CHAPTER

4

POLYMER PROCESSING

Polymer processing is the technique of fabricating the polymer into useful articles or shapes.

4.1. PLASTICS, ELASTOMERS AND FIBRES

Depending on their dominant property or use, polymeric materials can be classified into three categories. For example, those polymers which are capable of yielding fibres of high tensile strength and flexibility are grouped under the fibre forming polymers or synthetic fibres. Nylon 6,6 is a typical fibre-forming polymer. Those polymers which on pulling elongate to many times its length without breaking and return to their original shape on release of the stress are known as elastomers. This property is known as rubber-like elasticity and hence synthetic rubber is the important example of this class. Balloons, shoesoles, tyres, surgeon's gloves are examples of articles made of elastomers. All other synthetic polymers other than fibres and rubber are usually known as plastics and are widely used in mouldings, coatings and films. But it must be remembered that these are the main applications of a particular group of polymers and some polymers are used even in several different manners.

4.2. COMPOUNDING

Polymers in their pure form, as obtained from the manufacturing plants are called 'virgin' polymers. Most of the 'virgin' polymers are not suitable for processing straightaway. For example, virgin PVC can not be moulded without making it soft by the addition of a plasticiser. Similarly natural rubber requires a vulcanising agent to render it mouldable. Most polymers are protected from thermal, oxidative and photo degradation by adding suitable stabilisers. Sometimes, dyes and pigments are added to obtain articles of attractive colours.

Compounding is defined as the process of adding ingredients such as plasticisers, vulcanising agents, stabilisers, colouring matters into the 'virgin' polymeric substance.

Virgin resins of plastic materials such as polystyrene, polyethylene or PVC are usually available in powder form. Compounding ingredients in the form of fine powder or liquid are blended with fine powder of the 'virgin' polymer in mixers. Liquid polymers are compounded using stirrers.

Virgin resins of elastomers such as natural rubber, SBR etc are obtained in the form of crumbs physically compacted into thick slabs. These crumbs are milled down into pliable sheets and compounding ingredients are added to it.

Fibre-forming resins usually do not require compounding. Ingredients such as stabilisers, lubricants are straightaway mixed into the polymer melt prior to spinning.

4.3. PROCESSING TECHNIQUES

These are the techniques by which compounded polymer is converted into finished products. The important techniques are calendering, casting, moulding, thermoforming, foaming reinforcing and spinning.

4.4. CALENDERING

Calendering is a process used for the continuous manufacture of sheet or film. An outline of the calendering machine is given below. There is a set of metal rollers rotating in opposite directions. The gap between the rollers can be adjusted which controls the thickness of the sheet calendered out. Compounded

polymeric substance is, fed between the rollers which are maintained at an elevated temperature and the sheet coming out from the rollers is cooled by passing through cold rollers. The sheets are finally wounded up in rolls.

PVC, polyethylene, acrylonitrile-butadiene-styrene copolymers (ABS) and rubbers are among the main polymers which are usually calendered into sheets.

