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## CHAPTER THREE

### LIGHT METALS AND ALLOYS

#### 4.1 ALUMINIUM AND ITS ALLOYS

##### 4.1.1 INTRODUCTION

The metallic element aluminum is the third most plentiful element in the earth's crust, comprising 8% of the planet's soil and rocks (oxygen and silicon make up 47% and 28%, respectively). In nature, aluminum is found only in chemical compounds with other elements such as sulphur, silicon, and oxygen.

##### 4.1.2 PRODUCTION OF ALUMINIUM

###### RAW MATERIALS:-

The major raw material required for aluminum production is *alumina, carbon, power, aluminum fluoride and Cryolite*. Aluminum compounds occur in all types of clay, but the ore that is most useful for producing pure aluminum is bauxite (primarily a mixture of  $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{SiO}_2$ ).

###### 1. BAUXITE

Bauxite is the most important aluminous ore for the production of alumina. Bauxite occurs close to the surface in seams varying from one meter to nine meters, formed as small **reddish** pebbles (pisolites).

Bauxite contains **40 to 60 mass%** alumina combined with smaller amounts of silica, Titania and iron oxide.

###### 2. CAUSTIC SODA (SODIUM HYDROXIDE)

It is **used to dissolve the aluminum compounds** found in the bauxite, *separating them from the impurities*. Depending on the composition of the bauxite ore, relatively small amounts of other chemicals may be used in the extraction.

###### 3. CRYOLITE

It is a **chemical compound** composed of sodium, aluminum, and fluorine, is **used as the electrolyte** (current-conducting medium) in the smelting operation. Naturally occurring cryolite was once mined in Greenland, but the compound is now produced synthetically for use in the production of aluminum.

#### 4. ALUMINUM FLUORIDE

Aluminum fluoride is added as an additive to the Cryolite electrolyte used in the electrolysis. Its chemical formula is  $\text{AlF}_3$ . This chemical compound does not occur in nature. Aluminum fluoride is added to lower the melting point of the electrolyte solution.

#### 5. SODIUM CARBONATE OR SODA ASH

Soda ash is used as an additive to the electrolyte in alumina electrolysis. It is used as a source of aluminum and is much cheaper alternative to sodium fluoride. The chemical formula is  $\text{Na}_2\text{CO}_3$ . It is a white granular material. When soda ash is added to the electrolyte, large quantities of gas will be produced as carbon dioxide.

#### 6. CARBON

The other major ingredient used in the smelting operation is carbon. Carbon electrodes transmit the electric current through the electrolyte. During the smelting operation, some of the carbon is consumed as it combines with oxygen to form carbon dioxide.

#### **PRODUCTION METHODS:-**

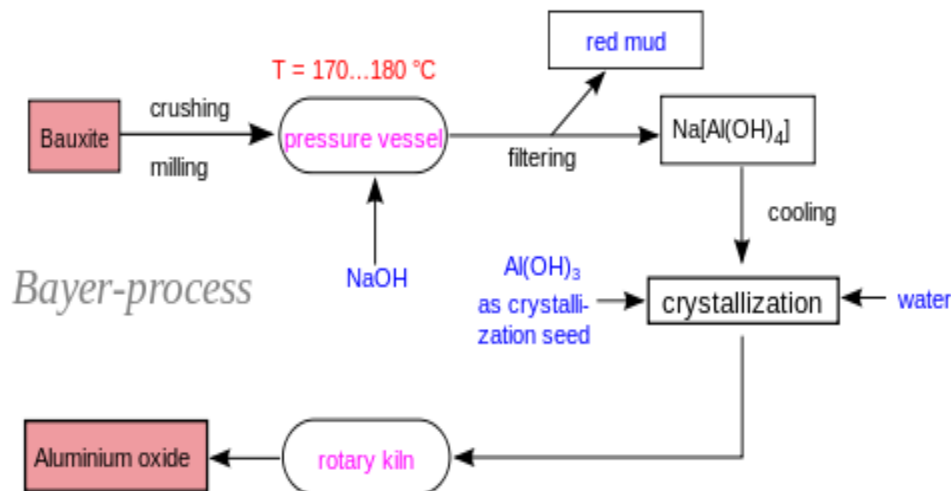
Aluminum is manufactured in two phases: the Bayer process of refining the bauxite ore to obtain aluminum oxide, and the Hall-Heroult process of smelting the aluminum oxide to release pure aluminum.

### **PHASE ONE (THE BAYER PROCESS)**

1. First, the bauxite ore is mechanically crushed. Then, the crushed ore is mixed with caustic soda and processed in a grinding mill to produce a slurry (a watery suspension) containing very fine particles of ore.
2. The slurry is pumped into a digester, a tank that functions like a pressure cooker. The *slurry is heated to 230-520°F (110-270°C) under a pressure of 50 lb/in<sup>2</sup> (340 kPa).*

Additional caustic soda may be added to ensure that all aluminum-containing compounds are dissolved. The digestion process produces a sodium aluminate solution. Because all of this takes place in a pressure cooker, the slurry is pumped into a series of "flash tanks" to reduce the pressure and heat before it is transferred into "settling tanks."

