending on the alloy composition.

2. High manganese (0.2 per cent. or over) or high zinc greatly modify the bad salt-water corrosion effect of high impurity containing alloys. This has long been recognized and is here again demonstrated.

3. The four-day corrosion test as used by Fox and Bushrod is not of sufficient duration to distinguish between alloys of low corrosion rates and those having fairly low starting rates, but which rapidly increase with time.

4. Compositions containing high iron and high manganese (e.g., 0.3 per cent.) of the type stated by Fox and Bushrod after four-day tests to be equivalent in corrosion resistance to high purity alloys have many times the corrosion rate of high purity alloys when subjected to the longer tests of the present authors.

5. It has been shown that the usual heat treating or heat treating and ageing has no significant effect on controlled purity alloys. In the case, however, of high iron Mg-Al-Mn alloys, even with 0.3 per cent. Mn, the corrosion rates became high after heat treating or ageing to the extent that they showed up badly on the four-day test and were completely disintegrated at the end of 14 days.

6. The four-day test showed no important corrosion rate differences between alternate immersion and constant immersion.

7. No significant differences in corrosion rates were noted between constant immersion tests made in buffered (pH 10.2) and unbuffered salt solutions.

8. No important differences were noted between corrosion rates of chill and sand castings.

9. There is no dependable correlation between salt-water corrosion test results and behaviour of magnesium alloys in ordinary atmospheres. Salt-water tests correlate in direction with the results of severe saline atmospheric exposures.

10. Common magnesium alloys are highly resistant to atmospheric attack, showing only small weight losses and negligible loss in properties even after years of exposure.

11. In atmospheric exposure, the effects of alloy composition or purity only show up, at least in terms of weight loss or property loss, when the atmosphere is sufficiently moisture or salt-water laden to cause local electrolytic attack.

Discussion

The main discrepancies between the results or, rather, conclusions of Fox and Bushrod as compared to Hanawalt, Nelson and Peloubet may all be traced back to the assumption by Fox and Bushrod that the 0.5-1.0 mg/cm^2/day corrosion rates they were obtaining *on four-day* tests were the equivalent of 0.2 rates obtained by Hanawalt, Nelson and Peloubet in longer time tests (usually 112 days). The four-day test, however, was too short to develop the corrosion characteristics of the specimen, and, as has been shown by data presented here, two alloys might appear to have the same corrosion rate when measured after four days in 3 per cent. NaCl, yet diverge, because of their different characteristics, to corrosion rates of 0.2 and 10 or 20 respectively at the end of a four-week test. The early paper of Hanawalt, Nelson and Peloubet might be criticized to some extent for failure to point out the significance of time; however, the later paper by Hanawalt and McNulty[6] specifically studied the corrosion as a function of time and gave the corrosion rate in terms of hydrogen evolution during the early stages of corrosion and up to 20 days.

Even the high purity alloys shown by Fox and Bushrod contain iron (0.004 per cent. Fe or over) in excess of the iron tolerance limit, and would not be expected to give corrosion rates of 0.2 mg/cm^2/day if tested for two weeks or over in 3 per cent. NaCl solution. Similarly, it has been pointed out that the nickel content is too high to permit the intended comparison of iron effects in Figures 1 and 2 in the most recent Fox and Bushrod paper.[13]

The written discussion given in connection with the Fox and Bushrod paper by Messrs. Crowther,[7] Liddiard[8] and LeBrocq[9] are of considerable interest. In addition to information elsewhere in this paper bearing on this discussion, it is desired to make a few further comments.

Whilst it is true that the largest number of samples dealt with in the original Hanawalt, Nelson and Peloubet paper were necessarily prepared with distilled magnesium as a base, many alloys both large and small had at that time been made from commercial purity magnesium and alloying materials by iron precipitation processes already known at that time and described in the literature.[10, 11, 12] An iron precipitation process involving treating the molten alloy with an excess of manganese is commonly used. This results in alloys that are always saturated with manganese at the temperature of pouring. No significant differences in corrosion rate have been noted between alloys prepared from commercial materials in this manner and those prepared from all pure materials provided, of course, that impurities are within the tolerance limits.

Since about 1941, the largest proportion of all magnesium-wrought alloys in the United States has been produced in the controlled purity type. These would meet the tolerance limit requirements set forth by Hanawalt, Nelson and Peloubet, even though the tentative specifications, as has been pointed out, would allow compositions outside those limits.

With respect to carrying higher manganese in common magnesium alloys, it has been stated that the manganese-treated wrought alloys in the United States are already saturated with manganese. In the casting alloy field, minimum specifications for manganese exist on all the alloys, and considerable trouble in foundries already arises in meeting these minimum values due to the limited solubility of manganese and the resulting tendency to settle out. Typical manganese values are, however, moderately high, running about 0.21 per cent. for H alloy (Mg-6Al-Mn-3Zn) and 0.18 per cent. for C alloy (Mg-9Al-Mn-2Zn). Even if high manganese accomplished the same results as does controlled purity, there are magnesium alloys for which high manganese is either impractical or undesirable for other reasons.

The justifiable criticism has been made that the Hanawalt, Nelson and Peloubet paper did not make clear why most, if not all, of the data were obtained on " as cast " metal. The premise on which this choice was made is clearly brought out in the present paper, but, unfortunately, was, through oversight, left out of the earlier work. The experimental result is that, whilst AC, HT and HTA states have large differences in salt-water corrosion rates if Fe is high, corrosion rate is independent of state for high purity Mg-Al-Mn alloys. This statement applies to heat treatments for Al solubility or precipitation as used in the present paper. Heat treatments at an entirely different temperature may provide another result.

With respect to the atmospheric data presented by Fox and Bushrod, the following comments are offered:—

1. Based on long experience with atmospheric exposure tests, it is felt that any time less than a year or two is far too short to show any dependable trends.
2. Weight loss data are also of questionable utility in atmospheric exposure evaluation. Most such data are presented in terms of percent. loss in tensile strength. The weight loss figures given by Fox and Bushrod would all be considered to be in the same scatter band with the exception of the one point at about 0.001 to 0.01 per cent. Mn.

In view of these considerations, the conclusion that atmospheric data indicate the need for high (0.2 per cent.) Mn seems unsound. The idea is not without merit, however, and the results of long-term tests would be anticipated with interest.

Summary

The significant factors concerning the corrosion behaviour of magnesium alloys are suggested in the following paragraphs:

Common magnesium alloys, regardless of their purity, are extremely resistant, even when unprotected, to the corrosion attack of ordinary atmospheres. When painted and protected in the recommended manner, they will show negligible change in appearance or properties after 10 years' atmospheric exposure.

If maximum resistance to salt-water corrosion, either in the form of coastal or shipboard atmospheres or direct immersion, be required, it is desirable to control the purity of the alloys to within the tolerance limits outlined in the earlier paper of the authors. If the alloys be of controlled purity, there is no harmful effect in the usual heat-treating or ageing procedures.

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ABSTRACTS.

[*] Alternate immersion tests in 3 per cent. aqueous sodium chloride solution were used to study the corrosion resistance of very pure (99.98+ per cent.) magnesium, and alloys with aluminium, magnesium, zinc, iron, nickel, copper, silicon and lead, singly and in various combinations. Pure magnesium is very resistant to salt-water corrosion, and this resistance is little affected by amounts of iron up to 0.017 per cent, but greater amounts of iron produce enormous increase in the corrosion. This "tolerance limit" is greatly affected by the presence of other elements, thus with 7 per cent. aluminium the tolerance limit for iron is only about 0.0005 per cent. Similar tolerance limits are found for nickel and copper, and are not connected with the solid solubility limits. An electro-chemical theory is advanced in evolving the conception that increased corrosion occurs when a critical concentration of cathodic particles is reached. An appendix is detailed of spectro-chemical methods of analysis.

[†] Magnesium alloys of the chemical composition required by D.T.D. specification 59A have been examined for corrosion-resistance. The specimens were in the form of cylinders machined from ingot and were in three different structural states: as cast, solution treated, and fully heat-treated. The samples had approximately constant aluminium (8 per cent.), zinc (0.5 per cent.), and manganese (0.25 per cent.) contents and carried varying iron contents down to 0.001 per cent. The nickel content of all specimens was 0.0022 per cent. or less. It has been found that where, as in this case, the manganese is in the range 0.20—0.30 per cent. variations in the iron content have no appreciable effect on the results of either atmospheric tests or total-immersion tests; this applies to all three structural conditions and to the alloys of very low iron content. It has been found that material in the solution-treated condition corrodes faster than that in other states when tested by complete immersion, irrespective of the iron content; under conditions of atmospheric exposure, however, the material in all three structural states shows similar corrosion-resistance. Possible reasons for this difference in behaviour under the two conditions of test are discussed.

Light Alloys in Structural Engineering

Concluding from "Light Metals," September, p. 468, an Account After Koenig in "Technische Rundschau," Nos. 32 and 33, August 4 and 11, 1944. Attention is Directed Particularly to the Illustrations Showing Valuable Application of Extruded Sections in Transport Engineering

TEMPERATURE limitations with respect to the use of light alloys clearly restrict their use in such fields as steam-turbine construction or for the more highly stressed parts of gas turbines; neither their corrosion resistance nor abrasion resistance are suitable for such purposes as these. However, in contrast to structures designed for use at high temperature, those designed for operation at moderately low or even extremely low temperatures can frequently make good use of light alloys. Thus, in the refrigeration industry and in transport designed for operation in polar regions or in the stratosphere, aluminium alloys offer great promise.

