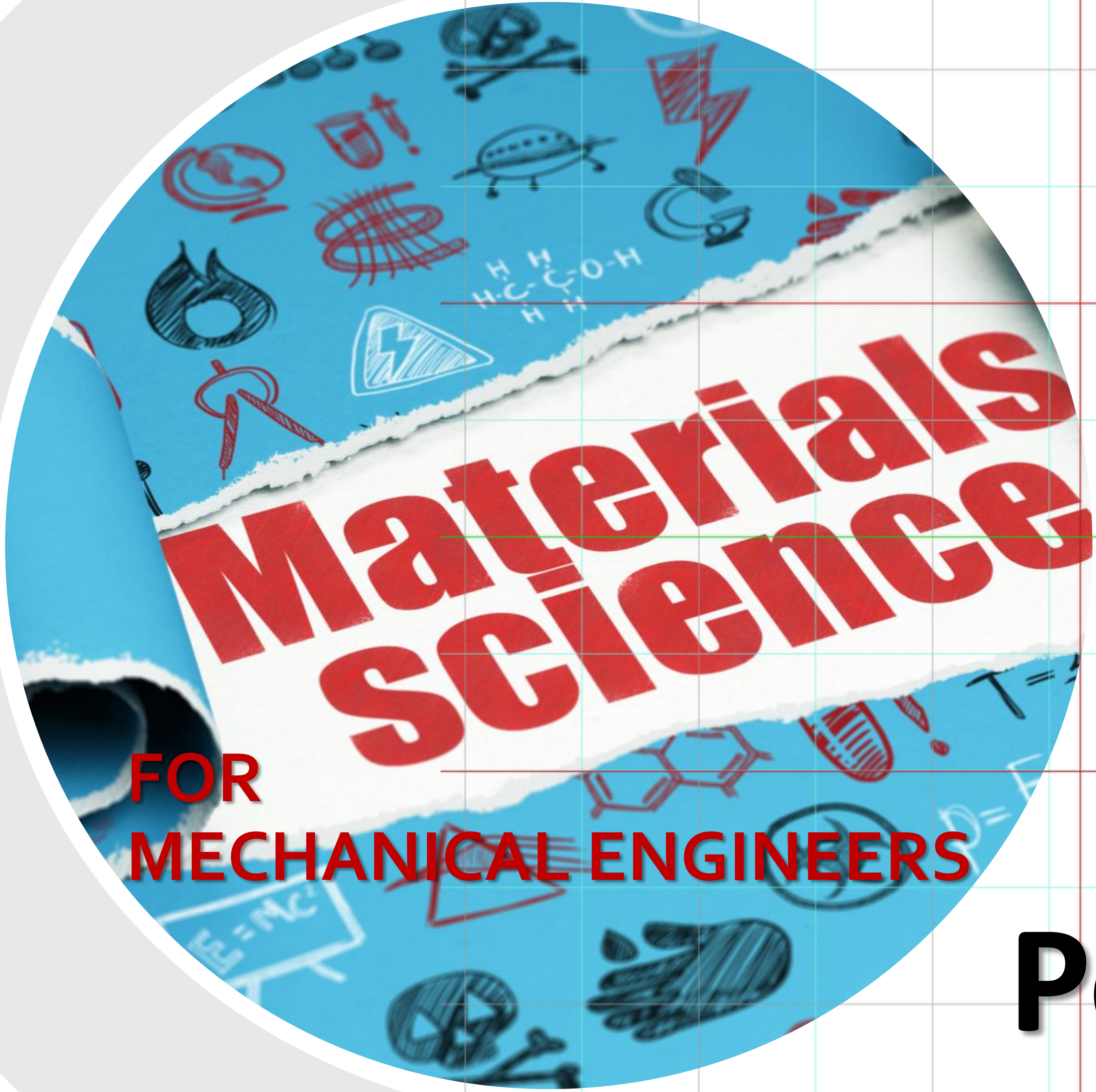


FOR
MECHANICAL ENGINEERS

Polymer Structures

SPRING 2022-2023

INTRODUCTION

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’.