3. The hot slurry, which is now a sodium aluminate solution, passes through a series of flash tanks that reduce the pressure and recover heat that can be reused in the refining process.
4. The slurry is pumped into a settling tank. As the slurry rests in this tank, *impurities* that will not dissolve in the caustic soda *settle to the bottom of the vessel*. One manufacturer compares this process to fine sand settling to the bottom of a glass of sugar water; the sugar does not settle out because it is dissolved in the water, just as the aluminum in the settling tank remains dissolved in the caustic soda. The residue (called "red mud") that accumulates in the bottom of the tank consists of fine sand, iron oxide, and oxides of trace elements like titanium.
5. After the impurities have settled out, the remaining liquid, which looks somewhat like coffee, is pumped through a series of cloth filters. Any fine particles of impurities that remain in the solution are trapped by the filters. This material is washed to recover alumina and caustic soda that can be reused.
6. The filtered liquid is pumped through a series of six-story-tall precipitation tanks. Seed crystals of alumina hydrate (alumina bonded to water molecules) are added through the top of each tank. The seed crystals grow as they settle through the liquid and dissolved alumina attaches to them.
7. The crystals precipitate (settle to the bottom of the tank) and are removed. After washing, they are transferred to a kiln for calcining (heating to release the water molecules that are chemically bonded to the alumina molecules). A screw conveyor moves a continuous stream of crystals into a rotating, cylindrical kiln that is tilted to allow gravity to move the material through it. A temperature of 2,000° F (1,100° C) drives off the water molecules, leaving anhydrous (waterless) alumina crystals. After leaving the kiln, the crystals pass through a cooler.



**Figure 4.1: Bayer –process of Aluminium oxide production**

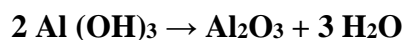
In the Bayer process, bauxite is digested by washing with a hot solution of sodium hydroxide, NaOH, at 175 °C, under pressure. This converts the Aluminium oxide in the ore to soluble sodium aluminate,  $2\text{NaAl}(\text{OH})_4$ , according to the chemical equation:



This treatment also dissolves silica, but the other components of bauxite do not dissolve. Sometimes lime is added here, to precipitate the silica as calcium silicate. The solution is clarified by filtering off the solid impurities, commonly with a rotary sand trap, and a flocculent such as starch, to get rid of the fine particles. The mixture of solid impurities is called red mud. Originally, the alkaline solution was cooled and treated by bubbling carbon dioxide into it, through which Aluminium hydroxide precipitates:



Then, when heated to 980°C (calcined), the Aluminium hydroxide decomposes to Aluminium oxide, giving off water vapor in the process:



The left-over NaOH solution is then recycled. This, however, allows gallium and vanadium impurities to build up in the liquors, so these are extracted.

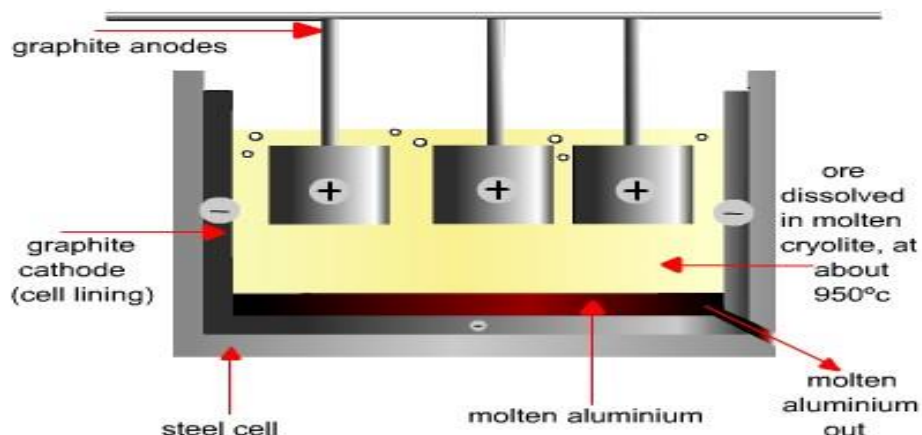
A large amount of the Aluminium oxide so produced is then subsequently smelted in the Hall–Heroult process in order to produce Aluminium.

