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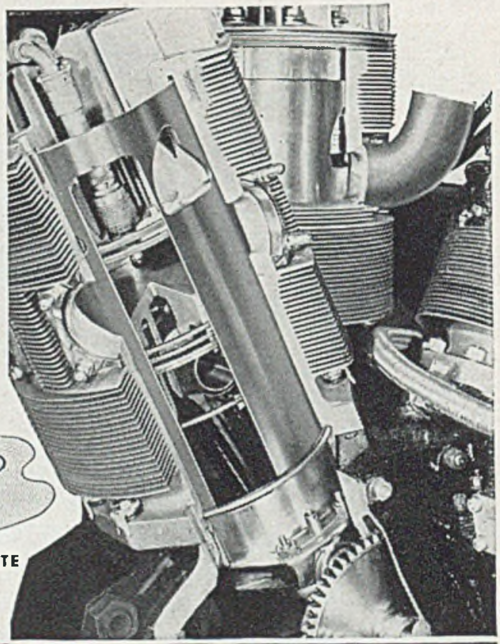

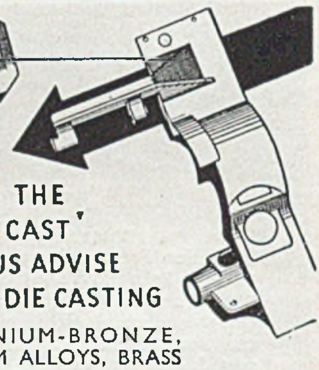

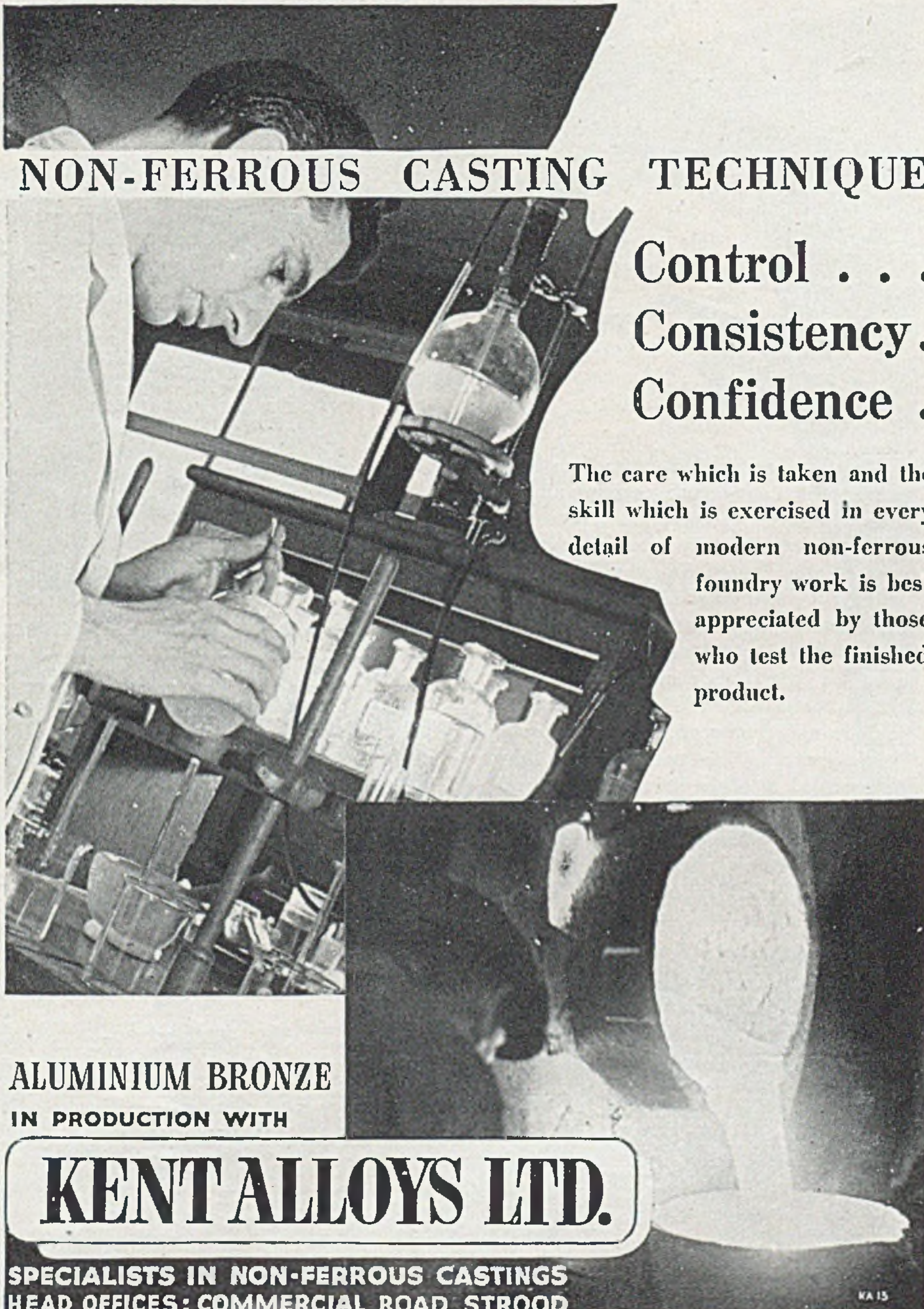

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LIGHT METALS

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

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

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

EDITORIAL OPINION

Kick It and See!

AMONGST the many irrational pastimes favoured by irresponsible youths some 20 years or so ago, was one which commenced with the careful wrapping, tying and sealing of a brick in brown paper. The resulting parcel was next deposited at some strategic point on the pavement and kept under surveillance from a well-guarded observation post, usually situated in a nearby basement area. Sooner or later, some curious passer-by would notice this apparently lost property and, invariably, before picking it up, give it a hearty kick; the more alarming his reaction, the greater the enjoyment of those responsible for the hoax.

It is not our purpose, here, to insinuate that the use of an aluminium brick would be less unkind to the victim's feelings. We do, however, suggest that, when contemplating the purchase of certain types of household equipment featuring light metal in their make-up, there is scope for the application of an empirical but convincing test of this sort—kick it and see! Or maybe, as the storekeeper might object to having his pots, pans and kettles punted around by discriminating buyers, a well-delivered blow with the knuckles at some telling point might answer the same purpose.

Now, in case the object of this discussion has, so far, been a little obscure, we must hasten to say that we are not attempting to popularize a new kind of light-hearted frolic; in all seriousness we are protesting against the use of unduly light-gauge aluminium sheet for household service. The fault of which we complain arises as a result of two causes, both equally to be regretted. In the first case, there is and always will be, obviously, attempts made to produce cheap, attractive-looking lines with the object of securing maximum profits for the smallest possible outlay in raw materials. Cunning production systems were devised to vest worthless spun ware with the semblance of solidity by thickening up edges or by ribbing and seaming. Here, to some extent, the buyer could protect himself by purchasing only from dealers or markets of known good repute.

The second cause of this misuse of sheet, however, is fundamentally of a far more serious nature, and arises, it would appear at least, from a lack of understanding of the service qualities required from the bulk of domestic apparatus, and indicates, too, a profound ignorance of certain basic principles in design.

The vastly increased application of light metals which is to be a feature of the post-war years demands, in the interests of everybody, that this state of affairs be put right. Two distinct classes of work may be considered: first, those utilizing large, unbroken areas of metal not backed up by a rigid filling directly in contact with the metallic surface. Here, the use of an inadequate gauge results inevitably in great difficulties in the production of a truly flat surface; waves and cockles will occur, often as a result of mere handling during assembly, and if such metal be designed for an artistic purpose, it must, on first principles, fail in this end from the very beginning.

If, however, it be desired to face some comparatively cheap material, say, wood or plastic, with aluminium, using a suitable adhesive for bonding together the metal and non-metal, the danger is hardly less great. Admittedly, any waviness may be ironed out, but unless the backing be extremely hard and rigid, then the slightest blow on the facing sheet will produce a dent which cannot be removed.

Broadly, then, no very great difficulty will be found in preventing the occurrence of this ill. In no circumstances should excessively thin sheet be used under the mistaken impression that the structure of which it is to form part demands nothing heavier. We ourselves prefer 16-gauge as a good average, 18-gauge or 14-gauge being used to meet special conditions. Naturally enough, where expense and circumstance warrant still heavier metal, then, of course, it should at all times be used (remember, we are talking now of general lines).

So, to purchasers of domestic equipment in aluminium we would recommend that an eye be kept always on the substance of the ware which they intend to purchase. The housewife cannot be expected to carry around a case of special micrometers for this purpose, but she can at least bang her fist on the bottom of the kettle, or give the anodized aluminium fender a discreet but compelling kick. If the gauge be adequate no damage will be caused.

Contents

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

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

Selection and Preparation of Aluminium Foundry Alloys

E. Carrington, M.Sc., Classifies Light Metals for Foundry Use From the Standpoint of Technical and Economic Considerations. Appropriate Specifications are Systematized and Some Practical Details are Given

FOR some years now, the aluminium-foundry industry has been using relatively few alloys, and the choice of these has been largely outside its control; there are reasons for this. In the first place, the supply position was difficult, and castings had to be made from the best alloy available. Also, with but a small number of alloys in use, especially if each foundry specializes in only two or three, it is much more easy to segregate the scrap, and return it to new melts of the same alloy, without adulteration. It must be admitted that it is quite unnecessary to have in use the large number of alloys at one time available, and that to increase the range can only aggravate the danger of using unsuitable compositions, or of adulterating good ones.

On the other hand, this does not mean that we have reached a point of stagnation, and that no more new alloys will be forthcoming. We have only to visit the research laboratories of the companies which supply aluminium alloys, to realize that constant and intensive efforts are being made to provide ever better materials. Moreover, as light metals become more generally available for commercial use, many customers will want castings made in alloys the same as those they used before the war: thus the number in use will increase appreciably. It is, of course, quite possible that even the Air Ministry (at present, still, by far the biggest customer of the aluminium-foundry industry), will use a greater range of alloys when the supply position improves, and more suitable compositions are available for special jobs.

It is certain now, however, even as a result of mere habit, that a large proportion of peace-time orders will be based on B.S.I. or D.T.D. specifications. A complete list of these is given in " Light Metals " for December, 1944, pages 576-581; on page 571 of the same issue the present writer briefly xplains how these are developed. Obviously, by ordering according to these specifications, a customer will know what he is ordering, and what physical properties he may expect from the metal used. He will probably be aware that these properties are not necessarily obtained from the actual castings, but they do, at least, form a basis on which to design the work in hand.

In many cases, a customer will simply ask for " aluminium castings," and leave it to the founder to select the most suitable mix. The founder, in his turn, will then have to consider the matter from various angles. In the first place, he will have to use an alloy which satisfies the customer's requirements and, in the second, he will have to give himself every possible chance of making good, sound castings. Sometimes the best alloy for the customer will be by no means the best for the founder, and a second best from both points of view may have to be selected, in order to obtain the most satisfactory all-round properties.

There are several ways of classifying aluminium alloys. One might, for example, place them in order of mechanical strength, ductility, corrosion resistance, machinability, foundry properties, etc., but the order of merit would be different in each case, and, therefore, for any specific purpose, a compromise alloy would have to be selected. Another important factor in the selection of the alloy would be the cost.

Again, if a large number of castings are to be made (and there is no doubt that this will be the case when peace comes), it may be advisable to plan a programme which includes the quick production of some sand castings, the production of a gravity die, as quickly as possible, and then the manufacture of a pressure die, in order gradually to step up output, whilst giving some castings at an early date. If this scheme be carried out, it will be advisable to use one of the alloys which can be used for sand, gravity and pressure work, so that the properties of the metal will remain reasonably uniform throughout, and so that scrap coming back from the customer will be of one assured composition.

As far as mechanical strength is concerned, aluminium foundry alloys may be divided into three classes, the high-, medium-, and low-strength alloys. The high-strength alloys with which the founder may come in contact, are given below:—

Specification number	Proprietary designation	Specified tensile strength	Elongation
D.T.D.131A ..	R.R.53	16 ton/in.^{2}	—
D.T.D.255 ..	Ceralumin C	18 ton/in.^{2}	—
D.T.D.269 ..	N.A.222	18 ton/in.^{2}	—
D.T.D.300 ..	N.A.350 B.A.29	16 ton/in.^{2}	7%
D.T.D.304 ..	N.A.225/T.92	18 ton/in.^{2}	4%
D.T.D.309 ..	R.R.53	19 ton/in.^{2}	—
D.T.D.361 ..	N.A.226	21 ton/in.^{2}	1%

These alloys have tensile strengths of 16 to 22 tons/in.^{2}, but to obtain such values heat treatment is necessary. This technique will demand laboratory supervision, as well as skilled knowledge, careful application, and special furnaces with accurate thermal control. However, if the foundry does not possess such equipment, there is little doubt that, in peace-time, plant will be available, to which the suitable castings may be sent for careful and accurate heat treatment.

A word of warning should, perhaps, be given regarding two of these alloys, namely, D.T.D.304 and D.T.D.361 (these are the same alloy) and D.T.D.300. In the case of D.T.D.304 (4 per cent. copper), high-purity metal is essential. Only 0.25 per cent. of iron and 0.25 per cent. of silicon is allowed, and if the iron exceeds the specified limit, the physical tests may be expected to be below specification. In the case of D.T.D.300 (10 per cent. magnesium) also, high-purity alloy is essential, and in this case very careful control of temperature is required. Another point which the founder ought to realize before he quotes, is that this last-named alloy must be quenched in hot oil. This does not mean that these two alloys are unsuitable for foundry use; they have both been employed to an enormous extent for very vital parts in our aircraft. If failure takes place, because of mounting impurities or wrong melting technique, it is the fault of the foundry, not of the metal. A great deal of development work has been carried out on these two compositions, and the suppliers of the metal will be pleased to give the foundry all possible assistance, including advice on the special foundry technique required for D.T.D.300.

The medium strength alloys have a tensile strength of 10 to 14 ton/in.^{2} and are listed below:—

Specification No.	Proprietary designation	Specified tensile strength, ton/in.^{2}	Specified elongation, %
D.T.D. 133B	R.R.50 heat treated	10	2½
D.T.D. 231 ..	M.V.C. alloy	10	5
D.T.D. 240	Wilmil "m" Alpax beta	11	1.5
D.T.D. 246	Wilmil "m" Alpax gamma	15.5	—
D.T.D. 250 ..	Ceralumin D	14	—
D.T.D. 264 ..	Birmasil special (not H.T.)	12	2
D.T.D. 272 ..	N.A.125/W.60 (H.T.)	11	2
D.T.D. 276 ..	N.A.125/T.67 (H.T.)	15	—
D.T.D. 287 ..	Ceralumin B	10	2
D.T.D. 294 ..	Aeral A	14	3
D.T.D. 298 ..	N.A.225/W.91	14	7
D.T.D. 313 ..	R.R.53C as cast	10	2
B.S.S. 2 L.24	Y alloy as cast	10	—
B.S.S. 2 L.33	Wilmil Alpax	10.5	5
B.S.S. L.35 ..	Y alloy heat treated	14	—

Most of these compositions, also, require heat treatment. D.T.D.294 requires careful melting technique, as it contains cadmium, which boils at 765 degrees C.; with reasonable care, however, it should present no difficulty.

One of this group, 2 L.33, may also be classed as the best alloy known for moulding thin sections. If large bosses be required, especially in die castings, care is necessary in order to avoid internal cavities, which cannot be seen until the bosses are machined. For all sand castings, and for some gravity die castings, it is necessary to "modify" this alloy. This consists in plunging into the pot, held at 750 degrees C., a definite amount of metallic sodium, and allowing the melt to stand quietly for a few minutes. The exact amount of sodium to be used depends upon the shape of the crucible, more being needed for a shallow die-casting crucible than for a tall crucible such as is used in sand foundries. It also depends upon the condition of the metal. Some metal is supplied already modified; at least one concern supplies it entirely unmodified, and perhaps this is the safest basis on which to work. The amount of sodium to add, however, still depends on the amount of modified scrap used in the melt, but this can be controlled and allowed for. A good amount to add for a first treat would be 1 oz. per 100 lb. of melt.

The fracture of a test bar of modified

metal should show a fine, white structure, with a silky appearance in places. The under-modified structure will appear either grey and coarse, or in the form of fairly large, shiny crystals. The over-modified metal will be grey, with circular cavities showing white surfaces. The modification should be carried out under laboratory supervision, and with constant care little difficulty is met with.

The low-strength alloys consist chiefly of the older-established foundry compositions which have given excellent service in their time, but have, to some extent, been superseded by the more modern types. They are as follow:—

Specification No.	Proprietary designation	Specified tensile strength, ton/in.^{2}	Specified elongation, %
D.T.D. 165 ..	Birmabright	9	3
B.S.S. 3 L.5 ..	—	9	2
B.S.S. 3 L.8 ..	—	7	—
B.S.S. 4 L.11 ..	—	7.5	1.5
D.T.D. 238 ..	R.R.53 as cast	9	—
D.T.D. 424 ..	—	9	2
D.T.D. 428 ..	—	8	—
No specification	Grade "D"	—	—

One of this group, namely, 3 L.5, is, perhaps, even yet the best all-round sand-casting alloy for lightly stressed parts. It was largely used before the war for car sumps, gearboxes, etc., and for crankcases for small aero-engines. As it contains about 13 per cent. zinc and 2.75 per cent. copper, it has a comparatively high density.

D.T.D. 424 and D.T.D. 428 were developed at the beginning of the war in order to put back into use all available aluminium alloy scrap. Aluminium refiners had for some time been collecting miscellaneous scrap from aluminium foundries and remelting it into ingots which were used for castings ordered in "aluminium alloy." Two kinds of ingot were obtained, those from foundries using 3 L.5, and, therefore, containing zinc, and those free from zinc. A fairly wide specification was issued for each of these, D.T.D. 424 (free from zinc) being so arranged that a considerable amount of wrought duralumin scrap could be included.

At first these mixtures gave a little trouble, but they are now firmly established and will probably continue to be used in large tonnages after the war is over, and when even greater quantities of scrap come on the market.

Grade D is simply remelted foundry scrap, with no specified composition. It is bound to vary in constitution, but it is quite useful, if the user keeps his eyes open and does not misapply it.

Light Alloys Control (L.A.C.) has issued several specifications which have brought into use again metal which was a little outside specification, but which could easily be used. These specifications are as follow:—

L.A.C. 112.—An impure 2 L 33 containing a fair amount of copper. Used in place of 2 L 33 for pressure die-castings. Specified tensile strength, 8 tons/sq. in. No elongation.

L.A.C. 113A.—An impure 3 L 5, used for sand castings. Specified tensile strength, 9 tons/sq. in. No elongation.

L.A.C. 10.—A high copper alloy, similar to L L 11, but with more allowable impurities. Very useful in the heat-treated condition for pistons intended for light duty. No tensile figures given.

During the war a committee has been formed to assist all the Government departments in the application of metals to their particular requirements. Dr. R. Genders is in charge of this work, as Superintendent, Technical Application of Metals. A considerable amount of work has been done and a schedule has been published, covering several groups of non-ferrous metals (copper alloys, lead alloys, etc.). This is known as the S.T.A.7 schedule, and alloy group No. 6 (Aluminium Alloys) will shortly be issued. This consists of aluminium in various wrought forms, wrought alloys and casting alloys. The latter are coded, A.C. 1, A.C. 2, etc. Those selected cover a wide range of possible applications and are all identical with, or similar to, one or other of the alloys listed above, except A.C. 12, the low-expansion piston alloy, which is identical with an American specification (A.E.L. 148). They are as follow:—

Casting Alloys for General Purposes

	Identical with
A.C. 1—Sand and gravity castings	D.T.D. 428
A.C. 2—Pressure die-castings	L.A.C. 112
A.C. 3—Sand castings ...	L.A.C. 113A
A.C. 4—Sand, gravity, and pressure castings ...	D.T.D. 424
A.C. 5—Sand and gravity die-castings	D.T.D. 165
A.C. 6—Sand, gravity, and pressure castings ...	2 L 33
A.C. 7—A: Sand and gravity die-castings ...	D.T.D. 133C
A.C. 7—B: Sand and gravity die-castings ...	D.T.D. 287

Casting Alloys for Particular Applications

	Identical with
A.C. 8—A: Sand and gravity die-castings ...	D.T.D. 240
A.C. 8—B: Sand and gravity die-castings ...	D.T.D. 245
A.C. 9—Sand and gravity die-castings	D.T.D. 300
A.C. 10—A: Sand and gravity die-castings ...	D.T.D. 298
A.C. 10—B: Sand and gravity die-castings ...	D.T.D. 304

Piston Alloys

A.C. 11—Sand and gravity die-castings suitable for pistons	Identical with L.A.C. 10
A.C. 12—A: Sand and gravity die-castings suitable for pistons ...	—
A.C. 12—B: Special quality die-castings suitable for pistons	A.E.L. 148
A.C. 13—A: Sand and gravity die-castings suitable for pistons ...	L 35
A.C. 13—B: Special quality die-castings for pistons	Similar to E. in C. Admiralty
A.C. 14—A: Sand and gravity die-castings suitable for pistons ...	Identical with D.T.D. 131B
A.C. 14—B: Sand and gravity die-castings suitable for pistons ...	D.T.D. 255

If ductility be required in castings, selection of suitable compositions is a fairly simple matter, because there are not many cast aluminium alloys which possess an appreciable amount of ductility. Perhaps the greatest contribution which could be made to the aluminium foundry industry, in fact, would be the discovery of a mix with good ductility, in addition to a medium-to-high tensile strength.

The most ductile non-heat-treated alloy is 2 L.33, if correctly modified. The specified elongation on 2 ins. is 5 per cent., but 11 per cent. is often obtained. The disadvantage is, of course, that modification is necessary, and if this process be not correctly carried out the ductility may, conversely, be very poor. The other two ductile alloys are the two high-strength alloys, D.T.D. 304 (which gives more ductility if heat-treated to D.T.D. 298, but less strength) and D.T.D. 300. For D.T.D. 298 and D.T.D. 300, 7 per cent. elongation is specified; with D.T.D. 298 11 per cent. is often obtained.

If corrosion resistance be asked for, the selection of the best alloy is by no means easy. Every effort should be made to find out under what corrosive conditions the castings are to be used. Too often, when resistance to chemical attack is mentioned, an alloy is selected which gives good resistance in the salt spray test, this being taken as a satisfactory guide to performance in service. Actually, however, the castings may be in contact with dyes, medicines, or foods, and the salt-spray test may give rise to an entirely wrong impression. The only way in which to approach this problem is, first, to find out all possible details regarding the corrosive conditions to be encountered and then to write to several of the companies which supply metal to see if they have had experience with alloys in similar circumstances. It is hoped that, some day, we shall have a central development association which will help foundries with problems of this kind. If, in the end, the metal suppliers cannot give the required advice, the founder will have to rely on the salt-spray test or try out a few alloys under working conditions, but, unfortunately, this will take time.

In general, aluminium-magnesium alloys may be expected to give the best resistance to attack, followed by the aluminium-magnesium-silicon alloys, after which would come the silicon alloys. If heat-treatable alloys are being used (especially if they contain copper), better corrosion resistance will probably be obtained if the alloy be used in its solution-heat-treated condition. The copper alloys give comparatively poor corrosion resistance, and this applies also to the zinc-copper alloy 3 L.5. Incidentally, a great deal of valuable information has been given on this subject in "Light Metals."[1]

As regards machining properties, the majority of aluminium alloys may be machined at a high speed, and will give good surface finish. The exceptions are the high-silicon alloys, 2 L.33, and the low-expansion alloy containing up to perhaps 14 per cent. of silicon. These alloys drag and, as they contain particles of silicon, tend to damage all but diamond- or carbide-tipped tools. In general, the high-copper alloys may be expected to give comparatively good machined surfaces. An outstandingly good-machining alloy is D.T.D. 294 (Aeral). Alloys with double heat treatment generally give rather better machining results than the same alloys with the single heat treatment.

If the castings are to be anodized or plated, it would be well worth while, beforehand, to ask one of the well-known concerns which carry out this work for advice as to suitable alloys. These surface treatments are definitely technical jobs, and should be carried out by those who understand them. The writer was recently privileged to see some of the experimental work which is being carried out in connection with anodic finishes, and was profoundly impressed with the high quality of the work and the rapidly extending field of use for it.

