

SOME ASPECTS OF THE USE OF ALUMINIUM IN SUBSTITUTION FOR OTHER MATERIALS

R. T. Parker

G. L. Jones

A STRIKING development of modern industrial societies is the way in which traditional materials are progressively being replaced by new ones, such as aluminium. There are several reasons why aluminium is now contemplated or actually preferred for applications which formerly were the province of steel, copper, lead, zinc and other long-established materials. The chief reasons are availability, price and technical suitability.

The Second World War gave an immense fillip to aluminium production in all the industrial countries, so that when peace came producers were well placed to meet existing and future demands. In the event, demand soon outstripped supply, and the aluminium industry found it necessary to expand productive capacity. Some idea of the rapid post-war growth in production (and consumption) may be gained from the fact that world production rose from 700,000 tons in 1939 to 4,200,000 tons in 1959—a six-fold increase in 20 years. At this rate the output may be expected to double or treble itself in the next ten years. Plans for future expansion of the industry are based on the expectation of continuous rising demand, not only in countries already highly industrialised but also in parts of the world like India, Africa, and Latin America, which are in an earlier stage of industrial development. Furthermore, aluminium has the advantage that it is obtained from minerals which are relatively abundant in the earth's crust, and of which immense reserves are available, so that ample supplies are assured for an indefinite period ahead.

Although the price of aluminium, in common with that of most materials, has risen over the years, the increase has been less than for many other commodities, and, equally important, the price fluctuations have been small.

These two factors—assured supply and stable price—have encouraged new uses. In addition, aluminium has proved itself to be technically the best available material for many purposes. It can be obtained in a

variety of forms and a range of compositions, to give alloys with the malleability of lead or with strength exceeding that of mild steel. The metal is about one-third the weight of steel, zinc and copper, and less than one-quarter the weight of lead. The electrical conductivity heat conductivity and reflectivity are all high. Because of the thin inert oxide film which forms on the surface of the metal on exposure to the air, aluminium is extremely durable in most environments. These qualities make aluminium a natural choice for some applications and a strong rival to traditional materials for others. Finally, when all factors are taken into account aluminium is often found to be the best material to use from the economic point of view.

Many of the uses of aluminium are well known and need no mention here. In the present paper it is proposed to describe some recent and perhaps unfamiliar applications where aluminium is replacing established materials and in the development of which we at Aluminium Laboratories Limited, Banbury, have had some interest.

Aluminium cladding

During the past ten or fifteen years the use of aluminium for building has grown so rapidly that in some countries it is now one of the most important applications. A great deal of aluminium is used for interior and exterior architectural trim, alongside or in competition with other materials. More recently the metal has achieved favour for use in curtain walls, largely because of the ease with which it can be extruded into complex shapes, its good appearance, durability, and the fact that it can be anodised and then coloured by dyeing. Such uses are growing, but the main application is the cladding of industrial, domestic and private buildings. Here its chief merits are permanence, ease of handling and thermal insulating qualities. There is ample experience of aluminium as a roofing material—installations are known which have endured for 50 years or more. Aluminium is often cheaper than alternative materials. Its lightness makes transport cheaper and site work easier. Although aluminium has a high heat

Dr. R. T. Parker, B.Sc., Ph.D., A.R.S.M., F.R.I.C., F.I.M., Vice-President and Director, and Mr. G. L. Jones, B.Sc., A.R.S.M., A.R.I.C., Aluminium Laboratories Limited, Banbury, England.

