Chapter Name: Engineering Materials

Natural Occurrence of Metals

The natural occurrence of metals refers to the way metals are found in the Earth's crust — either in their free (native) state or in combined forms as compounds (like oxides, sulphides, or carbonates).

1. Native (Free) State:

- Some metals are chemically less reactive, so they occur in pure form in nature.
- These metals do not easily combine with other elements such as oxygen, sulphur, or carbon dioxide.

Examples:
- Gold (Au)
- Silver (Ag)
- Platinum (Pt)
- Copper (Cu)

2. Combined State:

- Most metals are reactive and therefore occur in combined form with other elements.
- These combined forms are called minerals, and if extraction is economical, they are called ores.

Examples:

Metal	Form in Nature	Example (Ore)
Iron (Fe)	Oxide	Haematite (Fe_2O_3)
Aluminium (Al)	Oxide	Bauxite ($Al_2O_3 \cdot 2H_2O$)
Copper (Cu)	Sulphide	Copper pyrite ($CuFeS_2$)

Minerals

Minerals are naturally occurring substances (solid and inorganic) found in the earth's crust that contain metals or other valuable elements.
They are formed naturally through geological processes.

Example:

- Bauxite → contains Aluminium (Al)
- Hematite → contains Iron (Fe)
- Cuprite → contains Copper (Cu)
- Galena → contains Lead (Pb)

Ores

Ores are those minerals from which metals can be economically and conveniently extracted.

Example:

- Bauxite ($Al_2O_3 \cdot 2H_2O$) → Ore of Aluminium
- Hematite (Fe_2O_3) → Ore of Iron
- Cuprite (Cu_2O) → Ore of Copper

Difference Between Minerals and Ores

Basis	Minerals	Ores
Definition	Naturally occurring substances containing metals or their compounds	Minerals from which metals can be extracted profitably
Economic Value	May or may not have economic value	Always have economic value
Example	Iron found in FeS_2 (Iron Pyrite) – not used for extraction	Iron found in Fe_2O_3 (Hematite) – used for extraction
Metal Extraction	Not always possible	Always possible

Common Ores of Important Metals

Metal	Ore	Chemical Formula
Iron	Haematite	Fe_2O_3
	Magnetite	Fe_3O_4
	Limonite	$Fe_2O_3 \cdot 3H_2O$
Aluminium	Bauxite	$Al_2O_3 \cdot 2H_2O$
	Cryolite	Na_3AlF_6
Copper	Copper pyrite	$CuFeS_2$
	Malachite	$CuCO_3 \cdot Cu(OH)_2$
	Cuprite	Cu_2O

Gangue (or Matrix)

Gangue, also called Matrix, refers to the impurities that are naturally mixed with the ore.
These are unwanted materials such as sand, clay, limestone, mica, quartz, etc., that are found along with the ore in the earth's crust.

Example:

- In the ore Hematite (Fe_2O_3) → the gangue may be sand or clay.
- In Bauxite ($Al_2O_3 \cdot 2H_2O$) → the gangue may be iron oxide or silica.

Flux

A flux is a chemical substance added to the ore during metallurgical processes (like smelting) to remove the gangue (impurities).

Purpose:
The main job of flux is to react with the gangue and form a fusible compound (slag) that can be easily removed.

Types of Flux:

Type of Flux	Used When Gangue is	Example
Acidic Flux	Basic in nature	Silica (SiO_2)
Basic Flux	Acidic in nature	Limestone ($CaCO_3$), Magnesite ($MgCO_3$)

Slag

Slag is the fusible (molten) product formed when the flux reacts with the gangue during metal.

Example:
In iron extraction:

$$CaCO_3 \text{ (flux)} \rightarrow CaO + CO_2$$

$$CaO \text{ (basic flux)} + SiO_2 \text{ (acidic gangue)} \rightarrow CaSiO_3 \text{ (slag)}$$

Properties:
- Slag is lighter than molten metal.
- It floats on top and can be easily separated.

Type of Gangue	Flux Used	Type of Slag Formed
Acidic (e.g. SiO_2)	Basic (e.g. CaO)	Calcium silicate ($CaSiO_3$)
Basic (e.g. FeO)	Acidic (e.g. SiO_2)	Ferrous silicate ($FeSiO_3$)

Metallurgy – Explained Simply

Metallurgy is the branch of science and technology that deals with the extraction of metals from their ores, purification, and preparation of useful alloys or metal products.

