Aluminium in engineering

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SYNOPSIS

The paper reviews the uses and scope of application of aluminium in India in various engineering industries like transport industry, construction of railway coaches and wagons, automobile, machine tool, heavy electrical, mining and textile industries.

ALTHOUGH far more recent in origin than copper, zinc, lead and tin, aluminium has become the most widely used non-ferrous metal. This is particularly evident in India where its growing popularity is partly due to the non-availability of these other metals. But, on its own merits too, aluminium has come to stay as its unique combination of properties makes it the ideal choice in a variety of applications.

Until not so long ago, aluminium was considered suitable in India only for pots and pans. In recent years, however, the picture has changed markedly and today the metal is made use of in almost every industry imaginable. One major factor which has brought about this change is the development of a remarkably wide range of aluminium alloys having various combinations of mechanical strength, ductility, electrical conductivity and corrosion resistance. Currently, nearly 20 different alloys are being produced in India in wrought form alone, i.e. as rolled or extruded products, while an equal number is available as castings. The range of proof (yield) stress extends up to 42·5 kg/mm^2 (27 tons/in^2) which is greater than that of structural steels. Newer and more sophisticated alloys are constantly being introduced and one recent development of interest has been a 'self-ageing' aluminium-zinc-magnesium alloy which regains its mechanical properties after welding.

The availability of aluminium and its alloys in a variety of forms, and the ease with which they can be worked upon, are further attributes which have made their adoption so widespread. The extrusion process provides, in particular, unusual advantages for designers and manufacturers. Creating wide scope for ingenuity of design, extrusions offer many features not available in rolled shapes, like re-entrant angles, variable thicknesses and hollow sections, and a single extrusion can often replace an assembly of rolled sections, eliminating a considerable amount of jointing. Substantial economies can, therefore, be realised by the ability to position the metal in a section where it matters most.

The engineering industry is one of the foremost users of aluminium and within it—leaving aside the cable and conductor industry which is not dealt with in this paper—the transport industry leads the rest since the metal's high strength-to-weight ratio can be best employed here. This paper, while outlining the various uses of aluminium in the engineering industry, deals therefore with transport applications at some length before covering the other areas. Further, since it would be less meaningful if one were to merely list where aluminium has been used abroad, all the applications quoted here pertain to what has been adopted already or considered hitherto in India.

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Transport industry

Air

The most striking example of the use of aluminium in the transport industry is the aircraft body. The primary considerations weighing with aircraft designers in adopting aluminium alloys are—as mentioned earlier—the high strength-to-weight ratio and excellent corrosion resistance they afford. Aluminium being consistently specified for this application for more than six decades makes further elaboration unnecessary. The sheets, sections and castings which go to make up the body are, for obvious reasons, required to meet very stringent specifications. High strength 'alclad' aluminium-copper alloy sheets to Indian Standard IS : 3436-1966 (Specification for aluminium clad aluminium alloy sheet, strip and coil for aircraft purposes) and castings to IS : 202-1966 (Specification for aluminium casting alloy ingots and castings for aircraft purposes) are at present being produced indigenously, while trial production of aircraft quality extrusions is being taken up shortly.

Road

The objective of a reduced dead-load, without affecting the strength of the body, which principally figured in the use of aluminium in aircraft, has also led the road transport industry to use aluminium in a whole range of vehicles. The alloys normally employed in this field while not needing to meet the high-strength requirement of the aircraft industry, have mechanical properties very nearly those of structural steel. These medium-strength aluminium-magnesium silicide and aluminium-magnesium alloys are specified in IS : 733-1967 (Specification for wrought aluminium and aluminium alloys, bars, rods and sections) and IS : 737-1965 (specification for wrought aluminium and aluminium alloys, sheets and strips). Bodies of public transport buses, trucks, vans, tankers, tippers and dumpers are now being built in aluminium. The dead-weight reduction achieved, in the case of a single-deck bus with an aluminium body, is about 750 kg when compard with the same body in steel. This results in reduced tyre wear (about 15%), brake wear (about 12%), wear and tear on springs, shock-absorbers, etc. and—what is significant—reduced fuel consumption.

