Substitution of non-indigenous non-ferrous metals and alloys

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THE economic growth of any country is basically linked with her mineral resources and the means taken to exploit them. Mineral reserves are not seasonal or recurring assets and have, therefore, to be rationally utilized to lead to chain reaction growth of peace-time and defence industries and maximum overall growth of national economy. Mineral resources, in the background of their intrinsic value in directing the speed of a country's ecnomic development, may be utilized on an ad-hoc and empirical manner which in the long run will defeat the very basis of their economic importance. In the urge to industrialize and to do so speedily, a developing country such as ours has to have effective breaks as well as caution signs in planning the exploitation of mineral resources on a scientific and selective basis and rather more aptly put on "substitutional" basis.

In the wake of depleting mineral reserves and their shortages and in certain cases, in the almost total absence of some, researches and applied technological effects are continuously directed towards mineral conservation on the one hand and making the maximum optimum use of available resources on the other. In doing so, unconventional uses have to be made of different metals and their alloys through the judicious development of "substitute" ferrous and non-ferrous families of alloy compositions. The subject of substitute alloys has always tended to be somewhat controversial adjudged on the basis of indigenous availability of the primary metals not only in relation to metallurgical acceptability of the substitute alloys but also vis-a-vis their production economics, consumer acceptance and serviceability. The subject of "substitute ferrous and non-ferrous alloys" is, however, not new. During the last World War II, considerable strides were made in different countries to develop substitute alloys. Some of these substitute alloys have come to stay whilst others are being upgraded in relation to stringent properties' requirements for rigid service characteristics.

Metals in which, our country, whilst possessing some resources, is highly deficient are copper, zinc, lead, etc. The metals in which we are potentially rich are iron, aluminium, titanium, magnesium, beryllium, manganese, zirconium, etc. Metals such as nickel, tin, molybdenum, tungsten either do not exist or are perhaps found in isolated uneconomic pockets, even though with more intensified and comprehensive exploration and prospecting, some econmic deposits thereof may yet be discovered. The one non-ferrous metal whose resources are abundant in India is aluminium ; on account of the versatile properties possessed by aluminium, it has already found multiple end-uses, and new uses are fast developing in the face of acute competition with other alternative materials.

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Indian non-ferrous metals industry

According to Government of India's policy, prospecting for and mining of minerals are 'State' subjects. With the active co-operation of the Geological Survey of Indian Bureau of Mines, the Government have undertaken very extensive surveys of deposits of various important and strategic minerals in the country. The accompanying map of India shows the non-ferrous metal resources and industry in India. The Planning Commission's recommendations for the development of non-ferrous industry are as follows :

(1) Expansion of capacity in the aluminium industry by increasing the capacity of the existing plants and installing new plants.

(2) Installation of new plants for industries such as refining ores and scraps, so as to increase the supply of basic raw materials viz., copper, zinc, tin, etc. vital to non-ferrous industry.

Primary metal production industries

The progress of non-ferrous metals' production in India during the last eight years is given in Table I. To meet the incessantly growing requirements of the non-ferrous metals, India is dependent largely on the metals and semis imported from abroad.

The Indian requirements of some major non-ferrous metals based on their current demand pattern have

TABLE I Production trends of non-ferrous metals in India

				(in metric tons)	
	1956	1961	1962	1963	1964
1. Aluminium ingot	6 604	18 381	35 208	55 222	58 162
2. Copper ingot	7 750	8 336	9 781	9 857	9 475
3. Refined pig lead	2 536	3 662	2 851	3 537	3 624
4. Zinc concentrates	6 990	9 256	10 024	10 627	10 699
5. Antimony (from imported concentrates)	597	619	661	909	840

Source : The E.M.R., 8, 2, 1965, pp. 190-191.

been estimated by the Planning Commission for 1965-66, 1970-71 and 1975-76 to be as follows :

	1965-66 Tonnes	1970-71 Tonnes	1975-76 Tonnes
Aluminium	120 000	259 000	387 000
Copper	135 800	238 000	330 000
Lead	64 000	146 000	226 000
Zinc	136 000	225 000	340 000
Tin	8 000	11 000	15 000

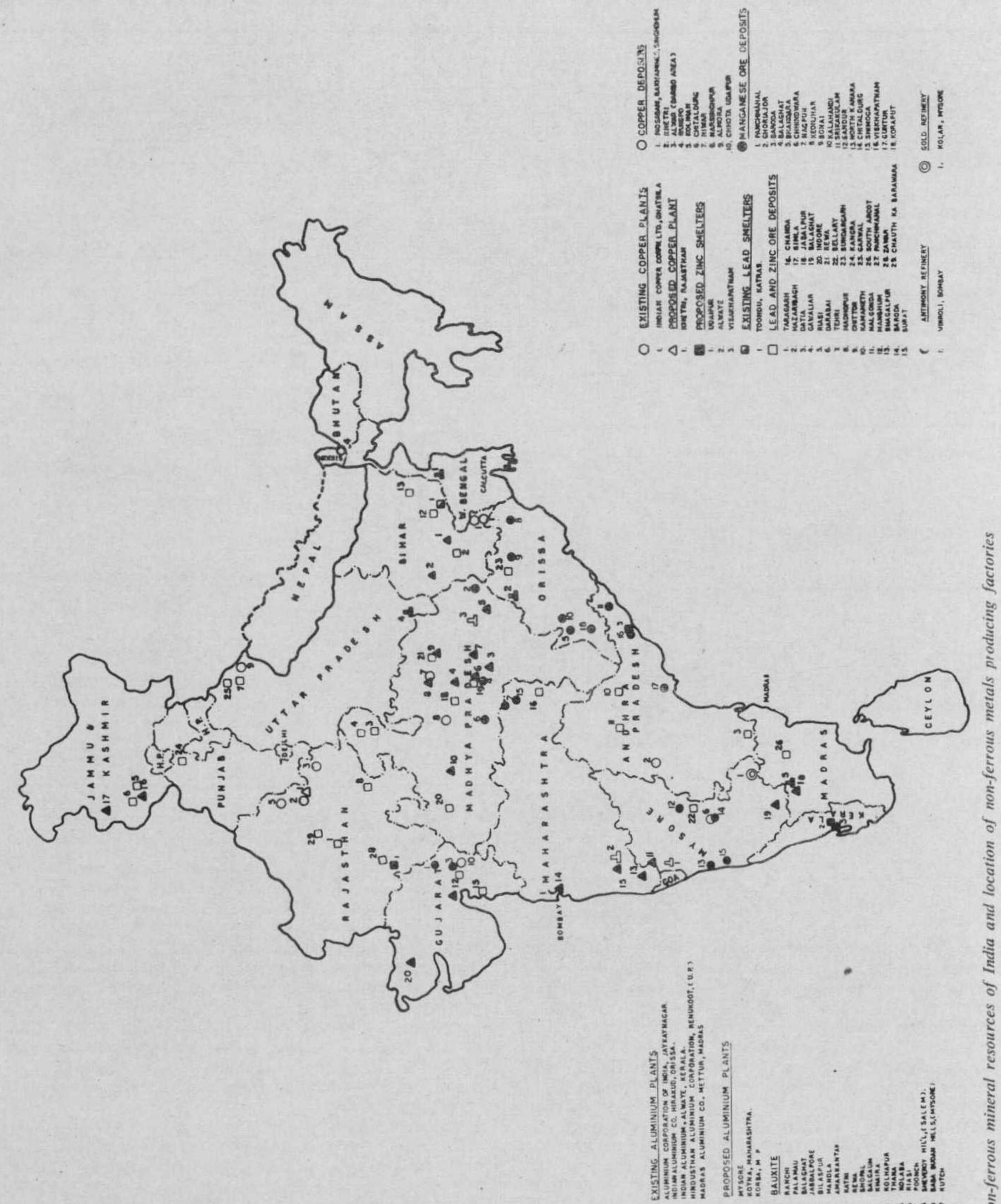
In Table II, the demand pattern of non-ferrous metals in India has been formulated on the basis of world consumption trends i.e. on the following basis. The annual consumption of non-ferrous metals in all leading countries has been compared with their ingot steel production for the corresponding periods. These consumption figures have been thereafter correlated with their corresponding annual ingot steel production of 15 million tons, 20 million tons, 25 million tons; incidentally these ingot steel production figures are closely related to Indian steel production projected targets, the figure of 25 million tons of ingot steel production has been projected for 1975-76 i.e. by the end of the Fifth Five-Year Plan and of 15 million tons by 1970-71 i.e. by the end of the Fourth Five-Year Plan.

