BERYLLIUM, LITHIUM AND MAGNESIUM AND THEIR ALLOYS, WITH REFERENCE TO THE POSSIBILITY OF THEIR MANUFACTURE IN INDIA

K. K. DAR

Mining Geologist, Atomic Energy Commission, Bombay

Abstract

The paper deals with the possibility of the manufacture of light metals beryllium, lithium and magnesium and their alloys in India. The Indian occurrences of the source materials of these metals are reviewed along with the part these metals play in world peace-time and war-time industries. The results of over-production of magnesium in the United States as an incentive for finding new applications for the metal are drawn attention to. It is pointed out that while Indian magnesite reserves are good, and those of beryl are proving to be fairly good, the position with regard to the reserves of lithium minerals is not so good, but may improve with future investigations. The main metallurgical aspects of the problem have been briefly correlated with the new hydro-electricity projects now under development.

Since the author believes that the importance of a material is best judged by its utilitarian aspects, he has laid stress rather on the uses of these metals and their alloys, etc., with the object of drawing the attention of the Indian geologist and metallurgist to the subject.

Introductory Remarks

S OME light metals have acquired a unique position in the metallurgical and engineering industries today on account of their several useful properties. Amongst these aluminium, beryllium, lithium and magnesium appear to be the most important. Our Five Year Plan incorporates aluminium and magnesium in the mineral development schemes and beryllium and lithium have not been mentioned.

While the general position of non-ferrous metal resources of the country is far from satisfactory, recent investigations have tended to show that the domestic utilization of some of them may in course of time become possible. India is well placed as regards its sources of aluminium and magnesium and recent surveys have shown that our beryllium resources are also fairly adequate. The position of lithium minerals is, however, not so good and we have to await the results of further work in this direction.

The writer has already drawn attention to the future of aluminium industry in India¹. In the present paper he has attempted to assess the position of the other three important light metals, beryllium, lithium and magnesium. The importance of a material is best judged by a consideration of its usefulness, the manner in which it can be obtained, and the problems connected with its applications. Attention has, therefore, been concentrated on these and similar aspects of the light metal industry in India; the object is to draw the attention of the Indian geologist and the metallurgist to these problems rather than to solve them. The sources from which the data for the present thesis are derived unreservedly have been acknowledged at the end of the paper.

Beryllium

Beryl, a silicate of beryllium and aluminium, $3BeO.Al_2O_3.6SiO_3$, occurs as an accessory mineral in acid igneous rocks, granites and pegmatites, and sometimes in metamorphic rocks such as schists and crystalline limestones. Economically workable beryl occurrences, however, are confined largely to pegmatites. Theoretically, beryl contains 5 per cent beryllium metal of which usually not more than 3 per cent can be recovered. Krishnan² states that beryllium produced by the German process is only 60 per cent of the metal content of the original ore. Amongst the several beryllium minerals known, the following contain high amounts of the element, although they are commonly not met with in appreciable quantities³.

	MINER	ALS
MINERAL	Theore- tical % Be	CHEMICAL FORMULA
Euklase	6.2	2BeO.Al2O3.2SiO2.H2O
Chrysoberyl	7.0	BeO.Al ₂ O ₃
Phenakite	16-2	2BeO.SiO ₂
Bertrandite	15-2	4BeO.2SiO2.H2O
Beryllonite	7-0	BeO.NaPO ₃
Herderit	5.0	Be(F, OH)PO ₃ .CaO
Hambergite	19.1	$4BeO.B_2O_3.H_2O$
Bromellite	36.0	BeO

India has not been the largest beryl producer, Brazil making the largest contribution to world production of the mineral. This small production is, however, not due to the paucity of the mineral in the country or to the general poorness of the pegmatites, but rather to the importance of the rare minerals not having been recognized till very recent years and the difficulties of working them consequent upon their sporadic and uncertain occurrence.

Indian Beryl Occurrences — Workable occurrences of beryl so far found in India are confined to the pegmatites intruding rocks of the Dharwarian age. Rajasthan, Bihar and South India are potential areas for beryl production. At present the biggest beryl producer in India is Rajasthan, but there is reason to believe that production of this mineral will considerably increase in the near future in Bihar and in South India.

In Rajasthan, important sources of beryl are in Mewar, Jaipur, Tonk, Kishangarh, parts of Jodhpur, Dungarpur and Banswara.

