University of Jordan

Department of Chemical Engineering

Polymers and Plastics Engineering (0905553)

10. Composites

A) Processing Reinforced Thermoplastics

Fibre reinforced thermoplastics can be processed using most of the conventional thermoplastic processing methods described earlier. Extrusion, rotational moulding, blow moulding and thermoforming of short fibre reinforced thermoplastics are all possible, but the most important commercial technique is injection moulding. In most respects this process is similar to the moulding of un-reinforced thermoplastics but there are a number of important differences:

- The melt viscosity of a reinforced plastic is generally higher than the unreinforced material. As a result the injection pressures need to be higher by up to 80% in some cases.
- The cycle times are generally lower because the greater stiffness of the material allows it to be ejected from the mould at a higher temperature than normal.
- A reciprocating screw machine is preferred to a plunger machine because of the better mixing, homogenizations, metering and temperature control of the melt.
- Particular attention needs to be paid to such things as screw speed and back pressure because these will tend to break up the fibres and thus affect the mechanical properties of the mouldings.

A practical difficulty which arises during injection moulding of reinforced plastics is the increased wear of the moulding machine and mould due to the abrasive nature of the fibres. However, if hardened tool steels are used in the manufacture of screws, barrels and mould cavities then the problem may be negligible.

An inherent problem with all of the above moulding methods is that they must, by their nature, use short fibres (typically 0.2-0.4 mm long). In recent years therefore, there have been a number of developments in reinforced thermoplastics to try to overcome these problems:

- One approach has been to produce continuous fibre tapes or mats which can be embedded in a thermoplastic matrix. The best known materials of this type are the Aromatic Polymer Composites (APC) and the glass mat reinforced thermoplastics (GMT). One of the most interesting of these consists of unidirectional carbon fibres in a matrix of polyetheretherketone (PEEK). The material comes in the form of a wide tape which may be arranged in layers in one half of a mould to align the unidirectional fibres in the desired directions. The assembly is then pressurized between the two matched halves of the heated mould. The result is a laminated thermoplastic composite containing continuous fibres aligned to give maximum strength and stiffness in the desired directions.
- Another recent development has been the arrival of special injection moulding grades of thermoplastics containing long fibres. At the granule production stage the thermoplastic lace contains continuous fibres and to achieve this it is produced by pultrusion rather than the conventional compounding extruder. The result is that the granules contain fibres of the same length as the granule (≅10 mm). These long fibres give better product performance although injection moulding machine modifications may be necessary to prevent fibre damage and reduce undesirable fibre orientation effects in the mould.

B) Processing Reinforced Thermosets

There is a variety of ways in which fibre reinforcement may be introduced into thermosetting materials and as a result there is a range of different methods used to process these materials. In many cases the reinforcement is introduced during the fabrication process so that its extent can be controlled by the moulders. Before looking at the possible manufacturing methods for fibre reinforced thermosetting articles it is worth considering the semantics of fibre technology:

- ***Filament***: This is a single fibre which is continuous or at least very long compared with its diameter.
- ***Yarn or Roving***: Continuous bundle of filaments generally fewer than 10,000 in number.
- ***Tow***: A large bundle of fibres generally 10,000 or more, not twisted.
- ***Fabric, Cloth or Mat***: Woven strands of filament. The weave pattern used depends

on the flexibility and balance of strength properties required in the warp and fill directions. Fig. 1 shows a plain weave in which the strength is uniform in both directions. The warp direction refers to the direction parallel to the length of the fabric. Fabrics are usually designated in terms of the number of yarns of filament per unit length of warp and fill direction.

