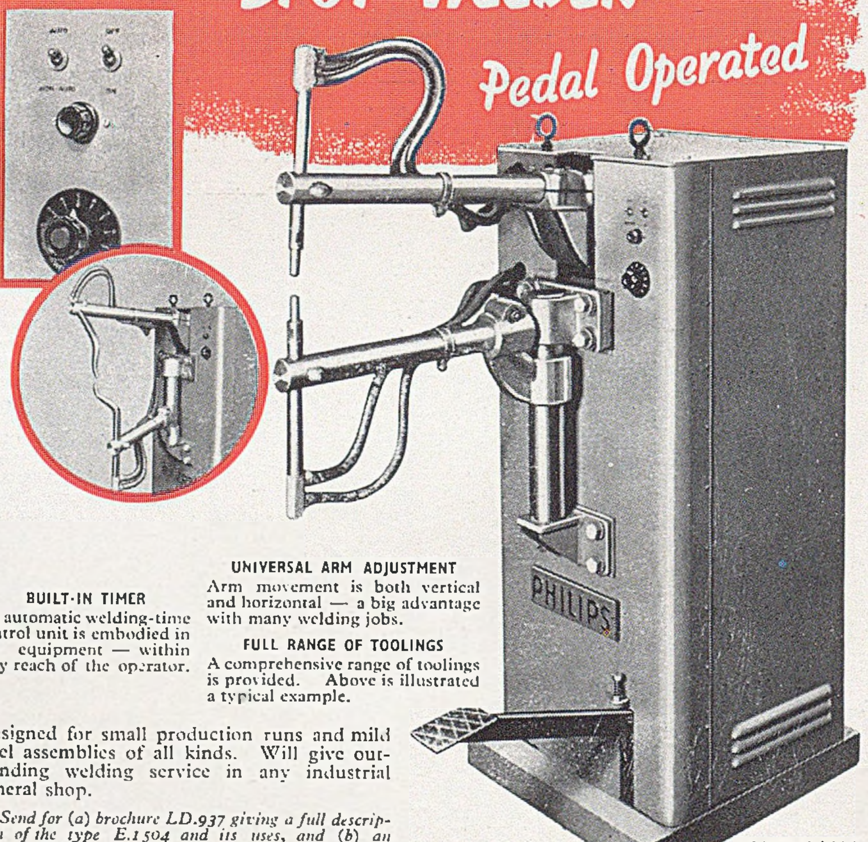
ALUMINIUM CANS—A CLEAN BILL!

LIGHT METALS

MARCH
1948

2/-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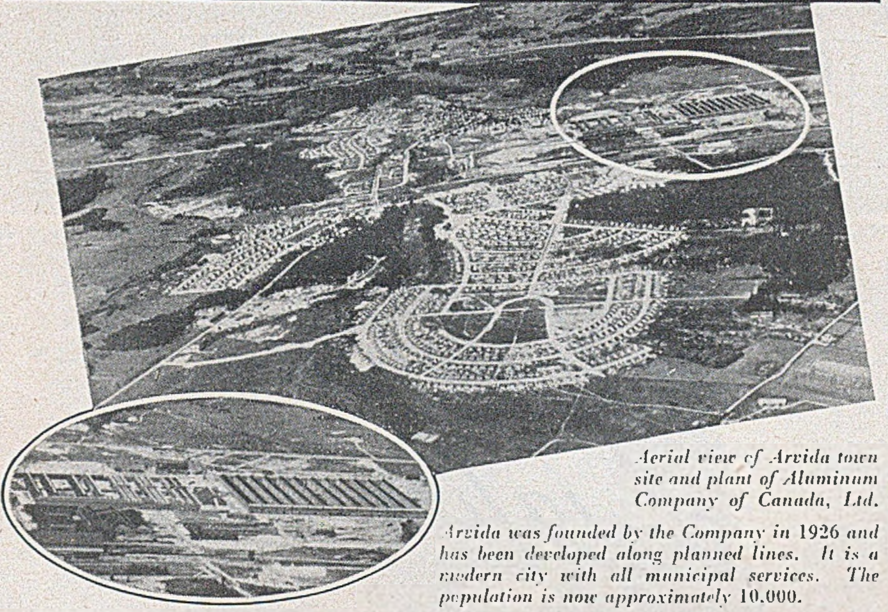
Background to Achievement



Aerial view of Arvida town site and plant of Aluminum Company of Canada, Ltd.

Arvida was founded by the Company in 1926 and has been developed along planned lines. It is a modern city with all municipal services. The population is now approximately 10.000.

THE world volume of aluminium production today ranks second amongst metals. This is the measure by which aluminium now serves mankind. Industrial history has, in fact, few parallels to the leap of the aluminium industry into its present position. Large-scale production has made possible a lowering of basic prices—a further incentive to the more abundant use of the metal. Here, essentially, is a story of drive and imagination—with Canada as the centre of the largest aluminium producing organisation in the British Commonwealth. For the Aluminium Limited Group, the story has involved vast new enterprises and operational activity. All this to one end—the growth of large-scale production and distribution of aluminium and its alloys from mine to market. The trade and industry of Great Britain have been well served: still greater service will be our constant object.

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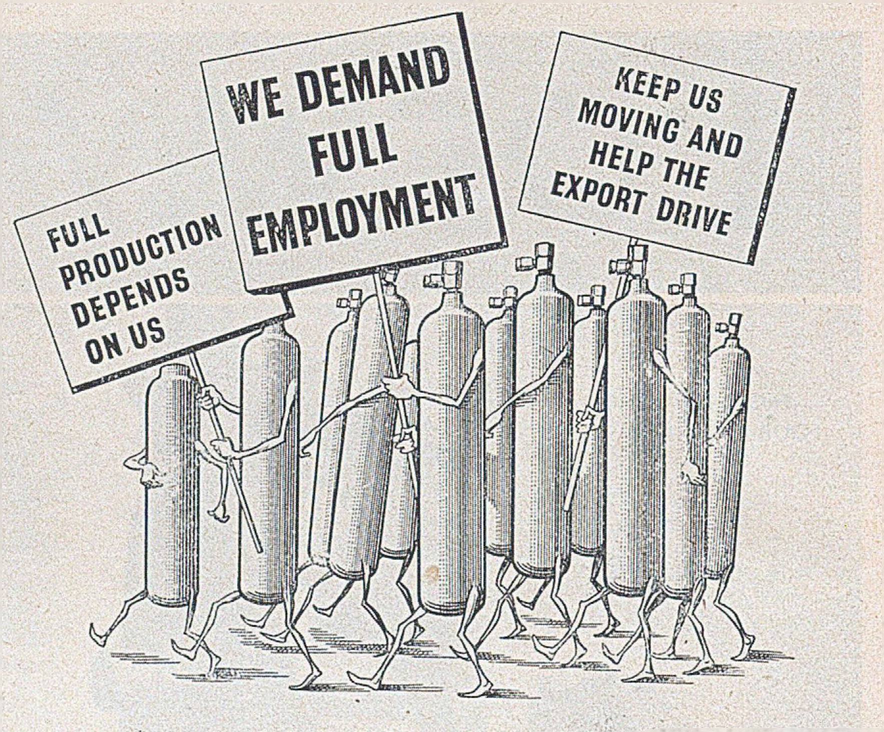
LOEWY


FULL PRODUCTION DEPENDS ON US
WE DEMAND FULL EMPLOYMENT
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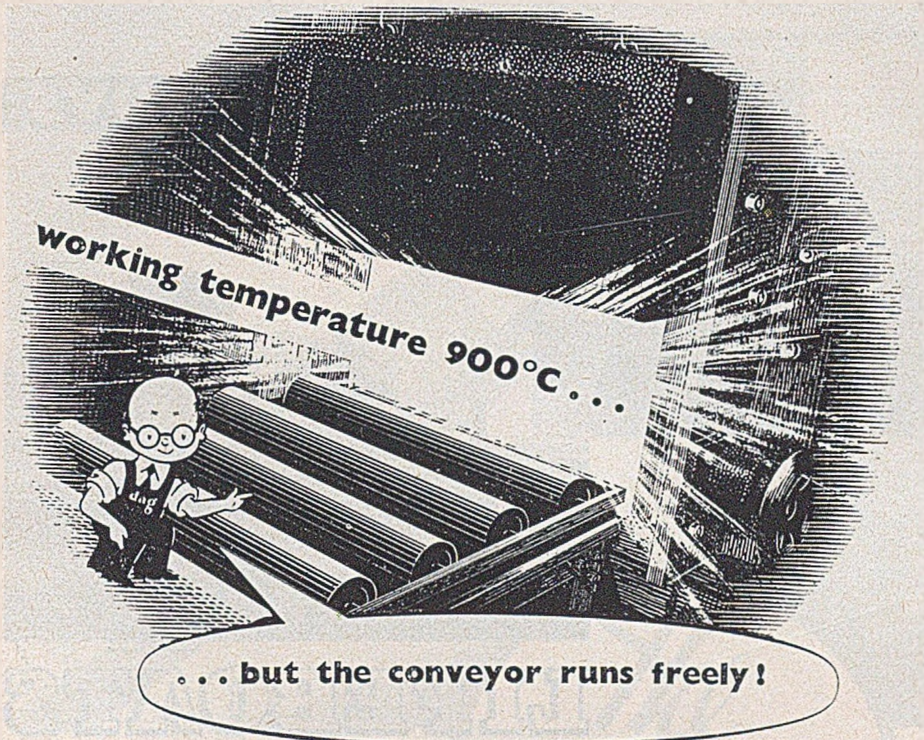
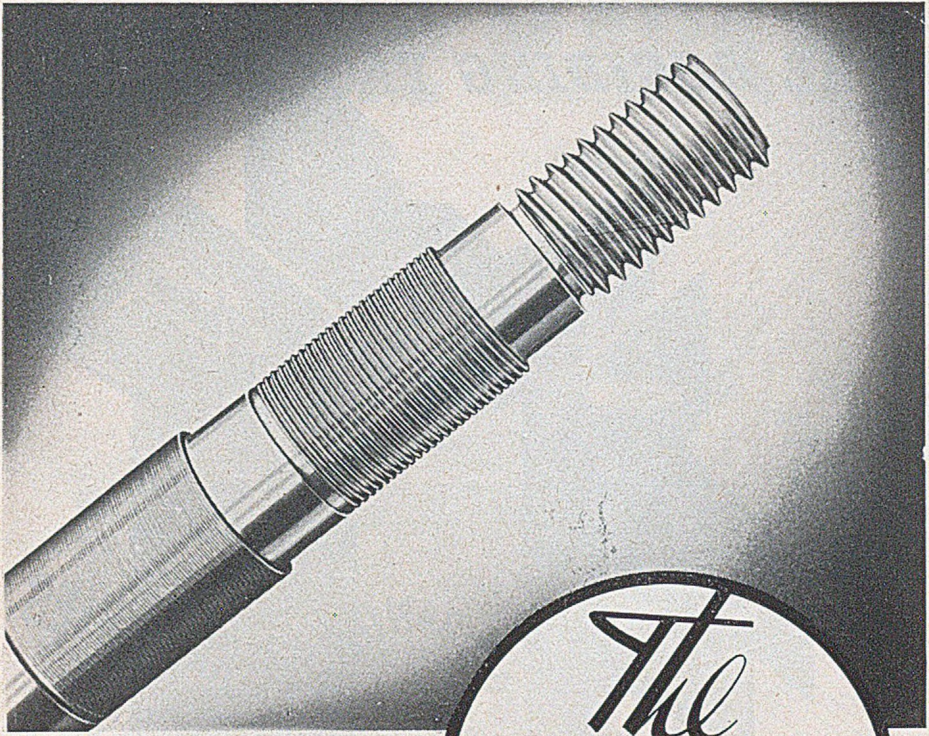
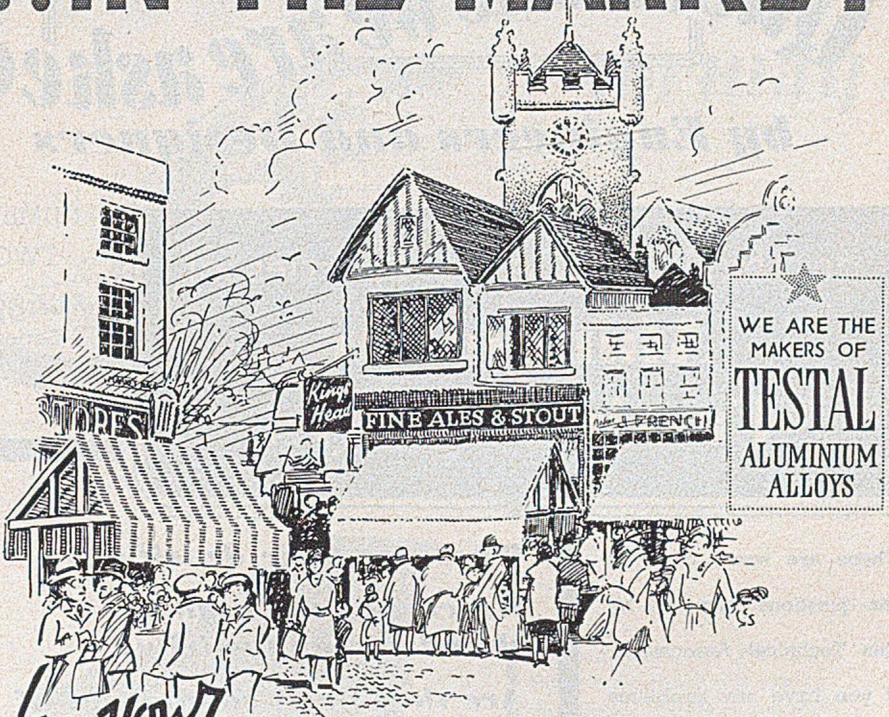

working temperature 900°C . . .
dag
. . . but the conveyor runs freely!



...IN THE MARKET



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by Engineers and Designers

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These are some more of the questions answered by this Technical Association. If you have any problems involving aluminium casting alloys, free and confidential advice may be obtained upon request to . . . . .

What are their densities?

Which has the highest electrical conductivity?

Are they good conductors of heat?

What are the values for the coefficients of thermal expansion?

At what temperatures do the alloys begin to melt?

etc. etc.

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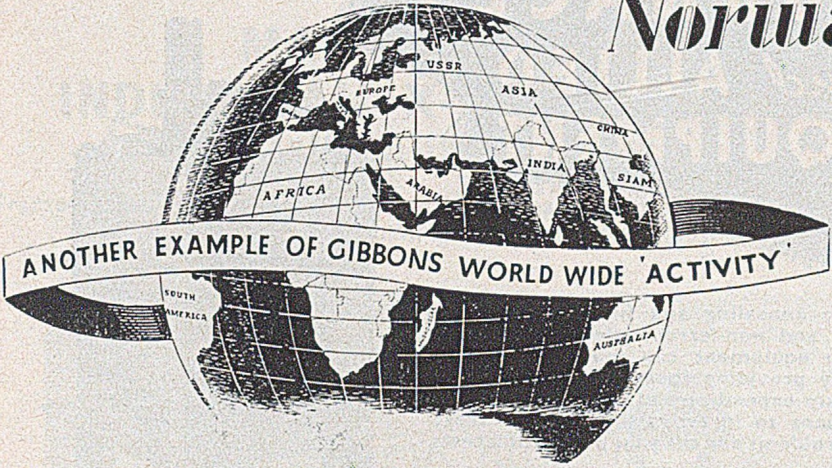
USSR
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SIAM
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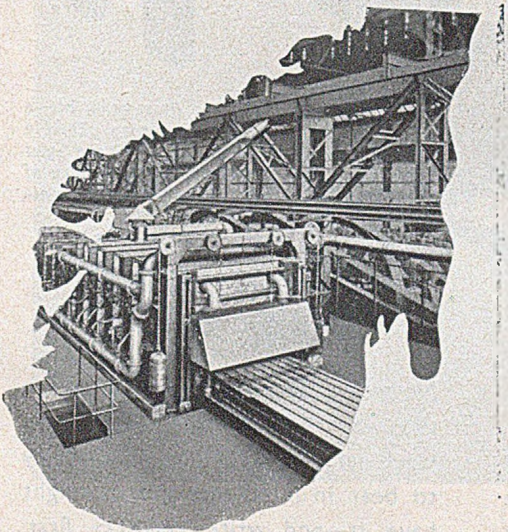
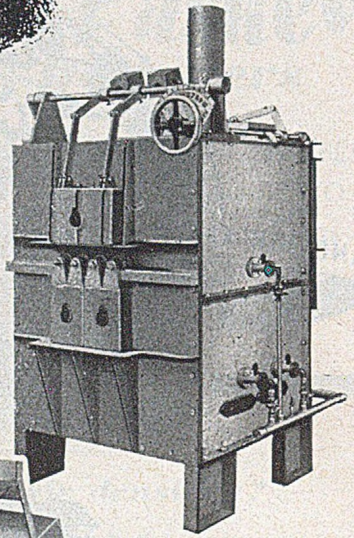
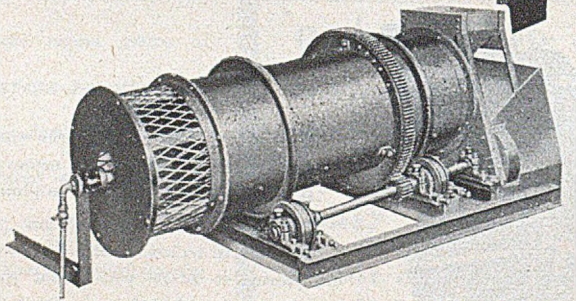
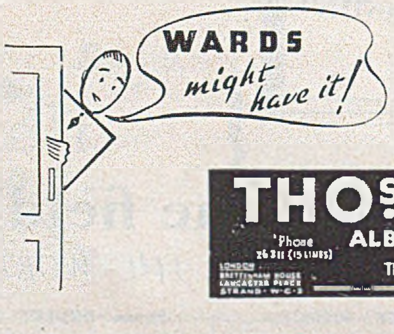
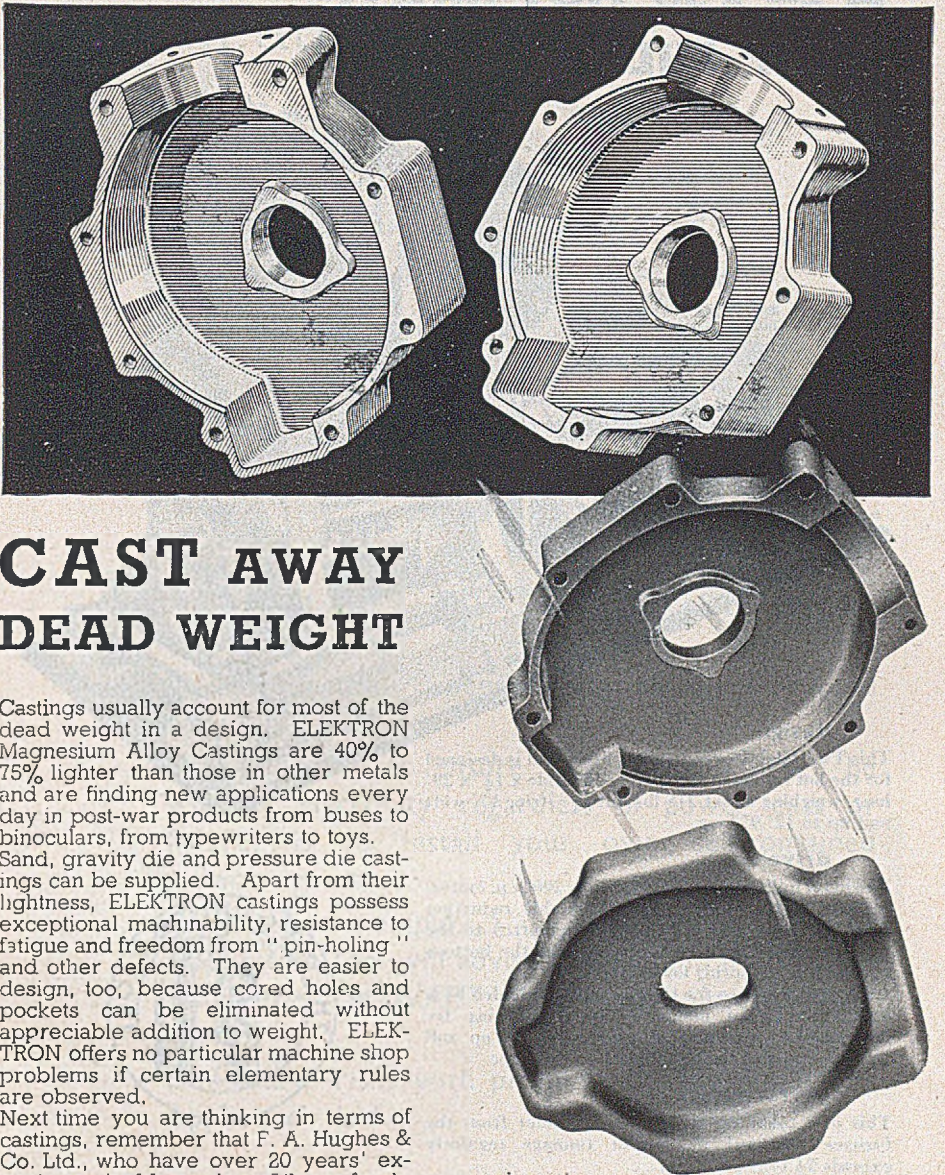
AFRICA
ANOTHER EXAMPLE OF GIBBONS WORLD WIDE 'ACTIVITY'
SOUTH AMERICA
AUSTRALIA



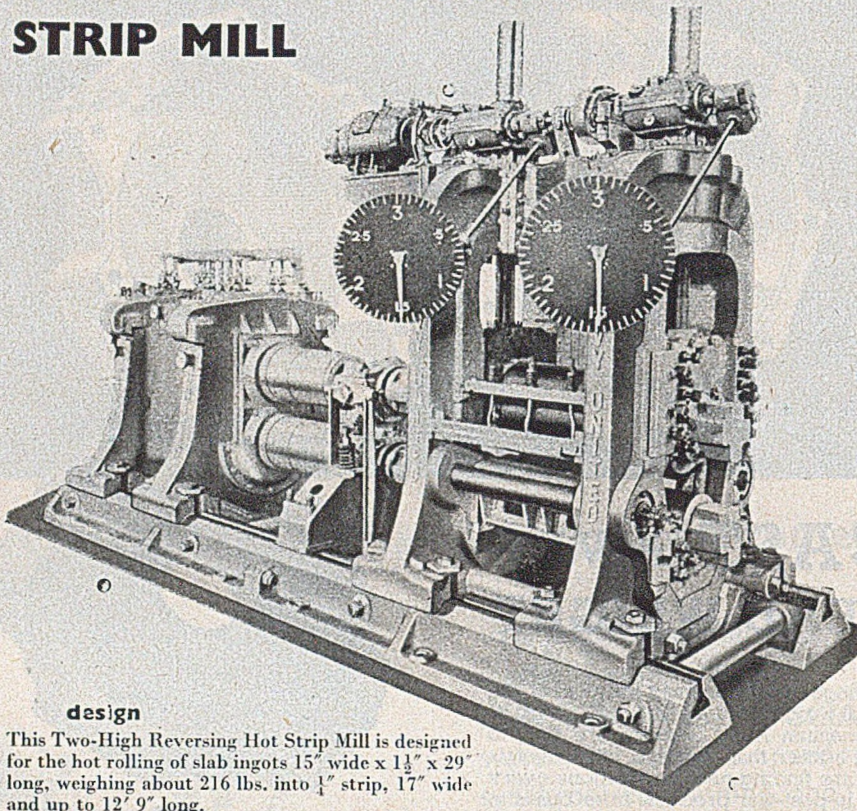





WARDS might have it!



A 24″ x 36″ HOT BRASS STRIP MILL



design

This Two-High Reversing Hot Strip Mill is designed for the hot rolling of slab ingots 15″ wide x 1½″ x 29″ long, weighing about 216 lbs. into ¼″ strip, 17″ wide and up to 12′ 9″ long.

drive

The main mill drive is provided by a 200-h.p. motor, running at 415 r.p.m. through double reduction gear. Weight balanced bearings are fitted to the top spindle while the balance gear for the bottom spindle is of the spring loaded type.
Electric screwdown for the top roll is provided by a 10-h.p. motor, a magnetic clutch allowing for independent operation of each screw. Top roll balance gear is of the underneath weight type.

performance

This mill takes up to 30 slabs an hour from the furnace line and its output tonnage regularly exceeds 2½ tons per hour.

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designed and built by

DAVY and UNITED

ENGINEERING COMPANY LIMITED SHEFFIELD

Proprietor of : Davy and United Roll Foundry Limited, Billingham.
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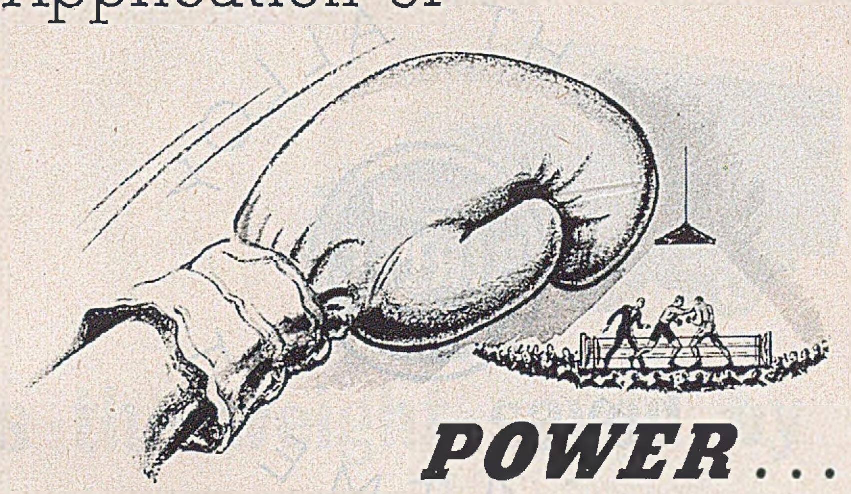

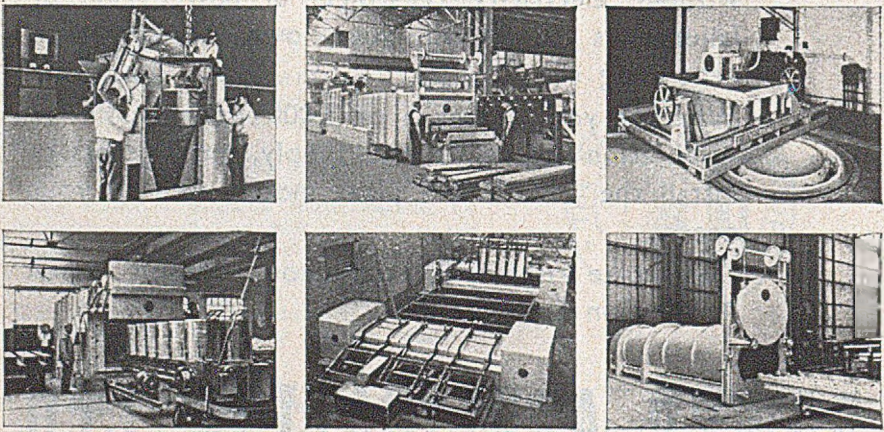

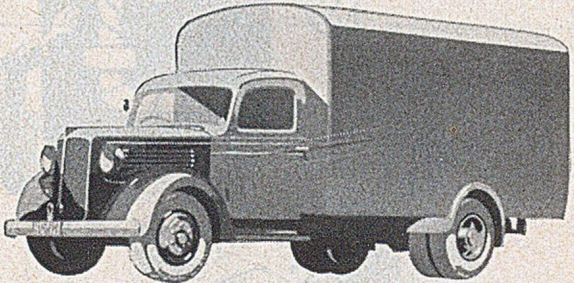


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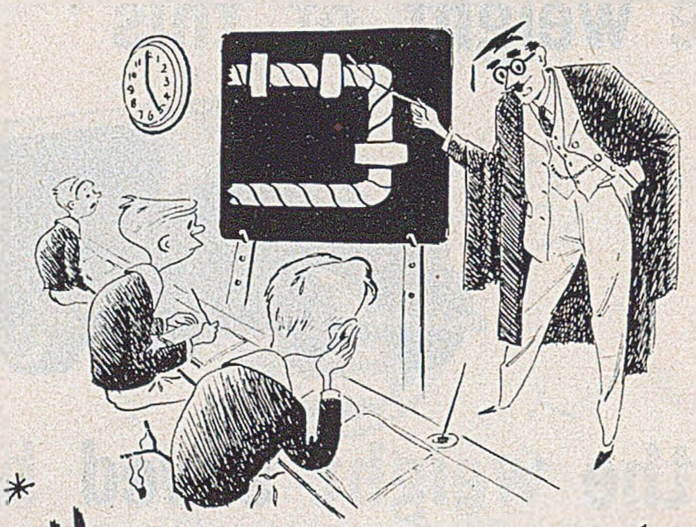


* HEAT CAN BE KEPT IN TOO!

Heat's natural instinct is to go out to play from all surfaces which store or convey it. Few people realise that if a 1″ steam pipe with a surface temperature of 200° C is unlagged for 20 ft., the heat lost by radiation and convection may waste nearly half a hundredweight of coal in the course of a working week.

Most likely your heated surfaces *are* lagged. But are they all lagged *efficiently?* Are regular checks carried out to ensure that insulating material is in good condition everywhere — including that dark corner where the pipes can't be reached without a ladder? Is the thickness of the material sufficient for the temperature of the surface it covers? Are you sure that flanges and valve bodies have not been left naked to make maintenance easy? The heat loss from a bare flange may be as much as that from a foot or more of bare pipe.

Proper lagging of boilers, cylinders, steam pipes and other heated surfaces pays the highest dividends in fuel efficiency for very little capital expenditure. Fuel Efficiency Bulletin No. 2 published by the Ministry of Fuel and Power is a little mine of information concerning this. The Ministry's Regional Office will gladly send you a copy if yours has gone astray.

