STRUCTURAL ALUMINIUM INDUSTRY

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Abstract

The paper opens with a brief description of the general trend of development in aluminium industry pictured against world production, price trends and the rating of potentialities of some of the important European countries. The major portion of the description centres round the mode of application of aluminium alloys in structures commonly met with in civil engineering practice with special reference to building construction. A survey is made of the uses of aluminium in different engineering industries in terms of percentage production of that country in order to give an indication of the existing and potential markets. Since the general index of a country's achievement is measured by its *per capita* production, an analysis on *per capita* production is made for different countries of the world including India, both for aluminium alloys as well as for iron and steel, in which is also incorporated the *per capita* production of electrical energy in kWh for U.K., U.S.A., Canada and India to give a very striking indication of the vast strides still necessary to be made by this country to stand in the front rank of industrial nations.

In dealing with the actual applications, the potentialities of light alloys in civil engineering structures are brought out through an explanation of their inherent characteristics. To evaluate the trend of industrial production in the field of building construction, the uses of light alloys are subdivided into six categories and the relative merits of each one discussed together with an indication of the manner in which production should proceed. It is shown that in India it would be futile at this stage to produce completely prefabricated aluminium houses, but to utilize aluminium components for the production of rural and industrial structures would be quite feasible and economical. A survey is made of the future of structural aluminium, incorporating ideas on rational methods of design based on the intrinsic characteristic of the material and emphasizing the inadequacy of merely copying conventional steel design. The paper forms a compact appraisal of one of the important facets of the Indian aluminium industry with special reference to structural engineering work, and forms a stepping-stone for future development in this field.

Introduction

THE acceptance of a new material like aluminium for engineering work represents a significant event in the history of a country's industrial progress. Steel, together with its multifarious alloys, has up to now been rightly regarded as the raw material of the present industrial and technological age and the entire gamut of engineering applications from screws to suspension bridges, or skyscrapers, has been carried out in this metal. As a result the claims of other non-ferrous metals were put aside in spite of their good intrinsic physical and mechanical properties. Aluminium is one among such non-ferrous metals as is evident from the fact that its commercial development has taken place within the memory of many now living. Metals like gold and silver and iron have been known since antiquity and can look back on several thousand years of development while aluminium and other light metals like magnesium and beryllium have been obtained in their metallic form from their ores only since the dawn of the 19th century. The chronological order[1] in which the production of various metals was begun is given in Table 1.

It can be clearly seen that aluminium is a comparatively young metal, although, surprisingly enough, next to silicon it is the most abundant material in the earth's crust, as shown in Table 2.

Production and Price Trends

The wide fall in the price of this metal from its early beginning to the present era forms a clear indication of its rising output. Thus some eight decades ago aluminium cost Rs. 11,43,520 per ton while the present cost

TABLE 1

Metal	Year of production
Gold, Silver, Copper	5000 B.C.
Tin, Bronze	3500 ,,
Lead, Iron	3100 ,,
Iron, beginning of systematic production	2000 ,,
Metallic aluminium	1825 A.D.
Metallic beryllium	1828 ,,
Metallic magnesium	1830 ,,
First commercially successful electrolytic reduction plant for aluminium	1886 ,,
First successful production of high strength aluminium alloy of 'Duralumin' type by Alfred Wilm and inauguration of large-scale industry	1909 ,,

TABLE 2

Metal	Percentage contents of the earth's crust
Silicon	25·80
Aluminium	7·50
Iron	4·70
Magnesium	1·90
Zinc	0·02
Copper	0·01
Lead	0·0008
Beryllium	0·0005
Silver	0·000004

of (virgin) ingots is round about Rs. 3000 per ton and for finished products like plates and sections anything between Rs. 4500 and 6300 per ton. The comparative prices prevailing in August 1953 in long tons for different non-ferrous metals in different countries are given in Table 3.

On an average, worked aluminium alloy sections cost from Rs. 2/4 to Rs. 2/12 per lb. as against As. 5 to As. 8 per lb. for mild structural steel. In order to bring down the price of the light metal, it is imperative to develop its productive side, especially in view of the fact that India ranks ninth among the 23 world producers of aluminium with a bauxite capacity of over 29 million tons and an estimated reserve of 250 million tons.

In 1891, an English scientist, attached to the Madras Engineering College, first proposed to the British Government for the utilization of water power for the production of aluminium. An expert committee went into this question and the matter dragged on for nearly ten years without avail till 1900, when a company was formed to develop manufacture of hollow ware in this light metal. Later, further schemes were worked out in the early years of this century including the Koyna Valley Hydro-electric Project, the Rewa State scheme in Central India and the Kolhapur State scheme. All these projects were turned down in the interests of the British Government, and India remained in the background till 1936/1937 when definite schemes were planned and a primary aluminium industry was born in this country. Actual production started in 1943 and has since been developing as shown in Table 4 which gives the production figures of both the ore and the metal, while for purposes of comparison production figures for other countries of the world are also given.

It is a common knowledge that the production of one ton of aluminium requires approximately 4½ tons of bauxite; 0·16-0·2 ton of caustic soda; 0·07-0·10 ton of cryolite; 0·035-0·04 ton of aluminium fluoride; 0·007-0·008 ton of fluorspar; 0·75 ton of petroleum coke; 0·2 ton of pitch; 4·0 tons of coal; 0·5 ton of furnace oil, and last but not the least 20,000-24,000 kWh. of electrical energy.