TABLE II Non-ferrous metal/mineral demand pattern for India

	(in metric tonnes)		
	15 million tons 1970-71	20 million tons	25 million tons 1975-76
Aluminium (primary)	250 000		450 000
Antimony	3 500	4 500	5 500
Beryllium	75	100	125
Bismuth	150	200	250
Cadmium	550	750	900
Chromium as chromite	110 000	150 000	200 000
Cobalt	300	400	500
Copper (refined)	225 000	300 000	390 000
Lead (refined)	100 000	150 000	180 000
Magnesium (primary)	8 000	10 000	13 000
Molybdenum	2 500	3 000	3 500
Nickel	15 000	20 000	25 000
Tin	8 000	10 000	13 000
Titanium sponge	1 000	1 250	1 500
Tungsten	1 100	1 500	1 800
Vanadium	450	600	750
Zinc	140 000	180 000	230 000

The metals in heavy use today are aluminium, copper and zinc. These three metals are needed in large quantities, whilst considerable progress has been made in the production and planning of production capacity for aluminium, the projected copper and zinc production has not materialised so far. It is imperative that recognizing the present chronic shortage of foreign exchange, urgent and immediate steps are taken to (i) procure concentrates of zinc from abroad (ii) produce concentrates from our own resources in Rajasthan and (iii) get the projected plants of copper and zinc at Khetri, Zawar, Vishakhapatnam and Kerala established in the near future.

Zinc consumption in India during 1960-61 was about 70 000 tons, which represented a 100% increase over the previous five years. The estimated annual requirements of zinc by the end of 1965 are about 185 000 tons which again represent more than 100% increase over the present Five-Year period. Even with the sett-



Non-ferrous mineral resources of India and location of non-ferrous metals producing factories ing up of the proposed plants at Udaipur, Alwaye and Vishakhapatnam in due course, smelting capacity of zinc in India would be far short of our increasing requirements. The big gap in indigenous capacity and requirements of zinc warrants an immediate consideration of replacing galvanizing by aluminizing since galvanizing industry in India consumes the major bulk of imported zinc.

As regards copper, a tentative production target of 45–50 000 tonnes has been set for 1970. A production of this order taking into account about 23 000 tonnes of scrap will leave a gap of 147 000 tonnes/annum to be met from imports.

Due to limited indigenous resources of ores of these non-ferrous metals, it will not be possible to achieve self-sufficiency in their production for a long time to come, except in the case of aluminium for which abundant supplies of bauxite are available in the country. In view of the paucity of indigenous supplies of ores for the manufacture of other non-ferrous metals, and in order to reduce the heavy drain on the country's foreign exchange reserves, it has become necessary to discourage the use of copper and zinc for non-industrial purposes. This would naturally mean that a greater role is to be played by aluminium in all fields, wherever its use is technically acceptable and economically feasible. Both copper and zinc are, at present imported, involving heavy drain on our foreign exchange. With the free availability of aluminium in India, copper and zinc can appreciably be replaced by aluminium and corresponding foreign exchange thus can be conserved.

In the field of non-ferrous metals, aluminium has been given the place of pride in the Five-Year Plans in view of the enormous reserves of indigenous ores and limited resources of other basic non-ferrous metals such as copper, zinc, lead, nickel, etc. The total reserves of all grades of bauxite have been established to be 276 million tonnes out of which reserves of high grade bauxite are estimated at 74·0 million tonnes. Production of bauxite during 1964 reached an all-time peak of 591 000 tonnes.

The main factors that have favoured the vast expansion of aluminium industry in India are :

1. Potentiality of aluminium to replace copper particularly in the electrical industries and other non-ferrous metals and steel and its stabilized prices over relatively long period ;

2. Inadequate deposits of ores for non-ferrous

TABLE III Installed and licensed capacity for aluminium production in India

Sl. No.	Name of company	Technical collaboration	Location of smelter	Present installed capacity tonnes/year	Licensed capacity by 1970–71 tonnes/year	Remarks
1.	Messrs Indian Aluminium Co. Ltd.	Aluminium Ltd. & Aluminium Laboratories Ltd., Canada	Alupuram-Alwaye (Kerala)	10 850	15 850	
2.	Messrs Indian Aluminium Co. Ltd.	do	Hirakud (Orissa)	20 000	20 000	
3.	Messrs Indian Aluminium Co. Ltd.	do	Between Hubli-Belgaum (Mysore)	—	30 000	
4.	Messrs Aluminium Corp. of India Ltd. (J. K. Industries Ltd.)	Aluminium Industries A. G., Switzerland	Jaykanagar (West Bengal)	7 500	12 500	
5.	Hindustan Aluminium Corp. Ltd.	Kaiser Engineers Corpn., USA	Renukoot (Uttar Pradesh)	40 000	60 000	Licence issued for raising production to 120 000 tonnes/year
6.	Messrs Madras Aluminium Ltd.	Montecaini, Italy	Mettur (Madras)	10 000	20 000	
7.	Messrs Bharat Aluminium Corp. (Public Sector)	Vereinigte Aluminium Worke, West Germany	Koyna (Maharashtra)	—	50 000	25 000 tonnes in the 1st stage
8.	Messrs Bharat Aluminium Corp. (Public Sector)	Hungarian up to Alumina stage	Korba (Madhya Pradesh)	—	100 000	Being negotiated with Russian assistance
				68 350	308 550	

metals such as copper, zinc, lead, etc. and restricted imports in view of tight foreign exchange position ;

3. Extensive bauxite deposits in the country and large demands for aluminium conductors of various types for power distribution and favourable price factor.