The peculiar properties conferred upon the massive metal by the naturally occurring oxide film which is always present may be considered in conjunction with the behaviour of aluminium at high temperatures. At one time, this thin film of alumina, the melting point of which lies somewhere above 2,000 degrees C., constituted the greatest hindrance to the development of a satisfactory gas welding technique. However, in another direction, the artificial thickening of the film by anodic oxidation has led to developments of the greatest technical importance, and has furthered the structural use of light alloys to no small extent. Thus, the anodic film may function not only as a purely decorative device,

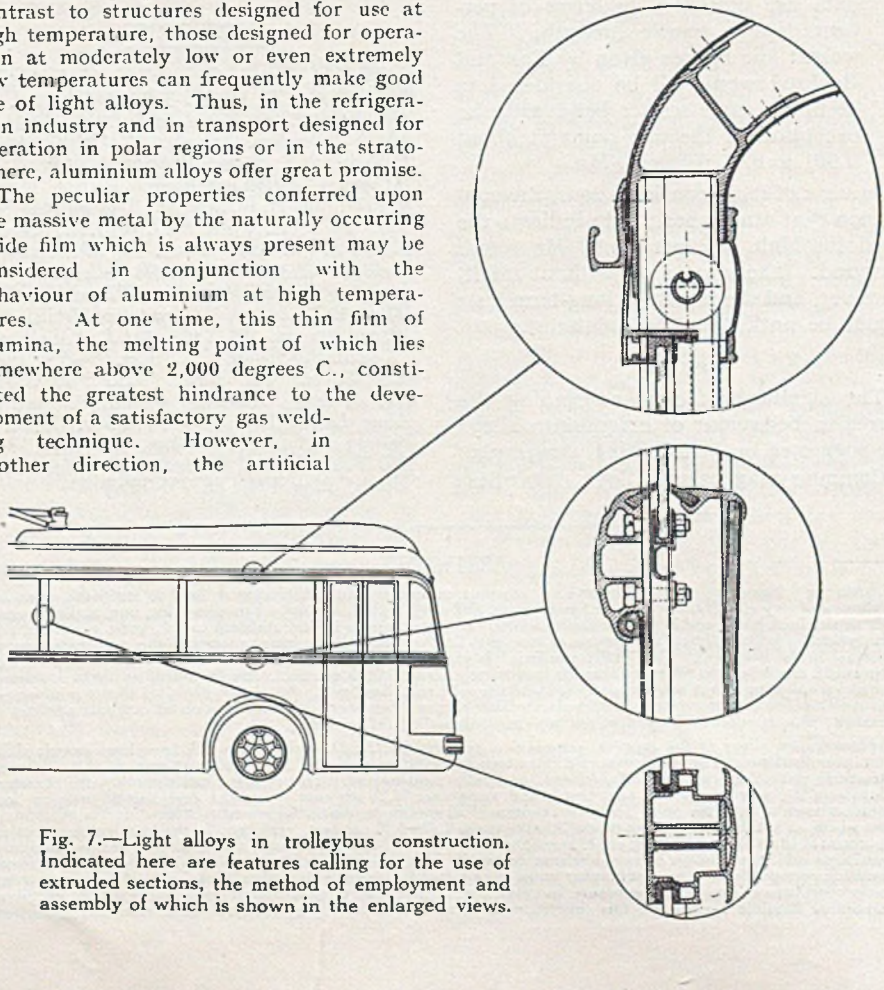


Fig. 7.—Light alloys in trolleybus construction. Indicated here are features calling for the use of extruded sections, the method of employment and assembly of which is shown in the enlarged views.

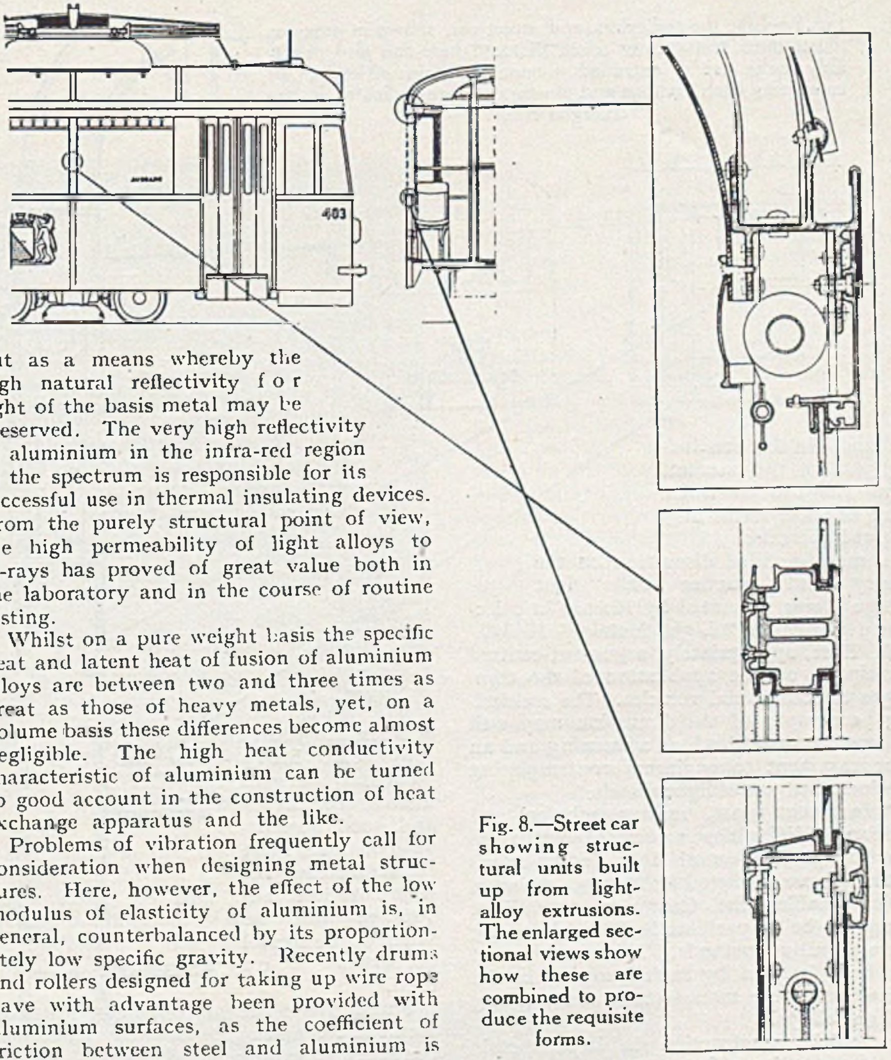


Fig. 8.—Street car showing structural units built up from light-alloy extrusions. The enlarged sectional views show how these are combined to produce the requisite forms.

but as a means whereby the high natural reflectivity for light of the basis metal may be preserved. The very high reflectivity of aluminium in the infra-red region of the spectrum is responsible for its successful use in thermal insulating devices. From the purely structural point of view, the high permeability of light alloys to X-rays has proved of great value both in the laboratory and in the course of routine testing.

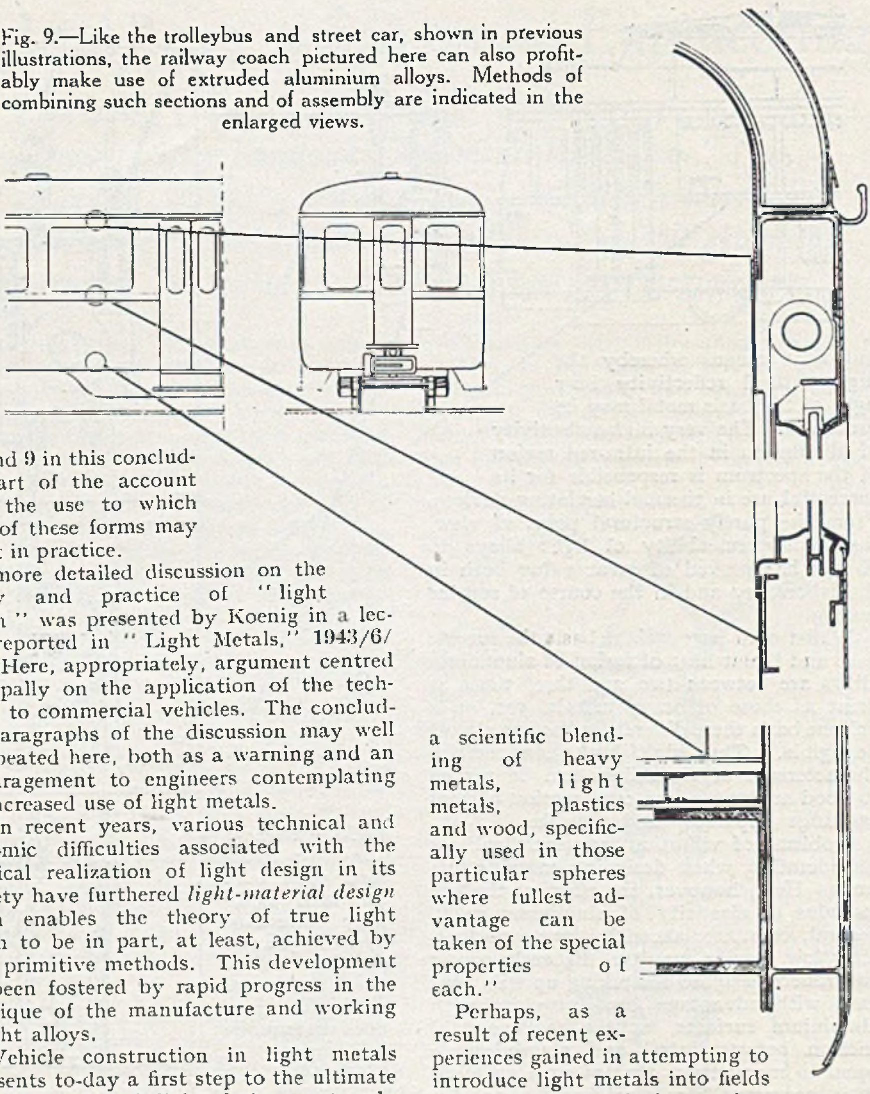
Whilst on a pure weight basis the specific heat and latent heat of fusion of aluminium alloys are between two and three times as great as those of heavy metals, yet, on a volume basis these differences become almost negligible. The high heat conductivity characteristic of aluminium can be turned to good account in the construction of heat exchange apparatus and the like.