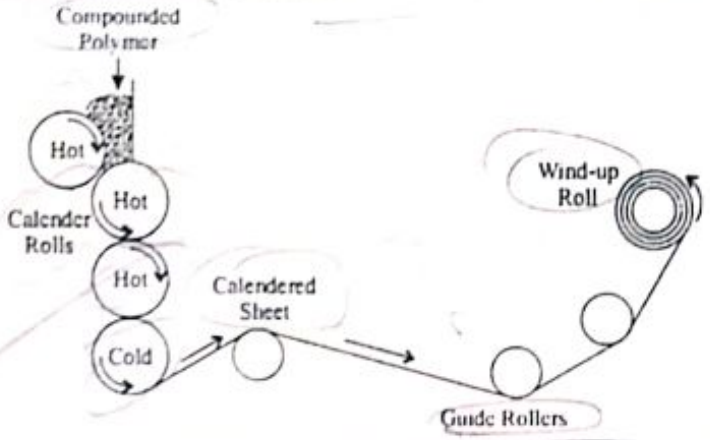

Fig. 1. Schematic diagram of a calendering machine

4.5. DIE CASTING

It is the process by which liquid prepolymer is converted into a solid object of a desired shape. A simple outline of the process is given in the figure. The compounded polymer is poured into a petridish. The dish is then kept in an oven at an elevated temperature for few hours. On cooling to room temperature, the solid product from the petridish is pulled out. The solid thus cast will have a shape identical to the interior of the petridish. Instead of a petridish, if a cylindrical glass tube closed at one end is used, we get the product in the form of a cylindrical rod. Polyesters, urethanes and epoxides etc, are suitable for die casting.

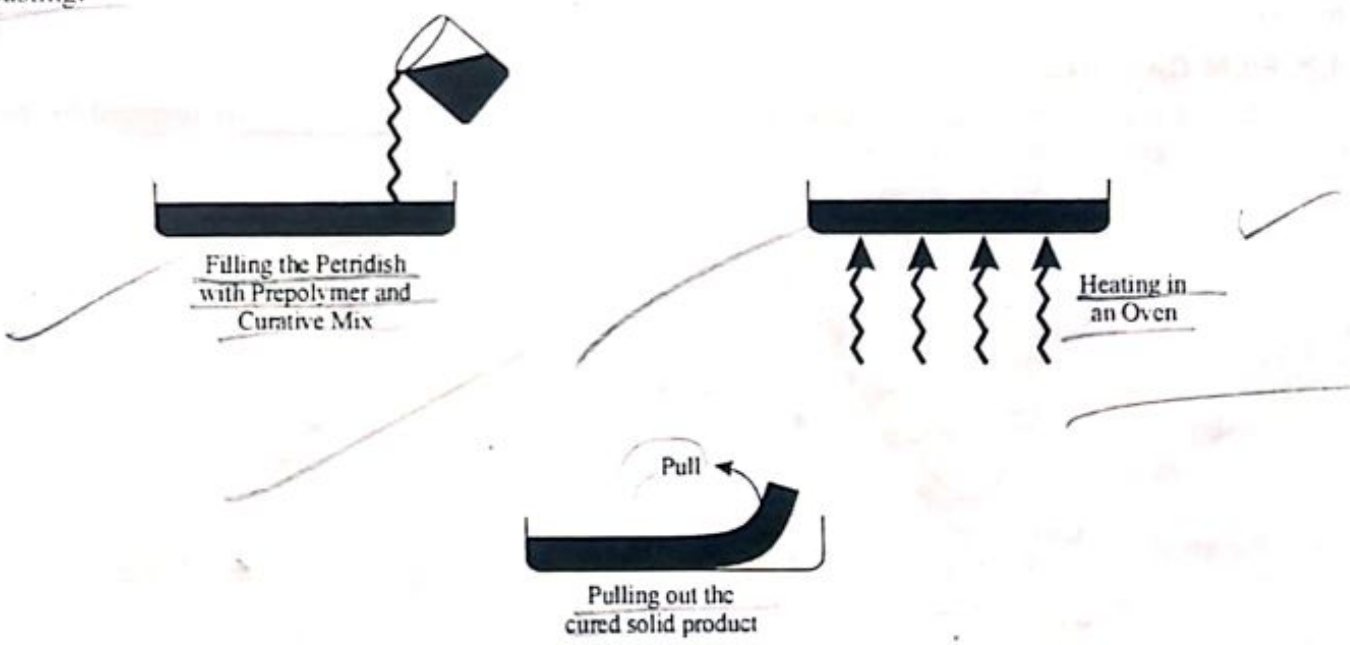

Fig. 2. Simple illustration demonstrating the casting process

4.6. ROTATIONAL CASTING

Hollow articles such as balls, dolls, rain boots etc, are prepared by a process called rotational casting. An outline of the apparatus used for this process is given below :

