Some aspects of redesigning in aluminium

DHARMENDRA KUMAR and V. S. SURANA

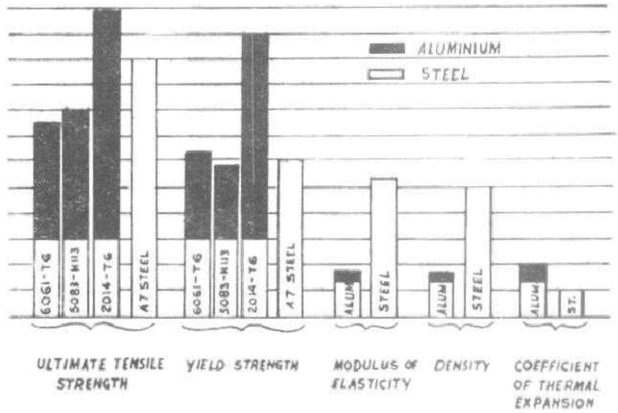
THE development of high strength aluminium alloys has provided a great incentive to many manufacturers to convert their products from other metals to aluminium.* In all such applications the specific mechanical and physical properties of each structural material have to be considered in the context of the material and labour costs which directly govern the efficiency and economy of a design ; a third indirect guiding factor being the cost of maintenance. One or more of the following characteristics has or have in many cases turned the decision in favour of using aluminium.

Light weight and high strength/weight ratio

Although the strength of pure aluminium is relatively low (6 kg/mm^2) it can be increased by as much as 10 times (60 kg/mm^2) by suitable alloying, heat treatment and/or strain hardening by cold work. Thus tensile and yield strengths comparaple or even superior to common structural steels can be obtained. Fig. 1 gives a comparison of the properties of aluminium and steel.

The density of aluminium is about one-third of steel—the resulting weight saving being 40 to 70% with substantial reduction in erection costs. Fig. 2 shows the stress strain curve of aluminium and steel. As no clearly defined yield point is exhibited by aluminium, a permanent set of 0·2% is specified as yield strength. In designing with aluminium as with other metals the safety factor can be applied to the ultimate strength or yield strength.

The modulus of elasticity of aluminium (7×10^3 kg/mm^2) is also about $\frac{1}{3}$ of steel and is the same in case of all aluminium alloys regardless of their strength. This merits careful examination in all design calculations requiring rigidity of sections. The low modulus of elasticity is, however, advantageous for structures subjected to impact loading—an aluminium structure absorbing three times the kinetic energy of a steel structure of equal size. Due to low modulus, stresses caused by temperature changes or misalignment are less for aluminium than for steel.



1 *Comparison of properties, aluminium vs steel*

Ease of fabrication and erection

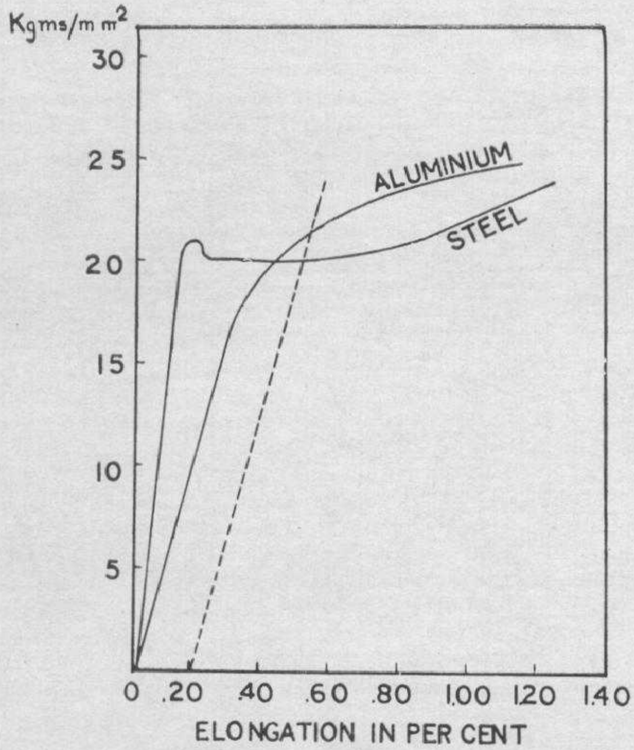
In steel the availability of various sections, which are mostly produced by rolling is limited to I, Channel, Tee and Angle sections. Aluminium shapes are however, produced both by rolling and extrusion, the latter permitting the manufacture of an unlimited variety of cross-sections, including complex hollow shapes not obtainable in steel. This under particular conditions of stress and loading can lead to substantial economies as well designed aluminium structures will weigh considerably less than similar steel structures. Aluminium like other metals can also be worked easily and the joining may be accomplished by rivetting, bolting, welding, brazing or adhesive bonding.