The ideal aluminium plant would be one situated near abundant raw deposits, adjacent to coal-mines and with limitless cheap electric power. In addition to these many other factors come into play and as such an accurate rating of the potentialities of all

TABLE 3 — BASIC PRICE OF UNALLOYED METAL IN RUPEES PER LONG TON

METAL	U.K.	CANADA	U.S.A.	FRANCE	WESTERN GERMANY	ITALY	JAPAN
Aluminium							
Ingot	2100	2156	2408	2618	2688	2968	3080
Sheet, 16 s.w.g.	3332	—	3920	—	—	—	—
Extruded bar, 1 in. diam.	2870	—	4186	—	—	—	—
Magnesium							
Ingot	4508	3640	3024	6440	—	—	—
Sheet, 16 s.w.g.	—	—	7336	—	—	—	—
Extruded bar, 1 in. diam.	—	—	6496	—	—	—	—
Copper							
Ingot	3290	3360	3332	3570	3500	3808	4550
Sheet	4074	—	5656	—	—	—	—
Extruded bar, 1 in. diam.	—	—	5740	—	—	—	—
Zinc							
Ingot	1022	1358	1232	1400	—	1666	2170
Sheet	1414	—	2576	—	—	—	—

TABLE 4 — ALUMINIUM PRODUCTION IN METRIC TONS

YEAR	INDIA		FRANCE	U.S.A.	RUSSIA	U.K.	ITALY	GERMANY
	Aluminium	Bauxite						
1943	1292	24548	46462	835000	62000	56557	46192	203068
1944	1751	12330	26154	—	—	36038	16796	191000
1945	2250	14116	37225	—	—	32432	4347	20000
1946	3240	7592	47952	372000	90000	32067	11040	—
1947	3220	11000	53225	—	—	29384	24859	—
1948	3372	19000	64785	—	—	30510	33083	7306
1949	3516	40650	54140	—	—	30832	25647	28848
1950	3590	—	61000	—	—	29941	37070	26951
1951	3876	—	91080	—	—	28200	49750	74136
1952	3566	—	106100	850000	300000	29000	52000	100000
1953*	1682	—	—	—	—	—	—	—

*Half-yearly.

countries as regards aluminium production is difficult. However, some idea can be had from the average statistical conditions of the production facilities of different countries and their comparison with India[2]. This comparison is given in Table 5.

It is evident from this table that in order to develop her aluminium industry, India

TABLE 5

Countries	Power	Bauxite	Coal	Transport facilities
Canada	A	E	A	B
U.S.A.	A	B	A	B
Germany	B	D	A	C
Russia	B	D	C	D
France	A	A	B	A
Italy	B	B	E	B
Norway	A	E	E	C
U.K.	D	E	A	B
Japan	D	D	C	C
Switzerland	A	E	E	D
India	D	B	C	D

A, excellent; B, good; C, average; D, fair; and E, poor.

must concentrate on power production and transport facilities if it is to make use of her latent sources of bauxite, since in these two items its standards are comparatively low.

Distribution of Consumption

Having considered the general trend of development and the wide potentialities of the aluminium industry it is necessary to visualize the manner by which the metal can best be utilized. The applications of aluminium in the general field of engineering are rapidly increasing[3-7]. In this paper, only one of the facets will be considered, viz. its utility in structures familiarly met with in the wide field of civil engineering. In India in 1951 the total consumption of aluminium in all forms was 16,000 tons. A break up of this figure as shown in Table 6 indicates clearly that over 62 per cent was being utilized in the manufacture of utensils and the remainder for other purposes.

These figures are compared with the applications of aluminium in foreign countries, especially in the field of building construction,

TABLE 6 — ACTUAL CONSUMPTION AS PERCENTAGE OF TOTAL PRODUCTION IN PRE AND POST-WAR YEARS

Mode of application	India, 1951	Europe, 1949	U.K., 1949	Switzerland, 1949	U.S.A., 1949	U.S.A., 1942	U.S.A., 1935/39	Italy, 1952
Utensils	62·5	5·0	8·4	9·0	14·0	1·0	12·0	10·0
S.C.A. conductors	15·6	10·0	—	—	10·0	—	—	—
Foil and packing	6·3	—	5·6	15·0	—	—	—	6·0
Mining and colliery equipment	—	—	0·3	—	—	—	—	—
Transport: air, rail and sea	—	35·0	24·7	15·0	29·0	63·0	22·2	20·0
Machinery / Electrical industry	—	5·0	{5·5 / 4·1}	9·0	15·0	6·0	{3·5 / 23·7}	27·0
Architecture and building construction	—	10·0	17·9	17·0	8·0	3·0	—	6·0
Chemical and food industry	—	5·0	1·2	15·0	11·0	5·0	—	6·0
Metallurgical industry	0·6	15·0	—	10·0	9·0	21·0	28·3	7·0
Armaments excluding aircraft	—	10·0	4·8	—	—	—	—	—
Direct exports	—	—	19·0	—	—	—	—	—
Miscellaneous	15·0	5·0	8·5	10·0	4·0	1·0	10·3	18·0
Total production in tons	16000	231890	230835	21000	617538	472700	234000	52000

to indicate the existing inadequacy of India's contribution.

As in other fields, an index of a country's achievement can be expressed on a *per capita* basis.

In Table 7 are collected statistics of different countries regarding the *per capita* production of aluminium and a comparison made with a similar index for iron and steel. Alongside are also given the *per capita* power consumption of the three leading countries of the world, to indicate the poor state of affairs still prevalent in this country.

In 1938 the major individual consumer of aluminium was Switzerland, while in 1949 the United States topped the rating, followed by Norway. In Europe, France increased its consumption, while Britain had also come into prominence. To enable a direct comparison to be made, the 1949 consumption is expressed in 1938 level, taking the latter as an index year, 100, as shown in the last column of Table 7.

The enhancement of India's aluminium production envisaged in the Five Year Plan will bring the capacity to a figure of 20,000 tons by 1955-1956, which can be roughly estimated at 1/170th of the world production. Even with this enhancement, the *per capita* rating will be 0·000055 as against the 0·00001 for 1949 level, i.e. approximately 36,000 times lower than the lowest European *per capita* producer of aluminium. It is, therefore, quite imperative to see that this capacity is still further increased by setting up a 50,000-100,000 tons production plant at a suitable site having cheap electricity and raw materials at hand. A site near the Bokaro Thermal Station appears to have wide possibilities for such a plant and requires to be thoroughly studied and investigated.