So far, the foundryman has been studying his customer's requirements. He must now consider his own, and think about the foundry properties of aluminium alloys. Certain qualities are common to them all, for example, comparatively low melting point. But because of their high heat capacity more heat is required to melt them than to melt brasses. They all have a low specific gravity and, because of this, much larger risers are required than are used with the heavy alloys.

A disturbing property of some aluminium alloys is hot shortness. This is characterized by extreme weakness at high temperatures. Hot shortness is a serious drawback to the strong alloy D.T.D. 304. If a simple plate, say, half an inch thick by a foot square, be die-cast in this alloy, and the die opened as soon as the riser is solid, it is possible to break the casting up like crumbly cheese, but if another casting be made, and allowed to cool to aid temperature, it will be found possible to bend it until the opposite sides meet, without any sign of cracks.

Another alloy which exhibits pronounced hot shortness is 3 L.5, and with this composition the trouble becomes worse as the iron content increases. A further property, which should perhaps be coupled with hot shortness, is high thermal expansion and contraction. When the casting has become solid it begins to decrease in size as it cools. If it be of such a shape that there is a long, thin section with large portions at each end which are retained by the sand or the die, the contraction is likely to cause cracks, and, of course, the alloys which are hot short are much more likely to fracture than those which are not. It is because of this defect that D.T.D. 304 can only be used for die-castings of a relatively simple shape, or, at least, are made in a die which is easy to dismantle. Aluminium dies are now being developed, and as they have the same thermal expansion as the casting, the danger of cracking is practically eliminated. The development of these dies (British Patent No. 543,577) would appear to be one of the biggest steps forward in the industry for some time (see "Light Metals," 1945/8/12).

Another factor governing the choice of alloys is prime cost, and here let is be said at once that the aluminium foundry industry has built up a valuable reputation for very high quality castings, many of which have successfully replaced forgings in aircraft. It is because of that reputation that a large proportion of the orders will come to the foundries when metal is again available to industry. Hence, every effort should be made to live up to the good name already obtained, by using alloys which will definitely do the job, preferably, with a little to spare. This is common sense, and sound business. On the other hand, there will be demands for a large variety of castings which have to stand no stresses, and for which, with due precautions, any alloy which makes a "sound" casting will be suitable. In many cases the chief factor which will influence the customer in his decision as to which metal to use will be the price. If a really cheap and satisfactory alloy is available for these simple jobs, the aluminium foundry industry may be able to obtain useful orders. Such an alloy, grade D, is on the market. It will be realized that it is probably a mixture of D.T.D. 424 and D.T.D. 428. Material of this kind was used for car sumps, induction pipes, etc., before the war, and it was quite satisfactory. It can now be obtained at £35 per ton, against a virgin aluminium price of £110 per ton. Its great disadvantage will be its variability, but laboratory control may be extended to alloys of this kind, and should enable them to be used with success. Always, however, the danger of misuse of uncritical compositions must be guarded against. (For horrible example see "Light Metals," 1945/8/86.)

Having considered the customer's requirements, his own requirements, and price, the founder should, with the assistance of the metallurgist, be able to choose his alloy. How will he obtain it? This depends upon his business policy. He may wish to limit his metallurgical problems by using as few alloys as possible, or he may be willing to supply castings in any alloy, even if this means making up small quantities specially, for small orders. In the great majority of cases the best policy will be to order the metal in ingot form from a concern which specializes in their preparation. These concerns may be relied upon absolutely to deliver metal which is correct to specification, both as regards chemical composition and physical properties. Moreover, consecutive deliveries will be reasonably uniform, thus enabling the founder to stabilize his conditions.

If the foundryman does, nevertheless, prefer to make up his own alloys, he may do this by melting aluminium, together with so-called "hardeners." These are aluminium compositions containing a much higher proportion of the added metal than is required in the final alloy to be made. It is necessary to know the exact composition of the hardener, and then to calculate the amount necessary to give the required alloy. The hardeners may be obtained in a wide variety of compositions, but certain mixtures have been found to be most convenient, and it is better to use these. In some cases hardeners may be bought, containing two added metals in a definite proportion.

If the founder has decided to make up his own alloys he may possibly say: "Why half do the job? I'll make my own hardeners, too." The reply to this is the same as Mr. Punch's famous answer—"Don't." Some of these hardeners—the copper hardener, for instance—are quite easy to make, but others, such as the titanium and nickel hardeners, present difficulties which the founder would find himself unable to overcome. Some of the Y alloy made in the early days contained very hard, tiny particles, which damaged tools. These were found to be due to unsatisfactory nickel hardeners. The sound policy, then, is to order all hardeners from concerns which have developed the technique necessary for their preparation.

Some of these hardeners have a melting point which is considerably higher than that of aluminium. In order to make sure that they pass completely into solution, it is good policy to melt them first, perhaps with a little of the aluminium. Having made sure that everything is melted, the remainder of the aluminium should be added so slowly that the metal never solidifies. As this is done, the melting point of the alloy becomes lower, and when the last aluminium is added, the normal casting temperature has been reached. This means that only a small percentage of the charge has been subjected to the high temperature which is so detrimental to the quality of aluminium alloys. Although the alloy is now at its casting temperature, it should not be used without analysis; moreover, ingotting will probably improve its quality, as will be seen later.

Sometimes scrap is available, and the founder would like to make his alloys up as cheaply as possible. With good laboratory control this may be feasible, but it should be remembered that one piece of metal of the wrong composition can make a nasty mess of a large melt.

Available scrap may be of the correct composition, but in an inconvenient form, such as turnings or swarf. This brings us to another property of aluminium, namely, its extreme readiness to combine with oxygen to form aluminium oxide or alumina. If a piece of sheet be clamped vertically by its top edge, and be then heated, it will change in shape; it will become much thinner at the top, but fat and rounded at the bottom. This is because the surface of the sheet, which had been converted to alumina at ordinary temperatures, was attacked much more strongly by oxygen at the higher temperature, and the film of alumina became much thicker. Meanwhile, the main mass of metal inside the sheet had melted, but the film of alumina was strong enough to hold the molten metal. This is very important. If turnings or foil be used in the foundry, they will be put into the melt a little at a time, and while they are getting hot there is an enormous area of metal available for attack by oxygen in the air; hence, a good proportion of the metal will become oxide, and if these strong oxide films catch on a corner of sand as the casting is being poured, the casting will be weak, because of lack of continuity of metal. If the metal added to the melt, and the ingots obtained, be weighed, a good yield may be effected, but some of it will consist of aluminium oxide, which is definitely detrimental. The obvious way to deal with this material is to briquette it and to plunge these solid blocks quickly under a bath of the already molten metal.

Another way in which melts of aluminium alloys may deteriorate is by the absorption of gas. Several analyses of this gas have been carried out, and all have shown it to be almost entirely hydrogen. It is generally accepted that this hydrogen is absorbed by the action of moisture on hot aluminium. An extremely important point to remember is that approximately five times as much of the gas can go into solution at 800 degrees C. as goes into solution at 700 degrees C. If, therefore, the metal be taken to a high temperature and held there for some time, it will absorb a good deal of hydrogen. As it cools, its ability to hold the gas gradually becomes less, until a point is reached when the latter starts to come out of solution, and rise to the top of the melt in the form of small bubbles. This continues until the metal solidifies, and some of the gas is trapped, to form the well-known "pin-holes." Obviously, gas cavitation must be removed before a sand casting is made. When die castings are made the rapid solidification of the metal prevents the escape of gas, and no cavities are seen. Actually, the pin-holes have much less effect than one might suppose on the tensile strength of the metal. Nevertheless, in a casting they could easily collect at some corner and very materially weaken the metal; they must therefore be removed.

There are several ways of removing gas from aluminium alloys. Archbutt[2] has advocated placing the molten ingots in a furnace and allowing them to cool very slowly with the furnace. By the time the metal is solid a very large proportion of the gas has escaped. This works well, but it is an expensive way to degas a melt.

Another method of degassing is to bubble chlorine through the melt. The bubbling should be vigorous and should be carried out for several minutes. Trials will show how long is necessary. Three minutes will probably be sufficient. This method is quite effective, but appears to increase the grain size of the castings. Another disadvantage is that the gas is poisonous and expensive exhaust plant has to be fitted, which is itself attacked by the chlorine.

Hanson and Slater,[3] for the British Non-Ferrous Metals Research Association, developed a degassing method which relies upon the action of dry nitrogen. The original plan was to pass a paddle through a lid which covered the top of the crucible. The paddle was partly submerged in the melt. Nitrogen, dried by passing through several feet of silica gel, was passed over the melt, while the paddle was rotated. A flux, consisting of fluorides and chlorides, was put on the melt. A few minutes' stirring under these conditions will, for practical purposes, completely degas the charge. It is certainly the most effective degassing method which the writer has used. Later the method was modified, the dry nitrogen being bubbled into the melt, and the paddle being no longer used.

In addition to these degassing methods, there are proprietary degassers on the market which appear to remove the gas mechanically. They generate a gas which bubbles through the melt vigorously and probably removes the gas in a similar way to the chlorine.

It is perhaps unnecessary to point out that these degassers should be used under the proper conditions. For example, if the metal is "degassed," at a very high temperature, a higher proportion of the hydrogen will remain in solution than would be the case if the metal were much cooler. Also, after degassing was finished, further gassing would take place while the metal was cooling to its casting temperature.

The best way to obtain a gas-free metal is, of course, to prevent the gas from entering the melt in the first place. Whilst it is impossible to have a perfectly moisture-free atmosphere, it is easy to ensure that no trace of moisture gets into the melt from damp ingots or tools. Some of the fluxes used during melting (which will be mentioned later) slowly take up moisture. If the tool used to plunge these into the metal be left with a cake of flux on it, an appreciable amount of gas may be introduced into the furnace next time it is used. There will also be rapid generation of steam with the ejection of metal. In order to avoid this risk tools should be kept clean and ingots warmed before they are put into the furnace.

Another way to prevent the entry of gas into the metal is to control the temperature carefully. There is no reason why the melt should not be heated up rapidly in order to give maximum output, but the furnace should be shut off, or turned down, some time before the required casting temperature is reached, so that the rate of approach to pouring heat can be controlled. The furnace should be worked in close collaboration with the moulders and should reach the required temperature when the moulders are ready for it. If the metal is heating up too rapidly a little cold scrap should be added to cool it down.

During the melting process it is inevitable that some aluminium will have been oxidized to alumina, and this will, in the ordinary course of events, be included in the melt. The films of alumina which form on the surface have approximately the same specific gravity as the metal. Hence, when the metal is stirred they become suspended in the melt and do not tend either to sink or float. The danger of their being included in the casting has already been pointed out. Aluminium oxide can be removed by fluxes. A great deal of development work has been done and is being done on these, and there are probably very few foundries which do not now use them. If for no other reason than this, it is perhaps wise to try to put them in their proper perspective in the foundry. Rather optimistic but vague claims are sometimes made about the power of the flux to cleanse, refine, deoxidize, etc., and in the case of one flux, used some years ago, it was claimed that it prolonged the life of the pot. How a flux containing fluorides is able to prolong the life of a silicious pot is difficult to imagine, but this flux seemed to be so good that it might almost have been expected to rectify an alloy which had the wrong composition! On the other hand, there are very reliable fluxes on the market to-day backed by people who make it their one job to prepare them and to help the foundries to use them, and these can be employed with every confidence; in fact they actually are used by most of the firms which prepare aluminium alloys.

It might, perhaps, be pointed out that the term "refine" as applied to iron, cannot be applied to aluminium alloys. No method of preferential oxidation, such as is used in the Bessemer process, or of chemical separation, has yet been found, whereby the metallic impurities may be removed from aluminium alloys, with the single exception of magnesium, a remover of which is on the market.* Aluminium fluxes, then, may be expected to prevent oxidation and the pick up of gases, and to remove oxide from a melt containing metal which has been melted a number of times.

There is little doubt that the benefit of the flux would be shown by an improvement in test-bar figures. Different grades of flux are on the market, which melt at different temperatures, and the makers will be very pleased to explain their uses. If remelted scrap be used it is probable that degassers will also be required. This is now generally supplied in tablet form, but the writer still prefers the powder, used perhaps a third at a time, in order to give a long period of action.

Another kind of flux contains a grain refiner. This is very useful to give castings with small, uniform grains. The grain refiner used is generally boron, and it is quite effective.

Whether or not complete degassification should be carried out is still a very controversial question, but its merits and demerits really come under foundry technique. It may be mentioned in passing that some die casters are so strongly of the opinion that some gas is necessary that proprietary preparations are on the market which actually add gas.

* Hexachlorethane.

It is thus possible, by taking precautions while melting, to obtain the required alloy in a clean, gas-free condition. If, however, care be not exercised when pouring, much of this good work may be undone. It is important that metal should be poured in a steady, unbroken stream, and that it should enter the casting cavity with the least possible amount of splashing.

In gravity, and especiallly in pressure dies, the design of the ingate is of the utmost importance. With tall sand castings the plunger runner may be used, or a funnel, with a long tube which reaches to the bottom of the down runner and can be raised as the metal rises. In the case of rolling billets the Zublin mould could be used (see Zeerleder "Technologie des Aluminiums," Leipzig, 1938, p. 159) or the mould suggested by Walker and Bridge (British Patent No. 558,596). Alternatively the metal may be poured down a vertical spiral channel which forms a hollow thread and is raised and twisted to give the motion of unscrewing a screw as the metal rises. With these methods it is important that the metal should be poured through a standard orifice, so that it always rises at the same speed, relative to the movement of the mould or pouring device.

Whilst most foundry alloys can be supplied by a number of manufacturers, the names of the concerns responsible for branding the compositions are as follow:—

Aeral A, William Mills, Ltd.

Alpax, Alpax Beta, Alpax Gamma, Light Alloys, Ltd.

B.A./29, British Aluminium Co., Ltd.

Birmasil and Birmabright, Birmingham Aluminium (1903) Co., Ltd.

Ceralumin B, C and D, J. Stone and Co., Ltd.

M.V.C., Vickers, Ltd.

N.A. alloys, Northern Aluminium Co., Ltd.

R.R. alloys, High Duty Alloys, Ltd.

Wilmil, Wilmil M., British Aluminium Co., Ltd.

Y Alloy, named by the National Physical Laboratory.

REFERENCES

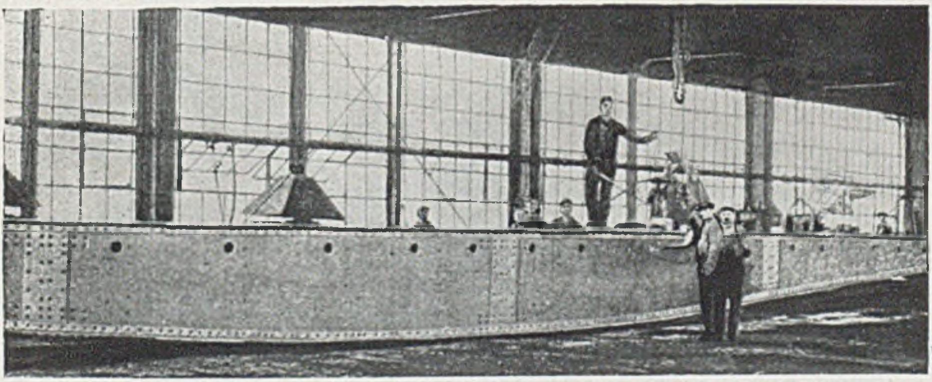
(1) *See* "*Light Metals,*" 1938/1/304; 1942/5/149; 1943/6/557; 1938/1/106; 1938/1/200; 1938/1/204; 1938/1/205; 1938/1/289; 1938/1/295; 1939/2/36, 199, 284, 404; 1940/3/198; 1941/4/9; 1942/5/305, 485; 1943/6/196, 209, 274, 421, 538; 1944/7/267, 352; 1942/5/190, 305. (2) "*Journ. Inst. Met.,*" 1925/33/127. (3) "*Light Metals,*" 1938/1/131. *Br. Pat.* 435,104.

Light Alloys in HEAVY ENGINEERING

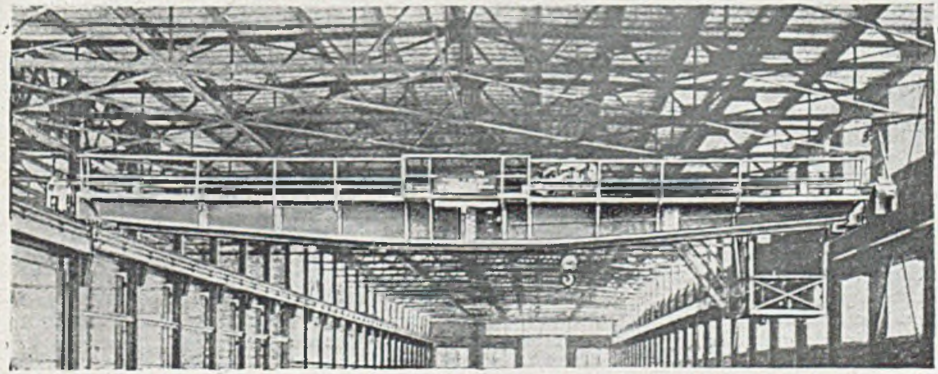
Concluded from "Light Metals," 1945/8/69, this Part of the Account Covers Chiefly Miscellaneous Uses of Aluminium and Magnesium in Specialized Branches of Civil Engineering and Allied Spheres

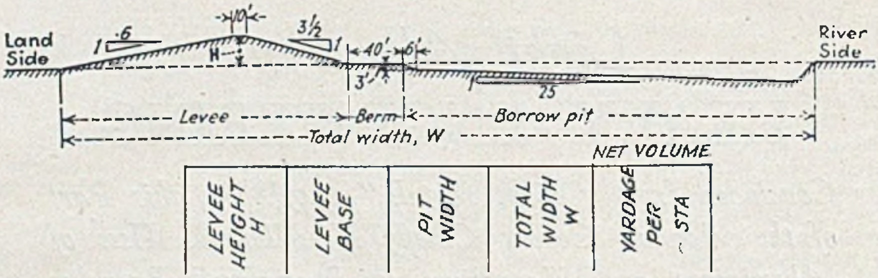
IT will be recalled that, in the opening section of this article, consideration was given mainly to the practical realization of light-alloy design in massive structural work such as cranes, mining equipment and the like. No less important, however, are applications of a less massive order; such uses frequently form an integral feature of the major assemblies previously described in detail.

In Germany, England, and U.S.A., too, aluminium has been employed as a packing or caulking material for pipes. In Germany economy regulations indicated a search for substitute materials, and aluminium wool was found to be very suitable. It could



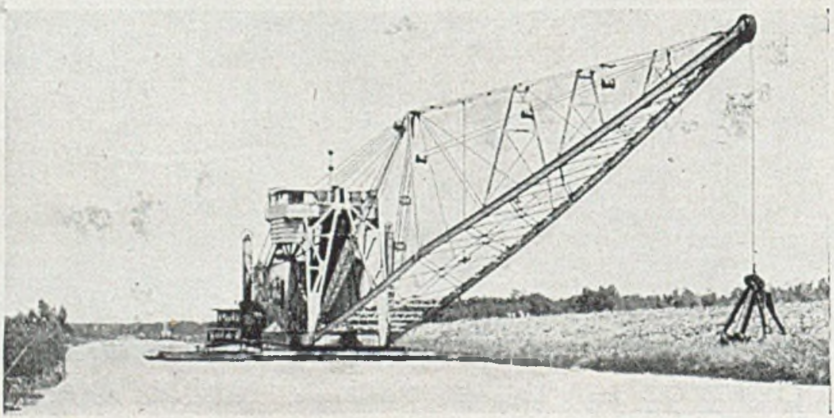
REPRODUCED from "Engineering News-Record," October 16, 1930, the uppermost illustration shows the fabrication of a 10-ton shop crane from aluminium-alloy sheet and sections. The lower illustration, from the same source, depicts, in use, a light-metal crane of 10-ton rated capacity and 72-ft. span.





Levee height, H	Levee Base	Pit Width	T·tal width, W	Yardage per sta.
10 ft.	100 ft.	126 ft.	271 ft.	2,130 cubic yds.
15 ft.	152.5 ft.	205.5 ft.	398 ft.	4,510 cubic yds.
20 ft.	200 ft.	285 ft.	525 ft.	7,780 cubic yds.
25 ft.	247.5 ft.	366.5 ft.	654 ft.	11,900 cubic yds.
30 ft.	295 ft.	448 ft.	783 ft.	16,920 cubic yds.

ABOVE. Section of Vicksburg-type levee (see first part of this account, "Light Metals," 1945/8/55); relevant data are presented in table at left. Below is the "Conical" dredger used for flood prevention on the Mississippi. The boom, 240 ft. long, with a swing of 180 degrees, incorporates two 75-ft. light-alloy sections.



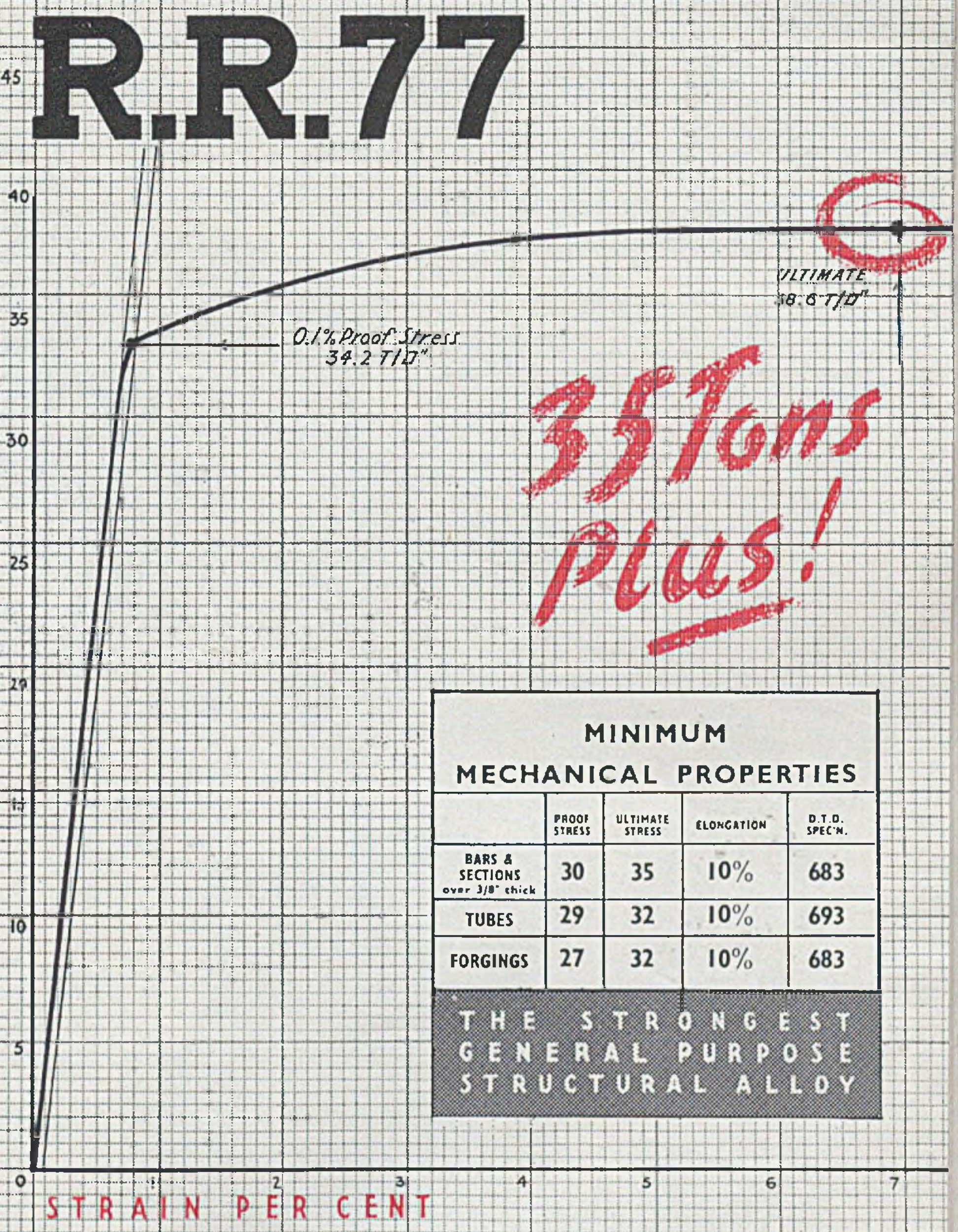
be used on the same type of work as the packing materials it replaced and, for its installation, it required the same tools and no special experience in the operator. Aluminium wool was supplied in plaited strands which could be hung over the pipe until wanted. Important where underground work was concerned was the fact that aluminium appeared to be unaffected by humic acids. Its cost was about the same as that of lead.