Corrosion resistance & modern appearance

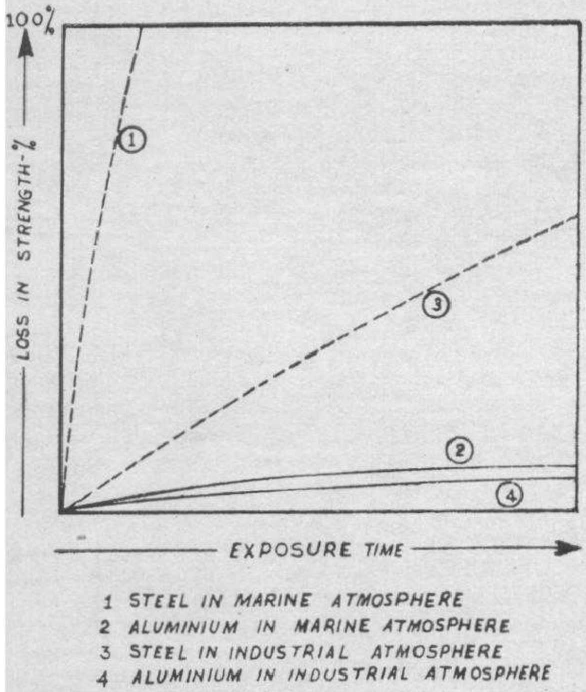
No extra allowance of metal in design thickness is necessary for rust losses as all aluminium surfaces are always covered by a highly corrosion resistant thin natural oxide film (Fig. 3). Most alloys can be used without any special surface protection, which also possess pleasant natural appearance quite adequate for most applications. However, if required many mechanical, chemical or electro-chemical finishes can be given as well as painting, lacquering and enamelling can be done to modify the surface appearance to suit any particular conditions and environments of service.

Dr Dharmendra Kumar and Mr V. S. Surana, Hindustan Aluminium Corporation, Renukoot.

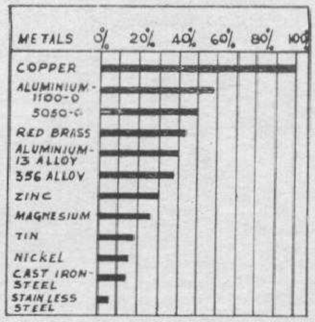
*The term 'aluminium' is broadly used here as representing different alloys of aluminium as well.



2 *Stress-strain curves for aluminium and steel*



3 *Relative loss of tensile strength in industrial, marine atmospheres*



4 *Relative thermal conductivity by volume*

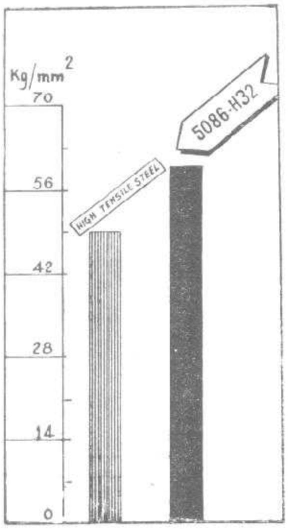
Good electrical, thermal conductivity and high refractivity