It is estimated that for a run of 40 000 km the savings on diesel oil alone will come to Rs 750/- per bus. Besides leading to appreciably lower operating costs, aluminium bodies are, by virtue of their excellent corrosion resistance and shock-absorbing capacity, far easier to maintain than steel or timber bodies. Several state transport undertakings in India, notably those in Maharashtra, Gujarat, Andhra Pradesh, Mysore, West Bengal and Delhi, have now standardised on all-aluminium buses and more than 10 000 such aluminium-framed buses are at present running in the country.

Saving in weight in goods transport vehicles can be taken advantage of in a more direct way, since this can straightaway be translated into a greater available payload—and hence enhanced revenue. Several aluminium-bodied trucks and tippers are giving excellent service all over the country. Road tankers, meant for transport of petroleum products, offer another example where light-weight construction can lead to substantial economies. Over 200 aircraft refuelling tanker bodies have been made in aluminium and are now being satisfactorily used in both military and civilian airfields. In this application, the metal's inertness to fuel oils is also a decided advantage.

The tough serviceability of some of the aluminium alloys is best appreciated by their use in aluminium rock dump bodies. Dump bodies are used for the haulage of ores, overburden and rocks in the mining industry. The body, as such, is expected to stand up to a high degree of impact loading and abrasion resistance. Two 15 cubic-metre capacity dumpers with aluminium bodies were commissioned in the bauxite mines of the Indian Aluminium Company Limited nearly 2 years ago. These rugged light-weight dumpers have an increased payload capacity of a straight 35%, thus cutting down by a quarter the number of trips originally required for the same haulage. This has resulted in considerable savings in the operating costs of these units. Both bodies were fabricated from indigeneous aluminium-magnesium alloy plates up to 65 mm thick, which were welded with semi-automatic inert gas metal-arc welding equipment.

Rail

Wide use of aluminium alloys has also been made in railway rolling stock, the reason for their adoption being again their light weight and remarkable durability. In passenger coaches, aluminium was first specified in India as far back as 1928 for the panelling of narrow gauge coaches on the Simla-Kalka line. Later, aluminium panels were standardised by the Indian Railways for all the timber bodied coaches that were then being built by the Railway workshops. With the advent of the all-steel coaches of stressed-skin design produced by the Integral Coach Factory, Perambur and Bharat Earth Movers Limited, Bangalore (previously Hindustan Aircraft Limited, Rail Coach Division), the use of aluminium for panelling was discontinued; however, large quantities of the metal are employed for the windows, doors, vestibules, seat frames, luggage racks, roof water tanks and battery-boxes in these coaches, the requirement per coach being 1½ to 2 tonnes. Flooring of coaches with aluminium chequered plate has also been standardised for Electrical Multiple Unit stock, as saving in weight is particularly important in inter-urban and suburban runs where frequent starts and stops have to be made. A lower mass needing to be accelerated or decelerated can lead to a direct reduction in operating costs. For the same reason, aluminium is actively being considered by the Railways Research Designs and Standards Organisation for the entire structure of diesel railcars. It has been estimated by them that the lowering in tare weight is likely to be as much as 7 tonnes per railcar coach, leading to a saving in fuel costs alone of nearly Rs 3000 every year; taking interest charges into account, it has been worked out that extra cost of the aluminium coach will be made good in just 2·1 years.