Later, however, it was found that aluminium foil was even better—it would, for instance, stand up to 25 atmospheres pressure without a cord packing. An example of the manner in which it was used (in Germany) concerned a cast-iron pipe of inside diameter 150 mm. Impregnated packing thread was packed into the sleeve joint to a height of 41 mm., after which a layer of aluminium foil 28 mm. high was applied to within 10 mm. of the front end of the plate.

In England, "Hopaco" sheet packing material and "Ovalhole" coil packing both utilize aluminium as an essential ingredient. "Hopaco" sheet packing consists of asbestos fibres and aluminium powder compressed together and is sold in sheets 1/64 to ⅛-in. thick. "Ovalhole" coil packing is made of hollow-centred fibre coated with powdered aluminium, the idea being to leave a film of aluminium on the rod or plunger to reduce friction.

The "Al-Lite" hoist illustrated has been described as the first chain hoist to be made of aluminium alloys. It was placed on the market by the Chisholm-Moore Hoist

R.R.77



MINIMUM MECHANICAL PROPERTIES

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

THE STRONGEST GENERAL PURPOSE STRUCTURAL ALLOY

HIDUMINIUM

High Tensile

ALUMINIUM ALLOYS

Specific Gravity 2·8

HIGH DUTY ALLOYS LTD SLOUGH

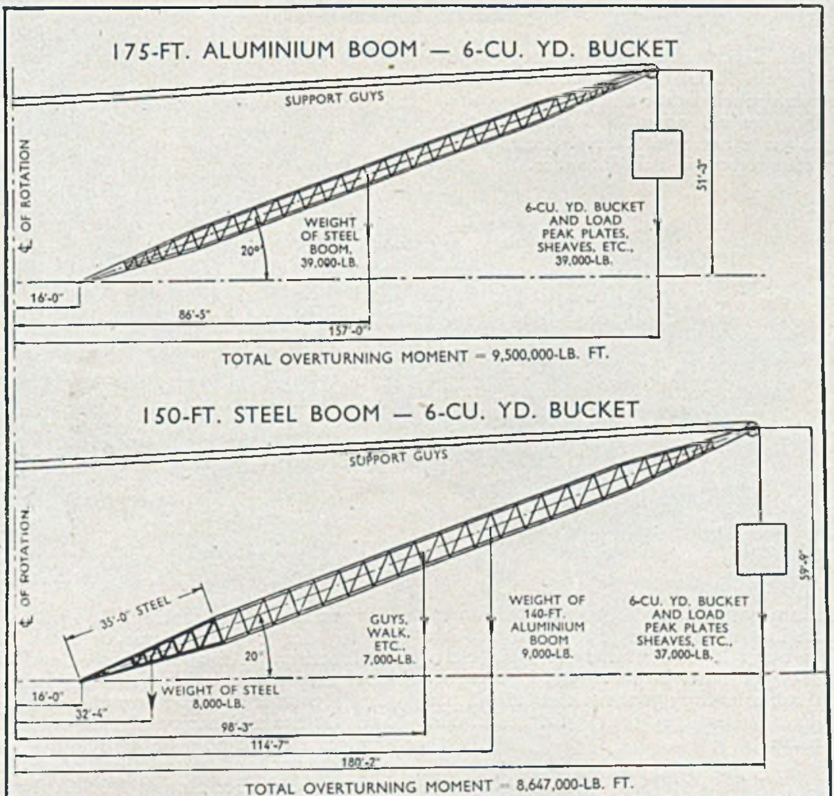
Corpn., Tonawanda, N.Y. One man could lift and carry this hoist which was one-third lighter than similar equipment made of heavier metals. Strength as well as lightness was obtained, the hoists being tested under a 50 per cent. overload. Planetary reduction gears were employed enclosed in a dust-proof housing. Other features included ball bearings, Alemite lubrication, and an adjustable brake which is secure and positive in action. The hoist was finished in bright aluminium and was shown at the second National Industrial Exposition held at Cleveland.

From Germany comes news of a duralumin block and tackle designed to lift 500 kg. which was made by the Gebr. Kerner. All parts except the chain were of light alloy (Leipzig Fair, 1938).

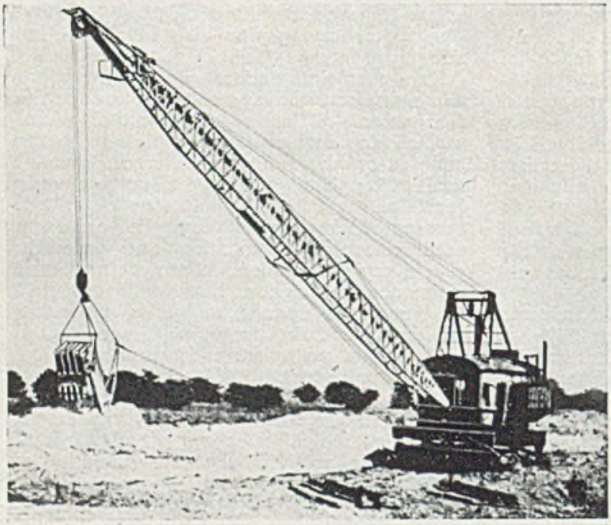
Illustrated is a Swiss production—a motor mowing machine built by F. and P. Aecherli and Co., of Reiden-Lucerne, in which the wheels were of Alufont II alloy. The motor casing was also in aluminium alloy (unspecified).

The corrosion resistance of aluminium alloys renders the material attractive for the fabrication of wire screen cloth where moderately corrosive materials are being handled or where all possibility of contamination by iron or copper or by their corrosion products must be avoided. Screens of woven aluminium wire are often used in such circumstances and generally give every satisfaction. Their strength and resistance to abrasion, however, are not all that could be desired, and it is sometimes preferred to make use of steel wire coated with aluminium by a hot-dip process.

U.S. patent 2,273,483 claims the production of a duplex aluminium-base wire for use in the manufacture of wire screen cloth in which a core of aluminium-magnesium alloy is coated with another

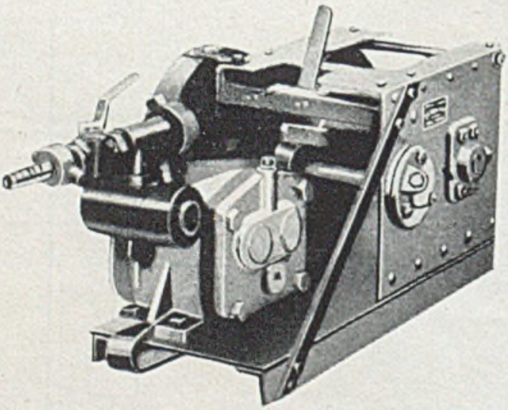


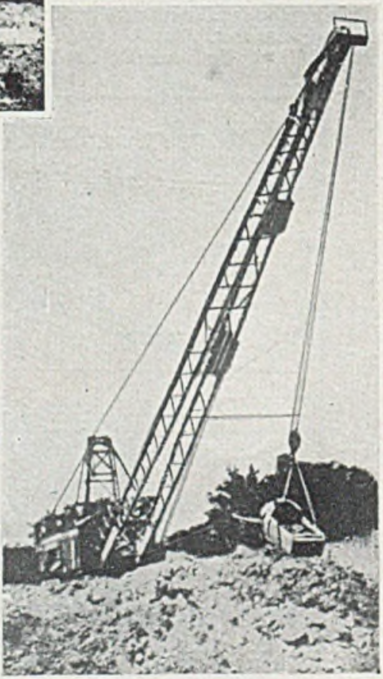
PRESENTED here, in diagrammatic form, are equivalent crane booms in light-alloy (uppermost diagram) and steel (lower diagram). It will be seen, from the data given, that the total overturning moment of the former is some 12 per cent. greater than that of the latter.



AT the left is illustrated a 175 ft. composite aluminium-steel boom with 7-cubic-yd. steel bucket, operated by Arundel Corp., New Roads, La. Below is a 150 ft. composite aluminium - steel boom with 8 - cubic - yd. bucket, operated by McWilliams Dredging Co., Transylvania, La.

THE lightweight, power-operated windlass shown below is of German origin and features much light-metal in its structure. It weighs, in all, about 100 lb., and may be operated either by a 2.5 h.p. electric motor, or by compressed air at 21 lb./sq. in.

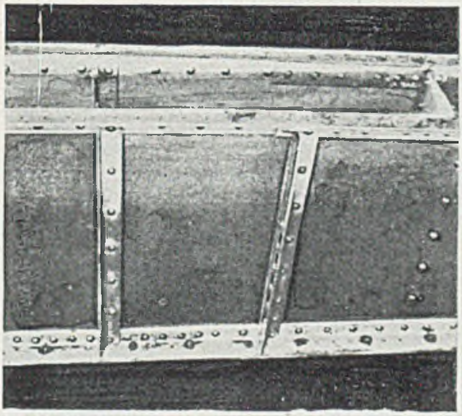


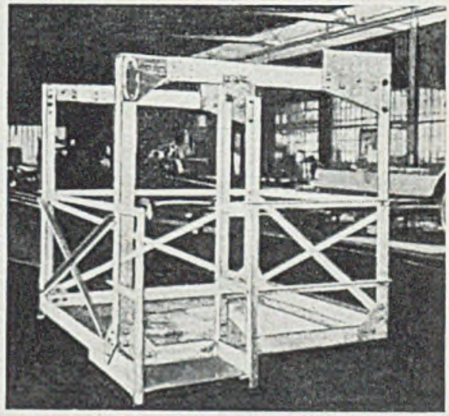


aluminium-base alloy The composition of the core is 4-6 per cent. Mg, remainder Al, and the outer layer contains 0.5-3 per cent. Zn, 0.5-2 per cent. Mg, 0.25-1.25 per cent. Si, and a hardening agent such as 0.1-0.5 per cent. Cr or 0.1-1 per cent. Mn, remainder aluminium.

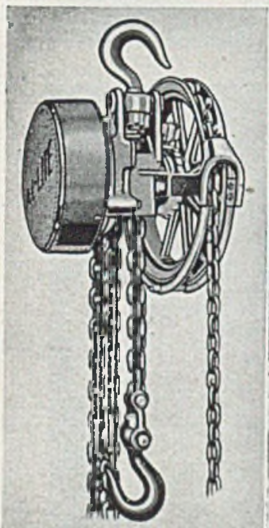
Magnesium-base Alloys

Magnesium-base alloys come quite considerably into the picture of heavy engineering. Illustrated is a magnesium alloy sandcasting weighing 550 lb. intended for a pump base. This is only one example from many instances in which large magnesium alloy castings have been produced for various purposes in heavy engineering. At the opposite end of the scale may be cited the Fenton-Smith pump, also illustrated, which weighs only 2½ lb. and yet has a capacity of 17.3 cubic ft. per min. of free air at a back pressure of 8 ins. of mercury and a suction of 6 ins. of mercury when running at 3,500 r.p.m. This appliance was designed for use on operational aircraft for actuating pneumatic blind-flying instruments and de-icing apparatus on the wing leading edges and other vulnerable portions of the aircraft. Ultra-light alloy was chosen partly to



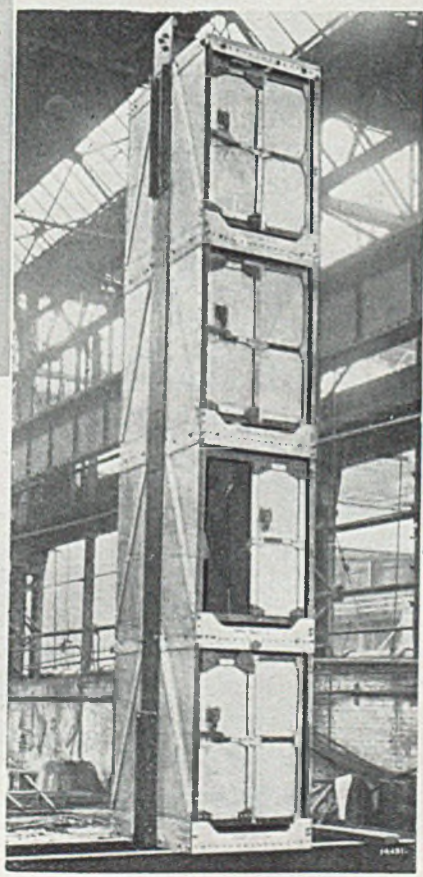


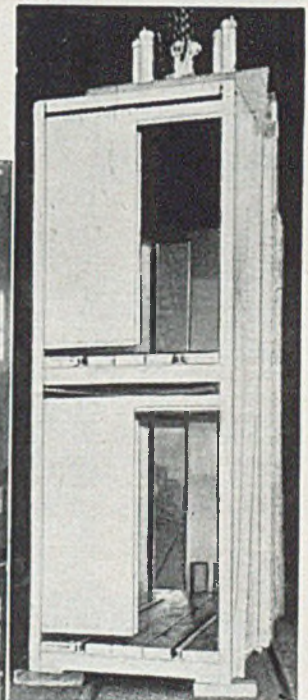
ABOVE (left).—Illustrating double-web construction of light-alloy girder for 10-ton shop crane shown on first page of this section of the article. Above (right).—Operator's cage for the crane, constructed of light-alloy angles and plates.



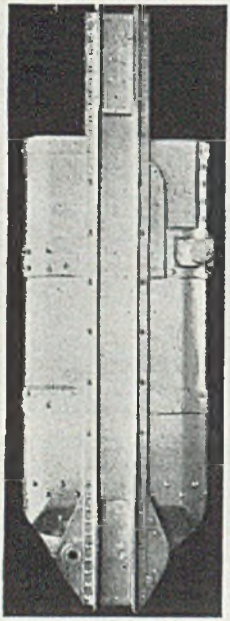
THE "Al-Lite" hoist, in which all parts, other than the chain, are made in aluminium alloy, is illustrated above.

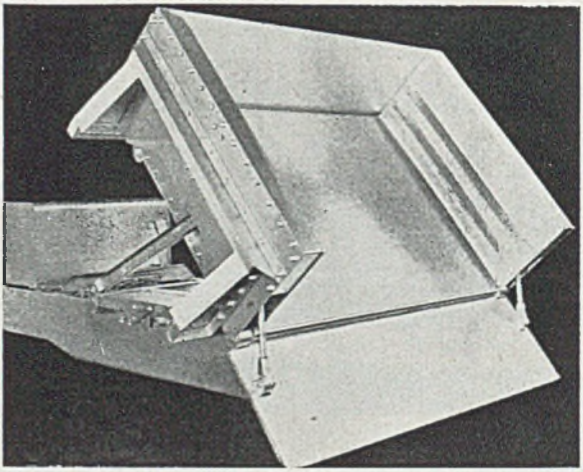
PICTURED at the right is a four-decker man cage constructed in duralumin and supplied for use in South African gold mines.

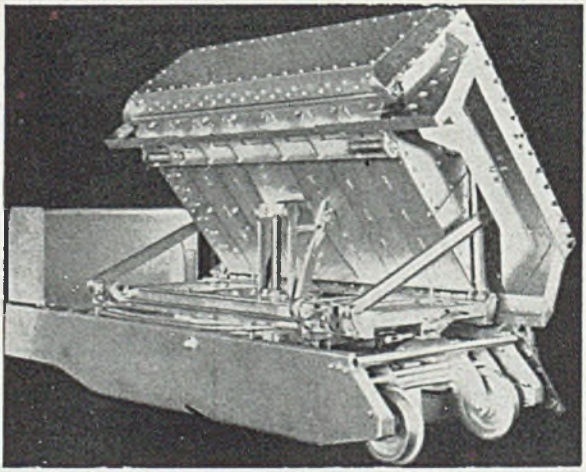




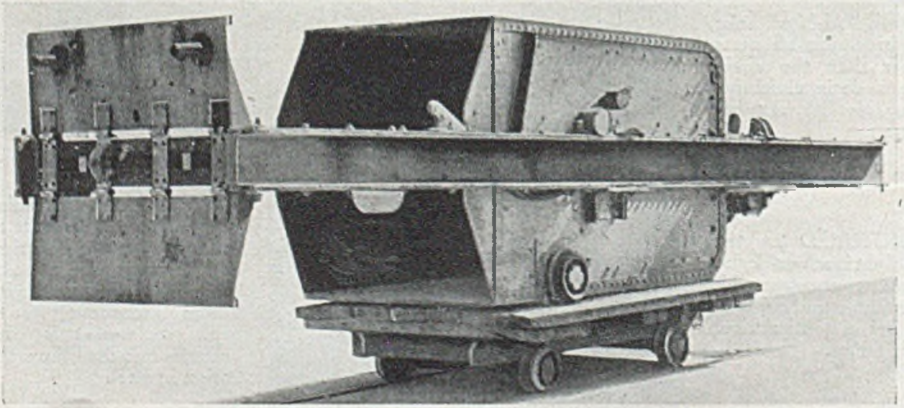
SHOWN above is a double-deck cage holding 50 men. It was constructed in 27ST plate and section, and 4S sheet and plate by the Lake Shore Engine Works, Marquette, Michigan. Its weight is over two tons less than the same design in steel.

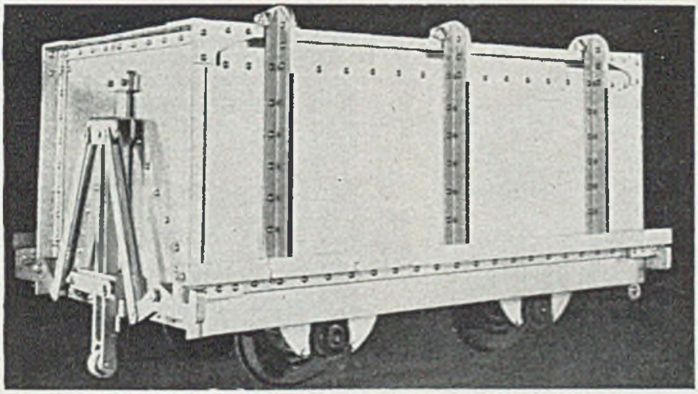




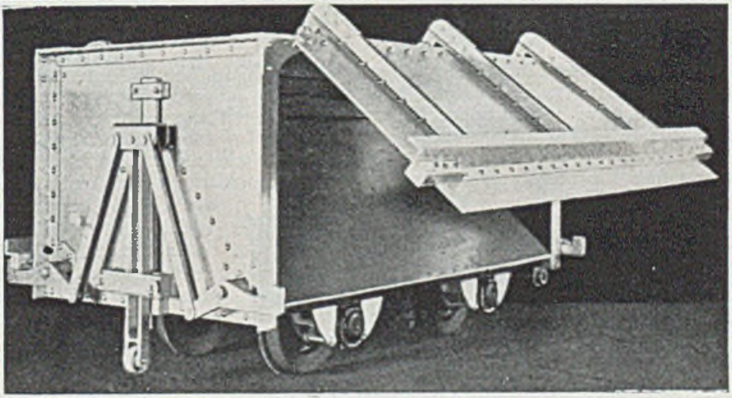


ABOVE, left: light-alloy skip hoist (Lake Shore Engineering Works). Top (right) and on the right are two views of a dump car, the bodywork and other parts of which are in light metal (Lake Shore Engineering Works). Below is a 7-ton mine skip in duralumin, by Vickers-Armstrongs.

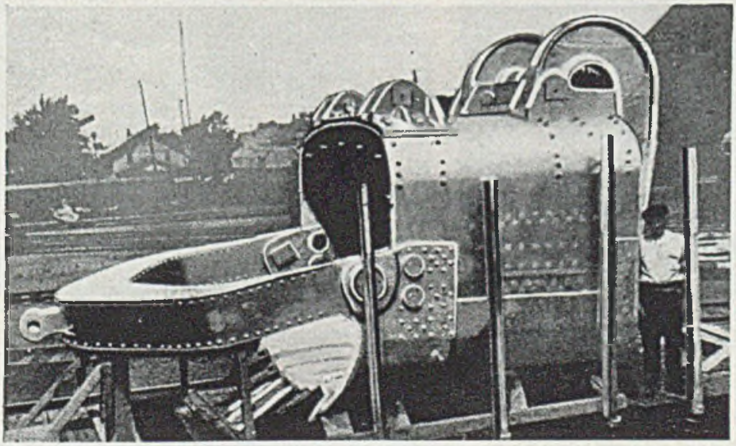




LEFT.—Use of light-alloy plates and sections in the construction of this electrically operated remote control stock-pile car of 140 cubic ft. capacity resulted in a 3,700 lb. reduction in deadweight and 50 per cent. payload increase. (See illustration below.)



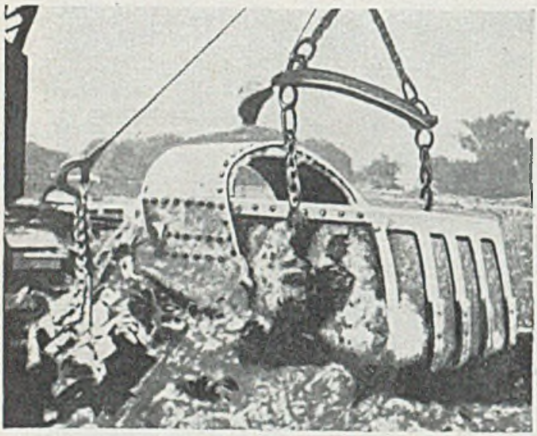
RIGHT.—Another view of light-alloy car shown above. The lift-up side is automatically actuated by a dump arm through a centre rail on the track.



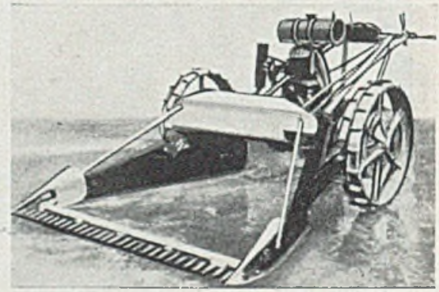
CONSTRUCTED by the Marion Steam Shovel Co., Ohio, the 17 cubic-yd. shovel dipper illustrated at the left is built almost wholly of aluminium-base alloys.

obtain a very low weight in the complete pump and partly to reduce the momentum of the high-speed moving parts, and there is no doubt that the result is a remarkably fine achievement.

Not infrequently magnesium alloys have been chosen for the construction of complicated housings because they are easy to form and machine and because the weight of the complete housing is low. Somewhat more unusual, however, is a pressure die-cast magnesium alloy gearbox. The weight of the gearbox is 2 lb. 3 oz. and, in its fabrication, 72 cores were employed



SHOWN at the left is a 2-cubic-yd. composite aluminium-steel bucket operated by Boone and Webster, New Madrid, Mo. Below is a mowing machine constructed by F. and P. Aecherli and Co., Reiden-Lucerne. The wheels and motor casing are in light alloy.



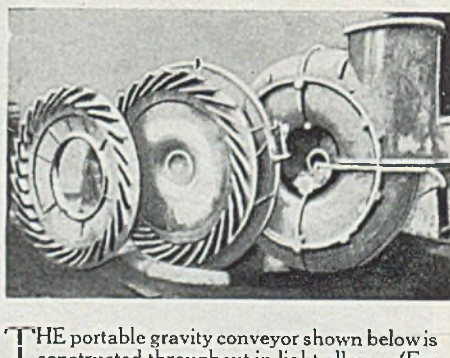
withdrawn from all sides of the box. Baseplates, covers, bearing blocks, belt wheels, and levers have been produced in magnesium alloys by the pressure die-casting process.

Finally, we would mention magnesium-alloy dies for press work. Pruess, writing in Metallwirtschaft, 1938, expressed the opinion that the use of magnesium alloys for the manufacture of dies for the pressing of automobile wings appeared likely to find extensive application in Germany. Considerable technical and economic advantages are claimed for this practice. The dies, which are supplied to the user in the as-cast state, are, of course, very much lighter than the correspondingly steel dies, and tooling operations are easier and more rapidly carried out.

