**3ME4-06 : MATERIAL SCIENCE AND ENGINEERING**

**Credit: 3 Max. Marks: 150 (IA:30, ETE:120) 3L+0T+0P**

**Subject notes**

**UT-4**

**Non metallic materials:**

**1. polymer**

**2. Ceramic**

**3. composite materials.**

**Polymer:** A polymer is a large molecule or a macromolecule which essentially is a combination of many subunits. The term polymer in Greek means ‘many parts’. Polymers can be found all around us. From the strand of our DNA which is a naturally occurring biopolymer to polypropylene which is used throughout the world as plastic.Polymers may be naturally found in plants and animals (natural polymers) or may be man-made (synthetic polymers). Different polymers have a number of unique physical and chemical properties due to which they find usage in everyday life.

**Application of polymer:**

* polypropene finds usage in a broad range of industries such as textiles, packaging, stationery, plastics, aircraft, construction, rope, toys, etc.
* Polystyrene is one of the most common plastic, actively used in the packaging industry. Bottles, toys, containers, trays, disposable glasses and plates, tv cabinets and lids are some of the daily-used products made up of polystyrene. It is also used as an insulator.
* The most important use of polyvinyl chloride is the manufacture of sewage pipes. It is also used as an insulator in the electric cables.
* Polyvinyl chloride is used in clothing and furniture and has recently become popular for the construction of doors and windows as well. It is also used in vinyl flooring.
* Urea-formaldehyde resins are used for making adhesives, moulds, laminated sheets, unbreakable containers, etc.
* Glyptal is used for making paints, coatings, and lacquers.
* Bakelite is used for making electrical switches, kitchen products, toys, jewellery, firearms, insulators, computer discs, etc.
* Polymerization is a process through which a large number of monomer molecules react together to form a polymer. The macromolecules produced from a polymerization may have a linear or a branched structure. They can also assume the shape of a complex, three-dimensional network. There exist several different categories of polymerization reactions, the most notable of which being step-growth polymerization, chain-growth polymerization (both of which fall under the category of addition polymerization), and condensation polymerization.
* A polymer is a substance that is made up very large molecules that are, in turn, made up of many repeating units called monomers. Polymerization is the process through which these monomers come together to form the macromolecules that constitute polymers. An illustration detailing the polymerization of the monomer styrene into the polymer known as polystyrene is provided below.
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* Depending on the functional groups present in the reacting monomers, the complexity of the mechanism of the polymerization reaction may vary. The most simple polymerization reactions involve the formation of polymers from alkenes via free-radical reaction. Polyethylene, which is one of the most commercially important polymers, is prepared via such a polymerization process (the reactant monomer used here is ethylene).
* It can be noted that polymerizations involving only one type of monomer are called homopolymerizations whereas those involving more than one type of monomer are called copolymerization processes. Polymerization in the simplest form can be described as a chemical process that results in the formation of polymers. In simple words, we can basically describe Polymerization as the process of creating polymers. When polymerization occurs, the smaller molecules which are known as monomers via chemical reaction are combined to form larger molecules. A collection of these large molecules form a polymer. The term polymer in general means “large molecules” with higher molecular mass. They are also referred to as macromolecules.

## Mechanism of Polymerization

Generally, polymerization consists of three steps which include initiation, propagation, and termination. As for the reaction mechanism, the process of polymerization mainly involves two different methods. These include the step-growth mechanism and chain-growth mechanism.

### Step Growth Polymerization

In step-growth polymerization, the polymers are formed by the independent reaction between the [functional groups](https://byjus.com/chemistry/functional-groups/) of simple monomer units. In step-growth, each step may consist of a combination of two polymers having a different or same length to form a longer length molecule.

The reaction is a lengthy process and the molecular mass is increased at a very slow rate. An example of step-growth polymerization is condensation polymerization where a water molecule is evolved in the reaction when the chain is lengthened.

**Condensation Polymerization**

In condensation polymerization, the formation of the polymer occurs when there is a loss of some small molecules as byproducts through the reaction where molecules are joined together. The byproducts formed may be water or hydrogen chloride. Polyamide and proteins are examples of condensation polymers.

Some of the different types of condensation polymerization are given below

**Polyamides**

They are synthetic fibres and are called as nylons. These polymers have an amide linkage between them. Condensation polymerization of di-amines with di-carboxylic acid and also of amino acids and their lactams will create a polyamide.

* Nylon 66: This polymer is prepared under the condition of high pressure and temperature by the condensation polymerization of hexamethylenediamine with adipic acid.
* Nylon 6: Prepared by heating of caprolactam with water under high temperature. It is used for tyre cords, fabrics and ropes.

