Magnesium – in Indian Context

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Magnesium, because of its good mechanical, physical and chemical properties can be considered as an awesome light metal for the future. Electrolysis and thermal reduction are the principal magnesium extraction processes. China continues to dominate magnesium production across the globe for the past 20 years. Commercial magnesium extraction in India is still in an infancy stage. Global magnesium research is increasing gradually whereas the situation in India is still snail-paced. India is one of the most energy starving countries that has to depend on oil imports for satisfying its needs. Automobile sector is one of the principal consumers of oil. The significance of using light weight alloys in automobiles is quite evident, considering the fact that weight reduction reduces fuel consumption as well as carbon dioxide emission. Biodegradability and biocompatibility properties make magnesium a candidate for bio-implants. Aluminium industry is flourishing in India and the role of magnesium industry is just supportive in nature. This has to change gradually for developing better alternative light weight alloys using magnesium.

Introduction

Magnesium (Mg) is the lightest of all structural metals in practical use, with a density of 1.74g/cc. There are over 80 different minerals known to have magnesium content of 20% or greater such as dolomite ($MgCO_3.CaCO_3$), magnesite ($MgCO_3$), olivine, carnalite ($KMgCl_3.6H_2O$), etc, making it the eighth most abundant element in the earth's crust[1]. Also magnesium is the second most abundant metal in seawater, after sodium. Hence magnesium can be considered as an inexhaustible resource. However, only dolomite and magnetite form the predominant ingredient for magnesium extraction processes.

The importance of magnesium metal lies in the properties they posses such as good strength-to-weight ratio, electro-magnetic shielding, good heat dissipation, vibration damping, dent resistance etc. Mg also has a moderately low melting temperature making it easier to melt for casting. Pure magnesium metal is rarely used because of its corrosion problems, insufficient strength, difficulty to deform due to the crystal structure (HCP), inflammability issues at elevated temperatures, etc. Alloying with one or more elements such as Al, Mn, Zn, Zr, Gd, Sc, Y, etc. is the best way to tackle many of the above-mentioned disadvantages. They have also replaced engineering plastics in many applications[2].

Resources and Raw Materials

India has vast resources of magnesium both as sea-water and as high grade mineral deposit. Coming to the two major ores of magnesium in the country-Dolomite[3] and Magnesite[4].

Workable deposits of dolomite are widely spread across the country. Total resources of dolomite as per UNFC (United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources) system as on 2010 are 7730 million tonnes. Eight states share about 91% resources: Madhya Pradesh (29%), Andhra Pradesh (15%), Chhattisgarh (11%), Orissa and Karnataka (9%), Gujarat (7%), Rajasthan (6%) and Maharashtra (5%). The remaining 9% resources are distributed in Arunachal Pradesh, Jharkhand, Haryana, Sikkim, Tamil Nadu, Uttarakhand, Uttar Pradesh and West Bengal. About 65% dolomite production in the country is contributed by 12 major producers. Details are given in Table-1 and Table-2. The total reserves/resources of Magnesite as per UNFC System as on 2010 are about 335 million tonnes of which reserves and remaining resources are 42 million tonnes and 293 million tonnes respectively. Uttarakhand has almost 69% of country's magnesite resources, followed by Rajasthan (16%) and Tamil Nadu (12%). Five producers are responsible for 95% of magnesite production. Details are given in Table-3 and Table-4.

Magnesium Extraction Processes

At the outbreak of Second World War, great enthusiasm for production of magnesium was supplemented by development of direct reduction process. Today, the two primary routes of magnesium production are thermal reduction and electrolysis[5].