#### STAGE TWO (HALL-HEROULT PROCESS)

### Converting Alumina to Aluminum

In 1886, two 22-year-old scientists on opposite sides of the Atlantic, Charles Hall of the USA and Paul L.T. Heroult of France, made the same discovery - molten Cryolite (a sodium aluminum fluoride mineral) could be used to dissolve alumina and the resulting chemical reaction would produce metallic aluminum. The Hall-Heroult process remains in use today. The Hall-Heroult process takes place in a large carbon or graphite lined steel container called a "reduction pot". In most plants, the pots are lined up in long rows, called potlines. The key to the chemical reaction necessary to convert the alumina to metallic aluminum is the running of an electrical current through the Cryolite/alumina mixture.

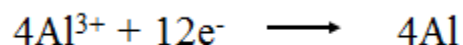
The immense amounts of power required to produce aluminum is the reason why aluminum plants are almost always located in areas where affordable electrical power is readily available. Some experts maintain that one percent of all the energy used in the United States is used in the making of aluminum.



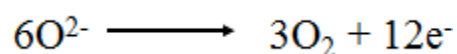
**Figure 4.2: Electrolysis Process for Aluminium Production**

Aluminum oxide is an ionic compound. The positive aluminum ions drift to the negative electrode (cathode) and the negative oxygen ions to the positive electrodes (anodes).

At the **cathode** the aluminum ions gain electrons and become aluminum atoms.



At the **anodes** the oxygen ions lose electrons and become oxygen atoms.



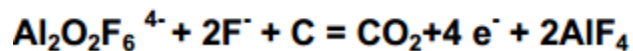
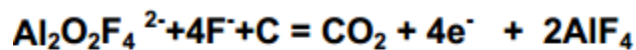
About 6.2 KWH (kilowatt hours) of electricity is required to produce one pound of aluminum from alumina.

**OR** Alumina, an oxide of aluminum ( $\text{Al}_2\text{O}_3$ ), is dissolved in molten Cryolite ( $\text{Na}_3\text{AlF}_6$ ) and decomposed electrolytically to give liquid aluminum. The anode of the electrolytic cell is made of carbon and the pool of already produced aluminum acts as cathode.

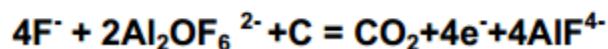
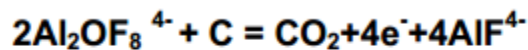
The oxygen of the alumina is discharged at the anode where it reacts with the carbon anode to produce carbon dioxide ( $\text{CO}_2$ ).

### **Anode Reactions:-**

During the electrolysis reaction gaseous;  $\text{CO}_2$  evolved. The carbon is provided by the anode material, the oxygen is transported to the anode in the form of AL-O-F complex anions. At high alumina concentrations the species  $\text{Al}_2\text{O}_2\text{F}_4^{2-}$  and  $\text{Al}_2\text{O}_2\text{F}_6^{4-}$  may be discharged as suggested by the reactions-



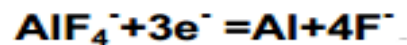
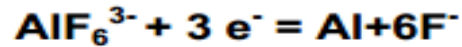
These reactions explain why the electrolyte becomes enriched in  $\text{AlF}_3$  or actually  $\text{AlF}_4^-$  close to the anode during electrolysis. At low alumina concentrations, where the  $\text{Al}_2\text{OF}_x$  (4-x) species may dominate, the reactions may be written as:



### **Cathode Reactions:-**

The only cation present in Cryolite-alumina melts is  $\text{Na}^+$ . Despite  $\text{Na}^+$  being the main current carrier, it has been showed that formation of aluminum is favored over sodium in the electrolyte compositions used industrially, since the reversible EMF is favorable.

As there is no evidence that  $\text{Al}^{3+}$  ions are present, all of the aluminum in the melt is bound in different anionic complexes. Al-O-F takes part in the anode reactions so the most probable cathode reactions involve the remaining Aluminium – containing ions  $\text{AlF}_6^{3-}$  and  $\text{AlF}_4^-$ . The overall reaction can be written as



A steel shell which is lined with carbon blocks and thermal insulation material contains the liquid Cryolite electrolyte and liquid aluminum. The process uses electrical energy to reduce electrolytically aluminum oxide and to keep the electrolyte at a temperature of about 950° C. During aluminum production the chemical reactions consume continuously alumina and anodes which must be added respectively replaced to the electrolytic cell. Aluminum and anode gases (in essence carbon dioxide and carbon monoxide) are produced and removed from the cell.

#### 4.1.3 ENVIRONMENTAL EFFECT OF ALUMINA PRODUCTION

When alumina is extracted from bauxite, the process creates about an equal amount of bauxite residue, also known as red mud. This needs to be managed properly to protect the environment, and is a challenging part of alumina production.

Other environmental issues related to alumina production:

- ✓ **Energy consumption** – a lot of energy is needed to make alumina.
- ✓ **Water management** – process water as well as surface water from precipitation and run-off from the bauxite residue deposits are cleaned before being discharged to the environment.
- ✓ **Impacts from the plant's infrastructure and the bauxite residue disposal** – when the bauxite residue deposits are full, they will be replanted with local species.