The author and his colleagues have also located beryl occurrences recently in some parts of Gujerat and in Bombay State.

In Bihar, beryl-bearing pegmatites are known in Gaya, Hazaribagh and Monghyr districts.

Several sources of beryl, particularly those of Nellore, are known in South India.

Other beryl occurrences are reported from the Sutlej and Chandra valleys in northwestern Himalayas.

Large prospective tracts await investigation in Hyderabad, Madhya Pradesh, Orissa and Assam.

The Indian beryl has an average analysis of 11-13 per cent BeO, and our resources of the mineral appear to be sufficient for a domestic beryllium industry. It will be useful to recall in this connection that the French beryllium refinery in 1946 was drawing upon the meagre 500-ton beryl stock in Germany following the prohibition of beryllium manufacture in that country by the Allied Occupation Authorities in February 1946⁴. With the embargo on Indian beryl, supply of this rare mineral for the domestic beryllium industry is assured.

Importance of Beryllium and Its Products in Modern Industry — The importance of beryllium in modern industry can be assessed from DeMille's⁵ statement that war demands accounted for 99 per cent of the available beryllium, and it is expected to find wider industrial application in peace-time. The importance of a material can only be judged by the variety of uses to which it, or its products, can be put. From some of these outlined below, it will be observed that this metal can serve many useful national requirements.

If metallic beryllium could be produced in larger quantities, its use in the metal industry would now rapidly increase. It is slightly heavier than magnesium and considerably lighter than aluminium (density: Mg, 1.75; Be, 1.85; Al, 2.7). Other valuable properties are its strength, resistance to heat and corrosion, and unexcelled resilience, which are imparted in greater or lesser measure to its alloys.

Metallic beryllium is used as a deoxidizer and desulphurizer in steel-making, in the casting of copper, and in limited amounts in the manufacture of 'windows' for X-ray tubes, for the production of neutrons for the splitting of uranium atoms, and for slowing down the high-speed fission neutrons emitted from uranium to control the chain reaction involved in the explosion of an atom bomb.

Due to its high fusion point and high vapour pressure at a temperature not much above the fusion point, beryllium can be hotworked. Extreme lightness causes it to

Cu-Be alloys are now available in standard commercial forms which include plates, sheets, wires, tools, leaf, helical, contact, Bourbon springs, valve guides for and engines, pumps, liquid meters, gears, plastic moulds, die-casting dies and welding elec-Other uses of Be-Cu alloys are in trodes. the setting of industrial diamonds, hubs of adjustable steel aircraft propellers, switch blades and jaws for electrical range switches, etc., camera parts, appliance plug clips, fuse clips, optical alloys, vibrator arms, petrol and oil pump parts, relays, brush holders, thermostatic controls, etc.

Other useful copper alloys are those containing 0.4-0.5 per cent Be and 2-3 per

SYMPOSIUM ON NON-FERROUS METAL INDUSTRY IN INDIA

Lithium Ores — The chief sources of lithium are spodumene (LiAlSi₂O₆), $3\cdot8-5\cdot6$ per cent Li; amblygonite [Li(AlF)PO₄]; and lithia mica, lepidolite (Li, K, Na)₂Al₂(SiO₃)₃(F, OH)₂. Amblygonite contains about 9 per cent and lepidolite about 4 per cent Li₂O on the average. Other occasionally mined sources are triphylite, (Li, Na)₃PO₄+(Fe, Mn)₃(PO₄)₂, $1\cdot6-3\cdot7$ per cent Li; petalite, LiAl(Si₂O₅)₂, $2\cdot7-3\cdot7$ per cent Li; lithiophilite and zinnwaldite.

The chief lithia-producing countries in order of importance are the U.S.A. (which supplied 50 per cent of the pre-war world output of ores), South-west Africa and Argentina. Canada, Sweden, Germany, Czechoslovakia, France, Spain, Portugal and Western Australia are comparatively minor contributors. War demand led to starting production in Argentina where its occurrence in commercial quantity was not reported previously. The U.S.S.R., Madagascar and India have deposits of commercial value.

