

### 15.2.2 Elastomerics

Elastomerics are popularly known as 'rubbers'. Balloons, shoe soles, tyres, surgeons' gloves, garden hoses are examples of articles made of elastomerics. Natural rubber is the most classical example of an elastomeric. There are several synthetic elastomerics now in use. These include polybutadienes, styrene-butadiene (SBR) and acrylonitrile-butadiene (nitrile rubber) copolymers, polyisoprene, polychloroprene (neoprene), ethylene-propylene copolymer, isoprene isobutylene copolymer (butyl rubber), polyfluorocarbon, polyurethane and silicone rubbers.

### 15.2.3 Fibres

We are all familiar with fibres of natural origin such as cotton, wool, flax and silk. We are also familiar with man-made or synthetic fibres made of nylon, polyesters, polypropylene and acrylics. One general definition of a fibre is that its length is at least hundred times its diameter. While natural fibres (except silk) occur as staples, synthetic fibres can be produced as continuous filaments or cut to form staples.

From the consumer's point of view, fibres can be classified into three types, viz., comfort fibres, safety fibres and industrial fibres. Comfort fibres are those used for making undergarments and garments. Fibres used for making underwears, socks, shirtings, suitings, ladies garments, etc., come under this category. Comfort fibres should have adequate strength and extensibility, softness, good moisture regain, and preferably some flame retardancy, and should be capable of being dyed. Cotton, silk, wool, nylon, polyesters, acrylics are common examples of comfort fibres.

Safety fibres are those used for making carpets, curtains, seat covers, draperies and so on. Such fibres should be strong, tough, durable and abrasion-resistant. The most important feature is that they should be difficult to ignite, have as low a flame spread as possible, liberate minimum heat, smoke and toxic gases if involved in a fire. Comfort fibres can be rendered flame-retardant and made to behave as safety fibres by adding small quantities of substances containing atoms such as B, N, Si, P, Cl, Br or Sb. While these subs-



tances serve as flame-proofing agents and delay the ignition and flame spread, they cannot reduce smoke and toxic gases if these treated fibres get involved in a fire. Recent investigations have shown that aromatic polyamides, polyimides, polybenzimidazoles and polyoxy diazoles are useful as safety fibres. These fibres have, however, a tendency to evolve toxic gases on burning owing to the presence of nitrogen in their molecules. Fully aromatic polyesters do not suffer from this disadvantage.

Industrial fibres are used as reinforcing materials in composite structures. These fibres are also called structural fibres as they possess very high modulus, strength, thermal stability, toughness and durability. Structural fibres are used to reinforce articles such as rigid and flexible tubes, pipes and tyres and also in composite structures called fibre-reinforced plastics (FRP) used in the construction of boats, cars, planes and even buildings. Uniaxially oriented fibres of aromatic polyamides and polyesters, carbon fibres and silica fibres come under this category.

### 15.3 COMPOUNDING

Polymers in their pure form, as obtained from the manufacturing plants after isolation and purification, are called 'virgin' polymers or 'virgin' resins. Barring a few (such as polystyrene, polyethylene or polypropylene), virgin polymers, as such, may not be amenable for processing straightaway. Virgin PVC, for example, is a material of horny texture and cannot be moulded without making it soft by the addition of a plasticiser. Natural rubber similarly requires a vulcanising agent to render it mouldable. Most polymers are protected from thermal, oxidative and photo degradation by incorporating appropriate stabilisers. Many articles are obtained in attractive colours by adding suitable dyes and pigments to the polymeric material prior to its moulding. Lubricants and process aids are added to most of the polymers to reduce friction and improve flow within processing machineries. Fillers are added to impart special properties and reduce the finished product cost.

The process involving incorporation of ingredients such as plasticisers, vulcanising agents, curatives, stabilisers, fillers, colouring agents, flame retardants and lubricants into the virgin resin is known as 'compounding' of the resin.

Virgin resins of plastic materials such as polystyrene, polyethylene,



polymethyl methacrylate and PVC are usually available as free flowing fine powders. Compounding ingredients in the form of fine powder or liquids are blended with fine powder of the virgin resin using planetary mixers, V-blenders, ribbon-blenders, Z-mixers or tumblers. Blending can be done at ambient or elevated temperatures which should, however, normally be much below the softening temperature of the polymer. Liquid prepolymers are compounded using simple high-speed stirrers.

Virgin resins of elastomerics such as natural rubber, SBR and nitrile rubber are obtained in the form of crumbs physically compacted into thick slabs called 'bales'. They are generally compounded with vulcanising agents, accelerators, fillers, antioxidants and lubricants. Since elastomerics are not free flowing powders (like virgin plastic materials are), they cannot be blended with a compounding ingredient using devices that are employed for virgin plastics. This is understandable as compounding of virgin plastic resins with other ingredients requires only uniform mixing to be achieved, whereas compounding of virgin elastomeric resins involves milling down the crumbs into pliable sheets and then incorporating the compounding ingredients. Compounding of elastomerics is done either on a two-roll rubber mill or in a Banburry internal mixing mill. Elastomerics in the form of latex or low molecular weight liquid resins, however, can be compounded by simple mixing using a high-speed stirrer.

Fibre-forming resins usually do not require compounding. Ingredients such as lubricants, stabilisers and fillers are straightaway incorporated into the polymer melt or polymer solution just prior to spinning.

## 15.4 PROCESSING TECHNIQUES

The very fact that polymeric materials are used in many forms such as rods, tubes, sheets, foams, coatings or adhesives and also as moulded and fabricated articles implies that there must be a variety of ways in which the compounded resins can be processed and converted into finished products. A majority of the articles are either moulded or fabricated, while many others are made by casting liquid prepolymers into a mould and allowing them to cure or cross-link. Fibres are made by a process known as spinning.

The process of moulding can be compared to making, for instance,



a toy horse out of clay; the fabrication process can perhaps be compared to making the toy by carving it out of a soap cake. In the moulding process, the compounded material in the form of powder, chips or granules is placed in a mould of the required shape and subjected to heat and pressure, after which, the final product is obtained. Fabricated items are made of simple forms such as sheet, rod or tube, using processes such as cutting, shaping, gluing, bonding and welding.

About 50 years ago, there existed only a few processes for converting polymeric materials into finished products. Today, there are many processes and automatic machines for this purpose, the important ones being calendering, casting, compression moulding, injection moulding, extrusion moulding, blow moulding, cold forming, thermoforming, foaming, reinforcing, melt spinning, dry spinning and wet spinning. The last three techniques are used for making fibres from fibre-forming materials, while the rest are used for converting plastic and elastomeric materials into moulded and fabricated articles. In the forthcoming sections, we shall give an outline of these important processes. For a more detailed account of these and other processes such as dip coating, fluidised bed coating, heat sealing, electronic sealing and welding reference may be made to specialised textbooks on 'polymer processing'. Similarly, details regarding coatings and adhesives are also beyond the scope of this book.

Before taking up various processing techniques, let us recapitulate that polymeric materials can either be thermoplastic or thermosetting. Once thermoplastic materials are moulded or shaped under heat and pressure, they are required to be cooled much below their softening temperature before being released out of the mould as otherwise they may get deshaped. In the case of thermosetting materials, however, there is no need to cool the article before releasing it out of the mould, since once set under the influence of heat and pressure, the article does not change its shape even when handled hot.

#### 15.4.1 Calendering

The calendering process, in its simplest form, is employed to produce continuous films and sheets. The main part of a calendering machine (Fig. 15.1) is a set of highly polished metal rollers rotating in opposite directions with provision for precise adjustment of the



gap between them. The gap between the rollers determines the thickness of the sheet calendered out. Compounded polymeric material is fed between the rollers which are maintained at an elevated temperature, and the sheet emerging from the rollers is cooled by passing through cold rollers. The sheets are finally wound up in rolls as shown in Fig. 15.1. If, however, thin films are required instead of sheets, a series of rollers with a successively diminishing gap between them is employed. Polyvinyl chloride, polyethylene, acrylonitrile-butadiene-styrene copolymer (ABS) and rubbers are among the main polymers which are usually calendered into sheets.

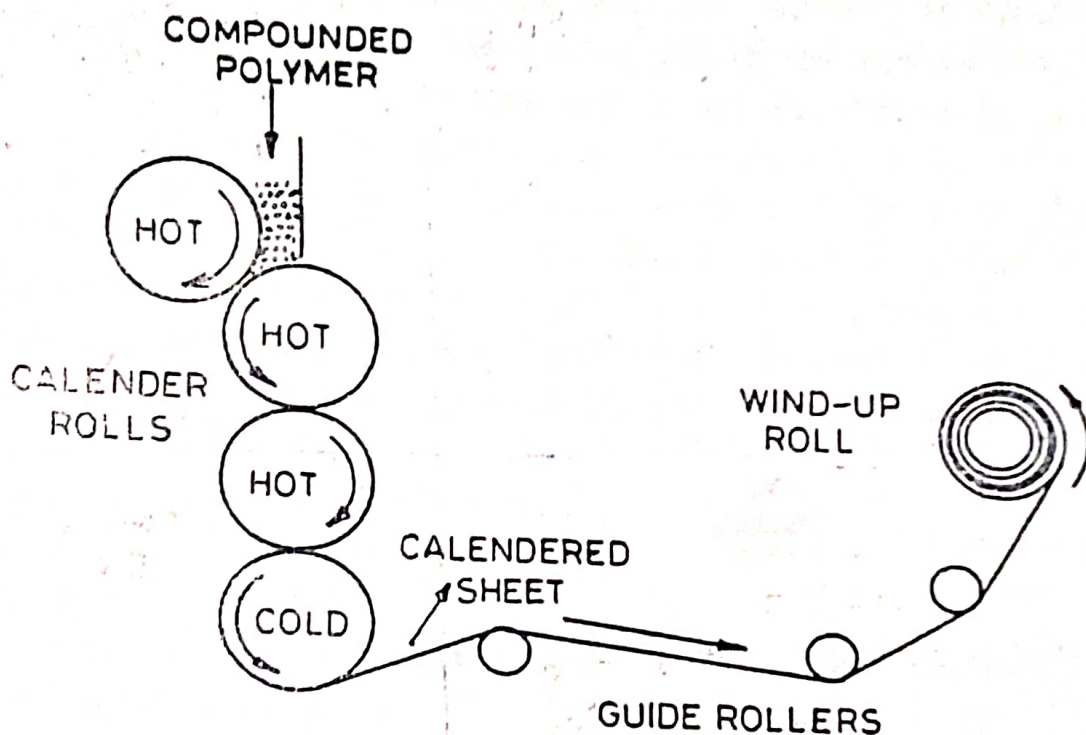


Fig. 15.1 Schematic diagram of a calendering machine.