Problems of vibration frequently call for consideration when designing metal structures. Here, however, the effect of the low modulus of elasticity of aluminium is, in general, counterbalanced by its proportionately low specific gravity. Recently drums and rollers designed for taking up wire rope have with advantage been provided with aluminium surfaces, as the coefficient of friction between steel and aluminium is equal to many times that of steel on steel. It is necessary here, incidentally, to distinguish carefully between an application of this type and one involving direct rubbing contact between normal aluminium alloys and other metals or light alloys; this should be avoided. It is also necessary to recall that where low coefficients of friction are desired, as for example, where steel shafts are to run directly against light alloy, then special compositions have been developed.

The precautions which must be taken in aluminium structures to guard against bi-metallic corrosion are well known; they usually involve the use of an inert layer between the two contacting faces concerned, or the employment of some medium for surface protection.

Very briefly we have presented here, in outline, certain of the fundamental factors governing the successful adoption of light alloys for engineering structures. It remains in conclusion to comment on the available forms in which the metal may be purchased for use; in this regard extruded sections claim chief attention. Figs. 5 and 6 on pages 467 and 468, respectively, of the September issue of "Light Metals," illustrate some possibilities in this regard. Figs.

Fig. 9.—Like the trolleybus and street car, shown in previous illustrations, the railway coach pictured here can also profitably make use of extruded aluminium alloys. Methods of combining such sections and of assembly are indicated in the enlarged views.



7, 8 and 9 in this concluding part of the account show the use to which some of these forms may be put in practice.

A more detailed discussion on the theory and practice of "light design" was presented by Koenig in a lecture reported in "Light Metals," 1943/6/514. Here, appropriately, argument centred principally on the application of the technique to commercial vehicles. The concluding paragraphs of the discussion may well be repeated here, both as a warning and an encouragement to engineers contemplating the increased use of light metals.

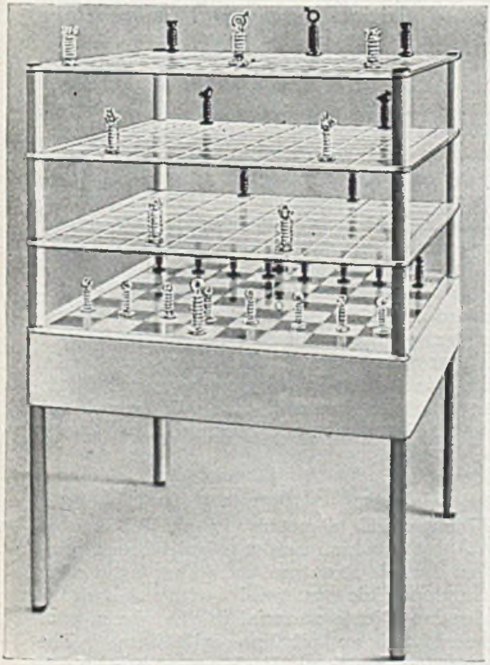
"In recent years, various technical and economic difficulties associated with the practical realization of light design in its entirety have furthered *light-material design* which enables the theory of true light design to be in part, at least, achieved by more primitive methods. This development has been fostered by rapid progress in the technique of the manufacture and working of light alloys.

"Vehicle construction in light metals represents to-day a first step to the ultimate attainment of real light design, not only because of the saving in deadweight effected, but also as regards the simplification in production and handling which aluminium and magnesium alloys have made possible. Where heavy metals have reached their limit in light design, then light metals come into the picture, to extend the evolutionary process.

"Finally, it should be realized that the light vehicle, whether the outcome of light design pushed to the limit demanded by theory, or attained in compromise by the use of light alloys, will be the resultant of a scientific blending of heavy metals, light metals, plastics and wood, specifically used in those particular spheres where fullest advantage can be taken of the special properties of each."

Perhaps, as a result of recent experiences gained in attempting to introduce light metals into fields hitherto considered the particular preserves of the heavy ferrous metals, emphasis must be laid on the need for assuring that all mechanical-properties data are up to date when considering the adoption of aluminium alloys. Older reference books, still accepted as standard works by many branches of structural engineering, are often hopelessly inadequate and misleading in this respect, and final decisions should always be based on information obtained from, or confirmed by, the appropriate departments of the light-alloy producing or fabricating concerns.

NEWS—General, Technical and Commercial



CHESS table for "quadrivalent total chess," according to the system developed by Charles Beatty. Designed and constructed by J. Starkie Gardner, Ltd., it is built in aluminium and Perspex.

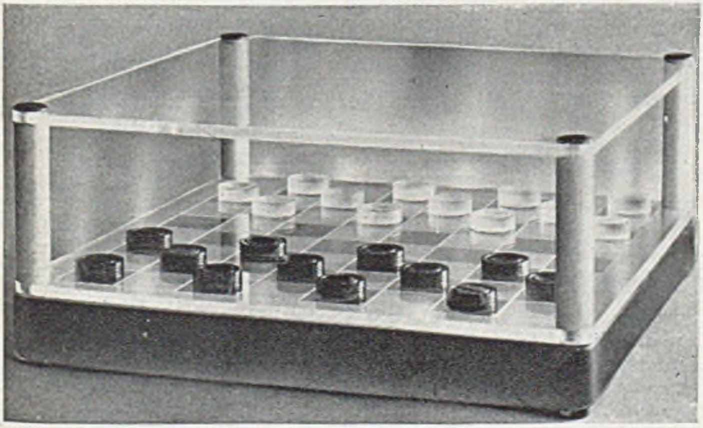
Total Chess

SHOWN here are views of boards for quadrivalent total chess and total draughts, according to the system devised by Charles Beatty, of Trelydan Hall, Welshpool, Mon.

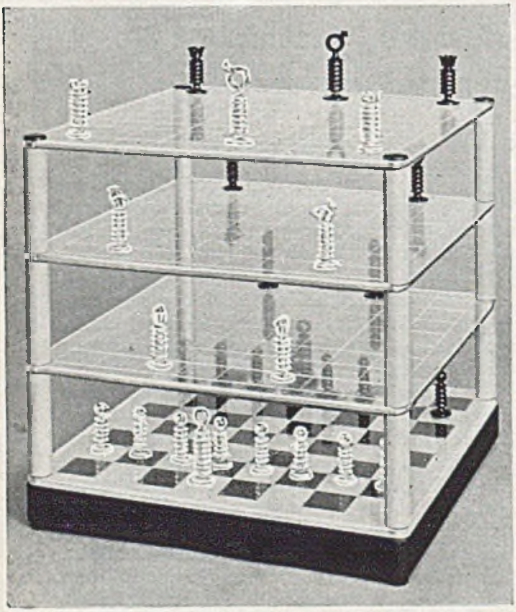
The board at the left, designed and constructed by J. Starkie Gardner, Ltd., consists, as may be seen, of a base built up of accurately machined aluminium squares alternately anodized to present a clear metallic surface and a black dyed finish. These squares are held together in an aluminium frame and are mounted on a heavy aluminium baseplate; their upper surface is covered with a sheet of clear Perspex. Superimposed above the squares are two or three sheets of heavy Perspex, accurately engraved into squares corresponding to those on the board; these subsidiary "planes" are located by means of four corner posts consisting of a through-rod passing through appropriate holes in the Perspex sheet, spacing being by means of tubular aluminium sleeves.

The chess men shown here were made by J. Starkie Gardner, Ltd., from a special design of Ralph Lavers. They are machined from solid Perspex left respectively clear and chemically finished in a black dye, the stem of the chess men is finished matt, base and head being polished.

The board is made with standard 1½-in. squares or in club size with 2¼-in. squares.



BOARD and men for "total draughts," according to the system of Charles Beatty. Like the chess table shown above, this set was designed and constructed in aluminium and Perspex by J. Starkie Gardner, Ltd.



FURTHER example of chess-board for "Quadrivalent total chess" by J. Starkie Gardner, Ltd. Materials used are, again, Perspex and aluminium. The men, designed by Ralph Lavers, are in clear and black-dyed Perspex.

We understand that printed rules for these games will shortly be made available by Mr. Charles Beatty. Incidentally, they show no radical departure from those applying to normal two-dimensional chess.

The lower illustration on the preceding page shows a board and men for "total draughts." Like the chess-boards, the former, built up of aluminium and Perspex, is the work of J. Starkie Gardner, Ltd. We are assured by Mr. Charles Beatty that "three-dimensional" draughts is, essentially, no more difficult to play than the normal game.

Welded Pontoon Bridge

JUST before the end of the Pacific War, the U.S. Army had approved fabrication of an aluminium pontoon bridge by welding with the atomic-hydrogen process, and also use of the more recently developed inert-arc, a.c. process without flux. Whilst the bridges are not likely to be built now, the approved method of fabricating is a step towards more welding of aluminium structures in peace-time.

The pontoon bridge consisted of a series of baulks or hollow square beams of aluminium alloy, light enough to be placed by hand, but strong enough to bear 50-ton loads. The beams lock together with pins and form a flooring which rests on pontoon boats. Original specifications for the baulks or beams required automatic carbon-arc welding on longitudinal seams, two seams being required to make a box section from two extruded channels of light alloy. Samples of atomic-hydrogen and inert-arc, a.c. welding were made up at the Copco Steel and Engineering Co. by G.E. engineers and submitted to the Army Engineer Board. The inert-arc process received approval for making manual closure welds on the ends of the baulks.

