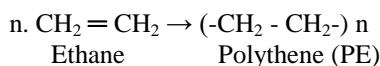


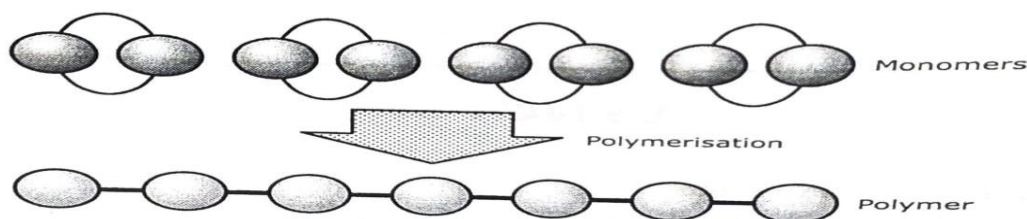
## MODULE 5: POLYMERS

**Definition:** A polymer can be defined as a substance of high molecular weight built up by linking together a large number of small molecules. The simple molecules of low molecular weight which combine to give a polymer are called **monomers**. Due to their large size they are also macromolecules.

Therefore the polymers have a repeated structural part. E.g.: Polyethene,  $(\text{CH}_2 = \text{CH}_2)_n$ .



Here ethylene ( $\text{CH}_2 = \text{CH}_2$ ) is monomer which is being converted into a polymer polyethene  $(-\text{CH}_2 - \text{CH}_2-)_n$ . A monomer molecule should possess at least two easily reacting positions.



Ex: Ethylene glycol,  $\text{HO}-\text{H}_2\text{C}-\text{CH}_2-\text{OH}$  possesses two reacting groups and it can form a polymer like polyester. The small molecules with a  $\Pi$  bonds can also function as a monomer. When the  $\Pi$  bond breaks, two reactive sites are formed on the neighbouring carbon atoms.

Example:  $\text{CH}_2 = \text{CH}_2$  (acetylene),  $\text{CH}_2 = \text{CH} - \text{Cl}$  (vinyl chloride) etc.

**Functionality:** It can be defined as the number of functional group or reactive sites present in monomer molecules. Monomers should have two or more functional groups to undergo Polymerization. For e.g:

**Bi functional** monomers such as ethylene, styrene ( $\text{C}_6\text{H}_5\text{CH} = \text{CH}_2$ ), vinyl chloride ( $\text{H}_2\text{C} = \text{CHCl}$ ).

**Tri functional** monomers such as glycerol ( $\text{CH}_2(\text{OH})\text{CH}(\text{OH})\text{CH}_2(\text{OH})$ ), phenol ( $\text{C}_6\text{H}_5\text{OH}$ )

**Tetra or poly functional** monomers Such as acetylene ( $\text{C}_2\text{H}_2$ ), butadiene ( $\text{H}_2\text{C} = \text{CH} - \text{CH} = \text{CH}$ ) etc.

**Polymerization:** The process of conversion of monomers (simple molecule) into polymers is called polymerization. By this process large numbers of monomers are joined to form large molecules of polymers. During polymerization, the polymer molecules formed are of different sizes depending on the number of monomers involved. For Example: a polythene molecule may contain 200-500 repeating units  $-\text{CH}_2-\text{CH}_2-$ . To know the size of the polymer, average numbers of repeating units are considered.

**Degree of polymerization (DP):** It is the average number of repeating units in the polymer molecule. It increases with time, temperature, concentration of monomer and initiator used in polymerization reaction. With increase in DP, the molecular weight increases and the strength increases in a non-linear way. For a polymer to have desirable properties, the DP should be such that the polymer has at least 20,000 as the molecular weight.

Relation between molecular weight (M) and Degree of polymerization:  $M = nM_0$

Where  $n = \text{DP}$ ,  $M_0 = \text{molar mass of monomer}$ .

Degree of polymerization plays an important role to decide the end properties of the polymer. If DP is below a limit, then the polymer is either fragile powder or liquid.

**Properties of Polymers:**

**1) Molecular Weight of Polymers:** For any chemical substance, the molecular weight is calculated by the following equation:  $M = W / N$  i.e., **Molecular Weight** =  $\frac{\text{sample weight}}{\text{no. of mole in sample}}$

Unlike a normal chemical substance, a polymer is usually a complex mixture of molecules of different molecular weight. The polymers are thus polydisperse and heterogeneous in nature. This means all polymer molecules in a polymer sample are not of equal size. They vary in size and thus their molecular weights are also different. Therefore the molecular weight of a polymer sample is actually an average of the molecular weights of constituent molecules. Different averages are obtained depending on the method of determination of molecular weight. The common methods for averaging are as follows:

- (a) **Number Average Molecular Weight ( $\overline{Mn}$ ):** The number average molecular weight of a polymer is the total weight of all the polymer molecules in a sample, divided by the total number of polymer molecules in a sample. It is denoted by 'Mn'

Consider a polymer sample in which  $N_1, N_2, N_3, \dots$  are the number of molecules having molecular weights of  $M_1, M_2, M_3, \dots$ , then the number average molecular weight  $M_n$  can be given as:

$$\overline{Mn} = \frac{N_1M_1 + N_2M_2 + N_3M_3 + \dots}{N_1 + N_2 + N_3 + \dots}$$

$$\overline{Mn} = \frac{\sum N_i M_i}{\sum N_i}$$

Where,  $N_i$  is the number of moles of  $i^{\text{th}}$  polymer having molecular weight of  $M_i$ .

$$\overline{Mn} = \sum X_i M_i$$

Where,  $X_i$  is the mole fraction of  $i^{\text{th}}$  polymer having molecular weight of  $M_i$ .