Naturally occurring polymers—those derived from plants and animals—have been used for many centuries; these materials include wood, rubber, cotton, wool, leather, and silk.

Other natural polymers, such as DNA, proteins, enzymes, starches, and cellulose, are important in biological and physiological processes in plants and animals.

Modern scientific research tools have made possible the determination of the molecular structures of this group of materials and the development of numerous polymers that are synthesized from small organic molecules.

Natural polymers

INTRODUCTION

Many of our useful plastics, rubbers, and fiber materials are synthetic polymers. In fact, since the conclusion of World War II, the field of materials has been virtually revolutionized by the advent of synthetic polymers.

Synthetic Polymers

The synthetics can be produced inexpensively, and their properties may be managed to the degree that many are superior to their natural counterparts.

In some applications, metal and wood parts have been replaced by plastics, which have satisfactory properties and can be produced at a lower cost.

As with metals and ceramics, the properties of polymers are intricately related to the structural elements of the material.

CLASSIFICATION OF POLYMERS

Polymers cannot be classified under one category because of their complex structures, different behaviors and vast applications.

Classification of Polymers based on the Source of Availability

There are **three types of classification** under this category, namely, Natural, Synthetic, and Semi-synthetic Polymers.

Natural Polymers:

They occur naturally and are found in plants and animals. For example proteins, starch, cellulose, and rubber. To add up, we also have biodegradable polymers which are called biopolymers.

Semi-synthetic Polymers:

They are derived from naturally occurring polymers and undergo further chemical modification. For example, cellulose nitrate, cellulose acetate.

CLASSIFICATION OF POLYMERS

Synthetic Polymers:

These are man-made polymers. Plastic is the most common and widely used synthetic polymer. It is used in industries and various dairy products. For example, nylon-6, 6, polyether’s etc.

CLASSIFICATION OF POLYMERS

Classification of Polymers based on the Structure of the Monomer Chain

This category has the following classifications:

Linear Polymers

The structure of polymers containing long and straight chains fall into this category. PVC, i.e. poly-vinyl chloride is largely used for making pipes and electric cables is an example of a linear polymer.

Branched-chain Polymers

When linear chains of a polymer form branches, then, such polymers are categorized as branched chain polymers. For example, Low-density polythene.

Cross-linked Polymers

They are composed of bifunctional and trifunctional monomers. They have a stronger covalent bond in comparison to other linear polymers. Bakelite and melamine are examples in this category.

CLASSIFICATION OF POLYMERS

Classification Based on Polymerization

- **Addition Polymerization:** Example, poly ethane, Teflon, Polyvinyl chloride (PVC)
- **Condensation Polymerization:** Example, Nylon -6, 6, perylene, polyesters.

Classification Based on Monomers

- **Homomer:** In this type, a single type of monomer unit is present. For example, Polyethene
- **Heteropolymer or co-polymer:** It consists of different type of monomer units. For example, nylon -6, 6

Classification Based on Molecular Forces

- **Elastomers:** These are rubber-like solids weak interaction forces are present. For example, Rubber.
- **Fibres:** Strong, tough, high tensile strength and strong forces of interaction are present. For example, nylon -6, 6.

CLASSIFICATION OF POLYMERS

- **Thermoplastics:** These have intermediate forces of attraction. For example, polyvinyl chloride.
- **Thermosetting polymers:** These polymers greatly improve the material’s mechanical properties. It provides enhanced chemical and heat resistance. For example, phenolics, epoxies, and silicones.