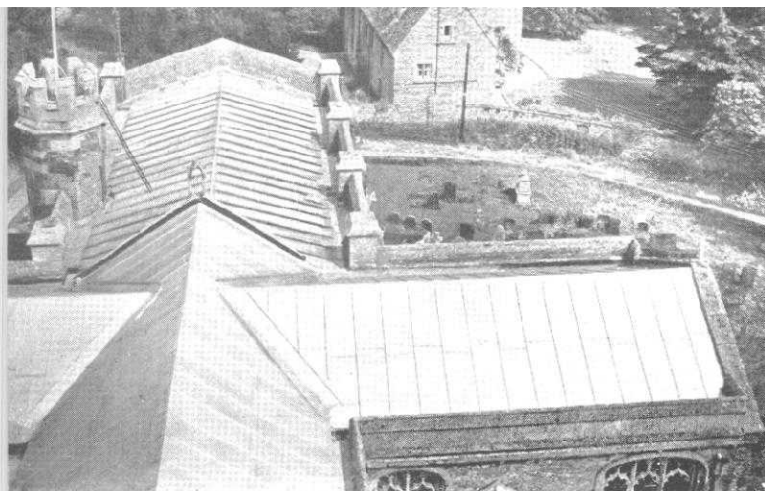


Fig. 1.
Fully-supported aluminium roof of St. Mary's Church,
Adderbury, England.



Fig. 2.
Garage roof of Noral industrial aluminium sheet.

conductivity, it is, paradoxically, a good thermal insulator when used in conjunction with an air space, because of its excellent reflectivity. Although aluminium gradually weathers in use this does not impair its insulation.

Aluminium cladding takes three forms: (1) fully supported roofing, (2) rigid roofing, (3) siding. Fully supported roofing consists of sheet in a soft grade of aluminium, laid on a continuous deck in the same way as lead, zinc or copper. The material used is

generally aluminium of 99.7% or greater purity, to ensure ready manipulation. The super-purity grade (99.99%) is almost as soft and malleable as lead, and is easily handled by the roofer. Aluminium can be laid on flat or pitched roofs, by traditional systems of covering, such as standing seam and batten and roll. It is used for the roofs of churches, hospitals and schools; in fact, wherever lead or copper would otherwise be adopted. In some instances aluminium has replaced lead with profit, the sale of the lead paying for recovering the roof with aluminium. The grades of materials used for fully supported roofing are also employed for aprons, flashings and gutters.

Rigid roofing, and siding too, nearly always consists of corrugated sheet in an alloy containing 1½% manganese to give the necessary strength and stiffness, and is laid over purlins at appropriate spacings. Corrugated aluminium sheet can be obtained in the standard semi-circular trough form, in a range of gauges, uniform with corrugated galvanised sheet, for which it can be substituted. For industrial buildings an improved roofing sheet has been developed, having troughs of truncated-V shape to limit deflection, permit greater purlin spacing and allow maintenance men to walk on the roof. This "Industrial" sheet is an economical type of cladding which has found wide application for power stations, factories, warehouses and other industrial buildings, both as roofing and as siding.

Where a closer purlin spacing can be provided another type of sheet is sometimes used, known as Mansard. This possesses wide-spaced corrugations; the rigidity is lower but is often preferred where appearance is important.

The reflectivity and consequent good heat insulation of aluminium has already been mentioned. The high reflectivity also gives improved internal lighting; this is useful in depots, warehouses, hangars and similar buildings. To enhance the heat insulation a sandwich construction can be used, or a lining, with or without aluminium foil insulation. Pre-fabricated insulated panels, ready for installation, are also made.

An interesting new development in the field of cladding systems is the introduction of Snaprib sheet. This consists of sheet corrugated at intervals, the corrugations being provided with a bead on one side lap, which snaps over a corresponding bead on the mating corrugation. Thus the sheets are secured to each other, and to their roof attachment clips, without visible fastening. A roof or wall clad with Snaprib has a good appearance and is leak-proof and easily erected. Snaprib has been installed on factories, schools, public buildings and private houses.

Lastly, it should be noted that it is possible to obtain aluminium corrugated sheet with a stucco finish to reduce sun glare and give a textured appearance. Chemical treatments can be given for the same purpose.

Electrical applications

The established material for electrical conductors is copper, whilst lead is generally used for underground

cable sheaths. Aluminium is replacing both these metals.

In industrial countries the demand for electrical energy doubles every 8 to 10 years. The corresponding demand for copper can only be met by bringing less profitable sources of supply into use. Thus in recent years the price of copper has advanced at a higher rate than that of aluminium, and the fluctuations in price have been much more severe. Aluminium has therefore become attractive as a substitute.