Table-1: Principal Producers of Dolomite, 2011-12 [Reproduced from Indian Mineral Year book (IMYB), Dolomite, 2012]

Name & address of producer	Location of mine	
	State	District
Steel Authority of India Ltd, Ispat Bhavan, P.B.No.3049, Lodhi Road, New Delhi-110003.	Chhattisgarh Jharkhand	Bilaspur Garhwa
Bisra Stone Lime Co.Ltd, A.G. Sourav Abason, Sector-II, Saltlake, Kolkata-700091.	Odisha	Sundergarh
Rastriya Ispat Nigam Ltd. Visakhapatnam Steel plant, Visakhapatnam-530031	Andhra Pradesh	Khammam
Tata Steel Ltd. Bombay House, 24, Homy Modi Street, Mumbai-400001.	Odisha	Sundergarh
South West Mining Ltd. 3rd Floor, 'The Estate' # 121, Dickenson Road, Bangalore-560042.	Andra Pradesh	Khammam
Manish Singh Banafer, P. O. Janjgir-Champa, Dist. Janjgir-Champa, Chattisgarh.	Chattisgarh	Janjgir-Champa
Mysore Minerals Ltd. 39-M.G.Road, Bangalore -560001.	Karnataka	Bagalkot
Electrosteel Castings Ltd. G.K.Tower, 19, Camac Street, Kolkatta-700017.	Maharashtra	Chandrapur
Aravali Polyart Pvt. Ltd. A-251(B-1), Road No.1, M.I.A, Udaipur-313003	Rajasthan	Udaipur
Raikar Mineral Mining & Processing Industries, Raikar House, Bagalkot - 587101	Karnataka	Bagalkot
Dolomite Mining Corp, Khamaria Shakti Road, Dist.Janjgir-Champa, Chattisgarh	Chattisgarh	Janjgir-Champa
Hira Power & Steel Ltd. Urla Industrial Complex, Raipur-492003	Chattisgarh	Raipur

Table-2: Statewise Production of Dolomite, 2008-09 to 2010-11 (Reproduced from Indian Mineral Yearbook, Dolomite, 2012)

State	2008-09		2009-10		2010-11	
	Quantity	Value	Quantity	Value	Quantity	Value
Andhra Pradesh	1254886	277705	1577072	317824	1072132	276549
Chattisgarh	1317858	361156	1286514	335580	1387985	301339
Gujarat	169447	22962	346234	50554	84477	10094
Jharkhand	301341	271207	422019	379817	429866	386879
Karnataka	354015	52262	385041	55044	423490	65720
Madhya Pradesh	199377	25986	277017	36190	243052	30079
Maharashtra	94896	16849	76625	15566	76907	12655
Odisha	1616347	502265	1316371	450677	1137103	388671
Rajasthan	147123	19807	224803	30966	206287	31826
Uttarakhand	53947	4532	63	6	3567	340
India	5509237	1554731	5911759	1672224	5064875	1504152

Quantity in tonnes; value in (₹ '000)

Table-3: Principal Producers of Magnesite, 2011-12 (Reproduced from Indian Mineral Yearbook, Magnesite, 2012)

Name & address of producer	Location of mine	
	State	District
Tamil Nadu Magnesite Ltd. 5/53, Olamur Main Road, Jagir Ammapalayam, Salem-636302	Tamilnadu	Salem
Almora Magnesite Ltd. Metela, P.O. Billori, Bageshwar, Uttarakhand	Uttarakhand	Bageshwar
Dalmia Magnesite Corp. Ltd. Dalmia Cement (Bharat) Ltd. Salem-636012	Tamil Nadu	Salem
N. B .Minerals Corp. Opp. Bhatt Colony Nawabi Road, Haldwani, Nainital -263139	Uttarakhand	Pithoragarh
Mysore Minerals Ltd. 39, M.G. Road, Bengaluru-560001	Karnataka	Mysore

1. **Electrolysis:** The process involves two stages:

   i) Production of pure magnesium chloride from sea water or brine

   Where sea-water is the raw material, it is treated with dolomite which has been converted to mixed oxides by heating to a high temperature. Magnesium hydroxide precipitates, while calcium hydroxide remains in solution. Magnesium hydroxide is filtered off and on heating readily forms pure oxide, which is subsequently treated with HCl to give $MgCl_2$.

   ii) Electrolysis of fused magnesium chloride

   The resulting anhydrous magnesium chloride is then fed to the electrolysis cell to produce Mg metal at cathode and Cl_2 at anode.

2. **Thermal Reduction (Pidgeon Process):** This process was invented in the early 1940s by Dr. Lloyd Montgomery Pidgeon of the Canadian National Research Council (NRC). The first plant was built in 1941 and operated by Dominion Magnesium in Haley, Ontario, Canada.