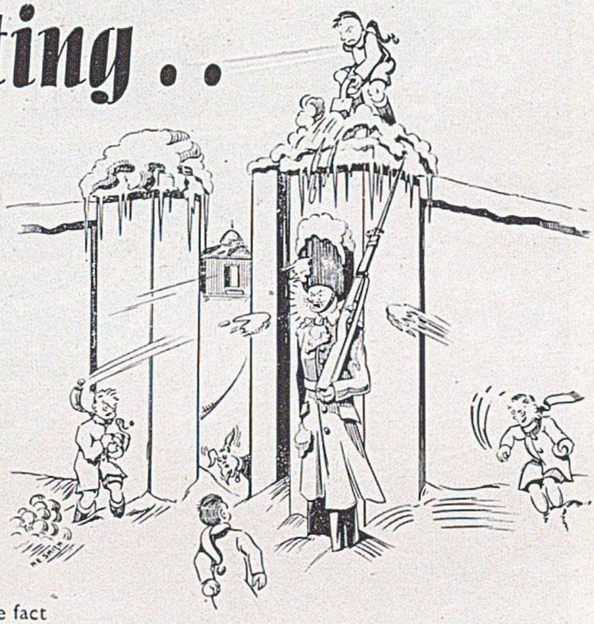
YOUR REGIONAL FUEL OFFICE

REGION	ADDRESS	TELEPHONE
Northern	Government Buildings, Ponteland Road, Newcastle-on-Tyne, 5	Newcastle 28131
North-Eastern	Century House, South Parade, Leeds, 1	Leeds 30611
North-Midland	Castle Gate House, Castle Gate, Nottingham	Nottingham 46216
Eastern	Shaftesbury Road, Brooklands Avenue, Cambridge	Cambridge 56268
London	Mill House, 87/89 Shaftesbury Avenue, W.1	Gerrard 9700
South-Eastern	95, High Street, Rochester	Chatham 3487
Southern	Whiteknights, Earley, Reading	Reading 61491
Wales	27, Newport Road, Cardiff	Cardiff 9234
South-Western	12/14, Apsley Road, Clifton, Bristol, 8	Bristol 38223
Midland	Temporary Office Buildings, Hagley Road West, Birmingham, 17	Bearwood 3071
North-Western	Burton Road, West Didsbury, Manchester, 20	Didsbury 5180-4
Scotland	145, St. Vincent Street, Glasgow, C.2	Glasgow City 7636
Scotland	51, Cockburn Street, Edinburgh, 1	Edinburgh 34881
Scotland	1, Overgate, Dundee	Dundee 2179

ISSUED BY THE MINISTRY OF FUEL AND POWER

TRADE TERMS TRAVESTIED · NUMBER TEN

Chill casting . .



USERS of TJP aluminium alloys don't have to rely upon the weather for supplies of coolth for chill casting. They can create the necessary chilly atmosphere at any season. It has even been known to permeate buyers' offices on rare occasions, but we have found that the charms of Priestman representatives soon warm up the welcomes! Seriously, though, we do want to draw your attention to the fact that there are several TJP aluminium alloys that produce sounder castings in a chill mould than in sand. Our advice on the selection of these is yours for the asking. They are absolutely reliable and true to specification; a confident assurance made possible by the good work of the TJP chemical and physical laboratory staff, in strict testing and checking at all stages of production. Profit by the QUALITY guaranteed by TJP!

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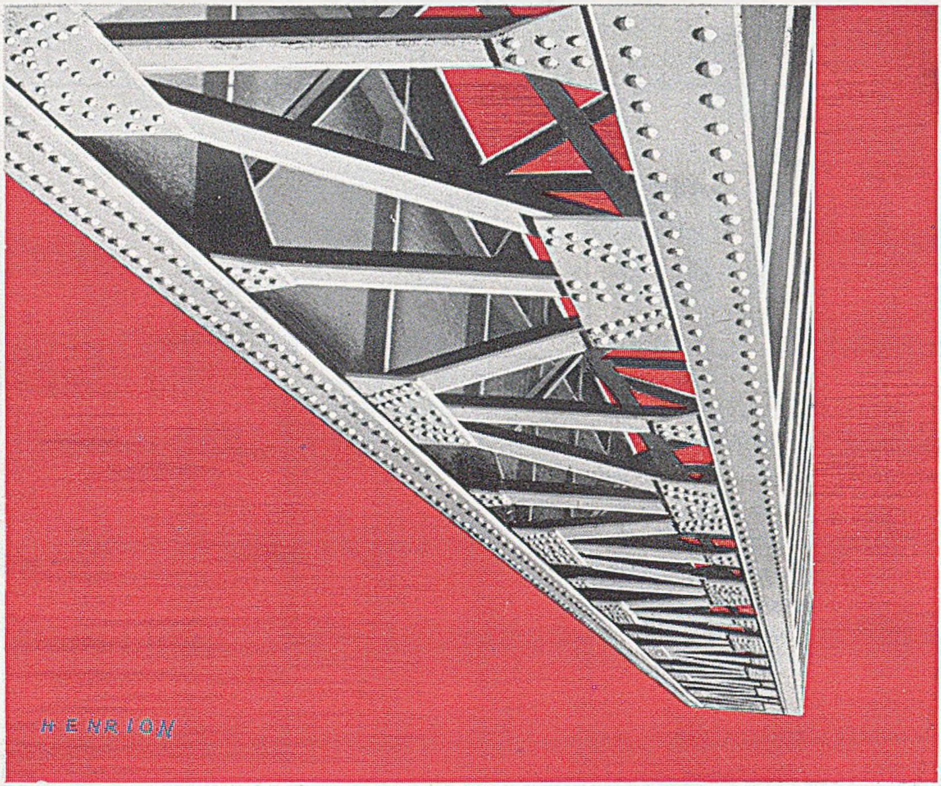
ALUMINIUM TPJ BRAND ALLOYS


HENRION

VOL. XI. No. 122.

MARCH, 1948

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.

Branch Offices at
BIRMINGHAM,
COVENTRY,
MANCHESTER,
and
GLASGOW

◆

EDITORIAL OPINION

Red Sea to Tyneside and the Clyde

"... *and the Tyrian monarch, nothing loth, equipped a fleet of 'ships of Tarshish,' at Ezion Geber.*" (*Rawlinson, "India and the Western World,"* C.U.P., 1916, *p.* 10.)

FROM the tumultuous days of Solomon and his friend, Hiram, King of Tyre, until the dawn of this present troubled phase in world history, shipwrights pursued their craft with but few fundamental changes in a technique limited by the one suitable material of construction they had at their disposal. Teak, greenheart, oak and the mahoganies, these and less familiar timbers obtained from the forests of the Eastern and Western Hemispheres formed the one and well-nigh inexhaustible resource upon which our Navies depended, until the coming of the iron ship somewhat above a century ago. With this, many of the old limitations of design and circumstance were gradually and successfully overcome; others came to light, however, as demands and duties changed, and for these, no immediate solution could at first be offered.

The merits of light metal for shipbuilding were first discerned and tested out in practice 50 years since, but the cost of aluminium, lack of suitable alloys, and absence of essential structural and design data together conspired to hold up development, and real progress has been made only during the past 20 years. Now the fruits of the work done during that time have come to maturity.

"Tentative Requirements for the Quality and Testing of Aluminium Alloys for Shipbuilding Performance," comprised within pages 43 to 45 of Lloyd's Register of Shipping, Notice No. 1879, marks an historic event. In the place of the customary steel, approval has been given for the use of plates in certain types of aluminium alloy, not only for superstructures but also for the main hull assembly of large ships. The schedule presented is admirable in its scope and flexibility; sufficient guidance is given to enable intelligent use to be made of existing materials and fabricating facilities, but ample opportunity is left for further development, either directly as a result of informed experimental enterprise, or, in consequence, generally of major advances in aluminium-alloy technology.

On an historical note we began, and on one such shall we end:—the triumph of

De Lesseps at Suez eclipsed Ezion Geber, so long familiar to the wooden vessels of Hiram and his successors in these waters. But History is temperamental and has a habit of reversing her judgments. It may yet be that, in the future, the glories of Aelana may be revived and, off the shores of Edom, above the worm-eaten ribs of the ships of Tyre, light-metal hulls will ride, as they break their long journey from the West to Ophir and beyond.

It's Good—it's Canned—in Aluminium

"On an empty stomach the mind is peculiarly open to morbid imaginations" (*Turton*, *"There was Once a City," Methuen*, *London*, 1927, *p*. 68).

ALTHOUGH we pay full tribute to Turton's axiom quoted above, we cannot believe that stringent rationing in these islands is, alone, responsible for a most unfortunate circular recently issued by the Ministry of Food. In this is indicated Ministerial disapproval of imported foods canned in other than tinplate containers. From what source did the inspiration come which led to the promulgation of this unhappy document? Whence its studied vagueness, and why, in fact, is it not made at once apparent that, specifically, the Ministry has developed an acute allergy to fish canned in aluminium?

Disquiet amongst light-metal can makers, and in the ranks of those who produce, market and consume foodstuffs packed in this material, is one immediate result. Norwegian enterprise is especially affected and, in that country, those interests which have suffered from the implied prohibition feel justifiably aggrieved.

The ill-defined nature of the charges which, we must presume, have been preferred against aluminium, give rise to the gravest suspicion concerning their origin and purpose; their misinterpretation by a technically and scientifically uninformed public may occasion harm to many thriving branches of industry, both at home and abroad.

It is inconceivable that aluminium producers should be expected to rush forward to the defence of their metal as regards suitability from the standpoint of hygiene. This was made clear during a recent minor outbreak of trouble in the U.S.A., arising as a result of mechanical damage to cans, the contents of which were, in themselves, above suspicion. Is it possible that the Ministry of Food, like a frightened horse, has shied at the echo of a whistle blown across the other side of the Atlantic, or is there, in reality, some trivial remedial point which the pundits who supervise the quality of our imported canned fish would like to see adjusted but are too modest to announce openly? Most likely, it would seem, some slight modification in boxing of the cans for transport would overcome the difficulty.

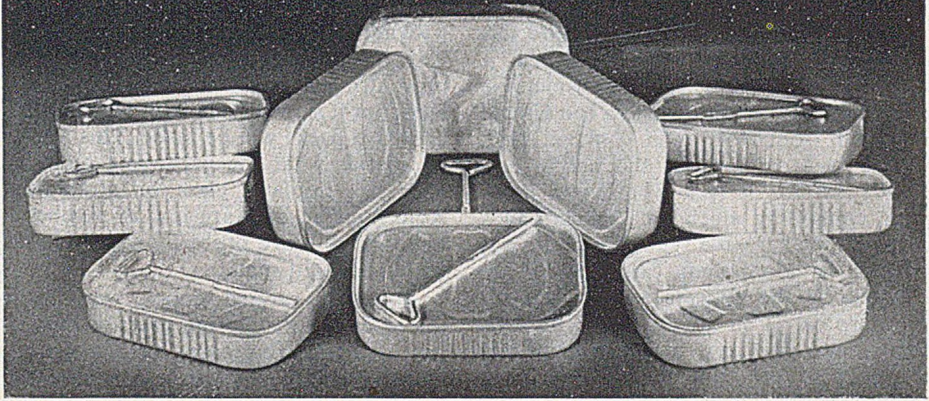
Contents

SPECIAL FEATURES

REGULAR FEATURES

"LIGHT METALS" is published in London, England, on the first Wednesday of each month. Annual Subscription Rate : 26/- post free. Shorter periods pro rata.

Aluminium Cans A Clean Bill!



An Examination of the Implications Contained in Circular C/26/J/66 of M.O.F., More Especially from the Standpoint of the Norwegian Canning Industry

SOME few months ago there was issued by the Ministry of Food in London a circular C/26/J/66, in which it is stated "Applications (for Import Licences) for goods packed in other than tinplate will not be supported." This has given rise to very serious misunderstandings and, in particular, has inflicted considerable hardship on the Norwegian canning industry in so far as not only does Norway export a large volume of her canned products to this country, but, furthermore, relies to a major extent on the use of aluminium as a packing medium. Somewhat naturally the viewpoint has been taken that the prohibition referred to here applies solely to goods packed in aluminium cans. The implication is justified, although it should be noted that no specific reference has been made to aluminium.

The case to be considered resolves itself under two main headings; first, that of the inherent suitability of aluminium as a canning material for many types of foodstuff and, secondly, the nature and properties of an aluminium (or a suitable aluminium alloy) can, as contrasted with those of a similar tinplate can.

The use of light metal for can-making, the technique of can production, and the hygienic aspects of aluminium for food canning have all been dealt with very fully in past issues of "Light Metals."* It is, therefore, proposed in this memorandum to refer merely to the causes responsible for the present temporary difficulty.

Information regarding this matter reached the Norwegian aluminium industry early in December, 1947, a copy of the Ministry of Food's circular being forwarded to Norway by an English importer of Norwegian canned products.

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* See select bibliography on page 119.

In a covering letter he wrote as follows:—"We ourselves hope that you, together with your canning associations, aluminium manufacturers and possibly your Government Departments, will take this matter up with the British Government as our own personal opinion is that for certain goods aluminium is perfectly satisfactory."

The main product, the import into this country of which is now prohibited, is cod roe and liver paste. Considerable quantities of this were sent to the United Kingdom from Norway in 1946 and 1947. It was well received by the public, and rightly so, for it is a wholesome foodstuff, containing much fat, protein and a number of valuable vitamins. It was packed in aluminium cans, which are claimed by the packers to be ideal for the purpose, in so far as, unlike tinplate, light metal does not blacken under the influence of the contents, nor are these themselves blackened or stained.

Recently, it appears, some details were given concerning a mishap with this product. A case of food poisoning occurred after the cod roe and liver paste had been consumed, and at the retailer's shop from which it had been purchased, were found a number of aluminium cans which were blown and partly damaged as a result of perforation by the accompanying key. It is not surprising that, as a result of exposure to external contamination arising from this damage, pathological bacteria were found in large numbers in the paste. Full appreciation of this point is of great importance:—*Infection occurred as a result of damage to the tin; at no time was any suggestion made that the aluminium itself was in any way responsible for the harmful effects.*

Close investigation which, off and on, has been pursued now for nearly half a century, has demonstrated quite conclusively that aluminium is probably the least toxic of all metals.* Now the incident referred to here happened some time *after* the issue of the Ministry of Food's statement, and it seems that, prior to the appearance of that directive, no complaints had reached Norway from Great Britain. It must not be inferred that no instances had occurred of defective cans being found; cans themselves are manufactured on mass-production lines, and packing itself is also practised in a similar way. Both operations are subjected to the most stringent safeguards and exhaustive tests, but it is inevitable that, occasionally, defective packs will be made. This applies no matter what the packaging materials may be—tinplate, glass or aluminium. Rejections at sight are few in number in any case, but are probably equal for tinplate and light metal.

Although canned goods were introduced during the closing years of the 18th century, and, therefore, have a century and a half of tradition behind them, it is not to be denied that a lingering prejudice still exists. This arose in the first place, probably, due to accidents or ignorance in earlier days, but these mishaps in the light of adequate scientific control are no longer possible. If, however, trouble does arise, it is commonly experienced that the old prejudice itself suffers a recrudescence. Aluminium as a canning material is comparatively new; where faults arise, many place the blame at once on the metal without considering fabrication methods or can design.

Obviously, however, it is not to these very elementary details that the issue of the Ministry of Food's circular can be imputed. We have already indicated that the non-toxicity of aluminium has been amply demonstrated. Furthermore, the metal can in no way be considered as exerting an inhibitory effect on the destruction of bacteria during processing. As a reason then for the issue of the statement, some other factors must be found.

It has been suggested that, because a trial import of Norwegian brisling in oil, packed in aluminium cans, were found to be unsatisfactory in 1933, this precedent was called upon to substantiate the

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* See, for example, "Aluminium and Food. A Symposium of Research by Independent Experts." Issued in folder form jointly by the British Aluminium Co. Ltd. and others. See also "Aluminium Vessels and Food Contamination." Dunbar Mitchell. Published by John Bale Sons and Danielsson, Ltd., London, 1933, "Aluminium in Food." Monier Williams, 1935.

present attitude. At that time hydrogen swell was common, due to slight attack on the metal which was used without the application of a surface finish. Chemical attack responsible for hydrogen evolution had been virtually eliminated by 1939 when all cans were produced by stamping from pre-anodized aluminium strip. Late in 1946 a minor outbreak of food poisoning occurred in U.S.A., as a result of which an embargo was laid by the New York City Health Department on sardines packed in aluminium cans. About one per cent. of a total import to the United States of nearly 300,000 ounces of aluminium cans showed a certain percentage exhibiting hydrogen swell. These cans were carefully investigated by experts, both from the United States and Norway. It is possible that officials of the Ministry of Food in London may have attached undue importance to this incident, but examination of the official statement which was issued will indicate quite clearly that the trouble was fortuitous and in no way attributable either to aluminium cans or to the goods packed in them.

The Norwegian Government agreed to withdraw some 1,000 cases of the sardines, the sale of which had been prohibited from the New York City market by the New York City Health Department. Health Commissioner Israel Weinstein announced that this action was wholly voluntary and the offer of the Norwegian Government was conveyed to the New York City Health Department by the Royal Norwegian Consulate-General in New York. Dr. Weinstein said that both the New York City Health Department and Norwegian Government Agencies had conducted extensive investigations into the matter. Jerome Tricter and Edwin Ludewig, respectively director and assistant director of the Health Department Bureau of Food and Drugs, went to Norway at the expense of the Norwegian Government and worked with Government and canning industry experts on the problem. Furthermore, Miss Valberg Aschehoug, bacteriologist in charge of the bacteriological section of the Research Division of the Norwegian canning industry, and Sigurd Buschmann, chemical engineer of the Norwegian Aluminium Company, came to New York and worked with Health Department experts on the investigation.

Results indicated, said Dr. Weinstein, that a very small number of cans had sprung leaks; this allowed the entry of bacteria, which might have caused the outbreak of illness; this, however, could not be proved by the subsequent investigation. A small percentage of aluminium cans exhibited defective seams, which resulted in leakers and swells. Jerome Tricter reported to Dr. Weinstein that the Norwegian canning industry, the hygienic aspects of which are under close supervision of the Government, had instituted rigid control over seaming equipment and seaming practice, in order to prevent recurrence of this trouble. It was emphasized that no criticism of the use of aluminium as a container was involved in the findings of the Norwegian and the U.S.A. investigators. Dr. Weinstein pointed out that aluminium had been used as a metal for food containers without ill-effects for many years. Norwegian sardines, whether packed in aluminium or tinplate, he said, are a safe and wholesome product, and the Health Department has no restrictions against their sale in U.S.A., where investigations of the Norwegian canning industry indicated that canned sardines were produced under sanitary conditions with every effort made to ensure high quality and a safe product.

Any consideration of the relevant merits of aluminium (or a suitable aluminium alloy) and tinplate as packing media is bound to involve comparison between the respective mechanical properties of these two materials. It has been stated that aluminium cans, as at present produced, lack the rigidity of tinplate cans and hence tend, under adverse conditions, to be damaged during transport. Only test results obtained in actual service can decide this issue, and it is a fact that although, prior to 1939, about half a million cases of aluminium cans were exported to U.S.A., no complaints in this regard were made; indeed, one large concern importing Norwegian sardines into the United States, demanded specifically that they be packed in aluminium cans.

Of the three rigid packing media commonly employed for foodstuffs, namely, tinplate, glass and aluminium, each possesses well-known properties which define not only limits of usefulness but also details of design, processing technique and even, to some extent, packing and transport systems. Thus the fact that aluminium is "softer" than tinplate is not to be considered necessarily a drawback. Aluminium cans must be handled with more caution than tinplate during fabrication, production and transport. The outer packaging must be adequate and so designed as to provide maximum protection against mechanical damage. In order to avoid perforation, opening keys, if these be used, must be of correct diameter and flattened at the end. The seaming of aluminium cans must, in every way, be as perfect as that required for tinplate cans, a soluble rubber compound being employed as a sealing medium. With correctly designed and operated seaming machines and proper control, safe and satisfactory seaming of the cans is assured beyond doubt.

Bearing these points in mind, there can be no question that the light-metal can offers itself as very suitable for a large number of food products. Aluminium imparts no metallic taste to the contents of the can, gives rise to no blackening and, as we have said before, is devoid of toxicity and of any destructive action upon vitamins. From the retailers' standpoint, light-metal cans possess a definite shelf appeal by reason of their clean silvery colour. They are light in weight and are easy to open.

As regards the present use of light-metal cans in Norway, material for these in the form of coiled sheet is being supplied to the canning industry at the rate of about 1,800 tons a year. Delivery is limited to this figure at the moment, on account of shortage of rolling capacity. In Denmark the canning industry is showing increasing interest in these cans, and the consumption of aluminium strip is now at the rate of about 700 tons a year.

From Norway, the principal export products are sild and brisling sardines in oil—these being packed in anodized aluminium cans—and kippered herring, packed in cans fabricated from the alloy 3S containing 1.25 per cent. Mn. Cod roe and liver paste in anodized cans is a comparatively recent product, but is now being packed in increasing quantities. Fish balls, cod-roe, fish cakes, shrimps and crab and a number of vegetables are also at the moment packed in aluminium cans and are showing satisfactory results.

Tabulated in this account will be found a survey of the present situation. It should be emphasized, however, that certain of the new synthetics may quite likely improve the storage capacity for a number of products packed in lacquered aluminium cans. An article in the Danish monthly publication "Konserves" for December, 1947, contains a report from the Official Laboratory for Food Conservation entitled "The Use of Aluminium Cans for Conserves." The article presents the results of numerous canning trials with unprotected, anodized and lacquered aluminium cans respectively. From these it was concluded that as a container material for food products, aluminium is just as good as tinplate, and, in some cases, even to be preferred. Slightly acid products may readily impart a metallic taste to foodstuffs packed in tinplate; this is not the case with the aluminium can.

No especially new developments are to be recorded in connection with the use of aluminium cans in Norway. The necessary "over-pressure" autoclaves are installed in all the principal canneries, and the experience of the industry with the metal and its treatment is growing. Previously, rubber rings alone were used as a sealing device, but now a "soluble" rubber compound is finding increasing favour; it is applied to the can lids by means of Dewey and Almy machines.

Storage Capacity of Food Products in Aluminium Containers.

Product	Can material	Storage time
Brisling in oil	Anodized 2S	Several years
Musse (Sild) in oil	Anodized 2S	Several years
Unsmoked sardines	Anodized 2S	Several years
Fresh fish fillets	Anodized 2S	Several years
Fish balls	Anodized 2S	Several years
Fish cakes	Anodized 2S	Several years
Codroe	Anodized 2S	Several years
Codliver	Anodized 2S	Several years
Mussels, stewed or natural	Anodized 2S	Several years
Crab, stewed or natural	Anodized 2S	Several years
Shrimps	Anodized 2S	Several years
Peas	Anodized 2S	Several years
Mushrooms	Anodized 2S	Several years
Blood pudding	Anodized 2S	Several years
Liverpaste	Anodized 2S	Several years
Unsweetened condensed milk	Anodized 2S	Up to 2 years
Sweetened condensed milk	Unprotected 2S	Several years
Brisling in tomato	Roll-lacquered, anodized 2S	Approx. 2 years
Musse (Sild) in tomato	Roll-lacquered, anodized 2S	Approx. 2 years
Kippered herring	Unprotected 3S	2 to 3 years
Carrots	Anodized 2S	Are packed on an industrial scale. Must presumably be packed in roll-lacquered anodized 2S to obtain quite satisfactory results
Cauliflower	Anodized 2S	
Parsnip	Anodized 2S	
Beans	Anodized 2S	
String peas	Anodized 2S	
Meat cakes	Anodized 2S	
Beef	Anodized 2S	
Anchovies	Roll-lacquered, anodized 2S	Industrial trials promising
"Gaffelbiter"	Roll-lacquered, anodized 2S	
Asparagus	Roll-lacquered, anodized 2S	
Kale	Roll-lacquered, anodized 2S	
Caraway (with evtl. addition of $CaCl_2$)	Roll-lacquered, anodized 2S	Must be packed in lacquered material. The length of storage time somewhat variable
Spinach (with evtl. addition of $CaCl_2$)	Roll-lacquered, anodized 2S	
Parsley (dependent on bleaching agents)	Roll-lacquered, anodized 2S	
Celery (dependent on bleaching agents)	Roll-lacquered, anodized 2S	
Mutton	Roll-lacquered, anodized 2S	

Fruit, berries and jam : Packed in spray-lacquered, anodized 2S. Usually very good results.
Fruit, berries and jam : Packed in roll-lacquered, anodized 2S. Special kinds promising.

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(2) A Comparison of the Production of a Container Cover in Alternative Metals. By P. S. Houghton. 1939/2/301-303. A detailed comparison of the operations requisite to the production of a simple cap for a cosmetic container in aluminium and in brass demonstrate the economic advantages of the light metal for the purpose and form a strong argument in favour of its extended use. 5 diagrams.

(3) Lacquer Coated Sheet (Impact Resistance). 1942/5/395-397. Results are given for impact and Erichsen tests on lacquered aluminium sheet for food containers. The advantages of pretreatment by the M.B.V. process are noted. 4 illus. 7 refs.

(4) Aluminium in the Canning Industry. 1942/5/426-436; 470-488; 526-540. A comprehensive discussion on the suitability of aluminium for use in the canning industry. Both in its application and methods of working, the light metal is compared in detail with tin plate. The influence of the properties of the metal on can design is exhaustively dealt with, particular reference being made to preferred modifications of conventional design. The final instalment deals principally with the provision of interior protective finishes for the can. 18 diagrams. 29 tables.

(5) Aluminium in Fish Canning. 1943/6/137-154. A critical summary of Lunde's investigations in Norway on the practicability of employing light metal cans for fish packing. Details are given of the metallographic examination, supplemented by numerous reproductions of photomicrographs, records of swelling, 34 packing test results, the amount of tin and aluminium dissolved by various canned fish and the relative corrodibility of tinplate and aluminium when used for fish packs. 15 illus. 7 tables.

(6) Aluminium Small Equipment in the Canning Industry. 1943/6/240-243. Brief notes with ample illustrations of the application of high priority unalloyed aluminium to ancillary equipment in the canning industry—pails, colanders, pans, trays, pots and kettles, 23 illus.

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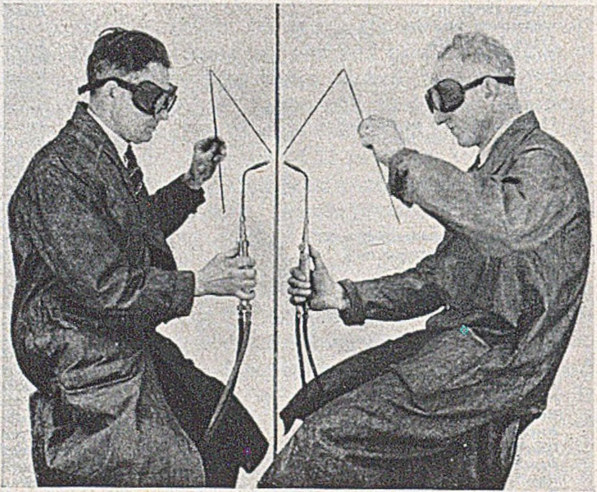
(9) Aluminium Cans in Norway. 1946/9/206-207. Some indications of the advances made in the use of aluminium for fish canning in Norway since 1939 by Dr. Mathiesen of the Government Canning Research Station at Stavanger.

WELDING THE LIGHT ALLOYS

Part II

In this, the Second of a Series of Four Articles, is Presented an Account of the Oxy-acetylene Welding Process as Applied to Sheet and Castings in Aluminium and Magnesium Alloys



OPERATORS welding sheet aluminium by the double operator vertical technique. This method is recommended for materials of ¼-in. section and over.

OXY-ACETYLENE fusion welding is at the present time the technique most widely used for the welding of light alloys. During the past 50 years a great deal of experimental work and research has been devoted to the development of suitable equipment and procedures for the fusion welding of aluminium and later magnesium, and a vast fund of technical knowledge and practical experience is at the disposal of those manufacturers who decide to turn to welding light alloys in preference to other methods of joining. A welder who takes up work in the light-alloys field after welding mild steel will find that his previous experience is not sufficient in this new work owing to the particular characteristics of these metals, and if he has had no training in this type of welding he will soon be in difficulties. The pitfalls which will beset him are however easily avoided, for efficient welding techniques have been evolved to overcome them, and with experience and practice the average welder will find that light metals are welded as readily as steel.

Apart from the fact that welding allows greater freedom to the designer, affords greater speed and economy in production, and considerable saving in materials and weight, fusion welding produces a joint which is stronger than the parent metal itself, and which, having the same characteristics as the parent metal presents a smooth inconspicuous joint of even contour. This is due to the fact that in fusion welding the two edges to be jointed are heated to such a temperature by the blowpipe-flame that they coalesce, and so form a homogeneous joint, becoming in effect a single piece of metal. If further metal is added to the joint, in the shape of a filler rod, as in practice it is to all but the thinnest sections, this is normally either of the same composition as the parent metal or so designed as to give superior metallurgical properties to the joint.

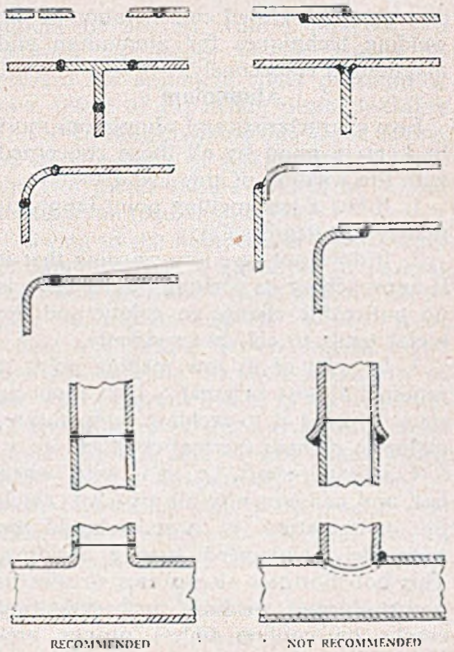
Equipment for Fusion Welding.

The high temperature (3,120 degrees C.) produced by the oxy-acetylene flame, provides a very highly concentrated heat source, which makes possible higher welding speeds and a narrower heat-affected zone than are obtained with other gases. Consequently acetylene is the gas most commonly used for welding. The oxy-hydrogen flame is also sometimes used but is not recommended as the temperature of this flame is 820 degrees C. below that of the oxy-acetylene.

The type of welding equipment used for fusion welding depends upon whether dissolved or generated acetylene is used as the fuel gas. High-pressure equipment must be used for dissolved acetylene, whilst low-pressure equipment must be used with generated gas.

The apparatus for use with dissolved acetylene is too well known to need lengthy description. For mobility the cylinders may be mounted on a trolley and the whole apparatus then becomes portable. Alternatively where repetition work is to be carried out by a number of operators, and the welding points can be fixed, it is often advantageous to connect the cylinders to manifolds from which a pipeline can be run. The advantages of using dissolved acetylene and high-pressure equipment are numerous, among them being the fact that the acetylene is thoroughly purified and dried before being compressed into cylinders, thus ensuring that no harmful impurities are present which might otherwise affect the reliability of the weld.

It is particularly important when welding the light alloys to ensure that the right welding rods and fluxes are used. Various ranges of welding rods have been developed by the welding industry, each rod being designed for a specific purpose or a particular alloy. These rods should never be used except on the range of alloys for which they were designed. In some cases strips cut from the parent metal may be used as filler rods, and in case of doubt the supplier of the alloy should invariably be consulted.