Aluminium has an electrical conductivity about 60% of that of copper, and a density of about one-third, so that for the same resistance the area of an aluminium conductor is about 1.6 times that of a copper one, but it has only half of the weight. This enables aluminium conductor to compete with copper on favourable terms, in spite of the fact that fabrication costs are higher per pound of aluminium (because conversion is on a volume basis). The cost of bare stranded aluminium wire for overhead distribution is about 50% that of copper, and it is not surprising that most high voltage overhead distribution lines throughout the world are now in aluminium, either steel reinforced (A.C.S.R.) or alloy.

There is long service experience with aluminium overhead conductors, which can now be regarded as fully established; the annual consumption of aluminium for high voltage transmission lines in U.K. alone is about 6,000 tons.

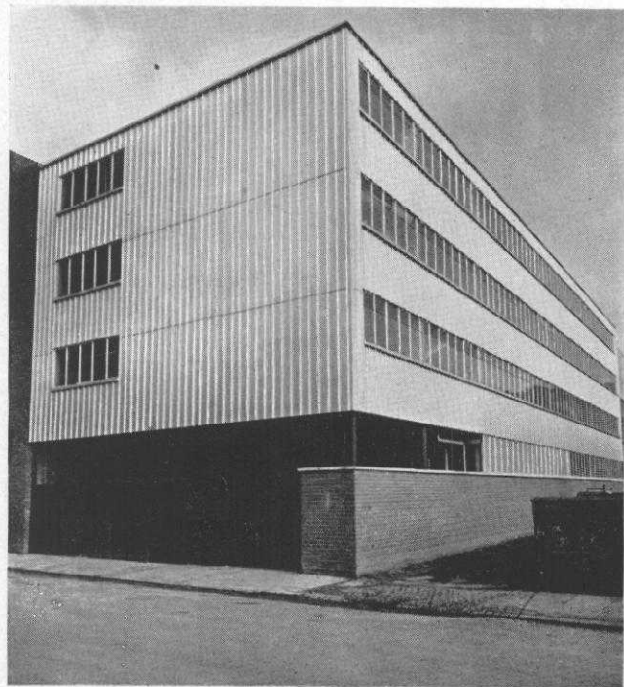


Fig. 3.
Warehouse clad with Snaprib sheet.

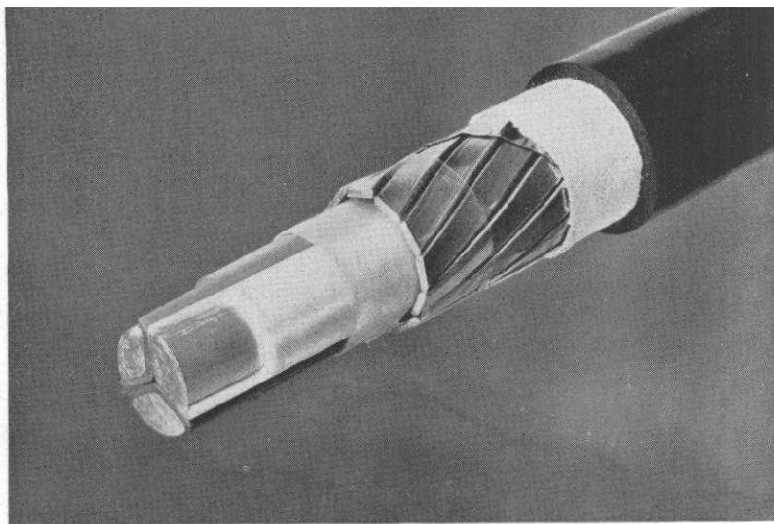


Fig. 4.
Solidal three-cored cable with concentric neutral.

Bus bars are another example of an application where aluminium is an obvious choice. Although for a given current carrying capacity an aluminium bar is larger than a copper one, it is cheaper, and, because of the lighter weight, easier to instal. Whilst aluminium of 99.5% purity is satisfactory for many purposes a stronger material, containing $\frac{1}{2}\%$ each of magnesium and silicon, with a slight loss of conductivity, is often to be preferred. In wire form this alloy is suitable for conductors in overhead transmission lines. The chief resistance to aluminium bus bars, as in so many other instances, is the natural conservatism of the user.