By incorporating a suitably engraved embossing roller in the calendering machine, embossed sheets of a suitable design could be produced. Besides this, special decorative effects (like marbleisation) could be achieved by feeding the calender with a mixture of compounded materials of different colours. The marbleisation technique is usually employed in the production of vinyl floor tiles made of PVC.

#### 15.4.2 Die Casting

Die casting is a relatively low cost process which consists of converting a liquid prepolymer to a solid object with a desired shape. Sheets, tubes, rods and the like in limited lengths, can be produced



by the casting process. Figure 15.2 illustrates the simplest version of the casting process. Here, the prepolymer compounded suitably with a curative and other ingredients is poured into a petridish, the latter representing the die. The dish is then kept in an oven at an elevated temperature for a few hours to complete the cure reaction. 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. Instead of a prepolymer and a curative, a mixture of monomer, catalyst and other ingredients can be heated to the polymerisation temperature and poured into the die. Polymerisation is allowed to continue inside the die till the solid product is formed. Acrylics, epoxies, polyesters, phenolics and urethanes are suitable for die casting.

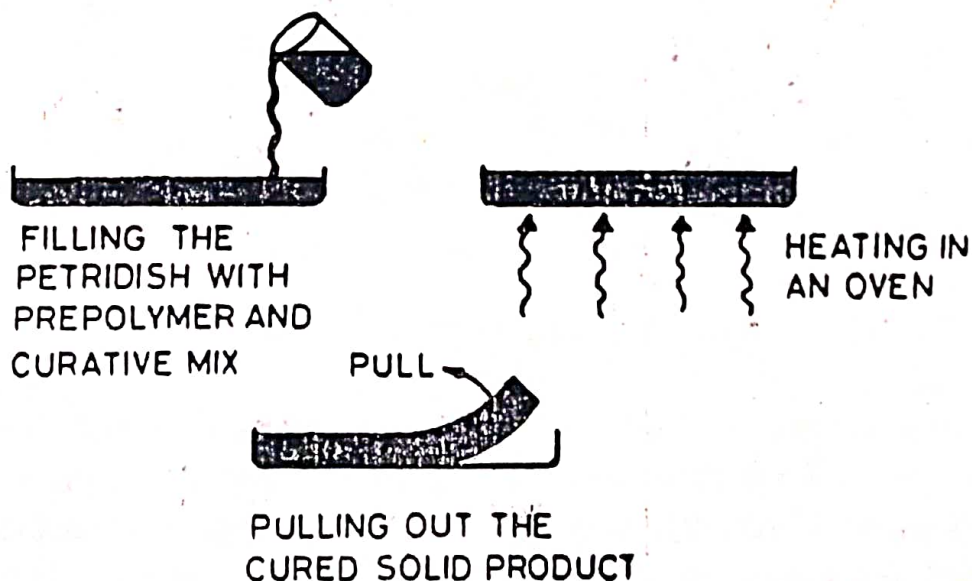


Fig. 15.2 Simple illustration demonstrating the casting process.

Depending on the convenience and availability, the dies for casting are made of plaster of Paris, lead or glass. During curing, the resin block shrinks in size which, in fact, helps in its removal from the die with ease.

### 15.4.3 Rotational Casting

Hollow articles such as balls and dolls are produced by a process called 'rotational casting'. The apparatus used for this process is shown in Fig. 15.3.

The compounded thermoplastic material in the form of a fine



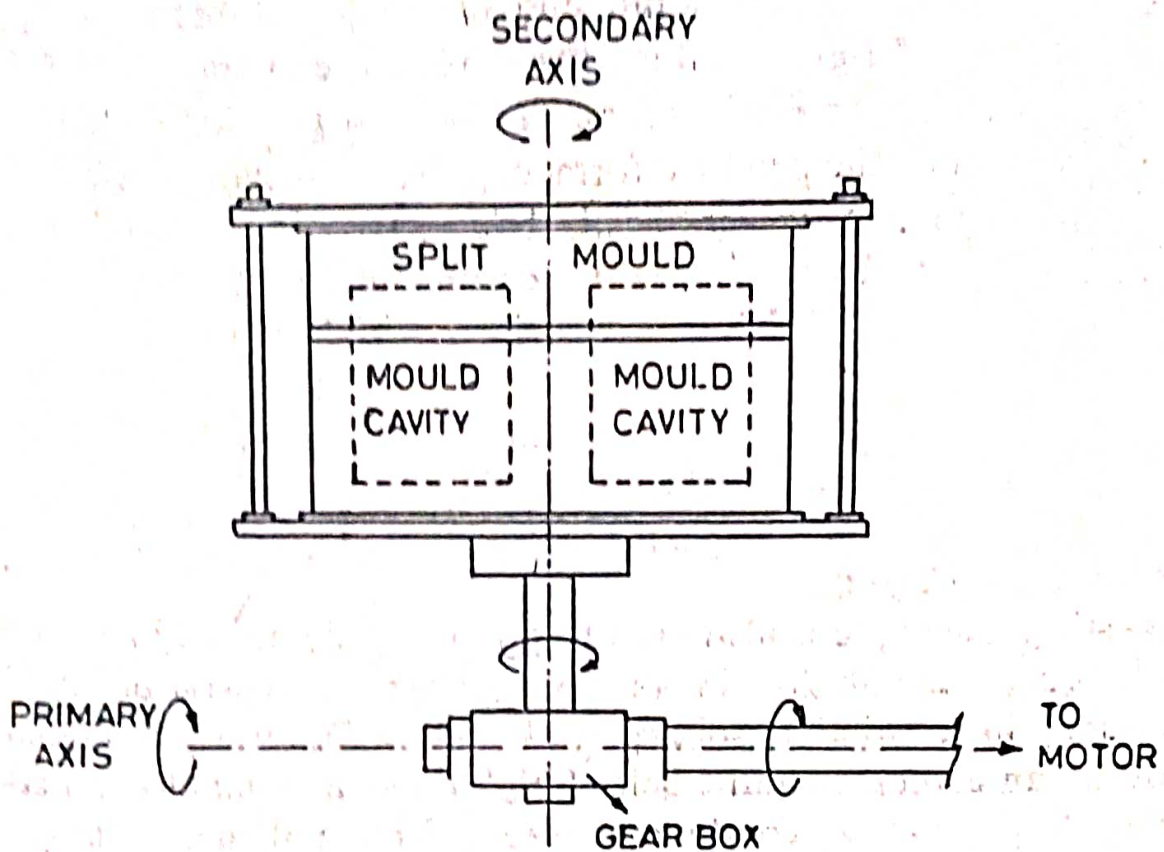


Fig. 15.3 Hollow moulds filled with the polymeric material being rotated simultaneously along the primary as well as the secondary axis during rotational moulding.

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. This distributes the molten plastic uniformly along the entire surface of the inside cavity of the mould. After a while, the mould, still under rotation, is chilled with cold water. Now, the molten plastic material uniformly distributed inside the mould surface cools down and solidifies in the shape of that surface. The mould can now be opened and the product removed.

Instead of thermoplastic materials, a thermosetting type prepolymer and curative mixture can also be fed into the mould in liquid form and curing done under rotation at an elevated temperature, when the product is formed.

To a large extent, PVC articles such as rainboots, hollow balls or doll heads are made by rotational casting. Curing of the PVC is done by a physical gelation between the PVC and a liquid plasticiser. Gelation takes place at temperatures around 150–200°C. Fine particles of PVC resin are dispersed uniformly in the liquid plasticiser together with stabilisers and colouring agents to get a pasty substance of a relatively low viscosity. This pasty material called



'plastisol' is fed into the mould and deaerated. Subsequently, the mould is rotated and heated for the required temperature and time, when gelation of the PVC occurs. The time of gelation controls the wall thickness of the product formed. After achieving the required wall thickness, the excess plastisol is removed for recycling. The gelled product is further heated inside the mould, which will ensure the final fusion of PVC resin particles with the plasticiser. The finished product is taken out of the mould after being cooled with a water spray. This method of rotational casting using a liquid material is referred to as 'slush moulding'.

#### 15.4.4 Film Casting

A casting technique is also used to produce polymeric films. In this technique, the solution in an appropriate concentration of the polymer in a suitable solvent is allowed to fall at a precalculated rate on an endless metallic belt of high finish moving at a constant speed (Fig. 15.4). A continuous sheet of the polymer solution is thus formed on the surface of the metallic belt. When the solvent is subsequently evaporated under controlled conditions, a thin film of the polymer is formed on the surface of the belt. The film could be removed simply by stripping. Most of the commercially available varieties of cellophane sheets and photographic films are prepared by this process.