THE importance of correct design of joint for fusion welding cannot be overstressed. These diagrams indicate how to avoid the inclusion of flux in welded joints.

A flux should always be used for welding both aluminium and magnesium to break down the oxide and allow smooth and free melting of the metal. Satisfactory results will never be achieved on aluminium or magnesium alloys unless the correct flux be used for the job.

The correct adjustment of the oxy-acetylene flame is also a matter of great importance. Excess of oxygen in the flame will produce oxidizing conditions which will make satisfactory welding impossible, while too much acetylene will cause porosity. The most satisfactory setting is a neutral flame with a slight haze or mistiness of acetylene to ensure non-oxidizing conditions.

With these general remarks on the fusion welding of the light alloys we may now pass to a closed consideration of the welding techniques for aluminium and magnesium respectively.

Aluminium

Five characteristics of aluminium must be kept in mind by all those concerned with the welding of this metal:—

1. It has a low melting point (approximately 650 degrees C.).

2. It does not give any warning that it is approaching its melting point; there is no noticeable change in colour and the metal tends to collapse suddenly.

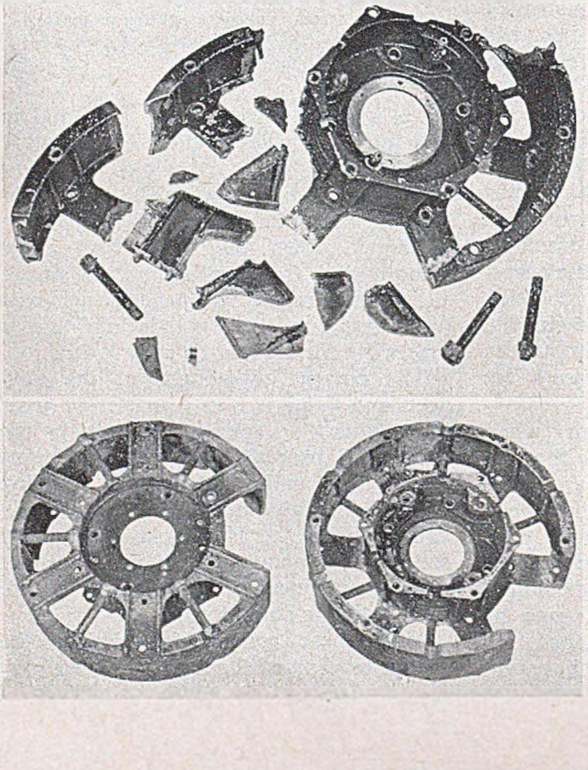
3. In spite of its low melting point it requires almost as great a heat input as steel to bring it to welding temperature, owing to its high thermal conductivity.

4. It is hot-short, i.e., it is weak when hot, and consequently all areas of which the temperature is raised should be adequately supported during welding. This hot-shortness also causes stresses to occur during welding, with resulting cracks on cooling unless proper precautions are taken.

5. The corrosion resistance of aluminium is derived from an oxide of aluminium which forms on all surfaces, and which must be removed if a successful weld is to be made. This oxide has a much higher melting point than that of the metal itself and so the heat of the blowpipe flame alone will not remove it. Therefore a suitable flux must be used which attacks the oxide forming a fusible slag; this slag rises to the surface of the weld-puddle and is thus removed.

It is upon these basic facts that the whole technique of aluminium welding has been built up, and it is for these reasons that some of the more complex aluminium alloys are not recommended for fusion welding. They are more liable to crack where free contraction is not possible, and the properties of the weld cannot achieve those of the unwelded parent metal, which may be due to heat treatment or cold working.

Design plays an especially important part in aluminium welding. The flux which must be used to remove the oxide and thus permit successful welding is also highly corrosive, and therefore all traces must be removed after welding. All joints should be so located that there is easy access to each side of the weld, and, where possible, butt joints only should be used. If lapped joints cannot be avoided the ends must be welded up to prevent moisture entering, which might set up corrosion with the entrapped flux. Where welds are carried out at corners, these corners should be radiused, so that the flux



A SHATTERED aluminium alloy casting before and after repair by oxy-acetylene fusion welding.

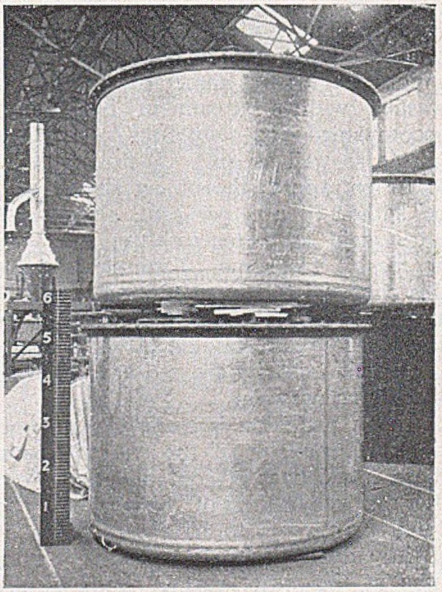
is not held at an acute angle. Cup-and-cone-type joints should never be made in tubes, and some means must always be devised of washing tubular assemblies after jointing. The types of joint which should be avoided are illustrated.

Edge Preparation of Aluminium Sheet

For thicknesses up to $\frac{1}{8}$ in. no bevelling is required, but the edges should be smooth and uniform and should be cleaned prior to welding with a wire brush or file. For thicker sections, up to $\frac{1}{4}$ in., a bevel to an included angle of 80-90 degrees is recommended, leaving a small nose at the bottom approximately $\frac{1}{16}$ in. thick to prevent over-rapid melting of the lower edge. For material over $\frac{1}{4}$ in. thick, a double bevel (80-90 degrees) and nose ($\frac{1}{16}$-$\frac{1}{8}$ in. in width, according to metal thickness) is necessary.

All oil or grease must be removed from the weld area before starting work.

The workpiece, wherever possible, should be set up with a tapered gap between the edges to be welded to prevent the adjoining edges overlapping as a result of expansion during welding and so causing cracking due to the setting up of stresses. If jigs cannot be used, the two pieces should always be tacked together at regular intervals.



NITRIC acid storage tank in aluminium with welded seams. Such tanks have been in general use for many years, and ably demonstrate the reliability of this method of joining. (Courtesy A. P. V. Ltd.)

Owing to the high rate of conductivity of aluminium it is advisable to preheat the whole job to be welded with the blowpipe before starting the weld, except where the article is very small. The speed of welding increases noticeably as the weld proceeds owing to the rapid rise in temperature of the surrounding metal caused by this high rate of conductivity, but this can be partially overcome by such preheating, and with practice the difficulties which this acceleration may at first produce will be entirely mastered.

Method of Welding Aluminium Sheet

On thin-gauge aluminium, welding is normally carried out in the horizontal or underhand position, using the so-called "leftward" technique. In this method the welder works from right to left and the flame preheats the edges to be melted in front of the weld-puddle. It is usually advisable to start the weld a short distance from the end of the edges to be joined in order to reduce the risk of cracking due to contraction stresses. The weld is carried on to the farther end and then the workpiece is turned round for the shorter weld to be completed. A procedure on these lines should also be evolved for complicated assemblies. The flux is applied by dipping the hot end of the filler rod into the flux powder and thereafter melting both rod and flux together.

On thicker sections of $\frac{1}{4}$ in. or over the "double-operator vertical technique" should be used wherever possible. This procedure offers several advantages in work on thicker material, among which are:—

1. The avoidance of any special edge preparation, apart from cleaning and

aligning, on thicknesses up to $\frac{3}{8}$ in. Above this thickness a double bevel of 80 degrees included angle is recommended.

2. Increased speed of operation.
3. Economy in gas and welding-rod consumption.
4. It is easier to achieve soundness of weld metal throughout the weld.
5. Perfect penetration, with building up on both sides of the metal, is assured.
6. Reduced fatigue for welders.

This method of welding derives its advantages from the fact that with two operators at work, welding together as a team, much smaller blowpipes can be used than for a similar thickness with one operator working in the underhand position. This results in savings of gas consumption of up to 50 per cent., whilst the fact that no edge preparation is necessary on thicknesses up to $\frac{3}{8}$ in. and that reduced angles of bevel are required above that gauge results in appreciable savings in welding-rod consumption and increased welding speed.

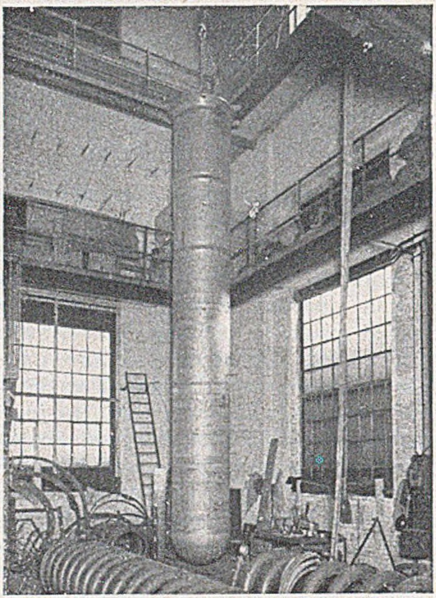
It is important that the two operators should work together at the same speed, and using the same flame settings and gas pressures. The close co-operation required is, however, easily achieved after a little practice.

It has been shown, by a long period of observation in welding shops, that welders are able to produce more consistent welds when using the vertical technique. Among the reasons for this is the fact that fatigue is reduced because the operator works in a natural and comfortable position and can use a smaller blowpipe.

Finishing the Weld

The finishing of the weld is as important as the welding operation itself, and there are three separate stages to be considered, namely, flux removal, cold working and heat treatment.

It has been pointed out already that the fluxes used for welding aluminium are of a corrosive nature, and must, therefore, be removed completely after the weld is finished. The flux residues dissolve readily in hot water, and small articles should be immersed in boiling water for 15-20 minutes. Large welded assemblies, which cannot be totally immersed, should be washed with a stream of hot water, accompanied by vigorous scrubbing (inside as well as out). If flux is likely to be entrapped, the object should also be bathed in a 5 per cent. solution of nitric acid at a temperature of 60-80 degrees C. for some 10 minutes. After this chemical treatment the metal should again be washed in warm running water in order to avoid staining. After washing, the article must be drained and dried as quickly as possible.



ALUMINIUM liner for nitric acid plant welded by the double operator technique. (Courtesy A.P.V. Ltd.)

Unless provision is made to drain off the surface water of the washing bath, there is a danger of contamination from flux residues floating on the surface. The usual practice is to have two tanks at slightly different levels, connected by a tube at the water surface level of the higher tank. Articles are immersed in the lower tank first for the main flux removal operation, and in the top tank for the final washing. A slow feed of running water is supplied to the top tank, and a drain pipe from the lower tank carries away the residue.

The metal which has been deposited during welding is of a cast structure and is rather coarse grained. In order to refine this structure, remove any surface porosity, and to consolidate the surface of the weld it is usually advisable to cold-work the weld metal after removal of the flux. This also helps to relieve any stresses which may be present.

The extent of working depends partly on the alloy involved and partly on the amount of spreading of the metal due to reduction in thickness. Generally speaking, the heat-treated alloys work-harden to a greater extent than those which are not, but with a greater risk of cracking. For this type of alloy careful hammering of welds at a temperature of 350-450 degrees C. is sometimes possible, but the job must be heat-treated again after hammering to restore the mechanical properties as far as possible

Cold-working is usually carried out with the flat face of a hammer or mallet, and the article must be rigidly supported during hammering, but wheeling or jenny-rolling is sometimes used instead for sheet assemblies.

After hammering, non heat-treated alloys are often annealed in order to increase ductility. This is normally done with the blowpipe flame, but in the case of large assemblies it may be preferable to carry out the operation in a furnace.

Heat-treated alloys cannot be annealed, but should be reheated to the appropriate temperature after hammering. But whilst this will improve their strength, it will not restore the full strength of the unwelded parent metal.

Welding of Aluminium Castings

Aluminium castings usually contain proportions of other metals, and it is, therefore, necessary to use a welding rod of the appropriate composition for each particular class of casting. The ordinary cast aluminium rod has the widest application, but 5 per cent. silicon aluminium, 10 per cent. silicon aluminium, and 5 per cent. copper aluminium rods, and certain other proprietary brands, are also available for specific purposes.

Most welding jobs of this type are on castings that have already been in use, and which consequently will probably be heavily contaminated with oil or grease. Complete removal of all oil and grease is essential, and should be carried out either in a proper bath or by washing in petrol, followed by dipping in a 10 per cent. nitric acid solution and rinsing in hot water. If such elaborate cleaning precautions are not possible for any reason, the edges to be welded should be made as clean and bright as possible by wire brushing.

The edges to be welded should be bevelled to an included angle of 90 degrees. Adequate arrangements for preheating the casting must be made, and this should normally be carried out in a suitable furnace of the type illustrated, which shows a cast-iron casting being preheated. Special care must be taken to support the casting so that it does not collapse on approaching the melting point. The casting should also be protected from direct contact with the preheating fire or flames by a shield of sheet metal. As aluminium gives no indication of temperature by colour change, other tests are required to ascertain when the casting has reached its proper preheating temperature. The most practical tests are either rubbing the casting with a stick of 50/50 solder which melts when the correct temperature is reached, or sprinkling sawdust on the casting.

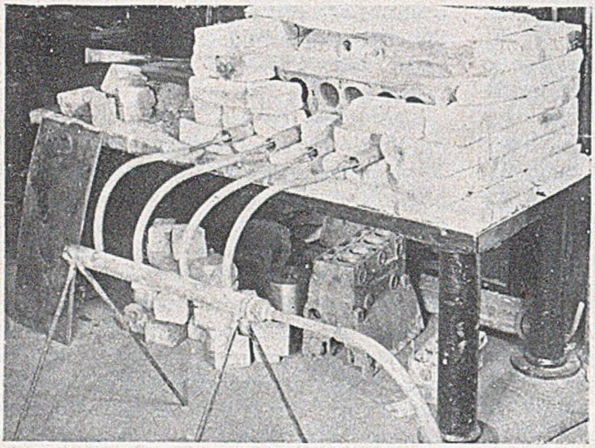
A flux must be used on castings, just as for aluminium sheet, and, generally speaking, the welding procedure is similar to that required for sheet-metal work. The filler rod must be melted into the weld vee with the flame, since the heat of molten aluminium is not of itself enough to melt the rod. The molten metal should be worked with the end of the rod to bring the oxide to the surface and to ensure complete penetration.

After the weld has been completed it is most important to allow the casting to cool slowly, away from all draughts, as cast aluminium is very susceptible to sudden changes of temperature. After cooling, but preferably while the weld is still hand hot, all traces of flux should be removed in the manner already described, but in no circumstances should cast-aluminium welds be hammered.

Welding of Magnesium Alloys

The magnesium alloys most widely used in fabrication contain 90 per cent. or more of magnesium alloyed with aluminium, manganese, zinc, silicon, and, more recently, zirconium. Most of these alloys can be joined successfully by oxy-acetylene welding.

In many respects the welding qualities of the magnesium alloys are similar to those of aluminium, in so far as they share some of their most important characteristics, namely, low melting points, lack of colour change on approaching melting point, high heat conductivity and high thermal expansion. Consequently, broadly speaking, the welding technique used for the two metals is very similar. But the risks of corrosion from entrapped flux residues are greater with magnesium than aluminium, and therefore greater attention must be paid to the avoidance of joints liable to cause this entrapment. Fillet welds are permissible provided the flux can be completely driven out, but otherwise oxy-acetylene welding is virtually restricted to butt joints. The development of Argonarc welding to overcome this and other problems connected with the welding of magnesium will be discussed in a later article.



TYPICAL furnace for heating castings prior to welding. In this instance a cast iron cylinder block is in the furnace ; the same arrangement is used for aluminium alloy castings.

Generally, magnesium alloys should be joined with welding rods of the same composition as the parent metal, and it is only in certain specific cases that satisfactory results can be achieved by welding metals of different compositions together. Special rods are prepared for the principal sheet, tube and cast alloys, and whenever there is any doubt as to the correct rod to be used the suppliers should be consulted without hesitation.

To prepare magnesium alloys for welding, first clean away all oil, grease and dirt; the corrosion-resisting covering of sodium dichromate being then removed with wire wool from both sides of the edges to be welded to a width of about 1 in. The welding rod should also be thoroughly cleaned by this method.

Magnesium is very susceptible to oxidation, and for this reason a flux must always be used for welding. Fluxes are supplied as a dry powder, but should be mixed with distilled water or commercial alcohol to form a paste before use. The paste can be painted on to the edges to be joined and on to the welding rod, or it may be applied from the heated end of the rod. It is especially important to paint the under side of the edges, as the under side of the weld is particularly liable to oxidation. Fresh paste should be mixed each day.

The edge preparation recommended for magnesium is similar to that already discussed for aluminium. Care should be taken in setting up the workpiece for welding, because magnesium is liable to warp severely at high temperatures and cracks may be caused. When jigs are used tight clamping should be avoided, so that the expansion and contraction of the metal is not unduly restricted. When seams are tacked prior to welding it will be found that a greater number of tacks will be required than for aluminium. On thin sections considerable warping may take place during tack-welding, which can be straightened out again with a wooden mallet. Tacks should be re-covered with flux paste before the main welding operation is started.

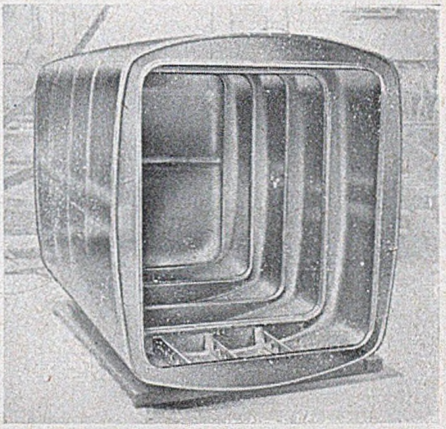
The technique recommended for depositing the weld metal is the same as for aluminium. If possible, everything should be so arranged that the weld can be carried out without interruption, for refluxing the rod, for instance, and great care must be taken at the beginning of the weld to see that the metal does not start to burn or oxidize. If the angle of the blow-pipe is not allowed to rise above some 30 degrees this will be avoided, but if the metal does start to burn the weld must be stopped and the burned area should be cleaned out carefully.

Welded magnesium assemblies are often left in the "as-welded" condition, but if the excess of weld metal has to be removed, this should be done by chipping or milling followed, perhaps, by hammering, but under no circumstances should the weld be dressed down by hammering alone.

The flux must be completely removed immediately after welding by scrubbing the weld area with a wire brush and hot water. If some parts are not accessible to the wire brush they can be cleaned by boiling in a solution of 0.5 per cent. sodium dichromate for 2 hrs. After cleaning, the work must be thoroughly dried and should then be given the normal sodium dichromate treatment which gives magnesium alloys their yellow appearance and provides protection against corrosion.

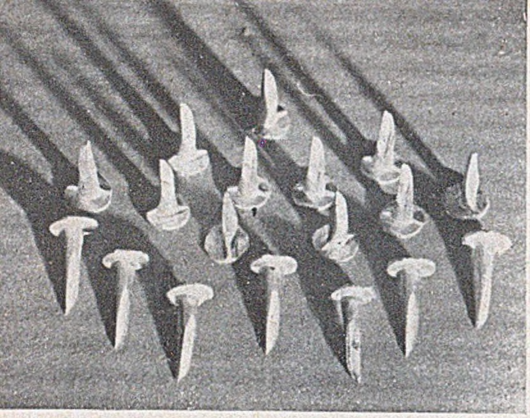
Welding of Magnesium Castings

The welding of magnesium-alloy castings also follows very closely the procedure adopted in the case of aluminium, and again rather more vigilance is required to ensure success. The recommended preheat temperature is slightly lower (350-375 degrees C.) and the danger of the casting collapsing through overheating is more apparent. This is avoided by ensuring that the casting is adequately supported, that heat is evenly distributed throughout, and that the metal is not allowed to come into direct contact with the preheating flames. As a guide to the heat of the casting, it has been found that it will be hot enough when white paper rubbed on the surface shows signs of discoloration, or when soap marks turn a light shade of chocolate brown.



MAIN petrol tank for a Shetland aircraft, fabricated in magnesium by oxy-acetylene welding. (Courtesy, Essex Aero Ltd.)

After the weld has been completed a further period of heating is required for aluminium castings, and the precautions required for magnesium sheet are also necessary. After-treatment of the weld is the same as for the sheet metal and the final requirement is once again a coating of sodium-dischromate solution.



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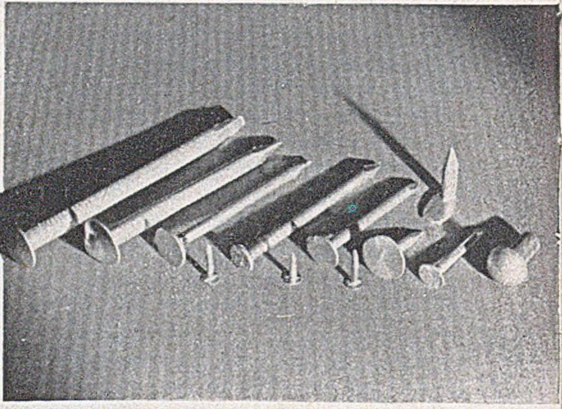
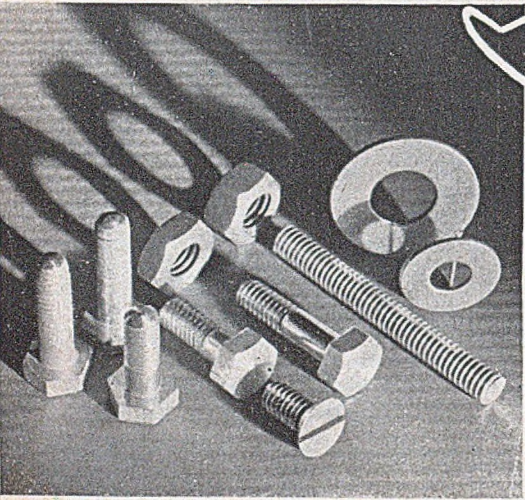
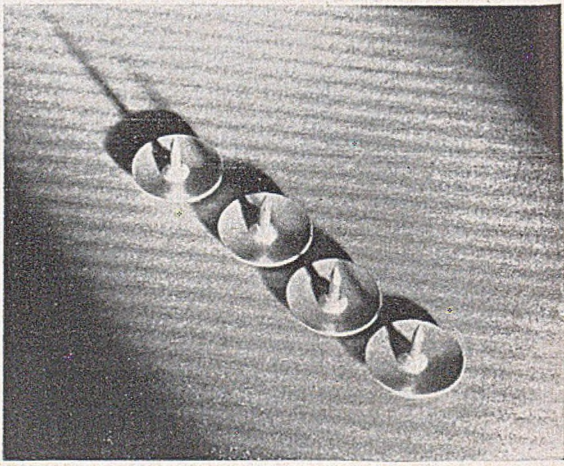
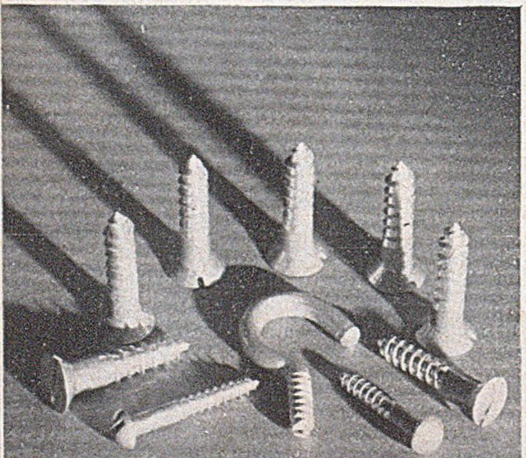
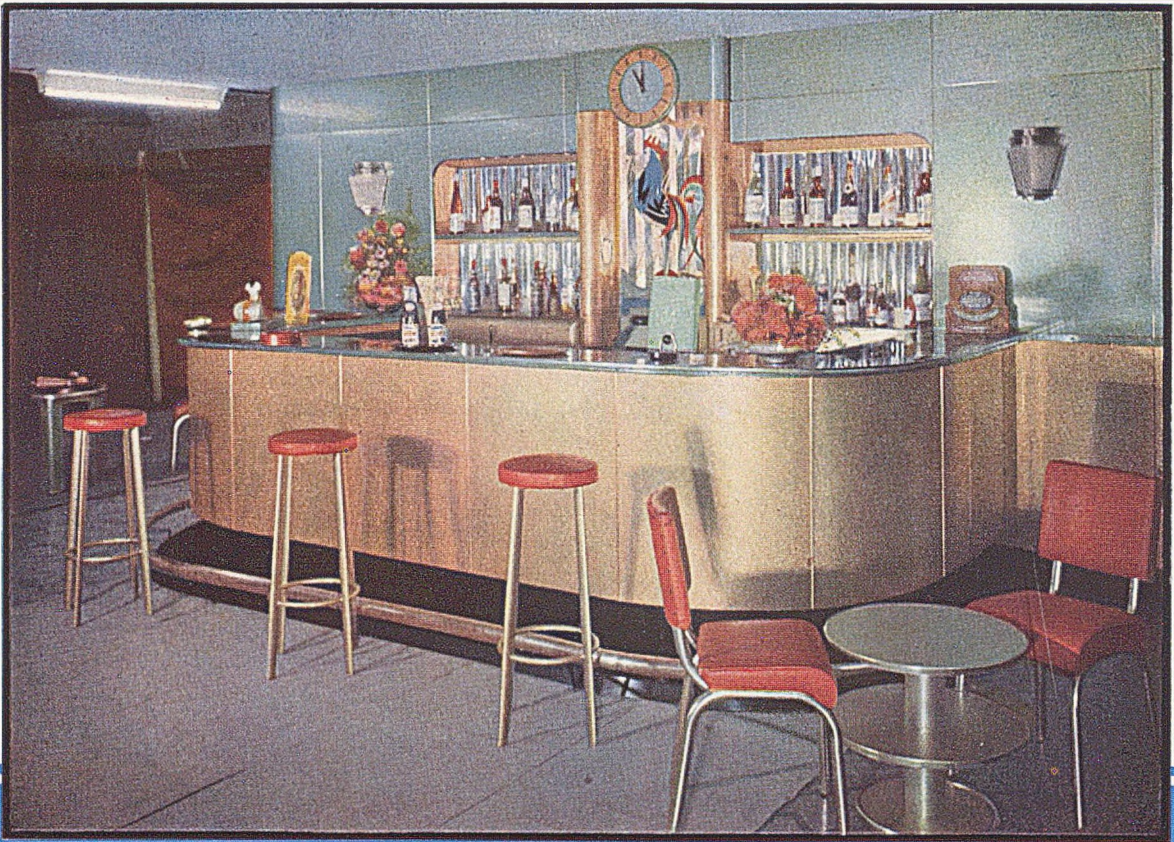








MARKETED by London Metal Warehouses Ltd., 15-17, Edgware Road, Marble Arch London, W.2, this useful range of aluminium-alloy tacks, nails, screws, bolts and nuts, illustrates the growing command exercised by light metal over industrial and domestic activities in everyday life, and emphasizes the developing co-partnership of aluminium and steel.



AN attractive American Bar exhibited at the recent Brewers' Exhibition and later at the Hotel, Restaurant and Catering Exhibition by Woodmet Ltd., Globe Lane, Dukinfield, Cheshire. Extensive use is made of impressed aluminium sheet anodized and dyed in pastel shades.


Victory over
g

Recent Intelligence

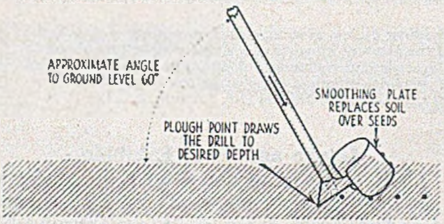
THE following announcements have been received:—

Northern Aluminium Co., Ltd. Two sales offices of this concern have moved to new addresses. The Birmingham sales office is now located at 14, Temple Street, Birmingham, 2. Telephone, Midland 5236. Telegrams, Noralumin Birmingham. The South-Western Area sales office is now at 18, St. Augustine Parade, City Centre, Bristol, 1. Telephone, Bristol 20351.

Wild-Barfield Electric Furnaces, Ltd. J. P. D. Coleman who joined the concern in 1919 and who since 1933 has been works director, has retired from the board and also from that of the associated company, G. W. B. Electric Furnaces, Ltd.

Sciaky Electric Welding Machines, Ltd., Farnham Road, Slough, Bucks. C. A. Burton, M.Inst.W., has been appointed sales manager. He joined the company in 1934 as chief test and research engineer, and, during the last war, was attached to the Directorate of Industrial Equipment as resistance welding advisor.

THE gardening tool illustrated on this page is the "Sow-Eze" seed sower. Made entirely from aluminium, the tool makes a drill, sows and covers the seed in one operation, thereby saving time and energy and ensuring a more uniform and economical distribution of seed. The chairman of the Hampton Allotment Holders' Association, shown above, praises the "Sow-Eze," and observes that it eliminates excessive trampling of the ground. (Courtesy, Steddall and Company, Ltd., 164, High Holborn, London, W.C.1.)



Henry Ford and Aluminium

FOLLOWING a recent Press reception held by Henry Ford in London, our associated journal "The Motor" addressed to him a series of questions concerning the Ford organization. We quote the following:

"Will the use of light alloys be much extended in motorcar production during the next few years?"

"We will use light alloys if steel is so scarce we cannot get it, but also use the lighter alloys if they come down to the point where they are economically feasible."

The Aluminium Courier

THE third issue of the Aluminium Courier has now been published. Each number of the Courier is devoted to one main topic which, this time, is small boats, and is an excellent summary of the considerable progress which has been made in this sphere of application.

Ideal Home Exhibition, 1948

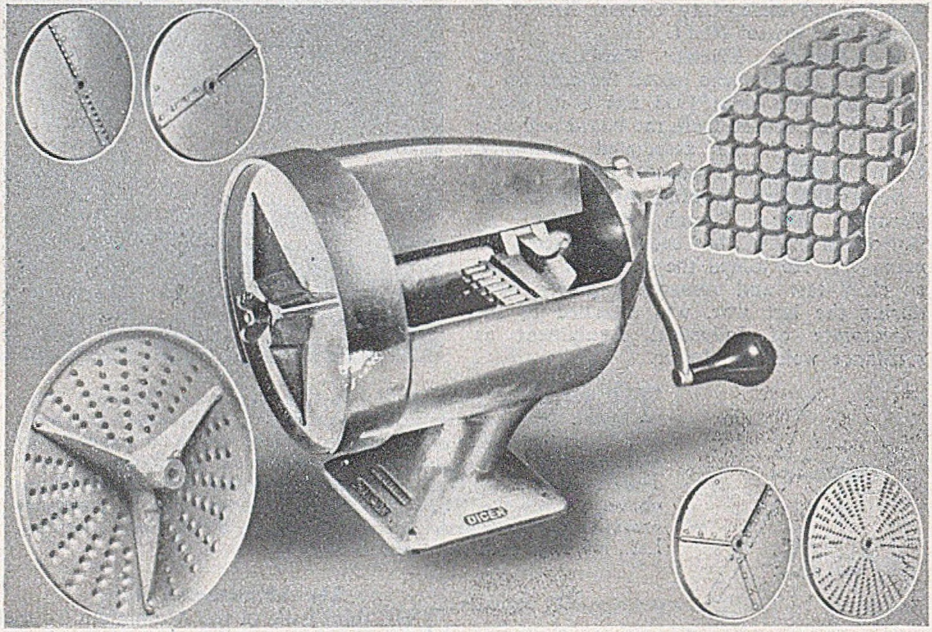
ONE of the main features of this year's exhibition is the two-storey aluminium house, shown in public for the first time. Last year the standard aluminium house roused great interest and, in spite of criticisms, has proved very popular.