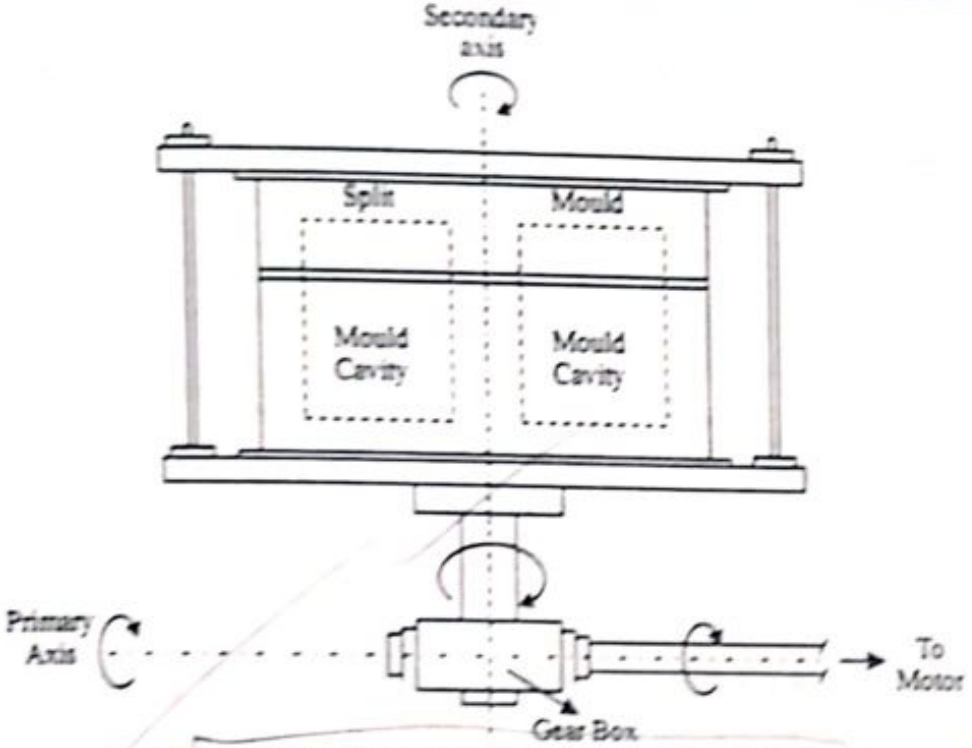

Fig. 3. Outline of the apparatus for rotational casting

The compounded thermoplastic material in the form of a fine-powder is taken in a hollow mould. The apparatus has provision for rotating the mould simultaneously along the primary and the secondary axes. After closing the mould, it is heated and rotated. The molten plastic is distributed uniformly along the entire surface of the inside cavity of the mould. The mould, still under rotation is then chilled with cold water. Thus the molten plastic cools down and solidifies. The mould is now opened and the product removed.

4.7 FILM CASTING

Most of the commercially available cellophane sheets and photographic films are prepared by this process. A diagram of the film-casting apparatus is shown below.

