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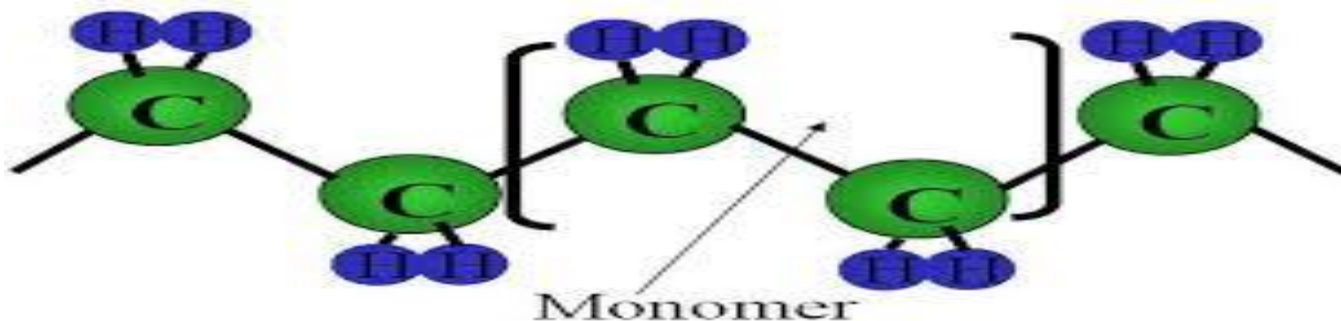
K J Somaia College of Engineering



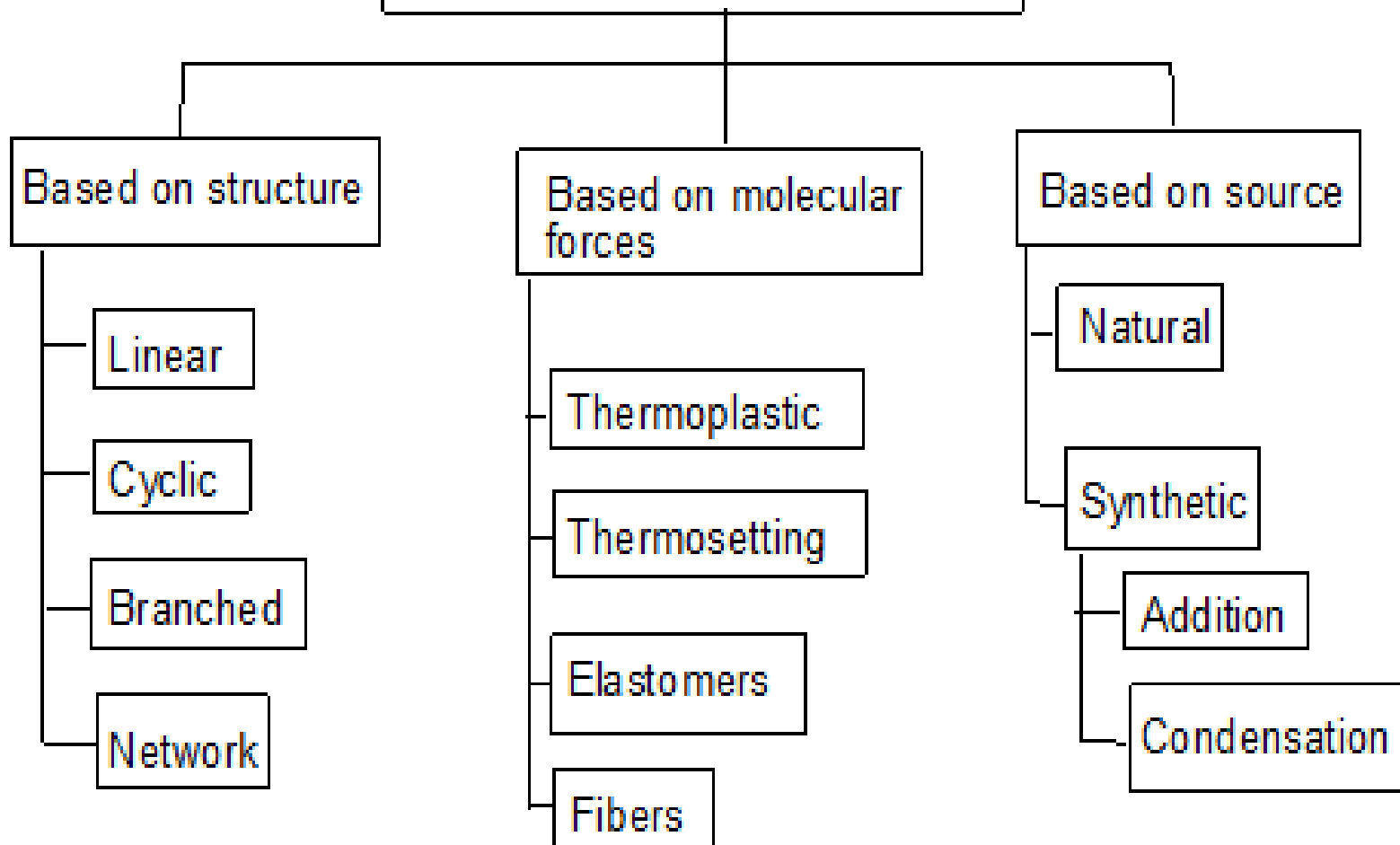
Polymers

Dr. Jitendra Satam

- A polymers are macromolecule with high molecular mass compound ranging from 5000 to one million
- Formed by combination of one or more low molecular weight compounds. The smallest unit from which polymer is obtained is called **monomer**.
- The process by which polymers are obtained is called polymerization
- For e.g. **polyethylene** is obtained by repeating ethylene unit as a result of polymerization.



CLASSIFICATION OF POLYMER



Classification based on source

- **Naturally occurring Polymers:** These occur in plants and animals and are very essential for life e.g. starch, cellulose, amino acids, etc.
- **Synthetic polymers:** These polymers are prepared in laboratory they are man made polymers e.g. plastics, synthetic rubbers, etc.
- **Semi synthetic polymers:** These are derived from naturally occurring polymers by chemical modification. e.g. vulcanized rubber, Cuprammonium silk and Cuprammonium rayon, etc.

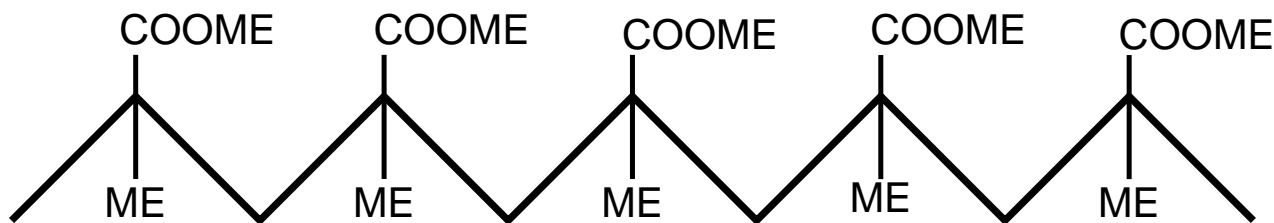
Classification based on Molecular forces

Polymers are classified into four categories based on magnitude of intermolecular forces

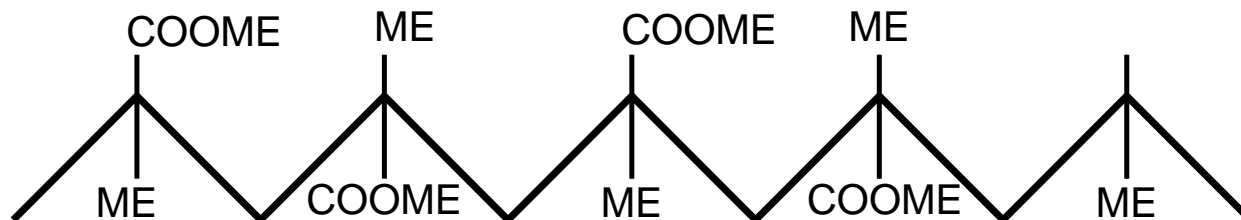
- **Elastomers:** In these polymers, chain are held by weakest intermolecular forces which permits the polymers to be stretched. The polymer regains its original position when forces are released.
- **Fibers:** In these polymers the inter molecular forces are strong due to hydrogen bonding, cross linking, cyclic structure
- **Thermoplastics:** These are polymers for which inter molecular forces between elastomers and fibers. Due to this they can be easily molded by heating.
- **Thermosetting polymers:** Thermosetting polymers undergo chemical changes and cross linking on heating and become permanently hard and infusible.