The number average molecular weight is determined by the measurement of colligative properties such as **freezing point depression, boiling point elevation, osmotic pressure and lowering of vapour pressure.**

- (b) **Weight Average Molecular Weight ( $\overline{Mw}$ ):** The weight average molecular weight of a polymer is based on the fact that a bigger molecule contains more of the total mass of the polymer sample than the smaller molecules do. It is denoted by 'Mw'. It can be given by the following expression :

$$\overline{Mw} = \frac{\sum N_i M_i^2}{\sum N_i M_i}$$

$$\overline{Mw} = \frac{\sum W_i M_i^2}{\sum W_i}$$

$$\overline{Mw} = \frac{\sum X_i M_i^2}{\sum X_i M_i}$$

Where,  $W_i$  is the weight fraction of the molecules of mass  $M_i$ .

The weight average molecular weight is determined from **light-scattering and ultracentrifugation techniques which measure the molecular size.**

The weight average molecular weight is always greater than the number-average molecular weight. As  $\overline{Mn} = \overline{Mw}$  for monodisperse system, i.e., the system in which all the molecules have identical molecular weight, the ratio or  $\frac{\overline{Mw}}{\overline{Mn}}$  may be used as a measure of molecular weight distribution and this ratio is called **Polydispersity index (PDI)**.

### Solved Numerical Problems

**Problem 1:** There is a polymer consisting of nine polymer chains as shown below. Calculate the number average molecular weight of the polymer.

Number of polymers, Ni	Molecular weight of each polymer, Mi
1	100
3	200
2	400
3	500
1	600

**Solution:** The number average molecular weight can be calculated by dividing the total weight by the total number of polymers.

$$\overline{Mn} = \frac{\sum Ni Mi}{\sum Ni}$$

$$= \frac{(100 \times 1) + (200 \times 3) + (400 \times 2) + (500 \times 3) + (600 \times 1)}{1 + 2 + 3 + 2 + 1}$$

$$\overline{Mn} = \frac{3600}{10} = 360.0$$

**Problem 2:** A sample of polymer contains 10, 20, 30 and 40 percent molecules of the polymer with molecular weights 10,000; 12,000; 14,000 and 16,000 respectively. Calculate the number average and weight average molecular weight of the polymer. Also calculate the *Polydispersity index*.

**Solution:** The total number of molecules = 100.

The number average molecular weight can be calculated as:  $\overline{Mn} = \sum Xi Mi$

Where Xi is the mole fraction

$$\overline{Mn} = \frac{10}{100} \times 10000 + \frac{20}{100} \times 12000 + \frac{30}{100} \times 14000 + \frac{40}{100} \times 16000$$

$$= (0.1 \times 10000) + (0.2 \times 12000) + (0.3 \times 14000) + (0.4 \times 16000)$$

$$= 1000 + 2400 + 4200 + 6400$$

$$\overline{Mn} = 14000$$

$$\text{Now, } \overline{Mw} = \frac{\sum Xi Mi^2}{\sum Xi Mi}$$

$$\overline{Mw} = \frac{0.1(10000)^2 + 0.2(12000)^2 + 0.3(14000)^2 + 0.4(16000)^2}{14000}$$

$$\overline{Mw} = \frac{10^7 + (28.8 \times 10^6) + (58.8 \times 10^6) + (102.4 \times 10^6)}{14000}$$

$$\overline{Mw} = \frac{200 \times 10^6}{14000}$$

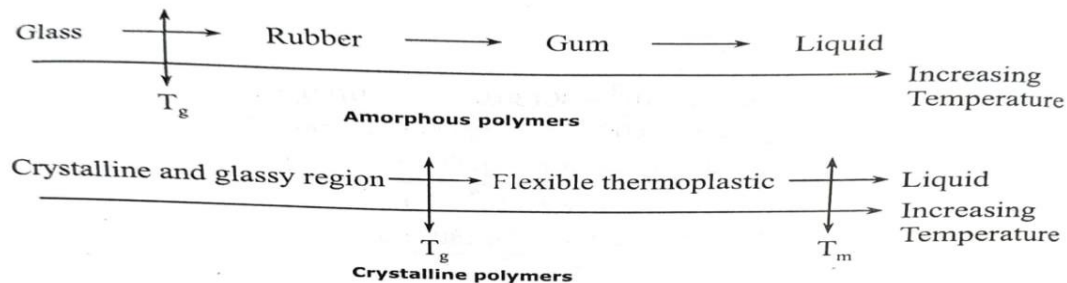
$$\overline{Mw} = 14,285.17$$

$$\text{Polydispersity index } \frac{\overline{Mw}}{\overline{Mn}} = \frac{14,300}{14000} = 1.02$$