#### 4.1.4 PROPERTIES OF ALUMINIUM AND ITS ALLOYS

Metallic aluminum has many properties that make it useful in a wide range of applications. It is lightweight, strong, nonmagnetic, and nontoxic. It conducts heat and electricity and reflects heat and light. It is strong but easily workable, and it retains its strength under extreme cold without becoming brittle. The surface of aluminum quickly oxidizes to form an invisible barrier to corrosion. Furthermore, aluminum can easily and economically be recycled into new products.

Aluminium has two main advantages when compared with other metals. Firstly, it has a low density, about one third that of iron and copper. Secondly, although it reacts rapidly with the oxygen in air, it forms a thin tough and impervious oxide layer which resists further oxidation. This removes the need for surface protection coatings such as those required with other metals, in particular with iron.

Generally the properties of aluminum and its alloys are:-

- Aluminum and its alloys are characterized by a relatively low density
- It is good resistant to corrosion due to formation of alumina.
- The chief limitation of aluminum is its low melting temperature [660C (1220F)], which restricts the maximum temperature.
- The mechanical strength of aluminum may be enhanced by cold work and by alloying; however, both processes tend to diminish resistance to corrosion.
- Good malleability and formability.
- Non- magnetic- can be used for electrical shielding purposes like enclosure for electrical equipment.
- Extensively used cooking utensils, food and beverage cans and welded assemblies.

#### 4.1.4. CLASSIFICATION OF ALUMINIUM ALLOYS

Aluminium alloys are alloys in which aluminum (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc.

There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable.

##### **Cast aluminum alloys:-**

Cast aluminum alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. About 85% of aluminum is used for wrought products, for example rolled plate, foils and extrusions. The most important cast aluminum alloy system is Al-Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics.

##### **Wrought Aluminum alloys:-**

Wrought alloys are identified by a four-digit system. Again, the first numeral indicates the major alloying element or group of elements.

The main groups of aluminum alloys which are the most often used in practice besides technically pure aluminum are AlMn, AlMg, AlMgMn, AlMgSi, AlZnMg, and AlZnMgCu alloys. These are wrought alloys which are shaped into products by rolling, extrusion, and forging. Each of the mentioned groups consists of numerous subgroups, depending on amounts of main and additional alloying elements, and they have tensile strength values varying in a wide range from 70 to 600 MPa.



**Difference between the two alloys of aluminum:** - is wrought alloys are hammered, pressed like forged, cold worked and heat treated while cast is just a casting of the metal. The main difference between the two is the way the fibers in the steel line up. Wrought alloys are much stronger, cleaner and are more ductile. Wrought alloys, have a low carbon content, but containing slag. It is a fibrous material due to the slag inclusions. This is also what gives it a "grain" resembling wood, which is visible when it is etched or bent to the point of failure. Wrought iron is tough, malleable, ductile and easily welded. Cast alloys identify a large group of ferrous alloys, which solidify with a eutectic point and have high carbon content.

Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Alloys composed mostly of aluminum have been very important in aerospace manufacturing since the introduction of metal skinned aircraft. Aluminium-magnesium alloys are both lighter than other aluminum alloys and much less flammable than alloys that contain a very high percentage of magnesium.

Aluminium alloy surfaces will formulate a white, protective layer of corrosion aluminum oxide if left unprotected by anodizing and/or correct painting procedures. In a wet environment, galvanic corrosion can occur when an aluminum alloy is placed in electrical contact with other metals with more negative corrosion potentials than Aluminium, and an electrolyte is present that allows ion exchange. Aluminium alloys can be improperly heat treated. This causes internal element separation and the metal corrodes from the inside out. Aircraft mechanics deal daily with aluminum alloy corrosion.

#### **4.1.5 APPLICATION OF ALUMINIUM AND ITS ALLOYS**

These properties lead to a variety of specialized uses.

**a) Lightness:** Use in aerospace and transport industries, as its lightness enables a greater volume of metal to be used, thus giving greater rigidity.

Also used in pistons, connecting rods, etc. to give better balance, reduced friction and lower bearing loads, meaning that less energy is required to overcome inertia.

**b) Electrical conductivity:** used extensively for electrical conductors, especially in overhead cables. However this requires a high purity grade (in excess of 99.93%).

**c) Thermal conductivity:** Extensive usage in heat exchangers, cooking utensils, pistons, etc.

**d) Corrosion resistance:** this is made use of in chemical plant, food industry packaging, building and marine applications.

e) **Affinity for oxygen**: This allows it to be used in explosives, as deoxidant in steels, in thermic reactions for welding and for the manufacture of hardener alloys such as ferro-titanium. In these applications a finely powdered form (and hence a high surface area to weight ratio) is used. This property also makes possible the thermite reaction, which produces molten iron.