Application Trends

The quality of the modern light alloys has been profoundly influenced by the discoveries of Wilm of Germany. Prior to his work, the light metal was mostly produced in an unalloyed condition used for pressing, deep drawing and in roofing work. Probably the

TABLE 7

COUNTRY	*Per capita* PRODUCTION OF ALUMINIUM, IRON AND STEEL IN LB.			*Per capita* POWER CONSUMPTION IN KWH.	ALUMINIUM CONSUMPTION IN 1949 EXPRESSED IN 1938 LEVEL
	Aluminium		Iron and steel		
	1938	1949	1948		
Switzerland	6·006	5·676	—	—	94
Germany	5·808	3·366	175	—	—
U.K.	2·860	8·184	670	1110	286
Sweden	2·288	7·590	407	—	331
France	1·474	2·640	398	—	179
U.S.A.	1·382	9·988	1210	2207	722
Italy	1·366	1·760	102	—	129
Japan	1·208	—	47	—	—
Canada	1·074	7·722	490	3905	719
U.S.S.R.	0·7084	—	260	—	—
Belgium	0·555	—	1022	—	—
India	—	0·00001	6	14	—
Norway	—	9·526	—	—	—
Holland	—	3·30	—	—	—
Austria	—	2·464	206	—	—

first use of the metal in the latter form was made in 1897 in the roof of the Roman Church of St. Gioacchino, the material being supplied by Aluminium Industrie A.G., Neuhansen, Switzerland. After 40 years' service it was re-examined and found to be in a perfect condition except a mean wear of the sheets by 0·01969 in. Since that period its applications have steadily grown all over, various structures having been installed in all parts of the world, such as the roofs in the A.I.A.O. structures in Leopoldsville, Belgian Congo, Kingstrand type houses in Israel and Karachi, Vallot Refuge on Mt. Blanc, approximately 14,300 ft. above sea level, and in several roofs over structures in Germany, Australia and other places [8-10].

In spite of these uses in roofs and a few other items, their major utility in structures was not recognized till a comparatively recent date. This is all the more surprising when it is known that ever since Wilm's discovery of age-hardening and the production of strong light alloys of 'Duralumin' type, the aircraft industry has made extensive use of aluminium alloys in major stress-carrying components. This particular state of affairs can be attributable to such factors as:

(a) Lack of knowledge of the principles of design and mechanical properties of aluminium on the part of designers outside the aircraft field;

(b) Difficulty of selecting alloys and sections due to a general non-standardization;

(c) Insufficiency of production of the right type of forms and sections in this country.

Combined with these factors there is a deep-set belief prevalent in India that aluminium is a metal fit for kitchen utensils only and is too soft and weak for any major engineering use.

As it often happens, it was only when both technical and commercial requirements combined to force the issue, as during and after the last war, that aluminium made some strides and established itself as a worthy piece of metal fit for use in major structural engineering work. Unfortunately at present the applications of this light metal are limited in a very large degree to copying steel construction, which prevents full exploitation of its inherent characteristics. Aluminium has come into the structural engineering field via the aircraft industry, and as such should furnish a striking proof of its beneficial and progressive influence provided it is not sidetracked into the familiar pattern of imitation of traditional materials as shown by the author elsewhere[11].

In the structural field, the building construction industry offers probably the largest single outlet and scope for utilization of aluminium, as is evident from the fact that next to the transport and aircraft industries, building industry is at present the largest user of aluminium in U.K. and U.S.A. consuming over 30 per cent of the output of all fabricated products. The science of building construction or, as a matter of fact, any other type of civil engineering construction predominantly centres round static or immobile structures, so that it becomes difficult to visualize the specific advantages that would accrue by using aluminium instead of traditional materials like bricks, timber, steel and reinforced concrete. The value of the metal lies in one or more of the following factors:

(a) The high strength/weight ratio of the metal, resulting in the utilization of reduced volume for the same strength or higher load-carrying capacity for the same volume.

(b) Superior resistance to corrosion and decay, resulting in the possibilities of use of much thinner sections than normally required in ferrous materials.

(c) Readiness and ease of machining and fabrication thereby reducing production costs.

(d) Lower overall density, resulting in economy in transport as compared with bricks stone, reinforced concrete and steel. Aluminium has the same density as glass, asbestos stone and slate and is nearly one-third the weight of brass and steel. It is nearly 40 per cent heavier than bricks, 60 to

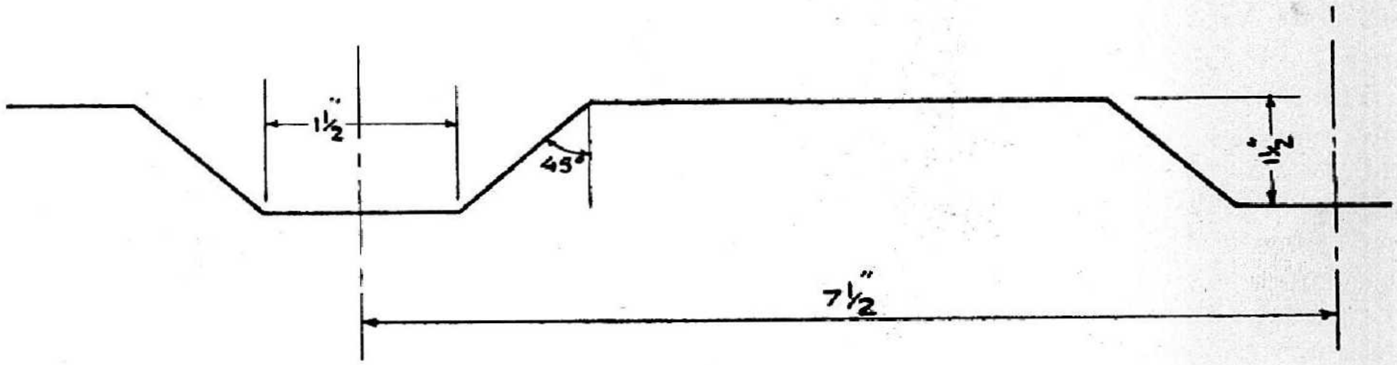

FIG. 1

70 per cent heavier than timber, and 10 per cent heavier than reinforced concrete.

(e) Its neat and pleasing appearance, which can be enhanced further by painting in any shade or colour or by anodizing.

(f) Good thermal and electrical properties rendering it useful in lighting conduction and busbars.

(g) High reflectivity of radiant energy in all wavelengths ensuring its suitability in coverings exposed to heat especially in tropical countries.

(h) The non-toxic, non-magnetic and insulating characteristics rendering it useful for refrigeration purposes.

(i) Comparatively low modulus of elasticity giving it a greater resilience during deflection and rendering it ideally suitable for diving boards and dance floors.