The use of aluminium in railway goods wagons has been equally extensive and aluminium panelling and flooring have been used with great success in 'KC' open-sided wagons in the Assam area for the transport of high sulphur-content coal, in the 'HS' wagons employed by the Calcutta Port Commissioners for carrying cinders and ash and also in 'CMR/A' wagons meant for transport of cattle. Resistance to corrosion is of particular importance in these applications and steel wagons under similar service conditions have badly suffered attack. Other significant examples are refrigerated vans, used for the transportation of fish, fruit and other perishables, in the construction of which aluminium has been employed to a very large extent—nearly 7 tonnes per van. This, in fact, has been the first structural application of aluminium in Indian rolling stock. The Indian Railways have also made a prototype 'CSR' wagon with an alumiuinm 'swing roof' which will permit overhead loading of goods, while trials with aluminium bulk-heads designed to compartmentalise the large 'BCX' covered wagons and aluminium sliding doors for these wagons have been proposed. Designs have also been made by them for tank wagons with aluminium barrels for the transportation of petrol and heavy oils; weight restrictions with steel barrels currently being used have made it difficult to fill the tank wagons to their full capacity. In a 'TPR' tank wagon, for example, the use of an aluminium barrel can bring about an increase in permissible payload of 3 tonnes, and the resulting additional revenue, together with savings on empty haulage, will amount to over Rs 4 000 annually. Many other similar applications are being thought of and it is hoped that before long the Indian railway network will boast of as many light alloy coaches and wagons as are in service in the more advanced countries.

Marine

Aluminium is particularly suited for marine applications on account of its outstanding resistance to corrosion by sea water. Unlike wood, aluminium does not absorb water, is not subject to attack by marine organisms, and is free from internal flaws originating from non-homogeniety. Compared to steel, on the other hand, aluminium does not rust ; hence little or no "corrosion allowance" need be given during the design stage—something which is unavoidable in the case of steel. Further, aluminium can be used in the unpainted condition while steel must always be kept painted. Besides these attractive features, aluminium's high resilience (three times that of steel) permits it to absorb shocks and easily withstand the stresses and strains encountered, for instance, in rough waters.

For marine applications, aluminium-magnesium alloys are invariably used because of their very high resistance to corrosive attack ; these alloys are also extremely tough. Marine alloys meeting the exacting requirements of the Lloyd's Register of Shipping have been produced in India for several years now.

Taking advantage of aluminium's properties, a large number of small boats have been made abroad entirely in this metal. These light-weight boats are easy to maintain and cost little on upkeep ; they can also operate in relatively shallow waters, since the reduction in weight means a reduction in draught. Such small boats in aluminium have not yet become very popular in India, although a recent development has been the Kerala Government's consideration of a scheme to set up an aluminium boat building yard with Hungarian collaboration for inland water transport and fishing boats. Aluminium sheathing of boat bottoms, in place of copper, has meanwhile been adopted with great success in Kerala and Madras in fishing fleets.

Aluminium has been extensively used abroad for the superstructures, funnels and life-boats of large passenger vessels. Three modern British ocean liners, the Oriana (40 000 tons), the Canberra (45 000 tons), and the Queen Elizabeth II (58 000 tons) have each employed over 1000 tonnes of aluminium. With lighter superstructures, the centre of gravity is effectively lowered, affording greater stability and—what is often overlooked—significant savings in driving fuel. In view of these advantages, the Hindustan Shipyard, Visakhapatnam, are considering using aluminium for the top decks of the passenger ships which they plan to build in the near future for the Shipping Corporation of India.

Yet another very promising application is the aluminium shipping container. The Shipping Corporation of India have recently introduced 4 aluminium refrigerated freight containers in their ships. Movement of freight in containers results in very significant economies to shippers by way of drastically cutting down on the labour and time involved in freight operations. Aluminium containers have proved superior to containers made of other materials as they have the requiste strength, are lighter by about 50% and outlast the others in durability.

Automobile ancillaries

Since weight saving has been the over-riding concern in all transport applications, it is only natural that increasing use of light alloys is being made for automobile components. The adoption of aluminium for the pistons of all types of engines has of course become well established ; the light metal has now been extended to connecting rods, cylinder heads, cylinder blocks, crankcases, transmission and clutch housings, induction manifolds, water pumps, cam-shaft covers and steering boxes. Almost all of these are castings and the alloys used for them are many and varied—containing silicon, magnesium and manganese for the lightly stressed parts, and copper for higher strength components. For pistons and cylinder heads, nickel is also added to impart high-temperature strength properties.