Demand and production

Demand of aluminium in India has been progressively increasing from 15 000 tons in 1951 to 27 000 tons in 1955–56 ; in 1960, it reached the figure of 45 000 tons.

The demand for aluminium in 1965–66 was estimated to be of the order of 1 20 000 tons. About 60 000 tonnes of electrical grade aluminium are mainly required for transmission and distribution lines, bus-bars and die-castings and for substitution in power cables and house-wiring. The principal uses of the commercial grade aluminium are domestic utensils, aluminium alloys, packing (foils), building construction, food, farming and sugar industries, etc.

Table III shows the present installed and licensed capacity for aluminium metal production in India. Till 1965, only three firms were producing aluminium in India viz. The Indian Aluminium Company, with smelters at Hirakud (Orissa) and Alupuram (Kerala) ; the Aluminium Corporation of India with smelter at Jaykaynagar (West Bengal) and the Hindustan Aluminium Corporation Ltd. with smelter at Renukoot (Uttar Pradesh). During 1965, the smelter at Mettur of Messrs Madras Aluminium Ltd. went into production in collaboration with Montecatini of Italy with a capacity of 10 000 tonnes of ingot aluminium per year, to be expanded to 20 000 tonnes during the Fourth Plan period. In addition, the expansion of Alupuram smelter of Indian Aluminium Co. to 10 850 tonnes/annum capacity has been completed, thereby raising the total aluminium ingot capacity installed in the country to 88 350 tonnes/annum. Further expansion of Alupuarm smelter to 15 850 tonnes/annum is in progress. Jaykaynagar smelter envisages an expansion to 12 500 tonnes/annum during the 4th Plan period. Recently, an agreement has been signed with the Hungarian Government for design of alumina plant of 200 000 tonnes annual capacity at Korba in the public sector to feed a smelter capacity of 100 000 tonnes of annual ingot aluminium production, for which Soviet assistance is under negotiation. A letter of intent has also been given recently to the Indian Aluminium Company Limited for setting up a 30 000 tonne/annum aluminium smelter at a site between Bubli and Belgaum in Mysore State with power supply from Shravathy project. Another public sector project of Bharat Aluminium Corporation envisages setting up a smelter at Koyna for 50 000 tonnes/annum capacity, the foreign collaboration is under negotiation with Messrs Vereinigte Aluminium Werks (VAW) of West Germany for the Koyna Project. By the end of the Fourth Plan period if all the expansion projects and the new licensed and projected plants are completed, a capacity of over 300 000 tonnes of ingot aluminium per annum would be achieved.

With the rising tempo of industrialisation during the last one decade, the general pattern of distribution of non-ferrous semis manufacturing industry in India has become more wide-spread ; the industry also has considerably diversified the output as well as increased the quantum of production. New plants have been set up in the last few years for the production of aluminium foils etc. Table IV shows the capacity and demand figures for aluminium semis manufacturing industry for 1965–66.

TABLE IV Estimated demand and capacity for Al semis manufacture for 1965

	Installed capacity	Production 1963	Projected capacity 1965–66	Estimated demand 1965–66
	Tonnes			
Al and alloy sheets circles and strips	26 200	22 244	44 210	60 000
Al and alloy extruded products	3 800	3 936	10 700	10 000
Al foils	3 000	2 844	7 500	9 000
Al wire rods for ACSR and AAC	61 300 (1964)	44 757 (1964)	85 300	55 000

The uses of aluminium are basically determined by the choice of versatile qualities in the context of favourable long term economic factors which this metal possesses, either by itself or along with suitable alloying elements. Amongst these qualities, the following are notable :

(i) Low density (2·74), ⅓rd of other common metals. Weight comparison of the various materials is given below :

Material	Weight (gm/cm³)	Material	Weight (gms/cm³)
Magnesium	1·74	Iron	7·86
Aluminium	2·70	Brass	8·10
Chromium	6·92	Nickel	8·90
Zinc	7·13	Copper	8·92
Tin	7·28	Lead	11·34

Aluminium is thus much lighter than ferrous as well as most non-ferrous metals. It has only ¼ the weight of lead ; 2/7 the weight of copper ; ⅓ the weight of steel, zinc, or tin ; and has roughly the same weight as asbestos, glass or mica.

(ii) High strength (with very high specific tenacity, i.e. strength/weight ratio) ; e.g. 'ALCLAD' 7075–T6 aluminium alloy has an ultimate tensile strength (at room temperature) of about 41 tons/sq. in. Mild steel has a tensile strength of about 30 tons/sq. inch.

(iii) High corrosion resistance and hence long economic life and low maintenance cost, as also high scrap value. The thin film of inert oxide always present on its surface confers excellent resistance to corrosion.

(iv) Non-toxic character and resistance to moisture, light and heat.

(v) High thermal and electrical conductivity. Pure aluminium has 62% of the thermal/electrical conductivity of copper, by volume, and more than 200% by weight.

(vi) High reflectivity of radiant heat and light.

(vii) Non-magnetic and non-sparking properties.

(viii) Ease of machining and fabrication (including high malleability, ductility, etc).

(ix) Extremely attractive brightness and finish.

Moreover, these advantages are inherent at a competitive cost which compares favourably with that pertaining to alternative materials. These favourable technical factors must be fully exploited with a view to overcoming the economic disadvantages of its high initial production cost.

On account of the wonderful versatility of qualities possessed by aluminium, it has already found multitude end-uses, and new uses are fast developing in the teeth of competition with a number of other alternative materials. Thus, aluminium sheets are competitive with galvanized steel sheets, for roofing and panelling purposes. Aluminium utensils are competing satisfactorily against stainless steel, copper, brass, enamel-ware and earthen ware. Aluminium foils are good substitute for lead, tin, paper and plastics. Aluminium electrical conductors are fast replacing copper, particularly in India.

Another notable fact is that the prices of aluminium products have remained steady over a number of years despite the inflation in many metal markets.

The principal fields, in which the consumption of aluminium is fast growing in India and is likely to further develop are the following :

1. The electrical industry
2. Domestic utensils and household appliances
3. Transportation
4. Building and construction
5. Canning, packaging and farming
6. Other industrial and engineering uses
7. Miscellaneous uses including export market.

Table V shows the trend in end uses of aluminium in U.S.A., U.K. and Italy compared with estimated uses in India.

TABLE V Trend in end uses of aluminium

				INDIA		
Aluminium use	U.S.A 1961	U.K. 1961	Italy 1961	1960/61 estimated	1965/66	1970/71 estimated
Per capital (kg)	11·0	5·4	2·1	0·11	0·25	0·45
Total ('000 tonnes)	1 800	282	105	50	125	259
By industries (% of total)						
(a) Electrical	12·1	10·8	7·3	35·6	48·4	48·2
(b) Utensils and durable appliances	12·2	10·8	7·5	24·4	20·0	17·3
(c) Transportation	23·6	30·4	10·1	15·5	10·4	10·5
(d) Canning and packaging	7·7	8·4	42·8	6·7	5·6	5·6
(e) Building and construction	26·9	10·1	10·8	6·7	4·0	5·0
(f) Other uses	17·5	29·5	21·5	11·1	11·6	13·2
Total	100·0	100·0	100·0	100·0	100·0	100·0
Plus exports as % domestic use	7·1	17·1	5·5	—	1·6	12·9

Source : 'Capital' (Calcutta) Indian Industries Survey 1964, p. 70.

