Applied Chemistry

Engineering Materials — Cement, Glass, Refractory and Composite Materials

(Elementary idea only — general chemical composition and composition-based applications; detailed chemistry and manufacturing processes are omitted.)

1. Portland Cement

Portland cement is one of the most widely used construction materials in civil and building engineering, manufactured by burning a carefully proportioned mixture of limestone (which supplies lime) and clay (which supplies silica, alumina, and iron oxide) at a high temperature, and then grinding the resulting clinker to a fine powder, together with a small quantity of gypsum.

1.1 General Chemical Composition of Portland Cement

Ordinary Portland cement is essentially a mixture of calcium silicates and calcium aluminates, formed from four main oxide constituents present in the raw materials. Its general composition, in elementary terms, is given below:

Constituent (Oxide)	Approximate Percentage	Compound Formed
Lime (CaO)	60 – 65%	Combines with other oxides to form calcium silicates and aluminates
Silica (SiO_2)	17 – 25%	Dicalcium silicate (C_2S) and Tricalcium silicate (C_3S)
Alumina (Al_2O_3)	3 – 8%	Tricalcium aluminate (C_3A)
Iron oxide (Fe_2O_3)	0.5 – 6%	Tetracalcium aluminoferrite (C_4AF)
Gypsum ($CaSO_4.2H_2O$)	2 – 3% (added separately)	Added to control (retard) the setting time of cement

These oxide constituents combine during the manufacturing process to form the main active compounds present in cement clinker, principally tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite, which together determine the setting behaviour and strength development of the cement.

1.2 Hardening of Cement

When cement is mixed with water, it undergoes a chemical process called hydration, in which the calcium silicates and calcium aluminates present in the cement react with water to form new, interlocking crystalline and gel-like products, principally calcium silicate

hydrate and calcium hydroxide. As hydration proceeds, these products gradually interlock and bind together the cement particles, as well as the sand and aggregate mixed with it, resulting in the progressive setting and hardening of the cement paste into a strong, stone-like solid mass.

This hardening process occurs in two broadly recognised stages: an initial setting stage, during which the cement paste begins to stiffen and lose its plasticity, and a subsequent hardening stage, during which the material continues to gain strength gradually over an extended period (often continuing for weeks or months), as hydration proceeds further within the material. The addition of gypsum during manufacture is important in controlling this process, since it slows down (retards) the otherwise very rapid initial setting reaction of tricalcium aluminate with water, allowing sufficient time for the cement to be mixed, transported, and placed before it begins to set.

2. Glasses

Glass is an amorphous (non-crystalline), transparent or translucent material, manufactured mainly by melting silica (sand) together with other oxide constituents at a high temperature and then cooling the molten mixture rapidly, so that it solidifies without forming a regular, ordered crystal structure. Different types of glass are produced by varying the additional oxide constituents combined with silica, giving each type distinctive properties suited to particular applications.

The general composition and typical applications of some common types of glass are given below:

Type of Glass	General Composition	Application
Soda-Lime Glass (Soft Glass)	Silica, sodium oxide (from soda ash), and lime	Window panes, bottles, jars, and general everyday glassware
Borosilicate Glass (Hard Glass)	Silica and boric oxide, with small amounts of soda and alumina	Laboratory glassware, oven-proof cookware, and equipment requiring resistance to thermal shock
Lead (Flint) Glass	Silica, lead oxide, and potash	Optical lenses, decorative cut glass, and electrical insulators, valued for its brilliance and high refractive index
Fibre Glass	Fine fibres of silica-based glass	Thermal and acoustic insulation, and as reinforcement in fibre-reinforced composite materials

3. Refractory Materials

A refractory material is a material capable of withstanding very high temperatures without melting, softening, or structurally deforming, while also resisting chemical attack from the substances (such as molten metal or slag) it comes into contact with at these elevated temperatures. Refractory materials are essential for lining furnaces, kilns, and other high-temperature industrial equipment used in metallurgical and manufacturing processes.

Refractory materials are elementarily classified according to their chemical nature, as summarised below:

Type of Refractory	General Composition	Application
Acidic Refractory	Mainly silica (SiO_2)	Lining of furnaces where the slag or environment produced is acidic, such as certain steel and glass furnaces
Basic Refractory	Mainly magnesia (MgO) or dolomite	Lining of furnaces where the slag or environment produced is basic, such as basic steel-making furnaces
Neutral Refractory	Mainly alumina (Al_2O_3) or chromite	Lining of furnaces where the slag may be either acidic or basic, providing general-purpose resistance

The choice of refractory material for a particular furnace lining depends mainly on the chemical nature of the slag or environment it will be exposed to, since an acidic refractory would be chemically attacked and rapidly worn away if used in contact with a strongly basic slag, and vice versa.

4. Composite Materials

A composite material is a material engineered by combining two or more distinct constituent materials, typically a matrix (the continuous, surrounding material) and a reinforcement (fibres, particles, or sheets embedded within the matrix), such that the resulting composite exhibits improved or combined properties, such as greater strength, stiffness, or reduced weight, that are not achievable by either constituent material alone.