Scope in Building Construction

Having considered the broad outline of applications, it is interesting to analyse the various specific categories in which the building industry should function from the point of view of production of components and other members used therein. Actually six major categories are recognizable as outlined below:

(1) Complete buildings prefabricated in aluminium, or buildings with an aluminium frame filled in with insulating material such as glass, foamed concrete, etc.

(2) Structural components such as roofs, trusses, beams, columns and sidings.

(3) Special structures such as large canopies, lifts, escalators, etc.

(4) Standardized components such as door, window and partition frames and filler material, electrical and other ducting and tubing, scaffolding, hoists, rainwater goods, soil pipes, etc.

(5) Hardware and other fittings such as locks, handles, nails, bolts, screws, etc.

(6) Decorative accessories such as railings, balustrades and window grilles.

Out of these six categories, it is necessary to investigate which one or more best suit the Indian conditions and can be fully exploited and developed.

(1) *Fully Prefabricated Buildings* — In the opinion of the author the time is not ripe for complete prefabricated buildings in aluminium to have a very wide market in this country, mainly due to the high cost of production. It may be true that in special circumstances, such prefabricated buildings may have certain advantages, but in the general industrial pattern they do not fit in well. An example of this type is the well-known Kingstrand frameless house built on the principles of stressed skin or 'monocoque' construction familiar to aircraft designers. Such structures have been used in thousands for housing colonies in the Damodar Valley Scheme, in Sindri Factory, in Karachi and in Israel. Walls and roof of this structure consist of troughed aluminium sheets of 0·032 in. thickness, as shown in Fig. 1, and are made of Noral 3SH alloy (Al+1·25

per cent Mn) having a tensile strength of over 11 tons/sq. in.

This forms the basic unit of the structure and resists all stresses coming within the roof and walls. These components are secured together by means of angles of the same alloy but varying in thickness from 0·0408 to 0·104 in. These angles act purely as brackets between wall and roof panels and, therefore, do not require to be stiff, although they are rigid enough for carrying handling stresses. Gable walls have horizontal angles at eaves level which are of a stiffer section to strengthen this part of the house.

Doors and windows are made of the same sections, and are stiffened and braced by top hat sections. The basic units are available in two or four-room houses with different types of verandah attachment, all of which can be bolted and set in position by four to five men in just three days. The weights of houses vary from 800 to 2300 lb. depending on the size.

The simplest design comprises a house of two rooms, 10 ft. × 12 ft. 6 in. each, and having an eaves height of 9 ft. and a ridge height of 11 ft. The largest type and the most expensive is an eight-room house with front and rear verandah. The four main rooms are 10 ft. × 12 ft. 6 in., the four secondary rooms 5 ft. × 7 ft. 6 in., and the two verandahs are 5 × 10 ft. each, the eaves and gable remaining at the same level as before. The cost of the former is approximately Rs. 2165 and of the latter Rs. 5065. As they stand, they cover respectively a plinth area of 250 and 750 sq. ft. including the verandah. This works out to Rs. 8/12 and Rs. 6/12 per sq. ft. The average cost is, therefore, Rs. 7/12 per sq. ft. To this has to be added the cost of transporting the imported structure to the site, labour for erecting it and providing the necessary flooring either in plane concrete or with any variety of paving required. Working on an average type of house, weighing about 1500 lb., the cost of the above ancillaries would work out to Re. 1/4 per sq. ft. or a total plinth area rate of Rs. 9 per sq. ft. If other facilities have to be installed, the cost would run round Rs. 10 per sq. ft., which, by any standard of measurement, is high for industrial and rural housing, since locally constructed structures range within Rs. 7 to Rs. 9 per sq. ft. The relatively high cost of the house arises from the fact that the troughed sections, which form the principal structural unit, cost Rs. 2/5 per lb. and each running foot of the unit, which is 2 ft. 6 in. × 12 ft., weighs 17 lb. In other words, a troughed aluminium alloy sheet in this type of house costs Rs. 2/2 per sq. ft. which is relatively higher than the cost of a 9 in. brick panel wall or a plain or corrugated G.I. or asbestos sheet used with timber supports for roof or even siding. However, it is a little cheaper than a 5 in. reinforced concrete flat slab used for roof and covered with the usual waterproofing medium, such as brickbat coba and plaster, or China mosaic or cement tile paving or bituminous compound layers. This example furnishes a striking proof that a completely prefabricated house built from imported sections entirely in aluminium cannot compete with the traditional modes except in special cases where there is a dearth of local materials or where the cost of transportation of such materials would be very high.

(2) *Structural Components* — The second category provides for components in aluminium, leaving out the structure to be erected in the best and cheapest possible material available. The author believes that this type of structure is best suited to Indian conditions where local materials are available in plenty and labour is comparatively cheap and abundant. From a wide global study it is evident that aluminium would be best suited for purlins, rafters, roof trusses and sheets, in both large and small-span structures. In the case of small spans up to 10 ft., a truss can be dispensed with and an ordinary 20-24 gauge plain or corrugated sheeting used with a central purlin if desired. A plain 20 gauge (0·036 in. thick) sheet weighing ½ lb. per sq. ft. costs Re. 1/1 per