The requirements of aluminium in India by consuming industries as estimated by the Perspective Planning Division of the Planning Commission are given in Table VI.

TABLE VI The requirements of aluminium by consuming industries

	(in thousand tonnes)		
	1960	1965–66	1970–71
1. Transport equipment	2·8	7·9	15·7
2. Electrical industries	17·1	52·0	108·1
3. Food/Textile and chemical equipment	0·8	2·3	5·6
4. Canning and packing	4·0	7·5	15·0
5. Building and construction	3·0	4·7	7·0
6. Domestic utensils and other commercial supplies	10·0	17·6	28·0
7. Defence and Ordnance	—	5·0	10·0
8. Miscellaneous	8·5	22·1	69·8
	46·2	119·1	259·2

Substitution of non-ferrous metals by aluminium

A certain degree of substitution of copper by aluminium has already been envisaged during the Third Five-Year Plan such as :

Replacement of bare copper conductors by aluminium canductors to the extent of 5 000 tons by 1965–66 and 15 000 tons by 1970. Substitution of 1 000 miles of paper-insulated cable based on copper wire by aluminium wire in 1965 and 2 500 miles in 1970. Substitution of copper by aluminium in heavier VIR and PVC wires to the extent of 200 million yards by 1965 and 600 million yards by 1970. Replacement of copper and copper base alloys by aluminium and other alloys for switch gears by about 10 per cent by 1965 and 20 per cent by 1970. Replacement of about 50 per cent of copper required for hardware by other metals and alloys. Substitution of copper utensils by aluminium initially and later by stainless steel—the actual extent of such substitution to be assessed subsequently.

Electrical applications

(a) Cables

The growth of cable industry in India during the last decade and half has covered a diversified range of products with increased electric power production and distribution in the country. The cable industry has already switched over to aluminium conductor cables for all but highly specialised items like trailing, signalling and flexible cables. The installed capacity in 1964, production and Third Plan targets of production and capacity are furnished in Table VII whilst demand estimates of cables and wires by 1970–71 are given in Table VIII.

There were 16 large scale units in 1964 manufacturing ACSR and AAC cables with an aggregated capacity of 42 564 tonnes. Four of these units were licensed for raising their capacities along with licences for setting up a new unit. There are a few small scale units engaged in the the manufacture of AAC. Total annual capacity

TABLE VII Installed capacity, production and Third Plan targets in cable industry

Sl. No.	Cables and insulated wires		3rd plan targets* for 1965–66		Installed † capacity 1964	PRODUCTION			No. of units
			Prodn.	Capacity		1962	1963	1964	
1.	ACSR & All Aluminium conductors	tonnes	55 000	68 000	42 564	28 656	32 412	45 360	16
2.	Bare copper conductors	tonnes	15 000	18 700	18 084	4 944	4 392	5 736	5
3.	VIR & PVC Cables	million core yds.	600	800 (core yards)	3 622 (lakh metres)	2 763	3 142	3 336	28
4.	Paper insulated power cables	kilo-metres	5 500 (miles)	6 500 (miles)	1 416	2 060	2 639	2 639	5
5.	Winding wires	tonnes	24 000	32 000	7 788	6 804	7 932	8 940	14

Source : * E. M. R. Annual No. 1965 p. 844. † Handbook of Statistics, Engineering Association of India, July 1965, p. 78.

TABLE VIII Demand of cables and wires by 1970-71

1.	Bare copper conductors	5 000 tonnes
2.	ACSR	90 000 tonnes
3.	All aluminium conductors	35 000 tonnes
4.	Paper insulated lead covered cables	35 000 tonnes
5.	Enamelled wires	25000 km.
6.	PVC Power cables	37 500 km.
7.	VIR wires	353 million core metres
8.	PVC wires	350 million ,,
9.	Paper covered strips and wires	30 000 tonnes

E. M. Review, August 15, 1965, p. 845.

is estimated at 62 200 tonnes. The requirements of high tensile galvanised steel wire would be about 25 000 tonnes by 1970–71 for ACSR. It has been reported that the requirement of electrolytic conductor grade aluminium in 1963 was of about 26 000 tonnes but only 18 500 tonnes was capable of being converted to rods by the cable industry and a substantial portion of the requirements was thereby imported. With the growth of the aluminium industry, increasing quantities of electrolytic conductor grade alluminium will be available to meet the demands of the high tensile galvanised steel wire for ACSR conductors, an output of about 7 000 tonnes from 3 units was available in 1963 and an estimated output of about 18 000 tonnes was foreseen during 1965 subject to adequate wire rod availability; estimated requtrements during 1970–71 will be about 65 000 tonnes. For electric power transmission lines, the ACSR cables have been in use for a long time. With the development of AAC and aluminium conductor aluminium reinforced (ACAR) conductors requiring no steel cores, the installation will be simplified due to lightness. An increasing application is being made of PVC insulated and sheathed cables in India. The requirements of lead for sheathed and paper insulated cables by 1970–71 are estimated at about 60 000 tonnes. It had been reported by the Sub-committee of the Development Council for Heavy Electrical Industries that it is possible to switch over almost 100% to PVC insulated and sheathed cables for voltage ranges up to 1·1 kV and thus substitute lead, thereby saving the latter to the order of about 40 000 tonnes by 1970–71. Beyond this range a suitably phased programme could be laid down.

The use of aluminium wire in buildings, of aluminium cable sheathing in underground cables substituting lead sheathing on both telephone and power cables, will be steps in the right direction for reducing the consumption of copper and lead in the country.

Transformers, capacitors, etc.

The electric fan industry has become a very important industry in India earning valuable foreign exchange and as such attention must be given to uniform substitution by all manufacturing units. Some of the leading manufacturers are using aluminium for die cast end frames in addition to the almost universal application of aluminium alloy sheet for fan blades, ceiling caps, etc. The use of aluminium for casting end frames by pressure die casting will improve the overall economics by mass production methods and will help to reduce the cost of the fan, enabling the industry to compete better in foreign markets.

The use of copper for windings and transformers in India was estimated at 2 440 tonnes in 1960 increasing to 6 650 tonnes in 1965–66 and 17 100 tonnes by 1970–71. Therefore, there is considerable urgency in converting these windings wherever feasible to aluminium. Aluminium has been used elsewhere for capacitors with foil or tape windings, coreless reactors with cables or rectangular bars, etc. Cast aluminium silicon alloys find wide application in motor-stator bodies, equipment casings, parts for high voltage switch gear, circuit breakers, etc. Aluminium foil is now being widely used for solenoids for heavy electro-chemical equipment, field coils for travelling wave tubes, TV transformers, etc. whilst anodised strip is used for dry type and oil filled transformers, magnet coils, etc. Aluminium foil or strip with insulating sheet layers in coils has become popular in automotive applications such as generators, motor starters, horns, starter relay coils, etc. Aluminium is regarded as a popular choice for busbar applications, especially in the field of heavy currents, where it is most economical. Aluminium busbars have been widely used abroad economically in many electric furnaces, eletrolysis plants, etc.