Classification based on Tacticity

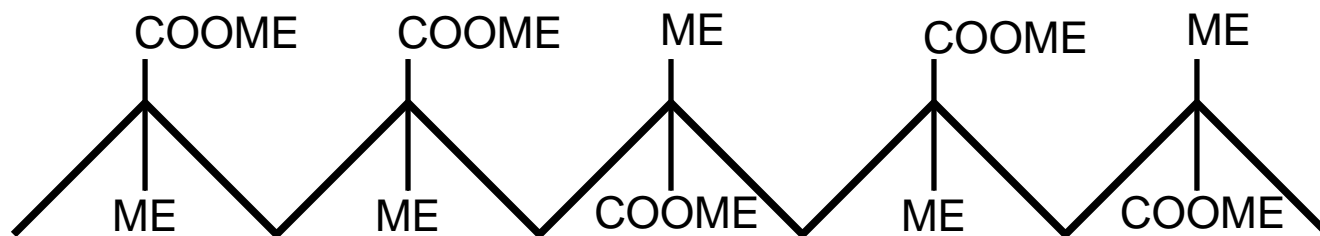
- Isotactic polymers: In isotactic, all the functional group lie on the same side of chain



- Syndiotactic polymers: In syndiotatactic, functional group arrangement is alternate



- Atactic polymers: In atactic, functional group arrangement is random



Every other carbon in the chain is a stereo-center

Classification based on Polymerization method

- Addition Polymerization:** A polymer formed by direct repeated addition of monomers is called addition polymerization. In this types of polymers monomers are unsaturated compounds or derivatives of alkenes.

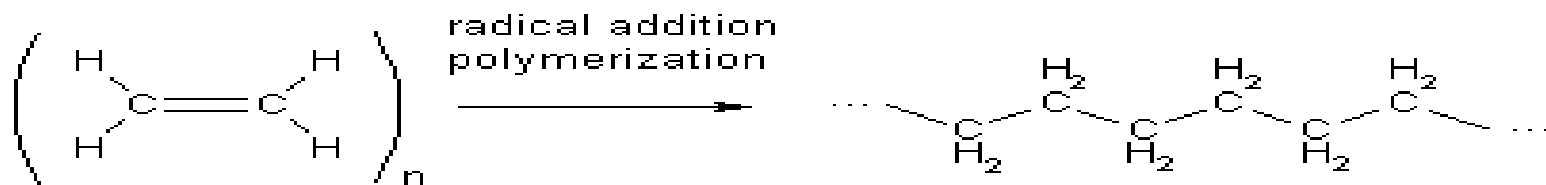
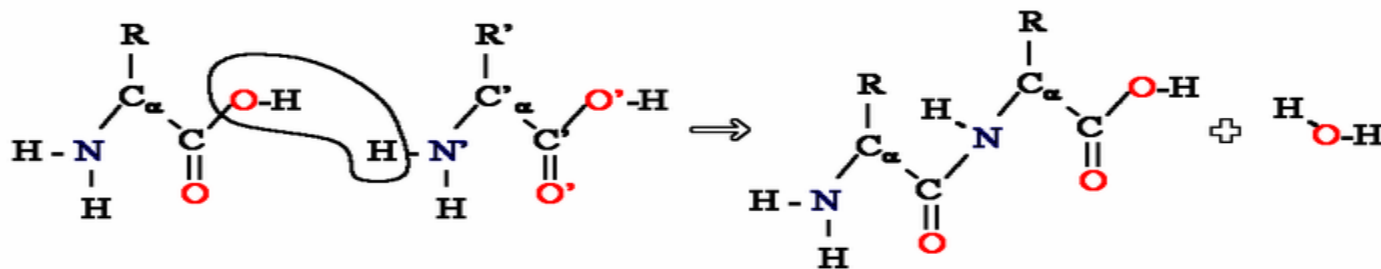


Fig 1: The polymerisation of ethene in to poly(ethene)

- Condensation Polymerization:** Condensation polymerization involves condensation of two different monomers which are normally bi functional group. During the process there is loss of small molecule such as water



	Condensation polymerisation		Additional polymerisation
(1)	It is also known as step growth polymerisation	(1)	It is also known as chain growth polymerization
(2)	It takes place in monomers having reactive functional groups	(2)	It takes place only in monomers having multiple bonds.
(3)	It takes place with elimination of simple molecule like H_2O , NH_3 , HCl etc.,	(3)	It takes place without elimination of simple molecule.
(4)	Repeat units of monomers are different	(4)	Repeat units & monomers are same.
(5)	The polymer is formed in gradual steps	(5)	Reaction is fast and polymer is formed at once.
(6)	The molecular mass of polymer increases throughout the reaction	(6)	There is very little change in the molecular mass throughout the reaction
(7)	Product obtained may be thermosetting/thermoplastic	(7)	Product obtained are thermoplastic
(8)	E.g.:- Bakelite, polyester ,polyamides etc.,	(8)	E.g:-Polyethylene, PVC, poly styrene.

Difference between thermoplastic & thermosetting resins:-

Thermoplastic resins (or) Polymers		Thermosetting resins	
(1)	These are produced by addition polymerization	(1)	These are produced by condensation polymerization.
(2)	The resins are made of long chains attached by weak Vander Waal's force of attraction	(2)	The resins have three dimensional network structure connected bonds.
(3)	On heating they soften and on cooling become stiff chemical nature won't change	(3)	On heating they become stiff & hard. No change on cooling. Chemical nature changes.
(4)	They can be remoulded		They cannot be remoulded because once set means they are permanently set
(5)	Scrap (waste product) can be used	(5)	Scrap cannot be used
(6)	The resins are soft, weak and less brittle	(6)	The resins are usually hard, strong tough & more brittle
(7)	These are easily soluble in some organic substances E.g.:- PVC, polyethylene etc.	(7)	Resins are not soluble in organic Solvents E.g.:- Nylon, Bakelite etc.
(8)	Contain long chain polymer with no cross linkage.	(8)	They have 3D network structure.

Plastics

- Plastic is a substance that can be easily moulded into a desired shape by the effect of mechanical force & heat.
- In the manufacturing of plastic raw materials like coal, petroleum, cellulose, salt, sulphur, limestone, air, water etc. are used.

Plastics as engineering materials:-

- Low fabrication cost, low thermal & electrical conductivities, high resistance to corrosion, Plastics are resistant to chemicals & solvents
- Plastics reduce noise & vibrations in machines
- Plastics are bad conductors of heat are useful for making handles used for hot objects, most plastics are inflammable.
- Plastics are electrical insulators & find large scale use in the electrical industry.
- Plastics are clear & transparent so they can be given beautiful colors.

Compounding of plastics

The process of mechanical mixing of various additives with polymers (resin) to impart some special properties to the plastics.

The additives gets incorporated with resins to give homogeneous mixture.

The principle **Additives / Ingredients** used in compounding are:

- Resin or Binder
- Fillers or extenders
- Plasticizers
- Pigments or Dyes
- Activators, catalysts or accelerators
- Lubricants
- Stabilizers

1. Resin (Binder)

- Resin is binder which holds the various constituents together
- High molecular weight substances such as, synthetic resins, cellulose derivatives etc.
- Binders influence the properties of plastics
- They also decide the type of treatment during moulding operation
- Eg. LDPE, HDPE, PP, PMMA, Phenol-Formaldehyde resin

2. Fillers or extender

- Fillers reduce the cost of plastic without affecting its original properties
- Imparts better tensile strength, hardness, finish, workability, opacity to the plastic
- Highest % can be up to 50 %, which depends upon type of plastic
- The fillers which increase mechanical strength are known as reinforce fillers
- They also reduce shrinkage and brittleness

Eg. **Organic fillers**: wood powder, cotton pulp, carbon black, graphite, powdered rubber

Inorganic fillers: Asbestos, powdered mica, clays, talc, Zn & Pb oxides, Cd & Ba sulphides, carborundum.

3. Pigments / Dyes

- Imparts desired color
- Organic dyes and inorganic pigments
- Eg. Azo dyes, chromate pigments

4. Catalysts or accelerators

- Used for thermosets to increase the rate of cross-linking
- Acidic or basic catalysts can be used
- Just the small quantities are required
- Eg. Benzoyl peroxide, hydrogen peroxide, metal oxides

5. Plasticizers

- This increase the flexibility and mouldability and decrease brittleness of the materials.
- It also lowers the temperature of moulding operation
- Increase workability and flame proof-ness of plastics
- Only used in thermo-softening plastics
- When they mixed with the resin, they get uniformly distributed between the molecules and reduce intermolecular attraction between original polymer molecules. Thus the plastic becomes flexible.

Plasticizers

- They can be added upto 10 %
- Generally liquid plasticizers are used, hence the only disadvantage is, if they are not consistent they could ooze out from the finished product.

Examples

- Cresyl diphenyl phosphate
- Tricresyl phosphate
- Triphenyl phosphate
- Esters of oleic and stearic acids

6. Lubricants

- Especially help during low or room temperature moulding
- This gives the glossy finish to the final product
- As lubricants get dispersed on the surface and occupies a layer between article and mould
- This prevents sticking of an article to the mould and its easier separation from the mould
- Eg. Soaps, waxes

7. Stabilizers

- Improves thermal stability of the plastics
- Generally helps in high temperature moulding operations, where some plastics decompose or gets decolorized
- This could be prevented with the help of stabilizers
- Eg.
 - Diethyl phthalate
 - Adipic acid esters

Molecular Mass of Polymer

- The molecular mass of polymer is an important property of polymer because many important properties are influenced by molecular mass. Polymers with higher molecular mass are tougher and more resistant. Their viscosities and softening temperature are also higher. Thus polymers with desired molecular mass are often required for particular purposes.
- Molecular mass of polymer is not a fixed or constant value like organic compound. Their molecular mass is controlled by polymerization reaction, which in turn depends upon availability of functional group, charge carrier, life time of charge carriers. Because of random nature of growth process, the product of polymerization process is mixture of chains of different length.
- Hence polymers are poly disperse mixture of various molecular mass polymers. Therefore molecular mass of polymers is average molecular mass

Fabrication (Molding) of Plastics

Giving any desired shape to the plastics (granules or powders) by using mould under the application of heat and pressure. A proper method is to be selected depending on the shape and type of resin used. Methods involves partial melting of resinous mass by heating.