Venesta, Ltd.

CELEBRATING their Golden Jubilee, Venesta, Ltd., Vintry House, Queen Street Place, London, E.C.4, have published a booklet under the title "Our First 50 Years." This history of the concern is presented most attractively, giving the reader an insight into the development of the plywood industry.

Readers of this journal may recall on page

636 of the December issue an announcement about "Vendura." This material is composed of aluminium sheet, with a wood veneer cemented on one or both sides. One interesting story that is recorded in the booklet is of the introduction of "Plymax," a metal-coated plywood. On one occasion in 1922, when loading a press, a face veneer was inadvertently omitted, causing the glue-covered centre ply to adhere to the steel platen. This mistake was soon turned to good account and repeated intentionally. A modification of the adhesives then made it possible to stick most metals to plywood.



PICTURED here is the "Champion" equipment for shredding, dicing, grating, chipping, scallop slicing and allied operations in the catering trades. The body of the machine consists of a single polished aluminium casting (shown here to a scale of $\frac{1}{8}$ linear) with numerous cast aluminium fittings. Cutter plates (not shown to scale) are in the form of heavy-gauge stainless-steel-sheet pressings attached to polished cast-aluminium-alloy spiders. This apparatus is manufactured by Medcalf and Co., Ltd., 141, Saffron Hill, London, E.C.1.

Also recorded in the booklet is how during the recent war the company were called upon to make a considerable tonnage of aluminium foil for a mysterious purpose. Later, this foil was to be found spread over a large area of Europe in the wake of our bombers, having effectively confused the enemy's radar instruments.

Altogether the booklet is a very fine blending of history and technology, and the company are to be congratulated on its presentation.

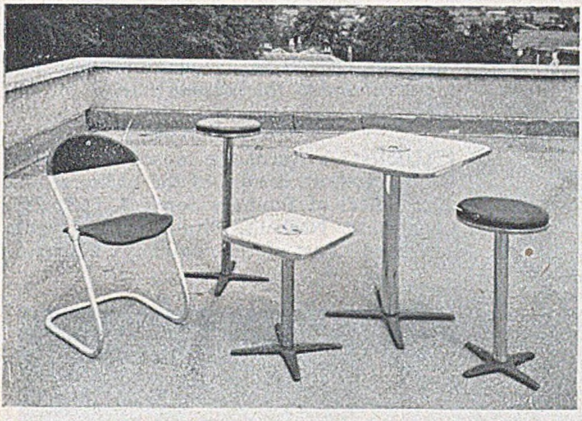
"Twenty Questions"

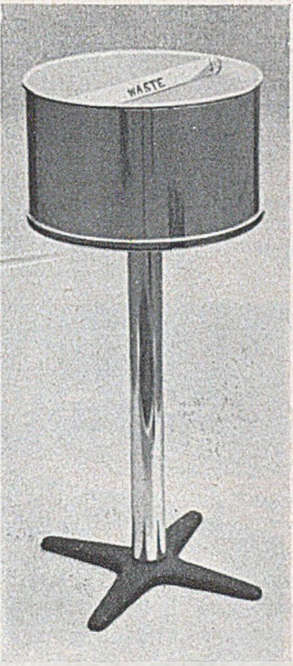
AWARE of the popularity of the Radio Programme "Twenty Questions," London Metal Warehouses, Ltd., have prepared a new leaflet containing twenty questions on aluminium alloys, with, of course, the correct answers. Copies can be obtained on application to the company at 15-17, Edgware Road, Marble Arch, London, W.2.

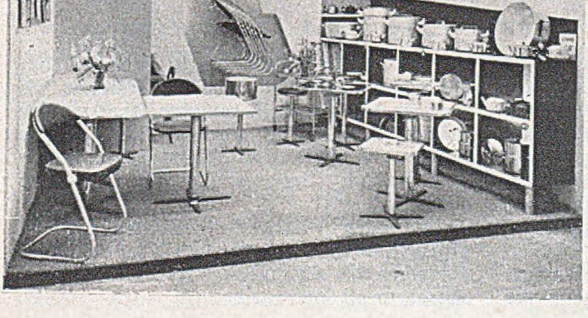
Gauge and Tool Exhibition

THE 1948 Gauge and Tool Exhibition was held at the New Hall, Vincent Square, London, from January 26 to February 6. Amongst the stands of 82 exhibitors were to be found gauges, measuring instruments and equipment, jigs and fixtures, press tools, moulds and dies, pneumatic and electrical portable tools, diamond tools and a wide range of engineers' cutting tools. In this excellent range of equipment were many items of particular interest to the light metals industry and some interesting developments were noted.

As in previous exhibitions dealing with engineering subjects, it was interesting to note a considerable usage of aluminium in







SHOWN on this page are some of the items exhibited by Warco Products, Ltd., Saltisford. Warwick, at the recent Hotel, Restaurant, and Catering Exhibition. Immediately above is a litter basket designed for use in lounges and bars, with bowl and pillar in polished aluminium. Above (left) the Warco unit furniture, including a table giving complete freedom of movement to the diner. The centre column is of aluminium, supporting a lightweight top, with the whole counterbalanced by a heavy cast-iron base. The table top is of plastic in an aluminium frame and is reversible, one side being covered with green baize. The aluminium nesting chair (centre, left) is exceptionally light and occupies an absolute minimum of space, whether in use or stacked. Other interesting exhibits shown on the stand (bottom, left) were a range of aluminium utensils for catering purposes, including large stewpans and some attractive teapots, enamelled and decorated with floral designs.

the machines. Again, over 20 per cent. of the exhibitors were using aluminium in the cast or wrought form in their products. Of particular interest to those who are concerned with the machining of light alloys were the many diamond cutting tools displayed.

The exhibition was organized by the Gauge and Tool Makers' Association in conjunction with the National Federation of Engineers' Tool Manufacturers.

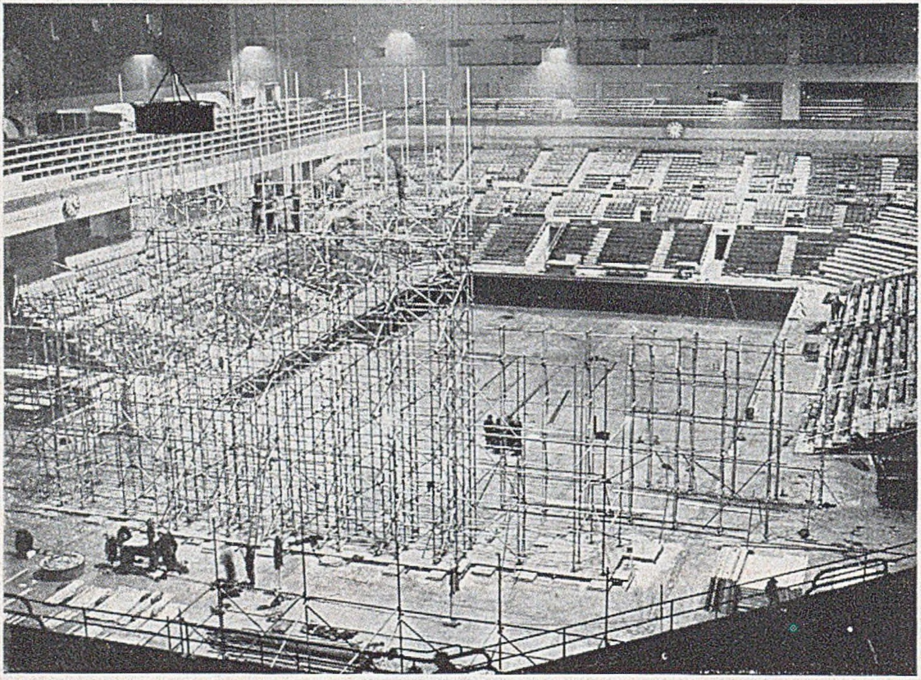
Rubber in Textile Factories

WE have received a small booklet issued by The British Rubber Development Board entitled "Rubber in Textile Factories," by Colin Macbeth, M.I.A.E., F.I.R.I. It covers the many applications of rubber in this industry and indicates in several ways how aluminium and indeed magnesium are to be found alongside rubber. It is particularly interesting from this view-point, in that not only does it adequately present the importance of rubber, but also gives a detailed account of an industry in which many aluminium and magnesium fabricators are interested at the present time.

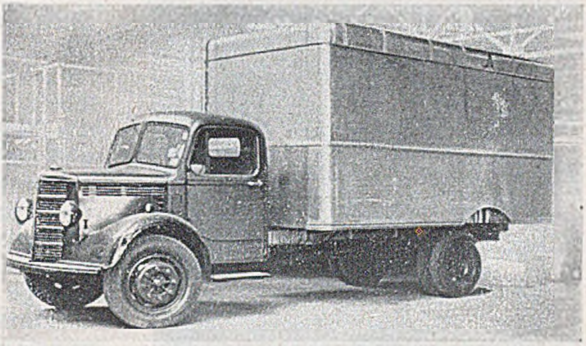
"Foundry Practice"

DURING a recent fire caused by an electrical short, certain of the technical and sales offices of Foundry Services, Ltd., 285. Long Acre, Nechells, Birmingham, 7, were destroyed. Part of the company's addressograph system was lost, and it is feared that the mailing list for "Foundry Practice" is now incomplete. It is suggested that regular readers who have not received No. 89 of this bi-monthly publication should get in touch with Foundry Services, Ltd., at the above address.

"Foundry Practice" is written for the practical man in the foundry to help him overcome his difficulties. It is sent free of charge to all interested.



THE Health and Holidays Exhibition was opened at Earls Court, London, on February 23, and closes on March 27. Shown here in the final stage of preparation is the central feature. Spectacular dives are made from the 74 ft. tower into a pool below. The scaffolding is of tubular steel and aluminium.



FINISHED pantechnicon body being mounted on a chassis at the Enfield works of Hays Wharf Cartage Co., Ltd.

Light Alloy Body-building Progress

QUANTITY production of all-light-alloy industrial-vehicle bodies on an ingenious constructional system is now in full operation at the Enfield engineering works of Hays Wharf Cartage Co., Ltd. In the method of frame-construction employed by this concern, and known as the "Fairal" system, frame members are made from square-section aluminium-alloy tubing, reinforced from within by round-section tubes. Under hydraulic pressure of 400 lb. per sq. in., the box-form tube is expanded by a maximum of 0.005 in. to allow the insertion of the round member. Expanded is, perhaps, not quite the right term. What happens is that the square tube tends to assume a round form, but becomes square again when pressure is released. The square tube then contracts and grips the core tube tightly, forming a unit of quite exceptional strength for its light weight.

As the tube is not suited for hot bending it is heat treated and then bent cold. Body-frame components are built up by the use of highly ingenious junction pieces, which are split along their longitudinal axes. With these, the most complicated angle joints can be made easily and rapidly. These special joints consist of square central bosses from which extend what might be termed split spigots (our American friends would probably call them junction-location members). These are inserted into the tubular frame members and the halves of each spigot are then forced apart by duralumin taper pins, the tubes being thus firmly gripped from within.

Should a pillar become damaged, the affected part is cut out and a split spigot, similar to a junction piece but without the boss, is inserted. The spigot is first driven into the upper part of the pillar and then drawn downwards into the lower one, thus joining the two. Taper pins are inserted and an efficient joint is made in a few minutes.

The "Fairal" method has proved admirably adaptable to quantity production, as it makes for speed and simplicity in the erection of body-frame skeletons. As in other systems of light-alloy body construction which we have dealt with in recent months,* frames are made up from partial assemblies. The roof, for instance, is constructed as a single unit and panelled before mounting. The centre section of the body, including wheel-arch framework and rear body sections, are other prefabricated units.

Corrugated Birmabright slats are riveted to the inner sides of body pillars to protect the outer panelling, whilst a Birmabright panel, also corrugated, of U shape forms the sides and ends of the

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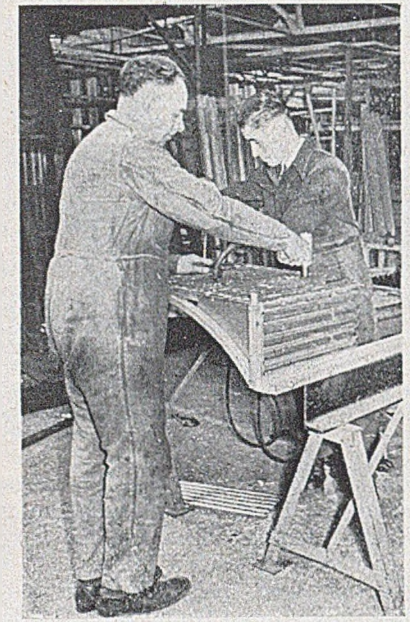
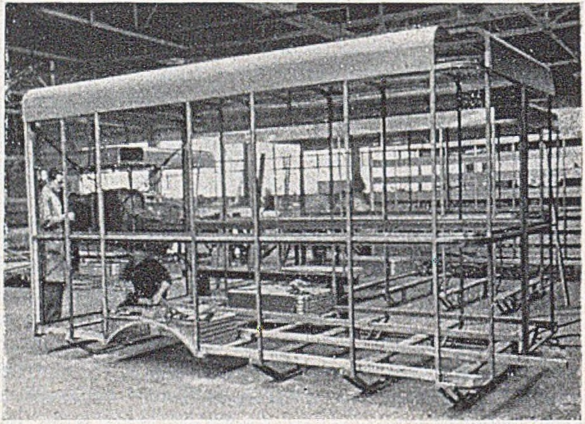
* See, for example, "Light Metals," 1947/10/629; 1948/11/84

wheel-arch enclosure. Break-stem rivets are used throughout in attaching panels. So adaptable is this particular system of tubular construction that elaborate body designs can be produced, when necessary, with little greater difficulty than those of most orthodox form. Body floors are of wood, screwed to timber inserted into a specially extruded bearer.

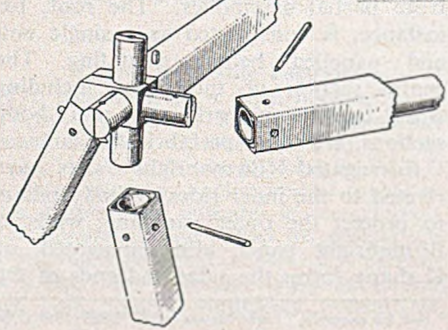
In a concern such as the Hays Wharf Cartage Co., Ltd., with all its varied departments, a very great variety of commercial bodies must be turned out. Commencing with the first prototype "Fairal" body in April, 1946, 740 bodies of all types, built on this system, were produced by the end of 1947. Out of this total, departmental allocations included 138 Bedford pantechnicons, each of 1,020-cubic-ft. capacity; 33 articulated trailer pantechnicons, each of 1,500 cubic ft.; 418 general-service bodies (2-ton, 3-ton and 5-ton); and in addition to these, 62 articulated trailer bodies.

The balance of the 740 represents a host of bodies for contract vehicles, all of which were constructed to special design. Material used in building these bodies presents some interesting figures. Amongst major requirements were 89 miles of square alloy tubing and 89 miles of round, 14 miles of alloy extrusions, 331,000 sq. ft. of aluminium sheet and 2,620,600 rivets.



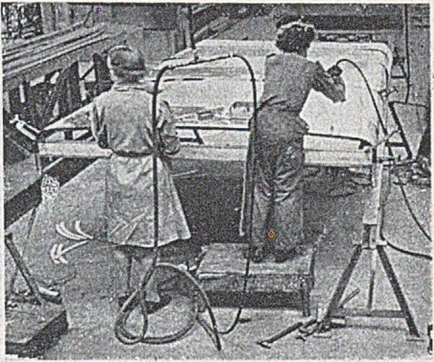


ABOVE, building the wheel-arch component of the "Fairal" body in corrugated Birmabright. Right, the first stage on the assembly line. The frame skeleton is erected in square-section tube, with a round core. The method employed for joining these sections is illustrated below.

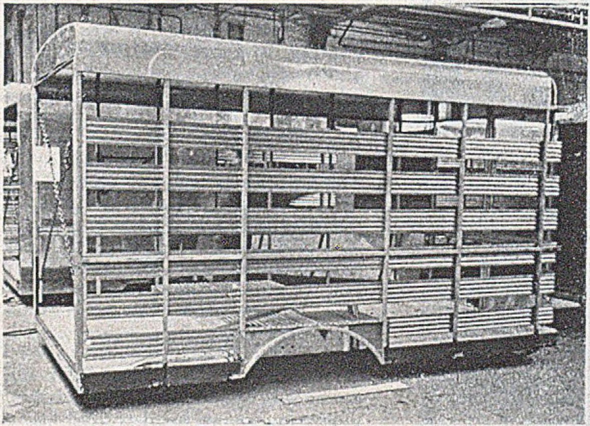


During 1947 production of "Fairal" bodies averaged 51.09 per month, but this has now been greatly stepped up and on a recent visit to the Enfield works we saw bodies coming off the assembly line really fast. While there we were shown a special van body for Parnell-Yate, Ltd. Arranged to carry heaters and electric washing machines on two floors within the body, this van is provided with a neat little hoist on the rear end of the roof, for ease in off-loading. The upper floor in the van is made up of sliding sections in light alloy, and the rails supporting these are continued on the inner sides of the rear doors so that the end section can be slid out under the hoist.

This van body, arranged on a 3-4-ton Bedford chassis, has a capacity of 770 cubic ft., is designed for a mixed load of 34 stoves and washing machines. The cooker weighs 2 cwt. and the washing machine about 1½ cwt. Thanks to the special hoist, these can be off-loaded by the van driver. The complete light-metal body weighs approximately 1 ton, a remarkably low figure for an assembly designed on such generous and roomy lines.

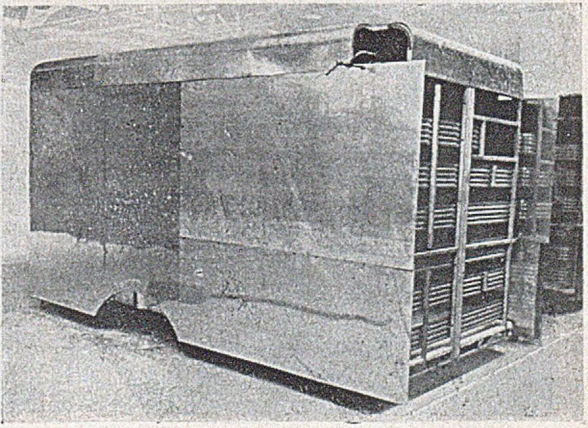


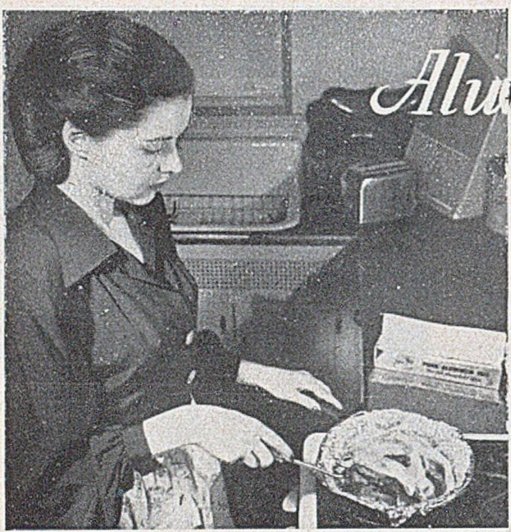
THE roof of the "Fairal" body, as illustrated above, is made as a single component and panelled before mounting. This work is done by women.



AT the left, the second stage on the assembly line, when the roof and Birmabright side slats are mounted.

BELOW, the third stage in assembly. Here the sides of the body are panelled and the interior fittings completed.





Aluminium Foil Wrapping

FEW people will disagree with the statement that the uses of aluminium foil are legion and it is hardly necessary to recall that for many years manufacturers have used this so-called "silver paper" to preserve a variety of products, such as chocolate and cigarettes. More recently it was shown ("Light Metals," 1947/10 278) that aluminium foil could be used to great advantage in storing apples and pears and this is now being practised commercially.

It is surprising that this product has not hitherto been made available to the general public to perform a multitude of domestic duties for which it is eminently suitable. Aluminium foil is now available to the Canadian housewife and depicted here are some of the many uses for which it is recommended, such as lining cooking utensils to eliminate washing-up (the used foil being discarded), packing picnic baskets, preserving paint brushes and lining larder shelves.

RESISTANCE WELDING
of Light Alloys

By E. J. Keefe, B.Sc.,* and L. B. Wilson, M.Inst.W.†

The Authors Discuss Spot and Seam Welding Techniques and Consider Certain Major Difficulties Hitherto Associated with the Application of these to Aluminium. A Patented System, Designed to Eliminate the Principal Difficulties, is Described, Together with some Experimental Results Obtained.

DEVELOPMENT of aluminium has, in the past, been severely hindered by two important factors, first, its prime cost, which, for many civilian applications, tended to limit its use to specific fields, and secondly, the fact that it could not, for general purposes, be satisfactorily soldered, or resistance-welded without special equipment.

The economic situation brought about by the second World War, however, gave a much-needed impetus to the development of our light-metal resources, and, as a result, supplies have become more abundant and the cost of the metal has been reduced. It was not until quite recently, however, that serious attention was given to the resistance-welding problem, for with other weldable materials readily available, there was little advantage to be gained in utilizing what was known to be a more hazardous process than that required for ferrous materials.

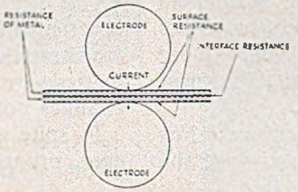


Fig. 1.—Sketch showing total resistance between electrodes.

The acute shortage of steel at the present time has placed an entirely different light on the subject, and attention is now being focused on aluminium as a likely substitute for steel in many diverse applications. The metal has, in fact, become a vital part of our national economy and it is clear that the welding problem must be considered as a matter of the highest importance. The authors believe that a solution has been found and are confident that the method of welding described‡ will have widespread industrial application.

Resistance-welding Technique

In order to understand more fully the problem of welding aluminium, it is first necessary to consider the fundamental principle of resistance-welding.

When it is desired to join together two or more pieces of metal by a spot or seam weld, the metal is held between two electrodes which conduct a current of high amperage through the pieces, the heat generated being directly proportional to the electrical resistance offered by the metal between the electrodes. With the current maintained until the metal reaches welding temperature, the electrodes are forced together and a unified weld is obtained. The pressure is maintained until after the current has been switched off.

The heat generated in this way can be expressed by the formula: —

$$H = I^2RT \times K.$$

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* Research Department, British Insulated Callender's Cables, Ltd.

† Welding Consultant to B.I.C.C., Ltd.

‡ Patent Applications No. 30,330/46, 2,071/48.

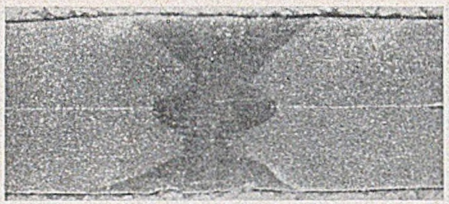


Fig. 2.—Macrograph of grain structure.

Where I is the current passing between electrodes, R is the total resistance offered by the metal (this is made up in the manner illustrated in Fig. 1), T is the time the current is maintained, and K is a constant for the particular application, depending on losses due to radiation and conduction and hence varying with the time and the material to be welded.

It will be seen that when aluminium is the metal to be welded, the constant K and the resistance R are low (assuming that there is no oxide present on the surfaces of the metal), so that for a given amount of heat the welding current must be increased to a very much higher value than that for steel, and thus when attempts are made to spot- or seam-weld aluminium by normal methods, machines of very much larger output than those required to weld steel of equal thickness must be used (see Table 1).

There are also other difficulties. For example, it is obvious that in view of the relatively low melting point of aluminium and most of its alloys, the useful plastic range will, in contrast to that of steel, be limited and, consequently, exceedingly accurate control is necessary. In addition, the surface of aluminium tends to oxidize rapidly in air, the surface resistance increasing in proportion, so that this high resistance film must be removed from all surfaces if satisfactorily consistent and uniform welds are to be made.

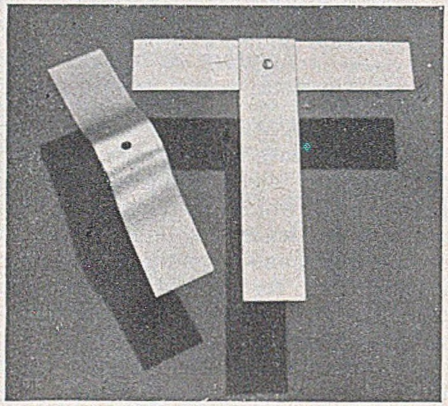


Fig. 4.—Sample of spot welding.

Another difficulty is the marked tendency for aluminium to alloy with copper, which causes "sticking," so that frequent changes of electrodes are necessary

In spite of the above difficulties, however, progress has been made with spot welding in recent years and, provided that accurate control is exercised and machines of high power output are used, good spot welds can be obtained by normal welding methods.

When seam welding is attempted, however, it is found that even when the on-off periods are reduced to the region of one cycle, the weld is not always continuous. This can be explained quite simply by a series of diagrams. Fig. 8 (a) shows the normal path of current for the first shot when two sheets of aluminium are being welded between electrodes. The sheets are then moved very slightly forward for the second cycle. The resistance built up by oxidation on the surfaces of the aluminium now causes most of the current to deviate from the direct path and follow the path of least resistance through the previous weld, as shown in Fig. 8 (b). This by-passing of current persists until the distance becomes too great, when a fresh weld is made, Fig. 8 (c).

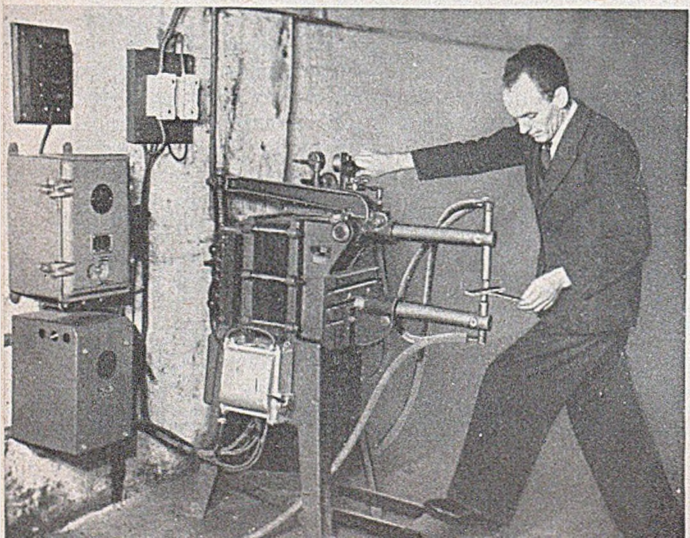


Fig. 6.—Spot welder in action.

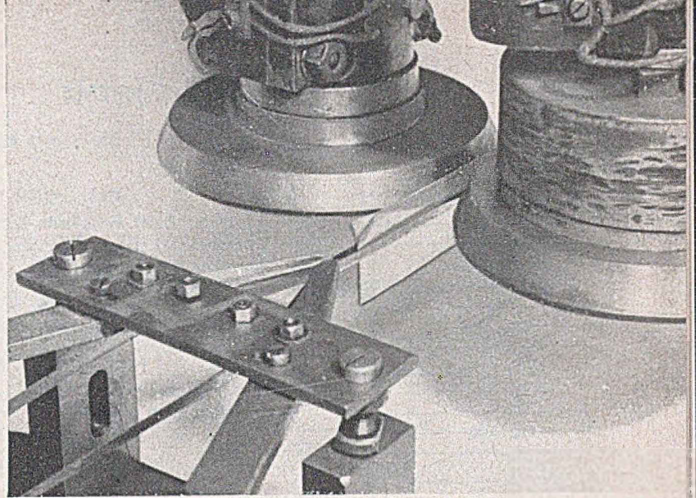


Fig. 3.—Seam welder in operation.

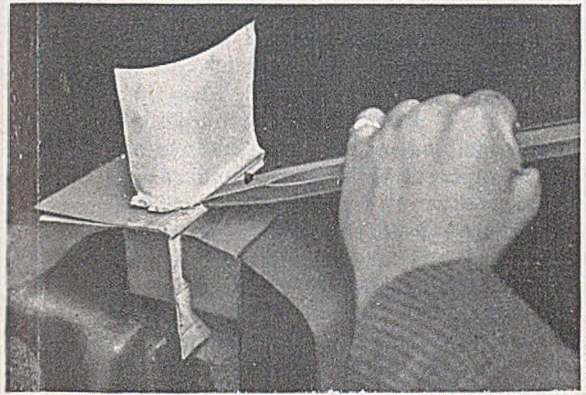


Fig. 5.—Weld being broken down by chisel.

The "seam" weld thus produced is in reality a series of separate spot welds at close intervals, and it is obviously useless for pressure vessels or liquid containers. Even when attempts are made to overcome this by using wider electrodes, high current density and relatively low speeds, with the centre of the spots well spaced but having sufficient spread to link up and overlap in the form of a "stitch" weld, it is difficult to obtain a satisfactorily gas-tight seam. Experiments have shown that in this method, with speeds of the order of 3 ft. per minute, machines of more than 200 kVA have been necessary. Fortunately, by the adoption of an entirely new technique in welding, this trouble can now be overcome.

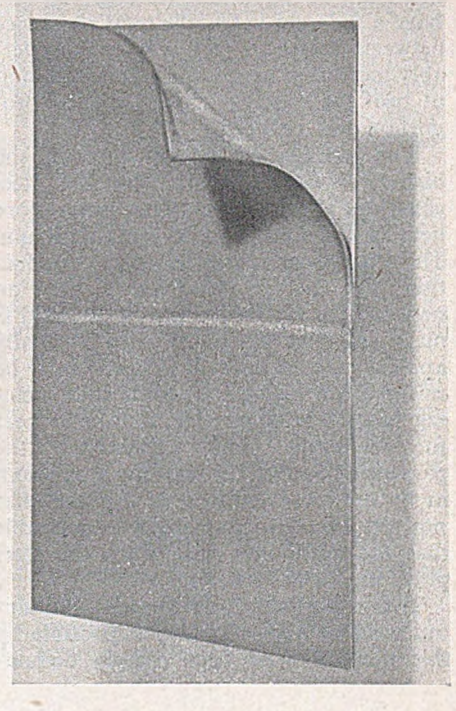


Fig. 7.—Typical weld obtained with new process.

