ME 216 – Engineering Materials II

Chapter 7

Production of Nonferrous Metals
Even though ferrous metals and alloys are the most important and widely used engineering materials, nonferrous metals and alloys also find significance in engineering construction.

They have a wide range of properties and uses for which ferrous alloys are not suitable.

Most of the useful engineering alloys are made from two or more of the following metals, and various types and grades of these metals are obtained from refining processes:

- Aluminum (Al)
- Copper (Cu)
- Lead (Pb)
- Magnesium (Mg)
- Nickel (Ni)
- Tin (Sn)
- Zinc (Zn)

In general, nonferrous metals and alloys are more expensive than any iron or steel, but they hold their place in industry since they meet special requirements (e.g. copper is most useful due to its electrical properties, aluminum and magnesium are very light and provide very high strength/weight ratios, tin and lead have good corrosion resistance).
Furnaces used for smelting nonferrous metals are different from those for iron and steel.

**Blast furnace** (similar but smaller than those for iron smelting) is used for reducing oxide ores of nonferrous metals (e.g. copper, tin, lead, zinc). Some ores contain sulphides which are decomposed in roasting ovens to drive off sulphur and leave the oxide. **Reverberatory furnace** (similar to open-hearth furnace) is often used to smelt nonferrous metals.

**Vacuum arc furnace** (consumable electrode unit) is a special type of electric furnace. It is used for melting various metals (such as high purity steels, titanium, zirconium). The metal used to charge the furnace is fashioned into long rods by briquetting and welding into electrode. Vacuum in furnace is constantly maintained to remove gases before being absorbed by metal. By this method of melting in water-cooled mold at the base of furnace, a solid ingot is gradually formed.
PRODUCTION OF ALUMINUM

Bauxite (about 4 kg)
- Gibbsite (Al₂O₃. H₂O)
- Diaspore (Al₂O₃. H₂O)

Bayer Process
(ore-dressing & calcination)

Alumina: 99.4% Al
(about 2 kg)

Hall-Heroult Process
(reduction by electrolysis)

Electrolytic Al: 99.6% Al
(about 1 kg)

Hoopes Process
(three-layer electrolytic cell)

Pure Al: 99.99% Al

BAYER PROCESS
1. MIXING
- Crushing & grinding bauxite ore.
- Mixing with caustic soda, lime, sodium hydroxite, and hot water.

2. DIGESTION
- Under high pressure & heat, caustic soda dissolves alumina in bauxite to form sodium aluminate.

3. CLARIFICATION
- Sodium aluminate remains liquid.
- Iron oxides and other solid impurities are pumped to disposal as red mud.

4. PRECIPITATION
- Sodium aluminate is seeded with aluminum hydroxite, and converted to aluminum hydrate.
- As cooling continues, aluminum hydrate settles to bottom while sodium hydroxite rises to top.

5. CALCINATION
- Aluminum hydrate is calcinated (roasted) at 1100 °C to remove water, and pure alumina (99.4%) is obtained.

Facts and Properties:
- Very ductile & malleable
- White or grey-white metal
- Better strength-to-weight ratio than steel
- Melting point of 660 °C
- Good thermal & electrical conductivity

HALL-HEROULT PROCESS

HOOPES PROCESS
PRODUCTION OF COPPER

Sulphide Ores
- Chalcocite (Cu₂S): 79.8% Cu
- Chalcopyrite (CuFeS₂): 34.5% Cu

Ore-Dressing
- Crushing in jaw crushers
- Grinding in ball mills
- Concentrating by froth floatation

Concentrated Cu

Smelting in Reverberatory Furnace
- Matte Cu: 40-45% Cu

Converting in Bessemer Converter
- Blister Cu: 98% Cu

Refining (Poling) in Reverberatory Furnace
- Tough-pitch Cu: 99% Cu

Electrolysis to deposit Cu on cathodes
- Electrolytic Cu: 99.95% Cu

Facts and Properties:
- Soft, heavy, reddish metal
- Melting point of 1083 °C
- High ductility
- Excellent thermal & electrical conductivity
PRODUCTION OF LEAD

Galena (PbS): 1-10% Pb

Concentrating by floatation

Roasting with O₂ (at 600-700 °C)
\[2\text{PbS} + 3\text{O}_2 \rightarrow 2\text{PbO} + 2\text{SO}_2\]