Indian Sources of Lithium — In India, very few and small occurrences of lithium ores are known. Lepidolite is recorded in the Bihar mica belt^{7,8,9}. The Bastar occurrence of Mundaval ($18^{\circ}39': 81^{\circ}56'$) is the biggest among the Indian lepidolite deposits so far known, the next occurrence being that of Bihar. In Bastar lepidolite occurs in large masses which, except for a little quartz, is free from impurities and has lead to further discoveries of source minerals of lithium. It is also possible that further exploration and prospecting at depth in Bastar may reveal greater reserves of lepidolite than are available now in the scattered boulders on the surface. The present lepidolite deposits are about 180 miles from the railhead at Dhamtari, but the distance from the Vizianagaram-Raipur chord is considerably less.

Application of Lithium - Lithium resembles the other alkali metals in its properties, is the lightest element which retains its form at ordinary temperature, and enters into numerous chemical combinations. Because it imparts additional hardness, toughness and tensile strength, it is important in the manufacture of bearing metal alloys, copper electrodes and lead cable-sheaths. When used alone or as an alloy in molten metals, it acts as a refining agent for them. It is employed with electric furnace carbon steels for steel castings, replacing aluminium as a deoxidizer. Both steel and copper castings which contain lithium can be poured at lower temperatures with high fluidity. Lead-lithium, the best known of the alloys (Bahn metal), contains only 0.04 per cent Li (with a little of sodium and calcium) which increases the hardness at higher temperatures and makes the products suitable for railway bearings. Other alloys, aluminium and magnesium, are reported to have

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and 188,000 lb. per sq. in. respectively and acquires a hardness of 600 Brinell.

Beryllium-aluminium alloys (70-80 per cent Be) have high strength, are easily cast and worked, but soon become work-hardened owing to segregation of Be and Al-rich grains. Addition of one or more metals may remove this defect.

Strong beryllium-magnesium alloys have not yet been produced, but an alloy containing 90 per cent Be and 10 per cent Mg is used for making certain Mg-Al alloys.

Small amounts of Be added to 18-carat gold increases the hardness of the product.

An alloy of 92.5 per cent Ag, 7.1 per cent Cu and 0.4 per cent Be makes the silver resistant to tarnish while retaining the colour of silver.

Platinum metals can be conserved by the addition of small amounts of beryllium.

Extraction of Beryllium - Beryllium of 99.5 per cent purity is obtained by the electrolysis of the molten fluoride in graphite barium or crucibles to which sodium fluoride is added. Beryllium separates out on a water-cooled iron tube serving as a cathode; the slag inclusions are eliminated by remelting with mixtures of alkaline-earth halides. The fluoride (2BeO.5BeF2) is prepared by fusing finely ground beryl with sodium-silicofluoride for several hours at 650°C.; the solution obtained after leaching with water is evaporated to yield crystalline beryllium fluoride, which is dissolved in water containing lime in excess and the beryllium oxyfluoride precipitate is drawn into solution with HF. The current density is 2-4 amp. per sq. cm. of cathode area.

Lithium

Lithium is the lightest of all metals (sp. gr. 0.543; m.p. 186°C.; b.p. 1400°C.) which has found a variety of important peace-time and war-time uses. As it deteriorates rapid-ly in air, it cannot be used for structural purposes, but amongst other applications may be mentioned its use in alloys to improve

their physical properties such as ductility, strength and uniformity. It densifies the grain in the metal and eliminates porosity in high-pressure castings. It is the only metal which, on combination with hydrogen and other gases, produces an initial alloy in a super-refined state. DeMille has quoted Dr. W. G. Pollard as saying, while discussing the chain-reacting pile at Oak Ridge, Tennessee (U.S.A.), that one pound of lithium burned with hydrogen would serve as a fuel for a year in a furnace requiring more than 4000 tons of coal to provide an equivalent amount of heat. The importance of the metal can be judged from the lithium ores mined in U.S.A. in pre-1946 years⁶.

TABLE	2 - LIT	HIUM	ORES	MINED	IN
U.S.A.	WITH	THEIR	APPRO	DXIMATE	
	LIT	HIA CO	NTENT		

Year	LITHIUM ORES (short tons)	APPROX. Li ₂ O CONTENTS (short fons)
1935-39 (av.	.) 1327	88
1942	5405	299
1943	8155	463
1944	13319	848
1945	2446	274
1946	3065	323

Gwinn⁶ states that 'although far below the volume of the recent war-time output, shipments in 1946 were 131 per cent above 1935-39 average, and the lithia content was 267 per cent greater '.