In case of **thermo-plasts** molten resin is introduced in die/mould and desired shape could be achieved by compression and further cooling.

In case of **thermo-sets** partially polymerized mass or raw materials are introduced in the die/mould, which further cured at high temperature in the mould itself to achieve desired shape.

Note:

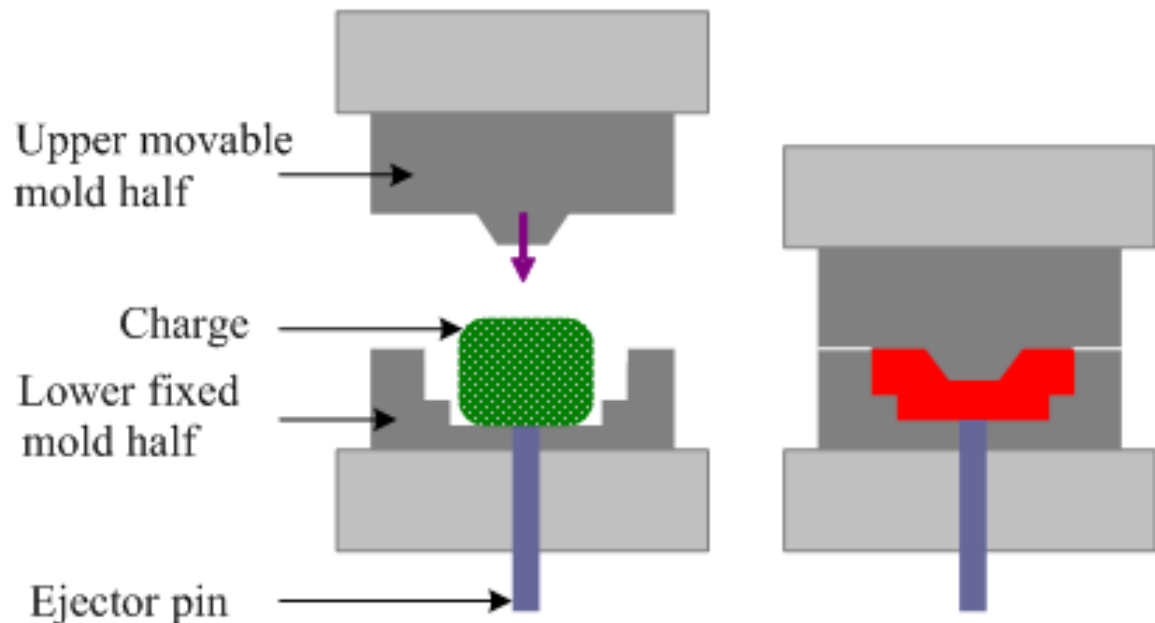
- In case of **thermoplasts**, curing is done at room temperature (low temperature), while in case of **thermosets**, curing is done at high temperature to obtain desired cross-linking

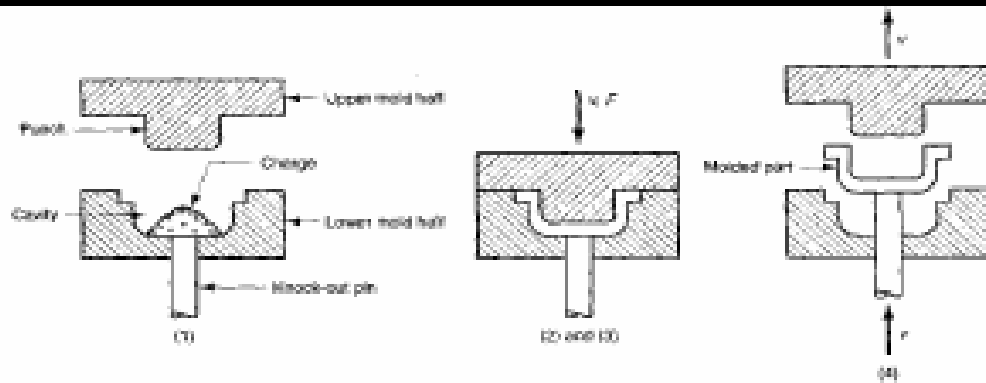
Four important types of fabrication Methods

- Compression Molding : (Suitable for Thermosets / Thermoplasts)
- Injection Molding : (Suitable for Thermoplasts)
- Transfer Molding : (Suitable for Thermosets)
- Extrusion Molding : (Suitable for Thermoplasts)

Compression Molding

1. Common and oldest method for molding thermosetting / thermoplastic materials
2. Compression of raw materials or soften resinous mass is done in the mould/die under heat and pressure
3. Predetermined quantity of raw materials is introduced carefully in the mould, further compressed by hydraulic pressure (2000 to 10000 psi)
4. Molten or soften resinous mass gets filled in the cavity of mould.
5. Curing is done by heating (Thermosetting) or by cooling (Thermoplastics)
6. Finally moulded article is separated from the mould by opening the mould apart.
7. **Applications** : Electric switch boxes, Ash trays, cabinets for radio, television, computers etc.