The high and variable price of copper, and the doubtful supply position have encouraged cable manufacturers and users to turn to aluminium both for conductors and sheaths (where it replaces lead). Most of the important makers in the U.K. can now offer aluminium-sheathed cable. Aluminium-sheathed cable is stiffer than lead-sheathed (though this can be remedied by using corrugated sheaths) and requires external protection in the form of a covering of P.V.C. or similar material. It is, however, lighter, and able to withstand severe vibration. Aluminium, unlike lead, is not easily extruded cold, even in the soft grade normally used, and in view of this other methods of sheathing are used, in addition to direct extrusion over the core. In one method the core is inserted in an oversize sheath, which is then drawn down to form the complete cable. In another, a tube is progressively formed from strip round the core and the seam is continuously welded.

Aluminium is sometimes regarded as having only a marginal advantage for insulated cable sheathing, but if the sheath is used as a concentric neutral conductor the saving in cost is clear. In high-voltage gas-filled cables the aluminium sheath also scores because it is strong enough to be used without steel reinforcement.

Aluminium can be used for the stranded conductors of underground distribution lines, but because of the larger cross-section required the saving in cost only becomes substantial in large sizes. The overall size



Fig. 5.
Solidal cable being installed underground.

can be reduced by using shaped conductors. The logical conclusion to this is the development of a cable consisting of solid conductors surrounded by insulation. Solidal, developed by the Alcan group of companies, is such a cable. It is based on solid, sector-shaped conductors of fully-soft aluminium, insulated by an extruded P.V.C. coating.

The conductors are laid up with a right-hand lay, and lapped with P.V.C. tape. Outside this is a single layer of rectangular hard aluminium wires applied with a left-hand lay, and having a total cross-sectional area equal to that of one of the cores. These wires provide a screen of low electrical resistance and high mechanical strength which also serves as a neutral conductor. Solidal is economically most attractive when used as a three-core cable with concentric neutral. Over the neutral armour wires a tape of aluminium foil may be laid to equalise current distribution in the wires. The outer covering is an extruded sheath of P.V.C.

Solidal is cheap, light and easy to handle. It withstands bending to small radii and re-straightening, and is easily joined by soldering or mechanical methods. Although relatively new, Solidal has already been installed in underground distribution lines in England, Italy and Switzerland. There is a large potential market.

One of the most interesting electrical developments is the use of aluminium for windings of transformers. Because of the larger cross-sectional area required, insulated aluminium wire has no great advantage over copper for the windings of electrical machines. However, if aluminium strip or foil is used as the conductor, the aluminium winding takes up no more space than that of a conventional winding of copper wire. Coils of aluminium strip or foil are easy to insulate and wind, whilst integral insulation capable of withstanding elevated temperatures may be provided by anodising the strip—a feature unique to aluminium. Welding

transformers and motor horn coils have been constructed with aluminium strip windings, and such applications may confidently be expected to increase.

Canning

When considering the possibility of using aluminium for food cans it is worth remembering that tin at one time gave its name to tin-foil, yet nearly all "tin-foil" made nowadays is in fact aluminium. Again, milk bottles were formerly capped with cardboard discs. For hygienic reasons these discs have been replaced by caps of aluminium foil; the annual consumption of aluminium for this purpose in U.K. is 5,000 tons. It should also be noted that the world consumption of tinplate—the chief canning material—was 7 m tons in 1955. If even a small proportion of this were replaced by aluminium it would represent a large usage of the metal. When utilised in the country of origin, tinplate is cheaper than aluminium as a canning material, but for certain packs, especially in countries which have no domestic tinplate supply, aluminium is able to compete on technical merit or cost, or both.