**Polyesters**

When dicarboxylic acids and diols undergo polycondensation, polyesters are formed. Prepared by heating a mixture of terephthalic acid and ethylene glycol at 460 k by using zinc acetate antimony trioxide as a catalyst. Dacron or terylene are the best-known examples for polyesters. And also they are used for glass reinforcing materials in safety helmets.

**Phenol-Formaldehyde Polymer**

These are the old [synthetic polymers](https://byjus.com/chemistry/synthetic-polymers/), obtained by condensation polymerization of phenol with formaldehyde in the presence of either an acid or base as a catalyst.



Novo lac on heating with formaldehyde undergoes crosslinking and forms an infusible sold mass named as Bakelite. They are used for combs, electric switches and phonograph records.

**Melamine – Formaldehyde Polymer**

It is formed by the condensation polymerization of melamine and formaldehyde in certain conditions. They are used for the manufacture of unbreakable crockery.

**Types of polymers**

* Commodity plastics
	+ PE = Polyethylene
	+ PS = Polystyrene
	+ PP = Polypropylene
	+ PVC = Poly(vinyl chloride)
	+ PET = Poly(ethylene terephthalate)
* Specialty or Engineering Plastics
	+ Teflon (PTFE) = Poly(tetrafluoroethylene)
	+ PC = Polycarbonate (Lexan)
	+ Polyesters and Polyamides (Nylon)

### ****1 – Polyethylene Terephthalate (PET or PETE or Polyester)****

### PET is also known as a wrinkle-free fiber. It’s different from the plastic bag that we commonly see at the supermarket. PET is mostly used for food and drink packaging purposes due to its strong ability to prevent oxygen from getting in and spoiling the product inside. It also helps to keep the carbon dioxide in carbonated drinks from getting out.

### Although PET is most likely to be picked up by recycling programs, this type of plastic contains antimony trioxide—a matter that is considered as a carcinogen—capable of causing cancer in a living tissue. The longer a liquid is left in a PET container the greater the potential for the release of the antimony. Warm temperatures inside cars, garages, and enclosed storage could also increase the release of the hazardous matter.

### ****2 – High-Density Polyethylene (HDPE)****

### Quite special compared to the other types, HDPE has long virtually unbranched polymer chains which makes them really dense and thus, stronger and thicker from PET. HDPE is commonly used as the grocery bag, opaque milk, juice container, shampoo bottles, and medicine bottle.

### Not only recyclable, HDPE is relatively more stable than PET. It is considered as a safer option for food and drinks use, although some studies have shown that it can leach estrogen-mimicking additive chemicals that could disrupt human’s hormonal system when exposed to ultraviolet light.

### ****3 – Polyvinyl Chloride (PVC)****

### PVC is typically used in toys, blister wrap, cling wrap, detergent bottles, loose-leaf binders, blood bags and medical tubing. PVC or vinyl used to be the second most widely used plastic resin in the world (after polyethylene), before the manufacture and disposal process of PVC has been declared as the cause of serious health risks and environmental pollution issues.

### In the term of toxicity, PVC is considered as the most hazardous plastic. The use of it may leach a variety of toxic chemicals such as bisphenol A (BPA), phthalates, lead, dioxins, mercury, and cadmium. Several of the chemicals mentioned may cause cancer; it could also cause allergic symptoms in children and disrupt the human’s hormonal system. PVS is also rarely accepted by recycling programs. This is why PVC is better best to be avoided at all cost.

### ****4 – Polypropylene (PP)****

### Stiffer and more resistant to heat, PP is widely used for hot food containers. Its strength quality is somewhere between LDPE and HDPE. Besides in thermal vests, and car parts, PP is also included in the disposable diaper and sanitary pad liners.

### Same as LDPE, PP is considered a safer plastic option for food and drink use. And although it bears all those amazing qualities, PP isn’t quite recyclable and could also cause asthma and hormone disruption in human.

### ****5 – Polystyrene (PS)****

### Polystyrene is the Styrofoam we all commonly used for food containers, egg cartons, disposable cups and bowls, packaging, and also bike helmet. When exposed with hot and oily food, PS could leach styrene that is considered as brain and nervous system toxicant, it could also affect genes, lungs, liver, and immune system. On top of all of those risks, PS has a low recycling rate.

**The effects of alloying elements:**

The different alloying elements have specific effects on the properties of a stainless steel. It is the combined effect of all the alloying elements, heat treatment, and, to some extent, impurities that determine the property profile of a certain steel grade. It should be noted that the effect of the alloying elements differs to some extent between the different types of stainless steel.

 **Chromium (Cr)**

This is the most important alloying element and it gives stainless steels their basic corrosion resistance. All stainless steels have a Cr content of at least 10.5% and the corrosion resistance increases the higher chromium content. Chromium also increases the resistance to oxidation at high temperatures and promotes a ferritic microstructure.