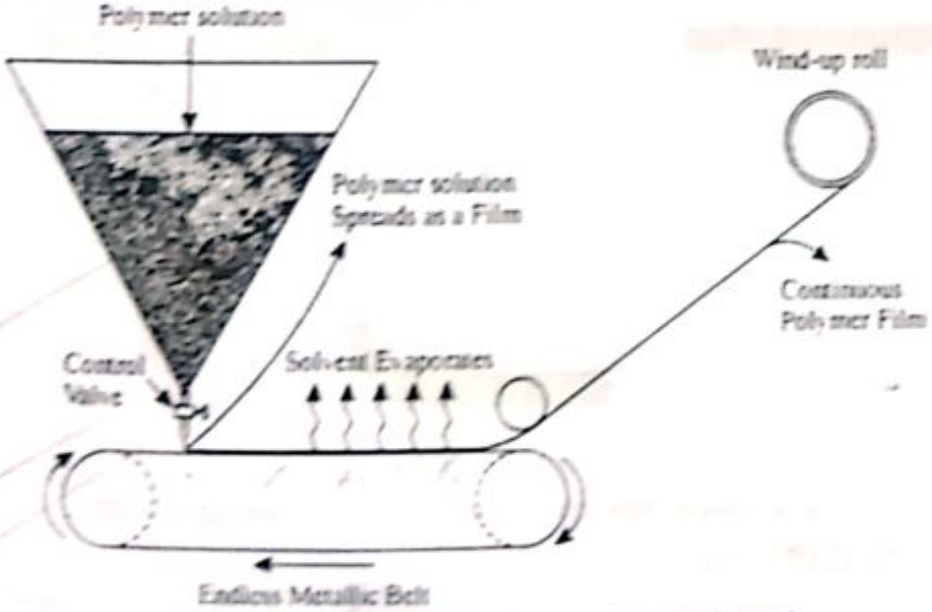

Fig. 4. Schematic diagram of a film-casting equipment

A solution of the polymer in a suitable solvent is allowed to fall on an endless metallic belt moving at a constant speed. A continuous sheet of the polymer solution is thus formed on the surface of the metallic belt. The solvent is now evaporated and at thin film of the polymer is formed on the surface of the belt.

4.8. MOULDING

Moulding processes are those in which a finely divided plastic is forced by the application of heat and pressure to flow into, fill, and conform to the shape of a cavity (mould). It is one of the oldest methods of polymer processing. Moulding can be carried out in many different ways.

Injection Moulding :

The injection-moulding process is useful for producing articles made of thermoplastic materials. A diagram of injection-moulding machine is given below :