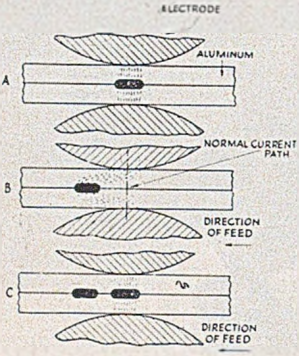


Fig. 8 (left). — Three sketches (A), (B), and (C), showing how intermittent weld is formed.

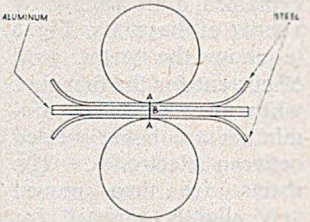


Fig. 9 (right).—Sketch of steel strip method.

After considerable experiment it was found that when aluminium was preheated to a certain extent and the current applied, a highly efficient weld was possible. A method was, therefore, evolved in which steel strips of definite thickness were interposed between the electrodes and the aluminium; the thickness of the steel strips being determined by the thickness of aluminium to be welded. The principle is illustrated in Fig. 9.

Applying the previous formula to this method, we find that although K will have a different value, the total resistance between electrodes (R), will be considerably increased; hence, for a given amount of heat the welding current will be proportionately reduced.

The passage of current through the higher resistance offered by the steel generates approximately four times more heat in the steel than in the aluminium. The aluminium is thus heated by conduction just before reaching a position between the electrodes where the weld is made, so that when the shot is finally applied, the temperature need only be raised a few degrees to reach exact welding heat. (Whether this additional heat for welding is actually obtained by the passage of current through the aluminium or by the increased heat of the steel, has not yet been ascertained; it is probable that the additional heat from the steel plays the more important part.)

That a perfectly uniform and continuous weld of high efficiency is possible by this method, has been amply demonstrated by convincing tests in which perfectly gas-tight seam welds with tensile strengths up to 92 per cent. of the parent metal have been recorded. Provided that correct welding pressures are used and fine adjustment of the current can be made, the steel does not stick to the aluminium.

In Fig. 7 may be seen a typical seam weld obtained in 20 S.W.G. aluminium. The sample shown has been anodized and dyed in order to illustrate the cleanliness of the seam weld obtained. This feature will be of particular interest to those concerned in the manufacture of fancy goods in aluminium. The strength of the weld is illustrated in Fig. 5. Here, the metal of the same sample has been opened out and an attempt is being made to separate the weld by chisel. It will be seen that the tear actually occurs in the parent metal.

The alteration in grain structure of the weld may be seen in Fig. 2, and in Fig. 10

Table 1.—Short circuit currents for resistance welding by normal methods.*

Electrode Pressure 10,000 lb./sq. in.
Tip Size .. .. 5/32 in. dia. 120° included angle
Time .. .. 5 cycles

Sheet Thickness (ins.)	Short Circuit Current (amperes)	
	Steel	BA 60 Aluminium
0.016	7,500	17,000
0.028	9,000	17,600
0.036	9,760	19,700

* Figures published by permission of the British Welding Research Association.

the variation in hardness across the weld is shown plotted.

Undoubtedly, the most important advantage obtained by the new method is that it is no longer necessary to use machines of large output for aluminium welding. The welds illustrated were, in fact, made on a conventional-pattern 30-kVA machine with the usual ignitron time control and running at a welding speed of 13 ft./min. when welding 20-s.w.g. aluminium alloy. Fig. 3 shows the seam welder in operation.

Spot Welding

When aluminium is spot-welded many of the difficulties hitherto experienced with seam welding do not, of course, arise, for the spots are spaced at sufficiently wide intervals to neutralize the effect of " by-pass " current. High-power machines of the order of 200 kVA output have, nevertheless, been required, and as the majority of the spot-welders are of comparatively low capacity for steel welding they have proved unsuitable for use on aluminium jobbing as well as their normal production work.

Application of the new method to spot-welding, however, will immediately increase the range of a large number of existing machines. How far their field of usefulness will be increased may be judged from Fig. 6, which shows a conventional-pattern 30-kVA welder being used for spot-welding three pieces of .080-in. aluminium alloy (1.25 per cent. manganese) to a total added thickness of ¼ in. The electrode pressure for this weld was 7,000 lb./sq. in. The strength of the weld so obtained is illustrated in Fig. 4, the top piece of aluminium having been torn away leaving a solid nugget of weld. Further welding data for this sample are:—

Short circuit current	9,000 amperes
Welding time	5 cycles
Electrode tips	¼" dia. flat.

Table 2.—Short circuit currents for resistance welding by new method.*

Electrode Pressure	10,000 lb./sq. in.
Tip Size	5/32 in. dia. 120° included angle
Time	5 cycles
Steel Strip Thickness	0.016 in.

Sheet Thickness (in.)	Short Circuit Current (amperes)
	BA 60 Aluminium with 0.016-in. steel.
0.016	8,700†
0.028	9,000
0.036	9,760

* Figures published by permission of the British Welding Research Association.

† This value may even be less with thinner steel strip.

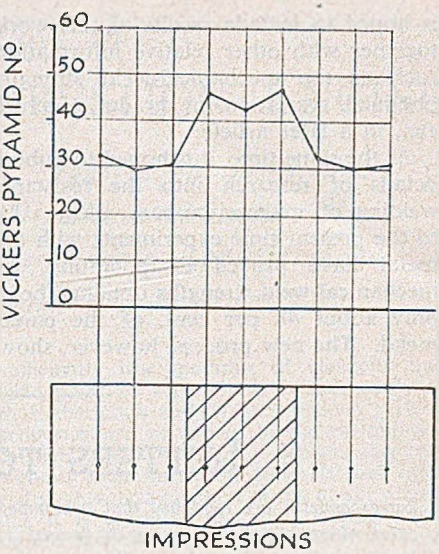


Fig. 10.—Graph of hardness.

In general, the tensile strength of a weld joining two pieces of 14 s.w.g. aluminium is 6.4 tons per sq. in. (over 90 per cent. parent metal).

In Table 2 the currents obtained with the new method of welding on aluminium of identical grade and thickness as that quoted in Table 1 are shown for comparison.

Present Work

Experiments with resistance welding are continuing, with an investigation into the maximum current required for welding various grades of aluminium, and it is hoped to include results of this work, together with other relative information, such as the mechanical-weld strengths obtained, variation in grade structure, etc., in a later article.

At the same time, it is hoped to publish details of research into the resistance welding of magnesium-base alloys. Up to the present time experiments with this metal have proved disappointing, the mechanical-weld strengths obtained being only about 48 per cent. of the parent metal. The new process, however, shows considerable promise with magnesium and successful welds will undoubtedly be achieved when the appropriate welding factors for pressure, speed and time are finally determined for the metal.

The author's acknowledgments are due to Mr. P. V. Hunter, C.B.E., Engineer-in-Chief, British Insulated Callender's Cables, Ltd., for permission to publish this article; to the British Welding Research Association for their collaboration, and to various colleagues for their assistance in the work.

LETTERS TO THE EDITOR

Correspondents are reminded that a stamped and addressed envelope should be enclosed in all cases where a personal answer is desired. It is understood that any letter received may be published at the discretion of the Editor.

Anodizing Plant

"I very much appreciate your kind assistance in helping me to obtain 17ST square tubes 45 by 45 by 2 mm. and aluminium-alloy cycle components, although I was unable to trace the translation of your article from 'Light Metals' which was published in a Norwegian paper.

"May I now ask for further assistance. I wish to contact a maker of plant for anodizing and dyeing aluminium alloys in silver and a range of colours. A description of plant, process instructions and a quotation will be greatly appreciated."—OLE HENSEN, Norway.

We would recommend that inquiries be addressed to William Canning and Co., Ltd., 133-7, Great Hampton Street, Birmingham, 18, England, and to R. Cruickshank, Ltd., 123, Gray's Inn Road, London, W.C.1. It will be advisable when ordering such plant to state very completely the purpose for which it is required, more especially as regards estimated metal area loading. An alternative to obtaining apparatus direct from this country would be to have it constructed in Norway to a detailed specification provided by a competent authority. We suggest in this connection that inquiries be directed to Mr. Peter Smith, of 30, Coval Gardens, East Sheen, London, S.W.14.

Decorated Metal Boxes

"On page 565 of the November issue of 'Light Metals' is a selection of decorated metal boxes for export markets, fabricated in aluminium and coloured by a printing process, which I have admired with great interest.

"As I am greatly interested in the importation of these boxes for the Spanish market, I should be very much obliged if you would put me in touch with the Metal Box Co., Ltd. Being well connected with a branch of the grocery and confectionery trade, I believe firmly that there is good business to be done with these articles."—V. L. de Ceballos, Barcelona.

We agree with Senor Ceballos as to the superb artistic merit of these decorated metal boxes, and would point out that those illustrated form but a section of a much wider range produced by the Metal Box Co., Ltd., the address of which is The Langham, Portland Place, London, W.1.

Light Alloys in THE INTERNAL-COMBUSTION ENGINE

Continued from "Light Metals," 1948/11/76, this Section of the Account Develops the Discussion on Light-Alloy Bearings and Concludes with the Possible Application of Light Alloys to Crankshafts and Camshafts

THE function of the lubricant in a bearing can be demonstrated by a small case-hardened shaft fitting closely into a case-hardened hole. Both surfaces should be of fine finish. If the shaft is spun with the fingers, friction is high at first, but as speed increases, a sudden drop in friction occurs, and the shaft spins freely for a time and then, as speed falls, it is pulled up sharply. During the period of free spinning the pin is running in air, due to the wedging action, and the only friction is due to the shearing of this air film. Friction is high, due to metal-to-metal contact, until the wedge has forced the pin away from the bore or when decreasing speed allows the wedge to disappear. The well-known Michel bearing takes advantage of these facts. It is, indeed, fortunate that this wedging action does take place, or no bearing would last very long.

Nevertheless, this ideal condition is constantly being interrupted. Pieces of grit and dirt, deflections of the shaft, froth in the oil stream, sudden or drastic changes in conditions, e.g., terminal velocity dives in a fighter aircraft, are continually altering the full fluid condition, and minute metal-to-metal contacts are constantly occurring. Moreover, no mechanism runs for ever and starting and stopping are critical periods in the life of a bearing. When metal-to-metal contact does take place, minute seizure or welds are liable to occur, and, with high speeds or high loads, the melting point of the bearing metal may be reached. The local melting frees the seizure and the molten metal itself acts as a lubricant in healing the seized spot. It is, consequently, advantageous for a bearing metal to possess a low fusion temperature or to contain low melting constituents, and if the molten metal does not wet the other bearing surface, a further safeguard against seizure is available.

A successful bearing metal should be able to absorb hard particles of metal, swarf, grit, carbon, etc., which always tend to cut the oil film and injure both bearing metal and shaft. A high fatigue strength at bearing temperature is essential, but it is of almost equal importance for a bearing metal to possess a sufficiently low modulus of elasticity and yield point to accommodate itself easily to shaft deflection and changes in load. These properties are, of course, in general opposed to high fatigue strength. Bearings are not without their corrosion troubles and especially when using certain of the newer refined oils it is essential that the bearing metal should possess an adequate chemical resistance. Good thermal conductivity is important to keep the bearing cool, and this means not so much taking heat from the shaft and oil as of dissipating the heat of the momentary seizures and melting into the body of the bearing metal.

By no means the least qualification of a bearing metal is its ability to be handled, cast and bonded. In these respects lead bronze, for example, fails lamentably and this has led to its disuse by many firms. Silver, too, is difficult to handle and could be put into production only when suitable plating technique had been developed after much laboratory work. The low melting point metals, of course, are easy to cast and handle.

On all these scores aluminium-base materials acquit themselves at least moderately well and, in practice, aluminium-alloy bearings have given remarkably fine service, often under arduous conditions. The main requirement appears to be that the running surface should be sufficiently hard, and with this proviso in mind satisfactory results appear to be obtainable with almost any aluminium-base alloy except under very favourably conditions. It has, for instance, long been the practice to run case-hardened steel gudgeon pins directly in aluminium piston bosses and the results have been nothing if not satisfactory.

In addition, we have mentioned the use in the Cross rotary valve engine of a nitralloy steel valve running directly in a split housing in " Y " alloy. Fraser and Chalmers in their large oil engines have used Y-alloy pistons of the spherical gudgeon type with tubular piston body and aluminium spherical bearings. It is stated(1) that they have always used aluminium bearings on the spherical engine and have not had the slightest trouble whatever. One noted maker of gas and oil engines has used simple sandcast bearings of B.S.$_3$L 11 (7-8 per cent. copper) for years throughout his range of products, simply because they were cheap, did the job satisfactorily, and were easy to cast, machine and fit.

"Quarzal," a continental alloy, contains 5-15 per cent. of copper, 2-3 per cent. of lead and/or bismuth, and works best at a pressure of half a ton per sq. in., but will take a ton. Another alloy of this class consists of 20-22 per cent. of silicon, 1.25 per cent. cobalt, 1.5 per cent. copper, 0.6 per cent. manganese, 1.25 per cent. nickel, 0.5 per cent. magnesium, the balance aluminium. The object of this intricate selection is to imitate white metal-hard particles embedded in a soft matrix. The alloy has a low expansion and a Brinell hardness of 120.

In some cases high contents of lead are incorporated, up to 20 per cent., in which case the metal ceases to become an alloy in the true sense of the word, but a mechanical mixture which calls for special technique in handling. An alloy developed by High Duty Alloys, Ltd., as a result of much experience and technical research on light metal bearing materials and which was used in various directions during the war is Hiduminium AC/9. This material is patented (Nos. 470, 248 and 472, 248) by Rolls-Royce, Ltd., and High Duty Alloys, Ltd., and an exclusive licence to manufacture has been granted to Wellworthy Piston Rings, Ltd., Lymington, Hants.

Curves in Fig. 22 ("Light Metals," 1947/10/452) show results of tests on the centre main bearing of a Rolls-Royce Kestrel engine using lead-bronze, white metal and aluminium-alloy bearing materials. All three bearings were run-in for two hours at 1,000, 1,300 and 1,700 r.p.m. at 80 degrees C. (± 5 degrees C.), the speed being then reduced to 1,000 r.p.m. at the commencement of the test. Speed and load were then increased by 200 r.p.m. and 200 lb./sq. in., respectively, at 15-minute intervals, and temperature to 100 degrees on the Thurston bearing-testing machine.

The curves demonstrate that, throughout the speed range of the tests, the aluminium-base material has a lower friction coefficient than the two other alloys with with it was compared.

In the July, 1939, issue of "The Foundry," mention was made of an alloy with bearing properties claimed to be equivalent to those of white metal, its constitution being as follows:—5.5-7.0 per cent. Sn, 1.5-1.8 per cent. Ni, 0.6-0.9 per cent. Cu, 0.7-1.0 per cent. Mg, 0.15-0.3 per cent. Fe, and 0.2-0.45 per cent. Si.

An issue of "The Automobile Engineer" (1946/36/480) describes three aluminium-alloy bearings developed in the U.S.A. for use as connecting-rod, main and thrust bearings in high-duty engines. The first alloy contains tin 6.5, copper 1, nickel 1 per cent., and aluminium remainder; the second has a similar composition with an addition of silicon; and the third is the first alloy in its wrought form. Laboratory bearing tests, heat-transfer properties, Brinell hardnesses, and machining properties of the alloys are discussed.

In Automotive Industries, October, 1939, L. Kempf, research engineer, and F. Jardine, chief automotive engineer of the Aluminum Company of America, describe the properties of an aluminium-base bearing metal recently developed. The fatigue strength of the alloy is claimed to be many times that of conventional by-metal bearings, whilst its resistance to corrosion by the breakdown products of lubricating oils is also of a high order. Fabrication of the bearing is not difficult, and the customary methods of finishing can be employed. For main and big-end bearings permanent mould castings are employed, but for camshaft bearings use is made of rolled sheet. It is pointed out that, whilst aluminium-alloy main bearings are but a recent innovation, the metal has been used as a material for aircraft camshaft bearings for a quarter of a century. Also, as is, of course, well known, aluminium has long been used for valve-tappet guides and as gudgeon-pin bearings in aluminium-alloy pistons.

An incentive to the development of aluminium-base bearing metals in Switzerland has existed for a number of years in the shape of a shortage of tin and other conventional bearing-metal constituents, and as a result three main compositions have been introduced—La 11, La 21 and La 31. These three grades differ in working qualities and in mechanical and physical properties, and one or other is selected according to service requirements.

Alloy La 11 consists of aluminium with small quantities of magnesium and zinc; it contains no additions which are not readily obtainable in Switzerland.

Alloy La 21 is the eutectic aluminium-silicon alloy with additions of copper, nickel, manganese and magnesium, the copper and nickel contents being about 6 per cent.

Alloy La 31 consists of aluminium with about 8 per cent. of tin, plus copper and nickel, together with some magnesium.

The medium-hard alloys, La 11 and La 31, are similar to each other in possessing good running qualities and good resistance to edge pressure. Alloy La 31 is preferred to La 11 when it is impossible to give the bearing surface a high finish and when it is not expedient to run the bearing in gradually under load. Alloy La 21 has approximately the same coefficient of expansion as bronze and is used mainly for bearings subjected to shock and high loads. It is also employed for metalling cast-iron bearing housings operating at high temperature. None of these three alloys is markedly affected by heating such as is likely to occur in normal operating ranges, aluminium-base materials being, in this respect, greatly superior to tin-base bearing metals.

La 21 follows the classical form, showing hard "bearing" particles (mainly silicon) in a moderately hard matrix. La 31, however, exhibits a soft, tin disperse phase in a moderately hard matrix, whilst La 11 shows the homogeneous structure of a solid solution. These physical differences influence "bearing" qualities and, according to the running conditions obtaining, account for occasional trouble due to overheating.

La 11 has little effect on a steel journal, whether this latter be of the alloy or plain carbon type. If, by any chance, seizing should occur, a thin layer of aluminium will be found adhering to the journal and can be easily removed. The hard, crystalline particles in La 21, however, may, in unfavourable conditions, score the journal. The tin inclusions in La 31 do, to a great extent, prevent seizing-up occurring with this alloy, particularly on machines of high capacity. Here, if overloading should occur, the bearing surface will remain usable for some time, the only alteration which occurs being an increase in clearance—a feature which may, in certain cases, be of great value.

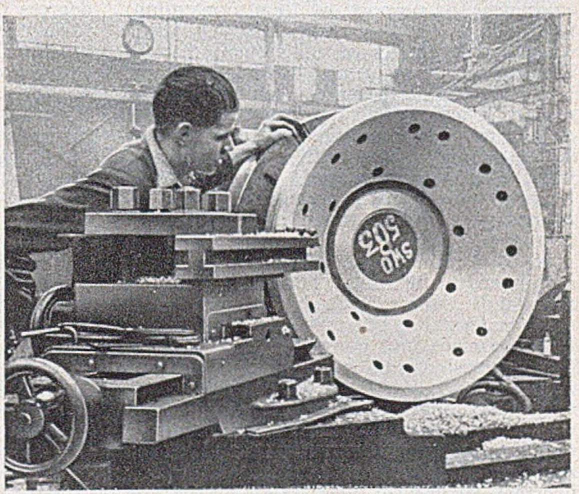


Fig. 51.—Piston, in DTD 424, for the scavenge pump of a C.I. engine built by John I. Thornycroft and Co., Ltd., Woolston, Southampton.

These materials are mainly employed in the form of solid or split bushes. The materials are supplied in the form of wrought rod and tube and as sand and chill castings. La 11 and La 31 can also be produced in the form of cold-drawn tubes in the usual manner. For example, a tube with an outer diameter of 2 ins. and about $\frac{1}{8}$ in. thick can be made to an accuracy of $\pm$ 0.007 in. on inside and outside diameters; hence, in the case of bearings with large clearances, assembly can be carried out without previous machining. For special purposes, for instance, as a lining in a supporting bearing. La 11 can be supplied in the form of sheet or strip; the cold-worked surface, which possesses good "running" properties is, obviously, ideally suited for a bearing.

The aluminium-base bearing alloys which have been described, together with a number of bearing bronzes, tin-base white metals and special cast irons, have been examined with respect to their bearing qualities on a special testing machine,(17) using forced-oil lubrication and a shaft rotating against the specimen to be examined. With loadings up to 800 kg./sq. cm. it was possible to run some journals at 2,000 r.p.m., corresponding to a surface speed of 1,520 ft./min., without trouble.

From the results obtained it was evident that the aluminium-base alloys could withstand very high loads, equal, in fact, to those sustained by the best lead-tin bronzes. All other bearing materials broke down under loadings of a very much lower order. Despite the fine machining which was given to it, special cast iron KA 12 proved inferior to the rest of the materials, which demonstrates that the inherent bearing qualities of the material are of importance even if the running surface be scrupulously lubricated and finished to the highest degree of perfection. The tests demonstrated, furthermore, that the aluminium-base alloys possess better running-in qualities than any of the bronzes or cast irons examined. In this regard, however, tin-base bearing metals remained unsurpassed.

Rapid increase in load and careless running-in are sustained better by the aluminium-base alloys than by any of the bronzes examined, this being due, probably, to the better cold-working properties of the light-metal compositions, their high capacity for oil adsorption and their good heat conductivity. Practical experience showed that the properties of these aluminium-base bearing alloys and particularly of alloy La 21 are, in general, sufficiently good for emergency running-in under conditions of poor lubrication.

Subjected to wear against the rough, hardened surface of a steel shaft under conditions of dry friction in a special testing machine, wear values obtained for the aluminium-base alloys were at least as good as those for the best bronzes. Again, La 21 proved to be superior, exhibiting greater wear-resistance than the bronzes.

At the time this report was made public (1944), these alloys had been in use for various purposes for some years, with excellent results. Deck$^{(17)}$ quotes numerous examples in support of this contention: bushes used on Swiss State Railway goods wagons with shafts of mild steel; Michell bearings in steam turbines; textile machinery; lathes; roll mills; planing machines; electric motors; machine tools lubricated with grease or oil and working against shafts in carbon and alloy steels (some merely in the hardened state, others case-hardened), and a flywheel bearing which when previously made of bronze gave rise to much trouble through corrosion.

He also quotes some examples from automobile engine bearings. Thus, he states that the Adolf Saurer A.G. have, since 1941, employed an alloy corresponding to La 31 for main bearings and connecting-rod bearings in compression-ignition engines. This concern observed that experience in practice was very good, and that aluminium-base alloys would undoubtedly continue to be employed now that the war is over. On account of the high heat conductivity of aluminium-alloy bearings, these have proved suitable for sustaining the very high loads met with in the modern high-speed high-output engine, where the consequences of seizure in bearings might be very serious.

Junker and Ferber, in Zürich, have also developed aluminium-based bearings independently of Saurer, and have used them in automobile engines of all types. Besides La 31 for main bearings and connecting-rod bearings, an aluminium piston alloy, similar to La 31 Novasil, has been used with great success for gudgeon-pin and camshaft bearings.

In selecting which of these alloys to employ in a particular situation, Deck advises that La 21 is most suitable for vibratory loads. It has a thermal expansivity similar to that of bronze, runs well with minimum lubrication, and may in emergency continue in operation even when strongly heated up (although in this case the shaft may be damaged).

La 31 is easily run-in and resistant to edge pressure, and shows no undue tendency to seize, even with minimum lubrication. La 11 is highly corrosion resistant, exhibits good adsorbing properties for an oil film, and is relatively low in first cost. It is generally used in the heat-treated condition, whereas La 21 and La 31 are more frequently employed without heat treatment.

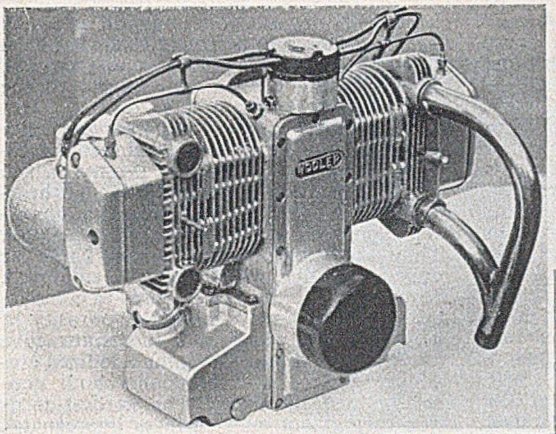
The best results are achieved with bearings and shafts of highest surface quality. The bearings are fine-turned with diamond or sintered-carbide tools, employing very small feeds; the journals are fine-ground or lapped. It is obvious that a surface fine-turned with diamond can bear heavier loads than honed or rough-turned surfaces, where a comparatively few raised points have to bear the whole load. In machining these three bearings alloys Deck recommends that the wedge or cutting angle should be about 45 degrees for high-speed steel, and 75 degrees for sintered-carbide tools. La 11 and La 31 are readily machined, but La 21 requires some care; the tool material must be of good quality, as La 21 contains hard particles. Both La 21 and La 31 are free cutting. Bearings can be trimmed by scraping where the journal runs at a slight angle, but since the degree of smoothness obtained is inferior to that resulting from diamond turning, maximum permissible loading cannot be applied.

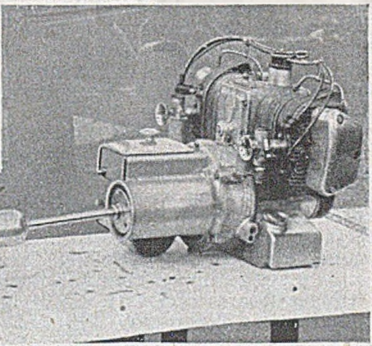
Any lubricating system is permissible with these bearings, but oil is preferable to grease. Pressure feed in conjunction with a reliable filter is to be recommended, but ring or drop lubrication is quite suitable. In the last case, it is suggested that the oil cup be provided with a felt wick. It is sometimes not appreciated that, by leading the oil ducts into grooves which expand in the direction of rotation, it is possible to obtain what might be described as automatic pressure lubrication; even if the oil supply be situated below the bearing level, the lubrication will be sucked up.

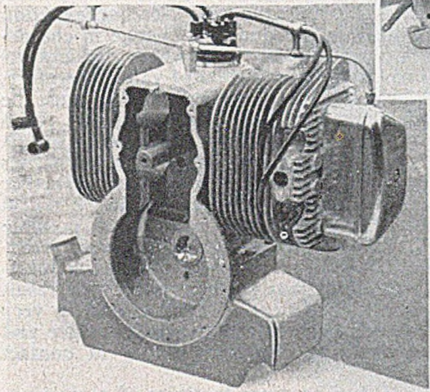
Lubrication with grease is suitable only for smaller loads, especially if the shaft be oscillating. In this case, contrary to oil lubrication, the load must not exceed 280 lb./sq. in. It is recommended that, for this type of lubrication, a device be designed which permits grease to be forced continuously on to the bearing surface. The change-over to aluminium bearings is not a difficult matter. In fact, Deck recommends that bearings of minor importance subjected to no very great loading can be replaced by aluminium-base alloys without alteration of design, that is, provided that the operating temperature does not exceed about 60 degrees C. and, of course, that lubrication is always sufficient and that no chance of serious corrosion attack is likely to occur.

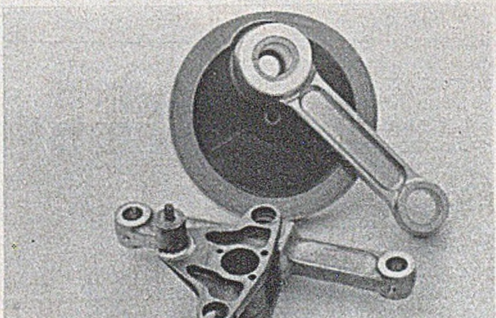
The good heat conductivity of these aluminium-base bearing alloys is of considerable importance. The heat conductivity of

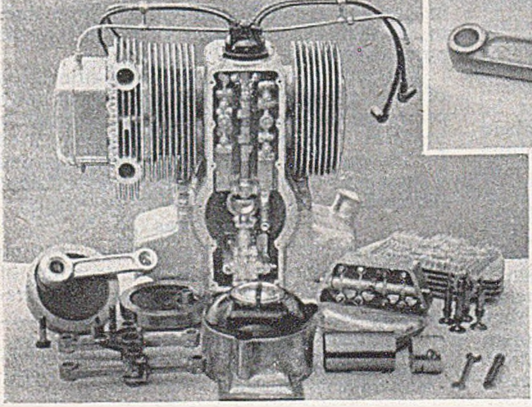
DEPICTED on this page are various views of an experimental engine for a motor cycle developed by the Wooler Syndicate, 121, Cannon Street, London, E.C.4. This is a 500 c.c. 4-cyl. horizontally opposed engine operating on the beam principle. The cylinder block is light alloy with steel liners and the majority of other parts, such as cylinder heads, rocker boxes and covers, connecting arms and the master connecting rod are of light alloy. The engine is a radical departure from traditional design and incorporates many novel features; for example, the whole machine including the engine can be dismantled with one double-ended spanner.











PICTURED immediately above is the connecting link assembly for the Wooler engine. The four connecting arms and the master connecting rod are light alloy forgings and operate directly on to nitrided steel surfaces. The bearings thus formed have been in use for twelve months, during which time the machine has travelled 10,000 miles. They are stated to be quite satisfactory and superior to bronze bearings. The master connecting rod and flywheel assembly has been specially designed to give a large bearing surface.

the light metals is approximately 0.4 cal./cm./degrees C., as compared with a figure of 0.13 for bronze, 0.1 for tin-base bearing metal and 0.07 to 0.11 for cast iron. Thus frictional heat is conducted much more readily from the rubbing surface of aluminium-alloy bearings than from those of other bearing materials, a point of some importance where heavy loads are concerned. However, gaps, insulating shims or openings which interfere with heat flow or transference must be avoided; for example, heat flow may be hindered by an oil film between the two parts of a split bearing. Again, to avoid any difficulty with heat transfer, the outer faces of the bushes should be in close contact with the matching faces of the bearing housing.