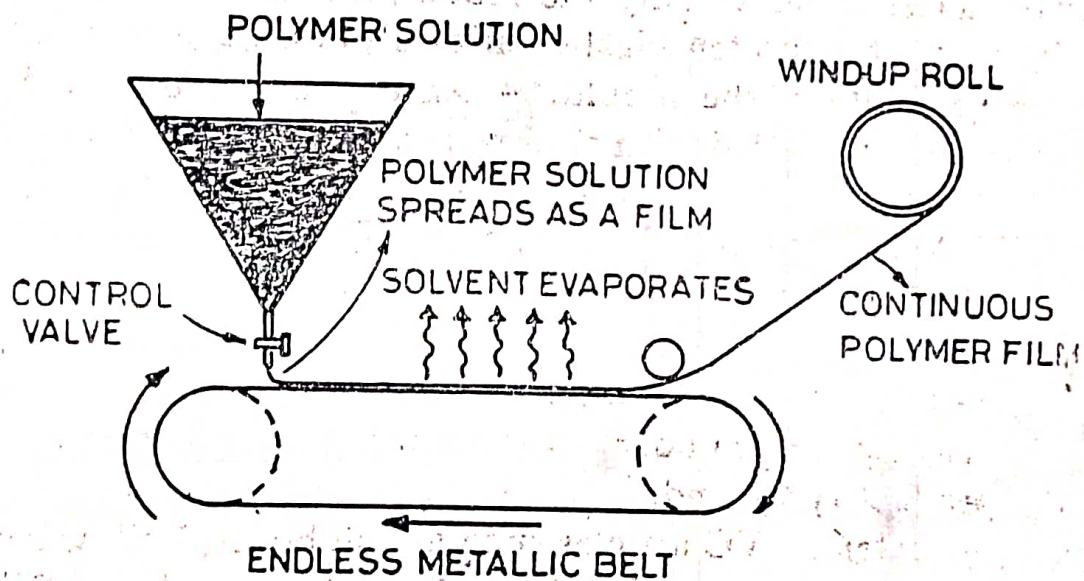


Fig. 15.4 Schematic diagram of a film-casting equipment.

#### 15.4.5 Compression Moulding

The compression-moulding process is very widely used to produce articles from thermosetting materials. Figure 15.5 shows a typical



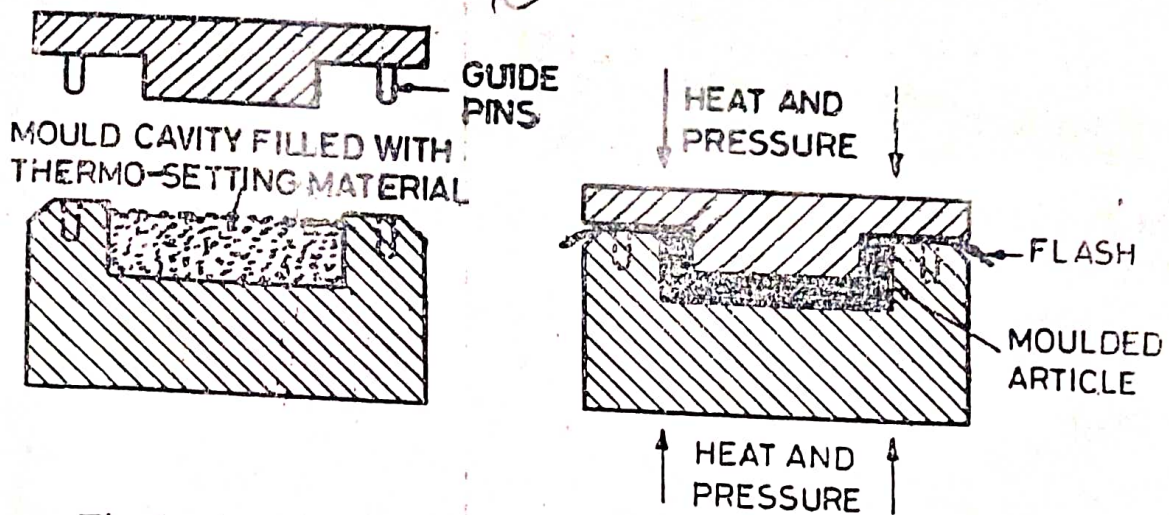


Fig. 15.5 Schematic diagram of a mould employed for compression moulding.

mould employed for compression moulding. The mould is made of two halves—the upper and the lower halves or the male and the female. The lower half usually contains a cavity and the upper half has a projection which fits into the cavity when the mould is closed. The gap between the projected upper half and the cavity in the lower one gives the shape of the moulded article.

In compression moulding, the thermosetting material is subjected to heat and pressure in a single stroke. This is accomplished by using a hydraulic press with heated plattens. Moulding temperature and pressure can be as high as  $200^{\circ}\text{C}$  and  $70\text{ kg/cm}^2$ , respectively. The actual temperature and pressure depends on the rheological, thermal and other properties of the plastic material to be moulded. The compounded material is placed in the cavity of the mould so as to fully fill the cavity. As the mould closes down under pressure, the material is squeezed or compressed between the two halves and compacted to shape inside the cavity. The excess material flows out of the mould as a thin film. This film expelled out of the mould is known as the 'flash'. Under the influence of heat, the compacted mass gets cured and hardened to shape. The mould can be opened while it is still hot to release the moulded product.

#### 15.4.6 Injection Moulding

The injection-moulding process is best suited for producing articles made of thermoplastic materials. Here, the equipment cost is relatively high but the main attraction is the amenability of the injection-moulding process to a high production rate. In injection moulding, a definite quantity of molten thermoplastic material is



injected under pressure into a relatively cold mould where it solidifies to the shape of the mould.

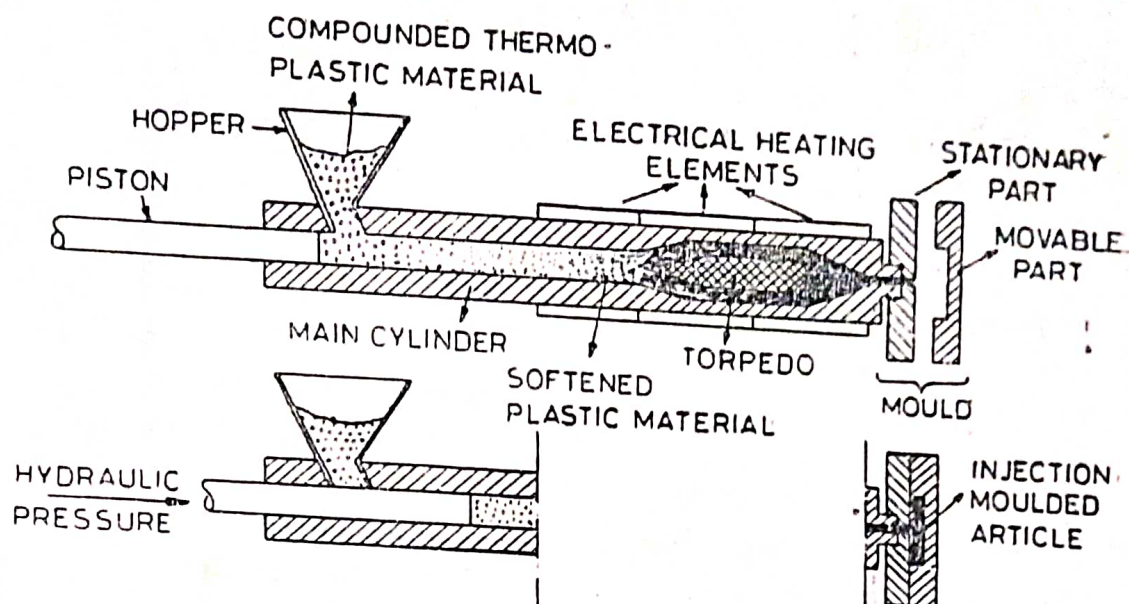


Fig. 15.6 Schematic diagram of an injection-moulding machine

The injection-moulding machine is shown in Fig. 15.6. The process consists of feeding the compounded plastic material as granules, pellets or powder through the hopper at definite time intervals 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. While moving through the hot zone of the cylinder, a device called 'torpedo' helps spread the plastic material uniformly around the inside wall of the hot cylinder and thus ensures uniform heat distribution. The molten plastic material from the cylinder is then injected through a nozzle into the mould cavity.

The mould used, in its simplest form, is a two-part system. One is a movable part and the other stationary (see Fig. 15.6). The stationary part is fixed to the end of the cylinder while the movable part can be opened or locked on to the stationary part. By using a mechanical locking device, the mould is properly held in position as the molten plastic material is injected under a pressure as high as  $1500 \text{ kg/cm}^2$ . The locking device has to be very skilfully designed in order to withstand high operating pressures. Furthermore, a proper flow of the molten material to the interior regions of the mould is achieved by preheating the mould to an appropriate temperature. Usually, this temperature is slightly lower than the softening temperature of the plastic material undergoing moulding.



After the mould is filled with the molten material under pressure, then it is cooled by cold water circulation and then opened so as to eject the moulded article. The whole cycle could be repeated several times either manually or in an automated mode.