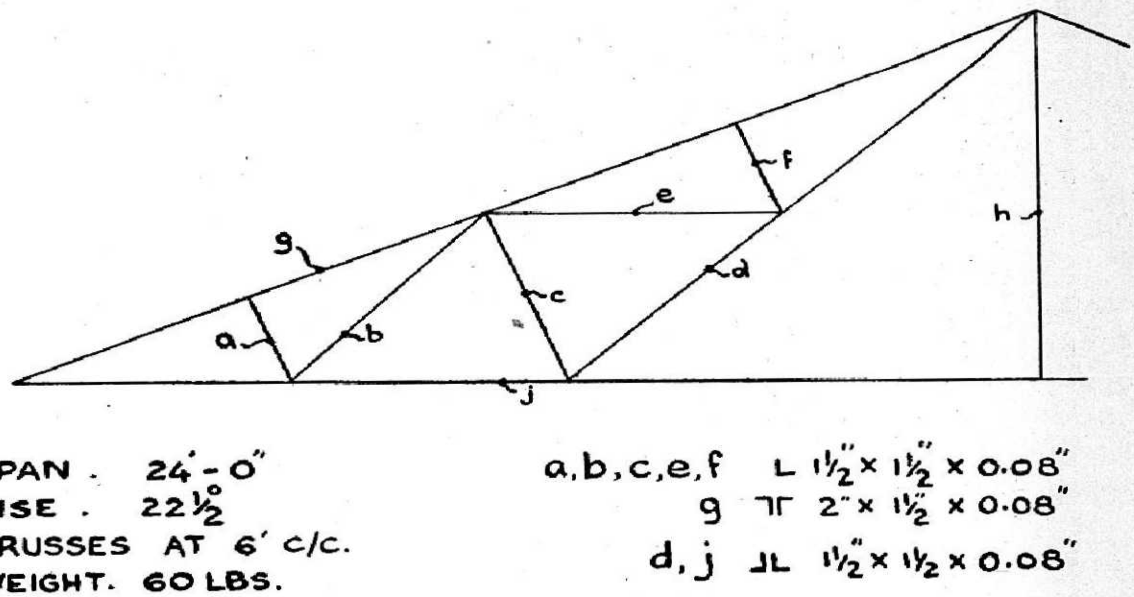

FIG. 2

sq. ft. (or Rs. 2/2 per lb.) and once installed requires little maintenance, as these light alloys do not rust, corrode or decay for a very long period. If it is found that a thinner sheet can be replaced, say 24 gauge (0·022 in. thick) weighing 0·31 lb. per sq. ft., it is advisable to use a corrugated section, as this form is capable of resisting higher stresses. A 10/3 corrugated sheet having 10 corrugations of 3 in. pitch, in 24 gauge, costs about Re. 1/13 per running foot, i.e. 31 × 12 in., or in other words As. 12 per sq. ft. It can readily be seen that this form of application becomes quite economical and can easily compete with the older accepted roofing materials. Experimental investigations have shown that due to high reflectivity of aluminium, most of the solar heat is reflected back and only a very small portion is allowed to pass through, generally in the vicinity of 10 per cent. Even this heat does not spread from the underside of the roof right down to the floor, but is localized in a portion just 10-12 in. immediately below the surface of the sheet. If for a place situated at 30° latitude, and having a wind speed of 15 m.p.h., a value of 300 B.t.u./sq. ft./hr. is assumed as the maximum value for solar radiation, then the amount of heat which would be transferred by aluminium sheeting would be only 76 B.t.u./sq. ft./hr., as contrasted with 154 B.t.u./sq. ft./hr. for asbestos sheeting and 250 B.t.u./sq. ft./hr. for galvanized iron sheets.

The surface of aluminium sheets requires no painting and presents a bright clean and well-groomed appearance. If, however, an additional aesthetic value is desired, they can be spray painted, the cost of which works to no more than As. 4 per sq. ft. Under very special cases anodizing can be resorted to, in which case the general cost becomes very high and the process prohibits a large-scale application.

The inherent characteristics of lightness of aluminium have been widely recognized in this application in roof trusses. Such structures, whether they cover large or small spans, can be easily fabricated in the workshop and brought to site and erected with a very light lifting tackle and a small labour gang. Economy in the speed of erection is, therefore, considerable as compared with a similar steel truss. An indication of these aspects is evident from Figs. 2 and 3 which show two trusses in aluminium.

The weight of the 24 ft. aluminium truss is 60 lb. and that of 52 ft. truss 360 lb.