During World War II, lithium was listed as essential both by the United States and Britain owing to its various applications of military importance. War demands for lithium salts led to an increase in 1942, in U.S.A., from 500 to 2000 tons a month in mill capacity for production of low-grade spodumene as a domestic source of lithia. Beneficiation of the ore by froth flotation yielded excellent results and the byproducts were low-grade feldspar and mica concentrated. Lithium Ores — The chief sources of lithium are spodumene (LiAlSi₂O₆), 3·8-5·6 per cent Li; amblygonite [Li(AlF)PO₄]; and lithia mica, lepidolite (Li, K, Na)₂Al₂(SiO₃)₃(F, OH)₂. Amblygonite contains about 9 per cent and lepidolite about 4 per cent Li₂O on the average. Other occasionally mined sources are triphylite, (Li, Na)₃PO₄+(Fe, Mn)₃(PO₄)₂, 1·6-3·7 per cent Li; petalite, LiAl(Si₂O₅)₂, 2·7-3·7 per cent Li; lithiophilite and zinnwaldite.

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Amblygonite is reported from Kashmir, but the occurrence appears to be insignificant.

No other lithium minerals have yet been reported in India. It is, however, within the range of possibility that future surveys may lead to further discoveries of source minerals of lithium. It is also possible that further exploration and prospecting at depth in Bastar may reveal greater reserves of lepidolite than are available now in the scattered boulders on the surface. The present lepidolite deposits are about 180 miles from the railhead at Dhamtari, but the distance from the Vizianagaram-Raipur chord is considerably less.

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Lithium compounds are used effectively in glass, optical, ceramic and air-conditioning industries. Both lithium metal and lithium amide can be used as an intermediate in building molecules for carbonols, nicotinic acid and other organic compounds. It is stated that the high hydrogen yield from the stable solid lithium borohydride (66 cu. ft. per lb. on contact with water) and gaseous lithium diborane (88 cu. ft. per lb. on contact with water) gives these derivatives important possibilities in chemical research to determine new applications, and the use of the hydride for hydrogen production for balloons has increased.

One of the most hygroscopic compounds, lithium chloride is an essential drying agent in air-conditioning units and blast furnace efficiency is said to increase by 10 per cent with dried air. Minor uses have been developed in the manufacture of optical, electrical, pharmaceutical and textile materials.

Spodumene and lepidolite have been used largely in inflating life-rafts, in making certain type of glass, in the ceramic industry and for drugs. Spodumene had been used as a substitute for glass-grade kyanite. Lepidolite is essential in the manufacture of borosilicate glass for electronic tubes and boiler gauges. Spodumene-feldspar mixtures have lower melting points than feldspar alone and are useful for ceramic purposes and spodumene has been proposed as a substitute for the more costly lithium carbonate in ceramic body materials, glazes and enamels. Amblygonite is used in opaque glass, lepidolite in flint glass; generally, lepidolite and, to a less extent, other lithium minerals are employed as opacifying agents in opal and white glasses. Lithium and fluorine in lepidolite are valuable fluxing agents in facilitating the melt in glass-making for which the scaly light purple varieties of the mineral are used.

Lithium salts are employed in the preparation of mineral waters, lithia tablets and medicine, and for many other minor uses. Lithium hydroxide is used with potassium hydroxide as the electrolyte in the Edison alkaline storage cell; lithium chloride, in signal lights to produce crimson flare; lithia with strontia and the fluorides is reported to be one of the most important substitutes for lead in pottery glazes and it is said that this application may compensate for the loss of

military uses in peace-time. A new synthetic low temperature grease with a lithium base, stable at temperatures from -100° to $+300^{\circ}$ C., has been developed. The new reducing agent, lithium-aluminium hydride, first made in June 1945, promises to be an important research and industrial tool in organic and inorganic chemistry, particularly in the reduction of unsaturated compounds as it does not attack carbon-to-carbon double bond.

Extraction of Lithium — The metal may be obtained from the electrolysis of a solution of lithium chloride in pyridine (C_5H_5N).