From all this it would appear that the major points in favour of aluminium-base bearing metals are four in number, namely, their high loading capacity, their reduced sensitivity to load variation, their light weight (important in the case of Diesel engine bearings) and their high heat conductivity. The upper limit for the specific bearing pressures of La 11, La 21 and L 3 are given as 750 to 800, 675 and 750 to 800 kg. per sq. cm., respectively. From the same source the corresponding figures for good quality cast bronzes, tin-base and cast-iron bearing metals are 450 to 800 (but mostly about 550), 400 and 250 kg. per sq. cm. respectively. The ability of aluminium alloy bearings in conjunction with hardened journals to take very heavy bearing pressures has been recognized in the heavy engineering industry and they are used for the main bearings of heavy rolling mills for that reason. In the internal-combustion engine this property is of value in allowing a possible reduction in length of the unit where this is fixed by the allowable bearing pressures and not, as is more frequently the case, by the dimensions of the cylinder bores.

Connecting rod bearings are quite satisfactory in aluminium alloy. In small engines using wrought aluminium alloy connecting rods the bearing may be machined directly in the rod. The cost of large connecting rods, however, such as those used in large Diesel engines, precludes the use of rods without renewable bearings for the small and big ends and this practice may be extended to the smaller rods as well. Where the crankshaft pins are hardened, aluminium renewable bearings in connecting rods function very satisfactorily.

The high thermal expansion of aluminium alloys is no major disadvantage in this application, although it means that careful design is required where exceptionally small clearances are called for. In fact, in practice it is more often an advantage since, if they overheat for any reason, they often obligingly expand and relieve the situation.

Perhaps the greatest disadvantage associated with the use of aluminium alloys as bearing metals is to be found in the hardness of the metal oxide. If particles from the oxide skin are broken off, scoring of the metal surface rapidly occurs.

The extreme hardness and wear resistance of the anodic film has prompted many investigations into the benefits, if any, which anodizing can confer on an aluminium bearing surface. One feature which is immediately apparent is that successful operation of the anodizing process seriously limits the range of alloys which can be employed. However, one other factor tends to compensate for this, namely, the initial porosity of the anodic film which leads to the attractive possibility of impregnating the anodized aluminium surface with lubricants both nonmetallic and metallic. The earliest trials were carried out with surfaces impregnated with ordinary lubricating oil, but they were rather disappointing. Whilst the results were excellent for a time, the oil rapidly oxidized and became so gummy as to be wellnigh useless as impregnant.* Re-impregnation was not possible due to a change in character of the anodic film which reduces its absorptive power. To be of value, therefore, a lubricant employed in this way must be permanent, and the suggestion has been made to try graphite and soft metals possessing exceptional lubricating properties (silver, lead, tin and even indium). Whether such impregnated surfaces would be useful remains to be seen. It is, however, possible that the combination of the high wear resistance of the films themselves with the lubricating impregnant in their pores will result in a low coefficient of friction and in very little wear both of the anodized surface and of the steel component sliding in contact with it.

The good heat conductivity of aluminium alloys aided, no doubt, by the greater availability of light alloy than many other metals in Germany in 1938 has prompted the use in that country of an aluminium-copper-magnesium alloy housing employing a liner in another metal.[18] Adhesion of the liner to the shell was promoted by a thin layer of pure aluminium.

The low proof stress and high elongation of the aluminium-silicon alloys has also prompted the use of this metal in automobile bearings. In this case the alloy was used for the cage for tapered roller bearings, and it was roll-moulded to the exact contour required.

Bearing Caps

High strength aluminium alloys function quite satisfactorily in the construction of bearing caps. They seem to crack less fre-

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* It is possible that anodized aluminium may act as a powerful catalyst in the oxidation of lubricating oil which inevitably takes place in service, thus accentuating the difficulty.

quently than cast iron, and large caps, as used on the big Diesel engines, can be handled fairly readily, whereas those in cast iron are most tricky and difficult to manage on account of their weight. The high stresses to which these parts are subjected make it necessary to use a high-strength alloy: RR 56 (D.T.D. 130A or 410), duralumin E, or Ceralumin F, with U.T.S. around 26 tons per sq. in., 0.1 per cent. proof stress around 20 tons per sq. in. and elongation about 10 per cent., are frequently recommended. A sound forging in one of these alloys is as strong as mild steel and a third the weight. The soundness of the structure desired and the lines of bearing caps suggest the drop forging process right away, but they may also be cast; die casting is particularly appropriate.

In fitting, through bolts are to be recommended in preference to studs.

Surprise has been expressed in various quarters that there has been comparatively little advance in the powder metalluragy of light metals and alloys, as applied to automobile construction, when the general application of powder metallurgy is considered. In a general sense, it is correct to say that many more advances have been made in applying powder metallurgy to the production of bi-metal porous bearings, bushes and thrust washers, clutch and brake friction plates, door snubbers, oil-pump gears in iron and steel, filters in bronze, nickel and stainless steel, and other components. It is true that so far the light metals and alloys have not received as wide application in the production of metal powder parts as had been hoped, but there are cogent and important reasons for this. Modern automobile engineering demands higher-duty material capable of standing up to heavy service over long periods with a minimum of attention. The light metals compact by sintering less readily than the bronzes, cast irons and steels; this, at least, is true of aluminium when normal techniques are adopted, and magnesium, too, requires careful control of the sintering process. Because of this, and in consequence of the difficulties of handling oxide-free powders of these metals, it is reasonable to expect certain limitations in the strength values which may be attained in sintered masses.

Having said all that, it must also be said that there has been progress in applying light metal and alloys to the automobile industry by powder metallurgy, and that all the signs point to a much more rapid development in the next few years than there has been so far. It is fair to remember that only now are we using light-metal alloys of outstanding physical properties in general construction work; that the development of higher tensiles and elongation has had to be balanced with other properties and conditions, and, as usual, the best results to-day represent a compromise. When the difficulties of reconciling the opposed characteristics in aluminium, aluminium-magnesium, duralumin and other alloys are considered it will be realized that the field is a difficult one, and the very characteristics which enhance the value of light-metal castings provide real problems in powder metallurgy, especially the precipitation-hardening properties of many of the light alloys.

Atomized powders are the rule in the powder metallurgy of the light metals, yet the process of atomizing is a quenching. Hence the troubles that a partially, or even a wholly, precipitation-hardened powder can give rise to are the first factor the powder metallurgist must consider. That does not mean the problems cannot be solved—it does mean that careful research is necessary; it probably means that pre-alloyed powders will not be the best material to use. Then there is also the ease with which aluminium, in particular, builds up or cold-welds to the

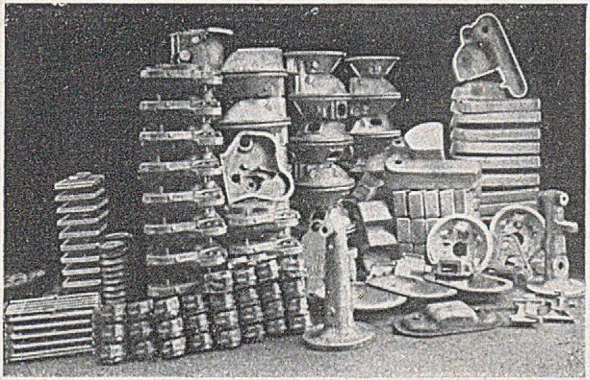
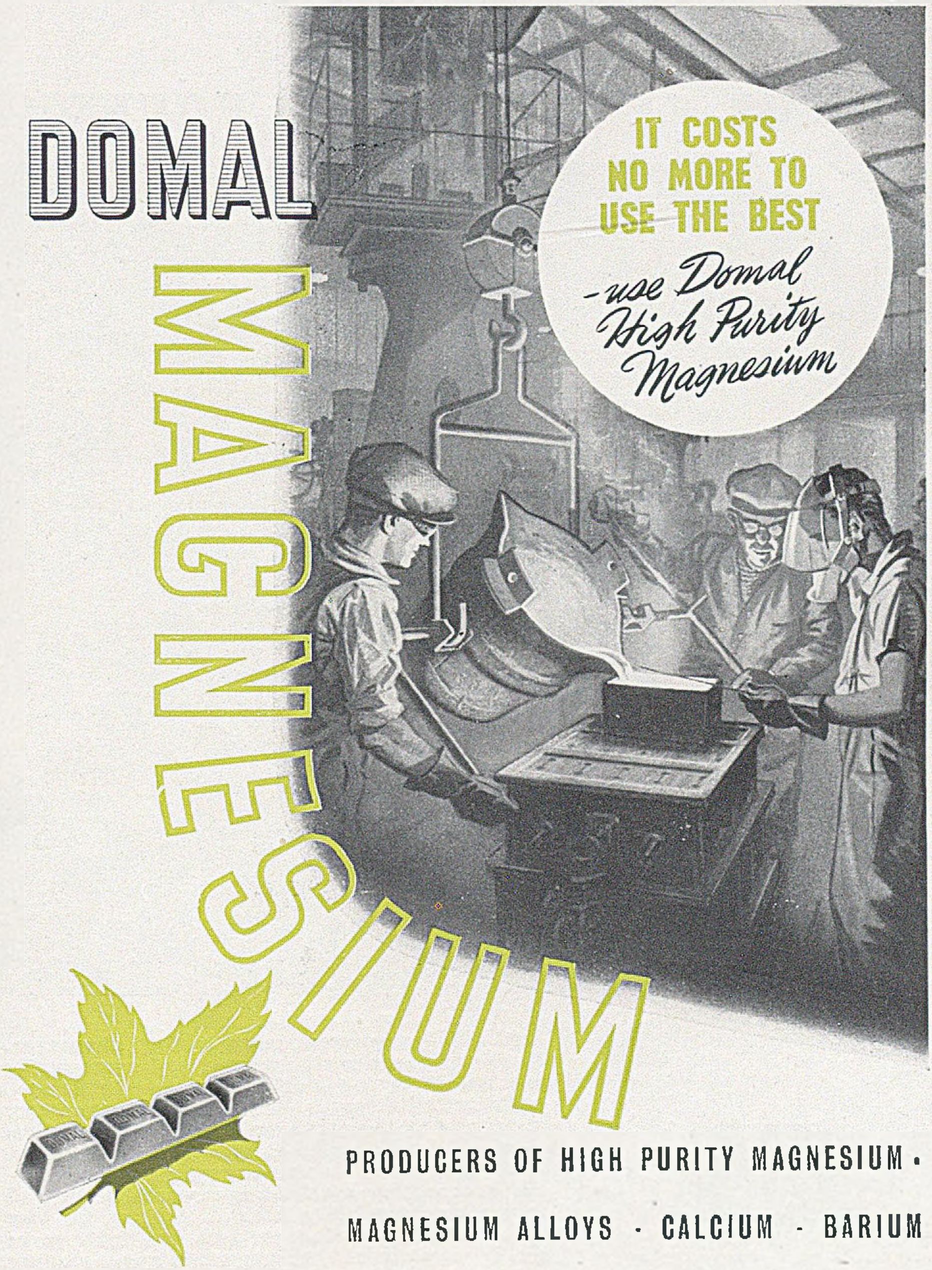


Fig. 51.—Reverse gear casings, chain cases, clutch housings and other aluminium alloy castings, principally for use on Thornycroft lorries. These are cast at the Woolston works of John I. Thornycroft and Co., Ltd.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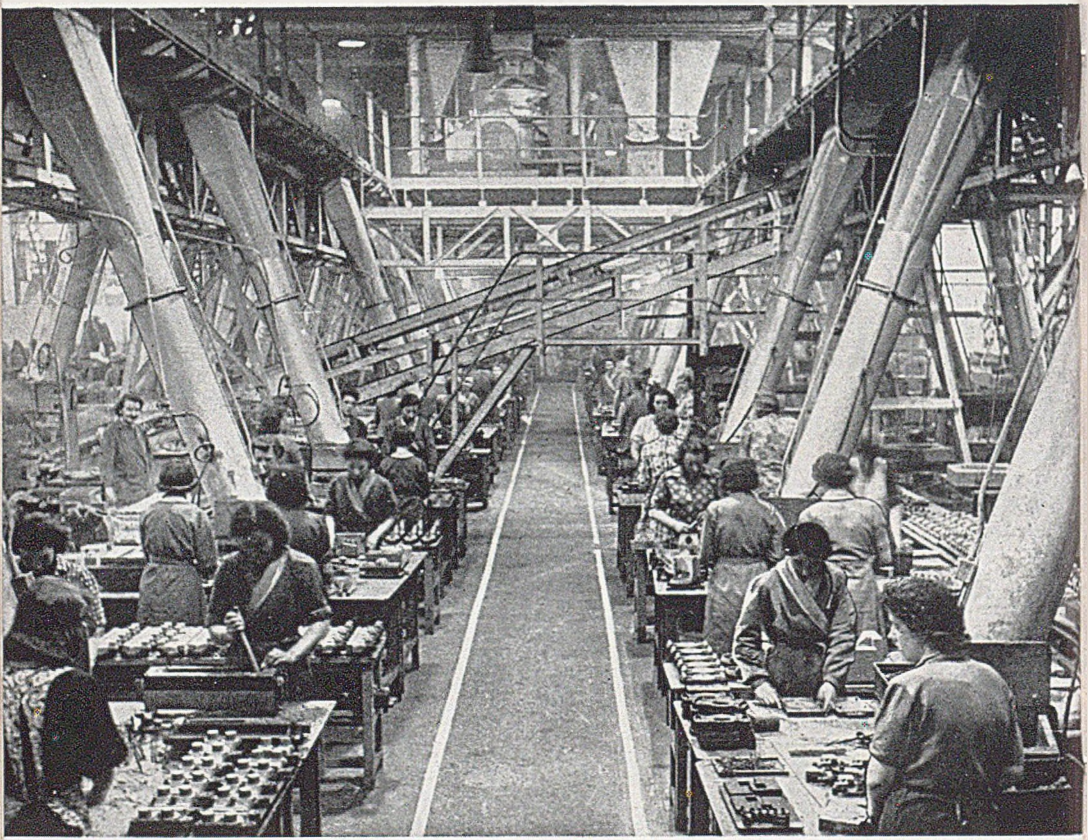
Core-making
IN A
FAMOUS LIGHT METAL FOUNDRY



British Industry needs more castings than ever. Renfrew Foundries, the largest and most highly mechanised light metal casting plant in Europe, can meet all demands. Output capacity and cost are such that they open new fields for the application of these tough, durable and light alloys. Abundant raw materials, fully mechanised production supported by outstanding research, design and engineering specialists, unique facilities for the quick production of prototypes are features of Renfrew service of vital interest to manufacturers pressed for delivery. Full co-operative service from drawing board to despatch.

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die walls with increasing pressure. Here there are several possibilities of ameliorating the trouble.

There is the promise lying in using a comparatively low initial pressure and following sintering with cold or hot forging. There is also the recognition that general lubrication through the powder mass before pressing is not necessary, that it is the powder in direct contact with the die wall that requires lubrication, and that the use of a selected lubricant can provide very much more efficient lubrication than the haphazard use of the first lubricant that comes to hand. There are possibilities of applying certain modern plastics in a layer only a molecule or so thick which may be of service. Finally, there is the choice of material for the die, or at least for the die liner, and here the wetting power of metal powders under varying pressures is of importance. The substitution of highly polished carbide liners is an obvious possibility, in view of the superior hardness of the carbides to corundum or aluminium oxide, for it is fairly obvious that the first stage in the build-up of aluminium on the die will be the scoring of the die wall by the oxide film on the aluminium grains.

This may appear a long apologia, but it is important to understand why the case of the light metals and alloys is different from that of the other metals as regards their powder metallurgy. It is also to be remembered that for low-strength components there are alternative economical methods of production, such as die casting and similar processes. Hence there must be outstanding advantages in components produced by power metallurgy to justify the process being used. As a rule these advantages are that the particular properties of the component can be obtained only by powder metallurgy, i.e., controlled porosity or a combination of metals not possible by other than powder-metallurgical technique. On the other hand, powder metallurgy may provide outstanding properties, as in the case of sintered-metal clutch linings, which gave long life without increased drum wear.

In this connection interesting experimental work was carried out in Germany just before the war, when mixtures of aluminium and magnesium powders respectively with kieselguhr and a phenolic resin were pressed and sintered, and provided results which clearly indicated that further work was essential. Details of other work on sintered bearings in many variants of aluminium-iron, aluminium-copper, aluminium-cadmium-lead eutectic, as well as magnesium alloys and mixtures, show that in the early years of the late war the Germans were pursuing inquiries in many directions into the possibility of utilizing powder-metallurgical methods with light-metal components.

An actual achievement in this field is the production of a self-lubricating powdered-aluminium bearing by the Amplex division of the Chrysler Corporation, which they claim to be equal in performance to self-lubricating bronze bearings. Another field in which developments are looked for is in cylinder liners, piston rings and similar components. As is well known, the grooves of light-alloy pistons wear badly with cast-iron piston rings. This suggests their production from light alloy also, but so far no practical and commercially successful component has appeared. That is no reason for not anticipating one. In Germany patents have been taken out for light-alloy piston rings containing appreciable quantities of cobalt-aluminium intermetallic compound, together with smaller quantities of cobalt, metal, manganese, etc., but so far as the latest information goes, the piston ring has not yet emerged from the experimental stage. The same would appear to apply to experimental work in this country on the production of pistons, cylinder heads and other components.

Even more remote from production achievement would appear to be useful sintered masses of magnesium-base alloys. This may be explained partly by reason of the hazards entailed in the free handling of large quantities of these materials in a finely divided form, and partly because of the lethargy which still characterizes the approach of so many branches of engineering towards the wider use of the ultra-light alloys. True, the automobile industry has not been slow in its appreciation of the merits of magnesium, and signs are not wanting of a vigorous outburst of renewed all-round interest.

All this indicates plenty of activity and suggests that there are still many undeveloped possibilities. A hopeful feature to-day is that progress is on a broad front, that many of the problems which handicapped workers before the war have now been partially or wholly solved, and that there have been massive advances in fundamental knowledge, which must always be the basis upon which any satisfactory investigation is based. There is also a growing recognition among automobile engineers that they can look to powder metallurgy to provide materials the older classical metallurgical methods can never supply. (Matter for this discussion on light-alloy powder metallurgy was furnished by courtesy of Powder Metallurgy, Ltd., Commonwealth House, 1-19, New Oxford Street, W.C.1.)

(*To be concluded.*)

CASE *of* TEMPERAMENT

A Review by F. A. Allen, A.I.M.

DESPITE the fact that physical metallurgy is taking its place amongst the exact sciences, production metallurgy, at least of the light-alloy variety, often appears to be compounded of inspired guesswork and just guesswork. The number of variables that may operate are known to be great, and when real difficulties are encountered in the production of castings, lengthy investigation must often be made merely to eliminate some of the possible adverse factors. But if such were the normal pattern of procedure this would not be as bad as the position that too frequently arises; for example, castings may be made successfully from pattern or die on four days out of five, but the fifth is hopelessly poor in production because of excessive scrap. The foundryman, in these circumstances, may blame " the metal " as all other conditions appear to be identical; if he be more charitably disposed to the metallurgist, or, more intelligent, he may, in all seriousness, blame the weather. If the truth be told, the conscientious metallurgist will secretly wonder if the trouble really is, after all, *not* with the metal, in spite of his assurances, dictated by shop psychology and a chemical analysis, that nothing is wrong.

The French journal " Fonderie," for February, 1946, discusses the problem, in a paper by M. Jean Duport, entitled "Difficulties encountered in the use of secondary alloys in gravity diecasting." The author states that he has visited many foundries to investigate difficulties apparently arising from the utilization of these materials. Two examples are quoted.

In the first foundry the composition of the secondary alloy used was as follows: iron, not more than 0.8 per cent.; silicon, 5.5-8.0 per cent.; copper, 3.0-5.0 per cent.; zinc, not more than 2.0 per cent.; magnesium, not more than 0.5 per cent.; manganese, not more than 0.7 per cent.; nickel, not more than 0.5 per cent.; chromium, not more than 0.4 per cent.; titanium, not more than 0.3 per cent. This alloy is designated 2 A-S5U, and is standardized by a French body dealing with secondary light alloys.

Some ten tons of this alloy had been received, and its use had unfortunately caused great disappointment. Responsible supervision recounted to the author some of the setbacks that been encountered.

The difficulties could be classified in four groups:

(1) When the metal is melted and held at casting temperature in the holding furnace, a tenuous skin is observed to form on the surface of the molten alloy: the skin immediately re-forms after the passage of a skimming-tool. It was noticeable that the film was more viscous and thicker than the film of alumina usually associated with molten aluminium alloys. Its presence signalized poor running properties giving frequent scrap particularly on thin-sectioned castings. This was the least serious fact observed.

(2) Under the same conditions, the formation of a very thick surface film may be seen, which cannot be eliminated by any of the usual refining fluxes. When the diecaster took metal from the bath, he could not avoid entraining fragments of this thick viscous scum. The metal ran sluggishly and many castings did not make.

(3) In the third case, it was observed that a porous, bulky cover formed on the surface of the metal. Whatever precautions were taken, the mass still developed. and in time, such was the progressive nature of the action, all the metal was reduced to this dross, and was therefore rendered unusable.

This case was the worst and most

serious of the metal troubles experienced and was due, it was found, to an abnormally high magnesium content.

(4) Occasionally, proneness to shrinkage defects in castings poured from secondary ingot was so marked that only scrap was produced, although the same die produced perfect castings without any difficulty when virgin ingot was used.

The 10-ton batch of metal, mentioned above, having shown difficulties of the type described in the second case, was analysed with the following result:—Iron, 0.55 per cent.; silicon, 6.70 per cent.; copper, 4.40 per cent.; zinc, 0.08 per cent.; magnesium, 1.00 per cent.; manganese, 0.65 per cent.

Comparing the above with the specification quoted of alloy 2A-S5U, it can be seen that the magnesium content is high. It appeared to confirm the impression that high magnesium was the cause of the trouble.

It was thought, however, that it was premature to draw conclusions from a single analysis; a second sample was taken and gave the following analytical result:—Iron, 0.57 per cent.; silicon, 6.09 per cent.; copper, 4.40 per cent.; zinc, 1.02 per cent.; magnesium, 0.39 per cent.; manganese, 0.54 per cent.; nickel, trace; chromium, nil; titanium, nil.

This sample was evidently within specification standards.

The following conclusions were drawn from this example: first, in any batch of metal it is wise to envisage the possibility of serious variations of composition. This state was explained by the fact that few French refiners are equipped with furnaces of large capacity; secondly, secondary alloy could be accepted on the results of a chemical analysis, and yet be practically unusable in the gravity die-foundry.

The second foundry visited specialized in the production of small- and medium-sized gravity die castings, which could only be produced after many attempts. The casting was of simple form, and the unaltered die had already previously successfully produced many castings. The technique of the die casters had not been changed. The author successively tried the following experiments:—

1. Varying the pouring speed.
2. Varying the height of the pour.
3. Varying the die temperature.
4. Varying the pouring temperature.
5. Vibrating the die table.
6. Tilting the die during pouring to fill the mould without turbulence.
7. Changing the die caster's ladles.

In spite of all attempts, it was not possible to produce more than 5 per cent. good castings.

But the next day's production, under the same conditions as far as was known, was good. Chemical analysis of castings representative of the two days gave the following results:—

	Al	Cu	Sn	Zn	Fe	Mn	Mg	Si
Scrap Casting ..	85.47	3.32	0.05	0.20	0.75	0.38	0.53	9.30
Good Casting ..	85.45	3.40	0.04	0.25	0.80	0.39	0.53	9.14

One would say that there was no practical difference in composition from one day to the next, although the result, in terms of castings, was very different.

The problem was now more defined, and the author was able to proceed farther. He considered the sources of material and detailed spot chemical tests for determination of alloy types, and concludes with a summary of essential foundry properties.

The most important is without doubt that of fluidity to which should be added freedom from cracking and shrinkage. In relation to the first property, the author found that the surface treatment of the die face was of great importance and found in general that the better a heat insulator the coat was, the better the apparent fluidity of the metal.

In a subsequent number of "Fonderie," de Kenny notes the influence of alumina in the metal.

In conclusion, the present reviewer would say that the British refining industry is in advance of the French counterpart. Although the states described by Duport are not unknown in this country, secondary ingot from reputable manufacturers gives little trouble provided melting technique is as efficient as that used in the treatment of virgin material.

CORROSION OF METALS WITH OXYGEN DEPOLARIZATION

Continuing from "Light Metals," 1948/11/112, the Next Section of Tomashoff's Work Deals with Cathode Characteristics with Special Reference to Aluminium and its Alloys

THE most complete guidance on the accelerating corrosive action of any cathode material on the corroding anodic structure can be obtained only from the examination of experimentally derived polarization curves, since these (as distinct from the theoretically deduced curves) quite accurately characterize the behaviour of a real cathode with regard to any other corrosion system.

It is known that experimental study of electrode processes, particularly measurement of cathode potentials under conditions of oxygen depolarization, tend to give results which are difficult to reproduce. This is due, mainly, to the following two causes:—(1) Non-attainment of equilibrium between the process of removing the oxide film from the electrode (on account of the cathodic polarization) and film formation (in consequence of the oxidizing action of the depolarizer upon the cathode surface); (2) the difficulty of creating and maintaining a uniform rate in the transfer of the depolarizer to the cathode.

In order to diminish the effect arising from the first cause, it is necessary to lengthen as much as possible the period of time at each increase of current density, and to use the corresponding values of potentials for the plotting of polarization curves.

To mitigate the effect due to the second cause, recourse has to be made to energetic agitation of the electrolyte and to precision regulation of the speed of rotation of the stirrer.

It follows, therefore, that the factor responsible for the deviation of the real cathode curve from the analytical one, attaches to the alteration of the state (and, consequently, of the electrochemical properties) of the actual cathode surface during cathodic polarization.

Chiefly to be considered in this regard are removal of the oxide film from the cathode surface (with increase in cathode-current density) and formation of the oxide film (when the cathode current decreases).

Let us consider the varying behaviours of cathodes

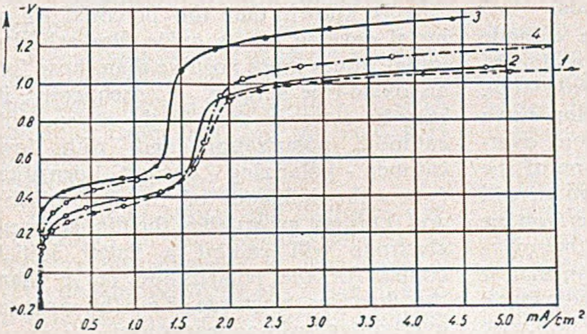


Fig. 29.—Comparative curves for cathodic polarization:—1, iron; 2, nickel; 3, chromium; 4, 18/8 stainless steel. (Figure 29 in Russian text.)

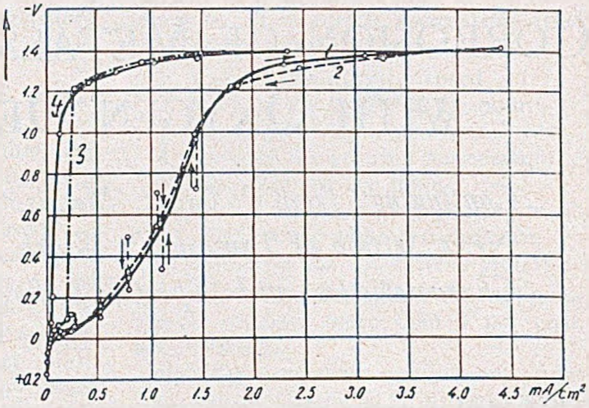


Fig. 30.—Curves for cathodic polarization of graphite : 1, direct course ; 2, reverse course ; 3, static electrolyte (for initial polarization of the electrode) ; 4, static electrolyte (for repeated polarization of the same electrode). (Figure 30 in Russian text.)

covered with, and free from, film (or, to be more precise, of a cathode having a more or less continuous surface film, and of one bearing a less continuous film). The corresponding polarization curves will also be compared.

Depending on the electro-chemical characteristics of the oxide film, the following cases are possible:—(a) The film possesses no electronic conductivity and cannot itself function as a cathode. In this event the oxide layer acts as a dielectric, which, subject to its continuity, insulates a greater or lesser part of the cathode surface. Under these conditions the cathode, covered with the oxide film, is liable, for given current densities, to be polarized more strongly than one free from the oxide layer or covered with a more porous film. In this instance the polarization curve for the cathode with a more continuous film will be definitely steeper, i.e., such a cathode should have a higher apparent oxygen over-voltage. The limiting diffusion current might, here, remain practically unchanged, as, with the frequent and uniform distribution of the film-free areas (pores), the power of diffusion will be determined not by the true working cathode surface but by an overall area of the electrode.

(b) If the oxide film at the cathode exhibits electronic conductivity, and, consequently, acts itself as a cathode area, then the course of the polarization curve in the zone of the ionization over-voltage of oxygen, or in the zone of the over-voltage of hydrogen evolution, will depend on the value of the over-voltage at the oxide film itself. If the over-voltage at the film be higher than that at the pure-metal surface, the cathodic curve for the film-covered electrode will rise more steeply; if the over-voltage at the oxide film be smaller than that at a pure-metal surface, the curve will run flatter than that for the film-free electrode.

(c) If the surface oxide film functions as the cathode, i.e., possesses electronic conductivity, but has, compared with metal, a markedly greater electrical resistance, then the measured potential will be affected by the value of the potential drop due to the film resistance $V_R = R.i$, where R is the resistance of 1 cm.^{2} of the film, and is the density of the polarizing current.

As a result, there will be some shift in the curve for cathodic polarization towards more negative potentials, the movement being proportional to the density of polarization current. If the resistance of the surface oxide film be considerable, the polarization curve will be determined, in the main, by the above equation, i.e., it will tend to become a straight line.

It is known that the potential of a metal covered by its oxide film exhibits initial values more positive than those for an oxide-free surface. Consequently, it may be assumed that, in the absence of cathodic polarization and with low cathode - polarizing - current densities (when the influence of factors (a), (b) and (c) is not great), then the film-covered electrode will exhibit a flatter initial course for the polarization curve than the film-free electrode, i.e., the oxygen over-voltage will appear lower.

(d) Variation of the true area of the electrode (for instance, in consequence of difference in surface treatment) will also exert an influence on the course of the polarization curve. In the first approximation, increase in cathodic activity of a material in relationship to oxygen ionization or hydrogen evolution may be considered as proportional to the increase of the true surface of the electrode.

(e) In examining the experimental curves it is necessary, in addition, to take into account the fact that some processes—for example, reduction of the oxide film (with corresponding increase in cathode-current density) or formation of the oxide film (with corresponding diminution of the cathode current)—tend to be slow. Equilibrium conditions, therefore, may not be reached, the deviation varying for different regions of the polarization curve. The result is that the direct and reverse loci of the true polarization curve may not coincide, but may, at various points, differ to a greater or lesser degree from one another.

Analytical and experimental investigation of cathodic processes with oxygen depolarization has revealed that: (1) the efficiency of the cathode will, with a sufficiently energetic transport of the depolarizer (oxygen), depend on the cathode material; (2) the efficiency of the cathode material in the process of oxygen depolarization may be estimated by the magnitude of the ionization over-voltage of oxygen; (3) the ionization over-voltage of oxygen, like the over-voltage of hydrogen evolution, bears a logarithmic relationship to the cathode current density.