   Here initially dolomite is calcined to produce MgO and CaO. Now ferro silicon is added to reduce magnesium oxide to a molten slag at a temperature between 1200^0C-1600^0C. A reduced gas pressure above the slag produces magnesium vapour. This vapour is then condensed into crystals[6].

Table-4: State-wise Production of Magnesite, 2008-09 to 2010-11 (Reproduced from Indian Mineral Yearbook, Magnesite, 2012)

State	2008-09		2009-10		2010-11	
	Quantity	Value	Quantity	Value	Quantity	Value
Karnataka	9591	14668	6437	13591	6974	14409
Tamil Nadu	188564	281693	235446	349195	164756	257984
Uttarakhand	54725	67153	59187	72332	58004	69127
India	252880	363514	301070	435118	229734	341520

Quantity in tonnes; value in ('000)

Historical Review

Commercial production of electrolytic magnesium began in Germany in 1886 and they were responsible for over 60% (20,000 tonnes) of the magnesium production across the globe before World War II. However, after the war, the total production got a huge setback, as the producers were not able to find economical extraction processes in order to compete with the price of aluminium[7].

For most of the second half of the twentieth century, seawater provided almost 50% of the magnesium produced in the western world and it remains a major source of magnesium oxide in many countries. The first magnesium metal extracted from sea-water was produced by Dow Chemicals at their Freeport, Texas plant in 1948. The Freeport facility operated until 1998, but the downfall was ignited because of the exploitation of Pidgeon process by the Chinese markets from 1993 onwards.

Along with these primary magnesium productions, secondary magnesium production also started to grow. It mainly included recovery of magnesium from its scrap. The main sources for magnesium scrap recycling are automotive components (primarily Volkswagen crankcase and transmission housings), chainsaw housings, scrap from wrought product manufacture and fabrication, general die-cast scrap, magnesium turnings etc. Economical recovery is obtained only when the magnesium content in the scrap is more than 15%. In USA, secondary magnesium production increased from 13% to 30% during 1983-1991[8, 9, 10].

According to Roskill, world production of primary magnesium showed a compound annual growth rate (CAGR) of 6.1% during the period 2002-2012. Global apparent consumption (production + imports – exports) of magnesium reached 10,50,000 tonnes in 2007, a CAGR of 8% from the 6,30,000 tonnes consumed in 2001, before falling by 11% in 2008 and by 15% in 2009, to 8,40,000 tonnes, as the global economic downturn significantly decreased demand for magnesium containing products[11].

In India, the golden era of magnesium extraction and casting of its alloys are yet to come. When it comes to metal extraction, the two small sized plants existed were- Southern Magnesium & Chemicals Ltd. (SMCL) and Tamil Nadu Magnesium & Marine Chemicals Ltd. (TMMCL).

Southern Magnesium & Chemicals Ltd. was started as a joint venture with the Andhra Pradesh Industrial Development Corporation, February 1985, located at Gowripatnam in Andhra Pradesh. The company acquired a pilot plant setup in the National Metallurgical Laboratory for the manufacture of magnesium metal by Pidgeon process. Initial capacity of the plant was 200 tonnes/annum (tpa) which was later enhanced to 600 tpa. Commercial production in SMCL commenced in 1990. Their major products included magnesium granules, magnesium powder, magnesium alloy and magnesium extrusion. The purity of magnesium extracted was upto 99.95%[12].

Tamil Nadu Magnesium and Marine Chemicals Limited was a Public Company incorporated on 10 February 1987, located at Valinokkam, in the district of Ramananthapuram, Tamil Nadu. The technology for this electrolytic plant was developed by Central Electro-Chemical Research Institute (CECRI), Karaikudi, Tamil Nadu. The plant capacity was 600 tpa[12]. The company stopped its production due to the high production cost. According to the Ministry of Corporation Affairs, TMMCL liquidated on 09/02/2001[13].