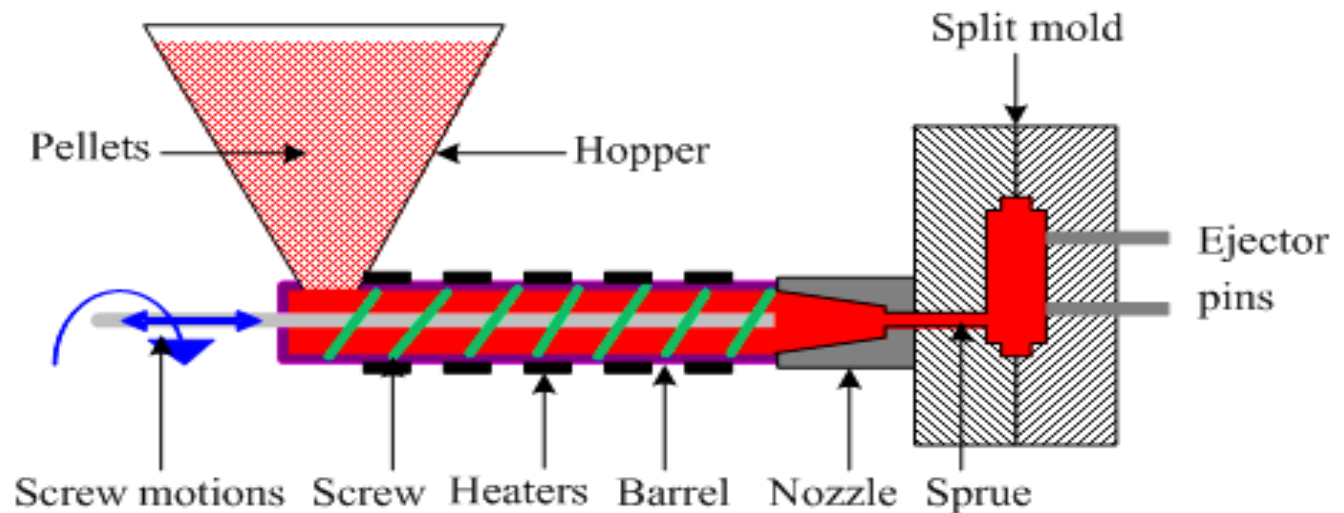


Compression Moulding

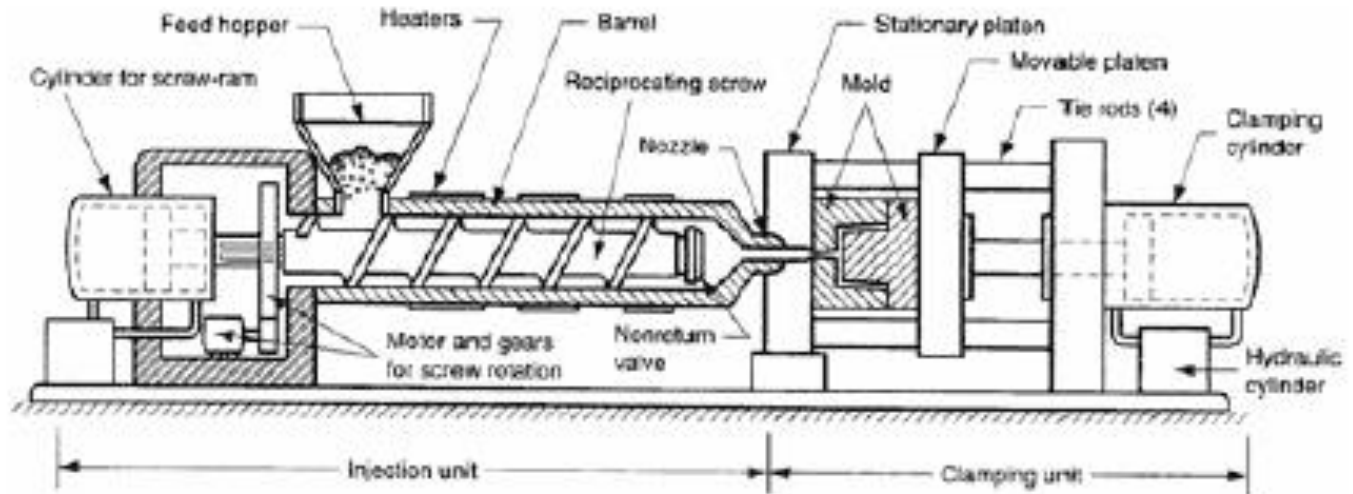
- ❑ This process was the first to be used to form plastics. It involves four steps:
 1. Pre-formed blanks, powders or pellets are placed in the bottom section of a heated mould or die.
 2. The other half of the mould is lowered and is pressure applied.
 3. The material softens under heat and pressure, flowing to fill the mould. Excess is squeezed from the mould. If a thermoset, cross-linking occurs in the mould.
 4. The mould is opened and the part is removed.
- ❑ When **thermoplastics** are used, the mould is **cooled** before removal so the part will not **lose** its shape.
- ❑ When **thermosets** are used, they may be ejected **while they are hot** and after curing is complete. This process is slow, but the material moves only a short distance to the mold, and does not flow through gates or runners. Only one part is made from each mold.

Injection Molding

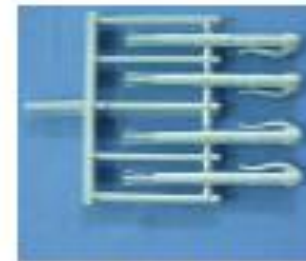
- Especially used for thermoplastic materials
- Powder or granular resin is heated in a cylinder and injected at a controlled rate in a mould
- Piston plunger or screw is used to force the material in mould.
- Pressure upto 1758 kg/cm^2 (125 psi) is used
- Once the article is formed mould is cooled and half mould is opened to remove the finished article.
- Disadvantage of the method is formation of air bubbles or cavities in the articles
- **Applications:** Smaller but large volume articles such as, pen caps, bottle caps, cups, containers, mechanical parts



Injection Moulding



Mobile Phone



Rubber Pen

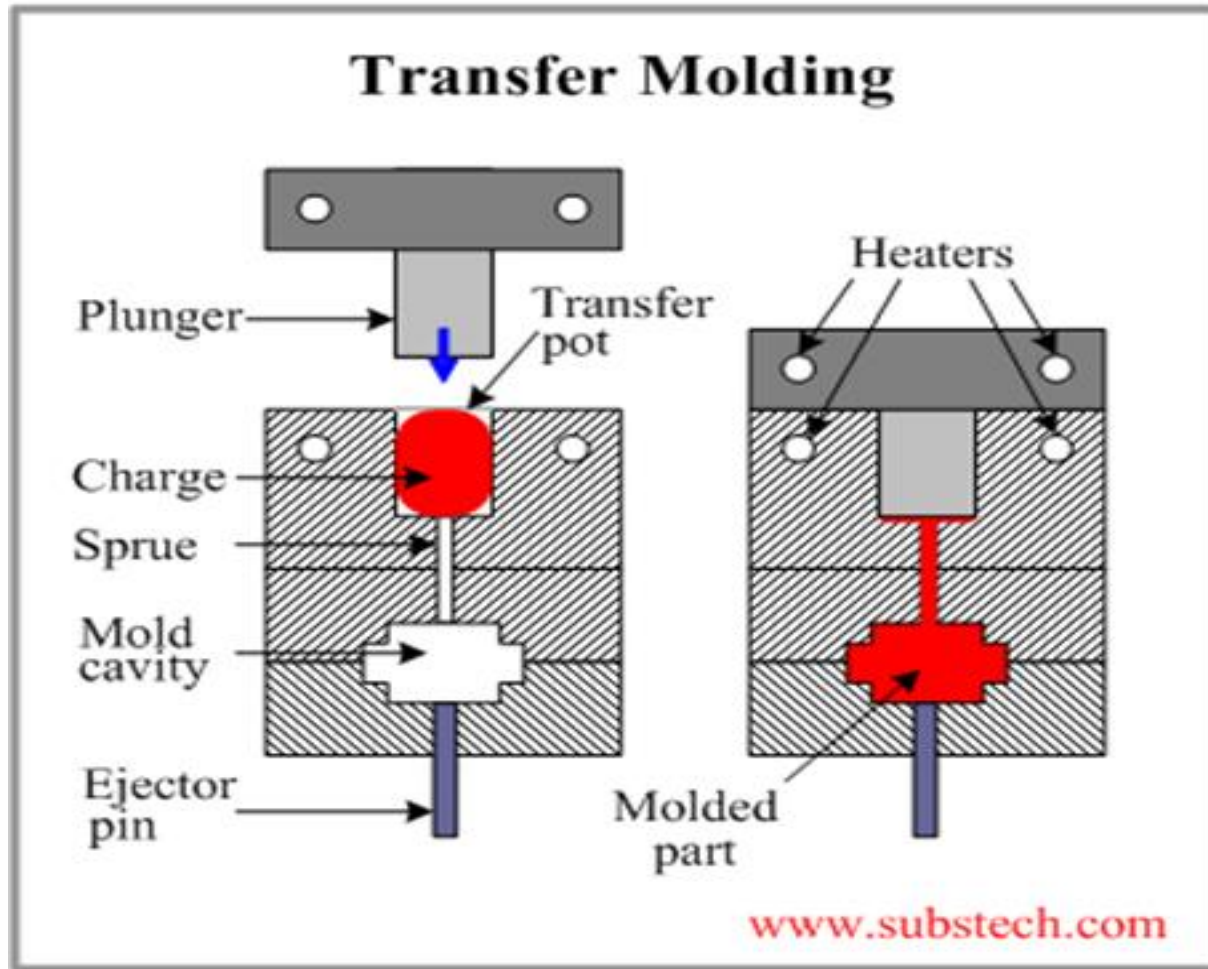
Transfer Molding

- The method combines features of both Compression Molding (hydraulic pressing of molding materials - thermosets) and Injection Molding (ram-plunger and filling the mold through a sprue).
- The method is used especially for molding thermosetting resins (thermosets)
- Products with relatively intricate designs could be fabricated with this method
- Powdered raw materials are heated at certain low temperature to soften and then introduced through an orifice or sprue in the mould
- Then it is cured in the mould at high temperature for certain time
- Finally the moulded article is removed by separation of mould

Advantages:

- Articles with intricate shapes could be designed
- Aerospace and automobile parts, car body, helmets
- The articles produced are blister free
- Fine wires and glass fibers can be inserted in the mould
- Even thick pieces can be cured completely and uniformly

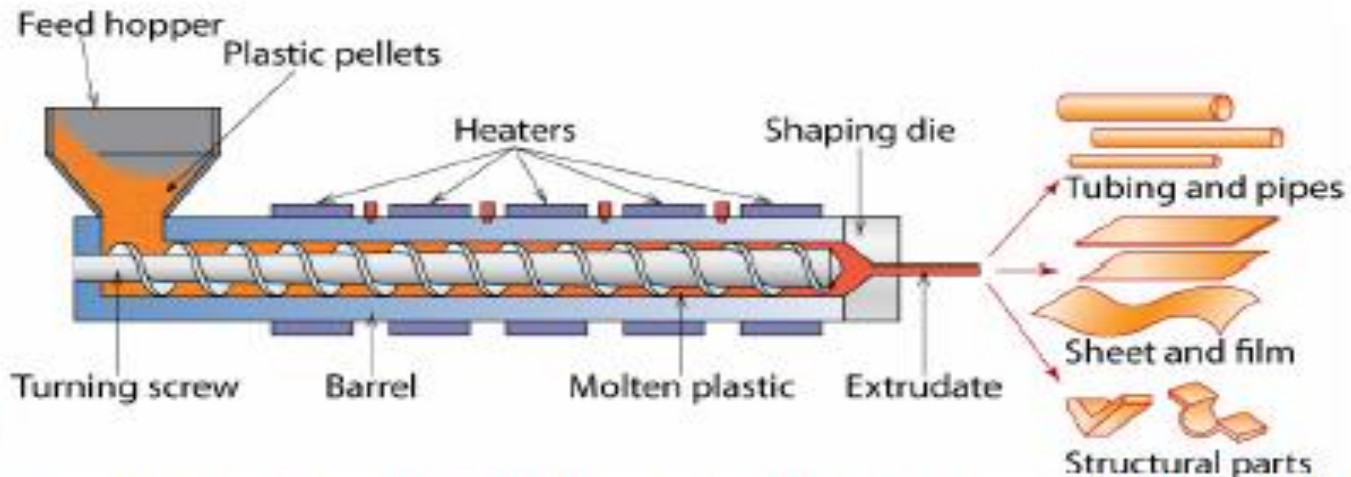
Transfer Molding



Extrusion Molding (Horizontal)