Magnesium

Nearly 40 years ago, magnesium had very few industrial applications, e.g. in pyrotechnics, as flashlight powder, for deoxidizing and desulphurizing other metals and alloys, specially nickel, brass and bronze, and in some amount in light alloys such as duralumin. In recent years, however, the metal has acquired great industrial importance and its demand has rapidly increased for the manufacture of light, strong magnesium alloys. It is the third most abundant of the engineering metals, surpassed in volume only by aluminium and iron, and is one of the sixteen non-ferrous metals used in substantial quantities in the pure state or as the base metal for alloys.

Sources of Magnesium — Several sources of magnesium are available. Major recovery has been from sea water, brines and salt deposits. A cubic mile of ordinary sea water is said to contain nearly 6 million tons of magnesium and the whole of the Dead Sea is estimated to contain 5,800,000,000 tons. Carnalite, KCl.MgCl₂.6H₂O, an important constituent of brines, may contain up to 34 per cent magnesium chloride. Sea water contains 0.4 per cent carnalite, i.e. 0.13 per cent Mg. Dolomitic lime is used for precipitation of magnesia from sea water. Brucite, Mg(OH)₂, contains 41.6 per cent Mg; magnesite, MgCO₃, 28.7 per cent; hydromagnesite, $3MgCO_3.Mg(OH)_2.3H_2O$, 26.5 per cent; dolomite, $MgCO_3.CaCO_3$, 13 per cent; serpentine, 25.8 per cent. The Canadian brucite deposits are the largest in the world. The sources of magnesium are abundantly distributed the world over.

Indian Sources of Magnesite — Krishnan has described the Indian magnesite deposits. Brucite and carnalite are not reported in India, but magnesite deposits occur in the chalk hills and other places in Salem, at Seringala in Coorg, on the Cauvery above Frazepet, at Muddavaram and Musila Cheruvu in Kurnool, in the Trichinopoly district, in Hassan and Mysore, near Dev Mori in Idar, and in Dungarpur, at Bhita Dari in Singhbhum and at Almora. The crude Salem magnesite has the following analysis¹²:

	Per cent
Silica	1-86
Iron oxide and alumina	0.08
Lime	0.81
Magnesia	46-41
Loss on ignition	50-64
Moisture	0.20

It has been stated that magnesium carbonate in ordinary samples averages 96-97 per cent³ and 99 per cent in picked ore.

So far, only the Salem and Mysore deposits and those of Almora appear to be workable. Reserves^{10,12} of the chalk hills deposits are roughly estimated at 90,000,000 tons, analysing over 96 per cent $MgCO_3$ (46.4 per cent Mg). Annual mine output is about 20,000-35,000 tons, part of it being used for nonmetallurgical purpose and a large part exported. Almora reserves are estimated at at least 20,000,000 tons. In addition to magnesite, large dolomite deposits are also known to occur in different parts of the country.

World Production and Trends in Magnesium Industry — The importance of magnesium is due to its high strength and its being 37 times lighter than aluminium. Its drawbacks are that it is anodic and the most corrosive of metals (although it resists alkalis), its surface oxidizes easily, it has a low modulus of elasticity and cannot freely and easily be cold-worked.

The world production of metallic magnesium, according to Jones¹³, was just under 20,000 tons, but it doubled in 1940, Germany producing almost half the total; United Kingdom and United States, about onesixth; and Japan, about one-tenth. Other magnesium-producing countries in order of importance are: France, the U.S.S.R., Switzerland and Italy.

World production of crude magnesite in 1937 was 2,150,000 long tons, to which the U.S.S.R. contributed 37 per cent; Australia, 21 per cent; Manchuria, 15 per cent; the U.S.A., 8 per cent; Greece, 7 per cent; Czechoslovakia, 4 per cent; Yugoslavia, 2 per cent; Chosen, 2 per cent; and India, 2 per cent.

The industrial importance of magnesium may also be judged from the production figures given in Table 3^{13} .