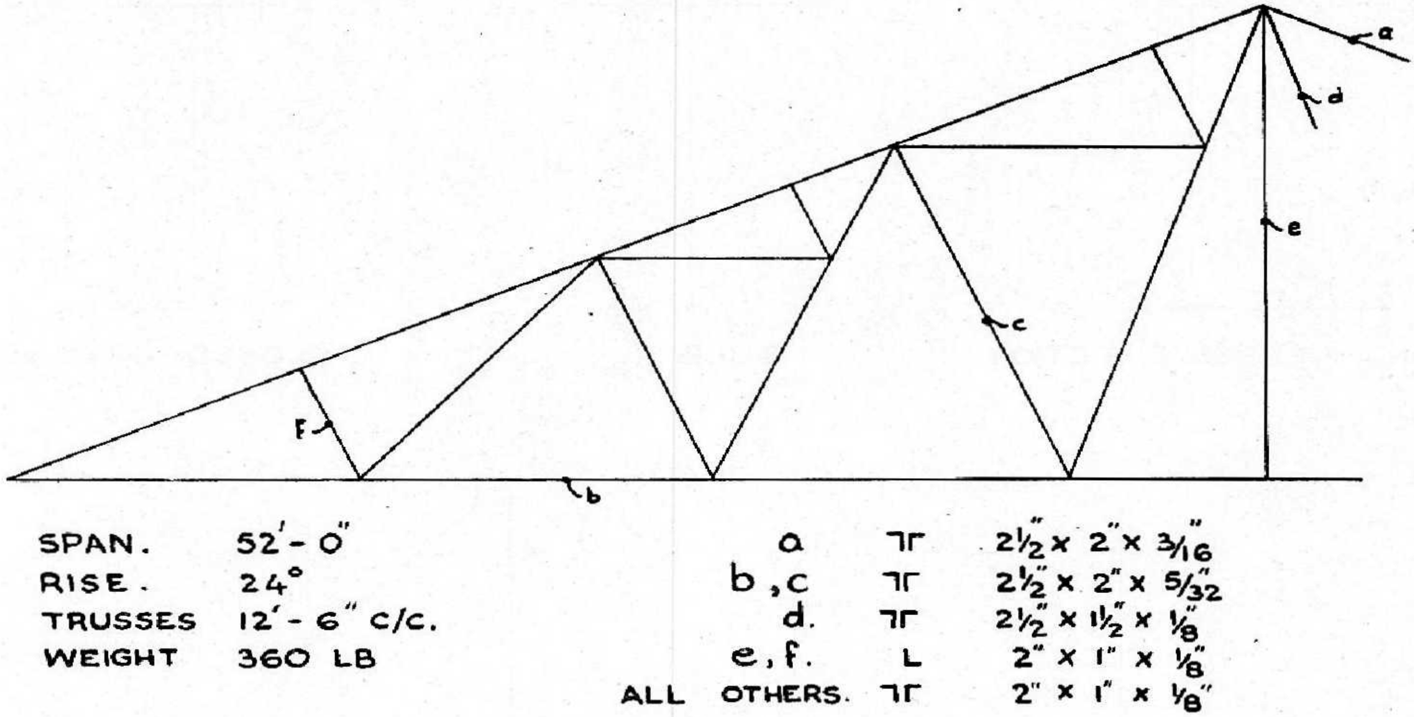

FIG. 3

A similar truss in steel would weigh 470 and 1500 lb. respectively. In addition to this saving in weight the supporting structures can be made much lighter, while maintenance cost for the trusses is practically nil. The overall economy in trusses does not lie in just substituting steel by aluminium, but in several other factors such as correct spacing of trusses, a good selection of roofing material; appraisal of wind loading, evolution of new sections, especially for large trusses for industrial structures such as N-lights; and the incorporation of stressed-skin principles in which the sheeting forms an integral part of the structure and in addition to acting as a mere covering also carries a part of the principal stresses.

The general principles of truss design apply equally well to aluminium beams and girders. An aluminium alloy beam of 25 T./sq. in. tensile strength shows for equal loading and strength a weight saving of nearly 60 per cent over steel, and for equal stiffness (i.e. equal deflection) a saving of nearly 38 per cent. In these cases the actual area of material used is 8-10 per cent more than steel for equal loading and strength. In the case of compression members the problems of elastic instability come into play, and every section has to be designed on its individual merits. The low elastic modulus of the metal results in a larger deflection and increased resilience, a property which can be put to good use in dance floors and diving boards, where fatigue can be minimized by this increased springiness. An excellent example of this property is furnished in aluminium bicycles which show considerable ease and lightness in riding than the conventional steel ones[13].

The future development of beams should proceed on the manufacture of unconventional sections such as the ones shown in Fig. 4, as these have proved to be more economical from the point of view of material utilization than the conventional forms of joists, channels, angles and tees.

A rational utilization of aluminium can only be made, when the correct mode of sectioning is recognized, and 'designing in shape' rather than 'designing in strength'

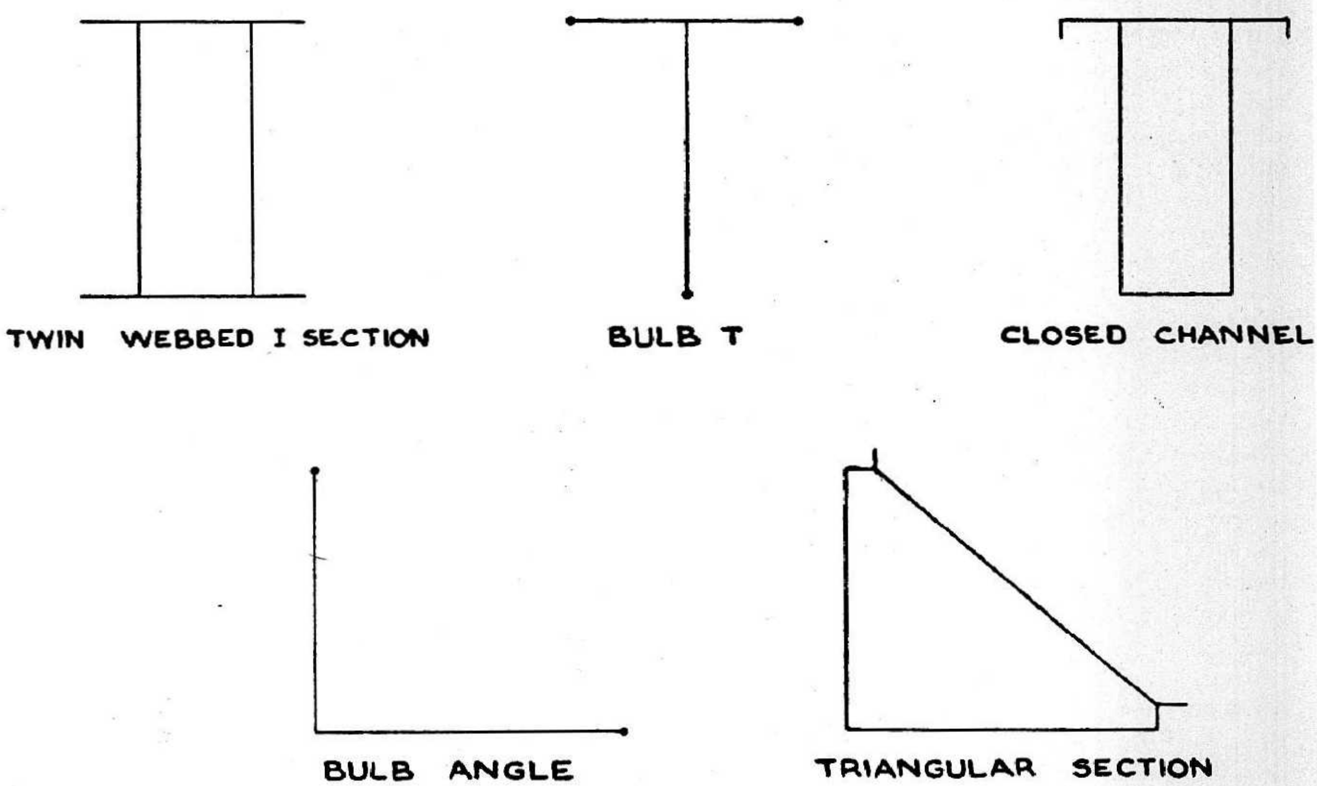

FIG. 4

is given due thought[12]. A correctly designed assembly would be one in which every component of the assembly and in turn every inch of the component is utilized to the limit of maximum permissible stressing. By avoiding the use of massive sections and using lattice structures and sheet-built members, material can be dispensed around the neutral zone and considerable economy achieved. Thus, for example, in Fig. 5 (a) and (b) are shown two 6 in. aluminium channels both having a weight of 2·91 lb./r.ft.

Channel (a) is of standard form while (b) is an extrusion designed to distribute the load more evenly. As a result of this change in form, channel (b) carries a load practically double of that which can be borne by channel (a) acting as a long column.

