Polymers, Ceramics, Glasses and Composites

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POLYMERS

INTRODUCTION

- Plastics production has long matched up with metal production
- used in an many applications, e.g. toys, home appliances, structural and decorative items, automobile parts, packaging, and many others.
- Most plastics are made of polymers.

- Polymers include: rubber, plastics, and many of the adhesives.

- Polymers are produced by ***polymerisation***, i.e. making large molecular structures from organic molecules obtained from petroleum or agricultural products.

- Polymer materials are mainly composed of ***carbon*** and ***hydrogen***.

Use of polymer materials mainly lies in their particular merits, including:

- Low relative density - leads to high strength & stiffness;
- Corrosive resistance;
- Mostly tough and resilient, with good vibration damping capacity;
- Low electrical and thermo conductivity;
- Low coefficient of friction;
- Ease of vibration;
- Cheaper than metals on a volume basis.

The disadvantages are:

- Low permissible operating temperatures;
- Low strength in comparison with metals;
- High thermal expansion;
- Degradable due to sunlight, in some instances;
- Inflammable.

CLASSIFICATION OF POLYMERS

Polymers can be classified in the following three ways.

1. **Polymerisation Mechanism**
2. **Polymer Structure**
3. **Polymer Behaviour**

1. Polymerisation Mechanism

- Polymerisation = chemical reactions in which comparatively simple substances (or even single molecules called ***mers***) react to give large, complex molecular forms with very high molecular weights.
- Single **mers** are termed monomers.
- Two types of polymerisation: ***Addition*** and ***Condensation*** polymerisation.
- Reactants in polymerisation are known as monomers; products are polymers.

Two types of polymers are identified under this classification;

(i) ***Addition polymers***: Produced by *covalently joining* the individual molecules producing chains that may be thousands of molecules long.

(ii) ***Condensation polymers***: Produced when two or more types of molecules are *joined by a chemical reaction* that releases a by-product, such as water.

2. Polymer Structure

- Addition polymerisation produces linear polymers.
- Condensation polymerisation may produce linear polymers or may give hard rigid network structure materials.
- Linear polymer materials may be converted to non-linear structures, giving modification properties by branching and cross-linking reactions.

This classification gives two types of polymers:

(i) ***Linear polymers***: These form long chains containing thousands of molecules. The chains may be formed by either addition or condensation reaction.

(ii) ***Network polymers***: These are three-dimensional framework structures formed by a cross-linking process that involves either an addition or condensation reaction.

3. Polymer Behaviour

The most commonly used method to describe polymer as by their behaviour when heated. Three main polymer groups are identified:

(i) ***Thermoplastic polymers***: These behave in a plastic manner at high temperatures. They are generally linear polymers, made up of long covalently bonded carbon chains, but some thermoplastic materials may be branched or be cross-linked types.

Softens when heated and sets into a rigid form again on cooling, the changes being reversible.

Properties are sensitive to temperature, structure and strain rate.

(ii) ***Thermosetting polymers***: These are network polymers formed by condensation reaction.

First heating, they melt and then set or cure into a hard rigid shape at room temperature.

During this curing or setting process, a full network molecular structure is developed producing a material which is a hard elastic solid. This process is non-reversible.

Cold setting plastics are of the same kind but in this case the curing reactions form network structures at room temperature once resin and hardener have been mixed together.

Elastomers:

- Elastomers (natural and synthetic rubbers) are made up of thermoplastic materials of low elastic moduli.
- Have large deformation under low loads and which return to their original dimensions when released.
- Possess linear polymer structures with a small number of cross-links between molecules
- Mostly, the molecules form into coils (or cross-links) behaving as minute helical springs, that cause the materials to return to the original dimension after load removal.

CERAMICS AND GLASSES

- Ceramic structures have survived longer than any other works of man.
- They include great structures like the great pyramids of Egypt, The Great Wall of China, and the Parthenon.
- They also include smaller structure like houses, works of art like China plates, etc.
- Man’s first cutting tools and weapons were made of flint – a glass.
- Pottery made about 5,000 BC still survives to the present day.
- Not as tough as metals, but are excellent for resistance to corrosion, wear, decay and corruption.

- Today, cement and concrete replace stone in most structures.
- But cement, too, is a ceramic: a complicated but fascinating one. The understanding of its structure has led to the development of special high-strength cement pastes which can compete with polymers and metals in certain applications.
- In recent years, high-performance engineering ceramics have been formed – with the potential to replace, and greatly improve on, metals in many very demanding applications.
- Cutting tools made of silicones or of dense alumina can cut faster and longer than the best metal tools.

- ***Engineering ceramics*** are highly wear-resistant: they are used to clad the leading edges of agricultural machinery like harrows, increasing the life by as much as 10 times
- They are inert and biocompatible, so they are good for making artificial limbs (where wear is a big problem) and other implants.
- Because their high melting points, they can stand much higher temperatures than metals:
- they are increasingly being developed for reciprocating engines, turbines and space crafts where high temperatures pose a serious problem with metals.