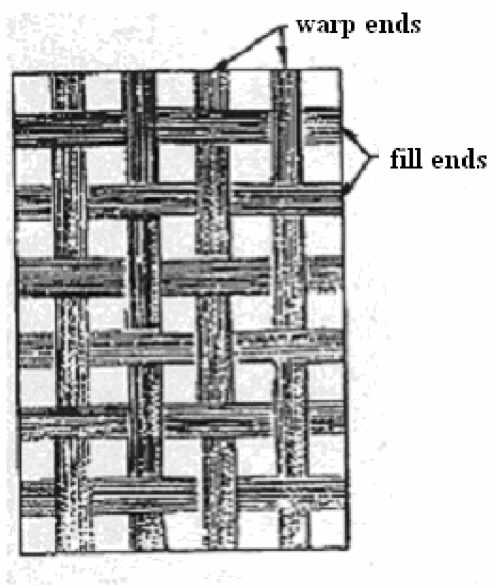

Fig. 1 Plain weave fibre fabric

- ***Chopped Fibres***: These may be subdivided as follows:
  - ***Milled Fibres***: These are finely ground or milled fibres. Lengths range from 30 to 3000 microns and the fibre *(L/D)* ratio is typically about 30. Fibres in this form are popular for closed mould manufacturing methods such as injection moulding.
  - ***Short Chopped Fibres***: These are fibres with lengths up to about 6 mm. The fibre *(L/D)* ratio is typically about 800. They are more expensive than milled fibres but provide better strength and stiffness enhancement.
  - ***Long Chopped Fibres***: These are chopped fibres with lengths up to 50 mm.
  - ***Chopped Strand Mat***: This consists of strands of long chopped fibres deposited randomly in the form of a mat. The strands are held together by a resinous binder.

Manufacturing Methods

The methods used for manufacturing articles using fibre reinforced thermosets can be divided into three main categories. These are manual, semiautomatic and automatic.

I. The ***Manual*** processes cover methods such as hand lay-up, spray-up, vacuum and pressure bag moulding.
II. The ***Semi-Automatic*** processes include processes such as cold pressing, hot pressing, compression moulding of SMC and DMC, resin injection.
III. The ***Automatic*** processes are those such as pultrusion, filament winding, centrifugal casting and injection moulding.

I) Manual Processing Methods

(a) Hand Lay-Up: This method is by far the most widely used processing method for fibre reinforced materials. Its major advantage is that it is a very simple process so that very little special equipment is needed and the moulds may be made from plaster, wood, sheet metal.

- The first step is to coat the mould with a release agent to prevent the moulding sticking to it.
- This is followed by a thin layer (approximately 0.3-0.4 mm) of pure resin (called a gelcoat) which has a number of functions.
    - Firstly it conceals the irregular mesh pattern of the fibres and this improves the appearance of the product when it is taken from the mould.
    - Secondly, and probably most important, it protects the reinforcement from attack by moisture which would tend to break down the fibre/resin interface.
- A tissue mat may be used on occasions to back up the gelcoat. This improves the impact resistance of the surface and also conceals the coarse texture of the reinforcement.
- When the gelcoat has been given time to partially cure the main reinforcement is applied.
    - Initially a coat of resin (unsaturated polyester is the most common) is brushed on.
    - Followed by layers of tailored glass mat positioned by hand.
    - A roller is then used to consolidate the mat and remove any trapped air as shown in Fig. 2.

The advantage of this technique is that the strength and stiffness of the composite can be controlled by building up the thickness with further layers of mat and resin as desired. Curing takes place at room temperature but heat is sometimes applied to accelerate this. Ideally any trimming should be carried out before the curing is complete because the material will still be sufficiently soft for knives or to be used. After curing, special cutting wheels may be needed.

Variations on this basic process are:

(i) *Vacuum bag moulding* where a flexible bag (frequently rubber) is clamped over the lay-up in the mould and a vacuum is applied between the moulding and the bag. This sucks the bag on to the moulding to consolidate the layers of reinforcement and resin. It also squeezes out trapped air and excess resin.

(ii) *Pressure bag moulding* which is similar in principle except that pressure is applied above the bag instead of a vacuum below it. The techniques are illustrated in Fig. 2(b) and (c).