It is claimed that use of either the atomic-hydrogen or inert-arc process will produce higher quality welds and better contours at higher speeds, and costs will be lower. In the case of the inert-arc, a.c. process, it is argued that time and cost will be reduced by the elimination of flux and usual pickling.

New Synthetic Stone

GRANTED a patent in the U.S. is a process which claims to produce a strong and durable structural substance by mixing alumino-silicic material with anhydrous alumino-silicate material in the presence of water and an alkaline-earth base. The patentees are Paul W. Jones and John W. Swezey, of Lafayette, Ind., who were granted Patent numbers 2,382,154 and 2,382,155 and assigned them to the Rostone Corp. of Lafayette.

The patents refer to the resulting substance as "stone." Solid materials in the formula are all finally divided in the process and only a moist heat treatment is claimed to be necessary to agglomerate the particles into the final conglomerate.

In Search of Aluminium

IT will be recalled that in the account entitled "In Search of Aluminium," which appeared in the September issue of "Light Metals," an outline was given of the present status of light alloys in France. Since then, further details have come to light. For example, at Chambéry, a school has been built for technical instruction in the working of light metals in industry. The course given here is intended to direct apprentices and young engineers into that branch of their profession most suited to their particular personal ability.

Aluminium—War to Peace

THE "Aluminium Kitchen Quiz," organized by A.D.A. in connection with the recent showing of the Aluminium Exhibition at Selfridges, London, has provoked the following commentary:—

"Looking through the August issue of 'Light Metals' in which my company is an advertiser, my attention was suddenly stopped by the article 'Aluminium Kitchen Quiz.' The article seemed of such interest that I took it home for my wife to read as we both of us are very interested in cooking, both English and Continental, and due to war-time domestic difficulties spend much more time in the kitchen than normally—probably to our great amusement.

"One point seems to have been completely overlooked in the article. It appears to be a universal wish that both saucepans and frying pans have a lip for pouring, but nothing has been said about the efficiency of this spout or lip for clean pouring. So many, even good quality pans, have lips that appear to be just a dent in the side which almost invariably will not pour properly. I have in mind a very good quality saucepan at home made of really heavy-gauge metal, flat-bottomed, with a lip at both sides which would only pour cleanly a very small stream of liquid. The slightest increase in volume immediately gives you a flood running down the outside of the saucepan. It would appear that the designing of a lip to pour cleanly under all reasonable conditions is a matter for great care and accuracy. This bad pouring facility is trouble enough with a saucepan containing ordinary liquids, but can be disastrous with hot fat from a frying pan.

"Secondly, all pans should have a really flat bottom, not necessarily machined to the degree of precision required for electric stoves, but at least approaching this standard. Modern gas stoves have a circular removable metal plate usually found over the griller. The full use of the waste heat from the griller can be made only if the bottom of the saucepan is flat and makes good contact with the metal plate.

"Thirdly—insulated plastic handles are essential. Those indicated in the sketches in some cases appear to be too long. In the case of small vessels sufficient for one hand to grip is all that is needed, but in the case of big frying pans and big saucepans the handles should be just long enough for a comfortable two-hand grip.

"Fourthly—kettles. The opening for filling should be large enough for the insertion of the hand. In districts where water is hard a considerable amount of 'fur' rapidly accumulates, and being heavy this is not the easiest thing to tip out. The question of refilling a kettle just used and the liability to scalding the hand from escaping steam from the body can perhaps be lessened by placing the opening and lid as far back as possible from the spout, and having the handle with a three-point support, more or less Y-shaped, a single leg being over the spout and the two remaining legs widely dispersed at the rear. This gives free access to the opening for the tap and carries the steam away from the hands. The steam escape hole or whistle can also be fitted right at the back.

"Finally—an article not mentioned in the Quiz, i.e., the triangular sink basket. I have seen this made of almost every material possible, from enamel ware to plastic, and every one that I have seen has the same fault. All of them have a number of fair-sized holes in the bottom, sometimes artistically arranged in pretty patterns, but not one of them has a hole *right in each of the three corners*. The result is that when the basket is drained previous to emptying the contents into the dustbin a teaspoonful or more of water remains in the pocket at the corner between the walls and the nearest hole."—W. G. CULLEN, Deputy Managing Director, Photostat, Ltd.

The Light-alloy Motorcar

THE subjoined abstract from the U.S. periodical, "Automobile Topics," June, 1945, indicates that the motor industry in America is likely to pay increased attention to light alloys:—"Aluminium 'Come-back' is a strong possibility for the near future. Four years ago the price was around 20 cents per lb., but increased production for war has reduced the price of ingots to about 15 cents and pig aluminium to 14 cents per lb. to-day, with corresponding reductions in price of fabricated products. In the automotive industry, aluminium has been used at various times for cylinder blocks and heads, pistons, crankcases, transmission cases, fenders, hoods, body panels, and structural shapes and sheets for bus and truck bodies and tanks. All of these uses may be revived and expanded, with lightweight Diesel engines offering an additional field for development."

Mistakes Aid Reconversion

BY the use of what was labelled "commercial-grade" aluminium, a wide range of manufacturers in the U.S. were enabled to reconvert to civilian production before top grade light metal could be released from war. The metal concerned consisted of sheet made for aeroplane fuselages and wings, but rejected by the Army or the Navy because of certain surface imperfections. This was disposed of to plants which had received cutbacks or cancellations of war contracts before the war's end and were able to reconvert to civilian output, but needed raw materials.

The result was that a considerable quantity of this *commercial-grade* aluminium began going into products such as chairs, burial caskets, meter boxes, frying pans, steak platters, cookie sheets, casseroles, dustpans, metal awning frames, costume jewellery, cake covers and pancake turners.

Aluminium Coaches and Trams in U.S.A.

WITH the object of reducing operational and maintenance costs and at the same time improving appearance, ACF-Brill Motors Co., Philadelphia, Pa., has brought out a line of aluminium-alloy buses and tramcar bodies. The body and underframe of the new bus are almost entirely of high-strength extruded aluminium alloy I-beams or structural shapes. Body posts are flanged extrusions of aluminium alloy and the side and panels are of aluminium sheet with riveted construction. Lower edge of each side of the bus is reinforced against damage by an extruded aluminium section which also adds stiffening to the body skirt. Aluminium is also used for many of the fixtures inside and for the extruded frames of the windows and the baggage racks.

In Chicago, Ill., the Travelite Trailer Co. has designed a new automobile trailer for family use which is claimed to save 600 to 700 lb. of weight by wide use of aluminium in the construction. Aluminium is used extensively in the body and frame and for interior fittings. The "Homette," as the trailer is named, contains three rooms, nine windows and a complete built-in kitchen and sleeping quarters for four persons.

Plastics Assist Aluminium

AN interesting example of co-operation between plastics and aluminium mentioned in Alco Newsletter is found in the design of a new type of fluorescent lighting unit, using a patented axial-plane mounting of lamps.

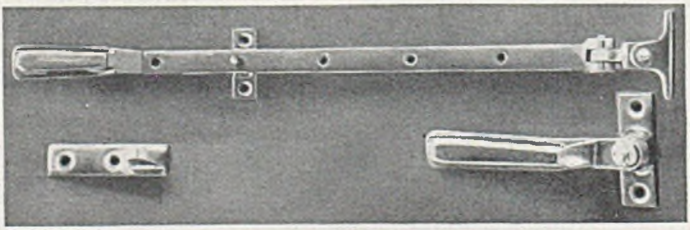
This involves the placing of one lamp in front of the other rather than in the conventional horizontal arrangement. The light from each lamp is thus reflected symmetrically from a smaller reflector. Aluminium specular reflectors are used, giving a combination of permanence and high reflectivity, while a louvred, laminated, cellulose acetate sheet is used as a shielding to prevent glare.

B.E.M.A. EXHIBITION

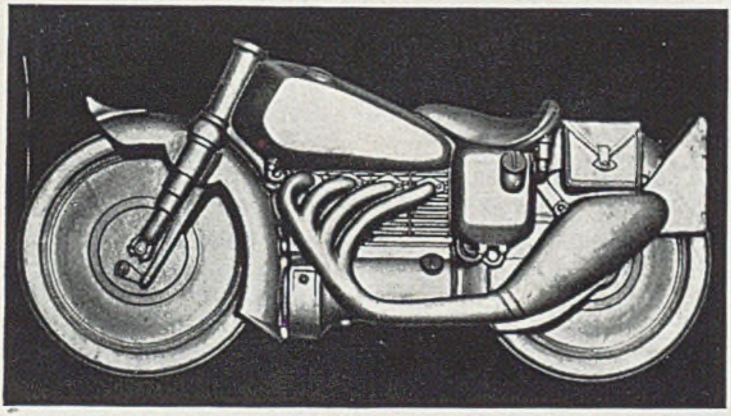
NOTABLE amongst the items shown at the exhibition recently organized at the Victoria Rooms by the Bristol Engineering Manufacturers' Association were those which, in various forms, made use of aluminium and magnesium alloys.

Magnal Products, Ltd., of Warmley, showed on its stand a variety of light-alloy castings in aluminium and magnesium produced by the sand, gravity and pressure methods. Of particular interest were sand castings simulating in appearance side views of motorcycles, tanks and jeeps. These castings, which are depicted in accompanying illustrations, form part of the assemblies which, ultimately, are to figure among the apparatus in an up-to-date amusement park.