**Effect of Heat on the Polymers (Glass Transition Temperatures):** The glass transition takes place in amorphous, i.e., glassy polymers. Even when the glass in liquid state is cooled, crystallization does not take place. This is because the polymer chains are not able to rearrange themselves into a three-dimensional, long-range and properly ordered structure. On cooling, the glass transition corresponds to increase in viscosity, and a gradual transformation from a liquid to a rubbery material and finally to a rigid solid. The temperature at which the polymer experiences the transition from rubbery to rigid state is termed as the '**glass transition temperature**' (Tg). When a rigid glass at a temperature below Tg, is heated, the sequences of events occur in the reverse order.

**(A) Glass Transition Temperature and Melting Temperatures;** the behaviour of a polymer is temperature sensitive. When a polymer is cooled slowly, it becomes hard solid and brittle and behaves like a glass. Glass transition temperature is defined as the lowest temperature below which the polymer becomes hard and brittle and above which it becomes soft and flexible. It is denoted by  $T_g$ .

On heating, the polymer becomes too soft, that it behaves like a fluid called as the visco-fluid state. The temperature at which the soft, flexible polymer goes to the viscofluid state is called the melting temperature  $T_m$ .



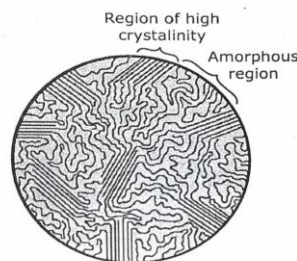
**Fig: Effect of temperature on polymer**

As compared to  $T_m$ ,  $T_g$  is more important because the value decides the properties and selection of polymer for desired purpose.

#### Factors Influencing $T_g$ :

- $T_g$  value depends on chain length. As the chain length increases, the molecular weight increases and hence  $T_g$  value increases. e.g., PE has a  $T_g$  value  $-90^\circ\text{C}$ , while PP has a value  $-18^\circ\text{C}$ .
- Cross linking increases the  $T_g$  value.
- Presence of bulky groups increases the  $T_g$  value.
- Polar side atoms or group of atoms increases the  $T_g$  value.
- Double bonds and aromatic chain groups which tend to stiffen the back bone increases the  $T_g$  value.
- Addition of plasticizer decreases the  $T_g$  value.
- Polymers having strong intermolecular forces of attraction increases  $T_g$  value.
- Coiled nature of the polymer molecules offers high flexibility and therefore  $T_g$  is less.

**(B) Polymer Crystallinity:** The degree to which polymer molecules are arranged in orderly pattern with respect to each other is a measure of its crystallinity. A small region of a macromolecular material in which portions of large molecules are linked to each other in some regular way is called a crystallite. No polymer is perfectly crystalline or perfectly amorphous. The longer molecules are more partially crystalline than the shorter molecule. Various polymers in use are made up of a mixture of crystalline regions embedded in amorphous matrix. The crystalline region provides the rigidity and hardness and the amorphous region account for flexibility.



**Fig.: Semi crystalline polymer**

**(C) Viscoelasticity:** Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like honey, resist shear flow and strain linearly with time when a stress is applied. Viscoelasticity is a molecular rearrangement. When a stress is applied to a viscoelastic material, such as polymer, parts of a long polymer chain changes its positions. Synthetic polymers, wood & human tissue, as well as metals at high temperature, show significant viscoelasticity.

### Properties of Viscoelastic Materials:

1. They behave like an elastic material as well as viscous material when stress is applied.
2. They dissipate energy in form of heat when a load is applied and then removed.
3. They have a viscosity factor and therefore they have a strain rate which depends on time.

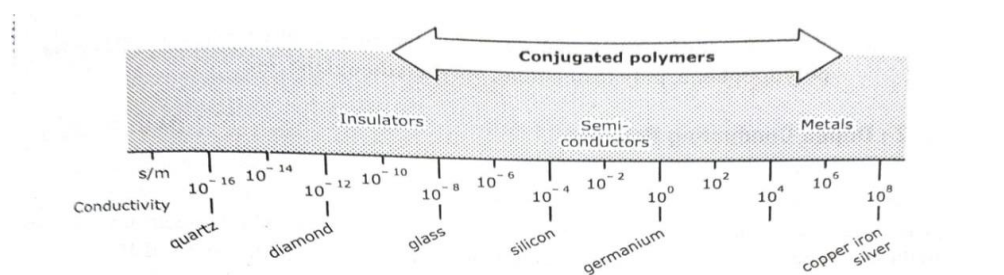
### Uses of Viscoelastic Materials:

1. They are used for isolation vibration.
2. They are used for dampening noise.
3. They are also used for absorbing shock.