## 4.2 MAGNESIUM

Although it is the eighth most abundant element in the universe and the seventh most abundant element in the earth's crust, magnesium is never found free in nature. Magnesium was first isolated by Sir Humphry Davy, an English chemist, through the electrolysis of a mixture of magnesium oxide (MgO) and mercuric oxide (HgO) in 1808. Today, magnesium can be extracted from the minerals dolomite ( $\text{CaCO}_3 \cdot \text{MgCO}_3$ ) and carnallite ( $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ), but is most often obtained from seawater. Every cubic kilometer of seawater contains about 1.3 billion kilograms of magnesium (12 billion pounds per cubic mile).

Magnesium burns with a brilliant white light and is used in pyrotechnics, flares and photographic flashbulbs. Magnesium is the lightest metal that can be used to build things, although its use as a structural material is limited since it burns at relatively low temperatures. Magnesium is frequently alloyed with aluminum, which makes aluminum easier to roll, extrude and weld. Magnesium-aluminum alloys are used where strong, lightweight materials are required, such as in airplanes, missiles and rockets. Cameras, horseshoes, baseball catchers' masks and snowshoes are other items that are made from magnesium alloys.

### 4.2.1 RAW MATERIALS OF MAGNESIUM

The main sources of magnesium compounds are:

- ✓ Seawater (magnesium chloride,  $\text{MgCl}_2$ ) and minerals:
- ✓ Dolomite ( $\text{CaCO}_3 \cdot \text{MgCO}_3$ ),
- ✓ Magnesite ( $\text{MgCO}_3$ ),
- ✓ Carnallite ( $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ).

### 4.2.2 PRODUCTION OF MAGNESIUM

Magnesium is principally produced by two methods:

- a) Thermal reduction of magnesium oxide
- b) Electrolysis of magnesium chloride

Before the expansion of production in China, electrolysis was the more common method of production in countries where electrical energy is produced relatively cheaply. Most Chinese

plants, however, use an updated version of the thermal reduction process originally developed in Canada in the 1940s to boost production during World War II (the 'Pidgeon Process').

**(a) Thermal reduction process**

Dolomite ore is crushed and heated in a kiln to produce a mixture of magnesium and calcium oxides, a process known as calcining:



The next step is reduction of the magnesium oxide. The reducing

Alumina may also be added to reduce the melting point of the slag. The reaction is carried out at 1500 - 1800 K under very low pressure, close to vacuum. Under these conditions the magnesium is produced as a vapor which is condensed by cooling to about 1100 K in steel-lined condensers, and then removed and cast into ingots:



The forward reaction is endothermic and the position of equilibrium is in favor of magnesium oxide. However, by removing the magnesium vapor as it is produced, the reaction goes to completion. The silica combines with calcium oxide to form the molten slag, calcium silicate:



The process gives magnesium with up to 99.99% purity, slightly higher than from the electrolytic processes.

**(b) The electrolytic process**

Outside China, the electrolytic process is usually the preferred choice.

The process involves two stages:

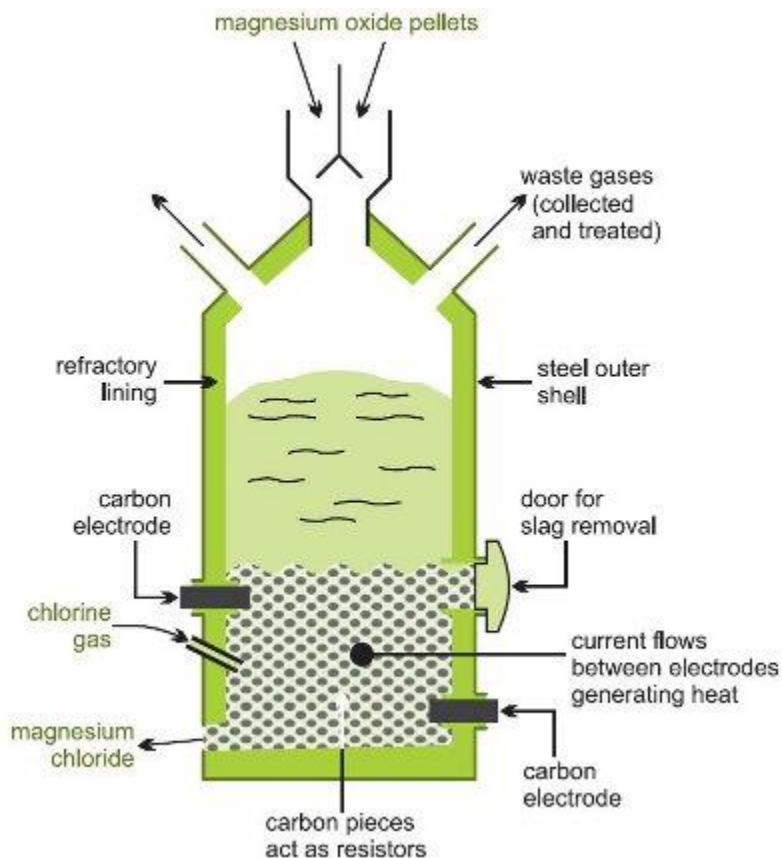
- i) production of pure magnesium chloride from sea water or brine
- ii) electrolysis of fused magnesium chloride