We are given to understand by Mr. Frank Hawtin, for whom they were made, that children of to-day are no longer satisfied with conventional roundabout horses, chickens and the like, but demand objects more in keeping with this mechanized age. We were further told that broad accuracy in outline and equipment is very



SPECIMENS of window furniture cast in light alloy by Magnal Products, Ltd. These items are polished and finished in natural aluminium colour.

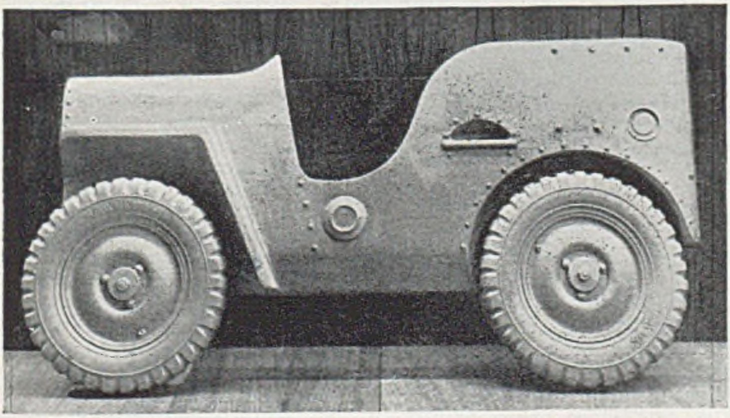


PICTURED at the left is part of a "motorcycle" assembly cast in light alloy for Mr. Frank Hawtin by Magnal Products, Ltd. It is designed for incorporation into the equipment of a Fair.

RIGHT. Another example of modern Fun-Fair apparatus; side casting for "tank" produced by Magnal Products, Ltd., for Mr. Frank Hawtin.

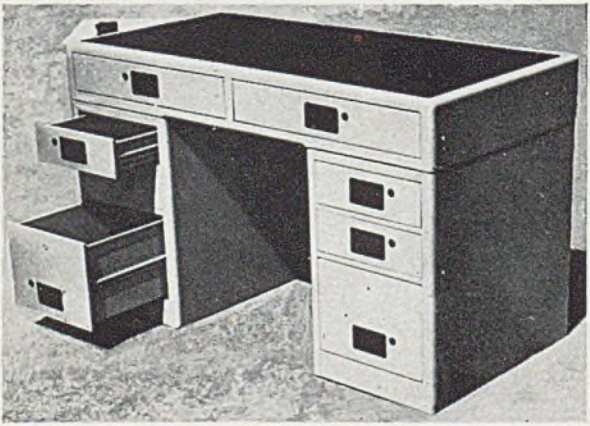
essential, as children will not tolerate any obvious inaccuracies.

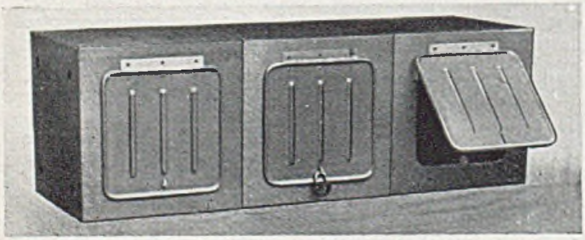
A further exhibit on the stand was a small group of window furniture in cast light alloy, finished in the natural colour of the metal. Particularly striking were one or two castings designed to illustrate the possibilities of a new lacquer finish developed by Magnal Products, Ltd. The colours—eau-de-nil, venetian red and chrome yellow—possessed notable "warmth" and "depth," and would seem to have particular value for interior decorative effects. The lacquers are, furthermore, excellent



SHOWN at the left, and analogous to the castings given above, is the side of a "jeep," a further unit to be incorporated by Mr. Hawtin into his Fun Fair. This casting, and the others on this page, are about 50 ins. long and weigh some 30 lb. each.

AT the left is shown a combined secretaire and chest of drawers fabricated in light-alloy sheet by E.S.S., Ltd. The same model with flap and drawer open is pictured at the right. Immediately below is a pedestal desk of conventional form, built up entirely of light-alloy sheet, whilst the bottom illustration shows a dirty-kit locker, also in light-alloy sheet, designed on severely utilitarian lines for ship's use.





surface protective media against corrosion. Another panel showed small samples of M.G.2 sheet anodized and dyed in a range of pleasing shades.

Bristol Metal Spraying and Welding Co., Ltd., again, amongst numerous other exhibits, showed one of particular interest: this was a knife roll in R.R.56. Designed originally to run with light-metal journals in direct contact with bronze bearings, it was found, in practice, that seizing occurred very readily. The journals of the roll were, therefore, cut back and faced with high-carbon steel applied by spraying. In this way, perfectly satisfactory running was achieved. Incidentally, one such knife roll was found in a building severely damaged by fire as a result of enemy action. It had been partly fused and, on examination, it was found that the light metal had run from the journal, leaving the high-carbon-steel facing annulus still intact.

Philpott and Cowlin, Ltd., of Victoria Street, Bristol, showed amonst its exhibits sand and die castings in Alpax. Amongst other exhibitors were Aero Engines, Ltd., on whose stand was shown a new Douglas transverse twin motorcycle. Bristol Aeroplane Co. showed its Hercules 14-cylinder sleeve-valve radial engine; this unit develops over 1,650 b.h.p.

E.S.S., Ltd., of Feeder Road, Bristol, showed, amongst their many exhibits, a combined secretaire and chest of drawers, a pedestal desk and a dirty-kit locker, all fabricated in light-alloy sheet. Detailed specifications for these are as follow:—

Combined secretaire tallboy and chest of drawers.

Mainly constructed of 18 S.W.G. L.16 aluminium.

Overall dimensions: 2 ft. 9 ins. by 1 ft. 9½ ins. by 5 ft. 4 ins.

Approximate weight: 126 lb.

Finish grey, stove enamelled.

Plastic handles and catches; black lino inlay on writing table.

(This item is made in three built-up sections to permit of easy passage through hatches and bulkhead openings. For use on shore establishments, it could be made in one-piece construction.)

Pedestal desk.

Mainly constructed of 18 S.W.G. L.16 aluminium.

Overall dimensions: 4 ft. 0½ in. by 2 ft. 0½ in. by 2 ft. 6 ins.

Approximate weight: 105 lb.

Finish grey, stove enamelled.

Plastic handles and catches; black lino inlay on top.

Dirty-kit locker.

Comprising one to five compartments, each measuring a cubic foot internally.

Constructed mainly of 22 S.W.G. body with doors in 24 S.W.G. D.T.D. 213.A aluminium-manganese alloy.

Anodized.

Piano-type hinges. Tucker hollow rivets throughout.

Approximate weight: 3½ lb. per compartment.

It should be added that the purpose of the dirty-kit locker is different from that of the other furniture, as it is installed in banks in the seamen's quarters and is used for the same purpose as a dirty-linen basket. No particular attention has, therefore, been paid to the decorative finish of this item, the sole consideration being to obtain as much space as possible within the weight limits and without waste of deck space.

Particular attention is drawn to these items, as, whilst they preserve the outward form and general appearance of the conventional wooden types, they do, in fact, represent radical progress in design, inasmuch as, in compactness and method of assembly and operation, they achieve a degree of perfection quite impossible of attainment by the cabinet-maker's art. Accompanying illustrations show the general appearance of the items enumerated.

Pressure Die Casting

In answer to Erickson's observations and criticisms contained on page 471 of this issue of "Light Metals," E. Carrington replies as follows:—

"I thank you for the opportunity of replying to Erickson's criticism of my notes on his article in 'Light Metals,' 1945/8/173. Let us take his four points.

"*Mechanism of Die Fill.*

"Erickson says that I have 'failed to demonstrate that the description in my article of the manner in which cavity CDE filled is not an accurate description of how the die actually did fill in use.' It was not up to me to do so. It is the job of the writer of an article to do the demonstrating, and I am simply showing that there are other ways of looking at the problem, and that one of them may be nearer to the truth than Erickson's. Erickson has not tried to demonstrate anything; he has assumed, and assumed without sound reason.

"I am, of course, quite aware that Erickson's cavity CDE has no restrictive gate, but is as shown in his Figure 3, Diagram B. My object in introducing Köster and Göhring's diagram was not to show what happened in the cavity CDE, but to show what could and probably did happen before the metal reached the cavity CDE. Erickson has completely ignored this point both in his original article and in his reply to my criticism. Köster and Göhring showed that when the molten metal passed along a curved cavity, it went along the outside of the cavity and trapped air on the inside. In Erickson's mould we have a butt, into which the metal is injected in a haphazard way, and this mixture of splashed metal and air is sent along a tube having a double bend. (Figure 2, original article, p. 174.) I think that it is quite logical to expect it to take a path roughly as shown in Fig. 1 in this reply, and hence, when the incoming metal reaches the narrow part of the cavity CDE, an appreciable amount of air is trapped and may still be trapped when the

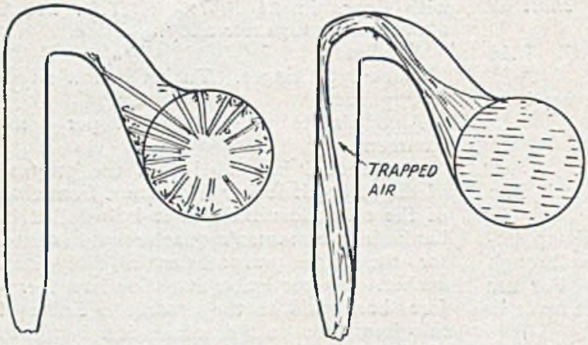


Fig. 1.—Suggested track of metal stream on entering cavity CDE: diagram at left—first injection of metal, splashing and admixture with air. Diagram at right—flow of metal after butt has been filled.

cavity GHI is filled. I hope that I have now made this clear, as it seems to me to be a point of fundamental importance. The design of that part of the die between the molten metal and the entrance to the cavity CDE requires a great deal of thought and experiment before it can be confidently asserted that the metal *reaches* the cavity CDE as shown in Fig. 1, and I must confess that I cannot think of a design which would satisfy the conditions required. In passing, I would point out that Erickson says in his criticism that ' the metal forced the air present in the cavity CDE and the air present in the runner ahead of it, leaving no air behind. (See Fig. 1.)' But in his Figure 2 (p. 474) he actually shows air being left behind at the point where the cavity CDE widens out again.