**Nickel (Ni)**

The main reason for adding nickel is to promote an austenitic microstructure. Nickel generally increases ductility and [toughness](https://www.outokumpu.com/en/expertise/stainless-basics/the-effects-of-alloying-elements#toughness). It also reduces the corrosion rate in the active state and is therefore advantageous in acidic environments. In precipitation hardening steels nickel is also used to form the intermetallic compounds that are used to increase strength. In martensitic grades adding nickel, combined with reducing carbon content, improves weldability.

**Molybdenum (Mo)**

Molybdenum significantly increases the resistance to both uniform and localized corrosion. It slightly increases mechanical strength and strongly promotes a ferritic microstructure. However, molybdenum also enhances the risk for the formation of secondary phases in ferritic, duplex, and austenitic steels. In martensitic steels it increases the hardness at higher tempering temperatures due to its effect on carbide precipitation.

**Copper (Cu)**

Copper enhances corrosion resistance to certain acids and promotes an austenitic microstructure. It can also be added to decrease work hardening in grades designed for improved machinability. It may also be added to improve formability.

 **Manganese (Mn)**

Manganese is generally used to improve hot ductility. Its effect on the ferrite/austenite balance varies with temperature: at low temperature manganese is an austenite stabilizer, but at high temperatures it will stabilize ferrite. Manganese increases the solubility of nitrogen and is used to obtain high nitrogen contents in duplex and austenitic stainless steels. Manganese, as an austenite former, can also replace some of the nickel in stainless steel.

**Silicon (Si)**

Silicon increases resistance to oxidation, both at high temperatures and in strongly oxidizing solutions at lower temperatures. It promotes a ferritic microstructure and increases strength.

 **Carbon (C)**

Carbon is a strong austenite former that also significantly increases mechanical strength. In ferritic grades carbon strongly reduces both toughness and corrosion resistance. In martensitic grades carbon increases hardness and strength, but decrease toughness.

**Nitrogen (N)**

Nitrogen is a very strong austenite former that also significantly increases mechanical strength. It also increases resistance to localized corrosion, especially in combination with molybdenum. In ferritic stainless steels nitrogen strongly reduces toughness and corrosion resistance. In martensitic grades nitrogen increases both hardness and strength but reduces toughness.

**Titanium (Ti)**

Titanium is a strong ferrite and carbide former, lowering the effective carbon content and promoting a ferritic structure in two ways. In austenitic steels with increased carbon content it is added to increase the resistance to intergranular corrosion (stabilized grades), but it also increases mechanical properties at high temperatures. In ferritic grades titanium is added to improve toughness, formability, and corrosion resistance. In martensitic steels titanium lowers the martensite hardness by combining with carbon and increases tempering resistance. In precipitation hardening steels, titanium is used to form the intermetallic compounds that are used to increase strength.

**Niobium (Nb)**

Niobium is a strong ferrite and carbide former. Like titanium, it promotes a ferritic structure. In austenitic steels it is added to improve the resistance to intergranular corrosion (stabilized grades), but it also enhances mechanical properties at high temperatures. In ferritic grades niobium and/or titanium is sometimes added to improve toughness and to minimize the risk for intergranular corrosion. In martensitic steels niobium lowers hardness and increases tempering resistance. In the US it is designated Columbium (Cb).

 **Aluminum (Al)**

If added in substantial amounts aluminum improves oxidation resistance and is used in certain heat-resistant grades for this purpose. In precipitation hardening steels, aluminum is used to form the intermetallic compounds that increase the strength in the aged condition.

 **Cobalt (Co)**

Cobalt is used in martensitic steels, where it increases hardness and tempering resistance, especially at higher temperatures.

 **Vanadium (V)**

Vanadium forms carbides and nitrides at lower temperatures, promotes ferrite in the microstructure, and increases toughness. It increases the hardness of martensitic steels due to its effect on the type of carbide present. It also increases tempering resistance. It is only used in stainless steels that can be hardened.

**Tungsten (W)**

Tungsten is present as an impurity in most stainless steels, although it is added to some special grades, for example the superduplex grade 4501, to improve pitting corrosion resistance.

**Sulfur (S)**

Sulfur is added to certain stainless steels to increase their machinability. At the levels present in these grades, sulfur slightly reduces corrosion resistance, ductility, weldability, and formability. At Outokumpu the trademark PRODEC (PRODuction EConomy) is used for some grades with balanced sulfur levels for improved machinability. Lower levels of sulfur can be added to decrease work hardening for improved formability. Slightly increased sulfur content also improves the weldability of steel.

**Cerium (Ce)**

Cerium is one of the rare earth metals (REM) and is added in small amounts to certain heat-resistant grades to increase resistance to oxidation at high temperatures.