In short:
🧪 *Metallurgy = Extraction + Purification + Alloy preparation*

Steps (or Stages) of Metallurgy

1. Crushing and Grinding:

- The ore is broken down into small pieces and then powdered.
- Purpose → To make metal extraction easier.

2. Concentration (or Dressing) of Ore:

- Gangue (impurities) are removed from the powdered ore.
- Methods include: Hydraulic washing, Magnetic separation, Froth flotation (for sulphide ores)

3. Reduction or Extraction of Metal:

- The metal compound (oxide, sulphide, etc.) is converted into the free metal by chemical reduction or electrolysis.
- Example: Iron → Extracted in blast furnace & Aluminium → Extracted by electrolysis of alumina

4. Refining (or Purification) of Metal:

- The crude metal obtained is purified by methods like: Electrolytic refining, Distillation, and Zone refining

5. Alloy Formation (optional):

- Metals are sometimes mixed with other metals or elements to form alloys with improved properties.
- Example:
  - Iron + Carbon → Steel
  - Copper + Tin → Bronze

Extraction of Iron from Haematite (Fe_2O_3)

1. Process Used:

Blast Furnace Method

2. Raw Materials:

- Haematite ore (Fe_2O_3) – Source of iron
- Coke (C) – Reducing agent
- Limestone ($CaCO_3$) – Flux

3. Reactions in the Blast Furnace:

(a) **Combustion Zone:**

$$C + O_2 \rightarrow CO_2 + \text{heat}$$

(b) **Reduction Zone:**

$$CO_2 + C \rightarrow 2CO$$

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

(c) **Formation of Slag:**

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + SiO_2 \rightarrow CaSiO_3 \text{ (slag)}$$

(d) **Molten Iron** collects at the bottom and slag floats above it.

Extraction of Aluminium from Bauxite ($Al_2O_3 \cdot 2H_2O$)

1. Process Used:

Electrolytic Reduction (Hall-Héroult Process)

2. Steps:

(a) Purification (Bayer's Process):

$$Al_2O_3 \cdot 2H_2O + 2NaOH \rightarrow 2NaAlO_2 + 3H_2O$$

$$NaAlO_2 + 2H_2O + CO_2 \rightarrow Al(OH)_3 + Na_2CO_3$$

$$2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O$$

(b) Electrolysis:

- Electrolyte: **Mixture of Alumina (Al_2O_3) + Cryolite (Na_3AlF_6) + Fluorspar (CaF_2)**
- **Cathode reaction:**

$$Al^{3+} + 3e^- \rightarrow Al$$

- **Anode reaction:**

$$2O^{2-} \rightarrow O_2 + 4e^-$$

(Carbon anode gets oxidized to CO_2)

Extraction of Copper from Copper Pyrites ($CuFeS_2$)

1. Process Used:

Roasting and Smelting

2. Steps

(a) Concentration:

Froth flotation method.

(b) Roasting:

$$2CuFeS_2 + O_2 \rightarrow Cu_2S + 2FeO + SO_2$$

(c) Formation of Slag:

$$FeO + SiO_2 \rightarrow FeSiO_3$$

(d) Smelting:

$$Cu_2S + 2Cu_2O \rightarrow 6Cu + SO_2$$

(e) Refining:

Electrolytic refining gives pure copper.

Alloys

Alloys are mixtures of two or more elements in which at least one is a metal. They are made to improve the properties of pure metals such as strength, hardness, and resistance to corrosion.

The process of making alloys is called **alloying**.