**Table: Differences between Elastic and Viscoelastic Materials**

Elastic Materials	Viscoelastic Materials
1. The material returns to its original shape and size when the applied forces are removed.	1. The material will not return to its original shape and size when applied stress is removed.
2. They do not have viscosity factor, and therefore their strain rate does not depends on time.	2. They have a viscosity factor, and therefore they have a strain rate which depends on time.
3. They do not dissipate energy when a load is applied and then removed.	3. They dissipate energy in form of heat when a load is applied and then removed.
4. Example: Rubber.	4. Examples : Wood, synthetic polymers and human tissues etc.

**Conducting Polymers:** Polymers are generally insulators due to lack of free electrons. To become electrically conducting, it has to imitate as metal i.e the electron needs to be free to move. Such type of polymers are called conducting polymers. Polymers with conjugated  $\Pi$  electron (i.e. system have  $C=C$  conjugated bonds) backbones display unusual electronic properties such as low energy optical transition, low ionization potentials, and high electron affinities. The result is a class of polymers that can be oxidized or reduced more easily and more reversibly than conventional polymers. The effect of this oxidation or reduction on Polymers is called “**Doping**” i.e convert an insulating polymer to conducting one.



**Fig.: Conductivity range**

The conductivity of polymers can be compared to those of other materials, from quartz (insulator) to copper (conductor). Polymers may also have conductivities corresponding to those of semiconductors.

### Two conditions for a polymer to become conducting are:

1. Polymer possesses conjugated double bonds.
2. Polymer has to be disturbed either by removing or adding electron to the material. This process is called doping.

### Types of conducting polymers:

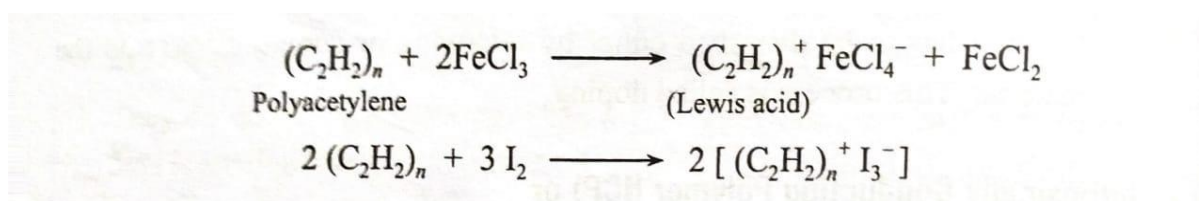
- ❖ **Intrinsically Conducting Polymer (ICP) or Conjugated pi-electrons Conducting Polymer:** This is a polymer whose backbones or associated groups consist of delocalized electron-pair or residual charge. Such polymers essentially contain conjugated pi-electrons backbone, which is responsible for electrical charge. In an electric field, conjugated re-electrons of the polymer get excited and thereby can be transported through the solid polymeric material. Overlapping of orbitals (of conjugated re-electrons) over the entire backbone results in the formation of valence bands as well as conduction bands, this extends over the entire polymer molecule. Presence of conjugated  $\pi$ -electron in a polymer increases its conductivity to a larger extent.

The following are the important commercially produced conducting polymers:

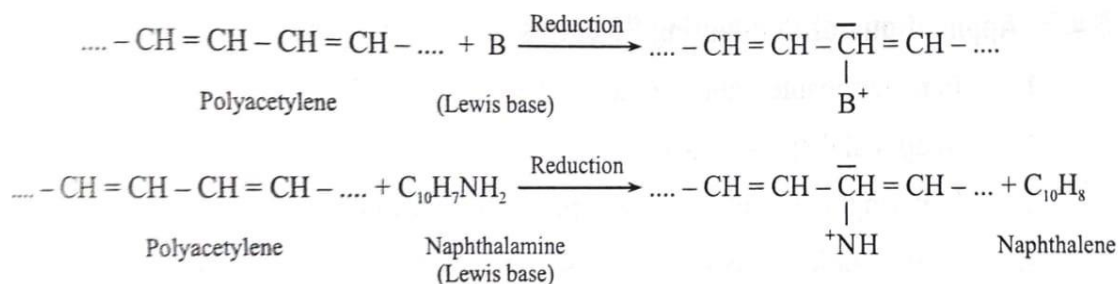
- Polyacetylene polymers e.g., poly-p-phenylene, polyquinoline, Polyphenylene -0-vinylene, poly-m-phenylene sulphide, etc.
- With condensed aromatic rings, e.g., Polyaniline, polyanthralene, polyphenanthralene, etc.
- With aromatic heteroaromatic and conjugated aliphatic units, e.g., polypyrrole, Polythiophenes, polyazomethine, polybutadienylene, etc.

- ❖ **Doped Conducting Polymer:** This is obtained by exposing a polymer to a charged transfer agent in either gas phase or in solution. Intrinsically conducting polymers possess low conductivity ( $\sim 10^{-10} \Omega^{-1} \text{cm}^{-1}$ ), but these possess low ionization potential and high electron affinities so these can be easily oxidised or reduced. Consequently, the conductivity of ICP can be increased by creating either positive or negative charges on the polymer backbone by oxidation or reduction. This technique, called doping (semiconductor), is of types:

**1) p-doping:** involves treating an intrinsically conducting polymer with a Lewis acid thereby the oxidation process takes place and positive charges on the polymer backbone are created. Some of the common P-dopants used are  $\text{I}_2$ ,  $\text{Br}_2$ ,  $\text{As F}_5$ ,  $\text{PF}_6$ , naphthalamine, etc.