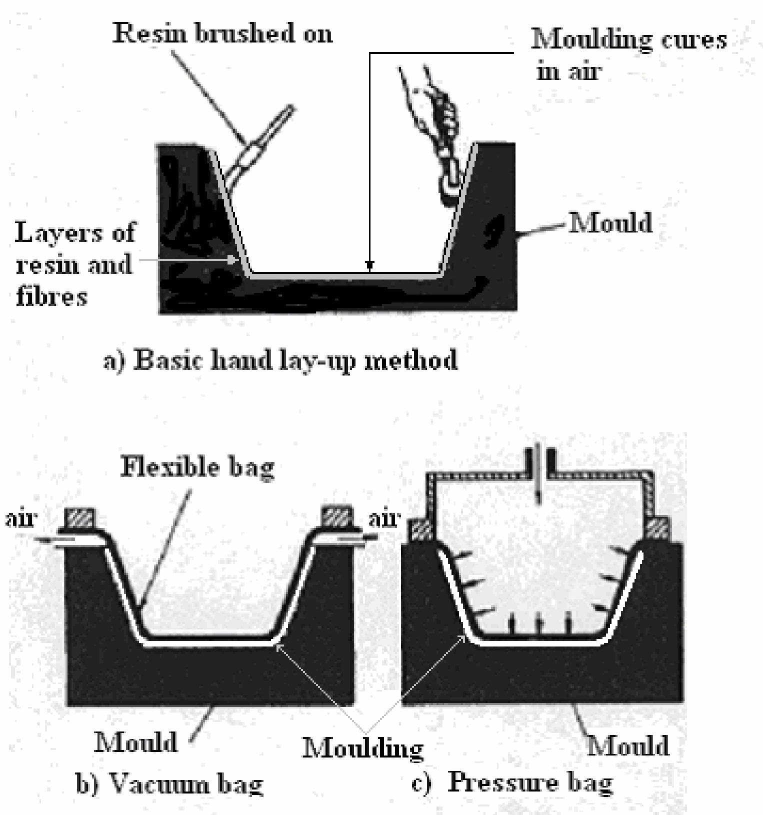

Fig 2 Hand lay-up techniques

(b) Spray-Up: In this process, the preparatory stages are similar to the previous method but instead of using glass mats the reinforcement is applied using a spray gun. Roving is fed to a chopper unit and the chopped strands are sprayed on to the mould simultaneously with the resin as shown in Fig. 3. The thickness of the moulding (and hence the strength) can easily be built up in sections likely to be highly stressed. However, the success of the method depends to a large extent on the skill of the operator since he controls the overall thickness of the composite and also the glass/resin ratio.

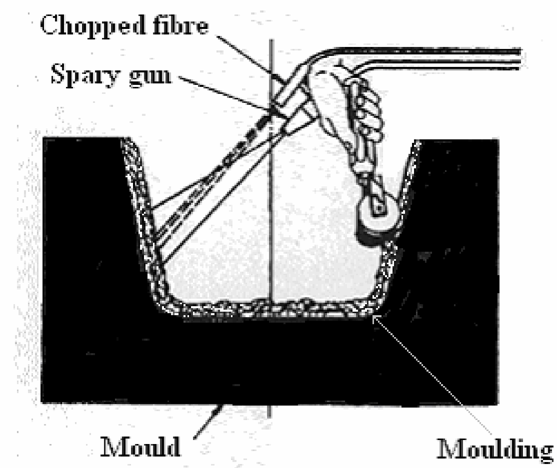

Fig. 3 Spray-up technique

II) Semi-Automatic Processing Methods

(a) Cold Press Moulding: The basis of this process is to utilize pressure applied to two unheated halves of a mould to disperse resin throughout a prepared fabric stack placed in the mould. The typical procedure is as follows:

- Release agent and gelcoat are applied to the mould surfaces.
- The fibre fabric is laid into the lower part of the open mould.
- The activated resin is then poured on top of the mat.

When the mould is closed the resin spreads throughout the reinforcement. High pressures are not necessary as the process relies on squeezing the resin throughout the reinforcement rather than forcing the composite into shape. A typical value of cycle time is about 10-15 minutes compared with several hours for hand lay-up methods. The process is illustrated in Fig. 4.