It can thus be realized that it is imperative for the structural aluminium industry to concentrate on the development of such sections for stress-carrying components instead of going in for the orthodox conventional forms suitable for steel construction.

(3) *Special Structures* — In special structures such as large canopies, lifts and escalators, aluminium is no doubt an ideal material.

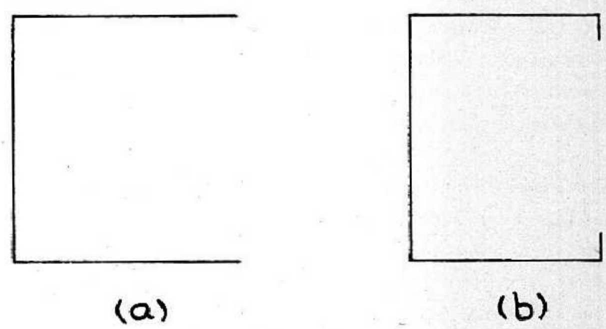

FIG. 5

Large stores in the United States, France, Switzerland and in other European countries have lifts and escalators in light alloys. In addition to the increased pay load and lighter handling, the electrical cost of running these structures is also reduced. Large ships like the *Queen Mary* and the *United States* have lifts in aluminium.

In a country like India, development of escalators does not appear very justifiable at this stage in view of its negligible demand. However, the use of light alloys in lifts is a very serious proposition and should be examined thoroughly as there is likely to be an appreciable saving in electrical energy, in spite of the initial high cost of installation.

(4-6) *Frames and Fittings* — Out of the remaining three categories, the development of door and window sections on a large scale and of other items like scaffolding tubes, railings, ducting and ornamental grillework on a smaller scale appears to warrant attention. Aluminium entered the field of window and door frames in 1920 and within a decade has established itself as a worthy material. The cost of an aluminium window installation mainly depends on design, for there are several instances when competitive work results if thought is given in using efficient sections not only in frames but also in glazing bars. In addition to the bare cost, the cost of maintenance requires to be duly considered, for, in aluminium, painting is rarely required and maintenance is reduced to just occasional cleaning. All the usual types of windows — casement, double-hung and fixed sash — are suitable for manufacture in aluminium, including the sliding variety, fanlights and roof lights. The extrusion process of manufacture allows more freedom than any other method in the design and permits efficient distribution of the metal to give maximum stiffness. Frames, particularly for double-hung windows, can also be cast in one piece by gravity diecasting process enabling the work to be turned out expeditiously provided a very large quantity is required. Many of the windows for the English Aluminium Bungalow, of which some 70,000 were produced between 1945 and 1948, were made in this manner. Generally greater care is required in transporting aluminium windows than is the case with steel, in order to ensure that frames do not undergo stresses greater than actual service and that packing is adequate to prevent undue distortion.

The portions of aluminium in contact with masonry or steel work are required to be painted for preventing any galvanic corrosion. Bituminous paint or compounds containing zinc chromate are quite satisfactory. All fixing clips and screws bearing on the frame should necessarily be in aluminium or galvanized or cadmium-plated steel. Once installed, aluminium windows require cleaning only by soap and water and compounds like 'Vim'. The windows of the New Bodleian Library, Oxford, were restored to original condition after six years of neglect during the last war by a mixture of light machine oil and furniture wax polish. In the windows of the New Cambridge Library, which required large openings for lighting the area contained over one and a half million books, some 28 tons of anodized aluminium had been used. In fact, at present most of the large shopping centres in Europe such as Milan, Zürich and Geneva have doors and window frames in aluminium, while its use in America is unprecedented anywhere. Two of the most conspicuous examples are in the United Nations Secretariat Building in New York and the 39-storey aluminium skyscraper built to house the offices of the Aluminium Company of America in Pittsburg.

For ornamental grillework, aluminium in the pure unalloyed state offers considerable scope in use in aesthetic architecture, while its use for rainwater goods and pipes requires to be developed. Scaffolding is another branch of building industry which offers unlimited scope of economy. By virtue of its lightness and long-range economy due to absence of maintenance and permanency as compared with the unsightly timber scaffolding, the light metal offers advantages which may not be apparent at first due to its high initial cost.

Commencing with the production of door and window frames, the industry should slowly start on the development of these auxiliary building necessities in order to cover the market on a bigger scale at a later stage. Initially, however, the main components of a building, especially the roofing side, offers a very wide market and requires to be concentratedly widened.

Bridges

Steel, reinforced concrete and timber have up to now been used in bridge construction. With developments in aluminium alloys, and a wider understanding of its properties, aluminium is slowly establishing itself as a valuable material for such structures. This is quite evident from the recently constructed bridges in aluminium, such as the Arvida Bridge over the Saguenay River, Canada, having a fixed arch span of 290 ft.; the floating pontoon bridges constructed by the Corps of Engineers, Army Service Forces, U.S. Government; the Double Leaf Bascule Bridge over the Wear River in Sunderland, England, having a clear opening of 90 ft.; and the Double Leaf Trunnian Type Bascule Bridge opened on 30 September 1953 at the entrance to the Victoria Dock, Aberdeen, Scotland, having a clear opening of 70 ft. and of quite an unorthodox design.

Although the advantages of using a light material in movable bridges such as bascule, swing, lift and Bailey type are self-evident, considerable economy can be achieved in static structures also.

It is a common knowledge that as the span of a bridge increases, the dead weight increases disproportionately till such spans are reached when it becomes a major consideration. It is for this reason that bridges over a mile in span are yet to be evolved, for with ordinary materials of construction and accepted methods of design, their own weight becomes so great that it bears a very disproportionate ratio to the live load and the whole feasibility becomes questionable. It is, therefore, evident that any material which would have the strength of steel but the lightness of timber would certainly carry the day. Aluminium is one such material, and should, with proper investigations, render itself ideal for long-span structures. It can be reasonably assumed that in view of the higher cost per pound weight, it would not reveal economies for short-span structures in all cases. However, in long-span bridges the difference in actual cost of steel and aluminium goes on diminishing till a point is reached when an aluminium bridge definitely becomes cheaper than an equivalent steel bridge. It is impossible to formulate exactly where this point is reached as a large number of variables enter into the design such as type of structure, nature of crossing and site, foundations, loadings and climatic conditions. Calculations made by Dr. Sutter of Aluminium Laboratories of Geneva have revealed that under certain specified conditions of loading and assumed foundation conditions, a double-track railway bridge in aluminium becomes economical for spans of 650 ft. and more. This indicates that the minimum economic spans for aluminium are not unduly long and can further be reduced by the use of high-strength aluminium alloys and adoption of advanced theories in design. General broad investigations appear to suggest that for spans of 600 ft. a weight saving of 60-70 per cent results while for higher spans it may be over 80 per cent. When the spans are under 600 ft., as is the case with the recently constructed bridges, the saving is anything between 20 and 60 per cent.