The attractive appearance of aluminium, which can further be enhanced by anodising, has also led to its being used in increasing quantities for automotive trim, such as front grilles, wheel hub caps, headlamp bezel, body trim, door handles, window and windshield frames, instrument panel boards and bumpers.

A development of far-reaching importance is the use of aluminium for automobile radiators, for which copper and brass are currently employed. One of the major problems in switching over to aluminium has been that of joining the tubes to the fins by a cheap and easy method, but this appears to have recently been solved by Ford and General Motors in the USA. With the critical shortage of copper and zinc in India, this application is of particular interest to us and it is expected that before long aluminium radiators will be introduced in this country. Some steps in this direction have already been initiated.

Airconditioning and refrigeration

As in automobile radiators, the excellent thermal conductivity of aluminium makes it eminently suited for heat exchangers, like condensers and evaporators, in the airconditioning and refrigeration industries. Replacing copper, first for the fins, then for the tubes themselves, aluminium evaporators are now used in almost all refrigerators, only the type of construction varying from make to make. Joining problems faced in the early stages of this development have been satisfactorily solved, due also in some measure to the efforts of the Central Mechanical Engineering Research Institute, Durgapur. The small-diameter thin-walled aluminium tubing suitable for evaporators is also being produced now indigenously.

Aluminium ice trays and shelves are also standard equipment in refrigerators, while—for decorative purposes—anodised aluminium is widely used for the body trim in both refrigerators and airconditioners.

Bearings

An outstanding use of aluminium is in anti-friction bearings which have, till recently, been made exclusively out of copper-lead, white metal, leaded bronze or phosphor-bronze, depending on the particular end-use in view. Extensive trials have established that aluminium-tin alloy bearings, either in the solid or backed condition, have properties very much superior to those of some of the conventional bearing materials. This directly derives from the alloy's extremely high fatigue and corrosion resistance, excellent embeddability, conformability and very good machining qualities. Solid aluminium alloy bearings are successfully being used in the machine tools manufactured by Hindustan Machine Tools at their various plants, which they estimate will save them 90% of the foreign exchange previously spent on this account. The Traction Divison of Heavy Electricals (India) Ltd., Bhopal, are now considering the use of similar solid aluminium bearings in their heavy-duty traction motors in place of the present babbitted-bronze bearings.

Where space is a limitation, steel-backed aluminium bearings offer an equally high degree of performance. Kirloskars in Poona are marketing reticular tin-aluminium steel-backed bearings, which are now used as original equipment for the crankshaft and big-end bearings of Fiat, Perkins and Leyland engines. Standard specifications for these, as well as the solid bearings, are being formulated by the Indian Standards Institution.

Electrical machinery

While the unparalleled use in India of aluminium cables and conductors for transmission and distribution of electrical energy is very well known, there is not so much awareness of its suitability for the windings of electrical machinery. Following extensive trials with the winding of stators of squirrelcage induction motors, blower and air-conditioner motors, and static equipment like chokes, enamelled aluminium wire has been established as a satisfactory substitute for copper magnet wire. Several hundred motors wound with aluminium wire are giving excellent service all over the country and it is estimated that even a partial switchover from copper winding wire can bring about foreign exchange savings to the tune of Rs 45 million by 1973/74.

Aluminium wires and strips have also been successfully used for winding transformers up to 1 000 kVA rating and it has more or less been decided that copper windings should not be employed any longer for transformers up to 100 kVA. Aluminium is moreover used almost exclusively for casting rotors of squirrelcage induction motors ; rotors up to 50 HP are common, while some manufacturers have used them for motors even up to 250 HP. Aluminium is also being increasingly used for the busbars in factories, distribution boards, the electro-chemical industry, substations and various types of switchgear.

Among the non-current carrying applications in other equipment connected with the electrical industry, mention can be made of aluminium lamp caps and lamp holders, fan blades and canopies, and rotor discs in house-service meters.