" In his Figure 1 (p. 473), Erickson shows a stream of metal injected into CDE through a small gate. It is obvious even to those without scientific training that the stream will not be straight as shown, but will be pulled down by gravity and will be more as shown in Fig. 2 here. It is important that such diagrams should be factual rather than ideal. Gravity cannot be ignored and will have a fundamental effect upon the kind of bars obtained.

" *Discarding Defective Test Bars.*

" I have again read Erickson's opening paragraph. It says: ' . . . to determine specifically the effect which *trapped air* (necessarily confined within the die cavity of the steel die moulds used in the manufacture of pressure die castings) has upon the solidification of the molten metal . . .' (The italics are mine.) In order to find the effect of trapped air, he throws away the bars which have most of it, or, at any rate, those in which it shows most! Incidentally, ' purpose of the experiment ' originally given is quite different from that given in (2), second paragraph.

" I am afraid that I do not understand the paragraph dealing with the comparison of sand and chill test bars. I have not come across the term ' host to defects,' and the whole illustration has little bearing on the problem. The inclusion of all the test bars was important from two points of view. In the first place, we are trying to get at the truth—the whole truth. Erickson is investigating the effect of trapped air. He gets

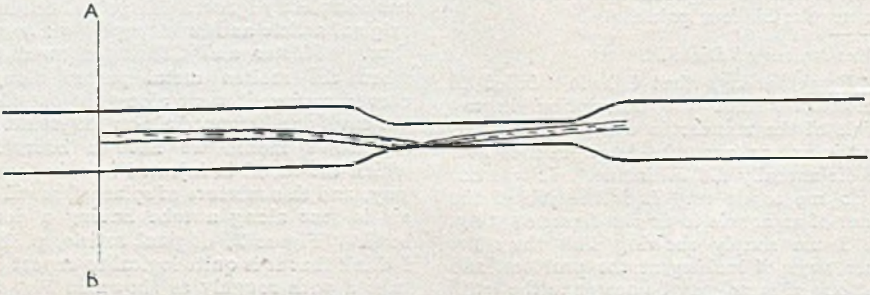


Fig. 2.—Probable track of stream of metal illustrated in Erickson's Figure 1 (p. 473) when allowance is made for effect of gravity. Note line AB in Erickson's Figure 1 and Figure 2 with blank space on left illustrating his complete indifference as to what happens to the metal *before* it reaches cavity CDE.

Aluminium WINDOW FRAMES WELDED WITH ACTARC *electrodes*

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bars which are ' defective,' not because of cold sheets, large grain size or any accidental cause, but because of *trapped air*—and they are thrown away! It is important that we should know how bad a bar can be when cast under those conditions, but, instead of finding out, he ignores the fact that it is bad at all. In his original article, second paragraph, Erickson says: ' This porosity is indirectly responsible for (1) the almost universal opinion of engineers that pressure die castings are inferior to sand and gravity die castings as regards *uniformity*.' He has shown this lack of uniformity quite glaringly in his experiments, but throws the bad bars away.

" The second point of view is the economical one. We must assume that these experiments are intended to have a bearing on practical die casting problems. Would Erickson throw away 70 per cent. of his commercial castings? If he were asked to quote for castings, would he ignore the possibility of 50 per cent. scrappers and risk a dead loss, or would he do some sums and work out a fantastically high price, based on high losses? His answer will probably be that the experiments are academic rather than commercial; but I say that, in any case, full facts should be reported. Moreover, if more than 50 per cent. of the bars have to be discarded, the discarded bars should be regarded as the type made under those conditions, and it would be better to scrap the whole lot than to report on the minority.

" *Failure to Employ Vents.*

" The question of venting is not important here. I merely thought that as Erickson mentioned it as a way of improving castings (third paragraph), it would have been helpful to have tried their effect in the course of the experiments.

" *Radiographic Inspection.*

" This portion of the criticism is most confusing. Erickson tries to explain at some length that radiography will detect pores, but not dissolved gas. He has strongly emphasized the point that the bars used in his tests were ' absolutely free ' from porosity and that hundreds of thousands of aluminium-alloy porous-free castings have been made in America. Now, in his criticism, he admits that ' micro-radiography, on the other hand, revealed the presence of ultra-fine evenly distributed micro-porosity.' What are we to make of all this? Surely micro-radiography is radiography, and surely micro-porosity is porosity? Either the pores were there or they were not, and no amount of hedging will hide the fact that they *were* there, and that radiography revealed them. I always take the expression ' absolutely free ' to mean, literally, ' *absolutely* free,' and the bars used did not come under this category as regards porosity.

" I do not think that any responsible radiographer in this country would fail to detect micro-porosity by ordinary radiography.

" I note that radiography was carried out to Government specifications. It is a pity that while Erickson describes his melting practice, which we should look upon as routine practice, he gives no details as to radiographic technique, which probably differs from British technique. Neither does he show any radiographs, although he shows a large number of photomicrographs.

" *Reply to Other Remarks.*

" Erickson says: ' Microscopic porosity-free aluminium alloy die castings are no longer a goal in U.S.A.—they're a fact '! and yet he now admits that his own ' absolutely porosity-free ' test bars contained micro-porosity. Moreover, in his original article he says: ' Manufacturers have attempted by the employment of various techniques to manufacture porosity-free pressure die castings for over 30 years,' but he doesn't say that they have succeeded, and I still don't see how they can. If they can, what is the use of research work such as Erickson's?

" As regards the gases used in earlier experiments, ' it is not stated that the gases were not dried.' Neither is it stated that they were, and I still say that this is an important point and should not have been omitted.

" As regards my point about the ' stewing ' experiments (' under such conditions, when neither oxidation nor gas absorption can take place '), I have not even put forward a hypothesis, let alone tried to conclusively verify it. I am simply making a statement based on years of melting practice.

" Before coming to the last paragraph, I would point out that Erickson has omitted to say one word about my criticism of his tables of physical properties, and I can only assume that he agrees that his conclusions cannot be substantiated.

" The last paragraph reflects the spirit of the whole criticism, which, in effect, says that those who disagree with Erickson have either failed to understand the various papers referred to, or have misinterpreted the original article. Other passages rather suggest that I am ' getting at ' him personally, and I am answered in the ' let me tell you ' style of one of our comedians. One of my own articles in your journal is at present being criticized by a responsible metallurgist, and I would not dream of answering in such a way. The object of technical articles, and of any discussion which they cause, is earnestly and humbly to search for the truth, and, in doing so, many of us will make statements which will be proved to be wrong, but that does not matter in the least so long as our search for truth is sincere and impersonal.

" I am one of those who have unbounded confidence in the future of aluminium alloys and who will do anything to encourage their use where such use would be worth while; but I shall always be ready to criticize any attempt to make these alloys appear better than they actually are.

" In my opinion, Erickson's investigation should have been preceded by a great deal of introductory work, to find out (1) how the metal actually did *enter* the mould. This would require a great deal of laborious trial and error. (2) The *actual* gas content of typical bars (' good ' and ' bad ' bars included) by vacuum fusion. (3) A correlation of gas content, micro appearance and radiographs. (4) How to obtain a reasonably uniform product. This work would occupy several months, but is essential if the actual investigation is to be started with some knowledge of what is happening and some means of checking the results.

" Finally, the question of the typist's errors, to which, I am told, I ought to have confined myself. These are a most extraordinary set of errors. I have never seen any like them and do not expect to do so again. In each case the sense of the passage has been completely altered, and it is most surprising to find, first, that they were made, and, second, that the author did not notice them. Actually, I only assumed No. 3 to be an error. I read the others as written, and, of course, criticized them as they appeared. Probably the fact that Erickson has said nothing about them until I have drawn attention to them is due to postal delays.

" I could say a good deal about serious errors of this kind in a technical article, but you, Mr. Editor, would not publish it, although, as you have had your leg pulled like the rest of us, you might be strongly tempted to do so. I will therefore refrain from tempting you, but will have the effrontery to rob you of one of your inalienable rights by saying, ' This correspondence is now closed.' "—E. Carrington.

LIGHT-ALLOY MOTORCAR

THE following letter has been received regarding a discussion, which appeared in " Light Metals," 1945/8/417, on the use of aluminium in automobiles:—

" Two points in ' The Light Automobile ' (' Light Metals,' September, 1945) need either correction or explanation.

" On the basis that ' every pound of light alloys introduced saves a pound in all-up weight ' and that ' it is possible to substitute about 40 per cent. of the ferrous material in a normal car by light alloys,' your contributor maintains that 0.30 ton of a 0.76-ton car is convertible into light alloys and that this would lead directly to a like saving of 0.30 ton in weight.

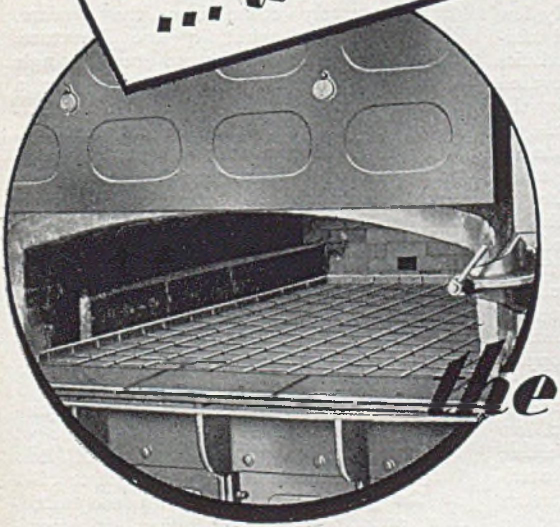
" In short, he proposes to exchange 0.30 ton of ferrous material for 0.30 ton of light alloys and to save 0.30 ton in the process. This certainly is not easy to accept.