#### 15.4.7 Blow Moulding

Most of the hollow plastic articles are produced by the blow-moulding technique. Containers (see Fig. 15.7), soft drink bottles and

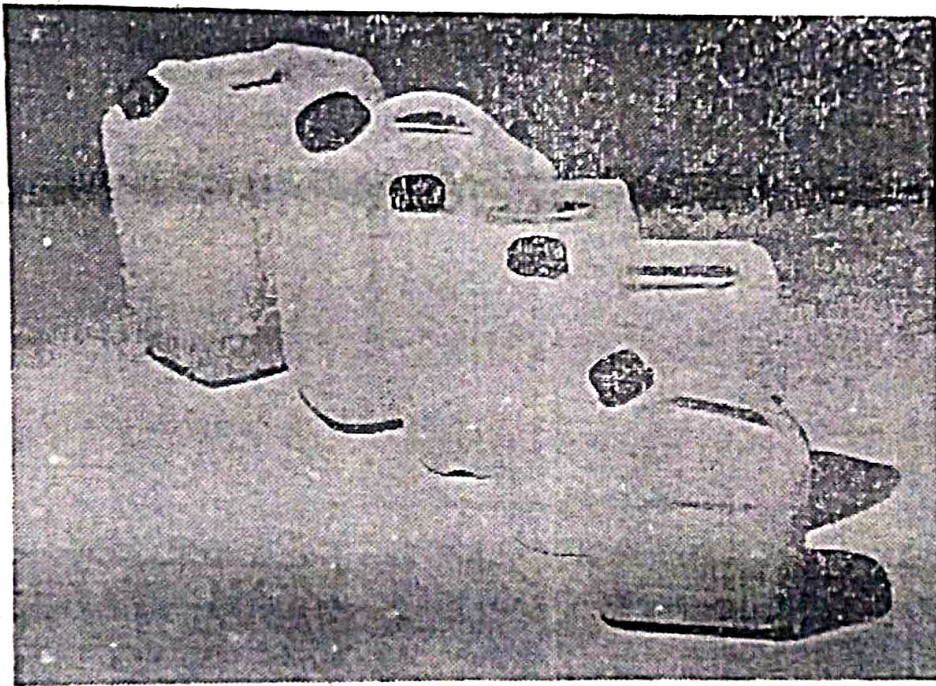


Fig. 15.7 Blow-moulded containers made of high-density polyethylene. (Courtesy: Blow Plast Ltd. Bombay, India.)

numerous other hollow articles are produced by this process. Thermoplastic materials such as polyethylene, polycarbonate, PVC, polystyrene, nylon, polypropylene, acrylics, acrylonitrile and ABS polymer can be blow moulded; however, high-density polyethylene tops the list in terms of annual consumption.

Blow moulding, in fact, basically belongs to the glass industry. The essence of the process is explained in Fig. 15.8. A hot, softened thermoplastic tube, usually called 'parison', is properly placed inside a two-piece hollow mould. When the two halves of the mould are closed, it pinches and closes one end of the parison and encloses a blowing pin at the other end. The parison is now blown by pressurising from within by blowing compressed air through the blowing pin. The hot parison is inflated like a balloon and goes on expanding until it comes in intimate contact with the relatively cold



spray can also be used for cooling. The product formed is cut to the desired length or wound on to rolls.

The extrusion process is also used for coating wires and cables with PVC or rubber and for coating roll-formed metal strips with suitable thermoplastics.

#### 15.4.9 Thermoforming

Thermoforming is a highly useful process for fabricating three-dimensional articles from plastic sheets. Even some large products, such as submarine hulls are made of ABS sheets by thermoforming techniques.

The technique can be outlined as follows. 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 duly assisted by the male half (Fig. 15.10). Now, the sheet assumes the required shape of the mould. On cooling, the shaped article becomes rigid and can be removed from the mould.

In a modified method, the hot plastic sheet is sucked into the

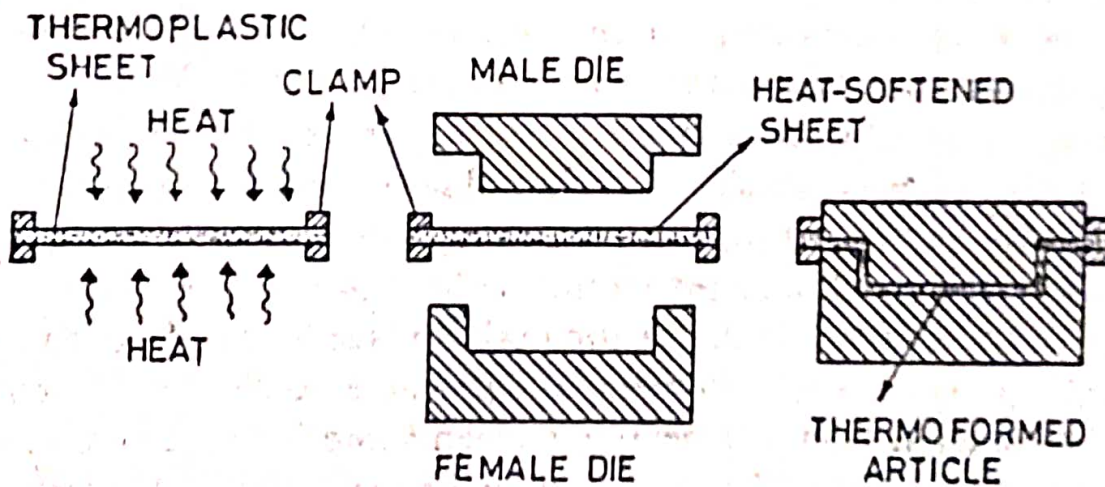


Fig. 15.10. Schematic diagram explaining thermoforming process.

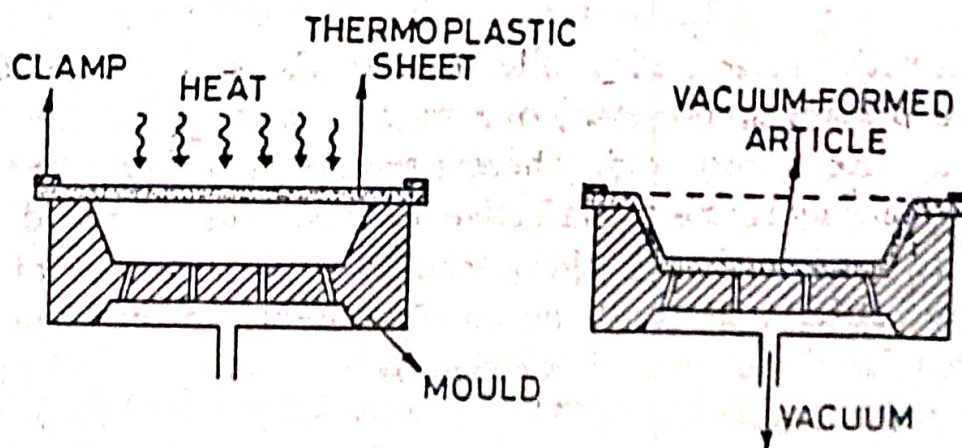


Fig. 15.11. Schematic diagram explaining vacuum-forming process.



cavity of the female mould under the influence of vacuum to give the desired shape (Fig. 15.11). This method is called 'vacuum forming'.

#### 15.4.10 Foaming

Foaming is an ingenious process for producing expanded or spongy materials. Special properties of this class of materials with cushioning ability, light weight and low thermal conductivity make them eminently suitable for several applications. The usual foamable polymers are polyurethanes, polystyrene, polyethylene, polypropylene, silicones, epoxy, PVC and the like. The foam structure consists either of discrete unit cells or of interconnecting cells. The discrete unit cells are closed cells and may enclose gases while the interconnecting cells are of the open type. The open type and closed type cell structures are schematically shown in Fig. 15.12.

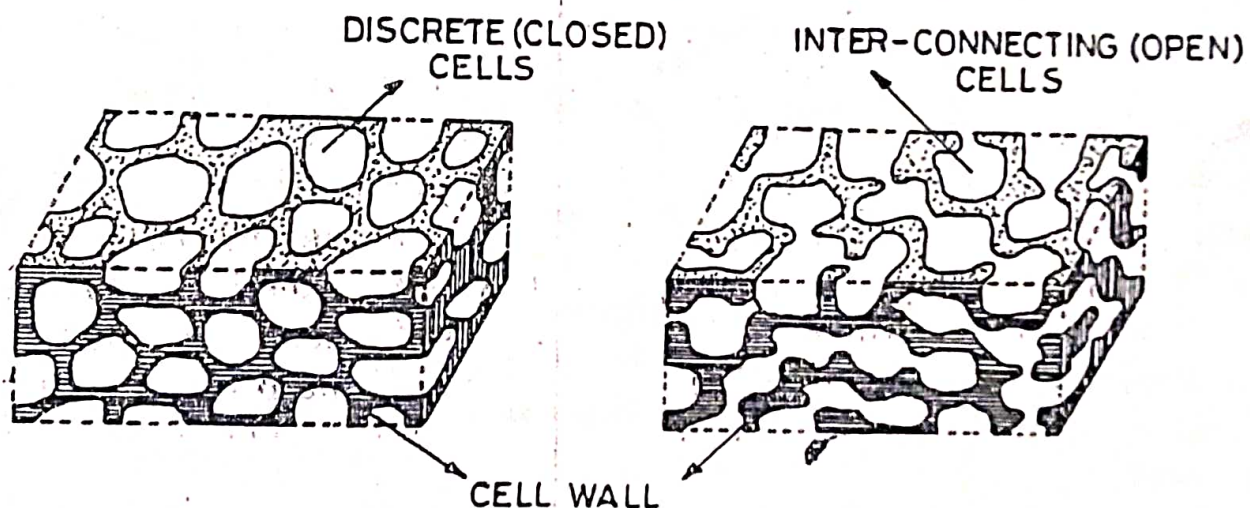
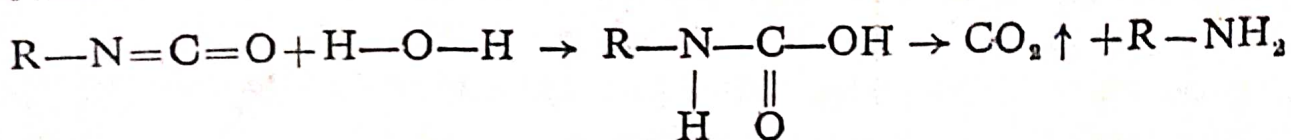


Fig. 15.12 Schematic representation of open type and closed type cell structures formed during foaming process.