Refrigeration and air-conditioning

In refrigeration industry for commercial refrigeration purposes, such as display cabinets, bottle coolers, water coolers, deep freeze cabinets, milk cooling units, etc. until recently compressors, controls, copper tubing and stainless steel continued to be imported. Finding substitute for stainless steel has also caused considerable concern. Both I.S.I. and the Government have set up panels to find out ways by which this extremely suitable metal could be replaced by black sheet spray metallised by aluminium, aluminising, etc. As far as replacement of copper tubing is concerned, a proper type of ERW steel tubing could be tried in certain applications. The use of aluminium tubing in the refrigeration industry in India remains unexplored. Some firms in the U.S.A. have started using aluminium tubing, but some research and basic design aspects have to be carefully looked into before the industry uses the aluminium tubing. However, in the industrial refrigeration and air-conditioning equipment field the largest field of air-conditioning, ERW tubes of aluminium could be used in the air-handling units of air-conditioning plants as also in condensers and chillers. In view of acute shortages of foreign exchange being faced by the country in order that air-conditioning industry can cope with the growing demand, the alternatives to copper should be seriously examined and tried out by the industry.

Economics

It is inevitable that aluminium should also be compared with copper on the basis of its replacement cost. In a symposium on 'Aluminium in Electrical Engineering' held in U.K. in May 1957, the economics of use of aluminium vis-a-vis copper was considered in detail. The general principle involved is set out in the following :

Effects of electrical properties*

To evaluate the relative costs of aluminium and copper as electrical conductors, it must first be taken into account that a given volume of copper weighs approximately three times that of aluminium. For equal electrical resistance, the volume of aluminium is 1·6 times the volume of copper, and because metal prices are always quoted by weight, both these factors have to be considered in deriving the relative cost of conductors of equal resistance.

The metal cost is, of course, only the basic factor, for ingot or wire bar must be fabricated. The rolling, extruding or drawing of the metal to the required dimensions involves costs based on volume rather than weight, so that when the price of the product is expressed at a price per pound these production costs are approximately three times higher for aluminium than for copper.

When dealing with short lengths of conductor where the current rating for a given temperature rise is more important than the resistance, the aluminium conductors will carry approximately 10% more current than the copper.

The principles relate to bare conductors, but the same principles apply to aluminium used as the conductor in an insulated cable. In this case, however, the saving in cost due to the aluminium conductor is further offset to some extent by the increased cost of insulation, because the diameter of the aluminium conductor is 1·25 times the diameter of the copper conductor of equal resistance.

It may not be out of place to note here the developments in the U.K. and U.S.A. towards adoption of aluminium for power conductors where economy rather than substitution is the main factor for making the choice. The British Electrical Supply Industry had been very conservative about switching to aluminium until about three years ago, but there has been a sweeping trend since that time with much of the growth in underground distribution cables, However, as reported recently by U.S. Aluminium Association, use of aluminium in electrical applications rose by 19% in 1964 to 838 million pounds in the U.S.A. Chief factors to account for the growth is economy ; since a pound of aluminium will go more than twice as far as a pound of any other material in this application. In addition lighter weight of aluminium makes possible wider spacing of transmission towers and utility poles resulting in more economical installation. Major growth areas foreseen by S. L. Goldsmith, Junior Executive, U.S. Aluminium Association in the United States,** are: (URD) underground residential distribution cable, aluminium building wire for industrial, commercial and residential use and further expansion of aluminium applications in extra-high voltage transmission lines and towers.

In the field of extra-high voltage lines there is a trend towards the use of cable reinforced with high strength aluminium alloys rather than steel. Especially in hard-to-reach areas there is a growing market for aluminium transmission towers where light-weight towers can be brought in by helicopters. Recently Alcan designed conductors have been used with 23 strands of D 50 S aluminium alloy with a tensile strength of 110 000 lb/in^2 for record breaking transmission of 735 000 volts at South Shore of St. Laurence (new Monecougan-Montreal Power line).

Economic effects of other properties‡

Dr West has appropriately summarised the economic effect of other properties of aluminium and forecast future trends of its applications as follows :

The full cost of any installation must take into account metal cost, and hence the work price of the components and assemblies, besides other factors. Among those favourable to aluminium are the transportation, erection and installation costs, maintenance required during the planned period of service, any incidental expenses resulting from failures which may, of course, be due to faulty conditions, and the scrap value. The ability of aluminium to form several major series of alloys permits its ready acceptance for many applications requiring an optimum combination of characteristics, for example, good electrical conductivity plus enhanced strength.

Aluminium and, particularly, its alloys can be fabricated by all the usual processes, including gravity and pressure die-casting to give components of good surface finish, high dimensional accuracy and the minimum weight. This process, like extrusion, permits the designer to dispose metal in the most favourable position from the point of view of strength and rigidity : for example, for purely structural purposes there exist both standard ranges of structural sections (B. S. 1161) and an infinite variety of special sections which can be extruded readily and cheaply.

The anodised coating can be varied by appropriate processing to give films up to several thousandths of an inch thick, wiih a wide range in hardness, porosity and electrical properties.

Technological advances in soldering, welding and other processes have made such jointing possible at no

* Dr E. G. West, Metallurgia, June 1957, p. 268.

** Light Metal Age—August 1965, p. 18.

‡ Dr E. G. West, Metallurgia, June 1957, P. 269

greater cost than those firmly established for older materials. The ability to weld aluminium alloy castings to wrought material, allows maximum economy to be achieved in designing complex assemblies.

Finally, in this context, account must be taken of the advantage of low weight for transportation of conductors and equipment from the works to the site and during installation of overhead lines, pylons, transformer stations, busbars, etc.

Future trends

Factors which favour the increasing use of aluminium are :

The long-term supply of aluminium is particularly favourable by comparison with the other non-ferrous metal concerned, due to the greater abundance of high grade ores and the establishment of very large modern production units now being set up in India.

Based on the long-term supply position and technical considerations of metal extraction and fabrication, aluminium conductors should continue to be appreciably cheaper than copper conductors for the same capacity, and it should also maintain its competitive position with lead and zinc at the present ruling prices.

Coupled with the present supply and cost trends is the important factor of price stability. This is favourable to aluminium on forward planning from the point of view of purchase, and also on the basis of scrap value when conductors or other equipment eventually become obsolete.

Considering the technical aspects of material usage, it appears that the working, jointing, installation and maintenance costs of aluminium conductors and equipment should be no higher than those incurred in carrying out similar operations on copper, lead, etc. Indeed, the lower weight of aluminium must result in some reduction in certain of these costs, such as transportation and erection.