The various cathode materials examined form, when arranged in the order of increasing oxygen over-voltage, a series different from that for the stationary potentials of the cathode materials or of hydrogen over-voltage.

The role of oxygen and hydrogen concentrations in the cathodic process, as well as the influence of roughness of cathode surface, speed of stirring of electrolyte, and the effect of various additions to the latter, were examined by Tomashoff in great detail for different corrosion systems.

For many cathode materials, a very characteristic value proved to be the difference between the direct and reverse polarization curve in the zone of oxygen depolarization. This deviation permits metals to be arranged in order of increasing hysteresis of potential for a given standard polarizing-current density.

Of all cathode materials investigated, tantalum exhibits maximum dependence on its surface oxide films; this is associated with the relatively high impermeability and stability of the oxide films formed. Polarization curves for the direct and reverse course for tantalum exhibit, for this reason, both in the field of oxygen over-voltage and in that of hydrogen over-voltages, the most marked hysteresis effects.

The polarization curve for the direct course shows that, in the presence of an undamaged oxide film at its surface, tantalum has a high oxygen ionization over-voltage, i.e., it operates as a low-efficiency (or passive) cathode during oxygen polarization. In the reverse course, when the protective surface oxide coating, after a prolonged polarization at high current densities, is, to a considerable extent, impaired, the oxygen over-voltage of the metal is of intermediate value. The hydrogen over-voltage for the tantalum electrode remains sufficiently high, regardless of the duration of cathodic polarization, even at the maximum current densities employed in these investigations.

It is of interest to note that the hysteresis in the cathode polarization of tantalum is fairly stable, as repeated polarization of the same electrode very closely follows the loci of the direct and reverse curves derived from the first polarization.

The initial potential of the tantalum electrode was equal to − 0.05 volt, and the final to ± 0.00 volt.

The lowest hysteresis was displayed by gold; this is attributable to the ease of reduction of the exceedingly thin oxide

Table 2.—Electrode Potentials and Over-voltages for Various Cathode-current Densities (Table 8 in Russian text)

Electrode	Particulars of experimental procedure	Potential of electrode relative to normal hydrogen electrode, in volts										Ionization over-voltage ; oxygen		Hydrogen over-voltage with current density 3 mA./cm.^{2}	
		With agitated electrolyte								With static electrolyte					
		No current		0.5 mA./cm.^{2}		1.0 mA./cm.^{2}		3.0 mA./cm.^{2}		No current (after experiments with agitation)	3.0 mA./cm.^{2} direct course	0.5 mA./cm.^{2}	1.0 mA./cm.^{2}	In agitated solution	In static electrolyte
		Initial	Final	Direct course	Reverse course	Direct course	Reverse course	Direct course	Reverse course			Direct course	Reverse course		
Aluminium, high-purity	Usual conditions ..	−0.83	−0.815	−1.02	−0.89	−1.115	−1.03	−1.395	−1.35	+0.86	−1.375	—	—	0.865	0.845
Aluminium, high-purity	0.5N NaCl	−0.48	−0.48	−1.17	−1.15	−1.315	−1.25	−1.405	− .40	−0.43	−1.335	—	—	0.99	0.92
Aluminium, technical purity	0.5N NaCl	−0.475	−0.46	−1.12	−1.06	−1.15	−1.13	−1.21	−1.21	−0.55	−1.23	—	—	0.795	0.815
Duralumin	0.5N NaCl	−0.44	−0.44	—	—	−1.04	−1.04	−1.15	—	−0.455	−1.08	—	—	0.735	0.665
Magnesium, high-purity	Usual conditions ..	−1.775	−1.735	−1.81	−1.805	−1.85	−1.86	−2.385	−2.39	−1.69	−2.48	<2.51	<2.55	1.055	1.95
Magnesium, oxidized	Usual conditions ..	−1.42	−1.73	−2.14	−1.80	−2.245	−1.86	−2.375	−2.385	−1.31	−2.44	<2.84	<2.945	1.845	1.91
Copper, electrolytic	Usual conditions, atmospheric air	+0.075	+0.135	−0.29	−0.22	−0.35	−0.32	−1.20	—	+0.07	−1.165	0.99	1.05	0.67	0.635
Iron ("Armco") oxidized	Usual conditions ..	−0.115	−0.11	−0.405	−0.395	−0.48	−0.515	−0.82	−0.80	−0.425	−1.06	1.105	1.18	0.29	0.53
Platinum <99.99% Pt.	Usual conditions, cleaned with finest emery paper	+0.41	+0.38	+0.05	+0.105	−0.005	+0.055	−0.76	−0.775	+0.395	−0.86	0.65	0.705	0.23	0.33

films on the surface of the metal even at very low cathode - current density.

The platinum electrode exhibited a small but noticeable hysteresis, associated apparently with the saturation of the platinum with hydrogen at high current densities and a certain lag in its expulsion with diminution of current density.

The presence of potential hysteresis is, essentially, an indication of the lack of equilibrium conditions for each density of polarizing current, for it is obvious that, should equilibrium be reached, the curves for the direct and reverse course would be coincident. As stability of potential for different cathode materials was accomplished by a standardized method, it follows that the observed hysteresis characterizes not only the ability of a given cathode to form an oxide film on its surface, but also the comparative stability of these films under the experimental conditions involved.

The main results of Tomashoff's experimental investigation of various cathode materials are given in Table 2. Attention is directed especially to the data respecting aluminium in its various forms and to magnesium. Reference should also be made to the corresponding curves noted in the text.

Aluminium and Aluminium-base Alloys

The cathode behaviour of an aluminium electrode is illustrated by the curves in Fig. 31. The aluminium employed contained not less than 99.99 per cent. Al, and was specially prepared for the purpose by the Soviet Aluminium Research Institute. Experiments concerning the cathode polarization of aluminium were carried out in 0.5N NaCl + 0.005M Na_2CO_3 + 0.005M $NaHCO_3$ and in 0.5N NaCl without a buffer.

In a buffered solution of sodium chloride with pH = 9.2 the initial potential was markedly negative (− 0.83 volt), this being a consequence of instability of the protective oxide films on aluminium with respect to alkaline solutions and the negative equilibrium potential of the metal. In a neutral solution of sodium chloride the potential was naturally more positive, about − 0.48 volt.

With regard to oxygen depolarization, aluminium has proved to be one of the least effective cathodes. The cause of the low efficiency of the aluminium cathode is attributable, not to any poor catalytic activity of aluminium itself in respect to the reaction of oxygen ionization, but to two other indirect factors, namely: (1) the strongly negative equilibrium potential of aluminium and (2) the instability of the protective oxide films on aluminium in relation to alkaline solutions. As soon as the process of cathodic polarization of the aluminium cathode commences, the surface oxide film begins to be etched off by the alkali developed in the neighbourhood. The potential of aluminium is shifted in the negative direction, not so much on account of polarization phenomena, but, rather, as a result of a diminution of the protective properties of the passivating film. This effect is particularly pronounced in a non-buffered solution, in which initial potential of aluminium, by virtue of neutrality of the medium, is reasonably positive. Furthermore, in this case, change in the pH value at the cathode during polarization is, due to the absence of a buffer, considerable. As is seen from the curves in Fig. 31, the aluminium cathode becomes so polarizable in this solution that even vigorous stirring of the solution produces practically no effect: the electrode in the agitated electrolyte is polarized almost as strongly as in the static solution.

In a buffered solution with agitation, we may still, it is true, observe a small inflection in the curve, indicating the commencement of concentration polarization (limiting diffusion current), but the inflection is not pronounced, as the potentials reached at these current densities are such as to give rise to rapid hydrogen depolarization, which will thus determine the whole subsequent course of the curve.

Hence it is to be concluded that in a buffered solution of sodium chloride (with agitation), the locus of the curve, prior to the energetic evolution of hydrogen (up to about − 1.1 volts), is determined by a complex process involving oxygen and hydrogen depolarization, as well as by degradation of the usual

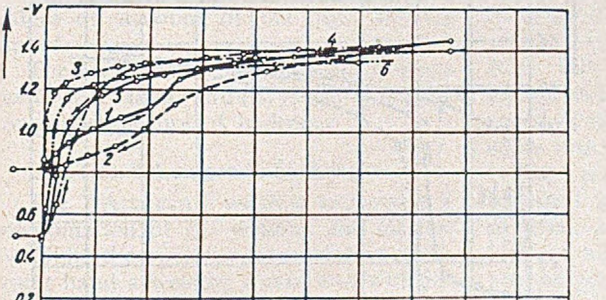


Fig. 31.—Curves for cathodic polarization of aluminium : 1, direct course (ionization overvoltage of oxygen, with increasing density of polarizing current), with agitated aqueous 0.5N NaCl + 0.005M Na_2CO_3 + 0.005M $NaHCO_3$; 2, reverse course (decreased density of polarizing current), with electrolyte as before, agitated ; 3, electrolyte as before, but without agitation ; 4 direct course in 0.5N NaCl, with agitation ; 5, reverse course in 0.5N NaCl ; 6, with static 0.5N NaCl. (Figure 31 in Russian text.)

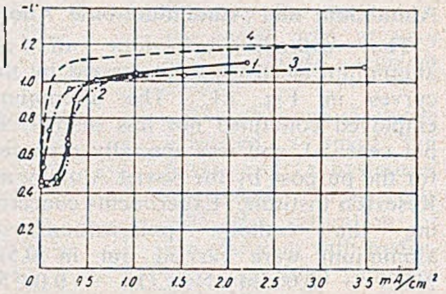
potential of the aluminium electrode due to the rapid alkaline dissolution of the protective oxide film during cathode polarization.

In a non-buffered solution of sodium chloride, and in a buffered but static solution, the course of the polarization curve is, in the main, determined, prior to reaching potentials marked by energetic evolution of hydrogen, only by the latter process of potential degradation.

With regard to the process of hydrogen polarization, aluminium is also a cathode of low efficiency, i.e., it has a sufficiently high hydrogen overvoltage. However, in this respect, the behaviour of aluminium is not characteristic, for some other cathode materials examined exhibited even greater hydrogen overvoltages.

Duralumin

The cathode polarization of duralumin was conducted in 0.5N NaCl in atmospheric air. Duralumin used was of the technical grade, having the following composition: 4.0 per cent Cu; 0.6 per cent. Mn; 0.4 per cent. Mg; 0.3 per cent. Si; 0.5 per cent. Fe. Experimental results are presented in Fig. 32. For the purpose of comparison, the polarization curve for high-purity aluminium obtained under the same experimental conditions is also given.



(32)

Fig. 32.—Curves for cathodic polarization of duralumin : 1, direct course, with agitated electrolyte ; 2, reverse course with agitated electrolyte ; 3, with static electrolyte ; 4, technical unalloyed aluminium in agitated electrolyte. (Fig. 32 in Russian text).

Examination of the cathode behaviour of duralumin has demonstrated that this alloy, like aluminium itself, is of low cathodic efficiency, especially in respect to oxygen depolarization. However, it is notably more effective than a high-purity aluminium. This point will be demonstrated by a direct comparison between the two electrodes in the next section of Tomashoff's work.

(To be continued.)

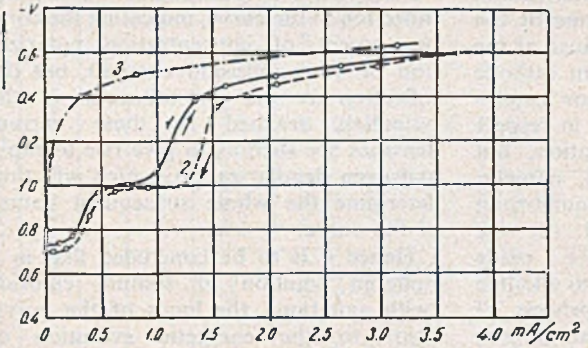


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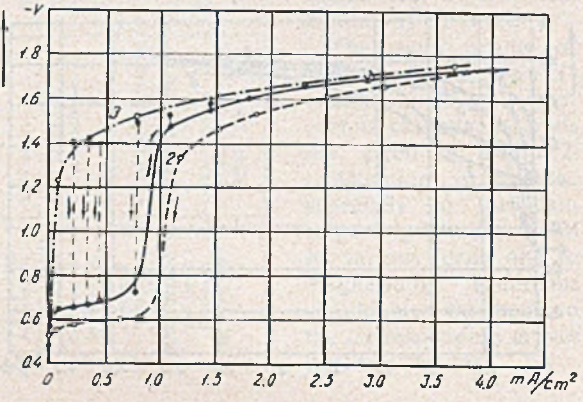
Fig. 33.—Curves for cathodic polarization of zinc : 1, direct course ; 2, reverse course ; 3, with static electrolyte. (Figure 34 in Russian text).



(34)

Fig. 34.—Curves for cathodic polarization of cadmium : 1, direct course ; 2, reverse course ; 3, with static electrolyte. (Figure 35 in Russian text.)

ARC WELDING of Aluminium and its Alloys

By A. Schärer,
Dipl.-Ing.-Chem. E.T.H.

The Author Concludes His Summary of Arc-welding Techniques and Passes On to a Consideration of the Specific Problems Involved in Welding Aluminium. Electrodes and Fluxes for Arc Welding are Examined.

CONTINUING the discussion on the "Arcatom" or atomic hydrogen process, from Light Metals," 1948/11/81, an alternating current for the arc is supplied from a special transformer. Due to the very high temperature developed, the speed of welding is considerably greater than in the case of gas welding and the heat-affected zone next to the welding seam is consequently narrower. This and the very intense heat make this process eminently suitable for the welding of very thin sheets where distortion must be avoided at all costs. It is also very suitable for the welding of Al-Mg (Peraluman) alloys. Application of flux and filler rod follows the same principles as in gas welding. The only exception is the welding of sheets 1.5-2 mm. thick, which should be welded with upturned edges on account of the high welding speed.

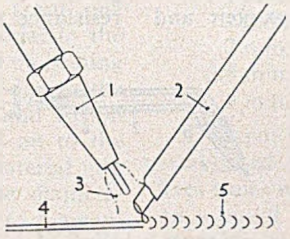


Fig. 6.—The "Arcogen" Process.
1. Torch; 2. Electrode; 3. Flame; 4. Workpiece; 5. Weld.

The atomic hydrogen process is more expensive than ordinary gas welding owing to the use of hydrogen.

The "Arcogen" Technique

The "Arcogen" welding process is a combination of gas welding and electric welding; the operator manipulating in his right hand a welding torch, and with his left hand the electrode. The torch flame ionizes the path of the arc between work piece and electrode to such an extent that only the light cone of the oxygen-acetylene flame should be held in the immediate vicinity of the electrode tip in order to generate an arc. Addition of filler metal can be interrupted by removing the electrode from the flame. This is also a means of controlling the temperature of the molten pool within wide limits. If cooling of this pool is desired, the electrode is dipped directly into the pool, thus extinguishing the arc by short circuiting. Melting takes place inside the protective shield of the autogeneous flame and the direction of the arc can be influenced widely by directing the flame. This contributes greatly to the ease of manipulation of the electrode. (See Fig. 6.)

Coated electrodes, such as used in electric arc welding are preferred for the welding of aluminium and aluminium alloys. However, it is possible to use filler rods which are coated with an autogeneous welding flux. The welding speed of the "Arcogen" process is of the same order as electric arc welding.

This process has not found many practical uses as much skill is required to make a homogeneous seam, particularly in aluminium and its alloys. The advantages of the system do not make up for its lower economy in which respect it stands behind most of the better-known and more widely practised methods.

The Heliarc Process

This new welding process was developed by V. H. Pavlecka, Director of Research of the Northrop Aircraft Corp., in collaboration with Ruth Meredith; early reports about the technique were published in " Light Metals " (November, 1942). It is stated that the process is suitable for welding aluminium, aluminium alloys and particularly magnesium alloys. The welding tool consists of a pistol-shaped holder which holds at its front end a tungsten electrode located at an angle, clamped into a nozzle system through which helium gas is supplied. Before striking an arc between the tungsten electrode and the work piece, the gas is directed against the weld area. The arc is then initiated by touching the work piece with the electrode. The helium emerging from the electrode ionizes the arc and, at the same time, forms an inert protective gas envelope round the molten pool, preventing access of oxygen and nitrogen from the atmosphere. A filler wire of the same composition as the parent material is fed into the molten pool. In order to obtain simultaneous and uniform melting of the filler wire, it is recommended to direct it towards the electrode. Fluxes are not required.

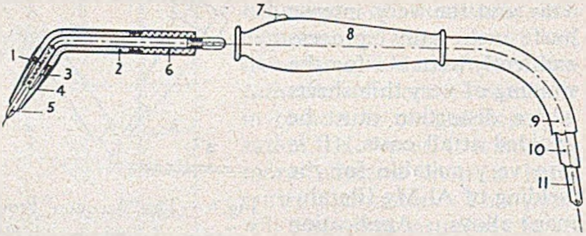


Fig. 7.—Welding Torch for the Heliarc Process.
1. Orifice ; 2. Heat insulation ; 3. Collar ; 4. Screw cap ; 5. Tungsten electrode ; 6. Plastic sleeve ; 7. Adjusting valve ; 8. Handle ; 9. Rubber insulator ; 10. Cable ; 11. Inlet for helium.

An ordinary D.C. welding generator with a rating between 150 amps. and 300 amps. can be used for welding, and the electrode should be connected to the negative pole. It is necessary to renew the tungsten electrode after a limited time, as it absorbs metal from the parent material. Traces of tungsten are transferred to the molten pool, but have little influence on the mechanical or chemical poperties of the weld.

Only high-purity helium is used, as even traces of impurities affect the welding process considerably, and nitrogen, carbon dioxide, hydrogen and oxygen must be eliminated. Traces of hydrogen cause porous welds, whilst oxygen oxidizes the surface of the molten pool, thus preventing addition of the filler metal. The use of helium is tending, even in the U.S.A., to be largely superseded by that of high-purity argon. Outside the U.S.A., the cost of helium is prohibitive and argon is used exclusively. Arc conditions for argon appear to differ slightly from those giving optimum results with helium.

Electric Resistance Welding

Spot, seam and butt welding are different forms of resistance welding which find increasing uses for the jointing of aluminium and its alloys. In contradistinction to soldering and autogeneous welding energy in the case of resistance welding is not applied in the form of heat but in the form of an electric current. Transformation of current into heat takes place in the weld area itself, where a homogeneous weld is obtained by the simultaneous application of pressure on the contacting surfaces which undergo fusion.

Butt welding is the simplest form of resistance welding. When two metal parts are clamped into vices a short distance away from their conducting surfaces, the supply of energy by a low-voltage current to the parts under pressure results in the generation of heat at the conducting surfaces owing to the transformation of electrical energy into heat, which may become so intense that these surfaces begin to melt. After cutting off the current supply, further pressure is exerted on the workpieces which results in extrusion of the viscous, partly oxidized metal from the contact area in the form of a flash round the weld area.

Current and voltage requirements depend on the electrical resistance of the material and the dimensions of the workpiece. The voltage of resistance welding machines is usually small, i.e., varies from 1 to 20 volts, whilst the current can be as high as 100,000 amps. or more, according to weld area and conductivity of the material. Transformers are required to reduce the mains voltage.

The principal difference between butt welding and spot welding can be found in the shape of the current-conducting electrodes, truncated cone shapes being used for spot welding. The sheets to be welded are held in an horizontal position between vertical electrodes which are squeezed together mechanically. After switching on, current flows from one electrode tip through the material to the other electrode; the maximum of heating occurs at the contact surface, due to the high resistance of this area, and fusion takes place. Pressure exerted on to the electrodes forms the molten material into the so-called weld nugget, the diameter of which roughly corresponds to the contact area of the electrode tips.

Continuous seams can be obtained by using copper wheels as conductors instead of spot electrodes; pressure is exerted on the wheels while the welding current flows. It is necessary to interrupt the current passing through these rollers at short intervals to prevent sticking of the rollers to the material. The number of interruptions is correlated to the welding speed so that the individual spot welds overlap partly. (See, however, page 139 in this issue of " Light Metals.")

Spot welding, particularly of heat-treatable alloys, has great advantages compared with autogeneous welding, as very little softening of the weld metal occurs. Spot welding is being used on an increasing scale to replace riveting for heat-treatable alloys, as for thicknesses up to 2 mm. the same mechanical properties can be obtained. Repeated heating of the contact area above the melting temperature of the weld metal followed by instantaneous cooling have very little influence on the material surrounding the weld nugget. The strength of a spot welded joint depends on the fact that the nugget has a cast structure which is less ductile and has less elongation than the base material with its rolled structure.

The stressing of a spot weld at right angles to the welded sheets will yield mechanical values lower than those of a riveted joint, particularly where dynamic or fatigue stresses are applied.

Current requirements for the spot welding of aluminium, according to P. Vögeli (" Schweizer Bauzeitung," Vol. 121, No. 1, 2.1.43), are as follow:—

Sheet thickness	Minimum welding current
.5 mm.	15,000 amps.
1 mm.	18,000 amps.
1.5 mm.	22,000 amps.
2 mm.	26,000 amps.
2.5 mm.	28,000 amps.
3 mm.	30,000 amps.

The spot welding of aluminium, by all established methods, requires four or fives times more energy than that of steel on account of its electrical and thermal conductivity. The welding of 1 mm. steel sheets, for instance, requires approximately 10,000 amps., the same weld in aluminium, 18,000 amps. Spot welding of aluminium and its alloys is much more difficult than welding of steel. Electrode pressure, welding current, pressure and current cycles have to be correlated very accurately. Soundest welds are obtained in pure aluminium on account of its narrow freezing range, whilst aluminium alloys, with a wider freezing range, yield a porous cast structure or contain shrinkage cracks in large nuggets. It is also necessary to take into account the presence of the oxide skin on the surface of aluminium which acts as an insulator and offers higher resistance to the welding current, thus causing sticking of the electrode to the sheets.

In order to obtain homogeneous spots,

the aluminium must be for a short time above its melting point, and if the current is too high, the danger of burning through is very pronounced. The electrode pressure should, therefore, be not too high to avoid an excessive indentation of the work piece. In conclusion, it should be stated that the resistance welding of aluminium requires very accurate setting of all welding conditions in order to be successful.

The Weibel Process

The Weibel process is of comparatively recent date and is, in fact, a resistance-welding process in which pressure is not used. The welding outfit consists of a transformer for 220 to 380 volts, three-phase current, with a nominal rating of 2.2kVA. The transformer is connected by means of two flexible cables to the electrode holder, which carries two carbon electrodes. The handle of the electrode holder consists of two parts, which may be pressed together by springs. During welding, each electrode touches one of the upturned edges whilst both electrodes are drawn along the intended seam. The heat produced between the electrode tips and the sheets causes melting down of the upturned edges. These edges must be coated with a flux before welding to prevent oxide inclusions. The most essential premise for a faultless joint is proper shape and preparation of the electrode. According to Helbing[18], hardness, electrical conductivity, heat resistance and shape of the electrode are most important factors. Fig. 8 shows the shape and method of application recommended by Helbing. (See "Light Metals," 1939/2/100.)

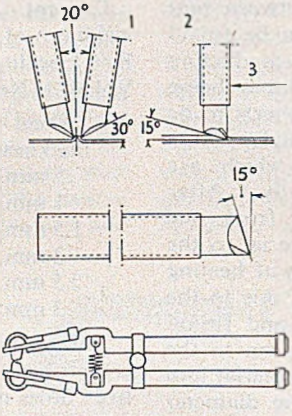


Fig. 8.—The Weibel process (modified by Junkers).
(Above) Recommended electrode forms.
1, front ; 2, side view ; 3, direction of welding.
(Centre) The proper sheathed carbon electrode.
(Bottom) Spring-type welding torch.

The electrodes are bevelled on their lower edges to increase the electrical resistance of the tips. Due to the considerably reduced area, the generation of heat in the tips is very intense. Helbing used carbon electrodes which were copper plated all over except the tips. Such copper plating increases the electrical conductivity on the surface. The electrodes are drawn along the upturned edges under an angle of 90 degrees. Irregular form or unsatisfactory set-up causes irregular heat transfer and faulty welds. The upturned edges must be freed from fat or dirt by brushing or pickling before welding; pickling is preferred as it leaves a cleaner surface, thus reducing wear on the carbons and yields longer seams. The electrode tips should be cleaned carefully with a carborundum rod or an emery wheel to remove the oxide skin which hinders the heat transfer between the electrodes and the sheet material. At the same time, this grinding operation may be used to reshape the electrodes so that they maintain their proper form. Sheets varying in thickness from .3 to 2 mm. have been successfully welded by the Weibel process. The height of upturned edges varies according to the gauge of the material and should be 2.5 mm. for thicknesses between .3 to 6 mm., and from 3 to 4 mm. for sheets between .8 and 2 mm.

The mechanical properties of Weibel welds are almost as good as those of gas welds. The tensile strength of pure aluminium welds is the same as that of annealed sheets. The very narrow heat-affected zone is a special advantage of this process, as it extends only to approximately .5 cm. on each side of the seam; in the case of cold-worked or heat-treated alloys there is only a small softened zone adjacent to the seam. Consequently, Weibel welds show greater resistance against deformation than gas welds. Distortion is very low, which is a further advantage over gas welding. The Weibel process is very suitable for the fabrication of thin gauge instrument cases and very often also used in aircraft construction. For series production, it is recommended to up-turn the edges by means of a folding machine and to use specially designed jigs for welding.

Electric Arc Welding

Arc welding of aluminium and its alloys is carried out in the same way as arc welding of steel, a process originally invented by Slavianoff in 1892. Arc welding is fundamentally a fusion process, using additional metal from a filler rod (see Figs. 9 and 10). An arc sustained by an electric current between electrode and work piece provides the source of heat. This arc causes fusion of the parent metal and melting of the filler metal at the same time. The work piece is preferably connected to the negative pole and the electrode to the positive pole of a source of D.C. power. Coated electrodes are used, the purpose of the coating being the removal of the oxide layer adhering to the molten metal. Conditions pertaining to the gas and arc welding of steel cannot be applied to the welding of light metals without reservation.

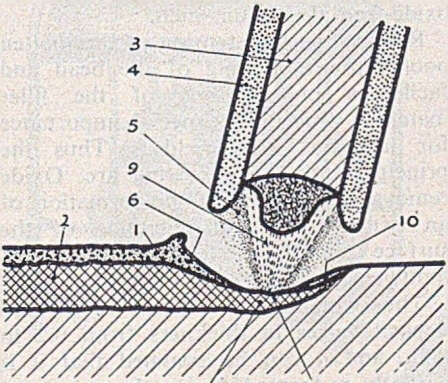


Fig. 9.—Electrode during welding. (Arc in existence.)

1. Slag ; 2. weld deposit ; 3. core wire ; 4. coating; 5. crater; 6 liquid slag; 7. molten pool; 8. cathode spot; 9. electric arc; 10. fluid slag.

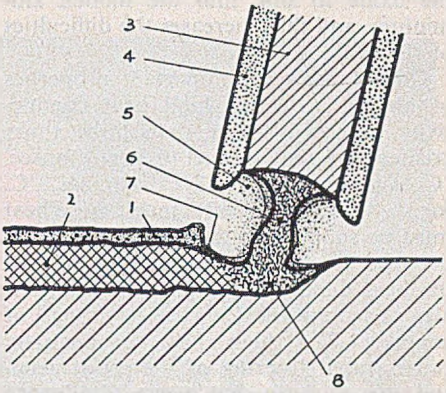


Fig. 10.—Electrode during welding. (Metal transfer.)

1, Slag; 2, weld deposit; 3, core wire; 4, coating; 5, crater; 6, liquid metal bridge; 7, fluid slag; 8, molten pool.

The physical and chemical properties of aluminium differ considerably from those of steel, and this accounts for differences in the welding process. In the following, the salient features of the arc-welding process for aluminium will be discussed.

The Weldability of Aluminium

Aluminium is a very reactive element which oxidizes easily. The process of oxidation takes place according to the following equation: $2\ Al + 3\ O = Al_2O_3 + 380$ kcal, from which it can be seen that a considerable amount of heat is set free. It exhibits high corrosion resistance, due to the very thin, invisible superficial oxide layer, which is very tough and adherent, cannot be reduced to the metallic state by the reducing atmosphere of the torch, and cannot be fused at the temperature of the welding process. The oxide skin can be removed mechanically, but a new skin is produced immediately whenever air or oxygen are present, the oxide layer preventing proper fusion between filler material and parent metal. Furthermore, the comparatively high specific gravity ($3.96\ g/cm^3$) of aluminium oxide as compared with that of aluminium metal ($2.70\ g/cm^3$) causes the oxide to sink into the molten aluminium, and thus increases the difficulties of removal.

One of the most important properties of aluminium is its high heat conductivity, which is more than three times greater than that of steel (0.5 cal/cm. sec. °C., against 0.1 to 0.17 cal/cm. sec. °C. for steel). Consequently, much more heat must be supplied to the welding point, as the heat input ought to be greater than the heat dissipation, a problem which is also encountered in the welding of copper. The high heat conductivity causes rapid freezing of the weld metal, and this, in turn, has a great influence on the structure of the weld deposit.

The high coefficient of linear expansion is also of importance in the arc welding of aluminium. In the case of mild steel, the thermal expansion between 0 and 600° C. is 8.79 mm. per metre length; for aluminium it is 17 mm. per metre. This high linear expansion, which is nearly twice that of steel, causes a great deal of trouble, especially in gas welding, as the surfaces which are preheated show a tendency to warp.

In the case of arc welding, the steep temperature gradient next to the weld is advantageous, as, to a large extent, it prevents warping of the work pieces.

The surface tension of molten aluminium is another important factor in welding. Portevin and Bastien ("Metal Industry," 19, 1936) found the surface tension of an aluminium melt from which the oxide skin had been removed to be 300 dyn./cm, whilst the value for a melt covered with an oxide layer was found to be 840 dyn./cm. This difference in surface tension between oxide-coated and oxide-free aluminium melts is remarkable, and the values are in good agreement with the behaviour of the molten pool during melting. Attempts to gas weld aluminium without employing fluxes are failures, as the molten metal drops on the parent material in the form of larger or smaller globules.