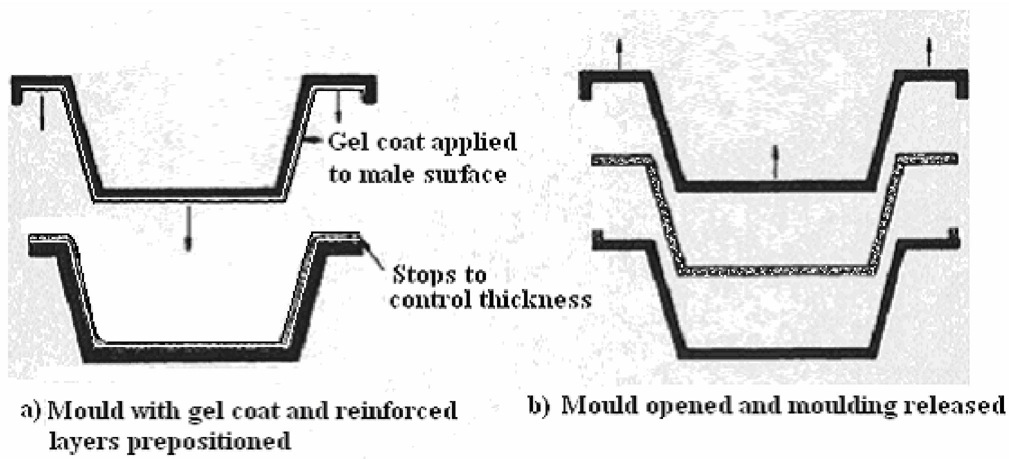

Fig. 4 Basic cold press moulding process

(b) Hot Press Mouldings: In this type of moulding the curing of the reinforced plastic is accelerated by the use of heat (≅ 180^{o}C) and pressure (≅ 15 MN/m^2). The general heading of Hot Press Moulding includes both preform moulding and compression moulding.

- ***Pre-form Moulding:*** This technique is particularly suitable for mass production and/or more complex shapes. There are two distinct stages:
  - A preform is made by, for spraying chopped fibres on to a perforated metal screen which has the general shape of the article to be moulded. The fibres are held on the screen by suction applied behind it (see Fig. 5).
  - A resin binder is then sprayed on the mat and the resulting preform is taken from the screen and cured in an oven at about 150^{o}C for several minutes.

Other methods by which the preform can be made include tailoring a continuous fibre fabric to shape and using tape to hold it together. The preform is then transferred to the lower half of the heated mould and the activated resin poured on top. The upper half of the mould is then brought into position to press the composite into shape. The cure time in the mould depends on the temperature, varying typically from 1 minute at 150^{o}C to 10 minutes at 80^{o}C. lf the mould was suitably prepared with release agent the moulding can then be ejected easily.

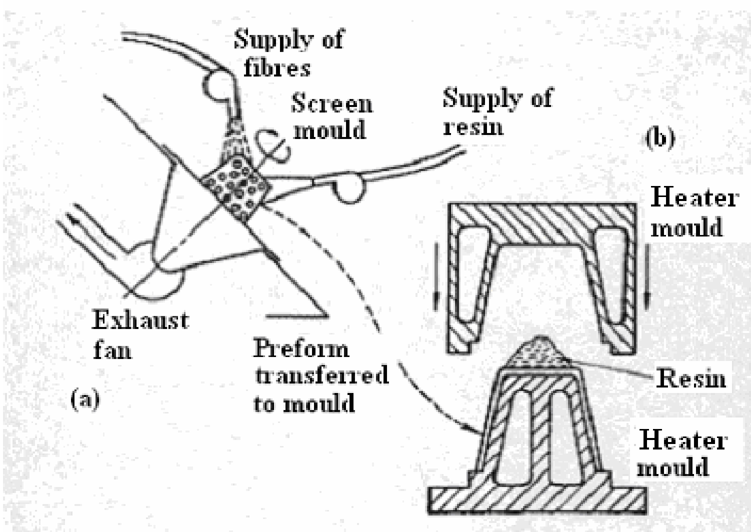

Fig. 5 Pre-form moulding

- ***Compression Moulding***:
  - *Sheet Moulding Compounds*: SMC is supplied as a pliable sheet which consists of a mixture of chopped strand mat or chopped fibres (25% by weight) pre-impregnated with resin, fillers, catalyst and pigment. It is ready for moulding and

so is simply placed between the halves of the heated mould. The application of pressure then forces the sheet to take up the contours of the mould. The beauty of the method is that the moulding is done 'dry' i.e. it is not necessary to pour on resins. Fig. 6 illustrates a typical method used to manufacture SMC material.