**2) n-doping:** involves treating an intrinsically conducting polymer with a Lewis base; thereby the reduction process takes place and negative charges on the polymer backbone are created. Some of the common N-dopants used are Li, Na, Ca, tetrabutylammonium,  $\text{FeCl}_3$ , etc.



- ❖ **Extrinsically Conducting Polymers:** are those polymers whose conductivity is due to the presence of “externally” added ingredients in them. These are of two types :

- Conductive element-filled polymer** is a resin or polymer filled with conducting elements such as carbon black, metallic fibres, metal oxides, etc. In this, the polymer acts as the binder to hold the conducting elements together in the solid entity. These polymers possess reasonably good bulk conductivity and are, generally, low in cost, light in weight, mechanically durable and strong, and easily processable in different forms, shapes and sizes. Generally, special grade conducting carbon block is used as filler, on account of its: (a) very high surface area ( $1,000 \text{ m}^2/\text{g}$ ), (b) high porosity, and (c) filamentous properties. Minimum

concentration of conductive filler in the polymer to start the conduction process is known as percolation threshold.

- 2) Blended conducting polymer is a product obtained by blending a conventional polymer with a conducting polymer either by physical or chemical change. Such polymers can be easily processed and possess better physical, chemical and mechanical properties.

❖ **Coordination Conducting Polymer (Inorganic Polymer):** This is a charge transfer complex containing polymer obtained by combining a metal atom with a polydentate ligand.

### Applications of Conducting Polymers:

1. In rechargeable light weight batteries. They may be 10 times lighter than conventional lead storage batteries.
2. In optical display and photovoltaic devices.
3. In wiring in aircrafts and aerospace components.
4. In electronic devices as diodes and transistors and telecommunication systems.
5. In solar cells etc.
6. In antistatic coating of clothing.

**Plastics:** Plastics are the polymer, which has a large molecular mass. The monomers of plastic can be natural or synthetic. Plastic is synthesized from petrochemicals. All plastics are polymers but not all polymers are plastic. Plastics are high molecular weight organic materials which can be moulded into any desired shape, when subjected to heat and pressure in the presence of a catalyst.

Plastics have certain important properties such as: 1. Good thermal and electrical insulation, 2. Good corrosion resistivity, 3. Light in weight, 4. chemically inert, 5. Good strength, 6. Easy workability and adhesiveness, 7. Low fabrication cost, 8. Insect resistivity, 9. Low decorative surface effect. 10. Low maintenance cost and high refractive index.

On the basis of setting manner in final stage of manufacture, plastics are classified as; thermo softening or thermoplastic and thermosetting plastics.

**Thermosoftening Plastics or Thermoplastics:** Those plastics which soften on heating and harden on cooling reversibly are known as thermoplastics. They have linear polymer chains or negligibly branched chains and are obtained by addition polymerization. But the polymers obtained by condensation polymerisation of bi functional monomers are also Thermosoftening.

When this type of polymer is heated, the linear molecule slide apart one over the other easily as the intermolecular force of attraction between them is very weak. There is no chemical change taking place even after repeated heating and cooling, because the changes are purely of physical nature. Some of the examples are polythene, nylons, polystyrene, Teflon, etc.

**Thermosetting Plastics or Thermosets:** Those plastics which do not soften on heating are thermosetting plastics. During moulding, they acquire 3 D cross linked structure with predominantly strong bonds. These bonds retain the strength even on heating. If heated beyond a limit, it get burn into black material. Once the shape is given, it cannot be changed by applying heat and pressure. But modification in their shape can be given by mechanical methods like cutting, drilling etc. There is excessive cross-linking in these plastics and different polymer chains held through strong covalent bonds forming a three dimensional network. Hence, once set, they cannot be remoulded. On heating, they first fuse to form hard mass and then burn. Some of the examples are Terylene, Bakelite, melanine, etc.