Present: Global and India

Ever since the entrance of China and their Pidgeon process plants, they literally dethroned almost all electrolytic route plants in the world. The main reasons for the spontaneous growth of Pidgeon process were; lower operating cost, flexible production capacity, significantly less reliance on economies of scale and can be built in a fraction of the time and at a fraction of the cost of electrolytic plants. Since then in China, according to the United States Geological Survey (USGS), magnesium production has been expanding at a fair pace, reaching 6,97,740 tonnes in 2012 comparing to 7,388 tonnes in 1992[11]. Dead Sea Magnesium Ltd. (Israel) is the only salt water magnesium producer left, a joint venture between Israel Chemicals Ltd. and Volkswagen AG.

The main primary magnesium producers outside China are VSMPO-Avisma and Solikamsk Magnesium Works in Russia, US Magnesium in the USA, Dead Sea Magnesium in Israel, Ust-Kamenogorsk Titanium and Magnesium Plant in Kazakhstan, Rima Industrial in Brazil, CVM Minerals in Malaysia, Magnohrom in Serbia and POSCO in South Korea.

According to Roskill, the estimated world production of primary magnesium was 9,05,000 tonnes in 2012. China continues to dominate primary magnesium metal production, with output exceeding 7,30,000 tonnes, equivalent to over 75% of total supply. Out of the top ten global producers, there are eight producers from China [11].

Global secondary magnesium production (recycling) is dominated by USA[9, 14]. Recycling is so efficient and requires only 5% more energy necessary to produce the primary product. Global capacity and production of secondary magnesium (excluding aluminium alloys which form a closed-loop cycle) is estimated at over 2,00,000 tonnes, about 40% of which is centered in the USA [8, 15]. Global magnesium consumption achieved a landmark of more than 1.098 million tonnes in 2012. Two-third of magnesium consumption is in die-cast parts and as an alloy in aluminium[11].

As stated in the past section, the present Indian scenario continues to be worse if we consider the metal extraction section and metal alloy castings in a commercial point of view. Even though CECRI and NML developed extraction techniques for TMMCL and SMCL, low volume of production is affecting the metal cost which makes importing a better choice right now[12].

Growth of Magnesium and Its Alloys in Automobile Industry

Magnesium usage in automobile industry had its ups and down over the past years. Steady growth ceased after the end of Second World War because of low cost alternative in the form of aluminium. Flammability issues also limited its use during late 1960s. High production of magnesium by China in 1990s and proper development in technology paved the way from then onwards. Now the use of magnesium and its alloys are increasing in a steady way. A brief highlight of the use of magnesium in automobile industry is given below.

- Elektron Piston in 1921.
- Elrasal process for melt treatment in 1923.
- Bulk usage of magnesium cast parts in trucks by German company Büssing in 1924.
- German company Adlerwerke started using magnesium cast and pressed parts in automobiles in 1927[16].
- Main car manufacturers used magnesium alloys for engines, oil pumps, gears, clutch, rear suspension, starter, ignition, steering, brakes, car body, seats, wheels (rims), etc. from early 1930s.
- The first commercial vehicle to use more than 40lb (20kg, mainly in crank case and transmission housing) was Volkswagen Beetle, introduced in 1938. Until when the company started using water-cooled crank case, magnesium usage was growing steadily reaching a peak of 42,000 tpa in 1971[17].
- Magnesium sheets were used in Bugatti Type 57SC (1935), Buick LeSabre Dream (1951), Corvette SS (1957).
- Cast magnesium wheels first used in Fiat 1967.
- In mid 1960s, Porsche introduced 6 cylinder crank case based on magnesium alloy. In 1970's Porsche withdrew using sand cast magnesium wheels due to some technological and economic problems and later started low pressure die-casting wheels.
- In 1973, General Motors started using Mg alloys for steering columns, followed by Ford in 1978 [18].
- Audi introduced first cross bar beam in instrument panel in 1989.
- In 1992, United States Council for Automotive Research (USCAR) was established by three automobiles companies-General Motors, Ford and Daimler for competitiveness and environmental measures. In 2001, a project named Magnesium Powertrain Cast Components Project was started with the collaboration of United States Automotive Materials Partnership (USAMP)[18].
- VW developed B80 gear housings in 1995.
- Audi introduced its first magnesium automatic transmission in 1999.
- Ford used large radiator support made of magnesium alloy in 2003.
- BMW introduced composite Magnesium crankcase in 2004 [17].