It is a truism that each metal will eventually find its appropriate level of application, based on its inherent properties and economic return, but it seems certain that the many applications of aluminium already established will continue to be acceptable. For certain applications, copper is still and may well remain, the most suitable of conductor materials and therefore it seems reasonable to suggest that copper should be used basically for these essential purposes.

Aluminium can replace lead for cable sheathing with economy in first cost, economy in maintenance and an assured supply of metal. Lead is essential for certain other purposes in the electrical industry, particularly for accumulators and for solders, for which aluminium cannot be used and should only be used for such purposes.

Aluminising

The big gap in indigenous capacity and requirements of zinc warrant an immediate consideration of replacing galvanising by aluminising in all possible applications as galvanising alone is responsible for most of the zinc consumed in India.

Aluminised steel is better corrosion-resistant than the galvanised material. Viewed in this context and also keeping in view that so far the country's entire requirement of zinc is met by import, the National Metallurgical Laboratory undertook a comprehensive research scheme on the development of suitable technique for the production of aluminised steel. Extensive work conducted in the laboratory had resulted in the successful formulation of three processes of aluminising which essentially differ in the types of flux used. To work out the economics of the process and to determine the feasibility of the methods for commercial production, a pilot plant was designed and fabricated in the Laboratory and highly successful pilot plant trials were conducted. Samples of aluminised wires produced at the pilot plant were sent to British Iron and Steel Research Association which has reported that the samples were exceptional in quality and set a very high standard. The NML process has been leased out to industry for commercial production of aluminised steel articles.

Aluminised steel possesses the mechanical strength of the base material with high corrosion resistance afforded by the superimposed surface layer of aluminium. It can resist corrosion in saline and industrial atmospheres containing sulphur. Due to good scaling resistance at room and a range of elevated temperatures it can be used for automobile parts such as manifold pipes, mufflers, for carburising boxes and other multitude applications requiring resistance to scaling at atmospheric and elevated temperatures. In India, where resources of zinc and tin are scarce but production of aluminium is rising steadily, the importance of making full uses of aluminium in sheet, wire, buckets, hollow-ware, and hard-ware aluminising needs a little emphasis.

Aluminium coated cast iron can find applications for oven linigs, hangers, conveyor parts, enamelling racks, furnace parts, thermocouple protection tubes, gate bars, heaters and radiators, etc.

Application of aluminised steel

(a) Aluminised steel will withstand temperatures up to 900°F without discolouration, and up to 1250°F it resists destructive scaling.

(b) Aluminised steel has good resistance not only to heat but to corrosive condensates that often form after cooling of a heat-resisting product or part. Such heat and corrosion resisting applications can be only handled by aluminised steel while zinc-coated sheets cannot withstand such service conditions.

(c) Aluminised steel can be used for oven liners, heating element reflectors, etc., where it turns back approximately 80 per cent of the radiant heat thrown against it while operating at temperatures up to 900°F.

The use of aluminised iron instead of brass in gas burners also requires consideration.

Lithographic plates

Aluminium is technically a very satisfactory replacement for zinc sheet and in one of the latest reports from 'Modern Metals' published in the United States, North America, is using 80% of their requirments in aluminium. Anodising processes have been developed for aluminium which make its use in most instances, superior to zinc technically.

Paints

Lead has to be imported for the manufacture of about 4 000 tonnes of red lead, used in paints. The major users, the Railways, the P.W.D. etc., should use composite aluminium primers so as to replace red lead in some major applications. Such aluminium primers have been under development at the Regional Research Laboratory, Hyderabad.

Zip fasteners

The Government estimate shows the use of 280 tons of copper in 1960 for zip fasteners estimated at a consumption going up to 600 tons in 1965/66.

Aluminium alloy (now available in India also) is absolutely satisfactory for this purpose and is used almost exclusively in North America, Japan and other countries.

Domestic utensils and household applications

Aluminium, with its excellent thermal conductivity (three times higher than that of iron) 'heats up' quickly and uniformly, thus saving time and fuel. Hard and resistant, aluminium will not break, is unaffected by shocks and does not rust. It is, therefore, easy to maintain, laborious cleaning is eliminated, which leads to substantial saving of time and cleansing material. Non-toxic and unaffected by most food-stuffs, aluminium conveys no extraneous taste to the products which are cooked or even left in the utensils. Its extreme lightness and mechanical resistance account for its great use in making camping utensils (especially for military purposes).

During the last two decades, aluminium utensils have gained tremendous popularity in India, for the reason that, compared with other conventional metals, aluminium is cheaper in price. As the shortage of copper and brass acutely persists, the use of aluminium will gradually increase.

With the rising standard of living, it is quite likely that the introduction of aluminium in various household applications will increase, with consumption reaching about 5 000 tonnes by 1965/66. The total consumption of aluminium for domestic utensils and household appliances is estimated at over 40 000 tonnes, by 1965/66.

Hardware industry

The continued manufacture of brass and bronze fittings should be discouraged, if not totally banned.

Construction and architectural application in buildings

Replacement of brass for applications such as builders hardware, namely, tower bolts, hinges, aldrops, door handles, etc. is making considerable headway.

Textile industry

A certain amount of substitution of stainless steel and brass tubes can be made by aluminium for use in guide rolls, bobbin holders, etc.

Tuyeres for blast furnace

Generally copper tuyeres are used in the blast furnaces. But use of aluminium has been investigated abroad and in some cases aluminium tuyeres have been adopted. One factor in favour of aluminium is its lower specific gravity which implies that an aluminium tuyere of the same dimensions will weigh about a third as the copper tuyere and thereby making possible a much quicker changing of tuyeres around a blast furnnce. The lightness of weight will also make the aluminium tuyeres cheaper in cost. The following grades of aluminium tuyeres have been used elsewhere.

(a) 99·25% aluminium at Hadir Co., Differdange, Luxemberg.
(b) Aluminium extruded tuyere at Huetten Betrieb, Duisburg-Miedrich, Germany.
(c) Light-alloy (3·5–5·0% Si, 0·55 to 0·85% Mn and 0·45 to 0·75% Mg alloy) at Society de Acieres de Pompey, Acerie Du Nord et de l Est (Louveroil) and Denain-Anzin, France.
(d) Aluminium tuyeres at Yawata, Japan.
(e) Welded aluminium plate tuyere (99·5% Al), silumin (10 to 14% Si rest Al) and light alloy (4% Cu, 2% Si, 1% Mn and rest Al) tuyeres have been used in Russia.*

Replacement of tin

An important use for tin and copper, namely, the bronzes, is for bearing metals. The Railways as well as the automotive industry should try the use of aluminium bearing alloys, a number of which have recently been developed.

Tin in India is a completely imported commodity and is a very high priced metal and the saving that can be effected in the use of tin will lead to a considerable saving in foreign exchange.

The major use for tin in India is for tin-plate, the demand of which is nearabout 300 000 tons/annum. Out of this, the tin component may not be more than about one per cent but nevertheless this will become an increasing demand. At present tinplate is still imported partially, but with the increasing demand for good packaging and canning, use of tin will increase.