- Dough Moulding Compounds: DMC is supplied as a dough or rope and is a mixture of chopped strands (20% by weight) with resin, catalyst and pigment. It flows readily and so may be formed into shape by compression or transfer moulding techniques. In compression moulding the charge of dough may be placed in the lower half of the heated mould, although it is generally wise to preform it to the approximate shape of the cavity. When the mould is closed, pressure is applied causing the DMC to flow in all sections of the cavity. Curing generally takes a couple of minutes for mould temperatures in the region of 120 – *160*^{o}*C* although clearly this also depends on the section thickness.

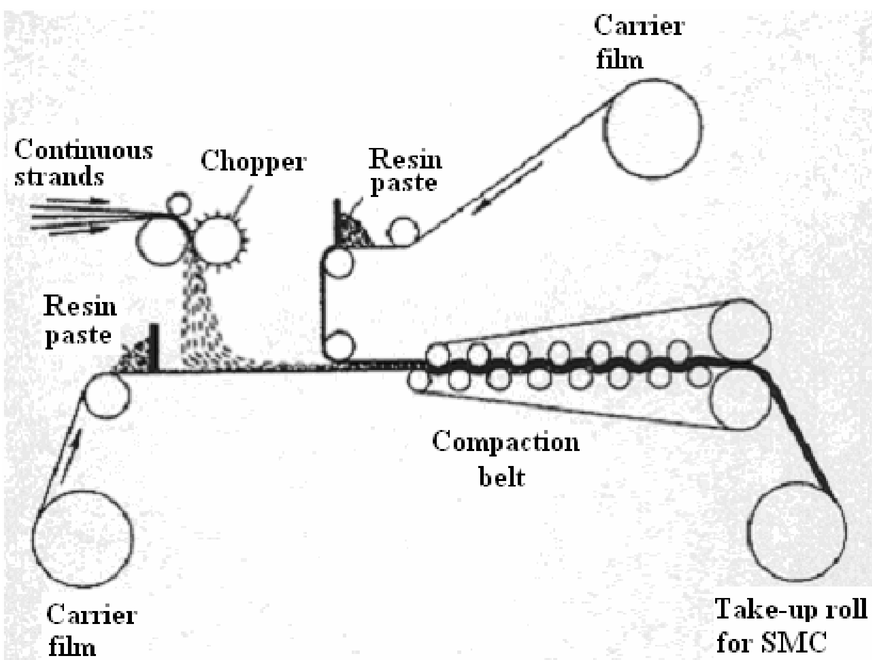

Fig. 6 Manufacture of SMC material

In general, SMC is particularly suitable for large shell-like mouldings - automotive parts such as body panels and fascia panels are ideal application areas. DMC finds its applications in the more complicated shapes such as business machine housings, electric drill bodies, etc. Its most famous application to date is the rear door of the Citroen BX saloon and the process is currently under active consideration for the rear door of a VW saloon car.

Other types of compression moulding and stamp forming used for continuous fibre reinforced composites are illustrated in Fig. 7.