There are different methods for producing foamed or cellular plastics. One method is to melt a compounded thermoplastic material and blow air or nitrogen in such a way that the whole matrix foams up. Addition of the surface active agents helps the foaming up process. When the required degree of foaming is achieved in the midst of blowing air or nitrogen, the matrix is cooled to the ambient temperature. In this process, the material is allowed to solidify in the foamed-up condition. Thermosetting liquid propolymers can be blown up cold and then heated to complete the cure in the foamed-up condition. Usually, however, foaming is achieved by the addition of a foaming agent or blowing agent. Such agents are low boiling solvents or certain chemical compounds. Solvents such as *n*-pentane



or *n*-hexane, under normal cure temperatures of polymeric materials, boil off and liberate large volumes of vapours. Certain chemicals, on the other hand, can be thermally decomposed to generate inert gases. Azobis isobutyronitrile can decompose thermally and liberate large volumes of nitrogen. Carbon dioxide gas, produced as an *in situ* blowing agent by the reaction between the isocyanate and water can also be used for producing foams, for instance, polyurethane foams:



Polyurethane is produced by a polyol reacting with a diisocyanate, 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 or foaming agents make the polymer matrix foam up. The polymer matrix in a foamed-up condition is cooled below the softening temperature (in the case of thermoplastic materials) or made to undergo the cure reaction or cross-linking (in the case of the thermosetting type) so that the matrix as a whole in the foamed condition attains structural rigidity to maintain the foam structure. This is called the 'stabilisation of the foam'. If the polymer matrix is not cooled down to below its softening point or is not sufficiently cross-linked, the gases and vapours may escape out of the system and the foam may collapse.

Foamed plastics could be made in flexible, rigid or semi-rigid forms. When foaming is carried out inside the mould cavity, articles made of foamed plastic can be directly obtained. Foamed sheets and rods can also be used for fabricating articles of different shapes. Depending on the nature and extent of foaming, foamed plastics can have a density anywhere between 20 kg/m<sup>3</sup> and 1000 kg/m<sup>3</sup>. Foamed plastics are put to several uses. The automobile industry consumes large quantities of flexible PVC and polyurethane foams as upholstery. These foams find a prominent place in the furniture industry also. Polystyrene rigid foams are widely used for packaging, and thermal insulation of buildings. For mattresses and similar other applications, rubber and urethane foams are used to a large extent. Urethane rigid foams also find application in thermal insulation of buildings and even in the making artificial limbs.



### 15.4.11 Reinforcing

Reinforcing a plastic matrix with a high-strength fibre material results in the formation of what are called fibre-reinforced plastics (FRP). FRPs have outstanding properties such as high strength-to-weight ratio and excellent corrosion resistance and are easy to fabricate. A wide variety of articles are made by the fibre-reinforcing process. A remarkably high strength-to-weight ratio is the main feature attracting spacecraft designers to use reinforced plastics in satellites. Elegance, light weight and corrosion resistance qualifies reinforced plastics for use in boat hulls which are required to rough through marine salt water. The corrosion resistance property of reinforced plastics is fully utilised when they are employed as huge storage tanks for storing acids.

Now, let us examine the physical nature and chemical composition of these extremely useful materials. As has been said earlier, they are basically polymeric materials which have gained special properties through the use of reinforcing fibres. The main reinforcing fibres (both short-chopped and continuous) are those of glass, graphite, alumina, carbon, boron and beryllia. The latest trend in this field is to use fully aromatic polyamide fibres which, it is claimed, give, in some cases, over 50% weight reduction compared to reinforced plastics made of conventional fibres. Natural fibres such as sisal, asbestos, etc., are also used for reinforcement. The selection of the fibre, of course, depends on the property one expects the final reinforced composite to possess. Among these, however, glass fibre is the most extensively used and continues to be the workhorse of the FRP industry. Properties such as the low coefficient of thermal expansion, high dimensional stability, low cost of production, good tensile strength, low dielectric constant, non-flammability and chemical resistance constitute the attractive features of glass fibre. The other fibres are used mainly when some specific added advantage or service conditions are to be fulfilled. They are generally costlier than glass fibres.

Reinforced plastics are produced by suitably bonding a fibre material with a resin matrix and curing the same under pressure and heat. The reinforcement could be in different forms. For instance, it could be short-chopped fibres, continuous filaments or woven fabrics. The common resin matrix used in FRPs includes polyesters, epoxy, phenolic, silicone, melamine, vinyl derivatives and polyimides. A large proportion of the reinforced plastics are



made of polyester resins taking advantage of their low cost. Phenolic resins are used wherever resistance to high temperatures is demanded. Epoxy resins impart extremely high mechanical properties to the FRP. Excellent electrical and thermal properties are obtained by using silicone resins.

There are several methods available for the production of reinforced plastics. Three of the most commonly used techniques are: (1) The hand lay-up technique; (2) The filament-winding technique; and (3) The spray-up technique.

### *The Hand Lay-up Technique*

This is probably the simplest method for producing reinforced plastic articles. The quality of the end product depends to a large extent on the skill of the operator. The whole process consists of the following steps. To begin with, the mould is given a thin coating with a release agent such as polyvinyl alcohol, silicone oil or wax. (This is done to prevent the final fabricated article from sticking to the mould.) The mould is then coated with a resin matrix. A pre-cut glass cloth or mat is then laid over the resin layer. Now, another layer of the resin coating is given over the glass cloth. Rollers are used to press the glass cloth on the resin uniformly and also to remove the entrapped air bubbles. Alternate layers of resin and glass cloth are laid in a similar sequence until the required thickness is built up (Fig. 15.13). The whole set-up is then cured either at the ambient temperature or at elevated temperatures. After the curing is completed, the reinforced plastic material thus formed is removed from the mould and subjected to trimming and

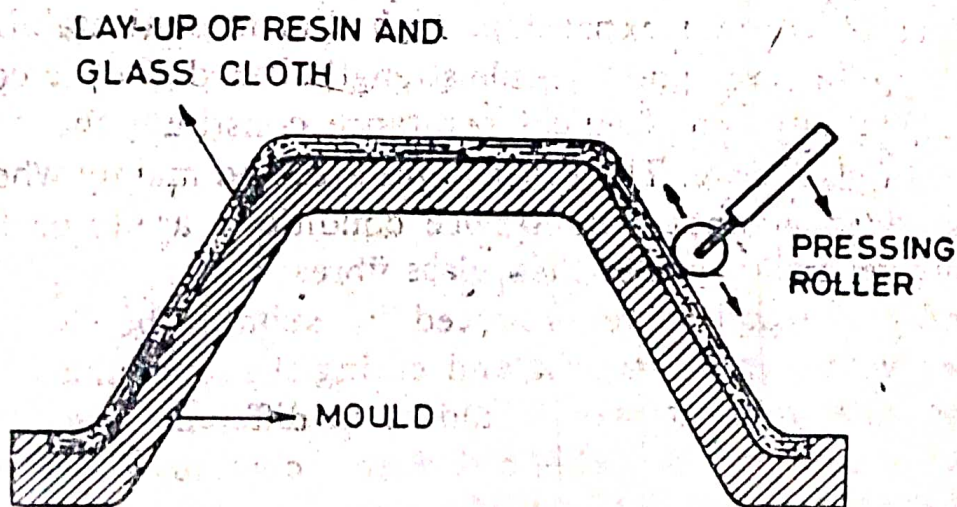


Fig. 15.13 Schematic diagram showing hand lay-up technique.



finishing. Sheets, auto body parts, boat hulls, ducts and building components are produced by this technique.

### *Filament-winding Technique*

This is a very widely used method for producing reinforced plastic articles such as high-pressure cylinders, storage tanks and rocket motor bodies. In this process a continuous length of strand, roving or woven tape of the fibre 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 filament or strand is then wound over a mandrel of the required shape and subsequently cured under the influence of heat. The winding machine (Fig. 15.14) is designed