**(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

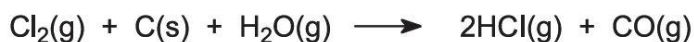
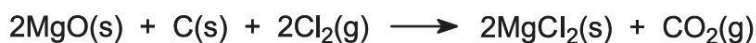
calcium hydroxide remains in solution. Magnesium hydroxide is filtered off and on heating readily forms the pure the oxide.

Conversion to magnesium chloride is achieved by heating the oxide, mixed with carbon, in a stream of chlorine at a high temperature in an electric furnace (Figure 1).



**Figure 1: Illustrating the production of magnesium chloride from magnesium oxide.**

Several reactions occur:



Where magnesium chloride-rich brines are the source of magnesium, the solution is treated for removal of various impurities and the remaining magnesium chloride solution concentrated by evaporation in several stages.

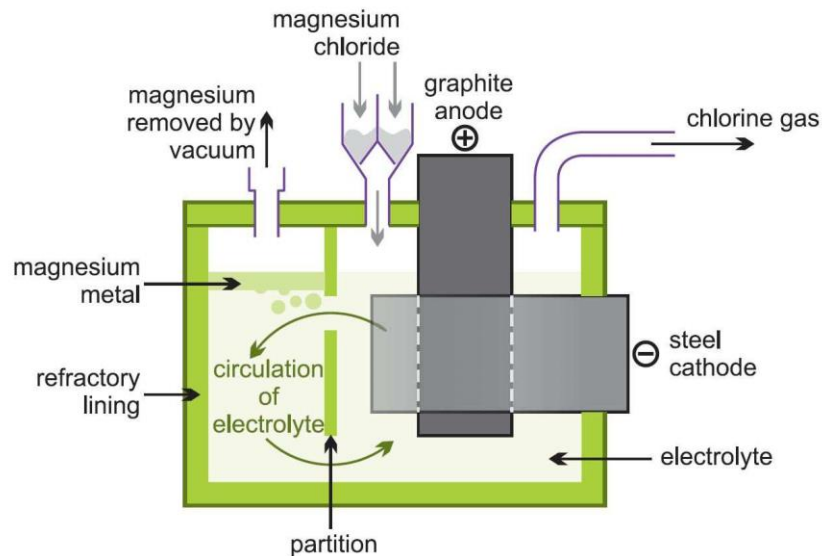
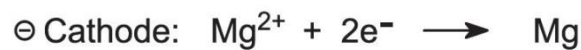
The last stage of dehydration has to be carried out in the presence of hydrogen chloride gas to avoid hydrolysis of the magnesium chloride:



### (ii) The electrolysis of fused magnesium chloride

The resulting anhydrous magnesium chloride is fed continuously into electrolytic cells (Figure 2) which are hot enough to melt it.

On electrolysis, magnesium and chlorine are produced:



**Figure 2: Illustrating the electrolysis of magnesium chloride.**

The molten metal is removed and cast into ingots. The chlorine gas is recycled to the chlorination furnace.

#### 4.2.3 PROPERTIES OF MAGNESIUM AND ITS ALLOY

Magnesium is the lightest structural metal used today, some 30% lighter than aluminum, and is generally used in alloys. Pure magnesium burns vigorously once molten, but magnesium alloys have higher melting points and are widely used in the automotive and aircraft industries.

- ✓ Limited cold working due to HCP structure.
- ✓ Usually hot worked.

- ✓ Al and Zn are added to increase strength.
- ✓ Alloying with rare earth elements (cerium) produces rigid boundary network.
- ✓ Tensile strength 179 – 310 MPa.
- ✓ Lowest density of all structural metals= 1.7 gm/cc
- ✓ Relatively soft and low elastic modulus (45 GPa)
- ✓ Have to be heated to be deformation processed
- ✓ Burns easily in the molten and powder states
- ✓ Susceptible to corrosion in marine environments
- ✓ High cost, low castability, low strength, poor creep, fatigue and wear resistance.

#### 4.2.4 APPLICATION OF MAGNESIUM AND ITS ALLOYS

Magnesium takes a big part of nowadays metallurgy, engineering and modern technologies. It is used mainly magnesium alloys for world industry - for pressure die casting, structural applications, numerous lightweight applications (automotive, hand tools, computers, etc.), and where the metal's damping capacity is of importance.