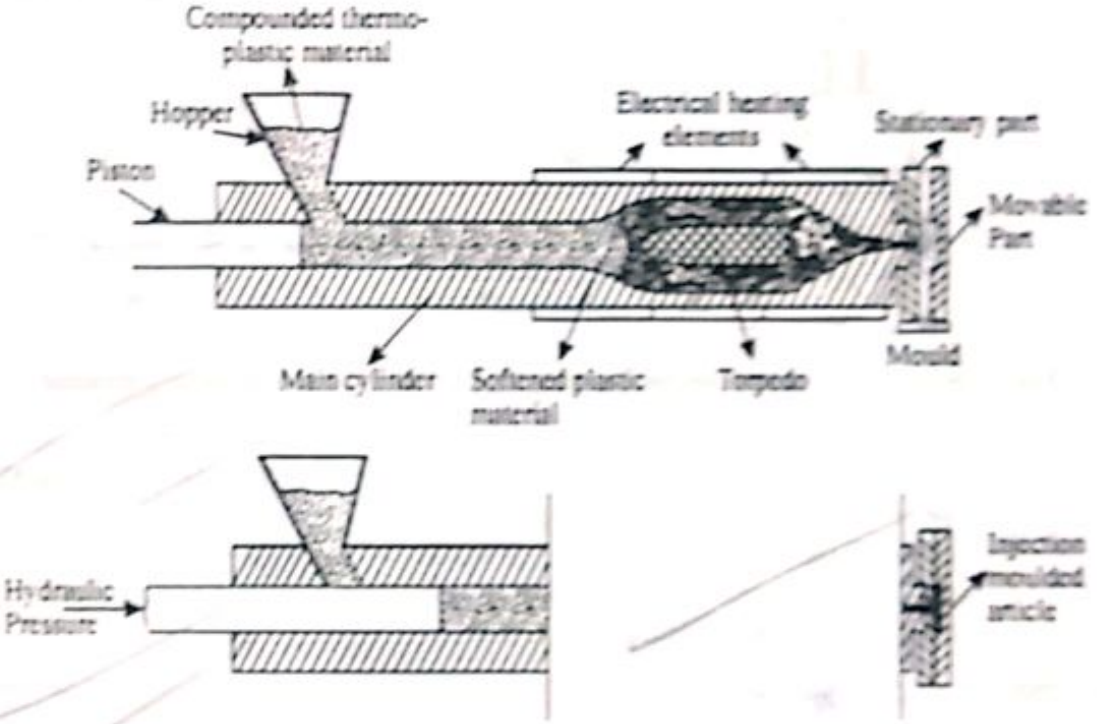

Fig. 5. Schematic diagram of an injection-moulding machine

The compounded plastic material is introduced through the hopper into the hot horizontal cylinder where it gets softened. Pressure is applied through a hydraulically driven piston to push the molten material through a cylinder into a mould fitted at the end of the cylinder. A device called 'torpedo' helps in spreading the plastic material uniformly around the inside wall of the hot cylinder. The molten plastic material from the cylinder is then injected through a nozzle into the mould cavity.

The mould used is a two-part system. One is a movable part and the other stationary. The stationary part is fixed at the end of the cylinder while the movable part can be opened or locked on to the the stationary part.

After the mould is filled with the molten material under pressure, then it is cooled by cold water circulation and then opened to get the moulded article.

Blow moulding :

Most of the hollow plastic articles like containers, soft drink bottles are prepared by this process. Thermoplastic materials such as polyethylene, PVC, polystyrene, nylon, polypropylene etc. can be blow moulded.