The general composition and typical applications of some common composite materials used in engineering are given below:

Type of Composite	Composition (Matrix + Reinforcement)	Application

Fibre-Reinforced Plastic (FRP)	Polymer matrix (such as epoxy or polyester resin) reinforced with glass or carbon fibres	Automobile body panels, boat hulls, aircraft components, sports equipment
Reinforced Cement Concrete (RCC)	Cement concrete matrix reinforced with steel bars (rebars)	Buildings, bridges, dams, and general structural and civil engineering construction
Metal Matrix Composite (MMC)	Metal matrix (such as aluminium) reinforced with ceramic fibres or particles	Aerospace components, automotive engine parts requiring high strength and low weight

Composite materials are widely used in modern engineering because they allow a designer to combine the most desirable properties of different materials, for example, the strength and stiffness of fibres with the lightness and mouldability of a plastic matrix, resulting in materials that are often stronger, lighter, or more durable than conventional single materials for a given application.

5. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. The main raw materials used to manufacture Portland cement are:

A) Sand and water only
B) Limestone and clay
C) Iron ore and coke
D) Silica and lead oxide

2. The approximate percentage of lime (CaO) present in ordinary Portland cement is:

A) 10 – 15%
B) 25 – 30%
C) 60 – 65%
D) 90 – 95%

3. Gypsum is added to cement clinker mainly to:

A) Increase its colour
B) Control (retard) the setting time of cement
C) Increase the silica content
D) Reduce its cost only

4. The hardening of cement after mixing with water is due to a process called:

A) Oxidation
B) Hydration, forming interlocking crystalline products
C) Evaporation of water only

D) Melting and resolidifying

5. Which compound in cement is mainly responsible for its early (initial) strength development?

A) Tricalcium silicate (C3S)
B) Tetracalcium aluminoferrite (C4AF)
C) Free lime only
D) Gypsum

6. The main raw material used in the manufacture of ordinary glass is:

A) Limestone
B) Silica (sand)
C) Iron ore
D) Bauxite

7. Soda-lime glass, used for window panes and bottles, contains mainly:

A) Silica, sodium oxide, and lime
B) Silica and lead oxide only
C) Silica and boric oxide only
D) Pure silica alone

8. Borosilicate glass is preferred for laboratory glassware mainly because of its:

A) High cost
B) Resistance to thermal shock (sudden temperature changes)
C) Bright colour
D) Softness

9. Lead (flint) glass, valued for its brilliance, is commonly used for:

A) Window panes
B) Optical lenses and decorative cut glass
C) Laboratory beakers only
D) Cement manufacturing

10. A refractory material is mainly valued for its ability to:

A) Conduct electricity well
B) Withstand very high temperatures without melting or deforming
C) Dissolve easily in water
D) Change colour with temperature

11. A refractory material composed mainly of magnesia (MgO) is classified as:

A) An acidic refractory
B) A basic refractory
C) A neutral refractory
D) A composite material

12. A refractory material composed mainly of silica (SiO_2) is classified as:

A) An acidic refractory
B) A basic refractory
C) A neutral refractory
D) A metal matrix composite

13. A composite material is best described as a material made by combining:

A) Two or more different materials to achieve properties not found in either alone
B) Only two metals in molten form
C) Water with cement alone
D) Only naturally occurring minerals

14. Fibre-reinforced plastic (FRP) is a composite material made by reinforcing a polymer matrix with:

A) Steel bars
B) Glass or carbon fibres
C) Limestone particles
D) Lead particles

15. Reinforced cement concrete (RCC), widely used in construction, is a composite of cement concrete reinforced with:

A) Glass fibres
B) Steel bars (rebars)
C) Carbon fibres
D) Ceramic particles

Answer Key

1. B) Limestone and clay | 2. C) 60 – 65% | 3. B) Control (retard) the setting time of cement | 4. B) Hydration, forming interlocking crystalline products | 5. A) Tricalcium silicate (C3S) | 6. B) Silica (sand) | 7. A) Silica, sodium oxide, and lime | 8. B) Resistance to thermal shock (sudden temperature changes) | 9. B) Optical lenses and decorative cut glass | 10. B) Withstand very high temperatures without melting or deforming | 11. B) A basic refractory | 12. A) An acidic refractory | 13. A) Two or more different materials to achieve properties not found in either alone | 14. B) Glass or carbon fibres | 15. B) Steel bars (rebars)

6. Broad / Long Answer Questions

1. State the general chemical composition of ordinary Portland cement, mentioning the main oxide constituents and their approximate percentages.

2. Explain, in elementary terms, the hardening (setting) of cement after it is mixed with water.

3. Explain the role of gypsum in Portland cement.

4. Mention the composition and applications of soda-lime glass and borosilicate glass.

5. Mention the composition and applications of lead (flint) glass and fibre glass.

6. Define a refractory material, and explain the elementary basis for classifying refractories as acidic, basic, or neutral.

7. Give the general composition and one application each of an acidic, a basic, and a neutral refractory.

8. Define a composite material, and explain how it differs from an alloy in terms of composition.

9. Give the composition and applications of fibre-reinforced plastic (FRP) and reinforced cement concrete (RCC) as examples of composite materials.

10. Explain briefly why composite materials, such as FRP and RCC, are widely preferred in modern engineering construction over single, conventional materials.