- The method is used for the manufacturing of continuous type of thermoplastic articles with constant cross-section. **Eg. Tubes, rods, strips, insulated electric cables**
- Dry powder or granules of thermoplastic materials are introduced through hopper and further melted by heating.
- There are two types of extrusion moulding:
 1. Vertical extruder moulding
 2. Horizontal extruder moulding
- Molten mass is pushed through the orifice of the die by using screw
- Once the article leaves the orifice, it is allowed to pass through water for solidification
- Proper temperature control of heating chamber and the speed of the screw are the major factors behind successful operation

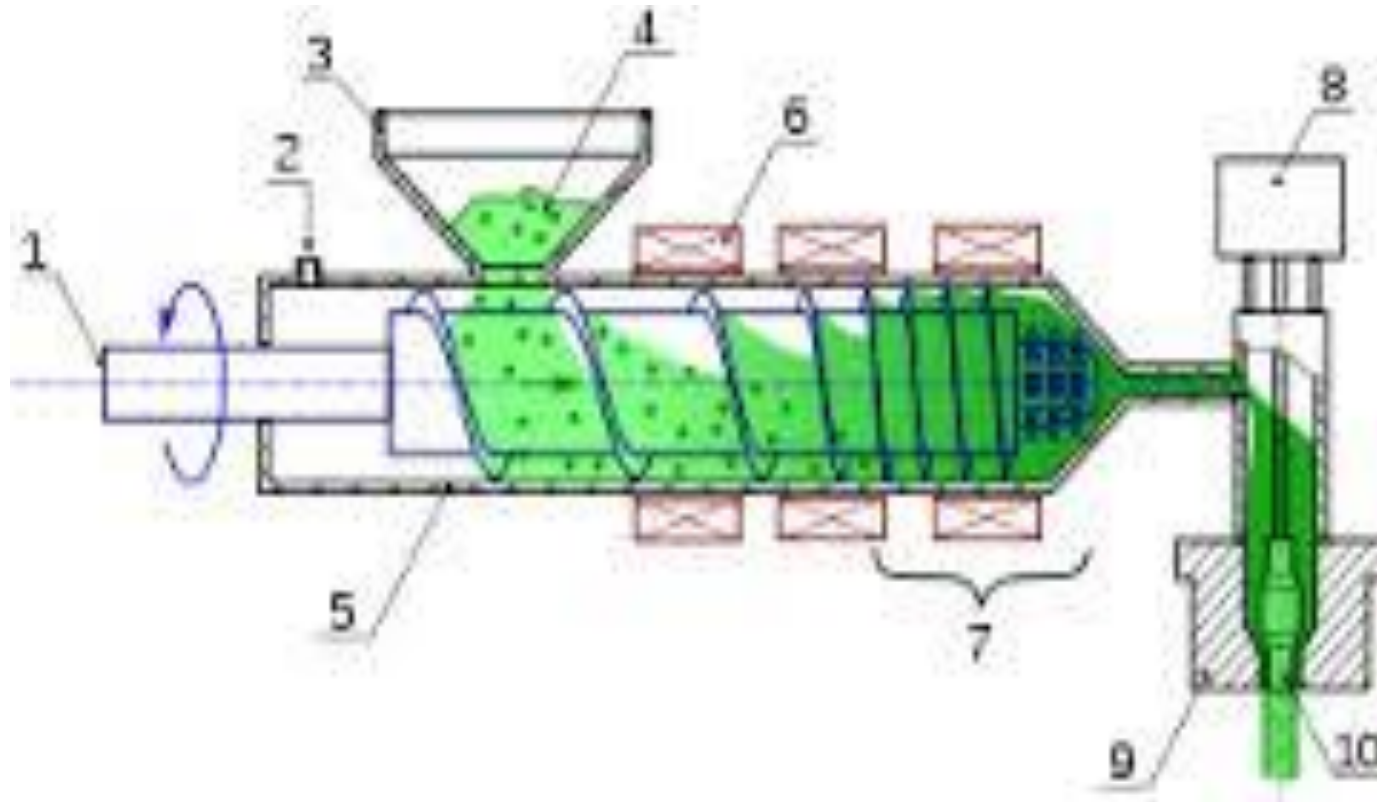
Extrusion Molding (Horizontal)



Extrusion

- ❑ This process makes parts of constant cross section like pipes and rods. liquid polymer goes through a die to produce a final shape. It involves four steps:
 1. Pellets of the polymer are mixed with colouring and additives.
 2. The material is heated to its proper plasticity.
 3. The material is forced through a die.
 4. The material is cooled.
- ❑ An extruder has a hopper to feed the polymer and additives, a barrel with a continuous feed screw, a heating element, and a die holder. An adapter at the end of an extruder blowing air through an orifice into the hot polymer extruded through a ring die produces plastic bags and films.

Extrusion Molding (Vertical)



Synthesis and Applications of Commercially important Polymers

[Preparation, Properties and Uses]

Some Important Polymers

1. **Poly Vinyl Acetate (PVAc)**
2. **Poly Methyl Methacrylate (PMMA)**
3. **Poly-Paraphenylene Terephthalamide (KEVLAR)**
4. **Polylactic acid**
5. **PDMS**

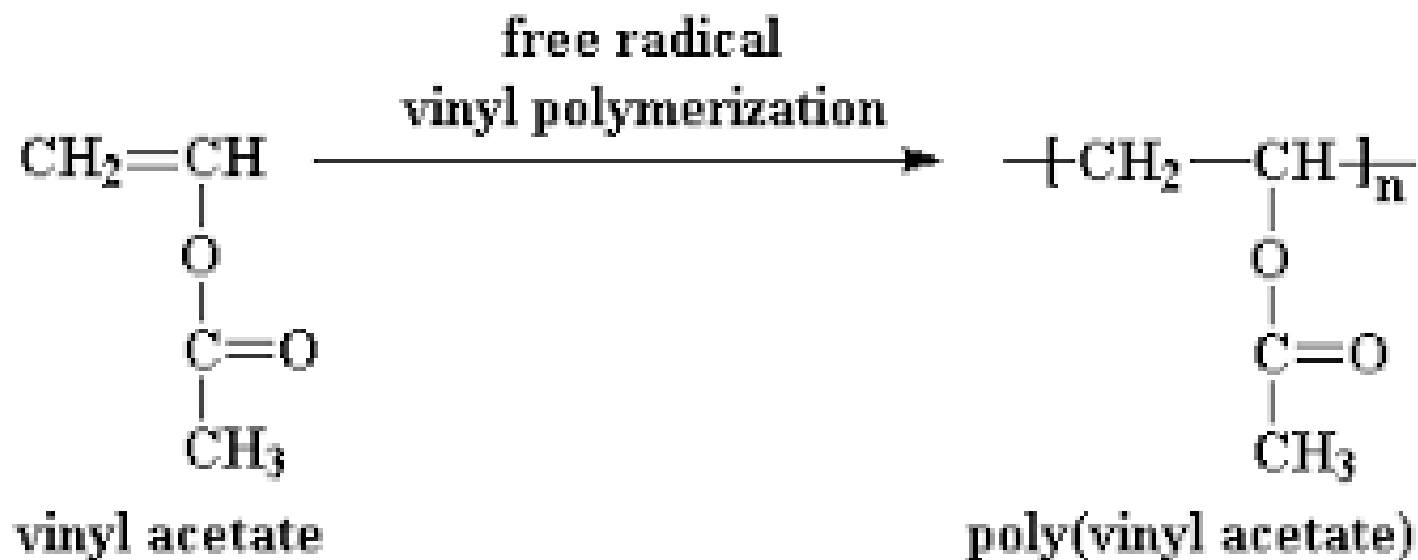
1. Poly Vinyl Acetate (PVAc)

- Polyvinyl acetate is a polymer produced through the combination of several units of monomeric vinyl acetate ($\text{CH}_3\text{COOCH}=\text{CH}_2$).
- The number of units so combined is typically between 100 and 5,000.
- This translates to an average molecular weight between 850 and 40,000.

1. Poly Vinyl Acetate (PVAc)

Preparation:

Vinyl acetate Monomer is prepared by reacting acetylene with anhydrous acetic acid in the presence of a mercurous sulfate catalyst; poly vinyl acetate is prepared by free radical vinyl polymerization as follows:



1. Poly Vinyl Acetate (PVAc)

Properties:

- Polyvinyl acetate is an amorphous polymer
- The hardest of the polyvinyl esters, polyvinyl acetate offers good adhesion to most surfaces.
- Unlike some other thermoplastics, it will not turn yellow.
- Polyvinyl acetate does not cross-link, and it can be dissolved in many solvents other than water.
- One slow-drying formulation combines 5 to 15 percent polyvinyl acetate with ethyl alcohol (ethanol).
- A fast-drying counterpart combines the same amount of polyvinyl acetate with acetone (dimethyl ketone).