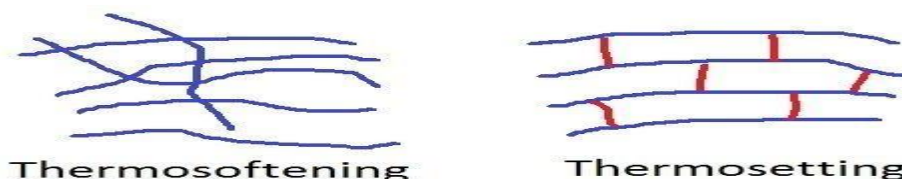


Fig.: Structure of thermosoftening and thermosetting polymers

### Differentiation between Thermoplastics or Thermosoftening and Thermosetting or Thermosets Plastics

Thermoplastics or Thermosoftening	Thermosetting or Thermosets
<ol style="list-style-type: none"><li>1. Formed by addition polymerisation</li><li>2. They are linear polymers with negligible branching.</li><li>3. Formed by monomers with C=C (bi-functional).</li><li>4. They soften on heating (and harden on cooling) because the linear chains can slip over each other very easily.</li><li>5. Soft, weak and less brittle.</li><li>6. Can be moulded and remoulded.</li><li>7. Soluble in some organic solvents.</li><li>8. Can be reclaimed from waste.</li><li>9. Relatively low molecular weight.</li><li>10. Examples: PVC, PE, Teflon etc.</li></ol>	<ol style="list-style-type: none"><li>1. Formed by condensation polymerisation.</li><li>2. They form 3 D network</li><li>3. Formed by monomers with higher functionality.</li><li>4. They do not become soft on heating, because cross links retain the strength on heating. But prolonged heating causes burning.</li><li>5. Hard, strong and brittle.</li><li>6. Remoulding is not possible.</li><li>7. Insoluble in almost all organic solvents.</li><li>8. Cannot be reclaimed from waste.</li><li>9. Relatively high molecular weight.</li><li>10. Examples : UF, PF, Nylon 6-6, etc.</li></ol>

**Table: Comparison of thermoplastics and thermosetting**

**Ingredients (Compounding) of Plastics:** Polymers are initially produced as powders, granules or laces (like straws). However they are seldom used in their pure form but are changed by adding other materials to give them their special properties. For example, they may need to be resistant to sunlight, very flexible or cheap. By using different types of additive the properties of the base polymer can be modified to the great extent so the range of their application can be extended.

**The main compounding ingredients are:**

**1: Resins:** It is the main constituent. Resins may be liquid, viscous or solid. It is the binder which holds the various constituents together. It determines which method of moulding is to be used. Resin part of the finished product may be 30 - 100%. Resins may be natural or synthetic. Thermoplastics or Thermosoftening and Thermosetting or Thermosets are the types of resin.

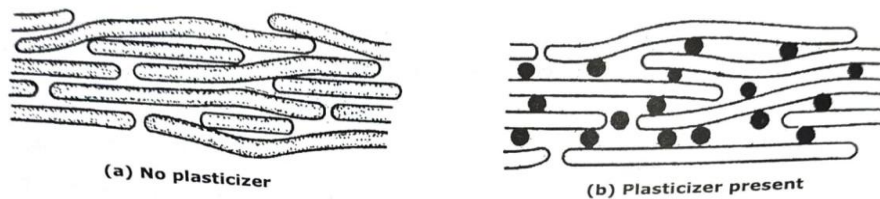
**2: Fillers or Extenders:** The term 'filler' is a name given to a range of materials that are added to polymers in order to modify their physical properties. They may also be added to a base polymer to lower the manufacturing cost of a product made from it. Their functions are: (a) reducing the cost of plastics. (b) Increases the tensile strength and hardness. (c) Reduces the flexibility. (d) Decreases the shrinkage during moulding. (e) Gives opacity to the product. Examples: mica, talc, asbestos, saw dust, chalk etc.

**3. Plasticizers:** Plasticizers are added to increase the plasticity and flexibility of the polymers. The plasticizer molecule occupies between the polymeric chains and neutralizes the intermolecular forces of attraction and thus allows freedom of movement.

The functions are: (a) increases the flexibility of the plastics. (b) lowers the softening temperature and hence moulding and remoulding can be done at low temperature. (c) Imparts flame proofness. (d) Reduces resistance towards chemicals, solvents etc. Examples: esters of fatty acids, vegetable oils etc. Plasticizers are not used with thermosetting resins.

The presences of small molecules of plasticizers reduce the attraction of the larger polymer molecules for one another and thus permit more flexibility and easier slip.





**Fig.: Effect of plasticizer on polymer chain**

**4: Lubricants:** These additives are widely used to help plastics flow in moulds. They are usually waxy materials that act by reducing the stickiness of the plastic on the mould surface. These additives are widely used to help plastics flow in moulds. They are usually waxy materials that act by reducing the stickiness of the plastic on the mould surface.

The functions are: (a) imparts glossy finish to products. (b) Prevent sticking of plastic to the mould. Examples: waxes, soaps etc.

**5: Pigments or Colouring Materials:** They provide colour to the final plastic material. Plastics can be coloured by using either dyes or pigments. Dyes give transparent colours and pigments give opaque ones. A very wide range of colours can be obtained from clear to opaque black with a naturally clear material such as acrylic. Examples: organic and inorganic dye stuffs.

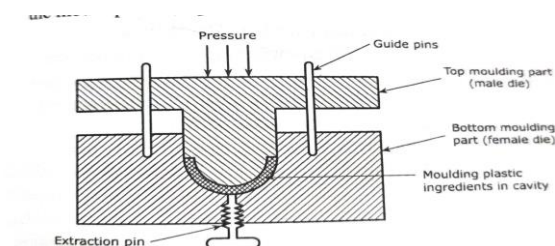
**6: Catalysts or Accelerators:** They are added only to thermosetting plastics. They accelerate the rate of polymerisation. Examples:  $H_2O_2$ , Zn, ammonia and its salts.