The very low density and excellent castability of magnesium is leading to increased use in various applications, especially in automobiles, despite poor galvanic corrosion resistance and a higher cost than aluminum. Further expansion of the magnesium market should come from reduced cost, an increased design base, a better understanding of the scientific underpinning of magnesium alloys, improved protection systems, and the development of cost-affordable cast and wrought products.

Other interesting uses of magnesium you can read below:

- For corrosion abatement as sacrificial soil and hot-water tank anodes because of electronegative character of magnesium.
- For military purposes and rescue systems - magnesium batteries with light weight and high energy content.
- For modern automotive, aerospace, and defense industries.
- Also for aircraft, car engine casings and missile construction.
- For needs of computer industry, for radio-frequency shielding.
- Uses in medicine and health way of life you can see in our 'magnesium in health' section at this site.

Magnesium alloys, typically containing over 90% magnesium, have a very low density, comparatively high strength and excellent machinability. They contain one or more of the elements aluminum, zinc, manganese or silicon in various amounts, depending on how the alloy is to be processed. Car components such as steering wheel cores, gearbox casings, dashboard structures and radiator supports are often made from high pressure die cast magnesium alloys.

### 4.3 TITANIUM AND ITS ALLOYS

Titanium is named after the Titans, the powerful sons of the earth in Greek mythology. Titanium is the fourth abundant metal on earth crust (~ 0.86%) after aluminum, iron and magnesium. It is not found in its free, pure metal form in nature but as oxides, i.e., ilmenite ( $\text{FeTiO}_3$ ) and rutile ( $\text{TiO}_2$ ).

Titanium is a low-density element (approximately 60% of the density of iron) that can be highly strengthened by alloying and deformation processing. Titanium is nonmagnetic and has good heat-transfer properties. Its coefficient of thermal expansion is somewhat lower than that of steels and less than half that of aluminum. Titanium and its alloys have melting points higher than those of steels. Titanium has the ability to passivate and thereby exhibit a high degree of immunity to attack by most mineral acids and chlorides. Titanium is nontoxic and generally biologically compatible with human tissues and bones. The combination of high strength, stiffness, good toughness, low density, and good corrosion resistance provided by various titanium alloys at very low to elevated temperatures allows weight savings in aerospace structures and other high-performance applications. The excellent corrosion resistance and biocompatibility coupled with good strength make titanium and its alloys useful in chemical and petrochemical applications, marine environments, and biomaterial applications.

#### 4.3.1 TITANIUM ALLOY

**Titanium alloys** are metals which contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, connecting rods on expensive sports cars and some premium sports equipment and consumer electronics. Auto manufacturers Porsche and Ferrari also use titanium alloys in engine components due to its durable properties in these high stress engine environments.

Titanium alloys are generally classified into three main categories: Alpha alloys, which contain neutral alloying elements (such as Sn) and/or alpha stabilizers (such as Al, O) only and are not heat treatable; Alpha + beta alloys, which generally contain a combination of alpha and beta stabilizers and are heat treatable to various degrees; and Beta alloys, which are metastable and contain sufficient beta stabilizers (such as Mo, V) to completely retain the beta phase upon quenching, and can be solution treated and aged to achieve significant increases in strength.

There are three structural types of titanium alloys:

- ✓ Alpha
- ✓ Alpha - Beta
- ✓ Beta

### **ALPHA TITANIUM ALLOYS:**

An alloy resulting from mixing alpha phase titanium and alpha stabilizers such as *aluminum and tin is called ALPHA TITANIUM ALLOYS*

Commercially pure titanium and alpha alloys of titanium are non-heat treatable and are generally very weldable. They have:

- ✓ Low to medium strength
- ✓ Good notch toughness
- ✓ Reasonably good ductility
- ✓ Excellent mechanical properties at cryogenic temperatures

Pure titanium and alpha alloys possess the highest corrosion resistance. More highly alloyed near-alpha alloys offer optimum high temperature creep strength and oxidation resistance.

### **ALPHA - BETA TITANIUM ALLOYS**

An alloy resulting from mixing alpha and beta phase titanium with alpha and beta stabilizers is called ALPHA - BETA TITANIUM ALLOYS.

**Alpha stabilizer:** An alloying element that favors the alpha crystal structure and raises the alpha-to-beta transformation temperatures. Alpha stabilizers include gallium, germanium, carbon, oxygen, and nitrogen.

Alpha- Beta alloys are heat treatable and most are weldable. Typical properties include:

- ✓ Strength levels are medium to high
- ✓ High temperature creep strength is not as good as most alpha alloys
- ✓ Cold forming may be limited but hot forming qualities are normally good



- ✓ Many alloys can be superplastically formed.