Furthermore, saving is effected in handling costs when the dies are in use

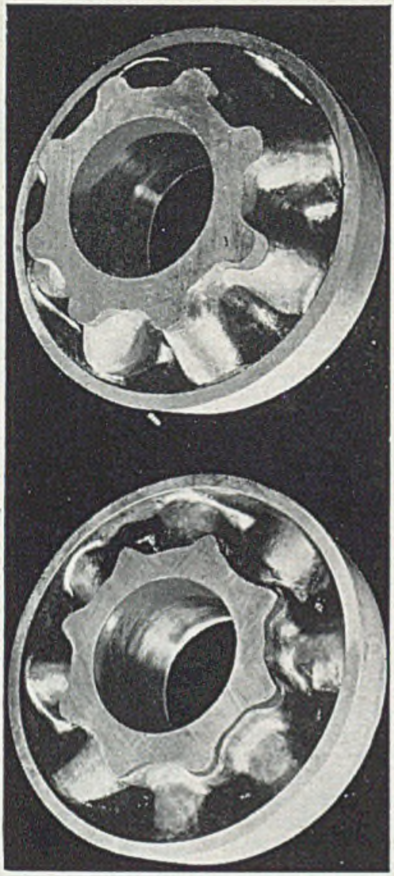
ABOVE. The casing and main structural castings for the assay muffle furnace at Chelsea Polytechnic shown here, are in aluminium alloy. Light metal withstands well the service demands called for in this equipment.

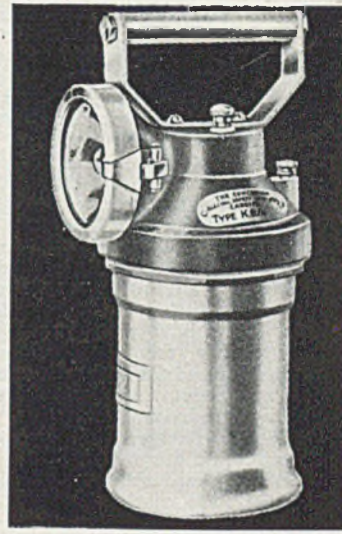
(Courtesy Gas Light and Coke Co.)



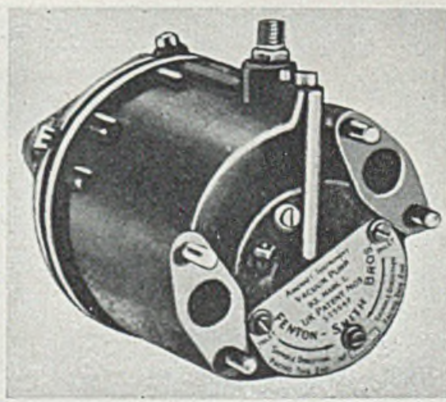
THE rotors and casing of the centrifugal pump shown dismantled (above right) were pro duced as aluminium-alloy sand castings by the Menziken and Gontenschwil Aluminium Products Co., Ltd., Menziken.

THE portable gravity conveyor shown below is constructed throughout in light alloys. (For detailed account of magnesium-alloy equipment of this type, see "Light Metals," 1939/2/216.)





LEFT. Two views of one half of a magnesium-alloy pulley for a 25-ton double-acting hammer. Cast by Sterling Metals Ltd., it is about 40 ins. in diam., and in the fettled state each half weighs about 520 lb. At the right is the "Concordia" electric safety lamp, the principal parts of which are cast in magnesium-base alloy. Below is the Fenton-Smith B3 Mark I vacuum pump, all of which, excepting gears, spindles and studs, are in "Elektron" magnesium-alloy.



due to their low weight, expensive lifting tackle being dispensed with, and it is interesting to note that definite economies are obtained in the power consumption of the press itself as the upper half of the die, being so light, does not require the consumption of so much energy to lift it when in operation. The life of these dies is believed to be satisfactory.

To sum up, it appears that the versatility of the light and ultra-light alloys enables them to fulfil a number of important applications in heavy engineering to definite advantage.

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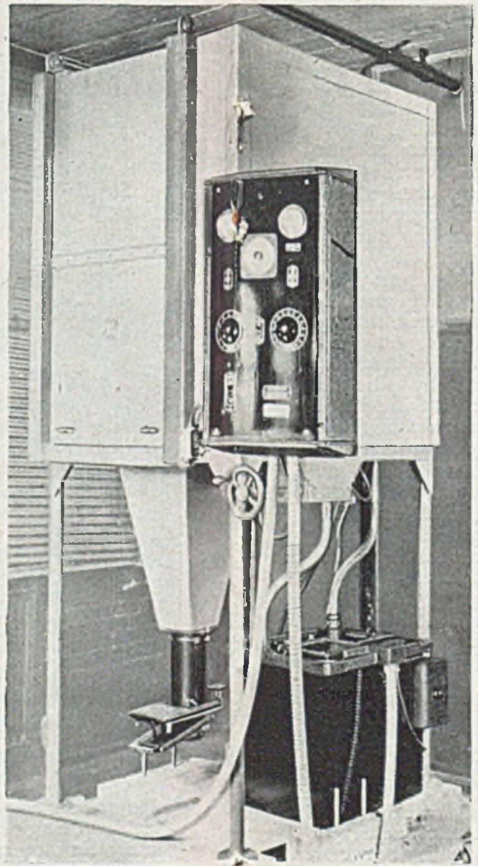
PHOTO-RÖNTGENOGRAPHY

F. A. Allen Describes a Modified Technique of X-ray Examination Designed Primarily to Economize in Time and Ex- — — pense and One Which at the Same Time is Possibly More Convenient Than Straightforward Radiography for Screening



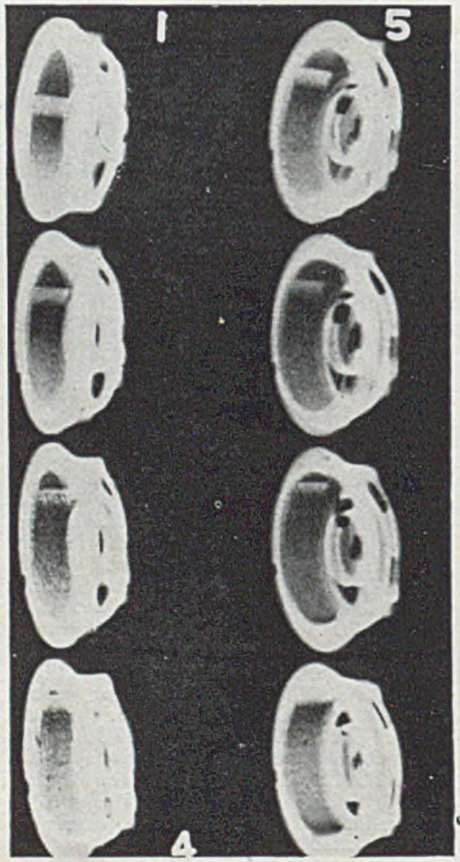
THE centre illustration is of an industrial Photo-röntgen apparatus manufactured by the Victor X-ray Corporation. With this equipment it is possible to obtain a photographic record on a reduced scale of a screened image. Reproduced at the left— —and right of these pages are typical examples obtained by this technique. The fact that resolution is little affected and that the image is obtained on a film of such small size, promises a keen industrial interest for post-war purposes.

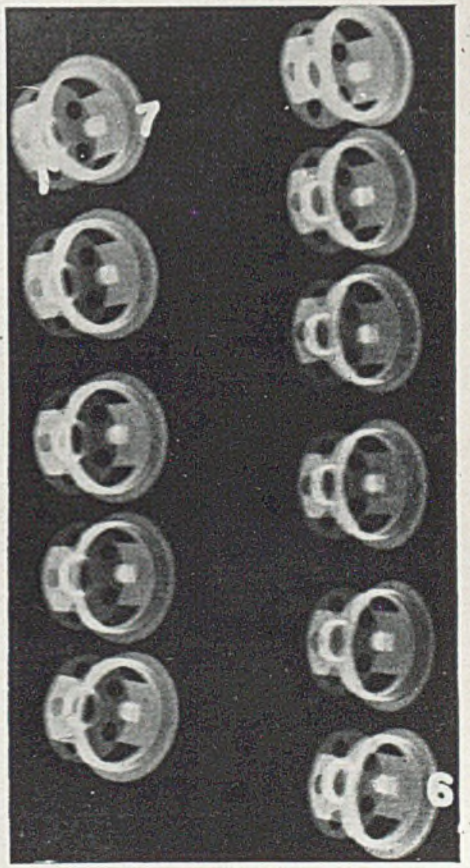
ONE of the problems facing the light-metal foundry industry in the change from war production to peace, will be that concerning the amount and kind of inspection applied to non-aircraft castings. It must be remembered that light-alloy foundries have, for a period of approximately ten years, been engaged almost exclusively on aircraft castings, the inspection of which has been subject to the requirements of the Ministry of Aircraft Production; and whilst such inspection has been vitally necessary in the national interest of building up and maintaining an Air Force second to none in the world, it does not follow that such excessive care is necessary for commercial earth-bound applications of the light alloys of aluminium and magnesium. Indeed, in normal commercial conditions inspection, as required for A.I.D. release, probably would not be an economic proposition.

Nevertheless, the present high standard of light-alloy castings is due, in no small measure, to just that strict inspection that must eventually be modified and relaxed. Without doubt, statistical methods of quality control will be more and more applied to visual and dimensional inspection giving the maximum certainty of standard with the minimum of indirect labour expense. It will be agreed, however, that the high standard of production is due, above all, to the application of X-rays as an inspectional tool, and a particular aspect of the problem is to what extent this method shall be retained in post-war days. Radiography, that is the production of film record, is an expensive process.

Whilst radiography cannot be waived in the examination of stressed aircraft castings, it should be remembered that this technique is not the only means of X-ray application to non-destructive testing. The second method is that referred to as fluoroscopy, more popularly as "screening," in which the shadow of the casting in a beam of X-rays falls upon a fluorescent screen. Provided the screen be suitably protected with lead glass, the image may be directly viewed. Now the image viewed on the screen is not as critical as the image fixed upon a photographic film by exposure according to officially accepted radiographic methods.

It is well known that the technique of radiography has improved greatly during the period it has been applied to metallurgical inspection. Improvements, in the main, are due to two factors: X-ray tube construction and photographic. In the first instance, the target, from which the rays emerge, has become successively smaller until now. For all practical purposes, the pencil of rays emerges from a point source, thus giving the maximum definition of discontinuities within the casting. The case is comparable to the shadow produced by placing an opaque object between a source of illumination and a screen: the smaller the light-source the sharper the shadow, broadly speaking. Second, manufacturers of photographic film have achieved material of remarkably fine grain. The improvements briefly outlined have resulted in really critical radiography: given the combination of modern fine-focus tube equipment and the latest fine-grained film, minor discontinuities in light-alloy cast structures, such as micro-porosity in magnesium alloys difficult to see ten years ago, are now easily discerned. Technique methods prescribed by the A.I.D. for the radiographic examination of specific castings often instruct that one or another brand of fine grain film be used.





The foregoing may be expressed briefly by stating that the sensitivity of radiography has improved.

Although perhaps not so much attention has been given to fluoroscopy, it is nevertheless no doubt true that refinements in the grain size of the chemicals composing the screen would give a parallel enhancement of sensitivity. It is hard to believe that the last word has been said on the subject of fluoroscopy. A safe assessment of sensitivity of the two methods is 2 per cent. for radiography and 10 per cent. for screening, sensitivity being defined as the dimension of a distinctly visible discontinuity expressed as a proportion of the cross-section containing the defect.

There are probably few peacetime commercial applications of light-alloy castings for which mechanical failure would be as serious a consequence as failure of stressed aircraft components, and, therefore, there is bound to be a big reduction in the amount of inspectional radiography in those foundries the peace-time production of which is entirely non-aircraft work.

This discussion suggests that the peace use of radiology will be of different intent from that at present. Radiography will continue to be used without doubt during foundry experimental work to determine moulding technique. This use of radiography has been amply proved to be of great assistance. Fluoroscopy will come back into its own as a means of ensuring that castings going forward to a customer's machine shop shall be at least free from gross defects the presence of which may cause trouble in process or may lead to waste of time in needlessly machining a casting ultimately found to be scrap.

Fluoroscopy suffers from numerous disadvantages, however. There is considerable fatigue experienced in viewing the screen, ray-proof equipment is expensive: and inspection is transient—there is no record. However, within its limitations, the method is cheap and speedy.

On the other hand, radiography is expensive and slow. It is expensive because of the double requirement of photographic materials and labour in the dark room; it is slow partly because of the time-lag due to processing the film (or films if the casting be of such complicated form that a multiplicity of exposures are required) and because of the necessary specialist viewing and interpretation of the film.

An aspect of post-war radiology not previously mentioned is that of consumer interest, for there can be little doubt that those machine shops that have dealings with radiographically inspected components for considerable war-time periods will have realized the advantages of receiving sound castings on which to work, and it is anticipated, therefore, that in the future many purchasing specifications for castings will insist upon some sort of radiological inspection probably based upon M.A.P. requirement now in use.

There are, it is submitted, two reasons why radiological inspection will continue even in commercial production: foundry-process control at the manufacturing stage, and because the customer requires it, provided he can get the service without the addition of too great a burden on his price.

There is no need to discuss here the use of X-rays in foundry control for this is a domestic use, the cost being charged to some sort of development account and recovered as a proportion of the factory overhead.

Inspectional radiology, then, may be either fluoroscopy or radiography. Fluoroscopy is likely to be used as a supplementary inspection of all production that will later have to pass through machining operations. What of radiography required by purchasing specifications? If these are modelled upon M.A.P. regulations, the customer will have the right to see radiographic results.

News from the United States tells of an interesting development combining the convenience and cheapness of screening with the permanence of radiographic record. The process consists in photographing the image on the fluorescent screen, and is known as "photo-röntgenography."

Many advantages are claimed for the process. In the first place, whilst visual viewing is transient, and insensitive to the visual sense, causing defects to be missed because of eye fatigue, photographic reproduction of the screen gives a much more detailed picture, for the photographic film may be exposed for suitable periods, and discontinuities hardly perceptible to the eye are hence revealed on the resultant film. A sensitivity of 5 per cent. is, in fact, achieved by this method, a nice compromise between the 10 per cent. sensitivity of the visually viewed screen and the 2 per cent. of normal radiography, and 5 per cent. sensitivity is likely to be adequate for most inspection of commercial castings. Further, the photographic film record obtained is of reduced size. Actually, the table on which the castings are placed is 17 ins. by 14 ins., the size of photo-röntogenographic record being 5 ins. by 4 ins., the reduction resulting from the system employed. Thus as many castings as may be accommodated on a 17 ins. by 14 ins. area may be processed at one time. It is estimated that the film cost is reduced to one-twelfth, and the smaller negative to be passed through dark-room processes again gives substantial processing economies, the total saving probably amounting to one-twentieth of normal radiographic costs.

The miniature films are viewed on an illuminated screen in the normal manner. It is advisable to mask the screen so that definition of the small film is at a maximum while viewing, and similarly black paper masks may be used to fix the attention on the image of one casting at a time when many small castings are reproduced on one film, or on part where one large casting is reproduced. If these simple practical precautions are taken, small defects may be easily seen.

The general arrangement of the equipment is shown in an accompanying illustration. Transformer and control switchboard are seen to be integral with the apparatus. The tube is situated within the protected box-like container, the castings to be examined being placed upon the fluorescent screen constituting the floor of this box. It will be seen that a sliding sash allows easy access to the screen platform. Below is situated the camera equipment. To demonstrate results, there are reproduced representative miniature films produced by the method and equipment described.

It may be pointed out, finally, that the equipment illustrated need not be solely reserved for the miniature radiography system described. Films up to the size of 17 ins. by 14 ins. may be placed on the table, the casting to be examined placed upon it, and the exposure made in the normal manner. With the limits of size, therefore, the photo-röntgenographic apparatus has a double purpose.

The system is attractive from many angles, and it is suggested that post-war radiological inspection of light-alloy castings may well be undertaken adequately by the method of photo-röntgenography.

Founding of Magnesium Alloys

The Properties of Moulding Sands for Magnesium Casting Having Been Dealt With in a Previous Section of This Account ("Light Metals," February, pp. 82-84), Specific Consideration is Now Given to the Practical Handling of Inhibitors

IT will be remembered that moulding sands for magnesium alloys were discussed from the aspect of suitable physical characteristics. These characteristics are necessary for the achievement and maintenance of high permeability. Oxidation of the molten metals in the mould was prevented by the addition to the sand of reaction restrainers or inhibitors.

The amount and type of inhibitor chemical used varies considerably with the type of casting and personal choice. A mould cavity requiring 100 lb. of metal to fill it will need a greater inhibitor content in the sand than a mould to produce a casting of a few ounces weight, for the reason that a greater volume of metal requires to be protected. Again, the sort of cross-section regulates the amount of inhibitor addition; thin sections produced by narrow mould cavities will not require so much inhibitor in the facing sand as in the sand facing a section of extreme thickness. It may be suggested that a lesson might be learned from present American sand-casting practice developed during the war to use women labour.

In order to achieve foolproof standardization of method, one American foundry at least produces aircraft engine cylinders in what might be described as composite moulds. Different sections of the mould are made by the use of sand of specific properties, so that the factors of solidification rate and ease of production may be definitely observed. This suggests that moulds for magnesium moulding may be produced from sands containing varying amounts of inhibitor; for example, sand forming the cavity of a massive section could be higher in inhibitors than the sand to make a thin section of the same casting. There is a good reason why this method should be adopted. Inhibitor contents should be the least possible to secure oxide-free castings, for a major increase in inhibitor content may mean that the margin between soundness and unsoundness may be small, especially in thin-section jobs and in those cases where permeability is decreasing. Absence of inhibiting substances gives rise to what has come to be known as "sand attack," in which it appears that a combination of molten magnesium, steam and the silica of the sand results in a chemical reaction with the production of unsightly defects on the surface of the casting.

Inhibitors are added to core sand mixes also, and although it is problematic as to the amount remaining after baking, it is certain that the residual trace assists in the production of castings of good cored appearance, whilst complete absence of inhibitors in cores may result in some sand attack, not, of course, due to moisture from the core itself, but possibly from the dilution of inhibiting gases within the mould.

In English practice, magnesium mould sand contains either sulphur and boric acid or ammonium bifluoride (ammonium acid fluoride); for castings up to 25 lb. weight, sulphur and boric acid content of approximately 5 per cent. and 1 per cent. has been found to be adequate. When the weight materially increases above this figure, it may be found necessary to increase the sulphur content, about 8 per cent. being the maximum figure for the largest casting at present in production. The fluoride sands contain between 1 and 3 per cent. of ammonium bifluoride, and with higher bifluoride content the moulding properties of the sand become very poor.

To those unacquainted with the more intricate branches of chemistry, certain of these statements may, at first sight, seem to be both confusing and contradictory. It will be remembered that the function of the inhibitors is confined, primarily, to the control of reactions at the surface of the metal. However, during the actual process of casting, the latter must be dealt with in both the liquid and the solid phase, the former being probably more sensitive and capable of transmitting surface effects to the interior of a mass of metal. The latter, whilst less likely to suffer deep-seated attack of any type, may, as we have seen, suffer reaction with sand (this occurring probably before freezing has been completed). Thus it has been demonstrated that inhibitors are required to control these surface effects, either by the production of a special atmosphere within the mould cavity and within the body of the mould itself, or, alternatively, by the production of resistant coatings on the freezing metal.

From this standpoint, therefore, it is not easy to appreciate why variation in casting section should imply some degree of change in the concentration of inhibitor used. However, it is necessary, again, to remember that, at its most reactive stage, the metal is in a liquid form and is entering the mould at a relatively high speed, displacing not only the gaseous contents of the mould cavity but, at the same time, exerting a powerful washing effect on the surface of this. The influence of these two actions will be proportionate, in a measure, to the amount of metal being run, and to the distance through which it runs.

So far as the harmful effects of excess inhibitor are concerned, it should be remembered that these additions to the sand are made purely to overcome special difficulties associated with the chemical reactivity of the metal; physically this must not be visualized as interfering with the mould surface: excess fluoride, for example, will obviously exert a harmful effect in this direction, whilst the use, too, of an over-abundance of sulphur is, clearly, of no value.

Magnesium moulding sand is prepared by mixing washed silica sand of the required grain size, distribution and the inhibiting substances. Bentonite is added and water slowly run on the mix to hydrate the bentonite to form the clay bond. The moulder speaks of the "feel" of the sand, by which, of course, he means his assessment of the moulding properties as made by inspection of the cohesion of a handful of sand. The amount of water added will be 4 to 6 per cent. to give a result that the moulder knows can be used. The permeability of magnesium sands so mixed, using the normal grades of silica sand, is 90 to 140 on the A.F.A. scale.

The period during which the prepared sand may be used is limited, for the artificial addition of water to a dry clay substance seems to give a clay having different properties from the natural clay associated with natural sands. The water seems to be more loosely held, with the effect that the sand, low in moisture at the outset, speedily becomes dry to the moulder's touch, and, in fact, unusable. This dryness is a real disadvantage in the use of synthetic sands.

Moulding and running methods for magnesium alloys follow closely the methods used for aluminium alloys. Bottom pouring is to be preferred as a general rule, but the chief consideration is the elaboration of methods to secure control of solidification. Efficient production can only be achieved by experimental runs in which the castings are subjected to radiographic inspection and fracture test, the results of such tests guiding the progressive modifications of moulding technique, until certainty of first-class castings is obtained.

Cores for magnesium sand casting are produced from similar synthetic-sand mixes as indicated, inhibitors being added, although some of the amount would be lost during baking. A coarser-base sand may be used with advantage, especially when the core makes contact with the moulding-box face; in this way the maximum permeability is used with the certain evacuation of the mould of air, moisture and gases as the molten metal fills the mould cavity.

(To be continued)

Light Alloys in Locomotive Motion

E. V. Panneil Discusses Theoretical and Practical Aspects of Light-weight Construction in this Specialized Branch of Engineering. Principal Consideration is Given to the Effect of the Use of Aluminium-alloy Assemblies on Stability

Locomotives versus Permanent Way

DURING the years 1930 to 1939, a very marked increase was noted in the speed of passenger trains. This acceleration was long overdue and its immediate effect was the increase of passenger travel and revenue; the public at large became, once again, more railway-minded, and the growing preference for long-distance road travel was partially checked. It will be fatal for the railways not to re-establish and extend high-speed travel as soon as the war-time loads cease to have first place, and the demand for comfortable fast transportation, long denied, will result in more passenger-miles and increased earnings if it be developed. Railways, in this and other countries, face increasing competition from road and air transport, and experience has shown that the only answer lies in high speed.

Very few of the public, however, are aware of the considerable problems which underlie passenger train operation at time-table speeds of 75 m.p.h. and over. Apart from traffic density and "working," two of the main factors are:

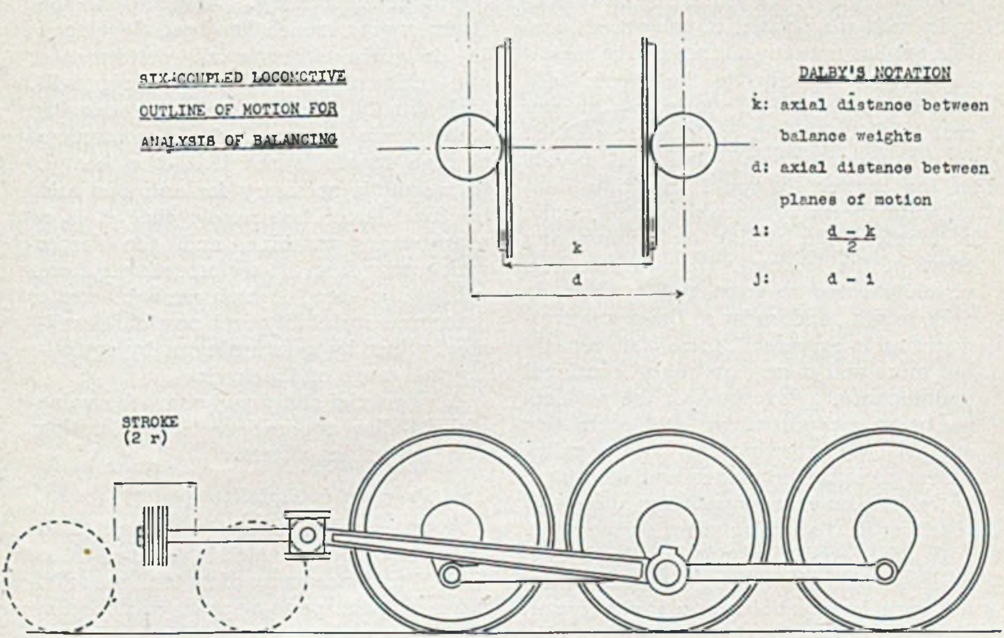


Fig. 1.—Outline of locomotive motion for the purpose of this study—the effect of substituting light-alloy connecting rods and cross-heads.