Construction industry

That the use of aluminium alloys are not limited to medium and light engineering applications can be seen by its widespread adoption in heavy construction equipment.

A launching truss employed in the construction of bridges is a good example where advantage is taken of the metal's strength and lightness. By the use of a launching truss in the form of an overhead girder the problems of placing bridge beams in position are easily resolved, particularly when access below the bridge for heavy lifting equipment is difficult or impossible. Since the bending moment, to which the supporting beams are subjected must, throughout the launching operation, be within the working capacity of these beams, the cantilevered truss and outboard mast are usually fabricated in aluminium alloy. Triangular lattice girder trusses in aluminium were employed some years ago for launching 50-tonne pre-cast concrete beams for the Hardwar Centenary Bridge, as well as for the Bayne Bridge in Central India. Recently, similar girders were used in the construction of the Rupnarain Bridge at Koilaghat.

Yet another interesting use of aluminium in construction equipment is the jibtype crane. For a given crane superstructure and driving machinery, the use of a light-weight aluminium alloy jib results in increasing the working reach of the crane, of its lifting capacity, without increase in wheel loads or overloading of existing foundations. Even where such restrictions do not apply, the reduction in the weight of the jib and the crane superstructure has resulted, in some instances, in a unit of lower capital cost. In India, a 15-tonne travelling derrick-crane with a 27·5 metres jib made out of extruded aluminium sections was used in 1959 for the erection of the steel girder spans of the Mokameh Bridge in Bihar. Of incidental interest, the main joints in this bridge were riveted from portable aluminium cage-type platforms.

Mining industry

Light-weight and durable aluminium alloys have also been satisfactorily used in mine equipment. Earlier, a reference was made to the light-weight aluminium dump truck bodies that have been recently introduced in this country. Equally good scope exists with aluminium buckets for increasing the carrying capacity of aerial ropeways used to transport minerals and ore from the mine face. Aluminium buckets tried out by the Indian Aluminium Company Limited for haulage of bauxite have proved more than adequate in strength for the tough service expected of them, while bringing about an increased payload of nearly 35% from 350 kg to 471 kg.

Within the mine, aluminium has found wide use for mine tubs and cages. Aluminium mine tubs have been employed in many Indian coal mines, notably in the Parasia Collieries of Shaw Wallace & Co. Ltd., Bird & Co's Loyabad mines and the Singareni Collieries in Andhra Pradesh. As in other transport applications, these light-weight tubs have made possible the carrying of greater payloads for a given haulage capacity. Aluminium construction for mine tubs has also been approved by the Indian Standards Institution.

Other applications

There are so many other applications of aluminium in the engineeering industry that it will be impossible to describe all of them within the scope of this paper. The metal is used in varying degrees in nearly every single industry ; for instance:

—in the *chemical industry* for pressure vessels, process piping, vats and heat exchangers,
—in *fertiliser plants* for the cladding of prilling towers and grid flooring,
—in the *textile industry* for spindles, bobbins, lays, heald bars, suction systems and humidifying equipment,
—in *bicycles* for spoke nipples, tube nozzles and mandrils, wheel rims and mudguards,
—in the *rubber industry* for coagulating tanks, tyre moulds, pyramid matting and vulcanising trays,
—in *sugar machinery*, such as juice heaters, evaporators, vapour pipes, settling tanks, macerating troughs and gutters,
—in *dairy equipment* like milk churns, cheese vats, milk pails, storage tanks, etc.,
—in *printing machinery* for quoins and lithographic plates,
—in *foundries* and even *steel plants* for deoxidising of steel,
—for all types of *fastenings* such as rivets, bolts, nuts, screws and washers,
—as a *paint* and *primer* for protecting steel and other meterials, and
—for such miscellaneous and diverse products like builders' hardware, zip fasteners, knitting needles, press buttons, shoe and sail eyelets, umbrella sticks and ribs, flash-light cases and pressure cookers, as also in foam concrete and thermit mixes.