Smelting with coke (in blast furnace at 900 °C)
\[2\text{PbO} + \text{C} \rightarrow 2\text{Pb} + \text{CO}_2\]

Crude Pb: 60-80% Pb

Refining by heating (in air at 400 °C)

Removing impurities
- Cu (by adding sulphur)
- Sb & As (by selective oxidation)
- Zn (by distillation)
- Ag (by electrolysis)

Pure Pb: 99.9% Pb

Facts and Properties:
- Heavy, greyish metal
- Melting point of 327 °C
- High malleability, low strength
- Good corrosion resistance
**PRODUCTION OF MAGNESIUM**

Seawater: 1300 ppm Mg

Mixing with milk of lime

Magnesium Hydrate

Adding hydrogen chloride (HCl)

Magnesium Chloride (MgCl)

Electrolysis with carbon anodes & steel cathodes using 60,000 A in an electrolyte (Ca + NaCl)

Pure Mg (deposited on cathodes)

Facts and Properties:
- Light, soft, silver-white metal
- Melting point of 650 °C
- Chemically active metal
**Production of Tin**

Cassiterite (SnO₂): tin stone (1-5% Sn)

- Washing to remove impurities
- Heavy tin oxide
- Smelting in reverberatory furnace (with powdered coal & lime at 1200 °C)
- Matte Sn

Refining in two stages:
- Liquation (at low temp.) to remove Cu, Fe, As
- Oxidation in open crucible (kettle) to remove Zn

- Pure Sn: 99% Sn
- Further refining by electrolysis

Pure Sn: 99.9% Sn

**Facts and Properties:**
- White coloured metal
- Melting point of 232 °C
- Good corrosion resistance

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**Production of Nickel**

Penthandite [NiS.(FeS)₂]

- Concentrating by floatation
- Smelting in furnace
- Matte Ni (having Cu & iron sulphides)

Refining by Mond Process:
- Crushed & heated to drive off sulphur
- Converted to NiO
- Treated with sulphuric acid to remove Cu
- Reduced with water gas (H + CO) at 300 °C

- Pure Ni: 99.8% Ni

**Facts and Properties:**
- Whitish metal
- Melting point of 1452 °C
- Low strength
- Resistance to corrosion & oxidation
PRODUCTION OF ZINC

Sphalerite (ZnS): zincblende, ruby jack

Floatation to remove Pb, Cu, iron sulphides

Concentrated Zinc

Roasting Roasting with O₂

Zinc Oxide

Purifying in two ways

Distillation in Zinc Retort:

- Zinc oxide (with coke) is pressed into walls of briquettes, and retorts are placed in furnace at 1200-1400 °C.
- Due to the reaction occurring in furnace at atmospheric pressure, Pure Zn is produced in vapour form and then condensed at 500 °C.

Roasting & Electrolysis

- Zinc concentrate is roasted & leached (i.e. soluble particles are removed) with a weak solution of sulphuric acid.
- Other metals are filtered out and the solution (zinc sulphate) is pumped into electrolytic tanks.
- Cathodes (pure Al) and anodes (Pb-Ag alloy) are lowered into tanks, electric current is passed through solution, and Pure Zn is deposited.

Facts and Properties:

- Bluish-white metal
- Melting point of 419 °C
- Low strength, low ductility
- Easily formable & machinable
- Readily attacked by alkalis and acids
Conventional crucible (melting) methods are **not possible at high temperatures** needed to produce these metals as liquids. Thereby, they are **reduced directly to powder form**. Later, metallic powder is **consolidated by sintering** in solid state.

Melting points of refractory metals and their processing are given below:

- **Tungsten (W, 3410 °C)** and **Molybdenum (Mo, 2610 °C)** are reduced from their oxides of scheelite (CaWO₂) and molybdenite (MoS₂), respectively. In both cases, first stage is to prepare **pure oxide powder** by chemical treatments. Then, it is reduced to metal by heating in a stream of **hydrogen gas**, which is an effective reducing agent for these metals. Such treatment gives a **clean metal**, and there is no problem of carbide formation.

- **Niobium (Nb, 2470 °C)** and **Tantalum (Ta, 2980 °C)** are more reactive metals, and hence their **fluorides** are usually reduced with **sodium**.

- **Rhenium (Re, 3170 °C)** is obtained as **by-product of extraction and refinement of Mo & Cu**.

- **Osmium (Os, 3000 °C)**, being the **heaviest known metal**, is found as a **trace element** in alloys (**mostly in platinum ores**).