1. Poly Vinyl Acetate (PVAc)

USES:

- Emulsified polyvinyl acetate is used in water-based adhesives, including pastes and glues.
- One of the uses for emulsified polyvinyl acetate is in bookbinding, depending upon the necessary lifetime of the book, the polyvinyl acetate chosen will either be co-polymeric or homo-polymeric.
- Polyvinyl acetate offers acceptable gap-filling capability.
- It may be used as a resinous component of latex paints, offering compatibility with a wide-range of other paint chemicals.
- Polyvinyl acetate may be used in the lamination of metal foils.
- Non-emulsified, or waterless, polyvinyl acetate is useful as a thermosetting adhesive.

2. Poly Methyl Methacrylate (PMMA)

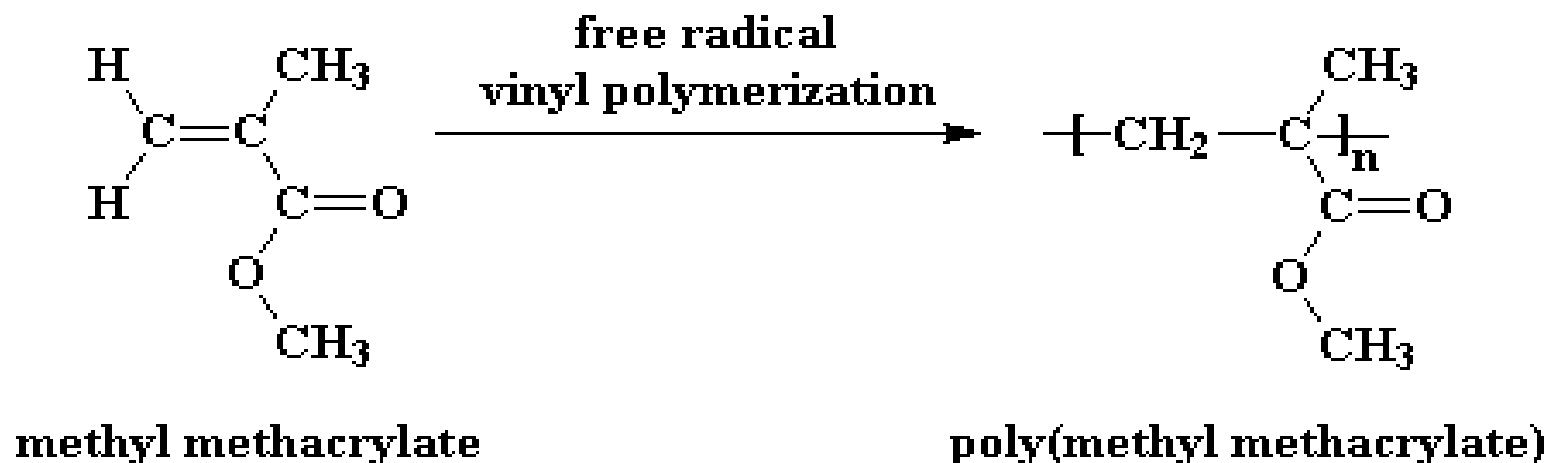
- Poly-(methyl methacrylate) (PMMA), also known as acrylic or acrylic glass as well as by the trade names Crylux, Plexiglas, Acrylite, Lucite, and Perspex
- It is a transparent thermoplastic often used in sheet form as a light-weight or shatter-resistant alternative to glass.
- The same material can be used as a casting resin, in inks and coatings, and has many other uses.

2. Poly Methyl Methacrylate (PMMA)

Preparation:

PMMA is routinely produced by emulsion polymerization, solution polymerization, and bulk polymerization.

It is generally prepared by radical initiation method.



2. Poly Methyl Methacrylate (PMMA)

Properties:

- PMMA is a strong, tough, and lightweight material.
- It has a density of 1.17–1.20 g/cm³, which is less than half that of glass.
- It also has good impact strength, higher than both glass and polystyrene. [PMMA's impact strength is still significantly lower than polycarbonate]
- PMMA transmits up to 92% of visible light (3 mm thickness), and gives a reflection of about 4% from each of its surfaces due to its refractive index (1.4905 at 589.3 nm).
- It filters ultraviolet (UV) light at wavelengths below 300 nm.
- PMMA swells and dissolves in many organic solvents; it also has poor resistance to many other chemicals due to its easily hydrolyzed ester

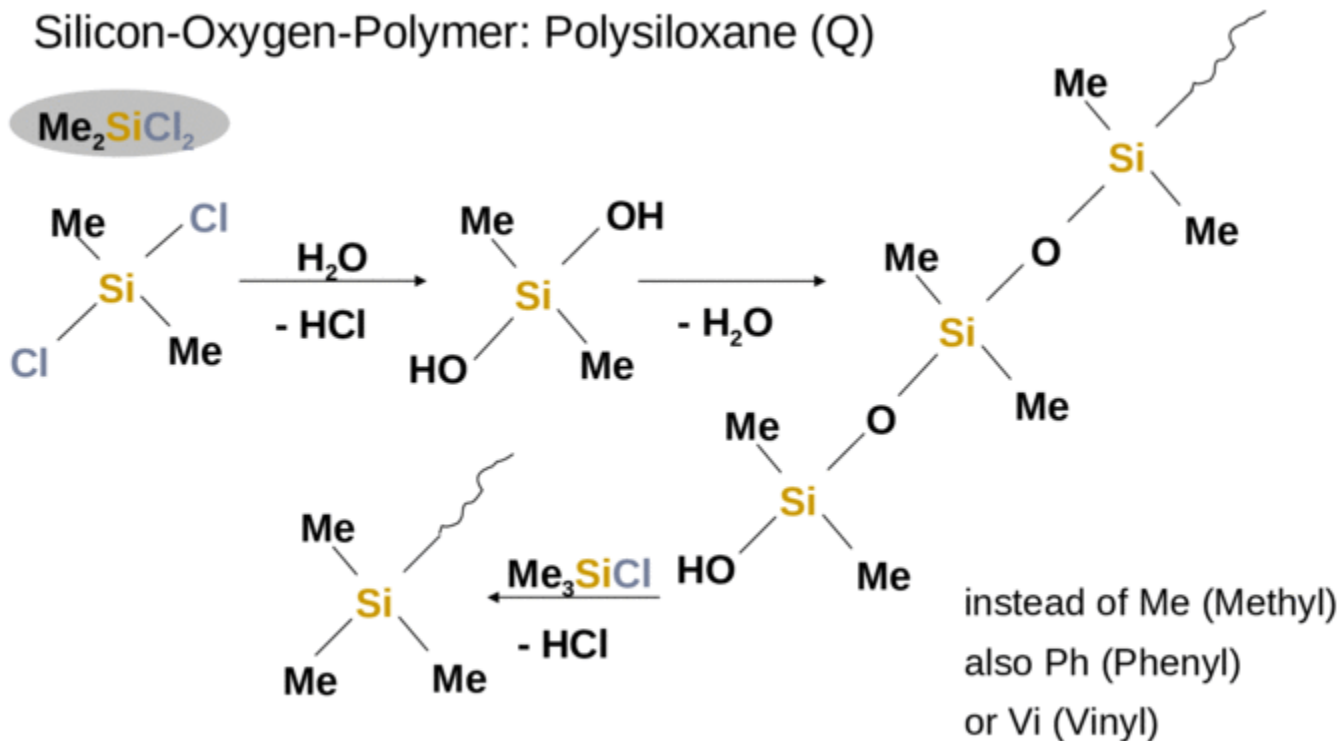
2. Poly Methyl Methacrylate (PMMA)

Uses:

- Being transparent and durable, PMMA is a versatile material and has been used in a wide range of fields and applications such as rear-lights, appliances, and lenses for glasses.
- PMMA is used for building windows, skylights, signs & displays, sanitary ware (bathtubs), LCD screens, furniture and many other applications.
- It is also used for coating polymers based on MMA provides outstanding stability against environmental conditions with reduced emission of VOC.
- Methacrylate polymers are used extensively in medical and dental applications where purity and stability are critical to performance.

3-PDMS

Silicon-Oxygen-Polymer: Polysiloxane (Q)



Properties-

- Good chemical resistance, low water absorption, good electrical properties, & available in flame retardant grade
- Service temperature to about 260 °C to -50 °C
- High molecular weight but not a solid, Ability to spread out on a wide variety of substrates
- Silky, non-tacky, film forming
- Lowest surface shear viscosity and low surface tension
- Lubricating, antifoaming, waterproofing, release properties
- High gas permeability, Excellent dielectric properties
- Very good thermo-oxidative stability, Good chemical inertness and temperature resistance

Uses-

- In the plumbing and automotive fields, silicone grease is often used as a lubricant. In plumbing, the grease is typically applied to O-rings in faucets and valves.
- In the automotive field, silicone grease is typically used as a lubricant for brake components since it is stable at high temperatures, is not water-soluble
- Biomedical applications, electronics applications, adhesives
- 3D-Printing applications, medicines, cosmetics, hair conditioners, contact lenses, mold release agent

4. Poly-Paraphenylene Terephthalamide (KEVLAR)

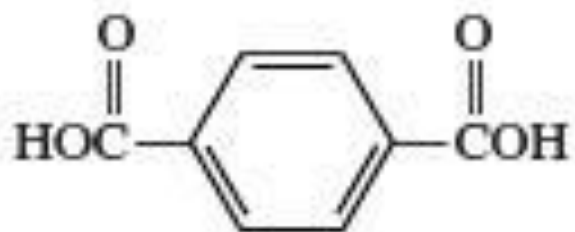
Poly-Paraphenylene Terephthalamide (KEVLAR):

Poly-paraphenylene terephthalamide (Kevlar) is a heat-resistant and strong synthetic fiber,

Preparation:

Kevlar is synthesized in solution from the monomers 1,4-phenylenediamine (*para*-phenylenediamine) and terephthaloyl chloride in a condensation reaction yielding hydrochloric acid as a byproduct.