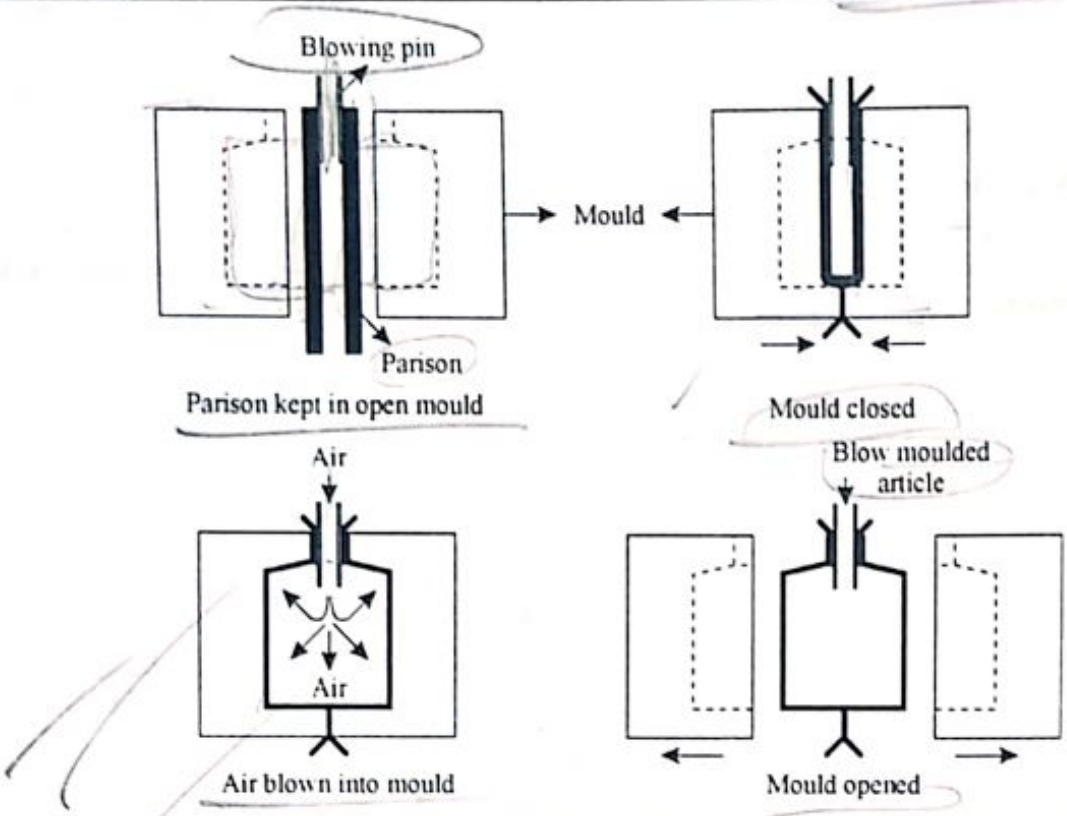

Fig. 6. Schematic diagram explaining the steps involved in low-moulding process

A hot, softened thermoplastic tube, usually called "parison" is properly placed inside a two piece hollow mould. The two halves of the mould are closed and the parison is blown by compressed air through the blowing pin, as shown in the figure. The hot parison is inflated like a balloon and goes on expanding until it comes in contact with the relatively cold interior surface of the hollow mould. Thus parison takes the shape of the hollow cavity of the mould. The mould is now allowed to cool and the rigid thermoplastic article formed is removed by opening the mould.

Extrusion moulding :-

Extrusion moulding is the process by which many common plastic products such as films, filaments, tubes, sheets, pipes, rods are produced. It is also used for coating wires and cables with PVC or rubber.

A diagram of the extrusion machine is given below :

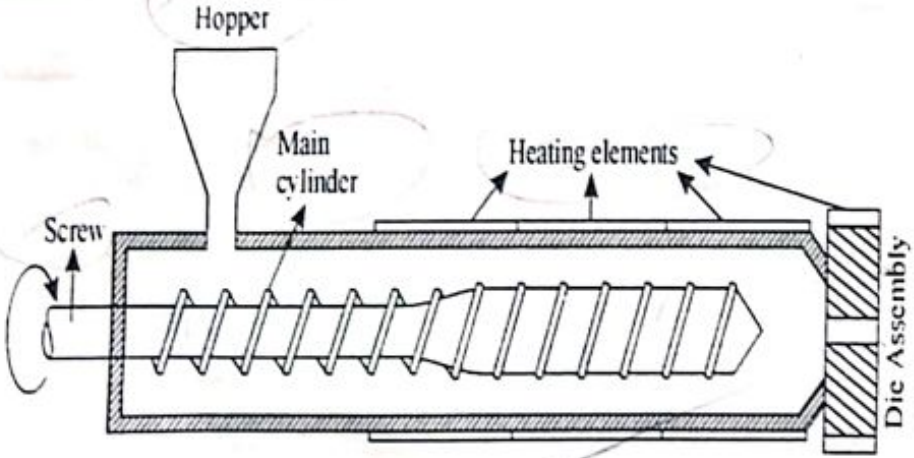

Fig. 7. Schematic diagram of a simple extrusion machine

The compounded plastic material is introduced through the hopper into a cylinder which is heated electrically to soften the material. The hot plastic material proceeds through the cylinder along with a helically revolving screw. The temperature of the plastic material further rises due to the frictional heat produced by the compression of the charge between the rotating screw and the cylinder surface. Due to the built up pressure, polymer melts and enter the die where it is cooled by cold air blast or cold water spray. The product formed is cut to the desired length or wound on to rolls.

4.9. THERMOFORMING

Thermoforming is a very useful process for fabricating three dimensional articles from plastic sheets. An outline of the process is given below :