For example: steel is an alloy of iron and carbon, which is stronger than pure iron

<u>Purpose of Alloying:</u>

- To improve hardness
- To increase resistance to corrosion
- To improve tensile strength
- To enhance appearance and durability

Types of Alloys

1. Ferrous Alloys (contain iron)

Alloy	Constituents	Properties/Uses
Steel	Iron + Carbon (0.1–1.5%)	Strong, hard – used in tools, machinery
Stainless Steel	Fe + Cr + Ni	Corrosion resistant – utensils, surgical instruments
Cast Iron	Iron + Carbon (2–4%)	Hard but brittle – used in engine blocks, pipes

2. Non-Ferrous Alloys (no iron)

Alloy	Constituents	Uses
Brass	Copper + Zinc	Electrical fittings, musical instruments
Bronze	Copper + Tin	Bearings, statues, coins
Duralumin	Aluminium + Copper + Mg + Mn	Aircraft parts, transport industry

General Chemical Composition and Composition-Based Applications

This topic gives an elementary idea about some important engineering materials — Portland cement, glasses, refractories, and composite materials — their chemical composition, uses, and basic principles.

Portland Cement

(a) Composition

Portland cement is a mixture of lime, silica, alumina, iron oxide, and gypsum.

Constituent	Chemical Formula	Approx. % by weight	Function
Lime	CaO	60–65%	Strength and soundness
Silica	SiO_2	17–25%	Strength and durability
Alumina	Al_2O_3	3–8%	Quick setting property
Iron oxide	Fe_2O_3	1–5%	Color and hardness
Gypsum	$CaSO_4 \cdot 2H_2O$	2–3%	Controls setting time

(b) Manufacture (Elementary Idea Only)

Raw materials: Limestone and clay.

Process:

- Mixed, crushed, and heated in a rotary kiln → produces clinker.
- Clinker is cooled and ground with gypsum → gives Portland cement powder.

(c) Hardening and Setting

When water is added to cement:

- Setting: Paste stiffens due to hydration reaction of compounds like tricalcium aluminate and silicates.
- Hardening: Gradual formation of calcium silicate hydrate (C–S–H gel) gives strength over time.

Main reactions (simplified):

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 4H_2O + 3Ca(OH)_2$$

(d) Applications

- Building materials, bridges, dams, and concrete structures.
- The main ingredient in concrete and mortar.

Glasses

(a) Definition

Glass is a hard, amorphous, and transparent material obtained by fusion of silica (SiO_2) with metallic oxides followed by rapid cooling.

(b) General Composition

Component	Formula	Function
Silica	SiO_2	Basic glass-forming material
Soda (Sodium carbonate)	Na_2CO_3	Lowers fusion temperature
Lime (Calcium oxide)	CaO	Adds hardness and durability

(c) Common Types of Glass

Type	Composition	Properties/Uses
Soda-lime glass	$Na_2O{\cdot}CaO{\cdot}6SiO_2$	Window glass, bottles
Borosilicate glass (Pyrex)	$SiO_2 + B_2O_3$	Heat resistant, lab glassware
Lead glass	$SiO_2 + PbO$	Sparkling appearance – ornaments, bulbs
Safety glass	Glass + Plastic layer	Windshields, safety panels

3. Refractory Materials

(a) Definition

- Refractories are materials that withstand very high temperatures without melting or softening.
- They are used to line furnaces, kilns, and reactors.

(b) Characteristics

- High melting point
- Chemical inertness
- Mechanical strength at high temperature
- Low thermal expansion

(c) Applications

- Furnace lining (steel, glass, cement industries)
- Crucibles, reactors, boilers

(d) Classification

Type	Example	Nature
Acidic refractory	Silica (SiO_2)	Resists acidic slags
Basic refractory	Magnesia (MgO), Dolomite	Resists basic slags
Neutral refractory	Chromite, Graphite	Stable in both acidic and basic environments

4. Composite Materials

(a) Definition

- Composites are materials made by combining two or more different substances (metals, polymers, ceramics, etc.) to obtain improved strength, durability, and lightness.

(b) Components

- Matrix phase: Continuous material (e.g. polymer, metal, or ceramic)
- Reinforcing phase: Embedded material that provides strength (e.g. glass fibers, carbon fibers)

(c) Applications

- Aircraft and automobile industries
- Sports equipment (rackets, bicycles)
- Construction and marine structures

(d) Types of Composites

Type	Example	Properties/Uses
Metal matrix composite	Aluminium + SiC	Aerospace parts, automotive components
Polymer matrix composite	Epoxy + Glass fiber	Boat hulls, helmets
Ceramic matrix composite	SiC + Al_2O_3	High-temperature applications

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