Modes of Industrial Development

At present, the utensil and domestic ware industry forms the single largest consumer of aluminium. With the increase in the production of the metal, especially with the envisaged Rs. 3 crore scheme for an aluminium factory and a thermal power station near Rewa to harness the rich potentialities of bauxite deposits in Vindhya Pradesh mountains, it is imperative that the structural aluminium industry should be developed to cope with the rising demands. However, this phase of the industry in particular and other engineering industries in general can only be set on their correct path through a wide dissemination of the basic properties and inherent potentialities of aluminium and a very exhaustive study of the modern design aspects of these alloys.

In foreign countries there exist research laboratories and investigation centres, either directly connected with the parent manufacturing concern or independent institutions for the spread of information on all aspects of aluminium technology. Among such bodies are the Research Laboratories of the Aluminium Company of America and the British Aluminium Company, England; the Research & Development Laboratories of Aluminium Limited, located at Geneva and feeding a group of aluminium concerns; S.A. pour l'Industrie de l'Aluminium, Chippis and Lausanne, Switzerland; Aluminium Research Institute, Chicago; Aluminium Francais, Paris; Beautechnische Auskunftsstelle, Stuttgart, Germany; Instituto Di Scienza Delle Construzioni, Milan, Italy; the Aluminium Development Association, London; and Centre Technique De l'Aluminium, Paris. Such technical associations exist not only for aluminium but have also been established for the development of other engineering materials such as the Copper Development Association, the Zinc Development Association and the Timber Development Association of England. The Aluminium Development Association (ADA), which represents the central co-ordinating body for research in the whole field of English aluminium industry, was established some eight years ago, with the specific object of spreading on a very wide scale the knowledge of the properties and applications of aluminium and its alloys and thereby increasing the consumption of the metal in all economically suitable forms. This object is carried out through direct advice to clients, publication of reports and bulletins, showing of films and giving lectures.

The author is of the opinion that India should establish a central disseminating agency on the lines of the ADA, with necessary modifications in its structure wherever justifiable. It is an accepted but lamentable fact that a vast majority of engineers and technologists of this country are still not fully aware of the importance of aluminium in the structural field as they are about steel or other materials of construction such as timber and reinforced concrete. Although considerable spadework will be required to establish such an organization, it is not beyond the bounds of possibility nor quite a new type of undertaking in this country. The latter aspect is evident from the existence, since the last 25 years, of the Concrete Association of India, an organization which is doing admirable work in the field of concrete technology.

As regards the modern design aspects of aluminium alloys, a careful preliminary study clearly indicates that very wide structural applications are possible through the use of ingenious ideas and conceptions based on fundamental theories in applied mechanics. Thus the principles of lighter type structure can be achieved in practice in aluminium through the use of space frames such as triangular trusses for bridges, coach bodies, aircraft fuselage, domes for roof, and hipped-plate structures. An indication where precise knowledge is required in designing can be had in the calculation of stresses in an aluminium plate girder. A plate girder with a span/depth ratio under 8 is designed as a panel, while for ratios above this value it has to be analysed as a beam. The tension field beam, not generally known outside the domain of aeronautics, is an excellent example of the manner in which the basic concepts can be advantageously applied in the structural engineering field. A tension field or semi-tension field beam is similar to a steel built-up girder with the difference that the web of this beam is made of very thin material, which is permitted to buckle or wrinkle under load. The wrinkled web acts like tension diagonals in an ordinary open-web truss and creates a tension field. A better-known counterpart of tension field beam is a sandwich panel, in which the flanges rather than the web are made of strong sheets. The core of the panel is formed of a low-density material like pulp-base products, while the facings are of thin aluminium sheets. The core provides suitable shear connections, increases the relative moment of inertia and also acts in stabilizing the relatively thin facings from buckling. Assuming the facings to be of an aluminium alloy of type 24 S.T. and a core material of density 0·01 lb./cu. in., it can be shown that in order to resist the same tensile loading, this type of sandwich panel would weigh 37 per cent less than a solid aluminium sheet, while for equal compressive loading the panel would weigh 21 per cent of the solid light alloy sheet.

Another interesting aspect arises in the riveting of aluminium structures. It has been recognized that the conventional rivet point shapes common in steel construction do not permit aluminium alloy rivets of a size greater than $\frac{5}{8}$ in. in diameter to be cold-driven with existing pneumatic hammers. Some point shapes are more easily formed than others, such as flat and conical, as compared with the counter-sunk types. Looking into these factors, a new trend in riveting practice is visible, wherein there is an increasing tendency to favour a small pan point for rivets up to $\frac{3}{4}$ in. in diameter and a drilled-end type for large rivets. Further it has been suggested that the grip of the rivet shank in the hole provides adequate resistance to tension under several conditions of loading, a suggestion which, if conclusively proved, will undoubtedly form a revolutionary idea of immense practical benefit in the field of fabrication of metals in general and light alloys in particular.

These few examples serve to indicate the wide and ever-growing adaptability of structural aluminium in hitherto unchartered fields and the limitless possibilities of its fertile consumption[14,15]. None of these are, however, possible to be put into the realms of practical engineering unless the actual production of the alloys is developed on a marked scale. This development can proceed speedily and efficiently provided the already established aluminium industry is correctly guided on its path, and a sound method of disseminating technical information in this field instituted. India, has vast resources of bauxite, and if it is properly processed, she can feed not only her own internal enterprises and the new-born shipbuilding and railway coach building industries, but also act as a world supplier of aluminium and its alloys, without having to restrict its exports merely to hollow ware to the meagre tune of 1000 tons per annum as at present.

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