High electrical conductivity of aluminium has led to its ever-widening uses in various electrical engineering applications. As the thermal conductivity of aluminium is better than most other metals (Fig. 4) and it does not corrode easily, efficient heat transfer is maintained for much longer periods. This has made aluminium popular for making cooking utensils where heat is evenly conducted to the food being cooked without causing burning. The advantage of high thermal conductivity in greatly improving the efficiency is demonstrated in internal combustion engines, where aluminium cylinder heads reduce temperature in the combustion chamber by about 40°C, thereby making it possible to obtain higher compression ratios by preventing detonation caused by a 'hot spot'. Like most materials aluminium tends to lose strength with increasing temperature. However, higher specific heat and thermal conductivity allow the absorption of over twice as much heat energy as steel before reaching a given temperature. This resistance to temperature rise offers valuable measure of safety to aluminium structures to withstand above-normal temperature conditions. Besides, aluminium parts protected by their constantly present oxide film show much less corrosion susceptibility whereas steel under elevated temperature conditions becomes markedly vulnerable and requires intensive maintenance measures.

Good reflectivity and low emissivity of aluminium make its ducts more efficient in delivering hot or cool air as compared to other types of duct construction like bare galvanized or metal ducts covered with asbestos paper. The lower heat losses combined with lower friction losses in aluminium ducts have led to their successful use in heating, ventilating and airconditioning systems. Other ways in which the high reflectivity is being used include roofings for buildings which keep cooler in summer, and various types of heat shields and light reflectors.

Non-toxic, non-magnetic and non-sparking properties

Aluminium is practically inert to many of the chemicals



5 *Comparative bending strength, equivalent stiffness, aluminium 44% thicker than steel*

and food stuffs and any reaction products resulting from even long exposure of aluminium to food are tasteless, odourless, colourless and non-toxic. This is of great importance for use in food processing, food handling and many types of chemical applications.

The non-magnetic properties of aluminium are useful for various electrical and electronic applications where a material unaffected by an electromagnetic field is essential. The non-sparking property is advantageous around inflammable or explosive substances such as enclosures, walkway structures, processing equipments, containers, nozzles and other similar equipments.

Economy and availability

In addition to the combination of a number of advantageous properties, the economy and increasing availability of aluminium steadily becoming less expensive in relation with other metals is a very important factor in the growing industrial stature of the metal. The production and supply of aluminium has increased tremendously in recent years and in contrast to many other metals, aluminium does not face the immediate problem of diminishing ore reserves or progressively increasing cost of extracting the metal. The capacity of aluminium smelters is constantly being increased, thereby assuring a continuous uninterrupted supply of the metal at a stable cost.

Thus the fullest advantage of using aluminium can be gained in all such applications where the economy of usage is tied up with reduction in dead load and low maintenance. These include long span structures, mobile and portable equipments, exposed surface in industrial and humid environments and many other applications involving long distance shipments and erections in difficult-to-reach locations. An important example of this is provided by aluminium towers for power transmission across rugged terrain. These withstand corrosion without maintenance and being light can be transported and installed by helicopters.

The design of each particular component requires careful examination keeping in view the stress requirements in service and the different mechanical and physical properties of aluminium alloys. Some broad considerations are discussed below :

Designing unstressed aluminium components

There are many components such as sheet hood, cover, ducts, light housing, etc. which are required to carry their own weight plus the normal stress of ordinary handling and wear. In all such applications it may be quite adequate to consider only the comparative stiffness (modulus of clasticity) of steel and aluminium. A sheet of aluminium approximately 44% thicker than one of steel will have equal stiffness and dent resistance (Fig. 5) and should satisfy the service requirements. Even after using thicker sheet, the weight will be only half that of steel. In many cases the original design is made according to the designer's personal inclination regardless of the actual stress requirements. In all such cases greater economy can be effected by proper investigations and the aluminium replacement may be no larger in dimensions as compared to the one originally installed.

Redesigning of stressed aluminium components

Redesigning in aluminium from the chief structural metal steel has to be considered in context of the following broad factors :

(a) Steel is used in structural engineering mainly as mild steel and sometimes as high tensile steel, whereas the number of aluminium alloys available and used for structural applications is more varied. Two heat treatable alloys 6061–T6 and 2014–T6 are best suited for structural design and three non-heat treatable high strength alloys 5083, 5086 and 5454 are particularly well-suited for welded structures. The nominal composition and typical properties of these are given in Table I.