STRUCTURE OF POLYMERS

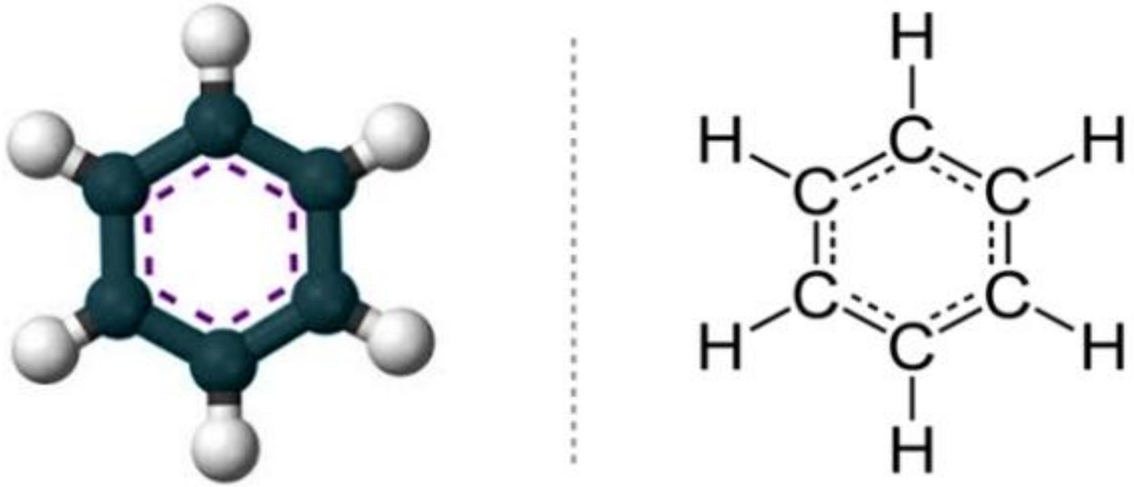
Most of the polymers around us are made up of a **hydrocarbon backbone**.

A Hydrocarbon backbone being a long chain of linked carbon and hydrogen atoms, possible due to the tetravalent nature of carbon.

A few examples of a hydrocarbon backbone polymer are polypropylene, polybutylene, polystyrene.

Also, there are polymers which instead of carbon have other elements in its backbone.

For example, Nylon, which contains nitrogen atoms in the repeated unit backbone.



Structure of Hydrocarbon

TYPES OF POLYMERS

On the basis of the type of the backbone chain, polymers can be divided into:
- **Organic Polymers**: Carbon backbone.
- **Inorganic Polymers**: Backbone constituted by elements other than carbon.

On the basis of their synthesis:
- Natural Polymers
- Synthetic Polymers

Biodegradable Polymers

The polymers which are degraded and decayed by microorganisms like bacteria are known as **biodegradable polymers**. These types of polymers are used in surgical bandages, capsule coatings and in surgery. For example, Poly hydroxybutyrate co vel [PHBV]

TYPES OF POLYMERS

High-Temperature Polymers

These polymers are stable at high temperatures. Due to their high molecular weight, these are not destroyed even at very high temperatures.

They are extensively used in the healthcare industries, for making sterilization equipment and in the manufacturing of heat and shock-resistant objects.

Few of the important polymers are:

Polypropylene: It is a type of polymer that softens beyond a specific temperature allowing it to be moulded and on cooling it solidifies. Due to its ability to be easily moulded into various shapes, it has a lot of applications.

A few of which are in stationary equipment's, automotive components, reusable containers speakers and much more. Due to its relatively low energy surface, the polymer is fused with the welding process and not using glue.

TYPES OF POLYMERS

Polyethene: It is the most common type of plastic found around us. Mostly used in packaging from plastic bags to plastic bottles.

There are different types of polyethene but their common formula being $(C_2H_4)_n$.

PROPERTIES OF POLYMERS

Physical Properties

- As chain length and cross-linking increases, the tensile strength of the polymer increases.
- Polymers do not melt, they change state from crystalline to semi-crystalline.

Chemical Properties

- Compared to conventional molecules with different side molecules, the polymer is enabled with hydrogen bonding and ionic bonding resulting in better cross-linking strength.
- Dipole-dipole bonding side chains enable the polymer for high flexibility.
- Polymers with Van der Waals forces linking chains are known to be weak, but give the polymer a low melting point.

PROPERTIES OF POLYMERS

Optical Properties

•Due to their ability to change their refractive index with temperature as in the case of PMMA and HEMA: MMA, they are used in lasers for applications in spectroscopy and analytical applications.