" Earlier in the same paragraph, on p. 423, your contributor calculates 40 per cent. of the ferrous material in a normal car of 0.76 ton total weight, and arrives at a figure of 0.30 ton, which would be approximately correct if all the 0.76 ton were ferrous. In fact, part of it consists of glass, rubber, battery, upholstery, and other non-ferrous materials. Analysis shows that not more than about 80 per cent. of a normal car is ferrous.

" It would seem, therefore, that the weight replaceable by light alloys is only 0.24 ton instead of 0.30 ton, and that this must be replaced by 0.12 ton of light alloys if there is to be a pound-for-pound saving in weight. In short, the weight saved would be 0.12 ton and the final weight of this car would be 0.64 ton instead of the 0.46 ton anticipated by your contributor.

" The difference is so great as virtually to destroy the whole of your contributor's subsequent argument, but I feel that the reduction of the weight of automobiles is so important that the article, as published, may create an expectation of bigger benefits from light alloys than they can, in fact, provide."

E. P. Willoughby.



Aluminium in the Coal-gas Industry

Presenting the First Part of an Exhaustive Survey of the Theory and Practice of the Application of Light Alloys in Coal-gas Production and Consumption

THE role of light metals in the gas industry forms a particularly interesting study for two reasons. First, unlike, say, the paint and varnish industry, where the use of light metals figures largely in the manufacture of the product but scarcely at all in its distribution and application, or in certain other branches of the chemical industry where the reverse conditions mainly apply, aluminium is equally important and exhibits a similar degree of versatility in the diversity of its applications both in the production and in the consumption of gas. In this respect, too, it differs markedly from its position in the gas industry's most serious competitor, namely, the electricity supply industry, where light metals are employed so extensively in the distribution of power and in its conversion into other forms of energy, but possess only a very limited application in the generation of electricity.

The second reason is that, with only few exceptions, the main attraction of aluminium is to be found in such characteristics as resistance to oxidation at certain elevated temperatures commonly met with in the production and consumption of coal gas and to tarnishing at ordinary temperatures, its good heat conductivity and low emissivity, the numerous attractive finishes in which it can be obtained, ease of fabrication, and, perhaps most important of all, its good resistance to the corrosive fumes and liquors indigenous to the production of coal gas and to the products of gas consumption, in which respect aluminium is vastly superior to iron, steel and copper-base materials. In other words, the value of aluminium to the gas industry is due in the main to characteristics other than low density and adequate strength properties, which are, perhaps, the best-known attributes of the light alloys and the properties for which they are so rightly famed in many branches of industry, including the chemical industry in many of its ramifications.

This is not to say that the low density and adequate strength properties of the aluminium alloys are unimportant. In point of fact, in the ensuing review, quite a number of instances will be given where these characteristics have been the deciding factors in the choice of material. It is, however, refreshing to find a field of industry in which other valuable characteristics of the light alloys have not been overshadowed by this particular property, excellent though it is, and a timely reminder that aluminium bases its claim for industrial consideration on a combination of properties which is unique among available materials of construction and which enables it to fulfil many roles in diverse fields of application with greater success than other available materials.

The particular properties which make the aluminium alloys of such value to the gas industry are not possessed to anything like the same degree by the ultra-light alloys and, in consequence, magnesium and its alloys scarcely come into the picture. Throughout the whole of the literature, there does not appear to be a single reference to either an actual, or even a potential, application of the ultra-light alloys in gas production or consumption. We can visualize a few; for example, certain parts of the framework of heavy street-lighting fixtures, minor parts of portable gas fires, wheelbarrows used in the gasworks and gas-fitters' tools, all applications where the utmost reduction in weight is to be achieved and where requirements as to corrosion resistance, etc., are less stringent. But these are all very minor applications and offer no challenge to the predominating importance of aluminium in this field.

We may add a third reason for the particular interest attaching to the use of aluminium in the gas industry, and that is simply that aluminium has so much to offer to the gas industry and, in consequence, the scope for aluminization is correspondingly wide. Already, many gasworks have made extensive use of the light metal and post-war industry is planning to make good use of it in domestic and industrial gas-consuming appliances.

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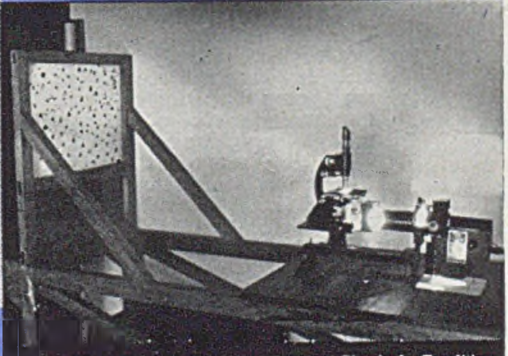

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A number of interesting exhibits at a recent exhibition in London provided an instructive illustration of some of the ways in which this is being achieved. Nevertheless, in reviewing the realized applications of aluminium in the gas industry one gains the impression that there is a large area of profitable ground still to be tilled and wide tracts which have, as yet, not even been charted. Altogether, the gas industry is a valuable field for the exploitation of aluminium and one in which this light metal can perform, and, indeed, is already performing, an extremely valuable function.

The Value of Aluminium to the Gas Industry. The Resistance of Light Alloys to Chemical Attack

When coal is heated out of contact with air, it undergoes certain complex changes which result in the production of numerous volatile gaseous, liquid and solid products together with a non-volatile residue of coke. The number of different products which have been identified in the volatile products of coal runs in to hundreds, so that the proof of satisfactory corrosion resistance lies more in the results of practical tests than on theoretical considerations.

The major materials present are, however, tar, ammonia, ammonium carbonate, ammonium sulphide, carbon monoxide,, carbon dioxide, sulphuretted hydrogen, sulphur dioxide, carbon disulphide, hydrogen, methane, nitrogen, cyanides, acetylene, benzene, ethylene and coal tar, the latter itself consisting of many different compounds, in particular, hydrocarbons, both aliphatic and aromatic, acid materials such as phenol, basic materials such as pyridine, creosote (again a mixture) and pitch. Of these substances, only ammonia and the ammonium salts, sulphuretted hydrogen, carbon disulphide, sulphur dioxide, phenol, pyridine, cyanides, creosote and pitch need be considered, the other substances being substantially without action on wood, iron, steel and the usual copper and aluminium-base structural materials.

The action of ammonia on aluminium is an interesting one. When dry, gaseous ammonia has no action on aluminium, not even at high temperatures. In aqueous solution, although an alkali, attack by all concentrations of ammonia on pure aluminium and on copper-free aluminium alloys is practically negligible at temperatures up to about 50 degrees C., and is only very slight at temperatures up to about 150 degrees C, due to the rapid formation of a protective oxide film. In consequence, aluminium is being employed quite successfully in such applications as the construction of ammonia stills, condensers and separating columns in coke-oven by-product plant, and in equipment for the production of synthetic ammonia and for heating concentrated ammonia under pressure. Traces of chlorides and other alkalies, however, dissolve the protective film and the metal is then attacked. Such impurities are, fortunately, not present in coal distillation volatile products. Thus, the corrosion of aluminium by moist ammonia, though unwelcome, is not particularly serious and is in great contrast to the action of ammonia and ammonia liquors on copper- and iron-base materials (excepting stainless steel), where the attack is often marked.

Sulphur and sulphurous gases such as sulphuretted hydrogen and carbon disulphide have a serious corrosive effect on copper and brass, but aluminium can be used freely in contact with them, substantial deterioration being prevented by the formation of a protective film.

Dry sulphur dioxide is without action on aluminium. Moist sulphur dioxide implies the presence of sulphurous and sulphuric acids which are corrosive to nearly all metals. At normal temperatures, however, the rate of attack on aluminium is practically negligible in the absence of certain impurities, mostly of the chloride type and which, fortunately, are invariably absent from coal distillation products, so that the presence of moist sulphur dioxide constitutes only a slight hazard in the presence of aluminium, whereas its attack on steel and copper is severe.

At normal temperatures, the action of phenols on aluminium is also negligible, whilst aqueous solutions at 60-80 degrees C. have only the slightest action on the metal. At higher temperatures, water-free phenols do attack aluminium vigorously, but this action may be stopped by the addition of water; it does not occur at ordinary temperatures.

Pyridine is virtually without action on aluminium. Creosote attacks the metal with the formation of a uniform black film. This action may be prevented by anodizing and apparatus so treated is quite suitable for the storage and handling of creosote. In the dilute form in which it is met with in gas production, it can be safely handled in aluminium plant without special protection.

Pitch occasionally gives trouble in contact with most metals, but not with aluminium. Corrosive attack on other metals is due, no doubt, to the retention of a proportion of phenol, to which aluminium is resistant.