* I. A. Astachow, 'Construktion Modernern Hochofen', published by Verlag Technik, East Germany.

TABLE IX Aluminium can production in USA

Aluminium objectives	Total potential annual market	Estimated aluminium cans produced			Estimated aluminium penetration (% of total cans)		
		1961	1962	1963	1961	1962	1963
		(millions of cans)					
Frozen juice concentrate	1 750	900	1000	1 400	51	57	80
Motor Oil	1 700	300	350*	800*	18	21	47
Aerosols	1 000	25	30	45	2	3	5
Beer cans	9 000	40	60	120	0·5	0·7	1
Beer lids (aluminium lids on tin plate beer cans)	9 000	25	600	3 600	0·3	7	40
Tuna and other drawn cans	1 000	25	70	300	2	7	30

* includes both composite foil-fibre cans and sheet aluminium cans.

Aluminium and its alloys have been used in considerable quantities in food packing in various countries. The growing popularity of aluminium as a canning material can be visualised from the U.S.A. figures where 'production of aluminium cans in 1963 will top 2 billion for the first time' as predicted by Paul Murphy, Vice-President of Reynolds Metals Company. The figure does not include aluminium lids on tinplate beer cans, estimated at a minimum of 3·6 billion.

The rapid growth of aluminium cans in U.S.A* is shown in Table IX.

The trend of end uses of aluminium in U.S.A.‡ during 1963–64 is given below :

			In million pounds	
			1963	1964
(1)	Building products	...	1 545	1682
(2)	Transportation	...	1 512	1598
(3)	Electrical	...	704	838
(4)	Consumer durables	...	651	766
(5)	Container/packaging	...	492	574
(6)	Machinery/equipment	...	463	505
(7)	Other	...	540	626
(8)	Export	...	470	582
		...	6377	7171

* Light Metal Age, February 1963, p. 11.

‡ Light Metals and Metal Industry, November 1965, p. 78.

As indicated in the above table in the United States of America consumer durables, packaging and electricals are the fastest growing markets for aluminium according to figures compiled by the U.S. Aluminium Association in October 1965.† Shipments to electrical market increased 19% in 1964 over 1963 to 838 million pounds, while the consumer durables segment of the industry rose 18% to 766 million pounds. The rapidly expanding containers and packaging market increased 17% during 1964 on top of nearly a one-third increase during 1963. This 48% jump since 1962 is the largest two-year per cent increase shown by any end use market. Shipments in 1964 totalled 574 million pounds.

When considering aluminium as an alternative to tinplate, it is well to remember that no ideal canning material has yet been discovered and that tinplate has held the field mainly because of its adaptability, ease of manufacture and resistance to corrosion towards a wide variety of canned goods. Aluminium possesses all the advantages of tinned steel and one more, namely that it is homogeneous and does not require plating to improve its normal resistance to corrosion. Primary advantages of aluminium (and its alloys) are lightness, ease of fabrication (bending, forming, flanging, pressing, etc.) resistance to corrosion, ease of jointing, and cleanliness and good appearance ; the last named can be improved by anodising for food canning. Exceptions to the use of aluminium are food, such as acid fruits, tomatoes or tomato sauces and pickles containing acetic acid. Brine used for canning peas and normally containing 2 per cent common salt with 2½ per cent sugar, cannot be used in ordinary aluminium cans but may be packed in an alloy containing 1–6 per cent

† Aluminium World, December, 1965, p. 5.

magnesium (B. S. L. 46 type) specially developed for resisting salt water.

Popular packaging and canning alloys registered with US Aluminum Association*

Chemical composition of aluminium sheet for packaging alloys :

	Magnesium %	Manganese %	Chromium %
5086	4·0	0·45	0·10
5082	4·5	—	—
5154	3·5	—	—
5052	2·5	—	0·25
3003	—	1·2	—

Major applications of these alloys are : 5052 is a popular alloy used for oil can ends, integral rivet citrus can ends, citrus can bodies, drawn containers for soup, meats and cheese, fish cans, bottle caps and is suitable for numerous other container and closure parts 3003 is primarily used for closures and thin sheet containers where excellent workability and medium strength are required. 5086 is primarily used for beer can ends and tabs on integral rivet can ends. 5082 developed by Alcoa is used for integral rivet beer can and soft drink can ends. Whilst 5154 alloy is primarily used for oil can ends.

Amongst the various items where aluminium and its alloys can be used as substitutes for the scarce non-ferrous metal alloys are : roller driers guides using copper ; brass parts in scientific instruments ; bronze and brass railway castings ; brass tubes in machine tool industry for oil or coolant circulation ; brass plates and screw parts in telephones ; brass zip fasteners ; brass printing furniture, zinc plates in printing trade ; brass and bronze fittings hardware ; stainless steel tanks, tinned milk cans, galvanized crates in dairy industry ; trimmings and fittings in automobiles ; household utensils ; lead and zinc paints—with aluminium paint and paste ; evaporator fins in air-conditioning and refrigeration ; rails, rivets, bolts and nuts of brass except where used on brass or copper parts : frame and dial parts of watches and clocks ; crown corks for aerated water bottles, etc.

Requirements of aluminium alloys for defence

It is also imperative that demand of aluminium and light metal alloys semis in the form of bars, tubes, strips, powder, extrusion, forged and rod-shapes and castings for defence requirements should also be kept in view. As for example, base plates which are used for mounting mortar barrels if fabricated in a suitable aluminium alloy of 24″ dia. can result in a saving of weight of about 25%, compared with the steel base plates weighing about 34 lb. This offers great advantages for field operations as mobility of the arm is greatly increased. Thin walled and rigid aluminium alloy tubes are required for use in range finders, etc., to keep the instrument light in weight.

Extruded sections of aluminium alloys are required for tail units of mortar bombs and for mass production it is desirable that suitable sections are made available which will reduce the cost, will ease machining and will be time saving.

In one design of high velocity missile, aluminium-zinc-manganesium alloy is used in the form of tubes, of 59/32″ outer dia. × 42/32″ inner dia. × 3 ft long, mainly from the light weight and strength points of view. Such high strength aluminium alloy tubes have to be developed.

Aluminium alloy cylinder blocks for water cooled engines, gear box casting, pistons, instrument panel boxes, rotary base junction castings, fans of approximately 30″ dia. etc., are required for armoured fighting vehicles, engines, etc.

There is no doubt that with their ready availability in India, light metal alloys will find a much wider application in the field of armaments. At the moment, the designers are handicapped to a great extent due to the limited shapes and forms in which light alloys are available for their use. Naturally where they could use light alloys conveniently, they have no other choice but to use other ferrous or non-ferrous alloys. The requirement on the other hand is to lighten the weapons and equipment by using light metal allloys wherever possible. It is, therefore, emphasized that various light metal alloys for armament use be developed in the country.