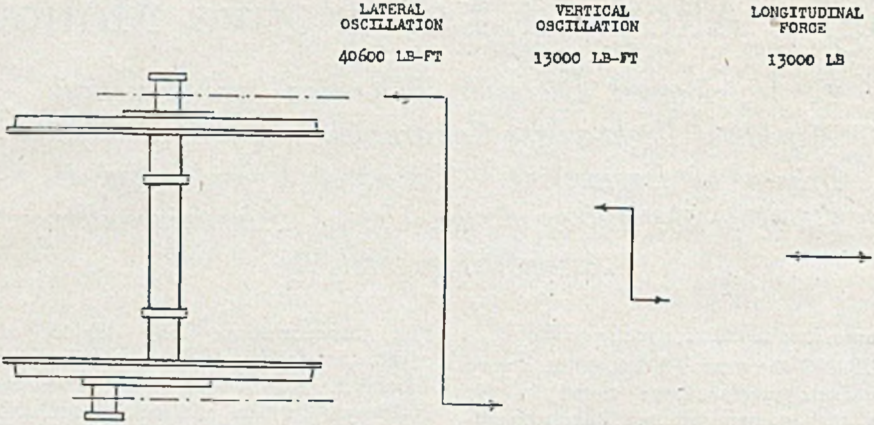


Fig. 2.—Oscillating couples at 80 m.p.h. due to the unbalanced proportion of the reciprocating weights.

(a) locomotive power and train design with the requisite reduction in weight and wind resistance, and (b) permanent way design and maintenance to stand up to the abnormal loads and shocks occasioned by fast and heavy trains. Practically all problems in movement increase in magnitude with the square of the speed, and this applies not only to locomotive steaming power, but also to the shock loads on the track; indeed, it is safe to say that the latter factor is the more serious. If the permanent-way staff had a vote in the matter it would probably limit all train speeds to a maximum of a mile a minute. The nosing and hammering effect of the locomotive on the track is virtually twice as great at 80 m.p.h. as at 60 m.p.h., and, so far as the permanent-way staff is concerned, there is no remedy but more and more careful and continual maintenance. Nevertheless, the problem is being recognized by the locomotive engineer, and, having produced a prime mover of immense power and efficiency, he is now concerned with the matter of reducing its disturbing effect on the road.

In other countries, notably the United States, high-speed long-distance trains are very largely built on a multiple unit principle. This involves a Diesel engine and generator housed in the leading vehicle and driving motors more or less distributed throughout the train. In this way not only are reciprocating masses absent from the driving motion, but the tractive effort is no longer concentrated in the leading unit and the track is no longer subjected to undue punishment by nosing or hammering. Nevertheless, the steam engine, which has been developed to its highest degree of performance and efficiency in this country, will undoubtedly dominate railway work for many years to come. Its disadvantage at high speeds is not that it is heavy, its weight is necessary for adhesion and tractive force, but simply that it is a reciprocating machine, and the forces which arise from its reciprocating masses will, if the speed is high enough, create dangerous instability and possible derailment either by overturning or by spreading the gauge of the track.

A very brief study will show the value of light-alloy applications in ameliorating these disturbing effects.

The Question of Stability

Apart from the sheer deadweight load of the locomotive, which is assumed to be limited to a maximum of 20 tons per axle, stresses in the permanent way arise from two main sources: (a) the nosing or spreading action which is caused by the couples formed by the inertia of the re-

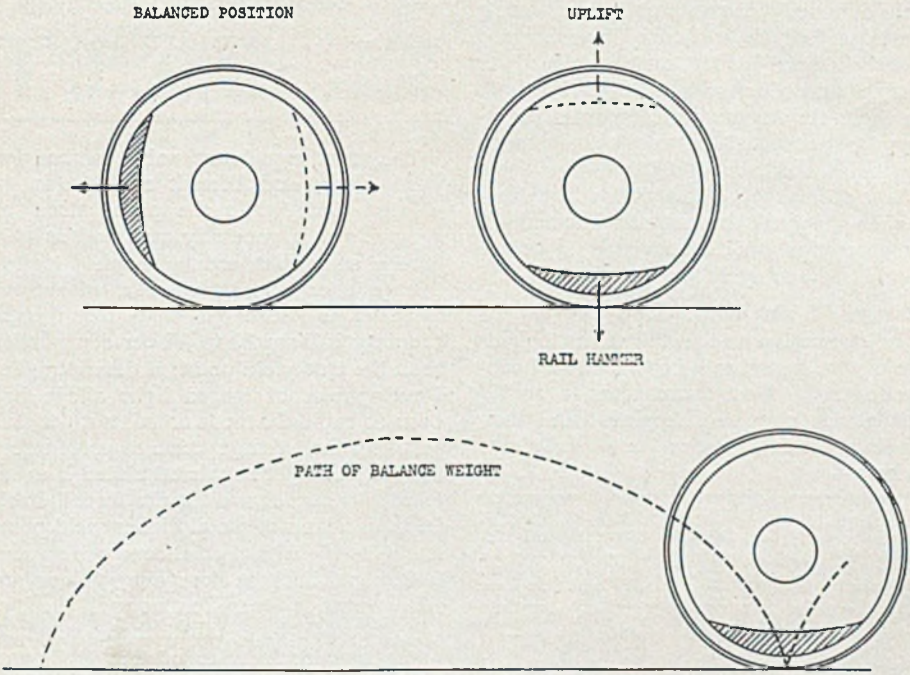


Fig. 3.—Action of the counterweights in driving wheel. Centrifugal forces balance the reciprocating masses only when they act horizontally. When acting vertically, either rail hammer or uplift results. The cycloid curve shows how the hammer effect is created.

ciprocating masses. This horizontal oscillation can be seen in any locomotive at speed, the entire frame swinging from side to side about a vertical axis and tending to spread the gauge or shear off the wheel flanges; (b) the hammer action which arises from the counterweights attached to the wheels to counteract in part the couples above mentioned. Beyond a certain point these counterweights are a remedy worse than the disease since, although their centrifugal forces balance the reciprocating parts when acting horizontally, they are themselves unbalanced when acting vertically, hence the alternate rail hammer and uplift at two positions in every wheel revolution. It would be possible to balance out the horizontal forces completely and so eliminate the disturbing couples, but the consequent rail hammer and uplift would be quite beyond the limits of tolerance. As a result it is common practice to balance only two-thirds of the reciprocating forces and, even so, the rail-hammer trouble becomes increasingly serious as the speed increases.

Such expedients as distribution of the counterweights between the coupled axles do indeed reduce hammering, but coupling is usually associated with increased tractive effort and heavier connecting rods and crossheads which again increases the burden. What makes the matter worse is the almost universal adoption of outside cylinders, which arrangement increases the disturbing effects by almost 50 per cent. This feature of design has been dictated by the increasing size of cylinder bore as well as by the high cost of the forged crank axle.

Four-cylinder engines have been designed which could be completely balanced, but this necessitates entirely separate valve gear for each cylinder besides involving a costly crank axle; not only does cost become prohibitive in such a design, but the cylinder diameters are strictly limited by the space between the frames, and the gear is difficult of access. In these circumstances it becomes necessary to accept the two-outside-cylinder engine as standard and to develop some means of improving its stability by reducing the weight of the reciprocating masses. What results can be expected from the use of light alloys?

Steel and Light Alloys Compared

In locomotive motion the main elements are piston, piston rod, crosshead and connecting rod. Most components, even the piston, are now steel forgings, and their leading characteristics are tabulated below:—

	A	B	C
Composition			
Carbon	.40 - .55	.40 - .55	.20- .30
Manganese	.60 - .90	.65 - .95	.65- .95
Phosphorous	.045 max.	.045 max.	.045 max.
Sulphur	.05 max.	.05 max.	.05 max.
Silicon	.15	.15	.15- .35
Nickel	—	—	2.5 -3.0
Vanadium	—	.15	—
Properties			
Tensile tons sq. in.	38.5	40.0	36.0
Yield point	21.5	27.0	25.0
Elongation (% on 2in.)	24.0	22.0	28.0

Comparative light-alloy forgings.

Designation	RR 56	RR 77	Dural G	Dural S
Tensile	28	35	30	32
Proof	22	30	21	28
Elongation	12	13	15	12

The most significant value is that for yield point, and here it may be interpolated that, while the proof stress of light alloys is generally accepted in lieu of the somewhat indefinite yield point, this practice affords a factor of safety, since it is estimated that the former property is from 10 to 15 per cent. lower than the true yield point, if determinable. Development of forged light alloys has been so rapid that it is noted, not without surprise, the average value of proof stress for the four light metals tabulated is equal to the average figure for the forged steel. In both classes of metal higher yield point is obtainable with special composition and treatment, but the foregoing values are representative ones for normal production. It will be recalled that almost 20 years ago locomotives of the Alton and Southern R.R. and the St. Louis and Ohio River R.R. were equipped with light

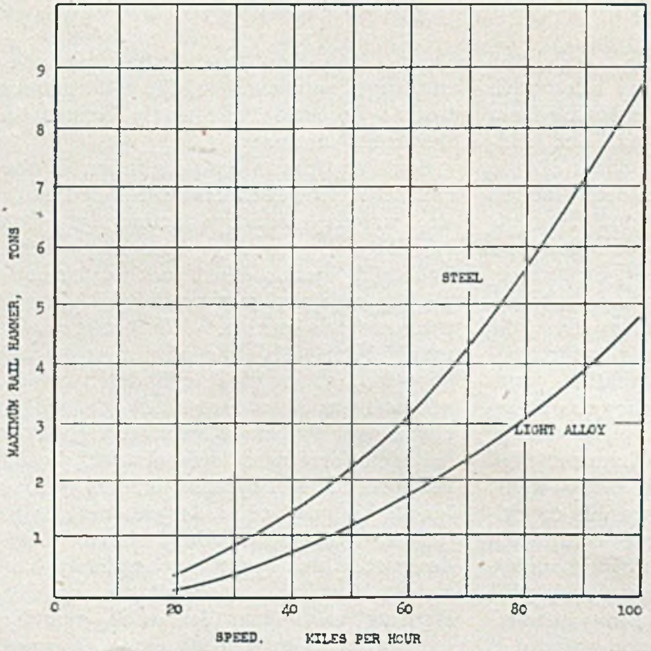
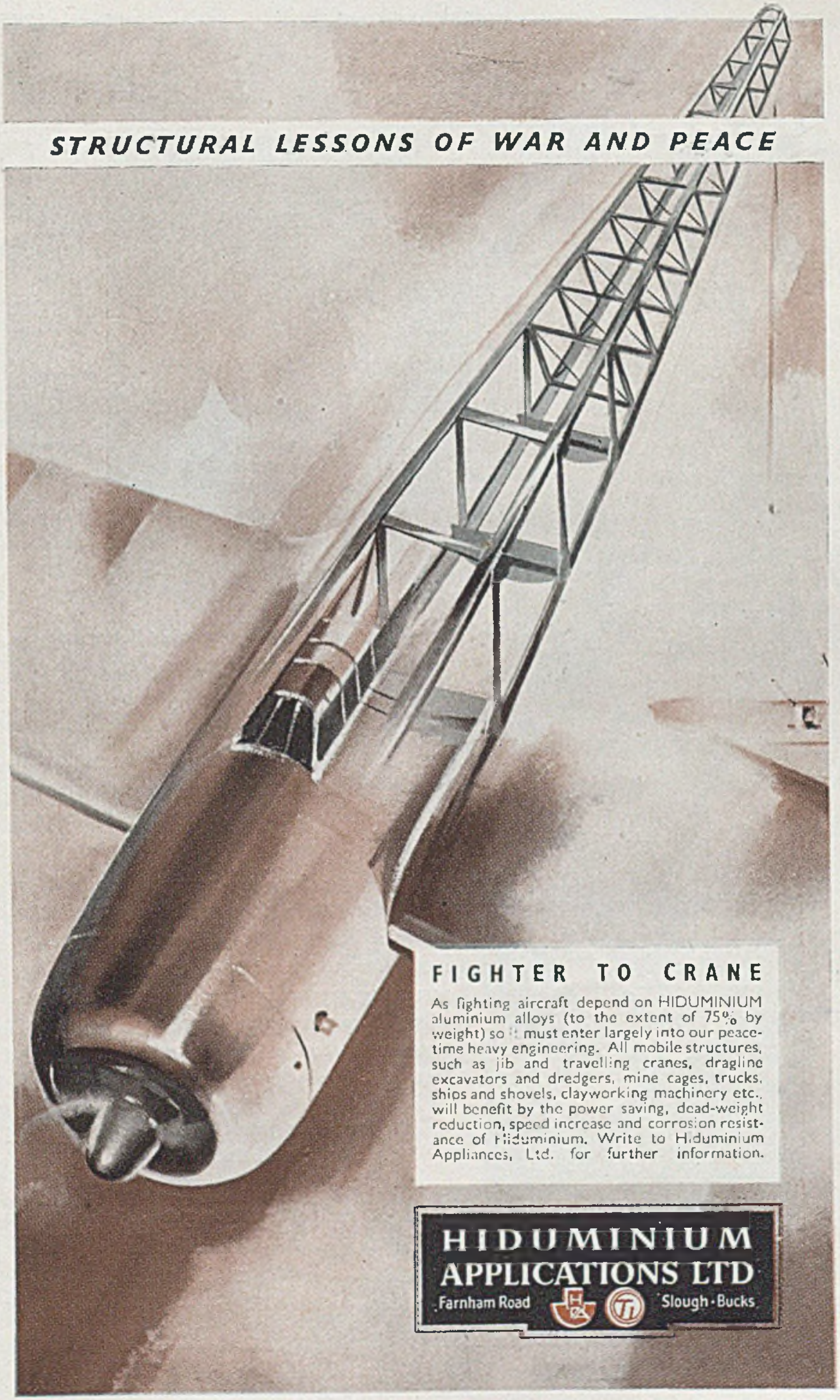
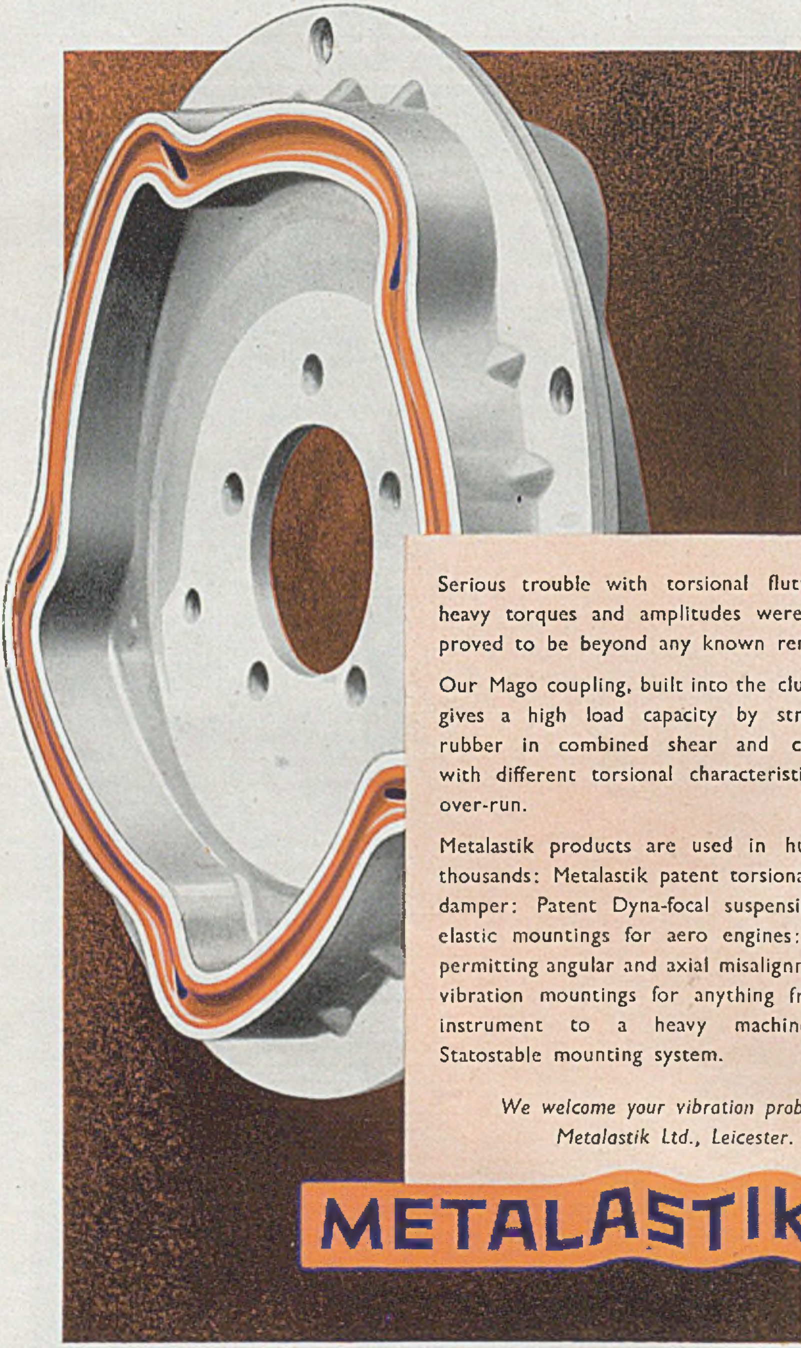


Fig. 4.—Increase of rail-hammer effect with speed. If a maximum rail-hammer blow of 5 tons can be tolerated, this will dictate a maximum speed of 75 m.p.h., for the engine with steel motion, and a maximum of 100 m.p.h. for that with light-alloy components.


STRUCTURAL LESSONS OF WAR AND PEACE
FIGHTER TO CRANE
As fighting aircraft depend on HIDUMINIUM aluminium alloys (to the extent of 75% by weight) so it must enter largely into our peace-time heavy engineering. All mobile structures, such as jib and travelling cranes, dragline excavators and dredgers, mine cages, trucks, ships and shovels, clayworking machinery etc., will benefit by the power saving, dead-weight reduction, speed increase and corrosion resistance of Hiduminium. Write to Hiduminium Appliances, Ltd. for further information.
HIDUMINIUM
APPLICATIONS LTD
Farnham Road
Slough · Bucks



alloy motion with highly successful results. What is important to note is the fact that the alloy used at that time had a yield stress of only 15 tons sq. in. In the course of progress this property has been improved by no less than 70 per cent., and this is coupled with collateral improvements in the size of presses and the technique of forging and treatment. Since a given section of a modern light alloy forging will withstand the same load as the steel equivalent, its weight might be expected to be some 65 per cent. less; in practice, however, such components are fitted with bronze bushings, steel pins and bolts, crosshead bearing and other attachments in heavy metal; for this reason the assembled component under working conditions will be somewhat heavier, and a fair ratio of weight may, in practice, be computed as 50 per cent. that of the steel member.

The reciprocating motion consists mainly of the piston and rod, connecting rod and crosshead, and for this study it is assumed that only the connecting rod and crosshead are converted to light alloy. Pistons and piston rods have been made and installed in aluminium, but this is not at present considered good practice, since the high degree of superheat and the absence of cooling overstep safe limits for light alloys. Coupling rods are successfully made and used in light alloy forgings and have a double advantage, as they not only are lighter but their balancing counterweight is reduced in the same degree. They do not, however, form part of the reciprocating system, and so have no influence on stability and balance.

Analysis of Typical Design

In the following calculations a modern 4-6-2 passenger locomotive is assumed having outside cylinders 21 ins. bore by 28 ins. stroke. Driving wheels are 6 ft. 6 ins. diameter, and the speed on which the balance is calculated is 80 m.p.h. An outline of the motion is shown in Fig. 1. Actual weights of the reciprocating members associated with one cylinder are as follow:—

Reciprocating masses	Steel	Light alloy
Piston	159	159
Piston rod	75	75
Crosshead	166	83
Connecting rod (reciprocating portion 40%)	178	89
Total (M)..	578 lb.	406 lb.
Weight balanced (2/3) M_b (for steel)	384	212
Weight unbalanced (1/3) M_u (for steel)	194	194

In the above it is assumed that 194 lb. is the maximum unbalance which can be tolerated, and this is identical in both designs. By maintaining this constant the full benefit of reduced weight can be applied to the relief of rail hammer.

Stability Couples.—These are three in number and are determined by Dalby's method.

(a) *Lateral oscillation* (nosing).—This not only tends to spread the gauge of the track but it causes a racking motion of the main frames and wear and heating of bearings; its value is given by

$$\pm\ 0.85\ M_u n^2 rd\ \text{(lb.-ft.)} \quad \ldots \quad \ldots \quad (1)$$

(where n = crank revolutions per second.
r = crank throw, feet.
d = distance between cylinder axes (in this case 6.25 ft.)

In the present example the couple at 80 m.p.h. is 40,600 lb.-ft.

(b) *Vertical oscillation* (galloping); this is due to the fact that the line of drawbar pull is offset from the horizontal plane of motion and the result is a see-saw effect causing uneven spring loading and straining of the main frames. The distance of the couple is seldom more than 1 ft. and is denoted " t."

$$\pm\ 1.7 M_u n^2 rt\ \text{(lb.-ft.)} \quad \ldots \quad \ldots \quad (2)$$

± 13,000 lb.-ft.

(c) *Longitudinal oscillation* (jerking) represents the variation in drawbar pull consequent upon the inertia of the reciprocating masses. It occasions great stresses in the drawgear, especially when the speed is high and the tractive force moderate.

$$\pm\ 1.7 M_u n^2 r\ \text{(lb.)} \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

± 13,000 lb.

These three forces are illustrated

diagrammatically in Fig. 2. Obviously, if the reciprocating masses were fully compensated these unstable couples and forces would disappear, but massive counterweights would be necessary and greater trouble would arise from rail hammer.

It is now necessary to consider the counterweights. For one line of motion

$$R.H. = \frac{m_c}{g} \omega^2 \sin \alpha$$

which expression gives the vertical component of the centrifugal force; it can be simplified to

$$R.H. = m_c\, 1.22n^2r \quad \ldots \quad \ldots \quad (5)$$

Reverting to the design already outlined with alternative steel and light alloy reciprocating motion:

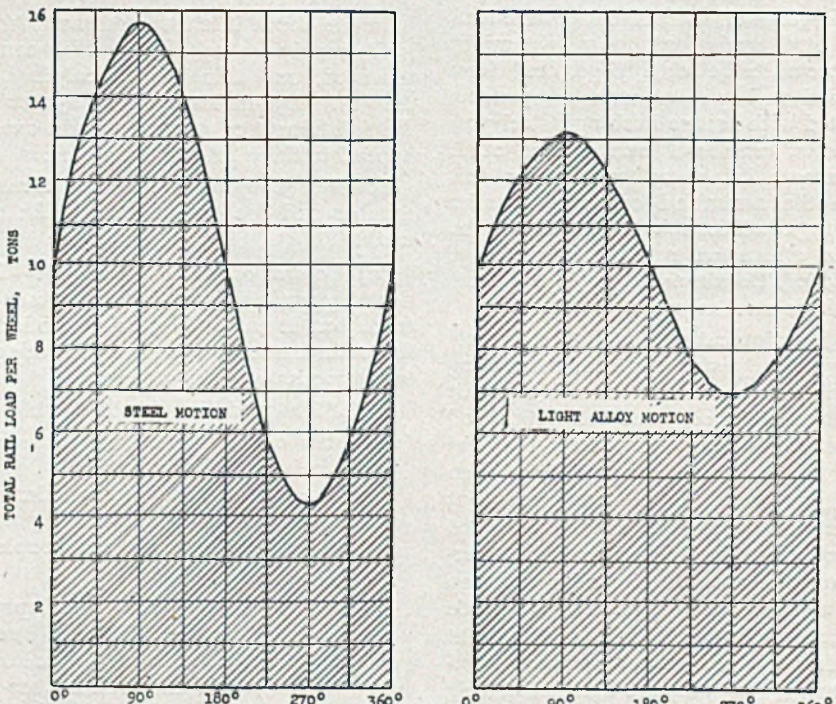


Fig. 5.—Maximum rail load for driving wheel. In these figures the rail hammer (+ or −) is superposed on the steady deadweight load of 10 tons per wheel.

the counterweight (considered at crank radius) to balance a reciprocating mass M_b is best ascertained from a vector diagram, but algebraically it is given by

$$m_c = M_b \frac{\sqrt{i^2 + j^2}}{k} \quad \ldots \quad \ldots \quad (4)$$

where k = distance between opposite wheel treads = 4.92 ft., $i = \frac{d - k}{2}$ and $j = d - i$

In the present example $m_c = 1.14M_b$

The rail hammer caused by a given counterweight at a given speed is

	Steel	Light alloy
Counterweight at crank radius, m_c	436	242 lb.
It is possible to reduce this by distributing 20 per cent. of the balance weight on the leader and 20 per cent. on the trailing coupled wheels leaving for the driver 60 per cent. or	264	146 lb.
The Rail Hammer at 80 m.p.h. from (5) now becomes .. : ..	5.70	3.12 tons
Reduction with light alloy motion	—	2.58 tons
Reduction with light alloy motion	—	45 %

The action of the counterweight in causing rail hammer is seen in Fig. 3; it is the centrifugal force of this mass which is concerned both in balancing (horizontally) and in hammering or lifting (vertically). If the rail hammer increases to the point where it substantially reduces or cancels out the deadweight on the wheel it may even lead to overturning by reason of its uplifting force. As will be seen in Fig. 4, the effect increases as the square of the speed, and if a suitable limit be assigned to the rail hammer factor this will set a definite maximum speed. A value of 5 tons per wheel is sometimes regarded as the maximum allowable; in the present instance this would allow of a maximum speed of 75 m.p.h. with steel motion, while 100 m.p.h. could be allowed with light alloy. Fig. 5 shows the loads on the rail under the driving wheel tread, including both the variable hammer effect and the deadweight loading of 10 tons.