As will be readily appreciated, the list can by no means be regarded as complete. Each day brings a new use of aluminium and—judging by the estimated 40 000 different applications that have already been established in the more advanced areas of the world —this growth in the use of the metal will take place at an increasing tempo.

With the development of more and more specialised alloys, improvement in fabrication techniques and better and more economical designs, it is but to be expected that a deeper penetration will be made by this light metal in applications and markets not even considered hitherto. Adding this to the fact that, of all the nonferrous metals, aluminium is the only one whose availability is assured, its future in India is certainly the brightest.

Discussions

Mr **K. C. Choudhuri** (Research Designs and Standards Organisation, Lucknow) : I agree with the author regarding a wider use of aluminium in rolling stock construction in order to increase the load. However, from design considerations, the modulus of elasticity of aluminium being about one third that of steel, an aluminium beam, under the same load, will deflect three times more than a steel beam. Increase in cross-sections has an adverse effect on costs because aluminium is very expensive in our country. Has Mr Gopalkrishnan studied the economic aspects involved in this problem ?

Mr **N. Gopalkrishnan** (Author) : Mr Choudhuri is quite right when he says that deflection of an aluminium beam will be three times that of a steel beam (because of its lower modulus of elasticity) under identical loading conditions and with an identical section. The point is that an identical section should not be used. It is possible to re-design the section in aluminium so that, keeping the deflection within the allowable limits, the overall cross-section does not increase appreciably. This point has arisen, not only in railway applications, but in all structural uses, and the problem raised by Mr Choudhuri is one that is not insurmountable. Recently, I have had occasion to discuss this subject with the Railway engineers dealing with the all aluminium coach project and have offered our assistance in designing the particular sections that might suggest a problem in re-design.

Mr **S. K. Sanyal** (Defence Research Laboratory, Kanpur) : Joining of aluminium cables poses a difficult problem because the metal forms a highly insulating corrosion product.

Mr **N. Gopalkrishnan** : I agree that joining of aluminium has presented several problems in the past, particularly in respect of aluminium cables, but I am also glad to say that almost all these problems have been satisfactorily solved. Many of the cable manufacturers offer specialised instruction in the joining of aluminium cables and also run classes to instruct cable jointers. If Mr Sanyal could let me have details of the specific problems which he has faced, I am sure we would be able to find a satisfactory solution to them.

Mr **U. P. Mullick** (Institute of Consulting Engineers, Calcutta) : The Indian engineering industry and consulting profession are keen on having a code of practice for structures in aluminium. Is any such handbook available ?

Mr **N. Gopalkrishnan** : Regarding a code of practice for designing structures in aluminium, I am glad to say that this matter has been engaging the attention of the Indian Standards Institution for quite some time and a code is now under preparation. It is expected that this code of practice will be finalised during the coming year. In the meantime, we are following several codes of practice that are being used in other countries. Codes have been made out in North America and also in the U.K. as for example by the Aluminium Association, U. S. A., the Canadian Standards Association, Canada and the Institution of Structural Engineers, U. K.

Mr **C. M. Daftary** (Crown Aluminium House, Calcutta) : The Railways are now finding it difficult to compete with road transport and recently they sent circulars to the industries intimating that they have devised large-sized steel bins for efficient transport of commodities in bulk. I feel this would be an ideal application for aluminium which will prove more economical than steel.

Mr **N. Gopalkrishnan** : Mr Daftary has raised the subject of containerisation. I would like to add, in this connection, that the question of using aluminium containers has been discussed over the last several years by us with the Railways' Research Designs and Standards Organisation. One problem that has been expressed by the Railways is the high cost of aluminium and they apparently find it difficult to justify the extra initial cost even though it is realised that on account of the lighter weight of the aluminium containers, overall economics will result and the extra investment will be paid back within a few years. One interesting development, however, is that private companies, who are users of the containers, might propose to own the containers themselves—for instance, one firm has recently proposed transporting pitch in their own containers—in which event, there is greater likelihood of aluminium construction being adopted, since commercial organisations might be more inclined to jump at such an opportunity to effect savings.