In many applications for Defence, aluminium and aluminium base alloys have to be increasingly used. In view of the Chinese aggression, the benefits from lightness of equipment using aluminium and its alloys are self-evident. The present practice of using large quantities of brass and copper by our Ordnance Factories for manufacturing according to British Defence specifications should be reconsidered and where necessary fresh specifications based on aluminium should be drawn up keeping in view our indigenous short supply of copper and its alloys.

Cartridge brass and light armour

In view of large quantities of brass required for the manufacture of cartridge cases and very stringent specifications regarding physical and mechanical property requirements to withstand the severe conditions of testing for restricted expansion and contraction during firing, the substitution by aluminium base alloys needs careful scrutiny and painstaking development work in collaboration with Defence Ordnance Establishments. In this connection, substitution of cartridge brass by B.S. 1472H-12 aluminium, 2–5% copper alloy could be explored for specific applications.

* Light Metal Age, February 1965, p. 6–7.

In the changing strategic armoury of the modern armed forces the world over, light armour development has been very much in the news in the recent years, especially in order to equip the modern armies with transportation vehicles which must have complete cross-country mobility under all terrain conditions, especially in the mountainous regions of India in the context of recent Chinese aggression and confrontation.

In the U.S.A. various aluminium alloys have been developed and employed in the manufacture of light armoured vehicles which have less than half the weight of previous steel armoured vehicles and far better manoeuvrability and higher speed. Alloys 5083, MIL-A-46027, 5456 and more recently alloy 7039 corresponding to Army specification MIL-A-46063 (0·2% Mn, 2·7% Mg, 0·20% Cr, 4·0% Zn, balance aluminium), have been developed and employed in the manufacture of light-weight armoured vehicles. The alloy 7039 possesses a maximum tensile strength of 60 000 psi and is considered to be far superior armour plate material with good toughness and weldability together with resistance to stress-corrosion cracking and favourable cryogenic temperature properties. More recently, with zirconium additions, a new alloy X7139 has been developed for these purposes. In view of the urgency and efficiency of these alloys, concerted and joint efforts with Defence and Ordnance establishments and the National Metallurgical Laboratory are required to develop the alloys suitable for light armour for service in high altitude regions of our country.

New aluminium alloys for heat exchangers*

Aluminium is today being used to an increasing extent in the manufacture of air cooled heat exchangers and a new alloy, Alcan GB-B 53 S, was introduced only a short while ago by Alcan Industries Ltd. specifically for this type of application, although it is also finding uses in other fields.

The heat exchanger is all aluminium, and has been made by Spiro-Gills Ltd. for the constructors. Bechtel International Ltd. for installation in part of the new Severnside chemical plant of Imperial Chemical Industries Ltd. where ammonia is the end product. Aluminium was specified for the components of the exchanger owing to its resistance to attack by the corrosive condensate.

Substitute bearing alloys

Interest is being laid on substitute bearing alloys more particularly of Al base alloys. In recent literature an alloy with composition having 3–4% Cu, 3–4% Pb, 0·2–0·6% Si, 0·2–0·5% iron and rest Al, has been recommended for Babbit. Another having 4–5% Cu, 2–3·5% Pb, 0·6–1·0% Si and 0·2–0·5% iron can be used in place of bearing bronze.† The aluminium 10% tin alloy has gained considerable popularity in the automobile industry. Substitute bearing alloys have been discussed in detail in two separate papers in the symposium.

* Light Metals, 27(315), August, 1964, p. 29.
† Metal Industry, January 1963, p. 44.

Free cutting aluminium alloys

Two methods have been developed to achieve the broken chip so desirable for high productivity, the first uses inclusions of soft, low-melting-point metals such as lead, bismuth and cadmium and the second with hard intermetallic compounds which were formed by peri-tectic reactions during heat treatment. A large variety of the first type of alloys gained popularity in America, these were straight aluminium-copper-base alloys with lead and bismuth additions. As lead-contaminated scrap could not be tolerated in the production of aluminium alloys required by the air-craft industry, the second type was developed in Europe, with additions of manganese, chromium and zinc in appropriate quantities to Al-magnesium type alloys. In more recent years in Europe the range of free cutting aluminium alloys has been extended to soft inclusions in Al-Cu-Mg, Al-Mg-Si and Al-Mg type alloys. In Australia, complex Al-Cu-Si-Mg type alloys with Pb and Bi additions have been used extensively. However, after detailed investigations in Australia* on different types of free cutting Al-base alloys, it has been concluded that the Al-Cu-type free-cutting alloys were superior to the other alloys examined in all machining operations and their introduction would raise productivity; a reduction in iron and silicon impurities markedly improved their machinability.

In view of the great necessity, in India, to replace the copper base free-cutting alloys in many applications, it needs little emphasis that further research and development work is undertaken in order to effectively substitute aluminium base alloys for such purposes.

Conclusions

The scope of research and development work on substitute alloys at the National Metallurgical Laboratory has been discussed at length in a separate paper. In this paper an attempt has been made to outline the vast potential field of applications of aluminium and other non-ferrous metals whose resources in India are quite considerable to adequately meet our requirements for decades to come. In view of continuation of ever-widening gap between the indigenous production and demand—in the foreseeable future years—of vitally important metals like copper, zinc and lead in India, it is imperative that every effort is made on the part of the Government of India to ensure speedy implementation of the major expansion programme in the Aluminium Industry, remove any hurdles standing in the way of supply or production of raw materials for aluminium producers such as cryolite, aluminium fluoride, petroleum coke, cathode carbon, etc. In addition, adequate power supply at sufficiently cheap rates and provision for the same for the proposed new or expanded plants should be ensured. Every effort must be made to bring

* Aluminium World, February 1965, p. 7–9.

down the price of ingot aluminium produced in India to bring it in line with the world prices, the future larger capacity plants and the envisaged expansion of the existing plants should also contribute towards this end.

The efforts of popularising aluminium and its alloys as substitutes for various non-ferrous metals together with the results of research and development work which will undoubtedly increase their field of applications considerably will go in vain if the tempo of increasing aluminium capacity within the country does not gain considerable speed.

Production of commercial grade, electrolytic grade, super-purity grades of aluminium, etc., development of aluminium, magnesium die castings, and other foundry casting capacity ; adequate rolling, extrusion and welding facilities ; aluminium alloy production, etc., have all to be stepped up in order to meet the traditional and substitution applications of these alloys which will be required increasingly by our Ordnance, Defence, Railways, Post and Telegraphs departments, aircraft and engineering and consumer industries. The production at cheaper rates and in quantities in excess of home demand should be aimed at in order to export aluminium in considerable quantities and thereby earn foreign exchange to import the other scarce non-ferrous metals.

In concluding, it is stressed that substitution of non-indigenous non-ferrous metals and alloys requires continued and painstaking research and development work and full co-operation of the industry in implementing the results of research efforts. The vast field covered in this paper would form the basis of research and development work at the National Metallurgical Laboratory during the Fourth Plan period in order to assist the industry in the adoption of indigenous metals and alloys in applications where traditionally indigenously scarce non-ferrous metals have so far been in popular usage.