**7: Stabilizers:** In order to prevent the decomposition and discolouration of the plastic at the moulding temperature, stabilizers can be used. Examples:  $PbCrO_4$ , stearates of Pb, Ca, Ba, Pb silicate etc.

**Fabrication of Plastics or Moulding of Plastics:** Fabrication of plastics is the technique of giving any desired shape to the plastics by the use of mould. Because of the properties of polymers it is possible to mould them and change their shape using a number of different repetitious manufacturing processes. A proper method is to be selected depending upon the shape and type of resin being used. Before moulding, it is essential to dry the resin in order to achieve optimum performance of finished products.

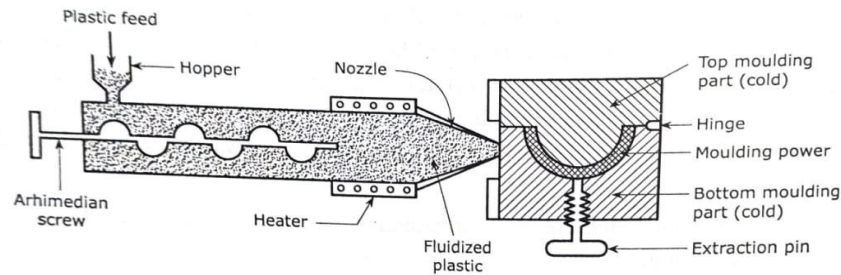
The most important types of Moulding:

**1: Compression Moulding:** This method is applied to both thermoplastic and thermosetting resins. Two half-pieces of mould capable of being moved relative to each other are filled by the predetermined quantity of plastic ingredients in proper proportions. Heat and pressure are then applied according to specifications. The cavities get filled with fluidised plastic. Two halves are closed very slowly. Finally curing is done either by heating in case of thermosetting resins or by cooling in case of thermoplastic resins. After cooling the moulded article is taken out by opening the mould parts.



**Fig: Compression Moulding of Plastics**

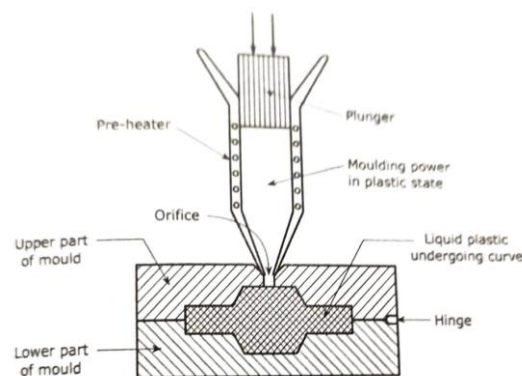
**2: Injection Moulding:** This method is applicable mainly to thermoplastic resins. The moulding plastic powder is fed into a heated cylinder. From there it is injected into the tightly locked mould at a controlled rate by means of a screw arrangement or by a piston plunger. The mould is kept cold to allow the hot plastic to cure and become rigid. When the materials have been cured sufficiently, half of the mould is opened to allow the injection of the finished article without any deformation. Heating is done by oil or electricity.



**Fig: Injection Moulding**

This method has high speed production, low mould cost, very low loss of material and low finishing cost. Hence, it is the most widely used method for moulding of thermoplastics. Since a large number of cavities cannot be filled simultaneously, there is limitation of design of articles to be moulded.

**3: Transfer Moulding:** This method uses the principle of injection moulding for thermosetting materials. The moulding powder is placed in a heated chamber. The chamber is maintained at the minimum temperature at which the moulding powder just begins to become plastic. This plastic material is then injected through an orifice into the mould by a plunger working at a high pressure. Due to great friction developed at the orifice, the temperature of the material rises, so that the moulding powder becomes almost liquid. Thus, it flows quickly into the mould which is being heated up to the curing temperature required for setting. The moulded article is then ejected mechanically.

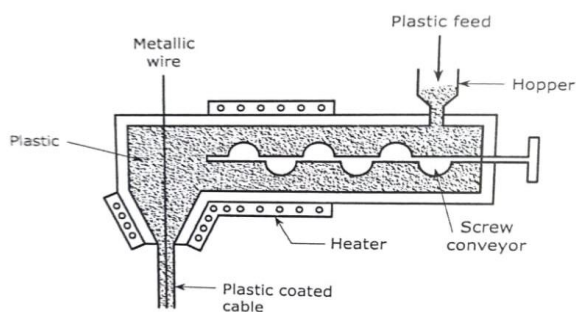


**Fig.: Transfer moulding of plastics.**

**Following are the advantages of transfer moulding method:**

1. Very delicate articles may be handled without distortion or displacement since the mix flows into the mould cavity in a highly plasticized condition.
2. Intricate shapes which cannot be attained by compression moulding, can readily be produced.
3. Article produced is free from flow marks.
4. Even thick pieces cure almost completely and uniformly.
5. The mechanical strength and density of fabricated piece is higher as the shrinkage and distortion are minimum due to uniform and thorough cure.
6. Finishing cost of fabricated article is eliminated.
7. Blistering is eliminated.
8. Mould cost is less as it involves very low abrasive action.