No less striking is the comparative immunity of aluminium to the action of the products of the combustion of coal gas, although some of the substances concerned have a very pronounced action on other metals. The 36th Report of the Joint Research Committee of the Institution of Gas Engineers and of Leeds University published in November, 1935, gives details of some interesting experiments on the corrosion of metals by gas combustion products. Tests were carried out on samples of coal gas with low, medium and high sulphur contents, these contents being 8, 25 and 50 grams respectively per 100 cubic ft. of gas, and the metals compared were used in the form of tubes fabricated from sheet and water jacketed to keep them at a temperature of 40-60 degrees F. As a result, water containing dissolved sulphur and nitrogen acids condensed on the inside of the tubes and, in certain cases, gave rise to corrosion. It was found that the 10 metals examined could be divided into three main groups as the result of these tests, namely:

Group I ..	Lead Tin Solder	Very good resistance
Group II ..	Aluminium Brass Copper	Good resistance
Group III ..	Iron Galvanized iron Zinc Nickel	Poor resistance

These results have reference only to the extent of attack and, on further consideration, aluminium shows to greater advantage. In Group I, solder is largely inadmissible as a material of construction if only because it melts below the temperature of burning coal gas; it is expensive and possesses very poor mechanical properties. Neither is lead a practical material. Tin is ruled out on the question of cost; tin plate is quite unsatisfactory because of its porosity, whilst, in addition, tin and tin plate soon acquire, when exposed to a source of heat, an unsightly black film which is objectionable in domestic apparatus. Thus, Group I is eliminated from consideration. Similarly, in Group II, the tarnish film formed so readily on copper and brass in sulphurous atmospheres is unsightly in the extreme and could not be tolerated where appearance is of the slightest consequence. Aluminium, on the other hand, possesses a high resistance to unsightly tarnishing as it does to corrosive attack, a resistance which is particularly marked where high sulphur content gases are encountered. In fact, the indications are that the higher the sulphur content the better does aluminium behave in comparison with copper, brass and the metals in Group I.

Practical considerations, then, put aluminium at the head of the list as regards corrosion resistance.

Other Considerations

An engineering material, however, has requirements other than chemical resistance to satisfy before it can be accepted as the chosen material of construction, requirements such as low cost, availability, ease of fabrication and finishing possibilities. On all these scores aluminium can give a satisfactory answer for itself. In comparison with copper-base metals, aluminium frequently proves to be the cheaper. Although the cost per ton of aluminium is more than that of a ton of copper or brass, one ton of aluminium occupies roughly three times the volume of the same weight of heavy metal, so that it does not follow that articles in aluminium are more costly than those in copper-base material. In fact, the reverse is often the case, and when components are compared on a strength to strength basis, or even on a basis of equal rigidity, it is frequently found that those in aluminium are the cheaper in the long run.

Other factors which make for economy in the use of aluminium and its alloys are the ready availability of the metal in a great variety of semi-manufactured forms and the ease with which it may be formed and machined. Apart from sheet, rod, wire, bar and billet, aluminium alloys are supplied in a wide range of extruded sections, the use of which can save plant constructors a great deal of fabrication which might otherwise be necessary. Such sections as H, I and T girders, angles, cover strips, drip plates, mouldings, and square, octagonal, oval, rectangular, round and split tubes have obvious applications in the construction of equipment for gas works.

Light alloys are also available as embossed sheet for use as tread plates and draining boards and as expanded metal, the last at once suggesting itself for use in the iron oxide gas purifiers as the base of the trays supporting the hydrated iron oxide purifying material. Aluminium rivets are, of course, already very well known in many branches of industry.

(To be continued.)

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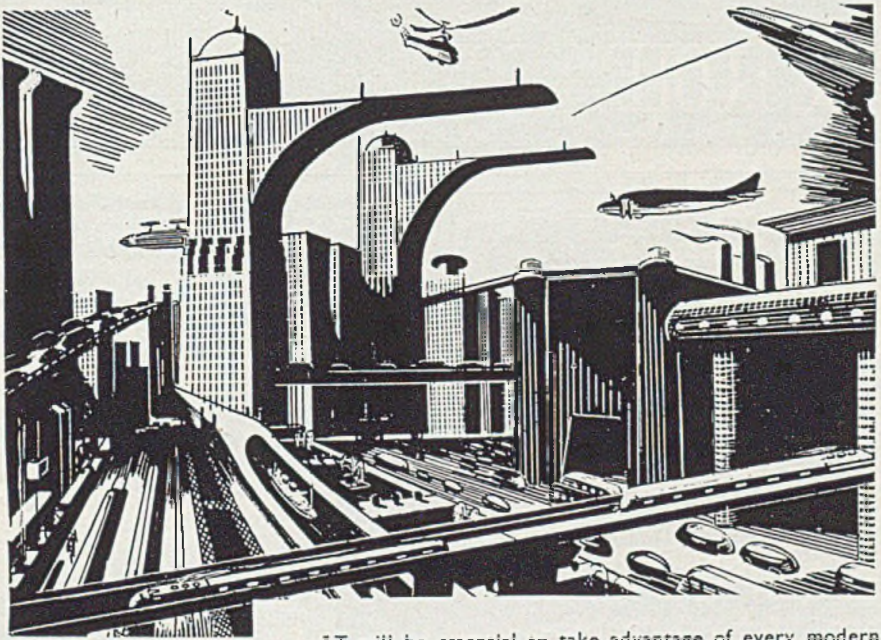

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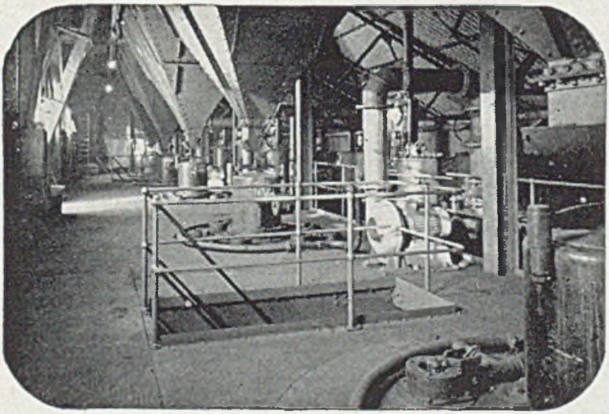

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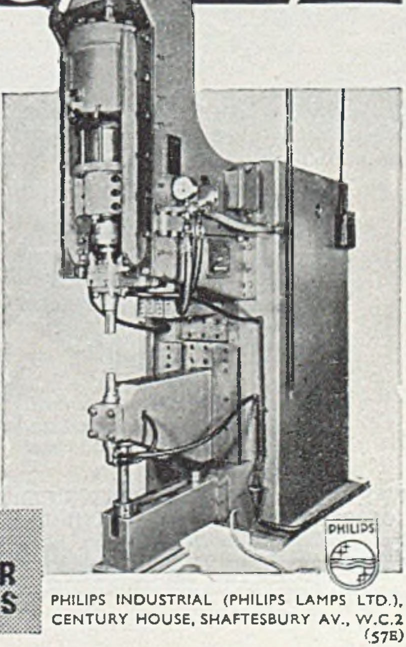

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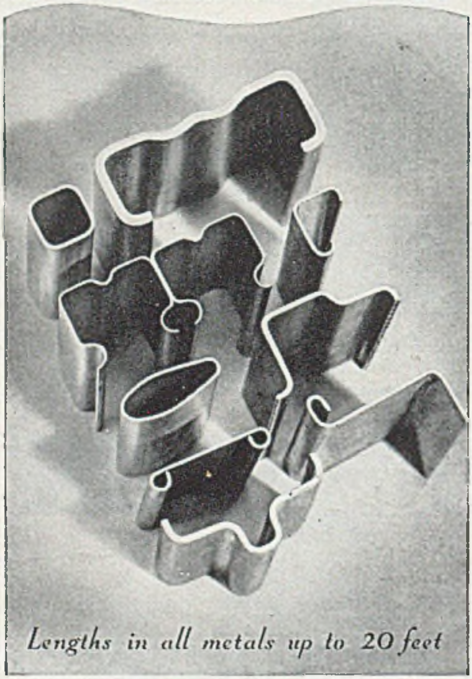
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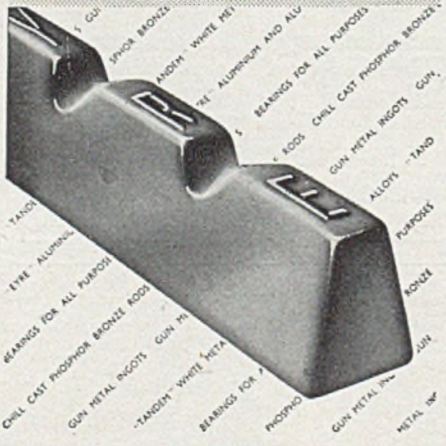

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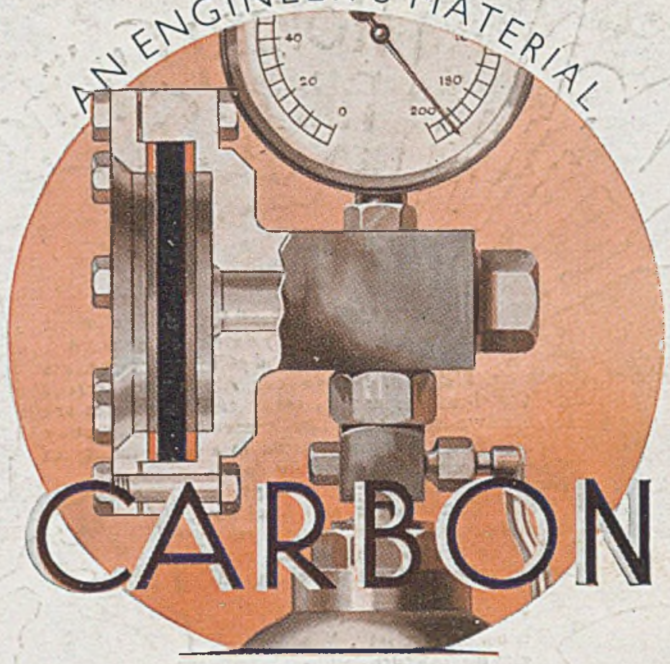

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