The most commonly used alpha- beta alloy is Ti<sub>6</sub>Al<sub>4</sub>V, developed in many variations of the basic formulation for the widest possible choice of key properties and for many widely differing applications.

### **BETA TITANIUM ALLOYS**

**Beta stabilizer** : An alloying element that favors the beta crystal structure and lowers the alpha-to-beta transformation temperatures. Beta stabilizers include vanadium, molybdenum, chromium, and copper.

The beta titanium alloys offer many advantages in terms of processing, mechanical properties, and low cost of fabricated components compared to conventional titanium alloys.

Beta or near beta alloys are:

- ✓ Fully heat treatable
- ✓ Generally weldable
- ✓ Capable of high strength
- ✓ Possess good creep resistance up to intermediate temperatures
- ✓ Excellent formability can be expected in the beta alloys in the solution treated condition

The attributes of titanium alloys of prime importance to the design engineer are:

- ✓ Outstanding corrosion resistance
- ✓ Excellent erosion resistance
- ✓ High heat transfer capability
- ✓ Superior strength-to-weight ratios
- ✓ Low thermal expansion co-efficient
- ✓ Non-magnetic character
- ✓ Fire resistance

### **4.3.2APPLICATIONS OF TITANIUM AND ITS ALLOYS**

Titanium alloys are used mainly in aerospace, marine, chemical, biomedical applications and sports.

#### **1. Aircraft Applications**

Aeronautical design engineers find in titanium and its alloys a metal whose light weight and high strength, particularly at elevated temperatures, render it a highly desirable material in aircraft construction.

Titanium, on the other hand, has a distinct high temperature strength advantage at temperatures up to 800°F (426°C); such elevated temperatures occur at high speeds due to aerodynamic heating.

The advantage of titanium substitution for steel in aircraft stems from its accompanying weight reduction with no loss in strength. The overall reduction of weight and the increased elevated temperature performance allowed by the utilization of titanium permit increased pay loads, as well as an increase in range and maneuverability. In view of this, effort is being applied to utilize this metal in aircraft construction from engines and airframes to skins and fasteners.

In jet engines titanium is chiefly used in compressor blades, turbine disks, and many other forged parts. The materials replaced in these applications are stainless and heat-treated alloy steels.

### **2. Marine Applications**

The corrosion resistance of titanium and its alloys makes this metal a prime consideration for use in marine environments. The Navy is thoroughly investigating titanium's corrosion resistance to stack gases, steam, and oil as well as sea water. Of almost equal importance in these applications is the high strength-weight ratio.

The light weight of the metal, in conjunction with the corrosion resistance, offers in naval vessels improved maneuverability, increased range, less preventative maintenance, and reduced power cost.

### **3. Transportation**

Many of the advantages indicated for armored vehicles also apply to the transportation industry. Decreased fuel consumption or increased pay load and better fatigue strength in piston rods and transmissions are possible advantages offered by the substitution of titanium for materials used in transportation industries today. In railway equipment applications, dead weight considerations are of utmost importance. Where the overall weight of a railway car can be substantially decreased by the application of titanium, it follows that the horsepower required to pull this lighter car will be markedly reduced, as will be the size required for the journals and the journal boxes.

Another application where load is a major consideration is in trailer trucks. Here, also, increased pay load can be achieved by the replacement of steel with titanium in such items as axles and wheels.

### **4. Chemical**

In the chemical industry the corrosion resistance of a metal plays the most important part. However, light weight and strength are desirable. The advantages described there indicate utilization in many industries once the price is reduced to a competitive level.

Production equipment which facilitates transportation of corrosive materials such as acid, alkali, and inorganic salts are logical applications for titanium. Manufacturing equipment such as vats, reflux towers, filters, and pressure vessels give additional opportunities for the utilization of titanium.

Titanium tubing can improve the performance of heating coils in laboratory autoclaves and heat exchangers.

### **Miscellaneous Applications**

The food, petroleum and electrical industries, as well as the field of surgical instruments and surgery itself, are representative of the diverse fields in which application of titanium has been found desirable.

Food processing tables as well as steam tables, where titanium has been substitute for stainless steel, have been evaluated and results indicate superior performance and potential utilization.

In oil and gas drilling applications, the corrosion problem is serious, and titanium substitution will permit less frequent replacement of corroding underground shafts. In catalytic processing applications and fuel pipe lines, titanium's high temperature properties and corrosion resistance are desirable. Increased utilization is again dependent upon increased supply of the metal at reduced prices.

The electrical industry is equally desirous of taking advantage of the metal's high strength-lightweight ratio and, in addition, its high electrical resistance and nonmagnetic properties for utilization as cable armor material.

Most industries employ fasteners in some form or other, and the production of titanium fasteners on a commercial basis has not been lacking over the conventional surgical instruments.