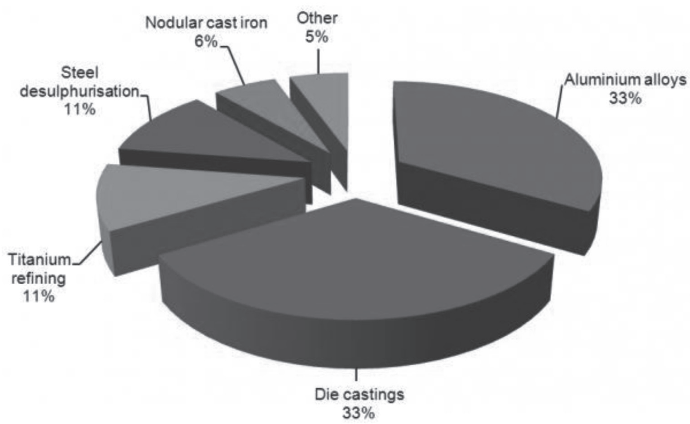

Fig.- 1: Global magnesium Consumption[11].

In 2012, the use of magnesium for aluminium alloying and production of magnesium die-castings were the two major consuming areas (Refer Fig.1), both using about 3,65,000 tonnes each[11]. Automobile sector was the main user of magnesium die-cast components. The global automotive magnesium alloy consumption for the year 2012 was about 214,000 tonnes[19]. Average use of magnesium per vehicle was 2.3 kg. Presently, around 14 kg of magnesium are used in the VW Passat, Audi A4 and A6. All of them uses AZ91D alloy for their transmission casing that weighs 20%-25% lighter than aluminium[20]. Other applications include instrument panels, intake manifolds, cylinder head covers, inner boot lid sections and steering components which utilize the more ductile AM50A and AM60B alloys. The GM full-sized Savana & Express vans use up to 26 kg of magnesium alloy[21]. BMW uses a 6-cylinder engine block while Daimler uses the 7G-Tronic transmission made of magnesium alloys.

Meridian, a Canada-based company, is one of the largest producers of magnesium components in the world, shipping about 40,000 metric tonnes of products annually. Their main partners are Audi, BMW, Daimler Chrysler, Fiat, General Motors, Tata Jaguar, Mercedes Benz, Opel, Paulstra, Tesla Motors. Similarly, Beijing Guangling Jinghua Science & Technology Co. Ltd., established in October 2001, is a well-known automotive magnesium alloy manufacturer in China. Five major areas covered by them are magnesium and magnesium alloys, sacrificial anode, mechanical parts, sections and magnesium sheet, with a capacity of 50,000 tpa. In 2013, they became a supplier of magnesium alloy auto parts for Volkswagen, Hyundai, Ford and other well-known car makers that are used in Indian roads too.

In India, Sundaram Clayton Limited, which is one of the largest suppliers of die-castings in automobile sector has started trial production of magnesium die-casting in 2011 with a initial production capacity of 1000 tonnes per annum.

Various US car manufactures have already planned to increase magnesium parts in automobiles to between 45-160 kg. According to the US Natural Resources Defense Council, reducing weight by 23 kg would boost vehicle fuel efficiency by around 1 per cent which would subsequently save 1,00,000 barrels of oil per day. USAMP in its mission 2020 have set a target of using 159 kg of magnesium in place of steel and aluminium in automobiles[18, 22]. Indian companies such as Tata Motors, Ashok Leyland and Mahindra have also expressed their initiative in using magnesium alloys.

Future: Where to Focus?

According to Roskill estimate 2013 (Refer Table-5), the consumption of magnesium is likely to reach 1.4 million tonnes with an average annual growth rate (AAGR) of 5%.

Major concern for scientists regarding magnesium's future is its corrosion problems. A recent research conducted by a group of international scientists, led by Associate Professor Nick Birbilis of Monash University in Melbourne, after testing more than 400 different alloy compositions have found that, adding small amount of arsenic, dramatically reduces rates of corrosion in magnesium. The initial experiments showed promise and were successfully repeated using solid magnesium alloys containing 0.37% arsenic. Arsenic acts as a cathodic poison by restricting the ability of hydrogen atoms to form magnesium corroding molecules. If their claim is true, then this alloy will be a real game changer in future [23].