Such factors as the torsional couple and other disturbing moments arise from the same causes and a thorough analysis is not possible in this study, but the 45 per cent. reduction in rail hammer afforded by the use of light-alloy connecting rods and cross-heads will effect a corresponding improvement throughout.

Practical Experiences

It is characteristic of most new engineering developments that they do not achieve wide publicity unless they are unsatisfactory, and while thousands may read of a bridge or dam failing in service, no one will give a thought to the innumerable examples of good engineering which stand up to their job without complaint. With no intention whatsoever of being deliberately provocative or offensive, this statement must, unfortunately, be considered as applying with particular force in that branch of engineering practice devoted to railways. Here, tradition springs directly from beginnings removed by little more than a generation or two from our own time, and based, necessarily, on the use of the ferrous metals. With these materials (and wood) designs were evolved, all earlier theory established, and our present complex rail-transport system developed. By far the greater number of light-alloy connecting rods and cross-heads installed on locomotives in this and other countries have given satisfactory service. Apart from the American examples already mentioned, British railways—notably the L.M.S. and L.N.E.R. —have equipped certain engines with light-alloy connecting rods on an experimental basis. More extensive application has been made of light-alloy valve gear. In this brief study no account has been taken of the reciprocating motion which actuates the valves, and adds its quota to the total mass which requires balancing and so accounts for heavier counterweights and increased rail hammer; valve motion levers are forged in light alloy and installed on an appreciable scale.

A 2-6-2 tank locomotive of the Eastern Railway of France was equipped with forged light-metal connecting rods some years ago, and this was followed by weekly inspection to check any tendency to incipient failure. The weight of the alloy rod was 95 lb. (without bushings) and that of the steel equivalent 157 lb., a saving of 39 per cent. The alloy used at the time had a proof stress of only 15 tons per sq. in., and the maximum stress allowed was only 3.60 tons per sq. in. It is obvious that a modern heat-treated alloy forging would do much better than this without impairing the necessary factor of safety.

A word about cost. All good engineering is good economics and vice versa, and *no new development can be considered if the cost be unreasonable in its relation to the advantages obtained.* It has been estimated that the substitution of light alloy in the place of steel connecting rods and cross-heads affects not more than 1 per cent. of the overall cost per locomotive. If this 1 per cent. result in reducing rail hammer by 45 per cent. and increasing permissible maximum speed by 33 per cent. it must be admitted that the cost is negligible.

NEWS—General, Technical and Commercial

Percy Pritchard, F.R.Ae.S., M.I.A.E.

Mr. Percy Pritchard

THE Midlands suffer a great loss by the sudden death of Mr. Percy Pritchard, F.R.Ae.S., M.I.A.E., of Estone Hall, Wootton Wawen, the deputy chairman and joint managing director of Birmid Industries, Ltd.

Mr. Pritchard was a man of great gifts, brilliant mental capacity, and unbounded energy. In 1914, in conjunction with Mr. Arnold Pearce, he started a small iron foundry for the manufacture of motorcycle cylinders, and from such humble beginnings built up the large group of metallurgical engineering companies that have achieved such signal success and which employ upwards of 10,000 people.

In addition, he, latterly, became an agriculturist, farming 1,000 acres himself, as well as taking a great interest in the tenant farmers on his large estate. His ability and enterprise were exemplified in the way in which he brought his knowledge of mechanization and industrial organization to bear upon his farming activities.

His was the scientific and analytical mind which cut to the root of any problem with exceptional rapidity and precision. His grasp of finance was phenomenal in a man whose avowed interest was applied science.

He took little interest in politics, but was a great believer in evolution as a practical method of improving the lot of the workers. His plans for the hamlet on his estate—held up owing to the war—were a model of what ought to be done in this direction.

Mr. Pritchard was chairman of the Midland Regional Committee of the Employers' Federation, president of the British Cast Iron Research Association, member of the British Non-Ferrous Metals Research Association, member of Council of the Wrought Light Alloys Development Association, member of the British Institute of Foundrymen, and Fox Gold Medallist (1941), and a member of the Institute of Metals. He was also a Fellow of the Royal Aeronautical Society and a member of the Institution of Automobile Engineers, upon whose council he had served. At the outbreak of war he became director of the Light Alloy Control (Castings).

Mr. Pritchard had a considerable interest in sports, but chiefly in those associated with the countryside, and particularly with water; he was a powerful swimmer, president of the British Hydroplane Racing Club, member of the Royal Motor Yacht Club, member of the Severn Yacht Club, and, in connection with his farming activities, he was a member of the Farmers' Club.

He was a great believer in technical education, and held the conviction that the salvation of this country in the post-war years could be achieved only through the technical excellence of its products. He built up a strong team of managers, technicians, and foremen to handle the various enterprises that he controlled.

Mr. Pritchard was a staunch Freemason, a Past Provincial Grand Deacon of Warwickshire, a Past Master of the Federation Lodge —for which he was a most successful almoner. He died in Lodge while in temporary occupation of the Master's chair. He was a man of the highest moral character, who insisted on high standards from all those around him. He was a man of few words, except on those subjects of which he was master; a modest man, but one who knew his own worth; an affectionate and kindly man, but one whose many benevolences were practical rather than sentimental.

Death of Mr. Norman Mander

WITH great regret we learn that Mr. Norman Mander, formerly Publicity Manager for Aluminium Union, Limited, has died of wounds in Burma.

Appointed to Aluminium Union, Limited, 10 years ago, Mr. Mander was formerly attached to Pritchard Wood and Partners.

Porous Tantalum Anodes

"IN view of the reference to porous tantalum anodes for electrolytic condensers made in the February issue of 'Light Metals' (pp. 99-100), a note on the patent position may be of interest.

"Electrodes for electrolytic condensers made by the processes of powder metallurgy from tantalum, niobium, or alloys of the two metals are covered by Brit. Pat. 511,805, taken out by the Fansteel Metallurgical Corporation and dated May 5, 1937 (U.S. Convention Date).

"A prior patent (Brit. Pat. 492,060, dated April 19, 1937) taken out by the writer covers the production of porous electrodes for electrolytic condensers by the pressing and sintering of metal powders. While aluminium is specifically mentioned, a general reference is made to the use of other suitable metals.

"This prior patent is mentioned in Brit. Pat. 511,805, which, consequently, refers specifically only to the use of tantalum and niobium, claiming that these metals are easier to sinter than aluminium powder. In this connection it may be mentioned that recent work on sintering aluminium and aluminium alloy compacts does not appear to confirm the anticipated difficulties due to the presence of the oxide film.

"In view of the general lack of interest at the time, Brit. Pat. 492,060 was allowed to lapse, which leaves the way open for improvements, which may perhaps be expected in these more enterprising and knowledgeable days, now that a lead has been given." A. BEHR.

Remarkable Development of Aluminium

IN a recent address to the Design and Industries Association, Dr. E. G. West, of the Wrought Light Alloys Development Association, had a significant message to give concerning the many and important possibilities of light metals in peace-time.

He pointed out that aluminium, although one of the most plentiful metals present in the earth's surface, was not produced on a commercial scale until less than a century ago. Yet to-day there existed remarkable and increased facilities for producing aluminium alloys in all forms for the requirements of both art and industry.

With the recent release of aluminium for purposes other than the manufacture of aircraft, a great opportunity was presented to designers in all branches of industry to make full use of the unique character of aluminium alloys. New knowledge had been gained in such processes as welding, and plant of enormous capacity had been installed to press and form a variety of components for aircraft. There are now, for example, hydraulically operated rubber presses of more than 10,000 tons capacity for the production of sheet-metal components, drop stamps up to nearly 20 tons capacity for forging tough and strong alloys, as well as mechanized foundries and large die-casting machines capable of making hundreds of thousands of components daily.

All these new facilities, combined with a profound increase in knowledge of the properties of light metals, must be used in many new fields of post-war application. Motorbuses and coaches, railway coaches, motorcars and all forms of transport would embody considerable and increasing quantities of aluminium, with a consequent reduction in weight and a saving in fuel, as well as an increase of safety.

Many components of both permanent and temporary houses, schools, ships, offices, hotels, restaurants, and other buildings would be of aluminium or aluminium alloys —alloys which, in many cases, would be coloured by the anodic oxidation process whereby dyes could be applied to the smooth and polished surface of the metal.

The use of certain aluminium alloys on board ship would reduce weight, thus increasing the stability and safety of the vessel. There was now, in fact, sufficient experience in these and other applications of aluminium to justify every confidence on the part of modern industrial designers in search of a new material.

Adam Hilger, Ltd.

We are informed that Dr. Aruja has joined the X-ray department of Adam Hilger, Ltd. Previous to this appointment, Dr. Aruja was attached to the Physics Department of University College, Newcastle, being formerly one of the Bragg School at the Cavendish Laboratory, Cambridge.

Cecil Kimber Killed in Rail Accident

THE death occurred on Sunday, February 4, of Cecil Kimber in a railway accident. Known to thousands of enthusiastic owners as the presiding genius of the M.G. Car Company, he had for some time been serving as a director of Specialloid, Ltd., piston manufacturers, and was on his way to visit one of their northern establishments when the accident took place.

Joining Morris Garages at Oxford in 1921, he constructed the first of what were to become the line of M.G. cars for his own pleasure in 1923. Building initially a few replicas, the business grew so that in 1929 the M.G. was being designed and built in its own works at Abingdon, where it continued in large-scale production throughout the decade which ended with the outbreak of war. During this period M.G. cars probably won more events than any other

British make, and at one time held all the Class H records, including several great achievements, the first 750 c.c. car to exceed 100 m.p.h. and the first 1,100 c.c. car to exceed 200 m.p.h.

Light Metals and Research

AT the opening of the two days' conference of "The Place of Science in Industry," Professor Kelvin was quoted as having said that a flight with appliances heavier than air is impossible. If we understand that one of the aims of science is to predict the future, he was certainly wrong. If we assume that a scientist should be careful and avoid "sweeping" statements, he was again wrong. But he was right if he assessed only the capacity of his age.

Research and development applied to light alloys was very ably represented at the conference by W. C. Devereux. He recalled that the battle cry of more research has already become a platitude, and, as one who had long advocated and practised the application of scientific methods to industrial problems, he could warn the audience that scientific research does not solve all our problems overnight. Opposition to the drive for more research is stamping some foreign research as mere window-dressing. He scored his first rhetorical success when he stated simply: "I see nothing wrong in window-dressing; in fact, I think that we, as a nation, have sadly neglected this important aspect of foreign trade promotion."

Then he dealt with the problem of the organization of industrial research, and, in view of a lack of suitable men, recommended that the universities consider the new position created by the demands of industry for fully qualified scientific research workers and engineers, particularly in equipping them for higher posts in research management and administration.

The contribution of this country to pure science and fundamental research was fully appreciated, but the application of this knowledge was certainly not carried out to the necessary extent. For this partly the lack of enterprise and partly the shortage of properly trained industrial scientists and technicians can be blamed. Unless the industry can enlist a sufficient number of men with the right kind of qualifications, then no benefit will come out of research for this country.

The development of alloys with improved properties calls for closest possible liaison with the designers and engineers using these materials and for the continuous improvement of technique and apparatus for testing. Laboratory research should be accompanied by applied economic and market research.

The speaker referred to his plan for the industrial reconstruction of West Cumberland as an attempt to assess thoroughly the natural resources of the area and the future demands for products based on those resources. By such a plan it may be possible to give full employment and raise the standard of living in a formerly "depressed" area. This sort of investigation should be greatly extended. The speaker further felt that we, in this country, failed on numerous occasions fully to exploit the results of our own scientific research work by not realizing the far-reaching effects of new inventions. "We have not had the courage to lay out the capital necessary to achieve a sufficiently large output to meet the demand, thus allowing others to get into the market on the 'ground floor.'"

Stereoscopic Radiography

An invention which seems likely to revolutionize the technique of medical and industrial stereoscopic radiography is to be described and demonstrated for the first time before the British Institute of Radiology on March 15. Inventor of the process is Mr. L. P. Dudley, whose name will already be known to readers as the author of numerous articles dealing with the structural applications of light metals.

The new process possesses great advantages over existing methods. No special viewing device, such as a stereoscope, is required for viewing the radiographs; a single film or plate is used, and the resulting radiograph exhibits a three-dimensional effect to the unaided eye. Moreover, varying the angle from which the radiograph is viewed causes the aspect of the image to change in a corresponding manner. This property is of great assistance in medical radiography in localizing an affected bone or tissue, and, in industrial radiography, in determining the position of an internal flaw in an engineering component. Existing X-ray apparatus can be adapted to the new process by the addition of comparatively simple equipment.

LIGHT ALLOYS FOR MARINE ENGINES

IN "Light Alloys for Marine Engines," A. J. Murphy presented to the Institute of Marine Engineers a useful summary of aluminium-base and magnesium-base alloys of interest to the marine engineer; it is thus complementary to the recently published papers on the aluminium alloys of interest to the naval architect. The present author makes the justifiable assumption that readers are familiar with the paper by

Mortimer and Paige (see "Light Metals," 1944/7/103), and also points out that he writes chiefly from the metallurgist's point of view.

Resistance to corrosion is of relatively minor importance in the engine-room, thus allowing a wider choice of alloys than is possible to the naval architect, and at the outset the densities of the light metals are compared with those of the long-established marine materials—cast iron, steel and gun-metal.

The consequences of weight-saving are mentioned briefly, and particular note may be made of the value of lower weights of inspection doors, etc., which require to be moved, for example, in confined spaces.

Pistons

Considerable attention is devoted to the properties of piston alloys; in particular, tensile strength at elevated temperatures, fatigue and creep properties at higher temperatures, and the effects of conductivity and coefficients of expansion. The author considers that the criterion is not tensile stress but a combination of creep and fatigue. The most important property is, therefore, the endurance at the highest temperature attained by stressed portions of the piston, but if the mean stress of the fatigue cycle is of appreciable magnitude, especially a tensile stress, there is a condition of creep coinciding with the fatiguing forces.

The specimens to which results were referred were cut from press-forged pistons and were submitted to alternating tension and compression simultaneously with a tensile stress of the desired magnitude. Consideration of the results included herein and others in the original paper lead to striking confirmation of the superiority of Y alloy over the other two mentioned under such conditions.

In addition to strength at raised temperatures the expansion and conductivity are important, and the balance between these opposing factors is discussed in terms of Y alloy and Lo-Ex. The coefficient of expansion is 0.000022 for Y alloy and 0.000019 for Lo-Ex, with corresponding thermal conductivities of 0.40 and 0.32 c.g.s. units, i.e., the expansion coefficient of Y alloy 16 per cent. greater than that of Lo-Ex but a conductivity 25 per cent. greater, one factor offsetting the other in some pistons. The properties—physical and mechanical—of magnesium-base alloys render them unsuitable for pistons.

Cylinder Heads

The same general principles apply to the selection of cylinder-head alloys as to piston alloys, but, compared with land or air engines, the marine engine head has an even more stringent requirement, namely, the risk of corrosion due to the use of sea water for cooling purposes. This is avoided by using a closed water circuit in which fresh water is passed round the cylinder head and cooled in a separate heat exchanger by sea water. The author suggests that this troublesome device might be avoided by using a Birmabright-type alloy for the heads, as the aluminium-magnesium series have proved satisfactory for sea-water-cooled exhaust manifolds. He is encouraged in this proposal by the examination of a cylinder head taken from a German B.M.W. 801 engine, the composition of which was:—

Magnesium ..	.. 5%	Approximately
Silicon ..	.. 1%	
Titanium ..	.. 0.1%	

The alloy was heat-treated and gave the following properties: —

0.2 % proof stress ..	.. 6 tons/sq. in.
Ultimate tensile stress	.. 11–12 tons/sq. in.
Elongation	.. 5–2 %
Fatigue strength ..	.. ± 3.8 tons/sq. in.

In such a trial contact corrosion would, of course, have to be avoided.

Corrosion

The author points out that corrosion-resistance is not of paramount importance for such engine-room items as crankcase inspection doors, gear casings and covers, hand rails, floor plates, brackets and the like. Steel components, which, in the engine-room, are regularly wiped with a greasy rag, do not rust or deteriorate due to corrosion and from this observation the author concludes that a wide range of light alloys may become available to the designer and builder of marine engines.

Mechanical Properties

Rather than attempt to summarize all the available alloys, the author selects some specific examples—a few wrought applications and several casting alloys.

Wrought aluminium alloys used for marine-engine forgings include RR.56, RR.59, Ceralumin F and Ceralumin 22, having tensile strengths of 27-30 tons per sq. in. at ordinary temperatures, which are retained at elevated temperatures. As alloys of the duralumin group lose their strength more rapidly at high temperatures, they are not suitable for pistons and cylinder heads. Forged pistons are used in the smaller engines and light-alloy connecting rods have reduced inertia appreciably.

Aluminium and Magnesium in the Electrical Industries

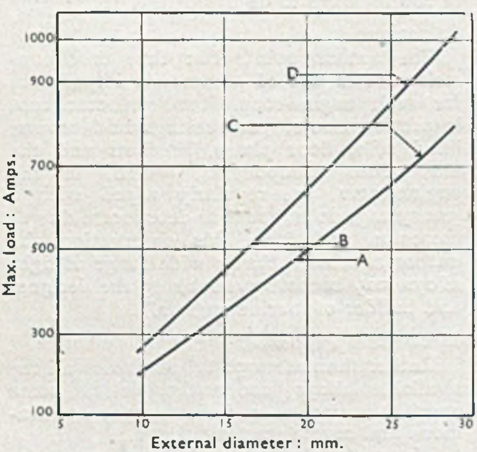
In this Section of the Account, Continued from "Light Metals," 1945/8/16, the Author Devotes Particular Consideration to the Theory and Practice, and Methods of Construction, of Hollow Conductors

By
B. J. BRAJNIKOFF

STRUCTURAL consideration of aluminium and steel-cored aluminium cables calls for particular care in the designation of cross-sectional area. In this connection, the stranding, which is essential in order to ensure flexibility, is also helpful in denoting the cable size by indicating the number of strands and the gauge number of each; these form an envelope around a centrally disposed conductor (with a core of one or more strands of steel in the case of reinforced aluminium), every such alternate layer being wound in the opposite direction to prevent " bird-caging " during bending.

The axial distance of such cable, corresponding to one complete turn of the spiral, is known as the lay, and the ratio between the numerical value of the lay and the outer diameter of the spiral is termed the pitch of winding.

As the length of each conductor in the envelope is greater than that of the central strand, this obviously increases the resistance to the flow of current along the various wires as they recede from the centre. Hence, in an aluminium or steel-cored aluminium cable, there must be dis-



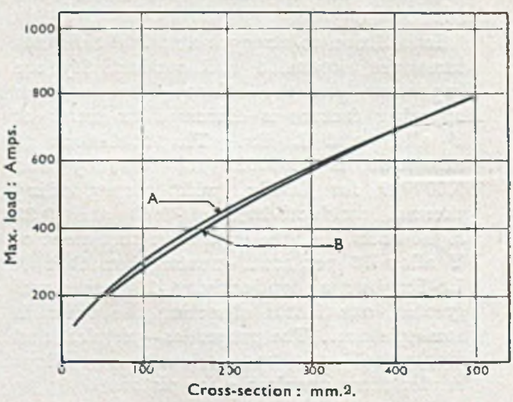


Fig. 1 (above).—Comparative curves for maximum continuous current load in amperes, and corresponding outer diameter in mm., for stranded aluminium conductors (C) and stranded copper conductors (D). B and A represent outer diameter in mm. of cables for overhead transmission. Fig. 2 (right).—Curve for maximum permissible current load in amperes, and cross-sectional area in mm.^{2}, for stranded aluminium cable: A, calculated; B, adopted as standard in Germany.

tinguished three different cross-sections: (1) the nominal cross-section, which is formed by the cross-sectional area of one wire in a plane at right-angle to its longitudinal direction, multiplied by the number of constituent conductors; (2) the actual cross-section, which is the oblique cross-sectional area resulting from the cutting of the stranded cable by a plane perpendicular to its core, multiplied by the number of component wires; (3) the equivalent cross-section is that cross-sectional area of aluminium or steel-cored aluminium cable which has, approximately, identical electrical resistance as a stranded copper conductor of a given cross-section made of hard-drawn copper wires (the conductivity of the steel core, if present, is neglected).

Basic Technical Requirements

Aluminium and steel-cored aluminium cables are made of round aluminium wires having a smooth and glossy surface,

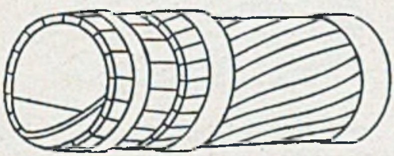


Fig. 3 (above).—Principle of construction of hollow conductor designed to obviate corona and to take advantage of skin effect in overhead transmission.

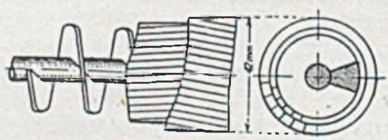
free from films, cracks or other defects. The number of strands and their gauge, permissible dimensional tolerances and maximum ohmic resistance, as well as mechanical strength properties of galvanized steel wires, their sizes and limits, should conform to specifications as prescribed by the existing standards of the industrial countries concerned. It is worthy of note that the mechanical properties of aluminium and steel-cored aluminium cables are determined on the basis of testing of separate wires constituting a given cable, just as an estimation of electrical resistance of aluminium wires is arrived at by the testing of individual component strands. All tests, which include the checking up of aluminium and steel wire gauges by means of the micrometer or by weight, thickness and the adhesion of the zinc layer to steel, are carried out in accordance with requirements of established standards.

In calculating data for overhead transmission lines the following general formula is used for determining the modulus of elasticity of a steel-cored aluminium cable:—

$$E = \frac{(9.6m + 30) . 705}{m + 1} \text{ kg./mm.}^2$$

where m denotes a ratio between the aluminium cross-section of the cable and that of steel; the modulus of elasticity of an aluminium cable is of the order of 5,400 kg./mm.^{2}; the modulus of elasticity of a steel cable is of the order of 22,000 kg./mm.^{2}; the coefficient of linear expansion of aluminium per degree C. is 22.8×10^{-6}. The coefficient of linear expansion of steel is 11.5×10^{-6} per

Fig. 4 (below).—Method of construction of tubular conductor in aluminium. This system is usually employed in the manufacture of steel-reinforced aluminium cables of this type for high-voltage overhead lines.



degree C. The coefficient of the linear expansion of a steel-cored aluminium cable per 1 degree C. is computed from the formula:—

$$L = \frac{(12.6 \text{ m} + 20)\ 1.8}{\text{m} + 3.13} \times 10^{-6}$$

where m stands for the same quantity as given above.

The average value for the electrical resistance of aluminium per 1 kilometre length having 1 mm.^{2} cross-sectional area, at a temperature of 20 degrees C., is of the order of 29 ohms.