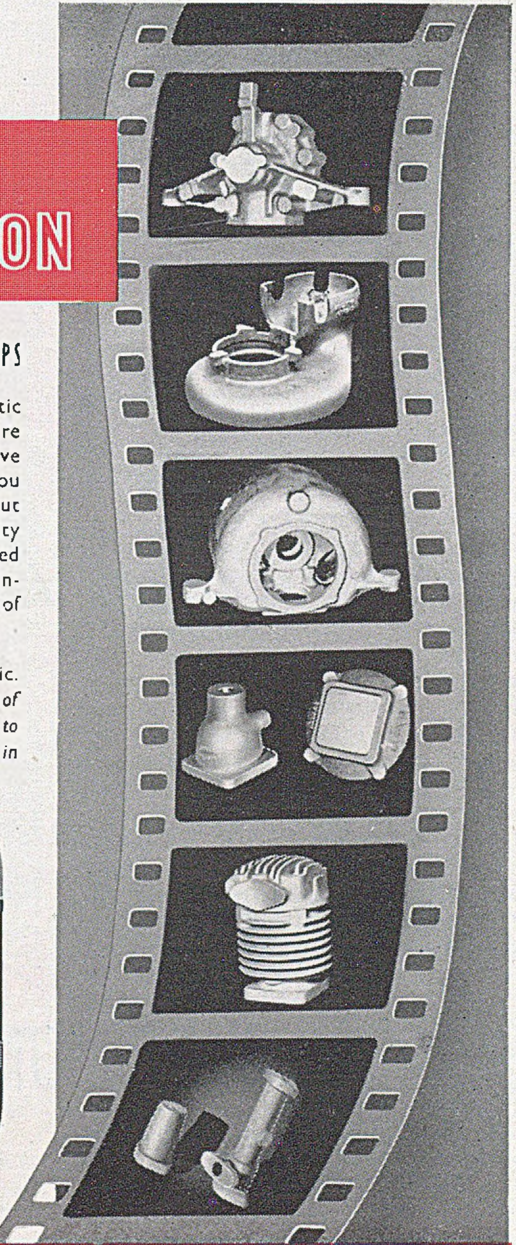
Attempts to arc weld aluminium with bare wire result in the same type of globules, which are propelled from the molten pool and drop on the parent material, but can be removed easily on account of the surrounding oxide layer, which prevents proper adhesion (Fig. 11—top).

It can be assumed that the metal which bridges electrode and molten pool during welding is surrounded by flux, a fact which prevents formation of an oxide skin (Figs. 9 and 10). If a pure aluminium wire be held almost horizontally into a Bunsen flame, warping of the heated end due to gravity can be observed as soon as the metal becomes plastic. Numerous wrinkles in the tough oxide layer are an indication that, in the interior of the wire, the metal is fluid, being contained by the oxide layer as in a "sack"; when this overheated part becomes too heavy it simply drops off.

If, however, the end of the aluminium wire be painted with a little flux, formation of globules is facilitated during the melting process because the flux removes the oxide layer and the change in surface tension promotes the formation of the globular shape of the melting tip. The more reactive the coating of an electrode, the higher is its power to remove the oxide skin. Futhermore, more reactive fluxes effectively prevent formation of a new skin, with the result that the surface tension of the molten pool is of the same order as that of an oxide-free aluminium melt.

Reduced surface tension of the molten pool causes flattening of the bead and facilitates proper flow of the filler material, which is of special importance for lap and fillet welds. Thus the principal tasks of a coating are: Oxide removal, prevention of the formation of an oxide layer, and reduction of the surface tension of filler material and molten pool.

The oxide on the surface of a weld deposit varies in thickness from 0.2 to 0.5μ, and it can be assumed that it is partially re-formed during the course of melting, and certainly whilst solidification of the metal takes place. From this point of view it is of great advantage if a flux freezes after solidification of the molten



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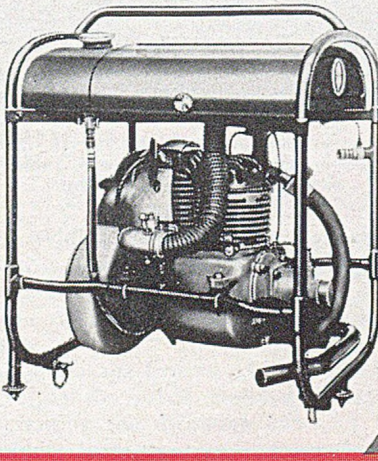

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aluminium has already taken place; in such cases the weld metal is still covered with liquid flux during the freezing period.

Accurate data with regard to the viscosity of molten steel or aluminium are not available, but comparative observations present the following picture. Molten aluminium is very fluid and has a tendency to burn through the sheet material whenever proper backing bars are not provided. Even in the case of gas welding, where temperature control of the molten pool is much easier, a more or less pronounced formation of drops can be observed on the back of a weld.

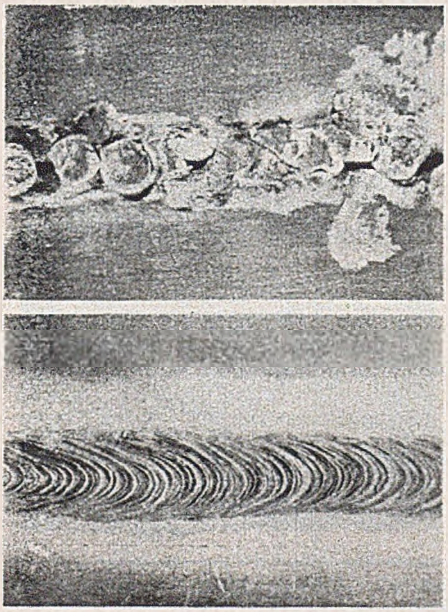

Fig. 11.—Comparison between two arc welds; above, with bare wire electrode; below, with a coated electrode.

The surface tension of the oxide layer covering the metal globules is actually preventing the dropping away of these globules from the root of the weld.

According to Portevin and Bastien, the oxide skin on the surface of molten aluminium has a strength of $2 kgs/mm^2$ (at the melting-point of aluminium). Whenever the oxide is removed by the flux (which is actually the case in arc welding), the oxide-free molten pool is very liquid and tends to flow away when the work piece is inclined.

The viscosity of molten steel is much higher and welding in the vertical and overhead positions is possible. Formation of drops underneath a steel weld is hardly ever observed.

The high viscosity of steel melts can best be shown when welding vertically up by adding successive layers of weld metal: the molten metal shows little inclination to run away.

Table 7 shows the more important physical properties of aluminium which are of influence for the welding process. The relative data for steel are also provided for comparison.

The Electrode

The coating of an electrode fulfills a purpose similar to that of a flux in gas welding. Fig. 11 illustrates the difference in appearance of a weld carried out with bare wire and with a coated electrode; it shows quite clearly that welding with bare wire is not a proposition in the case of aluminium, although satisfactory results can be obtained in the case of steel. When a bare aluminium wire is used, the arc is very often interrupted by copious oxide vapours and can only be maintained at very high temperatures. The filler material is immediately covered with a tough oxide skin and drops on to the parent material in the form of large globules. Oxide inclusions prevent a homogeneous weld.

The welding properties of an aluminium electrode depend entirely on the composition of the coating; it should be mentioned that an electrode coating has to fulfil additional requirements, apart from those required from a suitable gas welding flux. The latter should have good oxide-dissolving power, easy flow and a melting point slightly lower than that of the material to be welded. Gas welding fluxes in powder form are kept in tins and are mixed with distilled water shortly before use. A tendency to absorb water is, therefore, of no disadvantage. Whenever a gas welding flux is made up into a paste in order to prepare aluminium electrodes by the dipping process, unsatisfactory results can be expected, not only because the melting point is too low, but also because of the hygroscopic nature of the flux. Such electrodes absorb moisture from the atmosphere and, consequently, the coating flows off the core wire. Moisture containing coatings cause reaction of the molten metal with steam according to the equation: ($3\ H_2O + 2\ Al \longrightarrow Al_2O_3 + 3H_2$). The hydrogen developed is absorbed by the molten aluminium and causes porosity of the weld. Fig. 12 shows typical fractures through welds carried out with wet electrodes; the extreme degree of porosity due to hydrogen absorption is thus clearly illustrated. Experiments have shown that fluxes which are quite satisfactory for gas welding of aluminium, or its alloys, are entirely unsuitable as an electrode coating, apart from their hygroscopic properties. Excessive undercut, unstable arc, high sputter losses and irregular weld deposits are additional reasons why gas welding fluxes cannot be used for this purpose.

Table 7—Influence of some Physical Properties of Aluminium and Steel on the Welding Process.

Physical Properties	Aluminium	Steel	Influence on the Welding of Aluminium
Average Spec. heat	0.25 cal/g °C	0.11 cal/g °C.	Aluminium requires large heat input (high arc temperature an advantage).
Thermal Conductivity	0.5 cal/cm.s. °C.	0.1 - 0.17 cal/cm.s. °C.	Aluminium requires intensive heat input (for formation and maintenance of molten pool. Quick freezing of the weld.
Melting Point	658 °C.	1,528 °C.	Low melting point of aluminium requires a melting flux which freezes at an even lower temperature.
Specific Gravity at melting temperature	2.3 g/cm³	6.88 g/cm.³	Specific gravity of the flux in the molten condition should be lower than 2.3 g/cm³ to prevent trapping of slag.
Melting point of the oxides	Al_2O_3: 2,050 °C.	FeO: 1,377° Fe_2O_3: 1,565° Fe_3O_4: 1,527°	Aluminium Oxide does not melt at the welding temperature and has to be removed by means of the flux.
Boiling point	2,270 °C.	2,500 °C.	High arc temperature causes more rapid volatilisation of aluminium and consequently formation of oxides, extinguishing the arc.
Linear coefficient of expansion between 0° and 600 °C., referred to 1 m at 0 °C.	17.0 mm	8.79 mm	High thermal expansion of aluminium requires ample gap between sheets to be welded. Steep temperature gradient next to the seam prevents warping.
Surface tension of molten pool	Covered with oxide skin: 840 dyn. cm. Without oxide skin: 300 - 420 dyn. cm.	—	Flux has to remove the oxide skin to reduce surface tension of the molten pool.
Viscosity of the melt	Low	High	Thin sheets require backing bar to prevent dropping through of the weld.

The following eight features are required to produce an electrode suitable for arc welding: (1) The coating should not contain hygroscopic salts to allow satisfactory storing (moist coatings cause an unstable arc and porosity); (2) the coating should have high oxide dissolving power; (3) it should be homogeneous over the whole electrode length to ensure uniform burning; (4) it should be concentric with respect to the core wire to allow uniform deposition and easy manipulation of the arc; (5) it should adhere properly to the core wire, i.e., it should be reasonably robust, even at high temperatures; (6) the specific gravity of the molten flux should be lower than that of the molten aluminium to avoid flux inclusions; (7) the slag should easily detach from the weld and leave a light and shiny deposit; (8) the coating should be sufficiently thick to allow formation of a crater at the electrode tip, which helps in the maintenance of the arc by ionization. A thick and dense coating prevents overheating of the core wire tip.

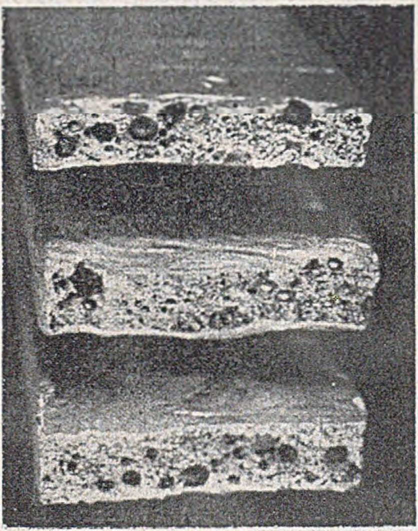

Fig. 12.—Typical fractures through welds carried out with moist electrodes coated with a gas welding flux.

The coatings of commercial aluminium electrodes contain, in most cases, fluorides and chlorides of alkali metals or alkaline-earth metals. It is of importance to note that the composition of these coatings differs considerably from that of gas-welding fluxes. Carbonates, sulphates, oxides and silicates are rarely used. The composition of electrode coatings is a matter of great secrecy, and the patent literature or any other literature dealing with the matter yield very little information.

An electrode coating should fulfil various functions. Apart from the fluxing agent proper, which can be considered as the vehicle for the oxide-removing components, which have no surface action on the aluminium in the molten state, there are other constituents which actually remove the oxides. To the former group belong the following: Sodium chloride, barium chloride, potassium bromide, potassium chloride, sodium bromide, which are compounded in such proportions as to yield a mixture of very low melting point.

Oxide-removing salts are the following: Cryolite, chiolite, sodium fluoride, potassium fluoride, strontium fluoride, lithium fluoride, magnesium fluoride.

Alkali chloride and alkaline-earth chlorides, when applied individually, do not act as oxide removers. It is, however, interesting to note that lithium chloride, in combination with small amounts of alkali fluorides, has excellent oxide-removing properties. The fact that lithium chloride and lithium fluoride, mixed with alkali fluorides, have a great dissolving power for aluminium oxide is, at the present moment, not properly understood; gas-welding fluxes or electrode coatings contain, in almost every case, lithium compounds as the active component. Sodium fluoride, cryolite and chiolite, when used with alkali or alkaline-earth chlorides, show some attack on the oxide layer in the molten state, but their activity can by no means be compared with that of lithium compounds.

Opinions about the actual process of oxide removal differ considerably. In the early stages it was generally assumed that this oxide removal is nothing else than a solution process, but recent investigations on this subject show the problem in a different light ("Light Metals," 1941/4/166). It has been found that the surface covered by the aluminium oxide is rather resistant to molten fluxes, and the term "oxide-dissolving power" is, therefore, unsatisfactory.

To determine the solubility of aluminium oxide in a flux, 30 gms. of flux were melted in a platinum crucible by heating up to 700 degrees C. under constant stirring with a platinum spatula; the gas supply of the Bunsen burner was then cut off and the flux left for 3 mins. to cool down slightly, when half of the molten flux was poured out. The analysis of the solidified flux indicated an aluminium content of 22.35 per cent.

The same procedure was then repeated, adding to the flux 1 per cent. of chemically pure aluminium oxide calcined at 900 degrees C. After cutting off the heat supply and allowing for a cooling period of 3 mins., the top layer of the melt was carefully removed by pouring at 630 degrees C. and the remaining flux subsequently analysed; only .4-.1 per cent. of the calcined aluminium oxide was dissolved by the flux.

(To be continued.)

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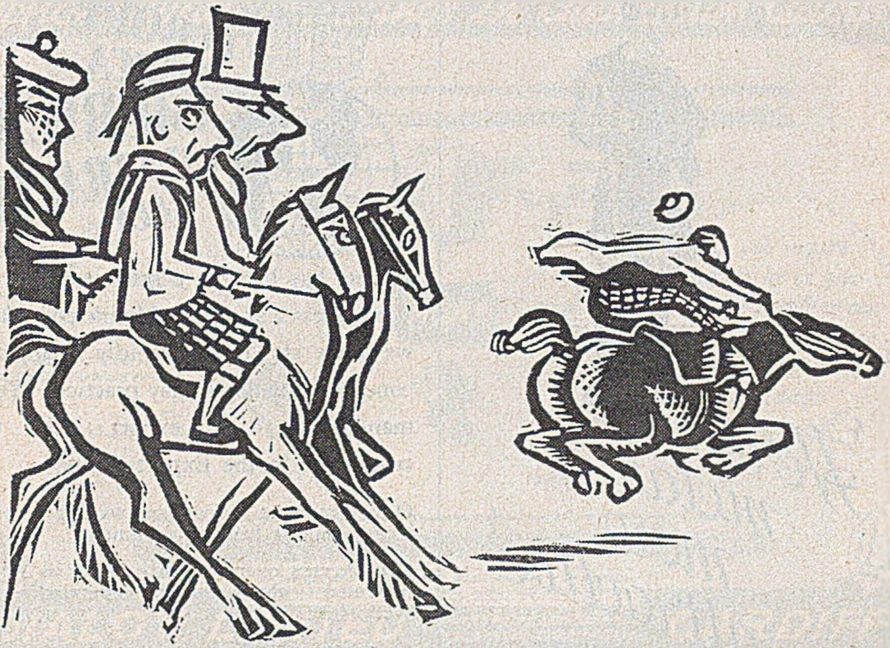


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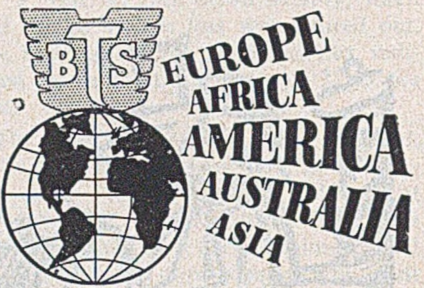
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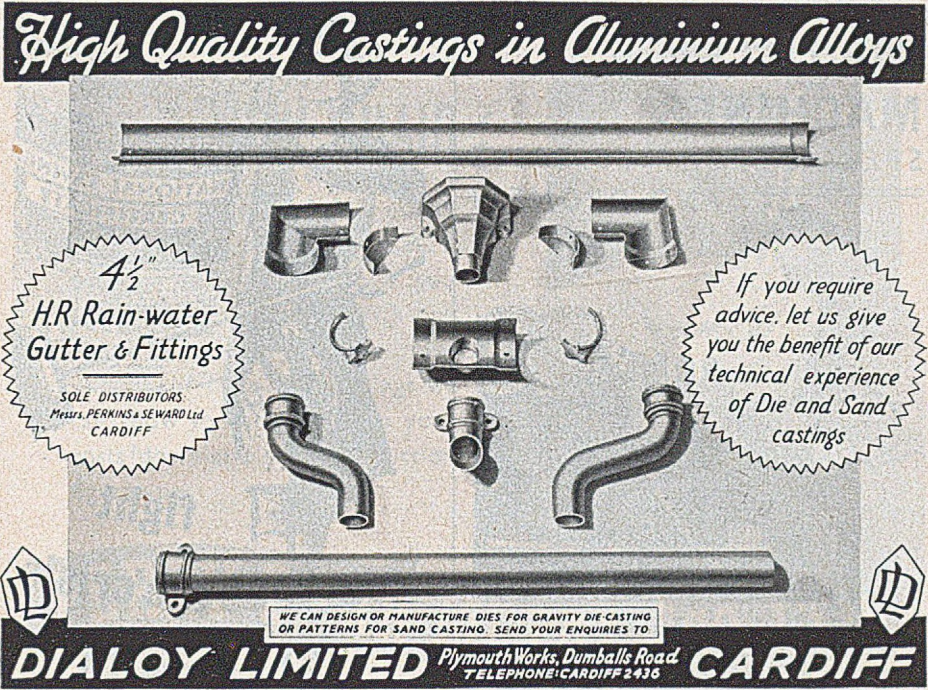

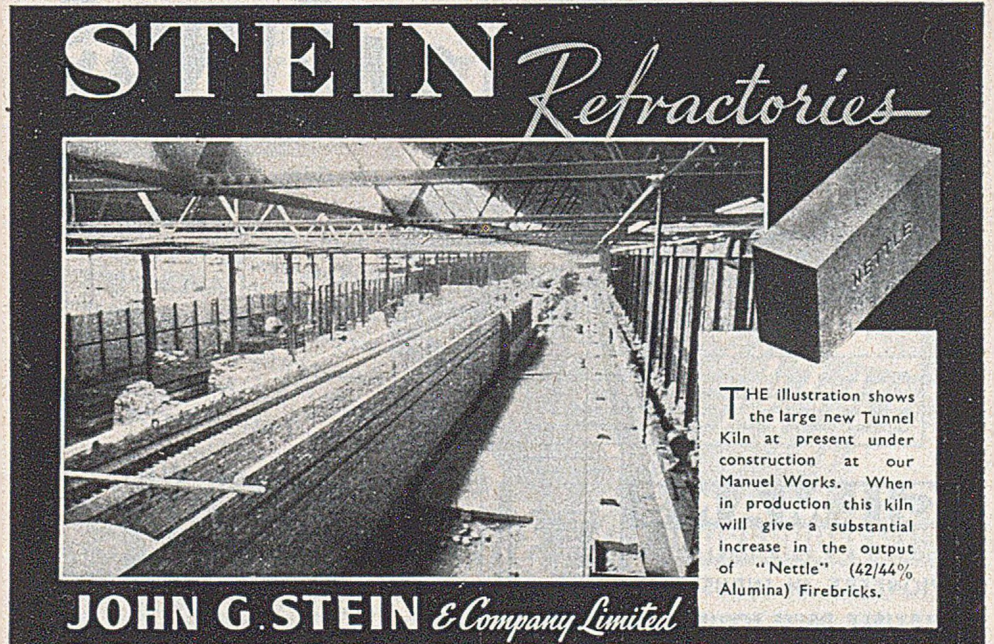

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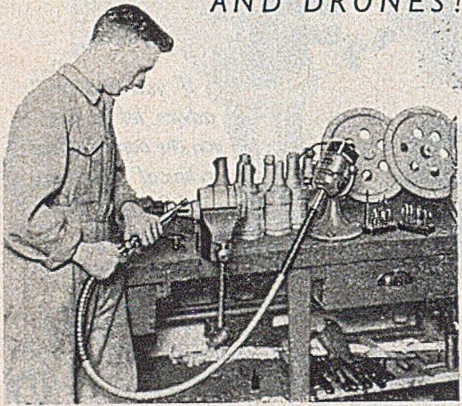

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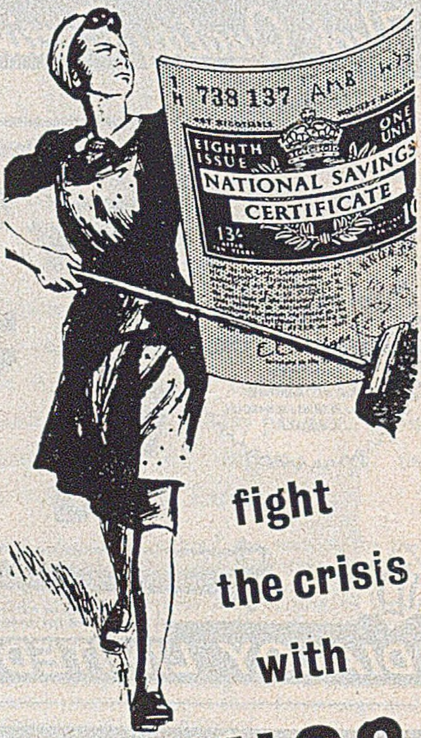

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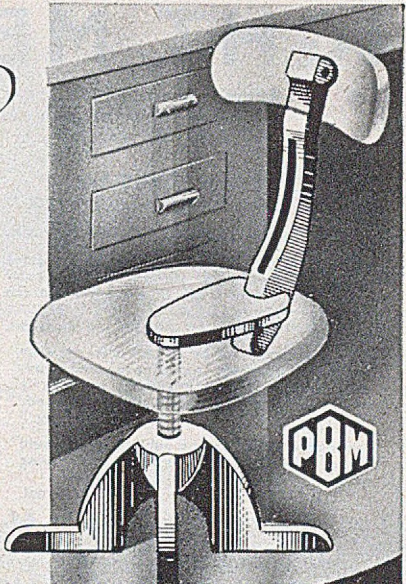
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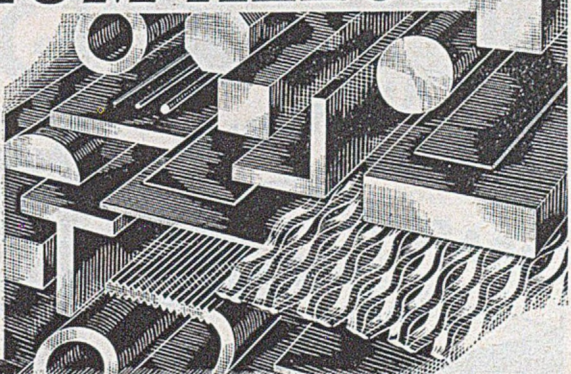

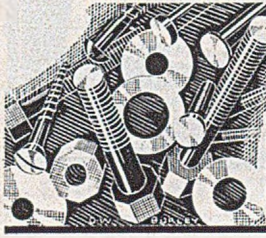

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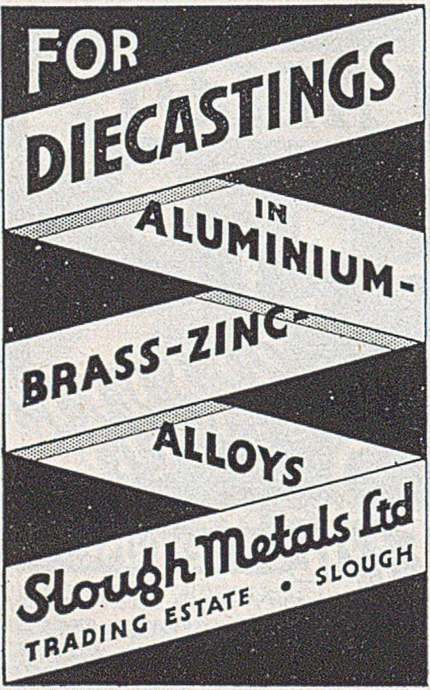

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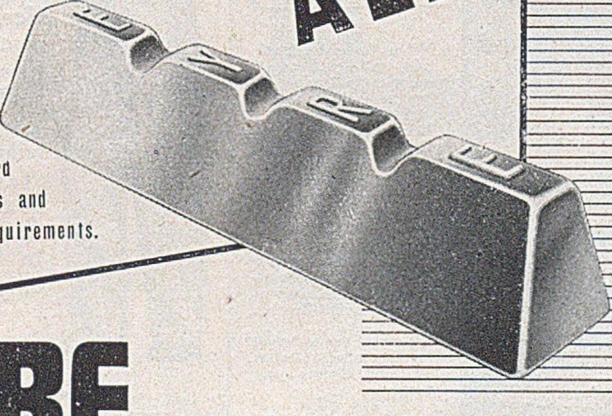
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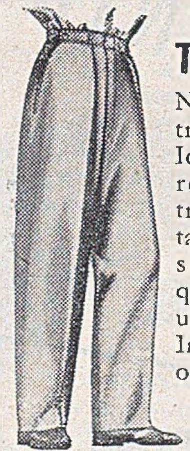

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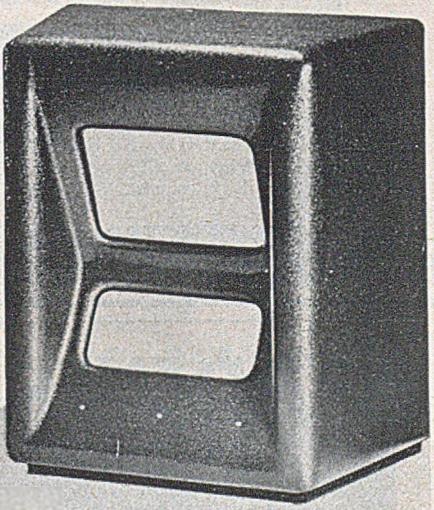

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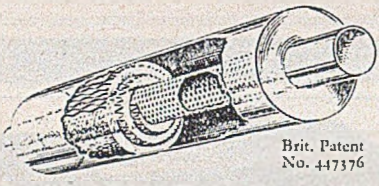

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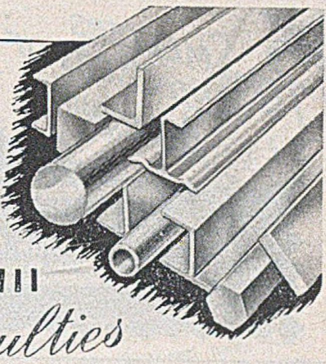

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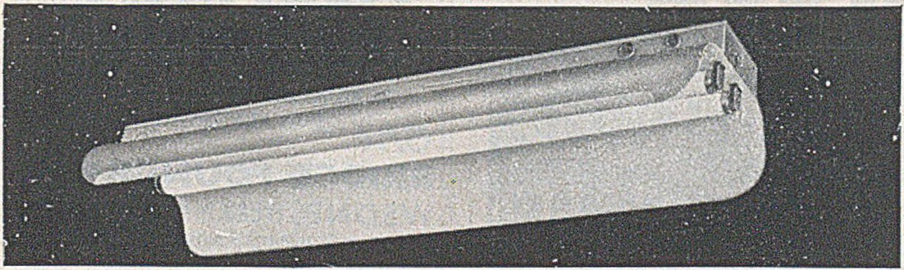

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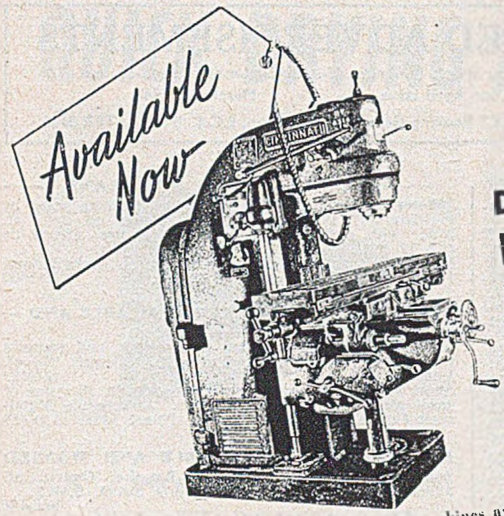

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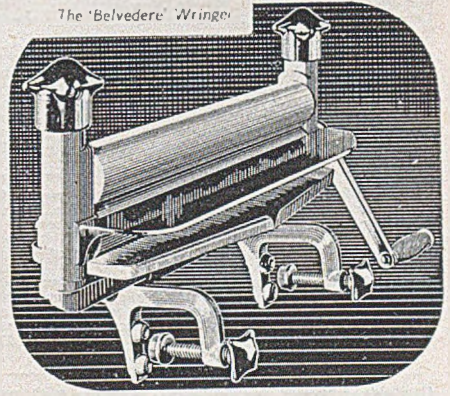

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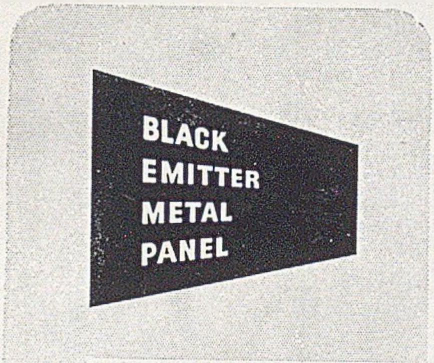

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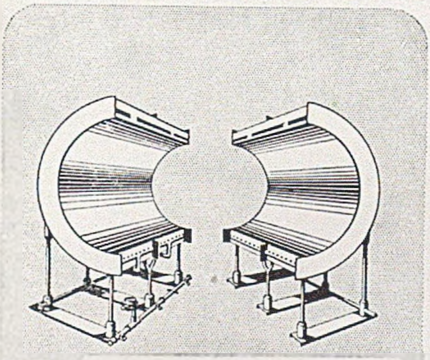

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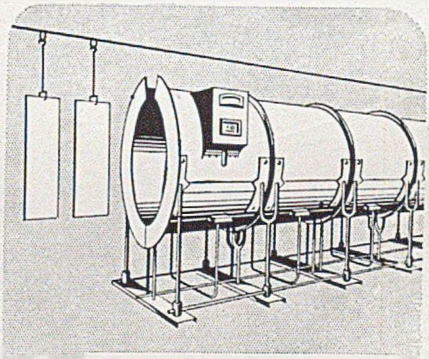

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