(b) Modulus of clasticity of aluminium is about $7{\cdot}03 \times 10$ kg/mm² as compared to $21{\cdot}09 \times 10^3$ kg/mm² for steel. Hence, it will be seen that an aluminium beam will deflect the same amount under its own load as an identical steel beam since the aluminium will weigh one-third that of steel. However, under the same applied external load the aluminium beam will deflect almost three times that of an identical steel beam. Stiffness equal to steel in such cases can be achieved by suitably increasing the section of the aluminium beam.

(c) The spread in tensile yield strength and ultimate tensile strength is smaller for aluminium alloys as compared to steel. Thus the yield and ultimate tensile strengths of A_7 steel are 26·7 kg/mm² and 42·2 kg/mm² respectively with an approximate percentage elongation of about 30%. The corresponding values for a typical aluminium alloy (6061–T6) are 28·1 kg/mm² yield strength, 31·7 kg/mm² ultimate tensile strength and percentage elongation of about 17%. Many designers, therefore, apply a somewhat greater factor of safety in redesigning to the tensile yield strength

TABLE I Characteristics of some structural aluminium alloys

Alloy	Nominal composition	Typical mechanical properties U.T.S. kg/mm²	Y. S. kg/mm²	% E (50mm length)	Modulus of elasticity kg/mm² $\times 10^3$
6061–T6	Si 0·4–0·8 Cu 0·15–0·4 Mg 0·8–1·2 Cr 0·04–0·35	31·6	28·1	17	7·0
2014–T6	Si 0·5–1·2 Cu 3·9–5·0 Mn 0·4–1·2 Mg 0·2–0·8	49·2	42·2	13	7·5
5083–H321	Mn 0·3–1·0 Mg 4·0–4·9 Cr 0·05–0·25	32·3	23·2	16	7·2
5086–H34	Mn 0·2–0·7 Mg 3·5–4·5 Cr 0·05–0·25	33·0	26·0	10	7·2
5454–H34	Mn 0·5–1·0 Mg 2·4–3·0 Cr 0·05–0·2 Si+Fe 0·40 max.	30·9	24·6	10	7·2
Steel A7	C 0·20–0·33 P 0·06 S 0·05	42·2	26·7	30	21

of aluminium alloys. It is noteworthy that in such calculations, the weight of the aluminium structural member would be approximately half of steel for an equivalent tensile load and a greater margin of safety against permanent deformation will be provided by the aluminium member.

Redesigning in aluminium

Where aluminium sheet is applied as a replacement for steel sheet, the following formula is generally used to calculate the equivalent gauge for aluminium as the rigidity of a section increases as the cube of its depth :

$$A = B \times \sqrt[3]{\frac{D}{C}}$$

where A is the thickness of aluminium sheet
B is the steel sheet thickness
C is the modulus of elasticity of aluminium
D is the modulus of elasticity of steel.

Substituting the appropriate values the increase in thickness for the aluminium sheet comes approximately 44% as compared to steel.

In other cases of redesigning in aluminium the design has to be based on considerations of basic strength of aluminium alloys and the stress analysis of the structures. Members in tension columns under compression or components under combined axial and transverse loads or shear along with joining methods have to be considered in the context of the requirements in service. Detailed formulae are available for such calculations and can be worked in detail to suit any particular applications. The final evaluation of course, has to be done on the economic plane in terms of both the initial cost as well as the recurring expenditure on maintenance.

References

1. Ghaswala, S. K. : Structural Theory and Design In Aluminium, The Indian and Eastern Engineer, March, April, July and October, 1962.
2. Standards for Aluminium Mill Products 1966, Aluminium Association of America.
3. Angermayer, K. : Structural Aluminium Design, Reynolds Metal Co.
4. Designing with Aluminium, Kaiser Aluminium Co.