- Five Classes of materials are of interest to engineers:
  - ***Glasses*** = all based on silica (SiO_2), with additions to reduce the melting point, or give other special properties.
  - ***Vitreous ceramics*** = traditional clay products; used in vast quantities for plates and cups, sanitary ware, tiles, bricks, etc.
  - ***High-performance ceramics*** = new and now finding application for cutting tools, dies, engine parts and wear-resistant parts.
  - ***Cement and Concrete*** = complex ceramic with many phases; an essential bulk material of civil engineering.
  - ***Rocks and minerals*** – including ice.

THE GENERIC CERAMICS AND GLASSES

- Number of different ceramics is too vast to mention/remember all.
- The generic ceramics listed above embody the most important features.
- They are potentially, or actually, cheap.
- Most ceramics are compounds of O, C or N with metals like Al or Si; all of which are plentiful and widespread elements in the earth’s crust.
- Processing costs are high, but the ingredients are almost as cheap as soil: soil, after all, is a ceramic.

Glasses

- Used in enormous quantities, comparing favourably with aluminium in annual tonnage used.
- As much as 80% of the surface area of modern buildings can be glass.
- Also used in a load-bearing capacity, such as in car windows and wind screens, containers, diving bells and vacuum equipment.
- All important glasses are based on silica (SiO_2).
- The most important glasses are common window glass and the temperature-resistant borosilicate glass.

Vitreous Ceramics

- The potter’s clay.
- Used since society developed.
- Remnants of past civilisations have survived the ravages of time.
- Modern pottery, porcelain, tiles, and structural and refractory bricks are made by processes which, though automated, differ very little from those of 2,000 years ago. All are made from clays, formed in wet, plastic state and then dried and fired.
- After firing, they consist of crystalline phases (mostly silicates) held together by a glassy phase based on silica (SiO_2).
- The glassy phase forms and melts when the clay is fired, and spreads around the inert, but strong crystalline phases, bonding them together.

High-Performance Engineering Ceramics

- Diamond is the ultimate engineering ceramic – used for cutting tools, dies, rock drills and as an abrasive for years because of its hardness.

- However, diamond is expensive.

- The hardness of a ceramic is determined by its ***toughness*** and the size distribution of ***microcracks*** it contains.

- A new class of fully dense, high-strength ceramics is now emerging.

- It combines a higher toughtness with much narrower distribution of smaller microcracks – giving these ceramics properties which make them competitive with metals, cermets and even with diamond for cutting tools, dies, implants and engine parts.

- This new class is also cheap in comparative terms.

Cement and Concrete

- Used in construction on an enormous scale – equalled only by structural steel
- ***Cement*** = mixture of lime (CaO), silica (SiO_2) and alumina (Al_2O_3), which sets when mixed with water.
- ***Concrete*** = sand and stones (aggregate) held together by cement.
- Concrete has excellent compression properties but rather weak in tension.
- Used with steel reinforcement to improve tensile properties.

Natural Ceramics

- ***Stone:***
  - The oldest of all construction materials
  - The most durable (the pyramids are 5,000 years old, the Parthenon 2,200).
  - Stone, when used in a load-bearing capacity, behaves like any other ceramic – and the criteria for design are the same.

- ***Ice:***
  - One natural ceramic that is unique.
  - Forms large volume of the earth’s surface. E.g. Antarctic ice cap is up to 3 km thick and almost 3,000 km across – something like 10^{13} m^3 of pure ceramic.
  - Its mechanical properties are of primary engineering importance – primarily in ice breaking, the construction of off-shore oil rigs in the Arctic region, and the construction of igloos by the Eskimos.

COMPOSITES

- In general, a ***composite material*** or simply a ***composite*** is a material made up of more than one material.

- The use of high strength of fibres to stiffen and strengthen a cheap matrix of material is an old engineering process.

- The ancient Babylonians used bitumen reinforced with straw or horses' hair to make a material for moulding bricks. These bricks had very improved stiffness and fracture toughness.

- The Egyptians used straw in clay to mould strong bricks (Exodus 5).

- Paper and concrete are both composites.
- Almost all natural materials that must bear load – wood, bone, muscle – are composites.
- However, the composite industry is new.
- It has grown rapidly in the past 40 to 45 years with the development of ***fibrous composites***.
- There include:
    - ***Glass-fibre reinforced polymers*** (GFRP or fibreglass)
    - ***Carbon-fibre reinforced polymers*** (CFRP)

- These are used in boats because of their light weight but good mechanical properties, particularly stiffness.
- Their increasing replacement of metals in aircraft and ground transport systems is accelerating.

- Composites need not be made of fibre.
- ***Plywood*** is a ***lamellar composite*** – giving a material with uniform properties in the plane of the board (unlike wood from which it is made).
- Similarly, sheets of GFRP and CFRP are laminated together for more improved but uniform properties.

- Cheapest of all are the ***particulate composites***.
- Aggregate plus cement gives concrete, and the composite is cheaper (per unit volume) than the cement itself.
- Polymers can be filled with sand, silica flour, or glass particles, increasing the stiffness and wear resistance, and often reducing the cost.
- ***Cemented carbide*** or ***hard metal*** is a particulate composite of tungsten-carbide particles in cobalt.
- This material is used in the heavy-duty cutting tool industry.
- Stiffness is not always the required property in making composites.

- ***Cushions***, ***packaging materials*** and ***crash-padding*** require materials with lower moduli than those of any solid.
- This is done with ***foams*** – composites of a solid and a gas – which have properties that can be tailored, with great precision, to match the engineering need.

The End