**4: Extrusion Moulding:** The thermoplastic materials are moulded by this method. They undergo continuous moulding to form articles of uniform cross-section. These articles include tubes, rods strips, insulated electric cables, etc. In this method, the thermoplastic materials are heated to plastic condition and then pushed by means of a screw conveyor into a die having the required outer shape of the article to be manufactured. Here the plastic mass gets cooled due to the atmospheric exposure. A long conveyor carries away the cooled product continuously.

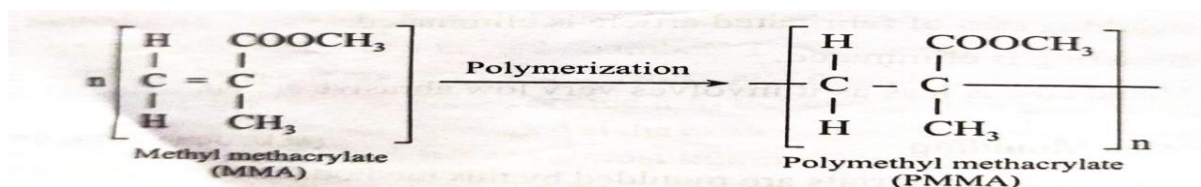


**Fig.: Moulding of insulated electric cable by vertical extrusion moulding**

### Preparation, Properties and Uses of Some Important Plastics:

**1: Polymethyl Methacrylate (PMMA):** This is an important thermoplastic resin. It is also known as Lucite or Plexiglass.

**Preparation:** It is obtained by polymerization of methyl methacrylate which is an ester of meth acrylic acid,  $\text{CH}_2 = \text{C}(\text{CH}_3)\text{COOH}$ , in presence of acetyl peroxide or hydrogen peroxide. It is an acrylic polymer.



### Properties:

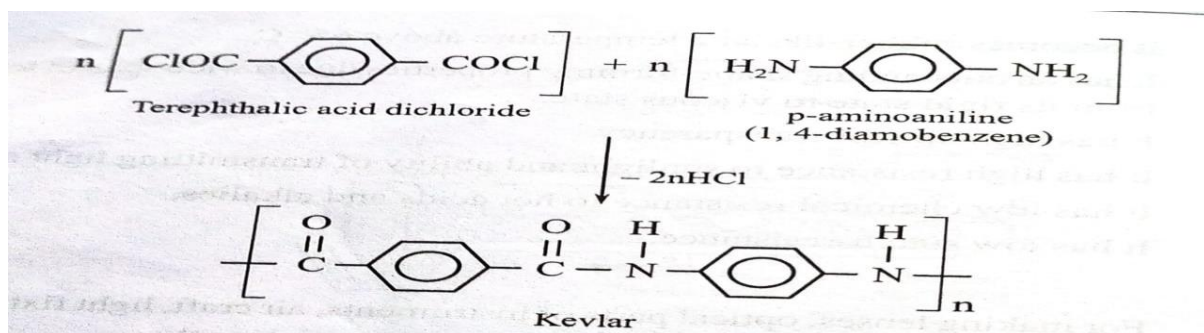
1. It is a hard, fairly rigid material with a high softening point of about 130 - 140° C.
2. It becomes rubber-like at a temperature above 65° C.
3. It has an outstanding shape-forming property due to wide span of temperature from its rigid state to viscous state.
4. It has high optical-transparency.
5. It has high resistance to sunlight and ability of transmitting light accurately.
6. It has low chemical resistance to hot acids and alkalies.
7. It has low starch-resistance.

### Uses:

1. For making lenses, optical parts of instruments, air craft, light fixtures, artificial eyes, wind screen, bone splints, decorative articles, etc.
2. As it is more transparent than glass, it is used for making window glasses.
3. It is found in paints. Acrylic "latex" paints often contain PMMA suspended in water.
4. It is used as a cloud and pour point depressant additives in lubricants. It does not get viscous in cold and the machines can be operated at low temperatures to - 100° C (-148° F).

**Kevlar (Poly Paraphenylene Terephthalamide):** It is an Aromatic polyamide with benzene rings linked to the amide group, - CONH- group.

**Preparation:** It is prepared by polycondensation between aromatic dichloride like terephthalic acid dichloride (terephthaloyl chloride) and aromatic diamines like 1,4-phenylene diamine (para-phenylene diamine or 1,4-diamine benzene or p-aminoaniline).



#### Properties:

1. It is exceptionally strong, 5 times stronger than steel and 10 times stronger than aluminium.
2. It has high heat stability and flexibility.
3. It does not lose its strength even at  $-196^\circ\text{C}$ .
4. It has resistance against almost all the solvents except some powerful acids.
5. It is known to degrade when exposed to UV radiations.

#### Uses:

1. It is used in aerospace and aircraft industries.
2. It is used for the preparation of car parts such as tyres, brakes, clutch linings, etc.
3. It is used for the preparation of ropes, cables, protective clothing, bulletproof vests, motorcycle helmets and other high performance materials.