Some Polymers and their Monomers

- Polypropene, also known as polypropylene, is made up of monomer propene.
- Polystyrene is an aromatic polymer, naturally transparent, made up of monomer styrene.
- Polyvinyl chloride (PVC) is a plastic polymer made of monomer vinyl chloride.
- The urea-formaldehyde resin is a non-transparent plastic obtained by heating formaldehyde and urea.
- Glyptal is made up of monomers ethylene glycol and phthalic acid.
- Bakelite or **polyoxybenzylmethylenglycolanhydride** is a plastic which is made up of monomers phenol and aldehyde.

TYPES OF POLYMERIZATION REACTIONS

Addition Polymerization

This is also called as chain growth polymerization. In this, small monomer units join to form a giant polymer. In each step, the length of the chain increases.

For example, Polymerization of ethane in the presence of Peroxides

Condensation Polymerization

In this type small molecules like H_2O, CO, NH_3 are eliminated during polymerization (step growth polymerization).

Generally, organic compounds containing bifunctional groups such as idols, -dials, diamines, dicarboxylic acids undergo this type of polymerization reaction.

For example, Preparation of nylon -6, 6.

MOLECULAR MASS OF POLYMERS

There are two types of average molecular masses of Polymers:

- **Number Average Molecular Masses**
- **Weight Average Molecular Mass**

Number Average Molecular Masses:

If N_1, N_2, N_3…. are the number of macromolecular with molecular masses. M_1, M_2, M_3….. , respectively then the number average molecular masses of the polymer is given by:

$$\bar{M}_n = \frac{N_1 M_1 + N_2 M_2 + N_3 M_3 + \ldots \sum N_i M_i}{N_1 + N_2 + N_3 + \ldots \sum N_i}$$

The number average molecular mass is determined by colligative properties such as Osmotic Pressure.

MOLECULAR MASS OF POLYMERS

Weight Average Molecular Mass:

If m_1, m_2, m_3…. Are the masses of a macromolecule with molecular masses M_1, M_2, M_3…, respectively, Then weight average molecular mass of the polymer is given by:

$$\overline{M}_{\omega} = \frac{m_1 M_1 + m_2 M_2 + m_3 M_3 + \ldots\ldots}{m_1 + m_2 + m_3}$$

$$\Rightarrow = \frac{\sum miMi}{\sum mi}$$

$$\Rightarrow \overline{M}_{\omega} = \frac{\sum NiMi \times Mi}{\sum NiMi}$$

$$\Rightarrow \overline{M}_{\omega} = \frac{\sum NiMi^2}{\sum NiMi}$$

MOLECULAR MASS OF POLYMERS

Polydispersive index: It is the ratio of weight average molecular mass and number average molecular mass of Polymers. For natural polymers PDI = 1

$$PDI = \frac{\overline{Mw}}{\overline{Mn}}$$

USE OF POLYMERS

Here we will list some of the important uses of polymers in our everyday life.

- 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.

USE OF POLYMERS

- 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.

COMMERCIAL USES OF POLYMERS

Polymer	Monomer	Uses of Polymer
Rubber	Isoprene (1, 2-methyl 1 – 1, 3-butadiene)	Making tyres, elastic materials
BUNA – S	(a) 1, 3-butadiene (b) Styrene	Synthetic rubber
BUNA – N	(a) 1, 3-butadiene (b) Vinyl Cyanide	Synthetic rubber
Teflon	Tetra Flouro Ethane	Non-stick cookware – plastics
Terylene	(a) Ethylene glycol (b) Terephthalic acid	Fabric
Glyptal	(a) Ethylene glycol (b) Phthalic acid	Fabric
Bakelite	(a) Phenol (b) Formaldehyde	Plastic switches, Mugs, buckets
PVC	Vinyl Cyanide	Tubes, Pipes
Melamine Formaldehyde Resin	(a) Melamine (b) Formaldehyde	Ceramic plastic material
Nylon-6	Caprolactum	Fabric

DISCUSSION QUESTIONS

How Can We Differentiate Natural Polymers from Synthetic Polymers?

How do polymers have different physical properties? Give examples.

What are biodegradable polymers? Give examples.

What do you mean by Engineering plastics and synthetic metal?

DISCUSSION QUESTIONS

Natural Polymers vs Synthetic Polymers | Starch A Natural Polymer (byjus.com)

Polymers - Classification, Types, Uses, Properties, Polymerization (byjus.com)