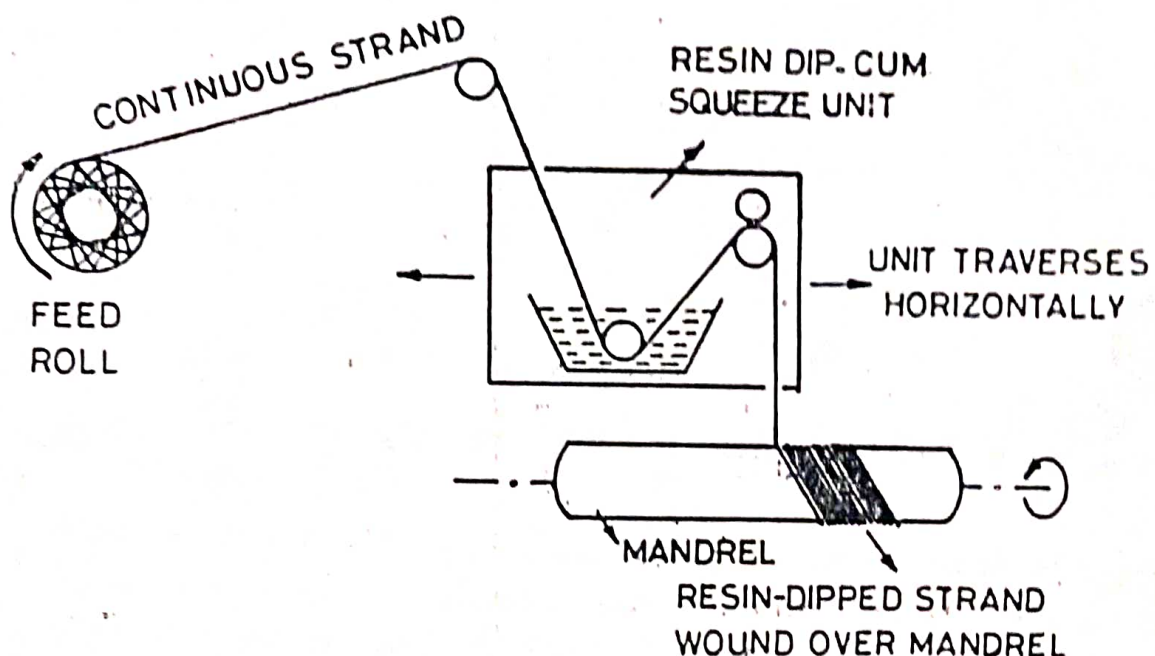


Fig. 15.14 Schematic diagram of a filament-winding machine.

in such a fashion that the fibres can be wound in a predetermined pattern to suit the job. The tension of the fibre and the pattern of winding are very important factors as they influence the ultimate tensile property of the finished product.

### *Spray-up Technique*

This technique employs a multiple headed gun. A spray of resin, a curative and chopped fibres are discharged simultaneously from a spray gun on the surface of a mould (Fig. 15.15) where they get deposited to a uniform thickness. The chopped fibre of a suitable length is obtained by continuously feeding rovings to the chopping head of the apparatus. Once the required thickness is built up by



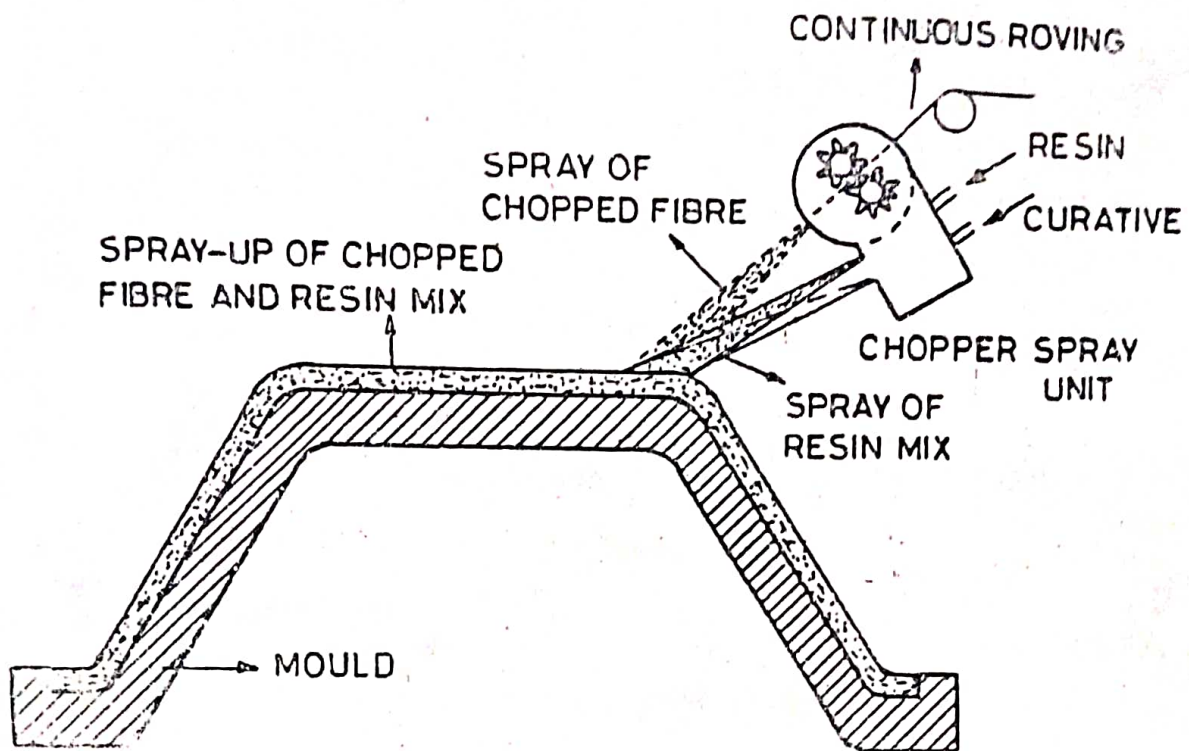


Fig. 15.15 Schematic diagram showing spray-up technique.

spraying, it is cured under heat. The spray-up technique is a quick method to cover large surface area moulds. Many present-day reinforced plastic articles such as truck bodies, storage vessels, lorry cabs and boat hulls are produced by the spray-up technique.

#### *Other Techniques*

Apart from the techniques described above, there are several other techniques available in the ever-growing reinforced plastic industry, each having a specific use. For example, a continuous laminating technique is used for producing continuous sheets of reinforced plastic laminates with varying thicknesses. In this process, individual layers of woven fabric are fed from individual rolls and impregnated with the resin and curative, and then pressed into a single layer by passing through a set of hot laminating rollers. The single layer coming out is cured by applying heat, which results in a laminate of a desired thickness (Fig. 15.16). The thickness can be adjusted by selecting the number of layers.

In yet another technique, known as 'pultrusion', articles such as tubing or fishing rods are produced from continuous strands of a fibre. The process is relatively simple. The continuous strands are pretreated by passing through a resin-curative bath and then pulled through a die of a suitable profile (Fig. 15.17). The die is heated



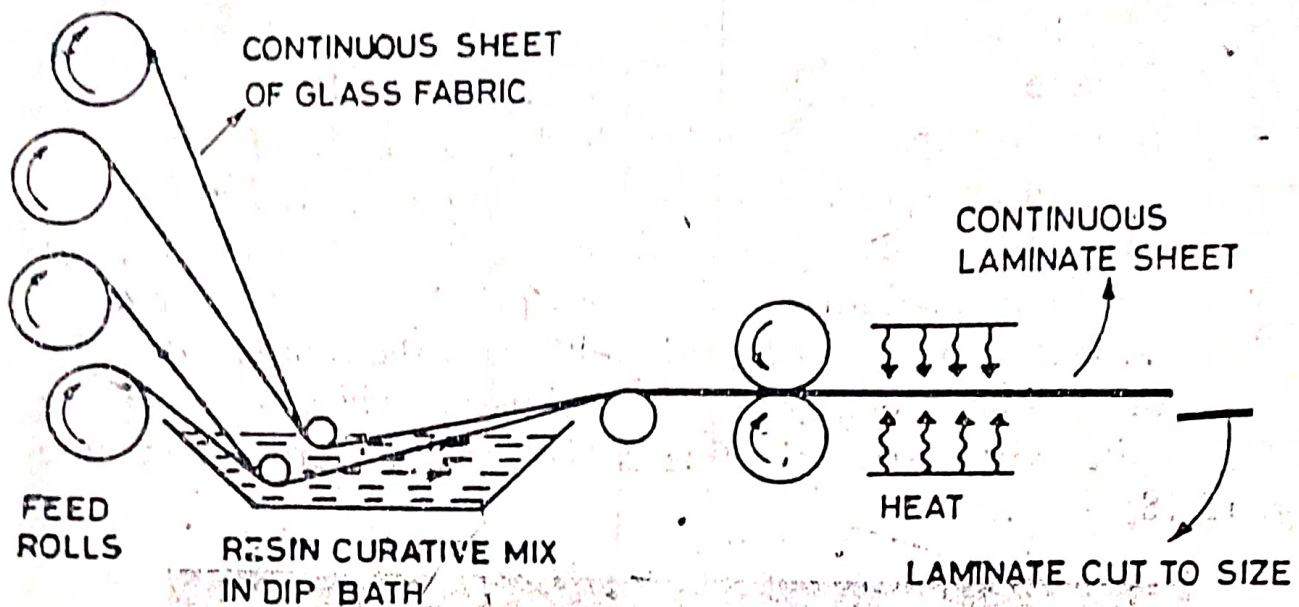


Fig. 15.16 Schematic diagram showing continuous lamination technique.