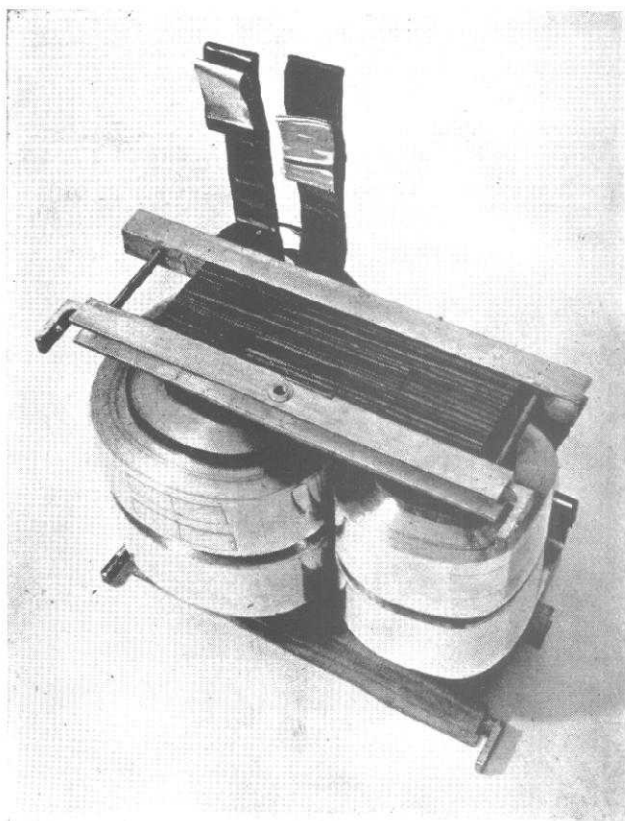


Fig. 6.
Welding transformer with aluminium foil coils.

At present aluminium cans are used in Norway, chiefly for packing fish (1,200 metric tons were used in 1956), in Switzerland and France for condensed milk, in Germany for beer, in U.S.A. for aerosols, beer and oil, and in England for aerosols and oil. The greatest usage of aluminium for cans is in Norway, where the metal goes into some 15% of all cans.

As a canning material tinplate has a background of development extending over more than a century. The aluminium food can is largely a post-war phenomenon. It is not therefore surprising that the introduction of aluminium for cans has required the solution of certain problems. Gauge for gauge, aluminium is less strong and rigid than tinplate, hence much attention has been devoted to the design of cans, and the development of canning alloys. Processed foods generally require the use of an internal lacquer to give an acceptable shelf life, since the oxide film cannot re-form itself if attacked by the contents of the can, or if defects are present. In Norway fish cans are produced from continuously anodised and lacquered strip. The anodic film, though thin, is thicker than the natural oxide film, and together with the lacquer, gives excellent protection and adequate shelf life. The cans are shallow drawn from an alloy containing silicon and magnesium to give sufficient strength.

Shallow aluminium cans, such as are used for fish, are produced by pressing from flat stock which may have been previously anodised, lacquered and printed. Deep cans are made by: (1) forming and seaming a cylindrical body from strip, and then seaming-on the two ends; (2) adding ends to a tube body; (3) deep drawing the body, and seaming-on the lid; (4) impact extruding the body and seaming-on the lid. The first method is used in the manufacture of tinplate cans, but like the second, is seldom adopted for aluminium. Because of its excellent working qualities aluminium lends itself well to impact extrusion and to deep drawing (with or without ironing) and most effort has been concentrated on these processes. We, at Aluminium Laboratories Limited, have been investigating both methods of production. We have also investigated the types of alloy suitable and the problems associated with the can-making processes, such as lubrication, degreasing and lacquering, and we have carried out extensive packing tests. These researches have shown that satisfactory aluminium cans can be made on a production basis, and that they are suitable for packing a large variety of foods and other products.

Rotary strip casting

Aluminium cans have certain technical advantages over tinplate—they are lighter and have a better appearance—but in countries where can-making is based on a domestic tinplate supply they are seldom competitive. However, when a small output is contemplated—say, less than 30 m cans per year—the lower capital outlay required for making aluminium cans is attractive. Moreover, it is possible for the can-maker, by installing appropriate melting and casting equipment, to produce the raw material (strip, or



Fig. 7.