Nighman and Trought¹⁴ record that, excluding exports, shipments of one-third million tons of metal from January 1942 through June 1945, according to War Production Board figures, comprised 44 per cent for production of aircraft, 34 per cent for incendiaries, 12 per cent for other military uses (principally tracer and incendiary

TABLE 3 - PRODUCTION	OF MAGNESIUM	IN THE	WORLD AND	THE U.S	S.A., 1942-46
	1942	1943	194 4	1945	1946
World (short tons)	115300	263000	232700	54500	13200
U.S.A., primary magnesium (short tons)	48963	183584	157100	32792	5317
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ammunition), and the remaining 10 per cent largely for aluminium alloys and, thus, the consumption was roughly half for structural and half for destructive purposes. In 1946, the first post-war year, while the primary magnesium production of U.S.A. declined to one-sixth of the 1945 output and one-thirtieth of the war-time record, the consumption of primary metal and alloy was one-fifth that of 1945 and five times the pre-war average. The recovery of secondary metal dropped 45 per cent from 1945, but nearly equalled the output of the primary. Estimated world production declined 76 per cent from 1945 and was about 5 per cent of the 1943 peak. High production of the secondary metal is considered as having been a powerful depressant of the primary, the ratio being extremely high and virtually double that of aluminium.

Essentially, magnesium was a war-time metal. DeMille⁵ states that its incendiary and oxidizing characteristics were employed in World War I for fire bombs and flares and for flashlight for night photography, but many new military and civilian applications were developed in World War II. The expanded world demand for magnesium in World War II is without parallel in the history of the use of metals — one group of uses being based on its chemical activity; the other, more important, on the engineering properties of its alloys. The magnesium structural products were consumed as follows in 1940:

	Per cent
Aircraft industry	75
Automobile industry	10
Tool and equipment industry	6
Textile, foundry equipment,	9
and other industries	

The distribution of output in 1949 was: incendiaries, 40 per cent; aircraft and many parts of war weapons, 30 per cent.

In 1943, potential new use requirements being many times the supply resulted in the fabrication capacity being expanded to meet the estimated requirement of 362,500 tons which proved to be too excessive and, at the end of 1944, the War Production Board stockpiles were twice the requirement. The Truman Committee was to have written off a large part of the magnesium industry as war loss unless new peace-time uses for the metal could be found. Dr. W. H. Dow suggested that the war-emergency plants could maintain capacity for production of magnesium wheels for automobiles, wheelbarrows and roller-skates, cigarette machines, printing presses, knitting machines, bread-slicing machines, various household appliances, portable hand-tools, radios, office machines and cameras. A 60 lb. canoe and 70 lb. row-boat were under construction in December 1945. In the second meeting of the Magnesium Association on 2 October 1945, many labour and energy-saving applications for magnesium were suggested which included, amongst those already mentioned, cages, trucks, buses, aircraft and railway cars, weaving machines, typewriters, etc. Magnesium forgings for aircraft were expected to compete with other metals. The Dow Chemical Company reported to the Congress that post-war consumption of magnesium, estimated at 30,000 tons a year, would be distributed as follows:

	Per cent
Manufacture of aircraft	45
Manufacture of automobiles, trucks and buses	11
Industrial machinery, tools and manually handled equipment	21
Furniture and other consumers' goods	8
Alloying element for aluminium	5
Chemical industries and photo- graphy	10

Magnesium Alloys — The special methods of casting magnesium and its alloys for their later fabrication into various articles were mainly pioneered by the Germans.

Al, the most important alloying element for magnesium, is added up to 11 per cent, but variable quantities of manganese are used in all the magnesium alloys mainly to reduce corrosion.

There are two types of magnesium alloys the casting and the wrought alloys - of which the casting alloys have again two types: those containing 2 per cent Mn, and those with 8-10 per cent Al, 0.5 per cent Zn, and 0.25 per cent Mn, the latter possessing good mechanical properties which can be further improved with heat treatment. The former type is usable in the wrought condition. The two widely used wrought alloys are: one, with 6 per cent Al, 1 per cent Zn, and 0.25 per cent Mn; and the other with 8 per cent Al, 0.5 per cent Zn, and 0.25 per cent Mn. While they possess a maximum tensile strength of about 20 tons per sq. in. and are as strong as the finest steel alloys weight for weight, their strength within the elastic range is not so great. The casings of incendiary bombs are made of a magnesium alloy containing about 5 per cent Al with a little manganese which also burns fiercely with the bomb explosion.

The chief and extremely important engineering advantages of magnesium alloys are their lightness, easier machinability than steel or brass, and amenability to all metallurgical treatment, such as shaping, casting, die-casting, rolling, forging, extruding and pressing. Chemical reactivity of the metal causes certain corrosion difficulties, but the pure metal corrodes less than iron and steel in the atmosphere. Corrosion can be prevented by immersion in cold, sometimes hot, solutions of chromate salts which form a protective coating or film of chromic oxide. A new anodic coating for magnesium alloys was announced in September 1944 and, in point of resistance to corrosion or abrasion, is claimed to be superior to that obtained by the acid dichromate and chrome pickle treatment.