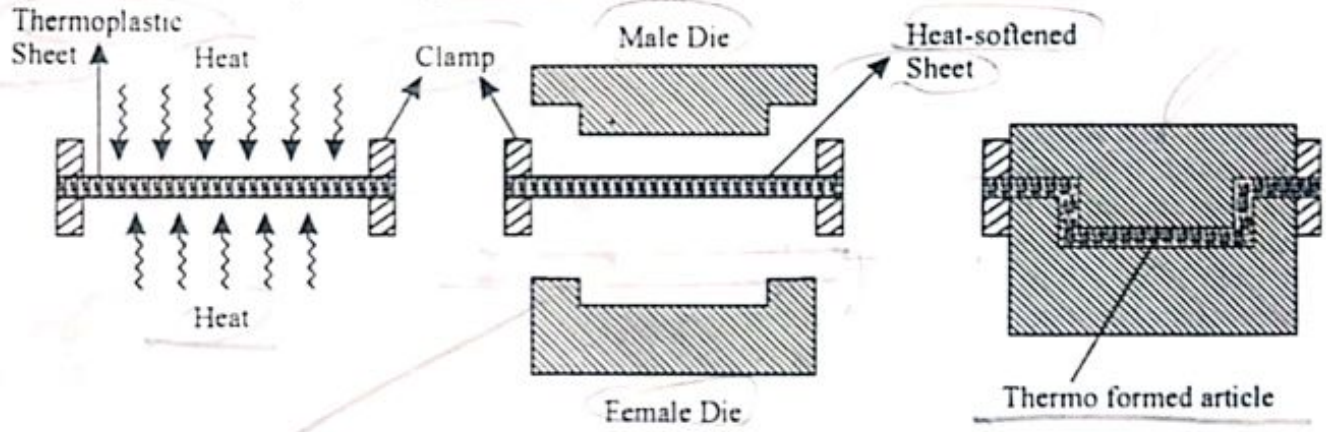

Fig. 8. Schematic diagram explaining thermoforming process

The thermoplastic sheet is heated to its softening temperature. The warm flexible sheet is then pressed into the female half of a matched metal die. When the male half is put over it, the sheet assumes the required shape of the mould. On coolings, it is removed from the mould.

4.10. FOAMING

Foaming is the process for producing spongy materials. The usual foamable polymers are polyurethanes, polystyrene, polyethylene, silicones etc. Foamed plastics are used mostly in automobile and furniture industry. Polystyrene rigid foams are widely used for packaging. For matresses and similar other applications, rubber and urethane foams are used.

There are different methods for producing foamed plastics. One method is to melt the compounded thermoplastic material and blow air or nitrogen in such a way that the whole matrix foams up. When the required degree of foaming is achieved the matrix is cooled and is allowed to solidify in the foamed-up condition. Usually foaming is done by the addition of a foaming agent or blowing agent. Such agents are solvents with a low boiling point like *n*-pentane or *n*-hexane which boil-off and liberate large volumes of vapours.

Carbondioxide gas produced by the reaction between the isocyanate and water can also be used for producing foams. For example, polyurethane foams :

$$R{-}N{=}C{=}O + HOH \longrightarrow R{-}\underset{\displaystyle H}{\overset{|}{N}}{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}OH \longrightarrow CO_2 + RNH_2$$

Polyurethane are produced by the reaction of a polyol with di-isocyanate and we have to only add some additional isocyanate and water to get the foam.

The large volumes of vapours or gases liberated by these blowing agents make the polymer matrix foam up. The polymer matrix in a foamed-up condition is cooled below the softening temperature so that the matrix as a whole in the foamed condition attains structural rigidity to maintain the foam structure.

4.11. REINFORCING

Reinforcing a plastic matrix with a high-strength fibre material gives us fibre-reinforced plastics (FRP). It has a high strength-to-weight ratio and excellent corrosion resistance. Due to these specific properties reinforced plastics are used in boat hulls and in storage tanks for storage acids.

The main reinforcing fibres which are generally used are those of glass, graphite, alumina and born. Aromatic polyamide fibres are also used which reduces weight by 50% as compared to others. The common resin matrix used in FRPs includes polyesters, epoxy, phenolic and silicone.

There are several methods for the preparation of reinforced plastics. Some are given below :

(1) The Hand Lay-up Technique : This is probably the simplest method for producing reinforced plastic. First, a thin coating of polyvinyl alcohol, silicone oil or wax is applied on the mould. It prevents the final fabricated article from sticking to the mould. The mould is then coated with a resin matrix. A precut glass cloth is then laid over the resin layer. Another layer of the resin coating is given over the glass cloth. Rollers are used to press the glass cloth on the resin uniformly. Alternate layers of resin and glass cloth are laid in a similar manner until the required thickness is obtained.