4. Poly-Paraphenylene Terephthalamide (KEVLAR)



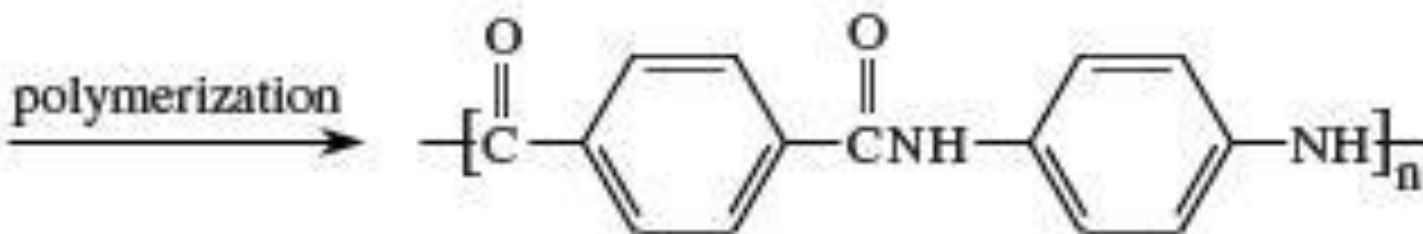
1,4-benzenedicarboxylic acid
(terephthalic acid)

+



1,4-benzenediamine
(*p*-phenylenediamine)

polymerization



Kevlar

4. Poly-Paraphenylene Terephthalamide (KEVLAR)

Properties:

- When Kevlar is spun, the resulting fiber has a tensile strength of about 3,620 MPa, and a relative density of 1.44.
- Kevlar maintains its strength and resilience down to cryogenic temperatures (-196 °C); in fact, it is slightly stronger at low temperatures.
- Kevlar's structure consists of relatively rigid molecules which makes them exceptionally strong
- They are high tensile strength-to-weight ratio; by this measure it is 5 times stronger than steel.



4. Poly-Paraphenylene Terephthalamide (KEVLAR)

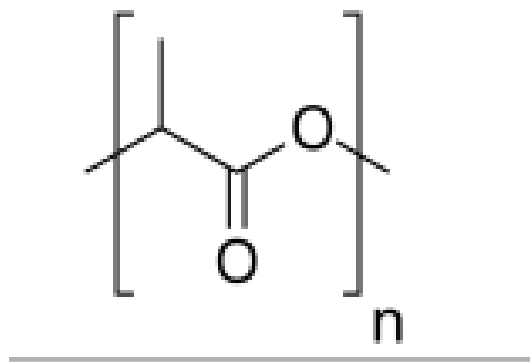
Uses:

- Kevlar has many applications, ranging from bicycle tires and racing sails to bulletproof vests,
- It is also used to make modern marching drumheads that withstand high impact.
- Kevlar is a well-known component of personal armor such as combat helmets, ballistic face masks, and ballistic vests.
- It is used for motorcycle safety clothing, especially in the areas featuring padding such as shoulders and elbows.
- Kevlar is often used in the field of cryogenics for its low thermal conductivity and high strength relative to other materials for suspension purposes.

POLYLACTIC ACID [PLA]

Polylactic acid, also known as poly(lactic acid) or polylactide (abbreviation PLA) is a thermoplastic polyester with backbone formula $(C_3H_4O_2)_n$ obtained by condensation of lactic acid $C(CH_3)(OH)HCOOH$ with loss of water (hence its name).

It can also be prepared by ring-opening polymerization of lactide $[-C(CH_3)HC(=O)O-]_2$, the cyclic dimer of the basic repeating unit.



The monomer is typically made from fermented plant starch such as from corn, cassava, sugarcane or sugar beet pulp.

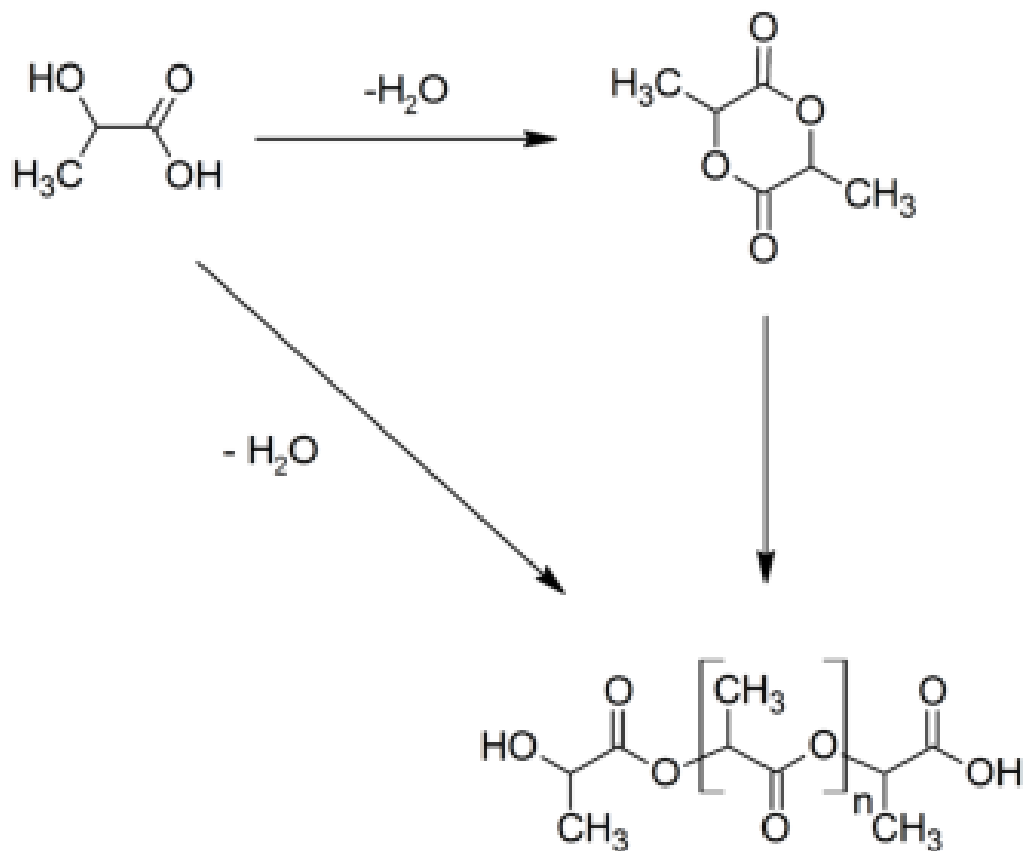
Several industrial routes afford usable (i.e. high molecular weight) PLA. Two main monomers are used: lactic acid, and the cyclic di-ester, lactide.

The most common route to PLA is the ring-opening polymerization of lactide with various metal catalysts (typically tin octoate) in solution or as a suspension.

The metal-catalyzed reaction tends to cause racemization of the PLA, reducing its stereoregularity compared to the starting material (usually corn starch).

The direct condensation of lactic acid monomers can also be used to produce PLA. This process needs to be carried out at less than 200 °C; above that temperature, the entropically favored lactide monomer is generated. This reaction generates one equivalent of water for every condensation (esterification) step.

The condensation reaction is reversible and subject to equilibrium, so removal of water is required to generate high molecular weight species. Water removal by application of a vacuum or by azeotropic distillation is required to drive the reaction toward polycondensation.