Norwegian vegetables canned in aluminium. The cans are shallow drawn from anodised and pre-lacquered alloy sheet.

impact extrusion slugs) and convert it into cans, all in a single plant. Within recent years several processes for continuously converting virgin metal into strip have been developed which require only a small capital investment and which can easily be incorporated in a can-making (or other) plant. They include the Rigamonti, Properzi and Rotary Strip Casting processes, and the Hazelett process. The latter is under development by our associates at Aluminium Laboratories Limited, Kingston. It is based on a machine consisting of two opposed water-cooled moving endless metal bands, enclosing a slab-shaped space into one end of which molten metal is poured, whilst the solidified strip emerges from the other. We, at Aluminium Laboratories Limited, Banbury, have been engaged in the development of a Rotary Strip Casting process using a machine comprising a rotating water-cooled wheel having on its periphery a groove closed over part of the circumference by a steel band (also cooled) so as to form a mould. Molten metal is fed into the mould near the top of the wheel, and the solidified slab emerges at the bottom. The Properzi and Rigamonti machines operate on much the same principle but differ in details. The former produces rod for drawing into wire; the latter, rolling slab. At Banbury we now have a machine capable of producing slab 8 in wide and 0.75 in thick at the rate of 6 tons per 8-hr shift. Molten metal is provided by two oil-fired reverberatory furnaces, one a lip-axis-pouring type of 1,000 lb capacity and the other a fixed tap hole type holding 2,500 lb of aluminium. The slab from the casting wheel is taken direct to a hot-rolling mill where it is reduced to 0.375 in thick. It is then drum coiled for stocking, used for the production of impact extrusion slugs or cold rolled to thin strip. Besides developing the machine from a series of prototypes (the present production machine is No. 6) we have investigated the effect of important variables such as the metal distribution system and the cooling conditions, and have also carried out tests for metal quality. Commercial purity slab produced on the machine has been found to be completely satisfactory

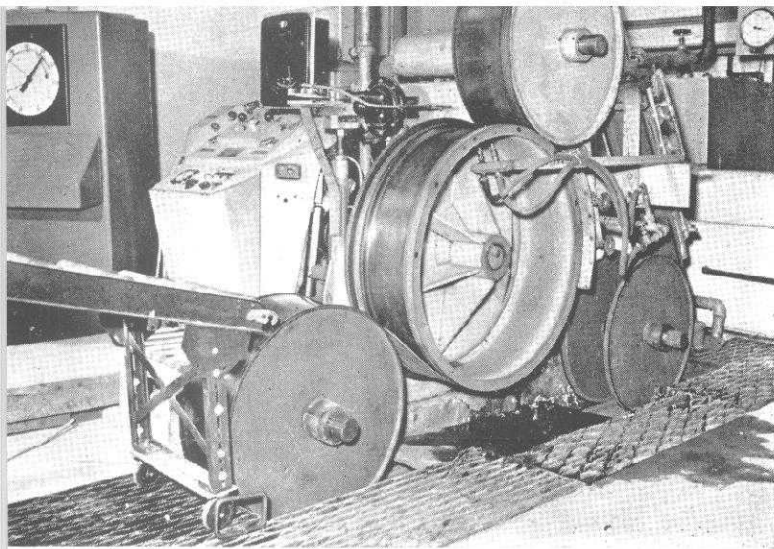


Fig. 8.
Rotary Strip Casting machine at Aluminium Laboratories
Limited, Banbury, U.K.

DISCUSSIONS

Dr. T. Banerjee, NML: Recently, the question of using aluminium cans for canning purposes has also been taken up in India. Because of the controversial data that we are getting regarding the canning of fish, we have not yet come to any final conclusion. Before more experiments are planned, furnishing of some data, regarding corrosion of aluminium in fish, especially those containing good amount of fat, by the author will definitely be helpful.

Mr. G. L. Jones (Author): Our associates, A/s Nordisk Aluminiumindustri, have a great deal of experience of aluminium sardine cans, and since 1951 they have successfully used anodized and lacquered sheet for this purpose. An alloy designated as C3S containing 0.4-0.6% Mn, 0.2-0.3% Si and 0.3-0.4% Fe, an anodic film 0.4 microns thick and a lacquer coating of 3 gm/sq m film wt have been found to be satisfactory for packs with a pH of 5 and over.