Magnesium alloys have been used in crankcases to save weight in lorries, in retractable undercarriage parts, pilots' seats, petrol tanks and a number of engine parts such as supercharger blower casings. The huge landing-wheels of heavy bombers are made of about 8 per cent Al; some weigh only 150 lb. each, which amounts to a saving of 140 lb. in weight for each bomber.

Extraction of Magnesium — The chemically active nature of magnesium necessitates unusual care in its production to ensure purity. Due to increased war production, the magnesium industry has undergone a tremendous expansion and the two basic processes, (i) electrolytic reaction and (ii) chemical reduction, have now six variations¹⁵, namely:

- (1) the Dow chloride process;
- (2) the Elektron process;
- (3) the Dow sea-water process;
- (4) the oxide process;
- (5) the Hansgirg process; and
- (6) the Pidgeon process.

It is difficult to say which of these processes will continue to meet competitive cost; much will depend on the nature of the raw materials available, location of the plant, cost of power, etc. It seems possible that the Dow chloride and the Dow sea-water processes may continue successfully. But, in India, where the raw materials are magnesite and dolomite, application of the Elektron process is indicated. The use of the oxide process was given up in 1927 as it could not compete economically with the chloride process.

The requirements of the Dow chloride process are 8-10 kWh. and 6-9 volts power ordinarily; hydrated magnesium chloride, sodium chloride and small amounts of ammonium chloride to prevent breaking up of $MgCl_2.6H_2O$ into MgO and HCl in the first evaporation of brines to crystallize MgCl₂. $6H_2O$, and graphite anodes. 4000 lb. of magnesium chloride produces 1000 lb. of metal. Average purity of metal is 99.9 per cent.

In the Elektron process, magnesia is briquetted with coke and peatmoss, treated with chlorine at 700°-900°C. to produce magnesium chloride, which is subjected to electrolysis; the chlorine is collected for re-use. In the Dow sea-water process, magnesium hydrate is precipitated from sea water, treated with HCl to form magnesium chloride and subjected to electrolysis. Metal produced has a purity of 99.90-99.95 per cent. Plant location has to be near the sea and used water has to be discharged sufficiently far to prevent dilution of the entering supply.

The Hansgirg process consists in the reduction of finely divided magnesia by finely divided carbon in an electric furnace at 2000°-2100°C., immediate chilling of magnesium vapour and CO by natural gas (25 volumes of natural gas being used for each volume of furnace vapour), collection of quenched magnesium in oil or large woollen sacks in a cooling chamber, and redistillation of dust still containing about 60-65 per cent magnesium in electric retorts at 750°C. under high vacuum. Purity of metal may be as high as 99.997+ per cent. Power requirement is about 9.5 kWh. per lb. of magnesium. Gas explosions, etc., are disadvantages.

In the Pidgeon ferro-silicon process, Al, CaCl₂, C or ferro-silicon are used for direct chemical reduction to magnesium at 1150° C. from dolomite according to the reversible reaction

$2MgO + Si \rightleftharpoons SiO_2 + Mg$

One lb. of 75 per cent ferro-silicon or its equivalent is required per lb. of magnesium which contributes substantially to operation cost. Power consumption is the lowest of any of the electrolytic processes. A suitable metal for the reaction tubes with a reasonable life offers difficulty and Fe-Ni-Cr heatresisting alloys have been used with slight success because of surface oxidation, and collapse under atmospheric pressure working outside against the vacuum inside.

Hydro-electric Power

Cheap and abundant electrical power is an essential for the extraction of the three metals discussed in the present paper. This should be easily available from the several hydel projects now under development in different parts of the country.

For the beryllium industry drawing its raw materials from Rajasthan and Bihar, power would be available from the Chambal and Kosi projects respectively.

For the lithium industry, if ultimately found to be feasible, it may be possible to draw electrical power from the Konya or the Krishna projects.

The magnesium industry in the south would be able to take electrical power from the Krishna project and that in the north, based on the Almora magnesite deposits, from the Rihand project.

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