In the estimation of tensile strength of steel-reinforced aluminium cables, use can be made of the fundamental data furnished by the National Physical Laboratory in Great Britain. Here experiments have demonstrated that a mean value for tensile strength of steel-cored aluminium conductors may be accepted as equal to 85 per cent. of steel and 98 per cent. of aluminium. The analogous data are found in the specifications of the British Standards Institution based on the results of experiments carried out by the British Electrical and Allied Industries Research Association.

The values for tensile strength of aluminium and steel components in steel-reinforced aluminium cables, adopted as

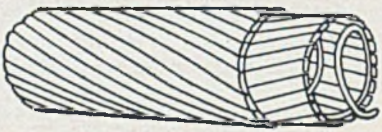


Fig. 5 (above).—Variation in design of hollow conductor. In the production of this type, electrically suitable aluminium alloys can be substituted for copper.

standards by the principal industrial countries, are given in Table 1.

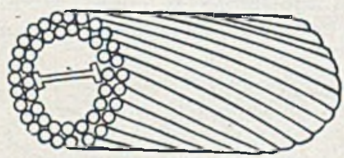
The relationship between maximum safely permissible, continuously applied, current load and the corresponding outer diameter of the stranded hard-drawn aluminium and copper cables, respectively, is shown in Fig. 1, as worked out by the Standards Department of the Russian Electrotechnical Association for overhead power transmission purposes.

As may be deduced from the curve in Fig. 1, the maximum permissible, continuously applied, current load for aluminium cables constitutes from 75 to 77 per cent. of the same cross-sectional area of copper conductors. The value accepted by Aluminium, Ltd., as a safe current load is 79.3 per cent. of that for the identical cross-sections of the copper cables.

Fig. 2 illustrates comparative values for maximum current load and the corresponding cross-sectional area of stranded hard-drawn aluminium conductor for overhead transmission: A – as calculated, B – as adopted by the Standards Institution of the German Union of Electrical Engineers (DIN of VDE).

The ratio between the cross-sectional area of aluminium cable and that of a stranded copper conductor of the same conductivity, adopted by the British Standards Institution and L'Aluminium Français, is 1.6, in Russia from 1.625 to 1.634, and in Germany from 1.74 to 1.80. The ratio of aluminium cross-section to that of steel adopted as a standard for steel-reinforced aluminium cables, according to specifications of the British Standards Institution, is 6 : 1 up to a cross-sectional area of 160 sq. mm., whilst for those above this section the accepted ratio

Fig. 6 (below).—Modification of tubular conductor. Here the envelope is supported by an inner spiral ribbon of double T cross-section. Both envelope and T may be made of appropriate aluminium alloys, for example Almelec, in place of copper.



is 4.29; L'Aluminium Français adopted a ratio of 6 : 1 up to cross-sections of 148 mm.^{2}, and for the values in excess of this, 4.29; the German Standards Institution specifies from 5.74 to 6.1, and Russia from 5.78 to 6.1.

A typical pitch of winding for the outer envelope in aluminium and steel-cored aluminium cables is from 11 to 14-fold of the outside diameter of a given cable, as specified by the leading cable makers in Europe. As to the spiralling of the inner strands, it is worthy of note that an appreciable economy of material can be attained, as in British practice, by the use of a pitch up to 20 times the diameter.

Hollow Aluminium and Steel-cored Aluminium Conductors for High-voltage Transmission

In electrical transmission systems operated at very high pressures, namely, those over 200 kv., the phenomena of corona discharge and skin effect acquire particular significance. Before, however, we proceed to a further investigation of these questions we must make a brief incursion into fundamental aspects underlying both properties, so as to visualize the conditions that are essential for their occurrence, their influence upon the behaviour of the conductors, and thus better to appraise practical methods for counteracting their ill-effects in electrical systems.

Electric Current and Magnetic Field Within a Hollow Conductor

There is no electric current without a magnetic field, and, conversely, there can be no magnetic field without an electric field in motion, i.e., without a current, no matter what material the conductor is made of or what is the source of the current. Magnetic field and electric current are two inseparable phenomena. There must be a magnetic field within a conductor carrying a current, for we may regard every conductor as composed of a very large number of thin parallel conductors, each of which must give rise to a magnetic field.

Let us consider first the case of a hollow conductor, i.e., a tube with very thin walls. A simple experiment with iron filings will show that, whilst in the external space the form of the magnetic lines of force is identical to that of a solid wire of the same cross-section, there is no magnetic field within a tube carrying a steady current in the direction of its axis. Thus the magnetic fields of the elementary current filaments compensate each other in the interior of the tube.

As a solid conductor may be regarded as composed of concentric tubes, each of which has an external magnetic field but no internal field, it follows, therefore, that the field strength is zero in the axis of the solid conductor, increasing in intensity as we pass outwards from the axis, and becoming at the surface of the conductor equal to the corresponding field strength as calculated for external space.

Variations of magnetic field strength within the conductor, in the case of an alternating current, give rise to a phenomenon of skin effect, causing the impedance of a straight wire to differ considerably from its ohmic resistance for direct current. Calculation shows that this difference is greatest for those lines of flow which are situated farthest from the surface. Thus the conductor no longer displays uniform behaviour throughout its interior; the electricity does not flow uniformly through the whole cross-sectional area, but passes more readily through the regions lying nearest to the surface. The impedance of a wire for alternating currents of sufficiently high frequency is, therefore, greater than its ohmic resistance for direct currents, and this difference becomes more and more marked as the frequency is increased. This skin effect has a relatively greater magnitude for conductors of larger cross-sectional area. At very high frequencies a hollow tube may conduct just as well as a solid wire of the same diameter.

Corona Discharge and Associated Phenomena

As the electromotive force between two electrodes is increased in air at normal pressure, it is often observed that the electrodes, when viewed in the dark, become covered with a number of luminous points or a luminous layer; at the same time, the leads are surrounded by a feebly glowing sheath. This phenomenon, known as the corona discharge, is accompanied by a humming or buzzing sound. In this kind of discharge, which is dependent to a great extent upon the shape of the electrodes, we are concerned with ionization processes in the neighbourhood of the electrodes, but which are unable to extend right across the gap between the electrodes on account of the relatively high pressure of the intervening gaseous medium.

According to the shape, capacity and distance apart of the electrodes, there may also occur other types of discharge. Thus, for example, as the potential difference between the electrodes is still further increased, luminous branching streaks are seen to stretch out into the air, this being the so-called brush discharge. Again, a special form of corona discharge may take place where one electrode is in the shape of a sharp point, which appears then as a luminous tuft. Another variety of discharge is that of the electric spark, which consists of a sudden leaping of the discharge right across the gap between the electrodes, in consequence of intense ionization of the interposed medium rendering the air electroconductive. The spark advances out of a corona discharge in a series of distinct jumps until, uniting with the discharge from the opposite electrode, the final true spark discharge occurs, i.e., there is a momentary enormous increase of current strength due to a sudden cumulative generation of ions. The heating of the cathode at the sparking point plays a decisive role in this production of carriers, as typified by the arc discharge, in which event the cathode is very strongly heated by the current process itself, thus becoming an extremely intense source of electrons. The peculiar sharp noise of the spark is due to the sudden intense heating of the air surrounding its path.

Table 1.

Country	Kg./mm. square	
	Aluminium	Steel
British Standards Institution, for diameter 2.37 mm. ..	19.5	113.0–140.0
British Standards Institution, for diameter 5.36 mm. ..	16.2	
British Aluminium Co., Ltd. (minimum)	14.2	112.0–140.0
Aluminium, Ltd. (maximum) ..	16.9	112.5
L'Aluminium Francais	20.0	120.0
German Standards Institution (DIN of VDE) (average) ..	18.0	120.0
Russia (average)	17.0	120.0

Principle of Construction of a Hollow Conductor

From considerations put forward in the preceding discussion it follows that corona discharges are very undesirable in electrical engineering, as they may cause appreciable energy losses at high electromotive forces, especially those above 200 kv. in overhead transmission lines, which are nowadays employed. Power losses due to corona arise and rapidly grow as soon as the intensity of the electric field between the conductors exceeds a certain definite value. For a cable of resistance R carrying a current strength I the energy loss per second due to Joule heat is I^2R; hence, the smaller I is made, the lower the loss. This is the reason for using such a high voltage in operating the modern transmission lines; as the power is measured by the product of the current strength I and the pressure V, in transmitting a given electric power it is possible to diminish I to any desired extent, provided that the pressure be correspondingly increased. Therefore, in dealing with very long cables it is advantageous to transfer electric energy by means of weak currents at high tension. The higher the pressure, the greater the saving in conductor material, as the current-carrying capacity of the line wires need not be so large. Of course, an upper limit is set to the voltage, which can be used in practice, by the finite capacity of insulating materials to resist breakdown. However, it should be borne in mind that, even at these high tensions, the current strengths are still very great.

None the less, at present, high potentials have to be employed in order to keep energy losses in overhead lines as low as possible; the fact that alternating currents may easily be stepped up or down is of value here.

Practical methods for the elevation of electric pressure in an overhead line can best be estimated from the following analytical considerations. Let us examine a three-phase transmission system, the conductors for which are located at the vertexes of an equilateral triangle; then the intensity of the electric field on the surface of the conductor in air is expressed by:—

$$\frac{dV}{dr} = \frac{V}{\sqrt{3} \cdot r \cdot \log_e \dfrac{2hD}{r\sqrt{D^2 + 4h^2}}}$$

INTERNATIONAL RECORDS

THE list of Olympic victors begins in 776 B.C. The modern series of Olympic games was initiated at Athens in 1896, since when the development of athletic prowess, as expressed by international records, has been remarkable. For the pole jump, the international record of 15 ft. $7\frac{3}{4}$ ins. was set up by Cornelius Warmerdam, of U.S.A., at Modesto, Cal., in 1942.

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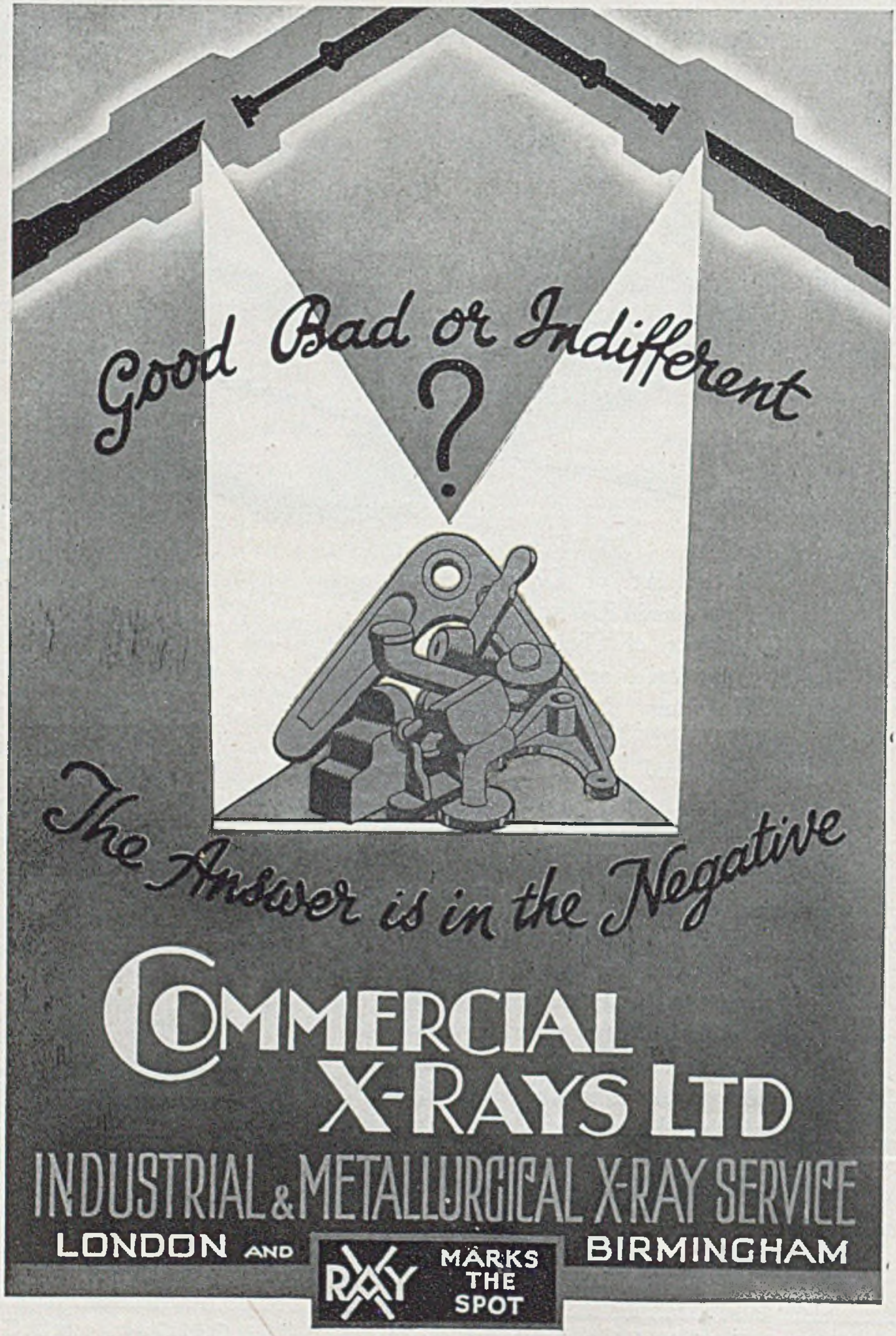
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where V denotes the value of the potential difference between two conductors; r is the radius of the conductor in cm.; D is the distance between the axes of the conductors in cm.; h is the distance between the centre of the triangle of the system of conductors and the ground in cm.

As the value of h is large in comparison with D, we may rearrange, without appreciable error in the result, the above formula as follows:—

$$\frac{dV}{dr} = \frac{V}{\sqrt{3} \cdot r \cdot \log_e \frac{D}{r}}$$

Thus it is seen that the possibility of raising the electric pressure of a transmission line can be achieved either by means of increasing the spacing between the conductors or by augmenting the diameter of the cables. In practice use is made of the latter condition, for increasing the distance between the conductors leads to very large values of D.

By attempting to increase the diameter of the conductors we reach sizes which preclude the application of orthodox design, for, apart from mounting losses due to skin effect, there is excessive increase in weight and cost of the conductor material. Consequently, the only alternative for solving this question is the application of a hollow conductor, the outer diameter of which corresponds to the voltage employed, and the thickness of the conducting envelope of which ensures adequate cross-section for transmitting the necessary current. The order of values for the diameters of cables and minimum cross-sections of the current-carrying part depending on operating voltage are summarized in Table 3.

Table 2.

Country	Electrical resistance of aluminium conductor, ohms per $\frac{km.}{mm.^2}$
British Standards Institution (average)	28.6
British Aluminium Co., Ltd. (maximum)	28.73
Aluminium, Ltd.	28.26
L'Aluminium Francais	29.5
International Standards for Aluminium	29.0
German Standards Institution (DIN of VDE)	29.4–30
Russia	30

Although, so far, no standardized technological method has been evolved in this field, the present-day constructions of hollow conductors may be divided into three principal groups:—

(1) Hollow cables having an inner support for the outer electro-conductive envelope.

(2) Hollow cables possessing a self-supporting outer envelope.

(3) Hollow cables combining a self-supporting current-carrying envelope, reinforced by an inner helical base or a core.

As might be expected, the construction of hollow cables presents considerable technical difficulties. From a practical point of view, most tubular conductors of the first and second categories have a number of inherent electrical and mechanical disadvantages, which, therefore, preclude their use, except only on a limited scale. Hollow cables of the third group, however, have found wide applications in industry. The best of them are those designs in which the conductor material is utilized in the most efficient way to meet the requirements to the fullest extent.

At this juncture it is instructive first to consider the case of hollow copper conductors, for experience gained during the past two decades since their early adoption in Europe must be of great value in assessing the fitness of certain aluminium-base alloys as the conductor materials in this kind of structure.

The form of the cable, which has proved itself most practical, is typified by the design illustrated in Fig. 3. Developed originally by Siemens and Schuckert, A.G., for networks equipped with copper hollow cables operated from 220 kv. to 380 kv., this design soon proved its worth, and has gained general recognition as a model of sturdy structure for tubular conductors.

The hollow-cable size ordinarily employed for overhead transmission at 220 kV has a diameter from 25 to 30 mm., and at 380 kV the diameter of 42 mm. The envelope of this cable is built up of two layers of ribbon conductor of rectangular cross-section, which are spiralled in the opposite direction round an inner helical support; the first winding forms a circular vault, the barrel of which serves as a base for an outer layer of flat wire of a finer gauge. Made in this fashion, the cable envelope is capable of withstanding both the radial and the axial loads encountered in service.

The inner support consists of a rolled copper ribbon 0.95 mm. thick, spiralled around its own axis. To prevent breaking of the edges, the ribbon, piror to coiling, is fluted. This original method of support possesses certain advantages over other designs, as it allows us to obtain a strong and dependable base of very light weight for superimposed electroconductive envelopes; according to the makers' claims, only 40 per cent. of the weight of the support is not utilized electrically, the remaining 60 per cent. constituting a supplementary cross-section for carrying the current load. With an outer cable diameter of 42 mm., the cross-sectional area of the envelope is 400 mm. sq.

Table 3.

Electric Pressure in transmission line, kV.	Construction of cable	Diameter of Conductor, mm.	Minimum cross-section of current carrying part of cable, mm. sq.	Cross-section of cable in the case of "solid" winding, mm. sq.
100	Normal	12	—	—
150	Normal	18	—	—
200	Hollow	25	185	500
300	Hollow	36	320	1,000
400	Hollow	50	520	1,900

Rigorous tests of tensile strength (13,400 kg.), and of the elastic and permanent elongations of this type of cable, have demonstrated that its structure, right up to the moment of rupture, suffers almost no alteration in shape, and under the action of ultimate stress the wires which compose the outer envelope break independently of the line of contact with the inner support, so that the helical vault of the double envelope takes up the applied load without unduly compressing its supporting base.

In spite of an elasticity lower than that of "solid" conductors, as well as other features peculiar to hollow cables (e.g., problems of jointing and attachment to line supports, etc.), which naturally require great skill and care in handling, it may be said that all the difficulties associated with the technique of their erection are things of the past; they are now employed successfully for heavy-duty lines.

At the present time, the advantages of this method for building the current-carrying layers of hollow cables are well appreciated, and this type of construction is being utilized by many manufacturers.

Of the very large number of different types of hollow conductors in use, we can only discuss a few of the most representative examples. Among hollow aluminium cables, of practical value, the design introduced by the Allgemeine Elektricitäts Gesellschaft, A.G., of Berlin, as illustrated in Fig. 4, is of particular interest. This structure consists of a core made of non-magnetic nickel steel able to bear the necessary mechanical load, with aluminium ribbon spiralled edgewise round to give support to one or two layers of aluminium conductors of rectangular cross-section, each wound in opposite direction. The current-carrying envelope superimposed on the aluminium spiral usually consists of 24 aluminium flat wires of 6 mm.^{2} cross-section, with a pitch of winding of 255 mm. in the case of a single layer, and 67 aluminium wires (32 in the inner and 35 in the outer envelope respectively) of 4.95 mm.^{2} cross-sectional area, having a pitch of winding of 515 mm., in the double-layer type.

Since the introduction of the first

designs for hollow conductors, the technique of production of these cables has made considerable advances. Improved construction was much facilitated by the use of suitable aluminium-base alloys, namely, Aldrey, Almelec, Aludur, Montegal, etc., which, together with their low density, possess very good conductivity and outstanding mechanical strength. Thus, by substituting them for copper in the prototype depicted in Fig. 3, we obtain hollow conductors, which combine adequate electrical conductivity with excellent mechanical properties and high resistance to corrosion.

Fig. 5 illustrates a structural modification in the design of tubular cable, in which Aldrey, Almelec, and similar aluminium alloys may replace copper.

Taking Aldrey as a representative of the group, this type of cable can be made on a spiral base consisting of a round Aldrey wire, which serves as a support for two layers of Aldrey conductors of rectangular cross-section wound in opposite direction. The inner support of the Aldrey wire of 2.3 mm. diameter, having a pitch of winding of 14 mm., thus forms a strong vault structure to act as a dependable base for the double envelope of a cable of the 42 mm. diameter and 400 mm.^{2} cross-section. Mention should also be made of the construction of the hollow cable shown in Fig. 6. This represents a variation of Siemens and Schuckert's design, in which is used an inner helical support consisting of a double-T cross-section instead of flat ribbon, the current-carrying envelope being formed of two layers of round wires wound in opposite senses. This method of construction, where copper can be replaced by Almelec or other suitable aluminium alloy, offers the advantage of enhanced mechanical strength owing to improved design and the superior characteristics of the light-alloy used.

Having regard to the much lower melting point of light metals in comparison with copper, it may be readily appreciated that, in order to prevent local overheating of the former due to arcing, particular attention should be devoted to the insulators and, if required, to the provision of special protective devices against flash-over.

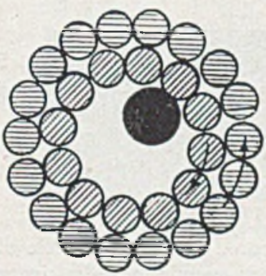


Fig. 7.—Method of construction of hollow Aldrey conductor containing an inner freely moving single core to suppress longitudinal vibrations.

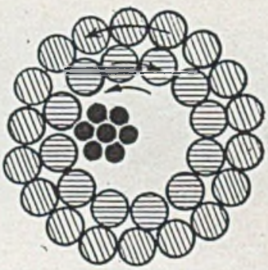


Fig. 8.—Variation of construction of the vibration-damping-type tubular conductor in Aldrey, having, instead, a stranded core of galvanized-steel wire.

As might be expected, the use of long spans and increase in the diameters of the conductors give rise to the longitudinal vibrations of the cable. These take place in a vertical plane and are in the form of stationary waves due to the action of a uniform continuous wind pressure. According to available data, the amplitude of the vibrations is of the order of 2 to 20 mm., at frequencies from 8 to 60 oscillations per second. They often lead to the destruction of the cable, and it is, therefore, of practical interest to mention a method developed in Germany to counteract such movement. A hollow conductor accommodates in its interior a parallel core, both parts being free to move relative to one another; by adjusting the respective mechanical tensions, we are enabled to keep each of the component parts at different frequencies and thus to neutralize stationary waves occurring in the principal cable.

Actual experience shows that the best results are obtained by using aluminium alloys (Aldrey and the like) as conductor material for winding the outer current-carrying envelope, which houses within itself a parallel freely moving component, the purpose of which is strictly mechanical and is confined to vibration-suppression; this part may consist either of a single core of nickel steel, as illustrated in Fig. 7, or a stranded core made of seven or more galvanized steel wires, as depicted in Fig. 8.

During the past few years further developments have taken place in Russia in utilizing aluminium and its alloys in the construction of hollow conductors for high-voltage overhead transmission purposes. One example of this work is a tubular cable, which can either be made of copper, or properly selected, electrically suitable aluminium alloys, the type as shown in Fig. 9, consisting of an inner fluted ribbon spiral, which gives support to the current-carrying envelope formed by two oppositely wound layers of flat wires. Detailed investigation of production technique for this type of conductor has been carried out at the Moscow State Cable Works.

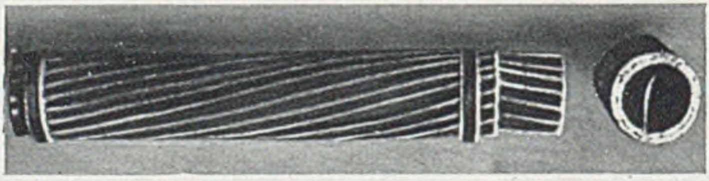


Fig. 9.—Tubular conductor of Russian construction for high-voltage overhead transmission.

Another type is represented by a steel-reinforced aluminium cable, designed for the 220-kv. overhead transmission line, 210 kiloms. long, connecting Magnitogorsk and Zlatoust in the Urals.

The body of the cable consists of a stranded core built of 19 galvanized steel wires each 1.8 mm. sq., with a ring of 12 additional windings of three-ply wires of the same diameter, having a total steel cross-section of 96 mm. sq. The current-carrying envelope of the cable is formed by two layers of 38 spiralled aluminium wires each 1.5 mm. sq., which, prior to use, are wound in a three-strand unit, thus giving a total electroconductive cross-section area of 201 mm. sq. With the outer diameter of 27.5 mm., the general weight of the cable is 1,337 kg./km. It is worth remarking that, compared to steel-cored aluminium cables of the normal design, this diameter corresponds to a cable, the aluminium cross-section of which equals 400 mm.^{2}

As the requirements which the conductor had to meet in the above-mentioned transmission line were specified as 28 to 30 mm. diameter and an equivalent copper cross-section of 100 mm.^{2} (that is, 160 mm.^{2} aluminium cross-section having identical electrical conductivity), it is obvious that the application of a steel-cored aluminium cable of orthodox structure would here be uneconomical.