Table-5: Consumption of Magnesium World–Forecast (kt) [11]

	2012	2017	AAGR (%)
Aluminium Alloys	367	468	5.0
Die-Castings	364	499	6.5
Titanium Refining	123	136	2.0
Steel Desulphurisation	119	148	4.5
Iron Nodularisation	65	79	4.0
Other	60	70	3.5
Total	**1,098**	**1,400**	**5.0**

Magnesium looks similarly promising for use in rechargeable batteries, including all-liquid batteries that could help store solar energy [24].

Usage of magnesium alloys as implants is something exciting to see in the future. Different alloys of metals such as titanium, copper, chromium, magnesium etc. can be used for making biological implants. Out of which only magnesium has an exception which makes it suitable for temporary implantations where it needs to last only until the body tissues are healed. All others being non-biodegradable are to be removed surgically[25].

Magnesium Researches in India

Magnesium activities in our country are limited to some research laboratories/ institutes and a few industries only. Details are given in Table-6.

Various Suggestions That can be Made for the Future in India

Growth of magnesium industry will take place only by cheap and abundant supply of magnesium comparable to that of aluminium. Since availability of electricity is a major issue, it will be better to focus on process where direct fossil energy can be used to produce magnesium. Mine tailings of chromate, diamond etc. contains silicates of magnesium such as serpentine and olivine. Pyroxenite, which are exclusively mined, are also a good source. A method to extract magnesium metal from these will be a great move. Alliance magnesium technology, developed in US makes use of serpentine rock as raw material. About 96% of magnesium is extracted from serpentine here. Developing/borrowing a similar technology will be helpful[5]. Keeping in mind the relevance of magnesium in future, proper government funding should be provided. A team of experts to monitor the work at the national level too help the cause.

Table-6: A List of Major Magnesium Research Laboratories/Institutes/Industries In India

Institute/R&D Division	Areas
1. DMRL, Hyderabad	Complex Mg alloy castings to DRDO for missile programmes.
2. HAL, Bangalore & Koraput	Developed fluxless melting technique, Mg alloy gear casings.
3. CSIR-CECRI, Karaikudi	Sacrificial electrodes for marine applications.
4. CSIR-NIIST, Thiruvananthapuram	Development of high temperature Mg alloy, magnesium metal matrix composites, methoding software for processing of Mg cast components, etc.
5. IISc, Bangalore	Studies on mechanical property correlation of magnesium alloys and use of magnesium in rechargeable batteries.
6. IIT Bombay	Development of corrosion resistant implants using rare earth elements.
7. ISRO	Development of protective coatings on magnesium alloys using polymers.

Conclusions

Magnesium can still be considered as one of most complex metallic element used in engineering applications. A better understanding of its mechanical, chemical and physical nature is required for the proper utilisation of magnesium metal and alloys for wider applications. Magnesium, being such a wonderful metal that can be used in numerous structural applications, is presently underutilised in India.

- Global trend for magnesium production and consumption shows that China is the main producer and consumer because of large labour, energy and material resources, and will continue to be the same, unless more stringent environmental laws are being implemented in China.
- It can be seen that global magnesium consumption has reached a new mile stone of 1.1 million tonnes in 2012, and 33% of which is for die casting sector. It points out to the growth of structural applications of the magnesium. Out of total die casting, 70% was used in automobile sector.
- Presently, it is not economically viable for magnesium production in India either by electrolytic or by thermal reduction (Pidgeon process).
- India's booming industries such as iron and steel, aluminium are the main consumers of magnesium. Majority of the magnesium foundries produces magnesium ingots only.
- Since the automobile as well as aviation Industry in India largely depends on imports, industry of the die cast as well as wrought magnesium products are not well- developed.
- Present condition of magnesium is similar to aluminium some 50 years back. If researches are going in the proper direction, magnesium can be a real threat to aluminium in future and has the potential to replace it in a large number of applications.

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