At Aluminium Laboratories Limited, Banbury, we have for some years been carrying out storage tests of aluminium sardine packs under normal room and accelerated (hot room) conditions using sardines from

for impact extrusion slugs. We are currently investigating the optimum conditions for production of slab in certain alloys. Rotary Strip Casting machines are in commercial operation, producing impact extrusion slugs in integrated plants in the U.K., and Rigamonti and Properzi machines are also in use in various parts of the world.

Conclusion

In conclusion, it is worth noting that aluminium is used most successfully as a substitute for other materials when its characteristic qualities are fully exploited. This may require a modification of manufacturing technique (as in making aluminium cable sheath), a new design of product (such as Solidal cable, Industrial sheet, and Snaprib) or the exploitation of fabricating possibilities such as deep drawing or impact extrusion. If fresh thinking is applied to the problems which arise and the many good qualities of aluminium are taken advantage of, the metal is able not only to compete with, but often replace, those which are familiar to us by traditional use.

various sources, caught at different times of the year.

The results of one such test may be of interest. Sardines from the Malabar coast, caught in November 1958, were deep frozen in India, flown to England and packed in aluminium cans within 36 hours of being caught. The cans were subjected to storage tests at 70°F and 95°F. The tests are continuing and present results suggest that a shelf life of 4 to 5 years at 70°F should be obtained.

Mr. D. V. Paranjpe, TISCO Ltd, Jamshedpur: I would like the authors to throw light on the thermal properties of aluminium with reference to its use as a material for manufacture of tuyeres for use in blast furnace.

Mr. G. L. Jones (Author): Aluminium has a lower melting point than copper (658°C for commercially pure metal, compared with 1,083°C for copper) and a thermal conductivity about 55% of that of copper. Although its thermal properties are less favourable than those of copper, it has been used for blast furnace tuyeres both experimentally and in production. An account of experience with aluminium tuyeres is given

in *Revue de l'Aluminium*, April, 1946 (an abridged version of this article appears in *The Iron Age*, October 10, 1946). This account indicates that although failures have occurred in some installations, there is also successful experience, suggesting that when properly used aluminium is a satisfactory material for tuyeres.

Mr. Narinder Singh, NML: I would like to know from the authors whether the "Solidal" cables containing three solid aluminium conductors possess sufficient tensile strength to stand the stresses, as aluminium conductors should have less tensile strength compared to the stranded copper wire conductors.

Mr. G. L. Jones (Author): In regard to Solidal cable, Mr. Narinder Singh is, of course, right to point out that the tensile strength of the conductors is somewhat lower than that of the equivalent copper conductor. This is also true of stranded aluminium conductors and there has not been found a drawback in any of the thousands of miles of aluminium underground cable installed all over the world.

There are three conditions where the mechanical strength of a cable is of importance:

(a) *Ground subsidence*: Under these conditions the stresses on the cable are so large that the small differences between aluminium and copper

are of no significance. It is important to design the system so that any failure occurs at a joint, as this makes repair work easier.

(b) *Short circuit*: It is well known that very high mechanical forces are imposed by short circuit—often enough to burst lead-sheathed cables. Tests on Solidal cable by the Electrical Research Association in England have shown that, in contrast, it is unburstable under short circuit, due mainly to its good design and the restraining effect of the Melinex binding tapes.

(c) *Expansion and contraction*: Tests have been carried out at Aluminium Laboratories Limited to examine the effect of expansion and contraction in Solidal cable. They have shown that the elasticity of the cable is more than adequate to take care of the stresses imposed by temperature changes much higher than any likely to be encountered in service.

In conclusion, we can say without hesitation that the Solidal cable has been subjected to a complete and exhaustive evaluation both in the laboratory and in the 15 major installations carried out over the past two years. The consensus of opinion of cable makers and users is that this new concept in cable making is one of the most important developments of the century.