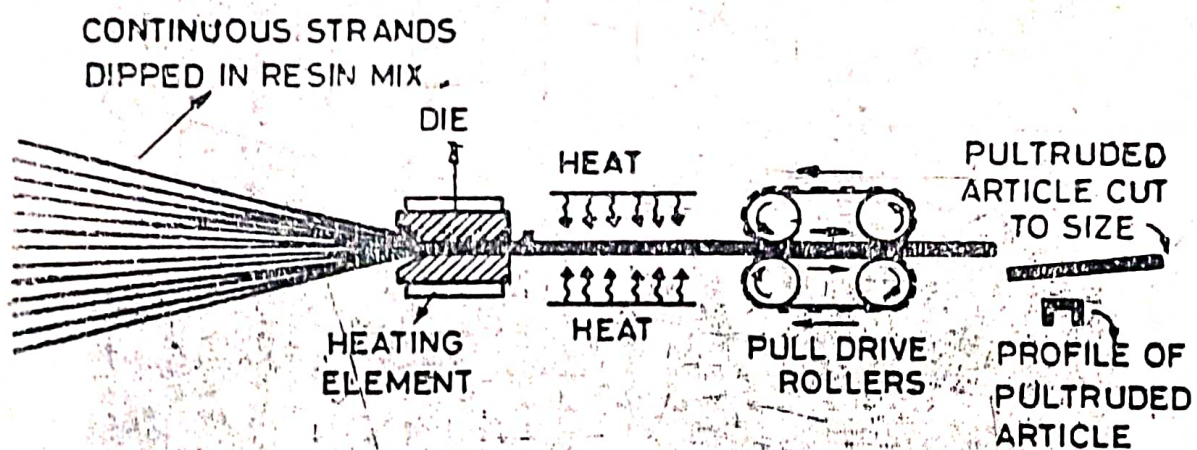


Fig. 15.17 Schematic diagram showing pultrusion technique.

and the compacted profile coming out of the die is also heated externally. The cured profile is continuously pulled out of the die which provides the driving force for the impregnated strands to be forced through the die. This process is similar to extrusion except that, in extrusion, the polymeric material is forced through the die from inside by a rotating screw, while, in pultrusion, the material is actually pulled through the die orifice from the outer side.

Apart from these methods, a mix comprising chopped fibres, resin and curative can be moulded by any of the conventional methods such as compression moulding technique. Thermoplastic materials filled with chopped fibres can also be moulded by compression, injection or extrusion to get a product with improved mechanical properties.



### 15.4.12 Fibre Spinning

Fibres are made from polymers by a process called 'spinning'. There are three principal spinning methods, viz., melt spinning, dry spinning and wet spinning. In the melt-spinning process, the polymer is used in the molten state, while, in the other two cases, the polymer is used as a solution in an appropriate solvent. In all the three cases, however, the polymer (either in the molten or in the solution form) is streamed through a spinneret which is a special kind of plate with extremely fine holes for the fibres to emerge (Fig. 15.18).

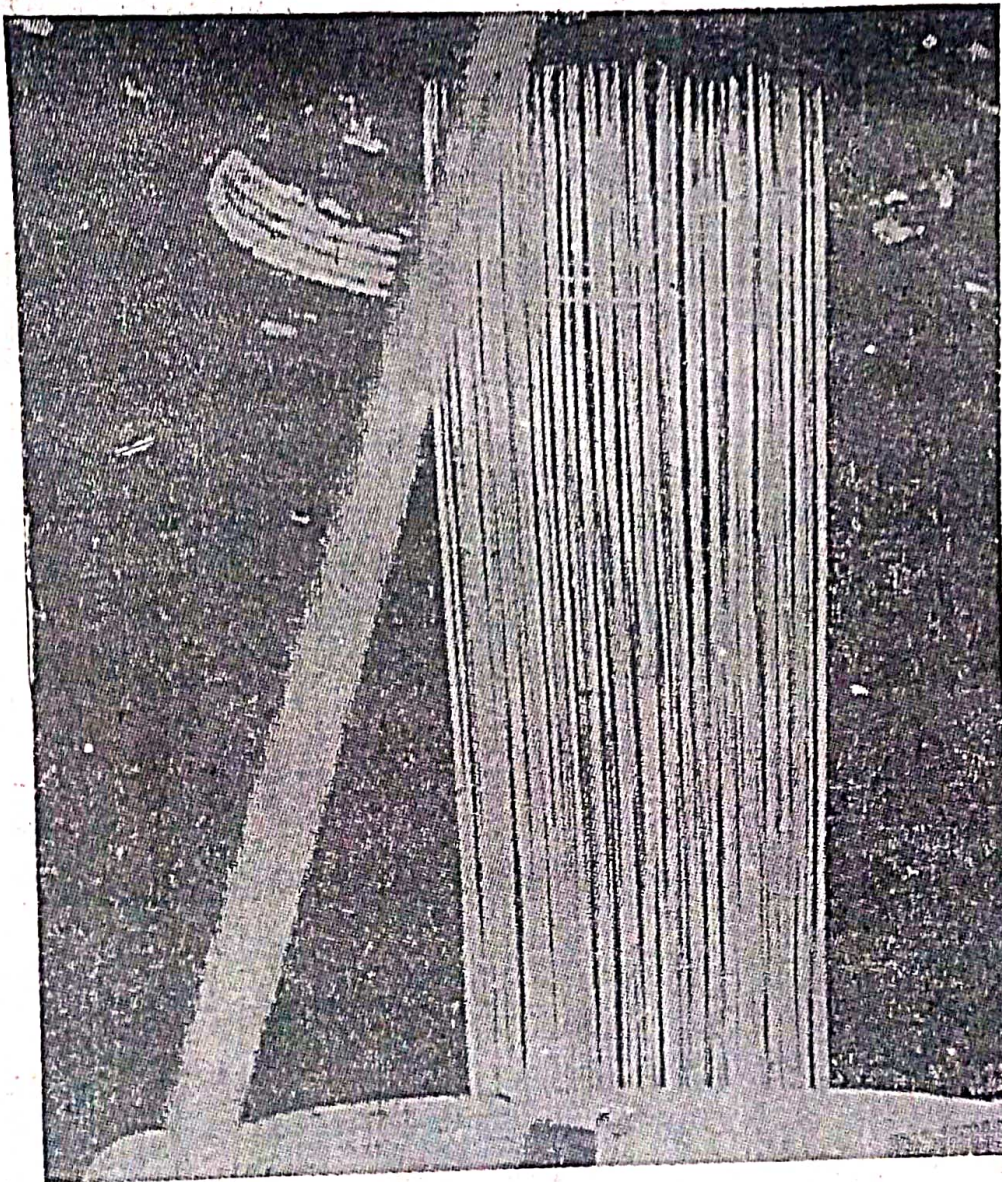


Fig. 15.18 Fibres emerging out of a spinneret. (Courtesy: Toyo Rayon Ltd., Japan.)

#### *Melt-Spinning*

In its simplest form the melt-spinning process may be described as



follows. Polymer chips are electrically heated and melted in a heating grid. This converts the solid polymer into a viscous mobile liquid. Sometimes, during this heating process, cross-linking or thermal degradation of the polymer may occur leading to formation of lumps. These lumps can be easily removed from the hot molten polymer by using a filter pack. Furthermore, the hot molten polymer should be protected from the surrounding oxygen to avoid oxidative degradation. This is effected mostly by creating an inert environment around the molten polymer with nitrogen, carbon dioxide or steam. The molten polymer then enters a constant rate pump (known as the metering pump) which, in turn, pumps the polymer melt through the spinneret at a specified rate. The polymer melt is thus forced through the fine holes of the spinneret from where continuous and very fine filaments emerge. The filament emerging from the spinneret solidifies as it comes in contact with cold air. The cooling and solidification process may be enhanced by a cold air blast. The solid filaments emerging from the spinneret are subsequently wound upon spindles (Fig. 15.19).

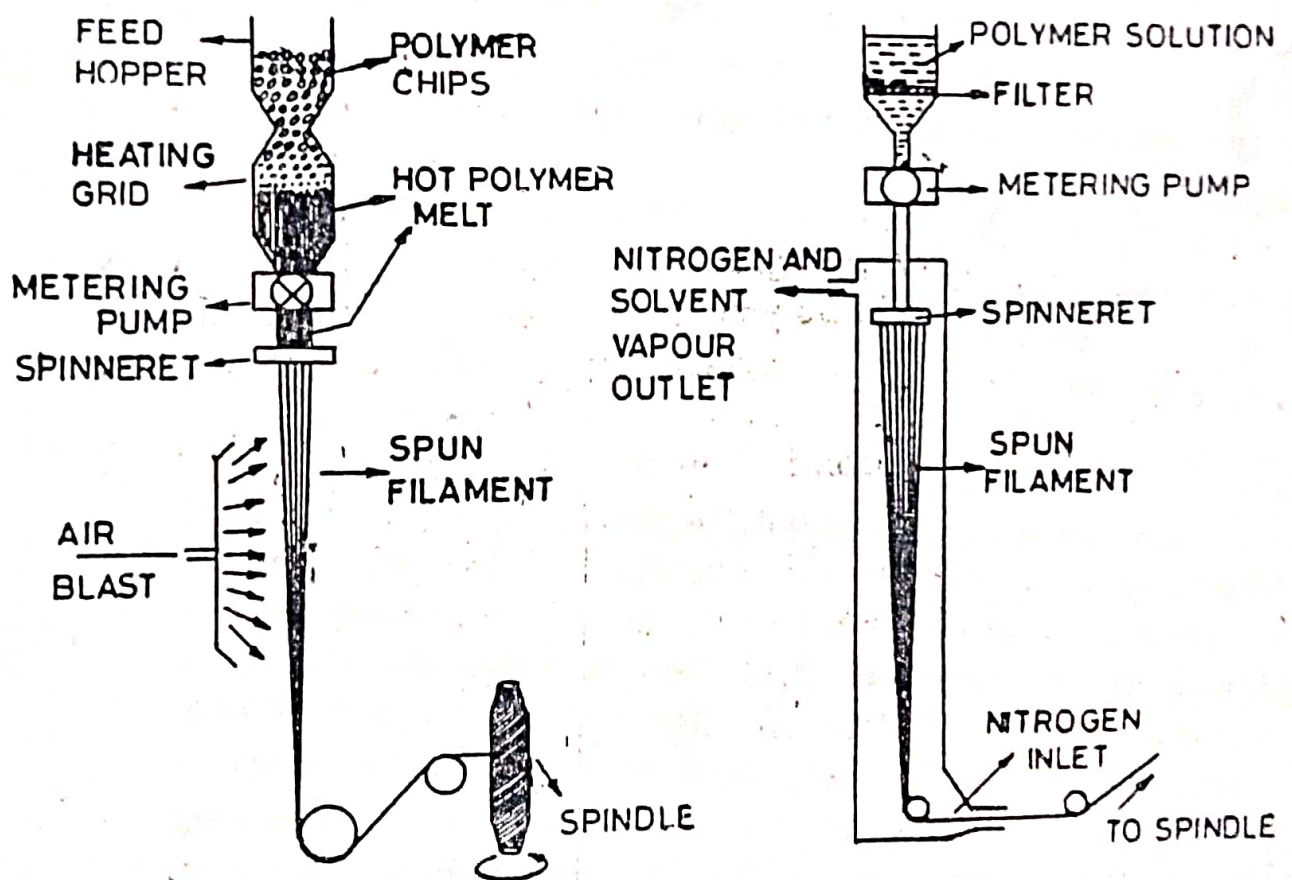


Fig. 15.19 Schematic diagrams of melt-spinning and dry spinning processes, respectively.