Finally, mention should be made of the construction of an aluminium conductor of special design produced by the North State Cable Combine in Leningrad for the equipment of the experimental overhead transmission line, 1,600 metres long, operated at 500 kv., at the Leningrad Electro-Physical Institute. This cable consists of 3 × 37 aluminium wires of 2.8 mm. diameter, the method adopted by the makers for increasing the cable diameter being to spiral not the separate aluminium wires, but three-ply aluminium strands. Thus, the coefficient of filling, which in the usual winding amounts to 0.75, in this case is reducible to 0.49, so as to produce a conductor of 680 mm. sq. cross-sectional area and 42 mm. diameter.

Tests on samples of this cable have indicated a breaking load of 10,600 kg., or, approximately, 98 per cent. of the calculated ultimate stress.

(To be continued.)

ALUMINIUM SPOT WELDING

After Irmann in "Schweizer Archiv," 1944/10/177. A Study is Presented of the Relationship Between Welding Conditions and the Mechanical Properties of Spot Welds in Light Alloys

THE quality of a spot-welded joint, as that of an autogenous weld or a riveted joint, is determined, in the first place, by examination of mechanical properties. In addition, however, the appearance of the welded spot also provides very good evidence as to whether or not the joint is satisfactory. The properties of the weld will depend not only on welding conditions but also on the thickness of the material and its inherent properties.

If consideration be given to the conditions under which the spot weld is effected between two sheets, then at once certain conditions are automatically determined regarding the nature of the welding process; furthermore, it is possible to derive certain conclusions as to the influence of the physical properties of the various aluminium alloys upon the welding conditions which must be adopted.

If two sheets be pressed between the electrodes and the welding current be allowed to pass through the system, then the greatest resistance, and, therefore, the greatest heating effect, occurs at the contact surfaces between the sheets. The resistance between the electrodes and the outer surface of the sheet itself is reduced to the lowest possible minimum by adequate scratch brushing or pickling. According to the nature of the alloy, the resistance of the sheet will, itself, to some extent vary, but, in any case, will be quite small in comparison to that between the contact surfaces of the two sheets being welded. Here electrical resistance depends not only on the surface finish of the sheets concerned (the faces of each being covered with an oxide film of varying thickness, depending on the nature of the alloy and the heat treatment which has been given it) but also on welding conditions.

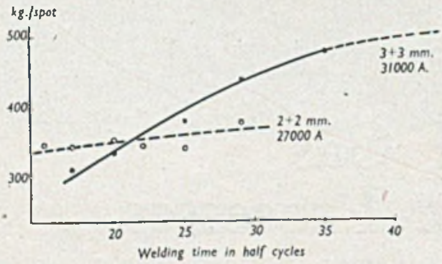
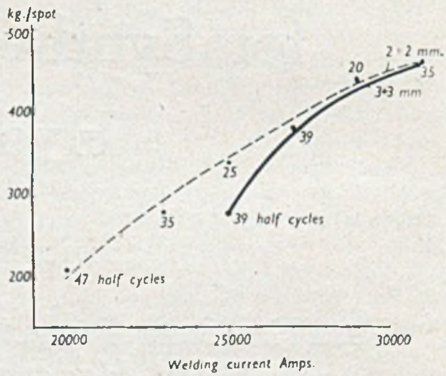


Fig. 1 (left).—Shear strength of spot welds in relationship to welding time for Anticorodal-B sheet-pairs respectively 3 mm. and 2 mm. in thickness. Fig. 2 (below).—Shear strength of spots in relationship to current density for material and gauges as in Fig. 1.



After melting has occurred at the contact surface between the sheets, heat is conducted readily through the mass, and further heating is possible only within narrow limits, due to the low electrical resistance which now obtains. Thus it follows that for welding to occur under these conditions current density must be raised to a reasonably high level, hence welding time must necessarily be short.

This chain of reactions is made very obvious if consideration be given to the effect of welding time and current density on the shear strength of spot welds in Anticorodal-B. In Fig. 1 is plotted the mean shear strength per spot in relationship to welding time in half cycles, for simple lap joints in sheet pairs 3 mm. and 2 mm. thick respectively. The welds are carried out on a machine with mechanical control. In the case of the 3 mm. sheet a current density of 31,000 amps was used, with electrodes 12 mm. in diameter and an electrode pressure of 500 kg. In the case of the 2 mm. sheet, a current density of 27,000 amps. was used with the same electrode pressure and electrodes of the same diameter.

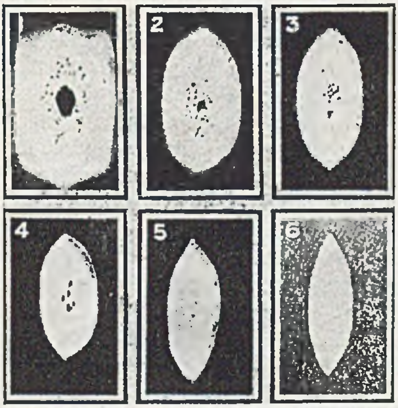
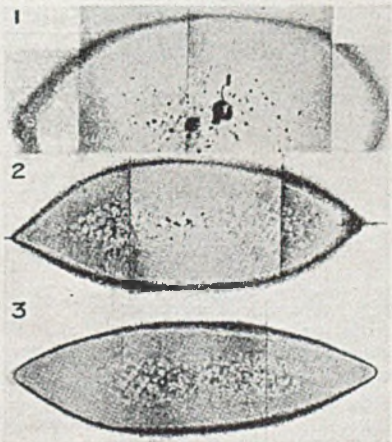


Fig. 3 (above).—Effect of electrode pressure on size of spots for welds in 3 mm. Anticorodal-B sheet (equivalent magnification in reproduction equals 9 dia). Commencing with "1," the macrographs here are representative of the results of gradually increasing electrode pressure, the spot illustrated in "6" being the smallest and soundest.

It will be seen that, especially in the case of thinner sheet, the effect of welding time is very small, whilst the use of the correct current density, as indicated in Fig. 2, has a most pronounced effect on the strength of the spot weld achieved. In spite of the decrease in welding time the strength of the weld increases strongly with increasing current density. However, the use of excessively heavy currents is limited by certain fundamental conditions, as the tendency of the electrodes to adhere to, or bite into, the sheet is much enhanced. Increase in the strength of the weld is, in all cases, to be attributed principally to more rapid melting at the contact surfaces and to the formation of a correspondingly greater area of interfusion.

Fig. 4 (below).—Appearance of spot in relationship to electrode pressure for weld in Anticorodal-B sheet 3 mm. thick. The macrograph "1," of a spot produced at low pressure, shows manifest unsoundness; an improvement is noticed in "2"; in "3" a small perfectly sound spot is evident.



It thus becomes clear that electrode pressure, which governs to a large extent the contact resistance between the sheets, promotes either a lesser or a greater degree of melting. For a given current density and welding time and varying electrode pressures, welding spots of various sizes are formed; this is shown in Fig. 3. The lower the electrode pressure the greater but more unsound is the area of interfusion. Blow holes and fissures decrease with increase in electrode pressure, as indicated very well in Fig. 4, which shows a series of welded spots between pairs of Anticorodal B sheet, each 3 mm. thick, with electrode pressures of 400, 700 and 1,000 kg. respectively. In the case of the 400-kg. specimen, the area of melting betrays numerous blow holes and fissures; these are still possible with an electrode pressure of 700 kg., whilst with a pressure of 1,000 kg. the fusion area is sound.

In Fig. 5 the width a and the height h of the fusion zone, together with the strength of the spot, are plotted against electrode pressure. Both spot width and height and spot shear strength decrease proportionately with increasing electrode pressure. The high spot strength which is obtained, however, with the lowest electrode pressure—for example, 300 kg.—promotes excessive fusion at the interface, and this causes not only blow holes and fissures in the zone of interfusion but also gives rise to the danger of melting through to the outer surface of the sheet. Hence in the case of 3 mm. sheet using 12 mm. diameter electrodes the lowest electrode pressure to be recommended is 500 kg. Furthermore, in practice it is more satisfactory with harder materials, such as Anticorodal B, to select electrode pressures as high as reasonably possible, for in this case, particularly when joining sheet or sections of large dimensions, inequalities at the contact faces tend to be reduced. In this connection it should be pointed out that higher electrode pres-

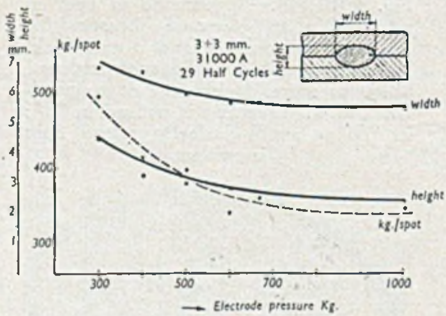


Fig. 5 (above).—Effect of electrode pressure on shear strength per spot and height and width of spot for welds in 3 mm. Anticorodal B sheet.

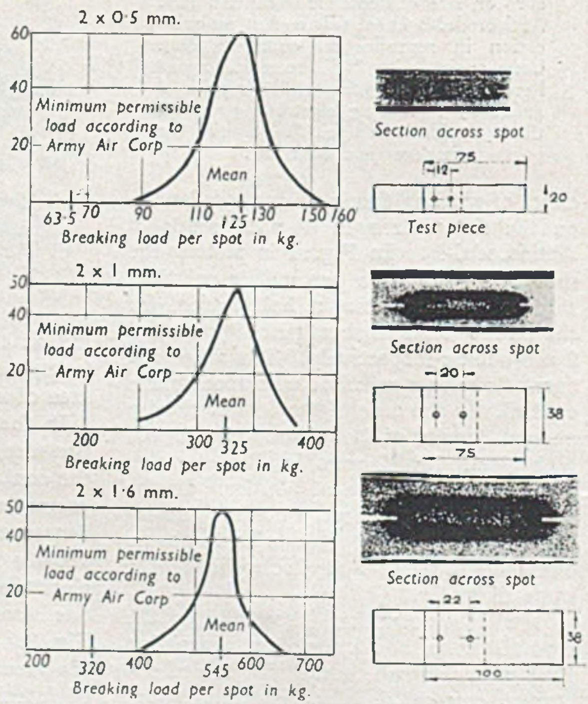


Fig. 6 (right).—Frequency curves for strength of spot welds in clad duralumin sheet. These welds were executed on a machine of the condenser-discharge type. The illustration is reproduced from p. 117 of the Welding Journal, 1941.

sures make necessary the use of electrodes the working faces of which should be given a very slight radius, for if a flat electrode be used the slightest tilting will

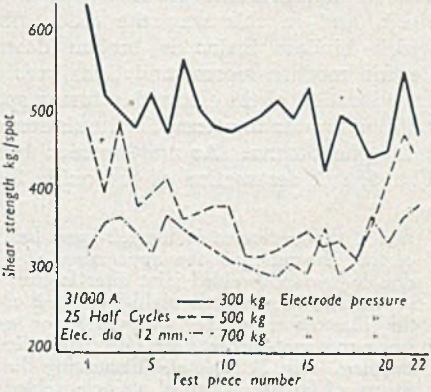
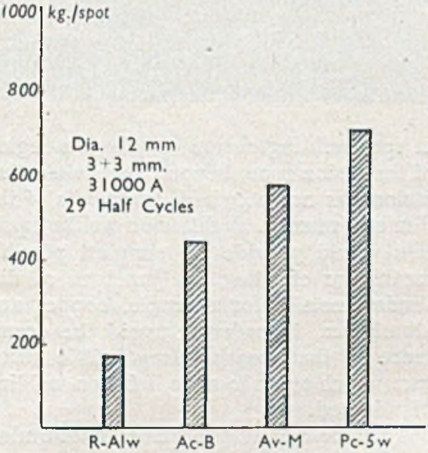
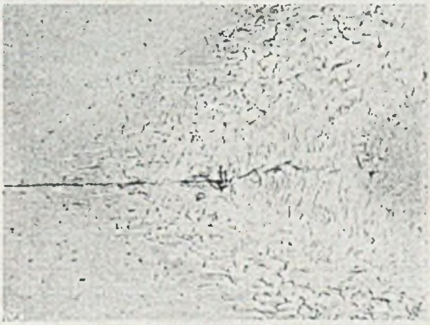


Fig. 7 (above).—Effect of electrode pressure on variation of shear strength in spot welds in 3 mm. Anticorodal sheet. Fig. 8 (right).—Micrograph showing oxide film at the spot interface of two spot-welded light-alloy sheets. Fig. 9 (below).—Mean spot strength for welds in soft unalloyed aluminium (RAl-W); Anticorodal-B (Ac-B); Avional-M (Av-M); and soft Peraluman-5 (PE-5W). Like welding conditions were observed throughout, and all sheet was 3 mm. thick.



give rise to most unsightly impressions on the surface of the sheet.

The electrode pressure has a very marked influence on the *range* of the mechanical properties exhibited by spot welds, and if welding conditions be not chosen with the utmost care, this range can be very great indeed. This is illustrated in Fig. 6, where variations in strength per spot are plotted for alclad sheet (dural core). In this case, values lie as much as 15-30 per cent. on either side of the mean. This variation, however, tends to decrease with increase in electrode pressures, as is shown by Fig. 7, for welds in Anticorodal B, with electrode pressures of 300, 500 and 700 kg. respectively. This indicates that control of the pressure cycle, which commences with very high pressure and which is only relieved during the passage of the current, can have a powerful effect in reducing



the tendency to strength variation in the spots.

As the oxide film on the sheets will vary in thickness according to the alloy, and according to the heat treatment which has been given it, and as, furthermore, this oxide film is not removed before the welding process is undertaken, the effect of pressure becomes obvious. At high pressures the oxide film is more easily broken down, hence the contact resistance between sheets which have not been pickled or scratch brushed becomes less; as a result of this, the area of melting, i.e., the size of the spot, also decreases if the current density employed be insufficient. Conversely, by artificially increasing the contact resistance, the area of the fusion zone may also be increased; for example, a strip of aluminium foil may be laid between the sheets being welded, or the surface of the sheets at the contact zones may be provided with a heavier oxide film; for instance, by M.B.V. treatment.

The relationship between variation in spot weld strength and surface treatment given to the sheet prior to welding is, at the moment, not entirely clear. According to investigations by Bollenrath (" Z. für Metallkunde," 1942/34/187), using all types of machines manufactured by numerous concerns, variations were obtained just as great as those indicated above, and these quite independent of the surface treatment given to the sheet before welding. The results of our own investigations have so far led only to this conclusion, that variation in mechanical properties tends to become more marked with increase in the thickness of the stock being welded. The fusion zone in the case of thick material shows a great tendency to become non-uniform and to exhibit blowholes and fissures, defects which are favoured by rapid cooling and steep temperature gradients.

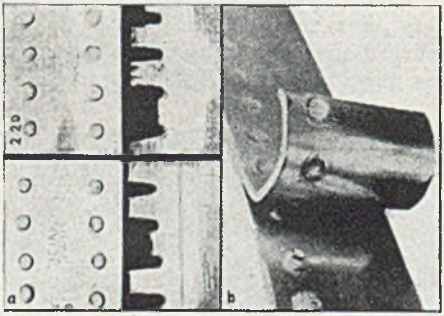
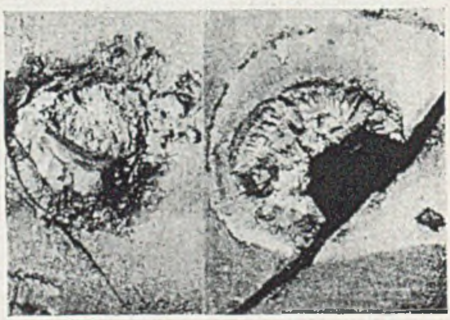


Fig. 10 (left).—Shown in the left-hand half of this illustration is the appearance of a double-row spot-welded joint after fracture in tension; shown in the right-hand half of the illustration is the appearance of a single-row spot-welded joint after failure in bending. Fig. 11 (below).—Illustrating the course of fatigue failure of a single welded spot in Anticorodal.



In this connection, the application of a controlled pressure cycle entailing after-pressing of the spot subsequent to the passage of the welding current, appears to be of value in so far as not only are porous spots consolidated, but, at the same time, in place of the gassy zone there is produced what might be described as a lightly forged structure. In principle it would be better, when spot welding, to set as the goal, not a junction by fusion, but rather joining by diffusion, such as takes place in the case of hammer-welded aluminium. Hammer welding, however, besides demanding the use of higher temperatures, employs high pressures and promotes flow similar to that occurring in the production of clad sheet, and in this way the oxide film which hinders fusion is broken down. Certain modern recommendations involving vibration of the electrodes during spot welding appear to attempt a simulation of these phenomena. As may be seen from Fig. 8, full destruction of the oxide film in spot welding occurs only in the region of the fusion zone; beyond this, where full fusion has not occurred, fragments of the film still remain. A diffusion welding process would provide the simplest possible means for effecting the juncture of dissimilar metals, for example, copper and aluminium, in order to avoid the occurrence of the unsatisfactory brittle structure which tends to arise if fusion welding be adopted.

To some extent, the welded spot undergoes a heat treatment process as a result of the very rapid cooling applied to the molten metal. Further improvements, however, might be effected in the structure of the welded zone by deliberately heat treating or by homogenizing: in practice, however, this is rarely likely to be possible. There are, however, interesting suggestions in this regard involving careful manipulation of the current and pressure cycles whereby, after junction has been effected under high pressure,

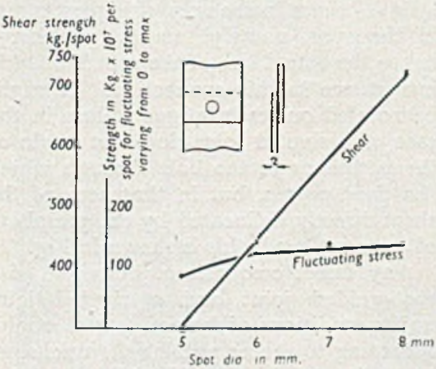
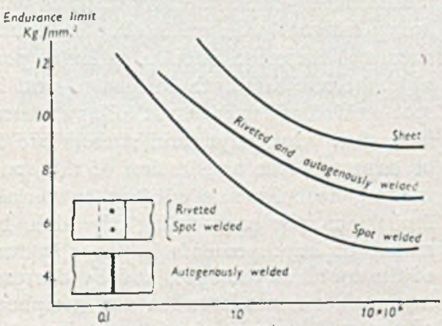
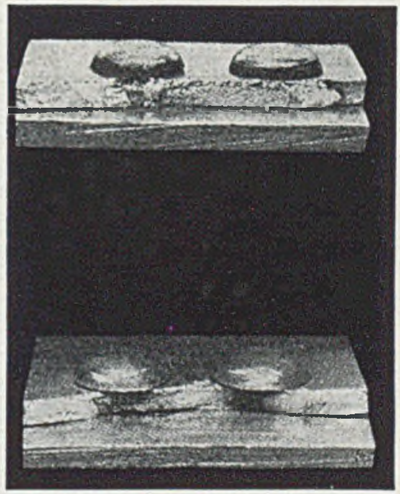


Fig. 12 (above).—Effect of spot diameter on shear strength, and resistance to fluctuating stresses (varying from 0 — Max.; i.e., Ursprungsfestigkeit) for spot welds in aluminium-copper-magnesium. Fig. 13 (right).—Course of fatigue failure in a riveted joint. Fig. 14 (below).—Alternating-bend strength for spot-welded joints in 1 mm. Anticorodal-B sheet. For comparative purposes, curves are presented for riveted joints and autogenous welds in the same material.



further heating is caused by the application of more current.

From these remarks it will be quite obvious that the quality of the weld depends very considerably on the structure of the weld metal which is obtained; hence any precise laying down of welding conditions is not possible, whether according to the type of alloy being welded, or in relation to gauge of stock; every case must be judged on its own merits. Fig. 9 presents in diagrammatic form the mean strength of welded spots in aluminium sheets and aluminium alloy sheets 3 mm. thick. In every case spot welding was carried out under the same conditions, and measurement of the size of the spot showed that shear strength per spot is, to some extent, governed by its dimensions; these are smallest in the case of unalloyed aluminium, and greatest in the case of Peraluman 5. From this it may be deduced that the shear strength of spot-



welded alloys is greater than in the case of spot-welded unalloyed aluminium.

The fact that the alloys which possess electric conductivities inferior to that of the pure metal exhibit greater weld strength might lead to the conclusion that the specific resistance of the sheet functions as a measure of the size of the spot which will be obtained. This, however, is obviously not the case; the thickness of the oxide film on the surface also plays its part, in so far as it promotes a greater or lesser degree of interfusion to occur between the sheets.

If the surface of sheared spot welds be examined, various types of fracture will be found, the nature of the broken surface depending not only on the quality of the weld itself, but also on the thickness of the material and the shape of the test piece. In Fig. 10, the specimen at the left, with two rows of spots, failed in shear by tearing of the edge of the sheet, as in the case of a similar riveted joint, the sheet being thin and the interval between the row of spots and the sheet edge definitely inadequate. In the case of a join made with a single row of spots, rupture in shear results in the spots being torn from the sheet, with the production of a hole, this process taking place the more readily the thinner and softer the sheet concerned.

Tensile stressing through the spot in a direction at right-angles to the surface of the sheet may arise as shown in the right-hand specimen in Fig. 10, by bending of the specimen. In such a case, the spot may be pulled apart with the production of a pit in one half of the joint, or a hole may be formed. If the shear strength of the spot be determined in this way, values will be obtained inferior to those resulting from true shear stressing carried out in a direction horizontal to the surface of the sheet.

Similar to these static tests, so also is the case of dynamic stresses: the strength of a spot weld will vary according to the direction in which it is loaded. The endurance limit of a spot weld is determined by the area of greatest stressing, that is, at its periphery. At this point, in the case of a simple joint with a single row of spots, peak stresses as much as five times as great as the mean stress will arise. In Fig. 11, two spot welds are shown after fracture under an endurance strength test. Progressive cracking has occurred around the edge of the spot and has proceeded in part towards the interior of the molten zone.

It is interesting to note that, by increasing the size of the spot, by using, for example, a higher current density, static strength is markedly increased, whereas dynamic strength, as determined by a load fluctuating between zero and max., is only slightly increased. Fig. 12 shows that the static strength per spot increases approximately linearly with spot diameter, whilst for a fluctuating load of the type we have described not only does the strength level lie lower, but, furthermore, exhibits only a minor rise. This becomes clear when we remember that failure by fatigue occurs in the area of highest stress in the spot, namely, at its periphery, hence the actual size of the spot is of little importance in this connection. It might be pointed out that fatigue failure in the case of a riveted joint does not begin at the periphery of the hole through which the rivet passes, but in that area of the sheet directly delineated by the periphery of the rivet head; this is shown in Fig. 13.

Any direct comparison, however, of a spot-welded joint and a riveted joint under conditions of dynamic stress would, according to earlier published work, seem to be impossible. In Fig. 14 are plotted alternating bend test curves (for stresses varying between positive maxima and negative maxima) for 1 mm. Anticorodal B sheet. The sheet alone for this type of stressing gives a value of 9kg./mm.^{2}, whilst a riveted joint and an autogenous weld in the same material give fatigue values of 7kg./mm.^{2}; the corresponding value for a spot weld is 5kg./mm.^{2}.

Alternating-bend stressing imposes very heavy fatigue loads on a structure; such stressing, therefore, should, as far as possible, be avoided both in riveted and in spot-welded assemblies. It follows, therefore, that where dynamic stresses are to be expected, the application of the spot-welding technique is subject to certain limitations, the overcoming of which, by means of improvements in the structure of the metal at the spot, and by decreasing peak stresses between the periphery of the spot and the sheet, must form the subject of further research. This, it is to be anticipated, will probably take the form of intensive investigation into the mechanics of the spot-welding process as applied to light alloys, with the object of further increasing the degree of control at present exercised over that part of the cycle involving the freezing of the fused metal.

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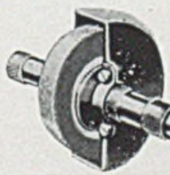

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