Properties

- PLA polymers range from amorphous glassy polymer to semi-crystalline and highly crystalline polymer with a glass transition 60–65 °C, a melting temperature 130–180 °C, and a Young's modulus 2.7–16 GPa. Heat-resistant PLA can withstand temperatures of 110 °C.
- The melting temperature of PLLA can be increased by 40–50 °C and its heat deflection temperature can be increased from approximately 60 °C to up to 190 °C by physically blending the polymer with PDLA (poly-D-lactide).
- The temperature stability is maximized when a 1:1 blend is used, but even at lower concentrations of 3–10% of PDLA, there is still a substantial improvement.
- In the latter case, PDLA acts as a nucleating agent, thereby increasing the crystallization rate[citation needed]. Biodegradation of PDLA is slower than for PLA due to the higher crystallinity of PDLA.
- The flexural modulus of PLA is higher than polystyrene and PLA has good heat sealability.
- Racemic PLA and pure PLLA have low glass transition temperatures, making them undesirable because of low strength and melting point. A stereocomplex of PDLA and PLLA has a higher glass transition temperature, lending it more mechanical strength

Applications

- PLA is used in a large variety of consumer products such as disposable tableware, cutlery, housings for kitchen appliances and electronics such as laptops and handheld devices, and microwavable trays.
- It is used for compost bags, food packaging and loose-fill packaging material that is cast, injection molded, or spun.
- In the form of a film, it shrinks upon heating, allowing it to be used in shrink tunnels. In the form of fibers, it is used for monofilament fishing line and netting. In the form of nonwoven fabrics, it is used for upholstery, disposable garments, awnings, feminine hygiene products, and diapers.
- PLA has applications in engineering plastics, where the stereocomplex is blended with a rubberlike polymer such as ABS. Such blends have good form stability and visual transparency, making them useful in low-end packaging applications.
- PLA is used for automotive parts such as floor mats, panels, and covers. Its heat resistance and durability are inferior to the widely used polypropylene (PP), but its properties are improved by means such as capping of the end groups to reduce hydrolysis.
- In the form of fibers, PLA is used for monofilament fishing line and netting for vegetation and weed prevention. It is used for sandbags, planting pots, binding tape and ropes .
- PLA can degrade into innocuous lactic acid, so it is used as medical implants in the form of anchors, screws, plates, pins, rods, and mesh.
- Depending on the exact type used, it breaks down inside the body within 6 months to 2 years. This gradual degradation is desirable for a support structure, because it gradually transfers the load to the body (e.g. to the bone) as that area heals.

Conducting Polymers

- Generally polymers are insulators because of the absence of free electrons.
- But they can be made conductive in certain cases by the process called doping.
- Two conditions for the polymer to become conducting are:
 1. Polymers should possess conjugated double bonds
 2. Polymer structure has to be disturbed either by adding or removing electrons by the process of doping.
- There are 3 major classes of conducting polymers
 1. Intrinsically conducting polymers
 2. Doped conducting polymers
 3. Extrinsically conducting polymers

1. Intrinsically conducting polymers

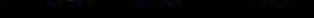
This belong to a class of organic materials consist of Conjugated pi-electrons in the backbone of their macromolecules which is responsible for high electrical conductivity.

In an electric field, conjugated pi-electrons of the polymer gets excited and can be transported through the solid polymer.

Overlapping of orbitals of conjugated pi-electrons over the entire backbone of the polymer results in the formation of valence bands and conduction bands. This induces conductivity in the presence of electric field.

For example:

Poly-acetylene, poly-aniline, poly-pyrrole and poly-thiophene etc.



- Due to their high electrical properties, ICPs are intensively investigated for application in electronics, microelectronics, optoelectronics mainly for areas in aerospace and automobile industries.
- Among the most promising applications of the ICPs are corrosion protection, solid-state charge storage devices, electromagnetic screens, antistatic coatings and gas separation coatings.
- However, poor mechanical properties, environmental sensitivity, moderate stability of electrical properties with temperature significantly limit the industrial applicability of ICPs.

2. (DCP) Doped conducting polymer

While the addition of a donor or an acceptor molecule to the polymer is called "**doping**", the reaction that takes place is actually a redox reaction. The first step is the formation of a cation (or anion), which is called a soliton or a polaron.

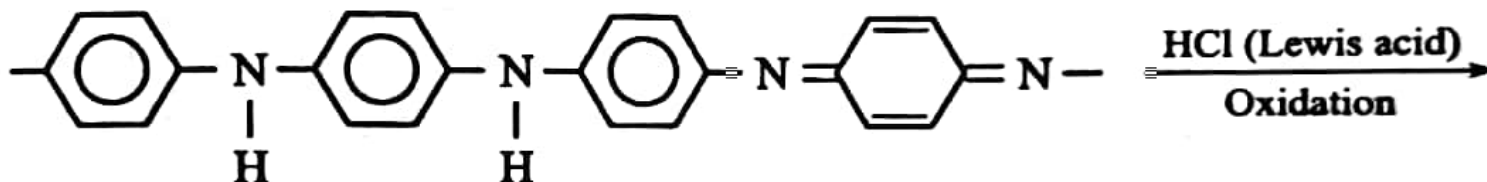
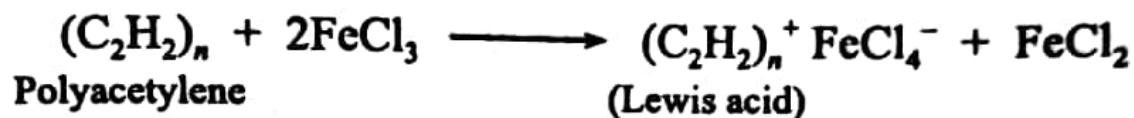


As synthesized conductive polymers exhibit very low conductivities. It is not until an electron is removed from the valence band (**p-doping**) or added to the conduction band (**n-doping**, which is far less common) does a conducting polymer become highly conductive.

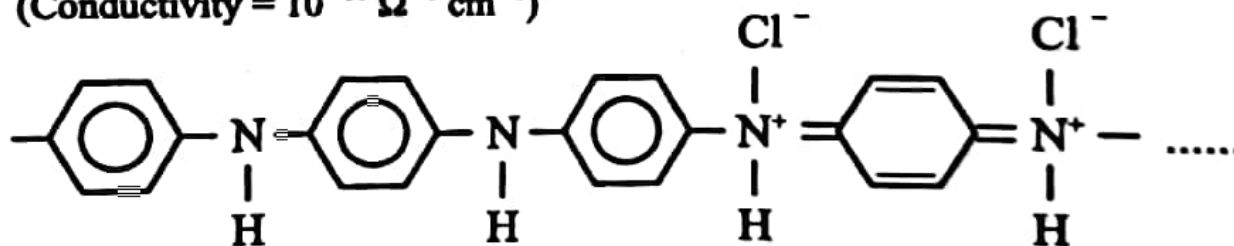
Doping (p or n) generates charge carriers which move in an electric field. Positive charges (holes) and negative charges (electrons) move to opposite electrodes. This movement of charge is what is actually responsible for electrical conductivity.

(DCP) Doped conducting polymer

- This is obtained by exposing a polymer to a charge transfer agent in a gas phase or in solution.
 - Conductivity of ICPs can be increased by creating positive or negative charges on the polymer backbone by oxidation or reduction by the process of doping.
1. **p-doping** involves treating intrinsically conducting polymer with a Lewis acid thereby oxidation takes place and positive charges on the polymer backbone are created. Some common P-dopants are I_2 , Br_2 , AsF_5 , PF_6 etc.

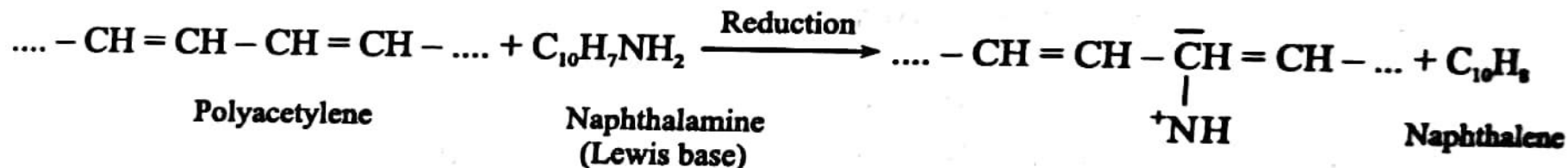
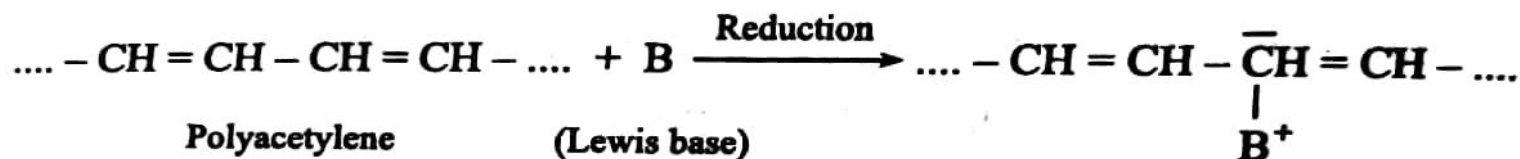


Emeraldine base (a polyaniline)
(Conductivity = $10^{-10} \Omega^{-1} \text{ cm}^{-1}$)



Emeraldine hydrochloride (a salt known as *synthetic metal*)
(Conductivity = $10^3 \Omega^{-1} \text{ cm}^{-1}$)

2. n-doping involves treating intrinsically conducting polymer with a Lewis base thereby reduction takes place and negative charges on the polymer backbone are created. Some common N-dopants are Li, Na, Ca etc.



3. Extrinsically Conducting Polymer

This type of conducting polymers possesses conductivity due to the presence of externally mixed conducting elements or compounds. These are of the following two types:

1. **conductive element filled polymer:** Such polymers contains non-conducting polymers (behaving as binder) holds the conducting elements or compounds (behaving as conducting filler) such as carbon black, metals, metal oxides, etc. Such polymers possesses good bulk conductivity, low cost, light weight, mechanically tough and easily processable.
2. **Blended conducting polymer:** such polymers are obtained by blending conventional polymers with conducting polymers either through physical or chemical process.

Applications of conducting polymers

- In rechargeable light weight batteries
- In optical display devices
- In aircrafts and aerospace components
- In diodes and transistors
- In solar cells