One important point to remember in the melt-spinning process



is that the diameter of the filament depends as much on the rate at which the molten polymer streams through the holes and on the rate at which the filament is pulled and wound up as on the hole diameter

### *Dry Spinning*

Many common polymers such as polyacrylonitrile or polyvinyl chloride are converted to fibres on a large scale by using the dry spinning process. The process is also shown in Fig. 15.19. The polymer is dissolved in an appropriate solvent to get a solution of high concentration. The viscosity is controlled by increasing the temperature of the solution. The hot viscous solution is pumped through the spinneret when fine continuous jets of the solution come out of the orifices. The filament is formed from these jets by the simple evaporation of the solvent. Solvent evaporation can be enhanced by passing dry nitrogen in a counter-current manner. Filaments formed from the polymer solution ultimately reach the spindle where they are wound. The rate at which the fibres are spun could be as high as 1000 m/min. Manufacture of cellulose acetate fibres from a 35% solution of the polymer in acetone at 40°C could be cited as a typical example of the utility of the dry spinning process.

### *Wet Spinning*

Wet spinning, like dry spinning, employs a fairly concentrated polymer solution. The increase in polymer solution viscosity is controlled by spinning the solution at an elevated temperature. The process details for wet spinning are shown in Fig. 15.20. Wet spinning also converts a viscous polymer solution into fine jets through a spinneret. These jets, however, are led into a coagulation bath containing a large volume of a non-solvent which can precipitate the polymer from its solution. When continuous jets of the polymer solution come in contact with a non-solvent, they precipitate in the form of fine filaments. The filaments formed are gathered on a spindle after undergoing washing, drying, etc. One important point to be borne in mind while carrying out wet spinning is that sometimes droplets are formed instead of continuous filaments. This happens as a result of the breaking of continuity in the jet as it emerges from the spinneret hole and is caused by the forces of interfacial tension acting on the newly formed jet. This could be avoided by increasing the viscosity of the polymer solution.



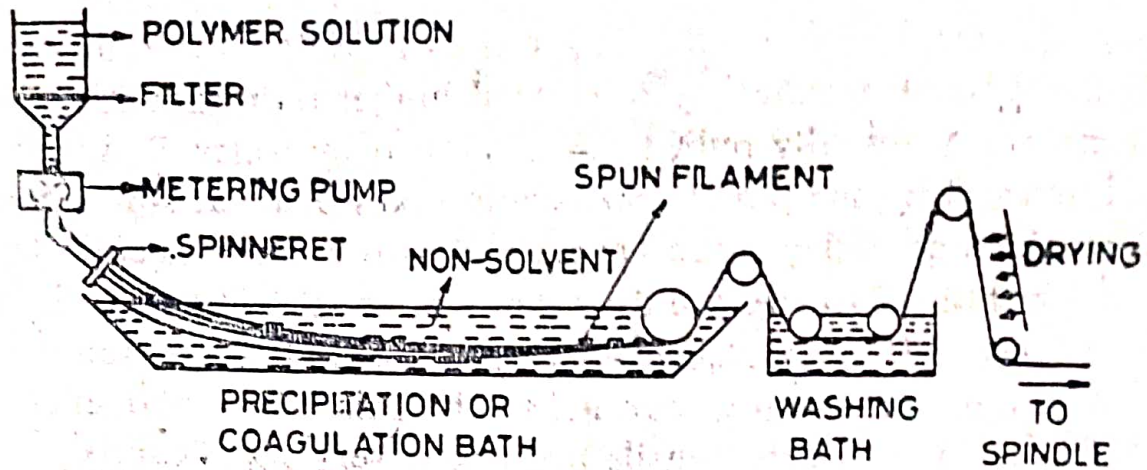


Fig. 15.20 Schematic diagram of wet spinning process.

Coagulation, an essential step in wet spinning, is a rather slow process. Hence, compared to the other two processes, the rate of wet spinning may be as low as 50 m/min. The wet spinning process is employed commercially to make fibres from cellulose, viscose rayon, polyacrylonitrile, etc.

#### *Uniaxial Orientation*

During the spinning of filaments from a polymer melt or solution, the polymer molecules in the filament are not properly oriented and, hence, the percentage crystallinity is relatively low. This will be reflected in poor physical properties of the fibre. To get better physical properties, the filaments are subjected to a process called uniaxial 'drawing'. This is done by employing a particular kind of stretching machine.

The main feature of the machine are two rollers (A and B shown in Fig. 15.21), revolving at different speeds. Roller B may be revolving 4 to 5 times faster than roller A. The spun yarn is sent in

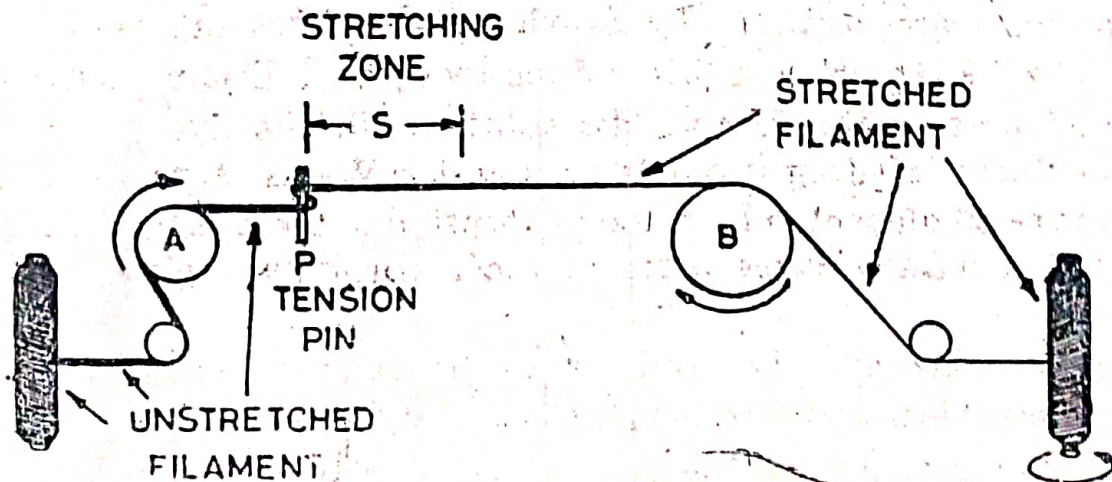


Fig. 15.21 Schematic diagram of uniaxial orientation done in a stretching machine.



through roller A and reaches roller B by passing over a tension pin P. Since roller B is rotating at a speed higher than that of roller A, the filament is actually pulled and stretched by roller B under tension imparted by the pin P. Stretching takes place at zone S. After passing through roller B the properly drawn filament is collected on a metal bobbin. During the drawing process, the filament diameter gets reduced as it is stretched under tension, but, at the same time, the molecules get oriented parallel to the axis of the filament. This orientation improves the tensile properties very significantly.

### *Post Treatments for Fibres*

Many special post treatments are given to fibres to make them more useful. The treatments include scouring, lubricating, sizing, dyeing, etc.

Soap and synthetic detergents are used for 'scouring'. Scouring, in fact, is nothing but the removal of dirt and other impurities from the fibre surface. 'Lubrication' is a treatment given to fibres to protect them from external friction that may be imparted on the fibre by neighbouring fibres or by a rough metallic surface with which the fibres may come in contact during processing. Mostly, vegetable oils are used as lubricants. Lubrication also helps to reduce static electricity build-up on the fibres.

'Sizing' is a process by which a protective coating is given to fibres. For many fibres, polyvinyl alcohol or gelatin is employed as a sizing material, which holds the projecting fibres on the main axis of the yarn and this ensures smooth weaving. Weaving is generally followed by dyeing and, hence, before dyeing the 'size' should be removed by washing.

Customers are attracted by providing an increasing variety of colours to the fabrics, and this is done by dyeing. Dyeing is carried out by immersing fibres into a dye solution till the dye penetrates into the fibres. Hydrogen bonds or van der Waals' type of bonds play a very significant role in the absorption of the dye by the fibre. Penetration usually takes place at the amorphous regions of the fibre.

Acid dyes are absorbed quickly by fibres made from cellulose or proteins. This is understandable as acid dyes can easily bond with amino or hydroxyl groups present in such polymers. The process of dyeing synthetic fibres such as polyester, acrylics or polyamides is rather slow. Elevated temperatures, of course, enhance the dyeing



process. Colouring of fibres made from polyvinyl chloride, polyethylene, etc., is practically impossible unless sites are made available for the absorption of dyes through copolymerisation or by chemical oxidation.

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