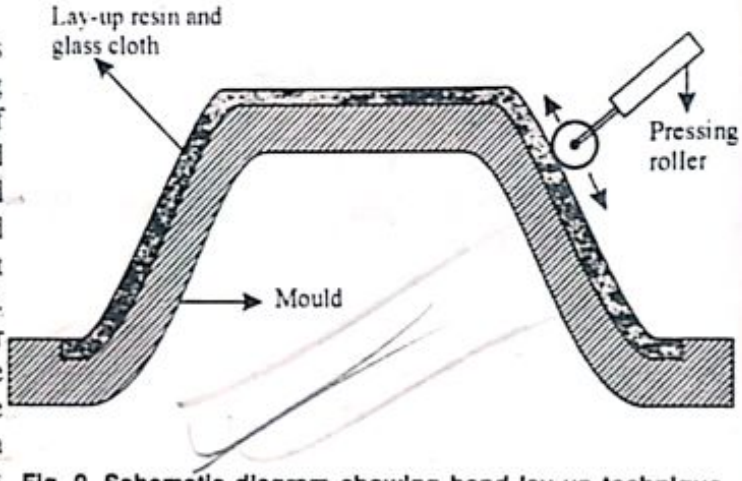

Fig. 9. Schematic diagram showing hand lay-up technique

Sheets, autobody parts, boat hulls are produced by this technique.

(2) Filament-winding Technique : This is very widely used method for producing reinforced plastic articles such as high-pressure cylinders, storage tanks. A simple diagram of the process is as follows :

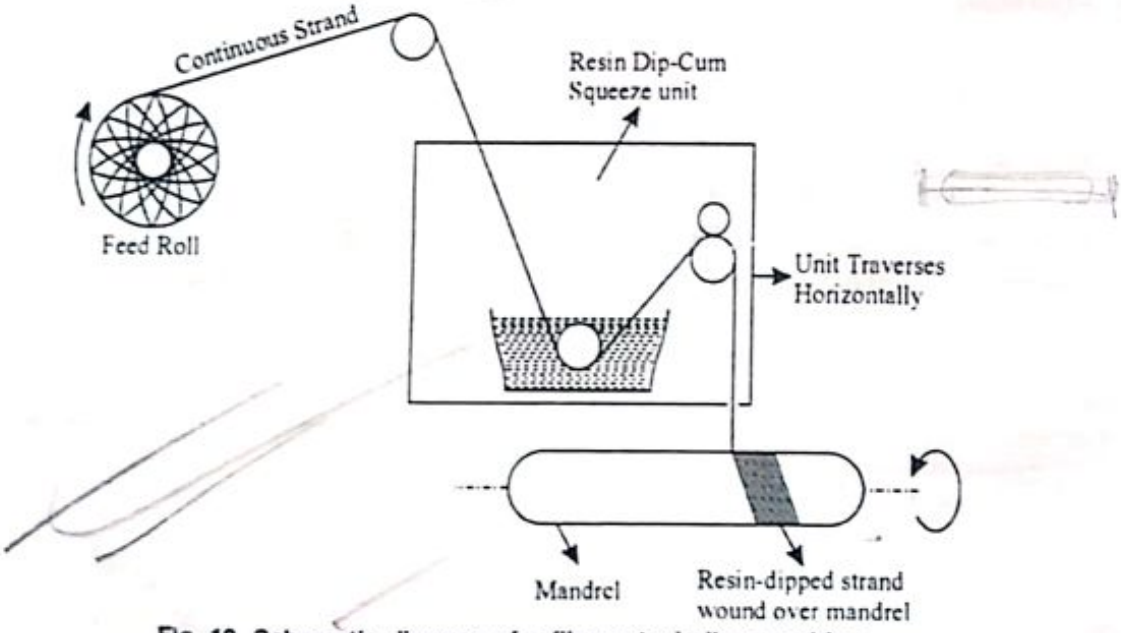

Fig. 10 Schematic diagram of a filament-winding machine

A continuous length of strand is passed through a bath of resin and curative. As the strand comes out of the bath, the excess resin is squeezed out. The resin-dipped strand is then wound over a mandrel of the required shape and then cured under the influence of heat.