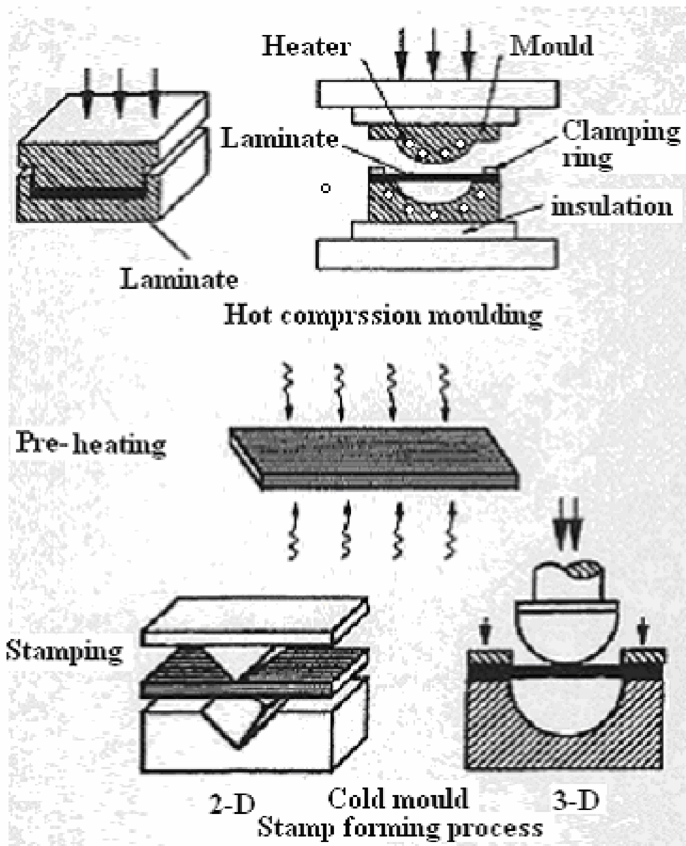

Fig. 7 Other types of compression moulding and stamp forming

(c) Resin Injection: This is a cold mould process using relatively low pressures (approximately 450 kN/m^2).

- The mould surfaces are prepared with release agent and gelcoat.
- The reinforcing mat is arranged in the lower half of the mould.
- The upper half is then clamped in position.
- The activated resin is injected under pressure into the mould cavity.

The advantage of this type of production method is that it reduces the level of skill needed by the operator because the quality of the mould will determine the thickness distribution in the moulded article (see Fig. 8).

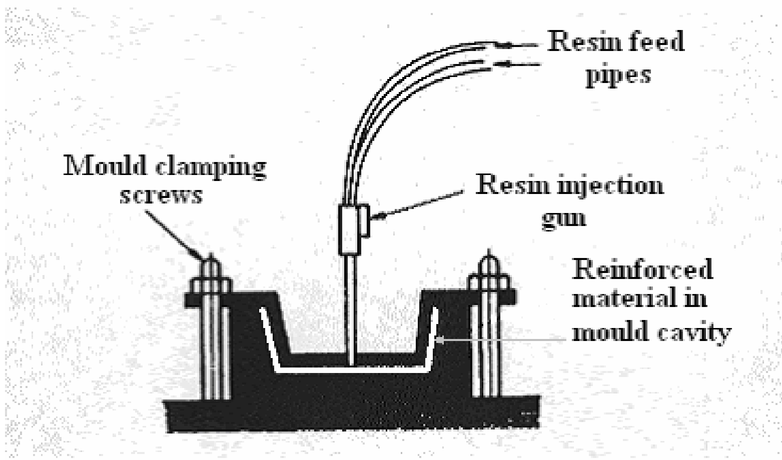

Fig. 8 Resin injection process

***(d) Vacuum Injection*:** This is a development of resin injection in which a vacuum is used to draw resin throughout the reinforcement. It overcomes the problem of voids in the resin/fibre laminate and offers faster cycle times with greater uniformity of product.

III) Automatic Processes

(a) Filament Winding: In this method, continuous strands of reinforcement are used to gain maximum benefit from the fibre strength. In a typical process rovings or single strands are passed through a resin bath and then wound on to a rotating mandrel. By arranging for the fibres to traverse the mandrel at a controlled and/or programmed manner, as illustrated in Fig. 9, it is possible to lay down the reinforcement in any desired fashion. This enables very high strengths to be achieved and is particularly suited to pressure vessels where reinforcement in the highly stressed hoop direction is important.

In the past a limitation on this process was that it tended to be restricted to shapes which were symmetrical about an axis of rotation and from which the mandrel could be easily extracted. However, in recent years there have been major advances through the use of collapsible or expendable cores and in particular through the development of computer-controlled winding equipment.

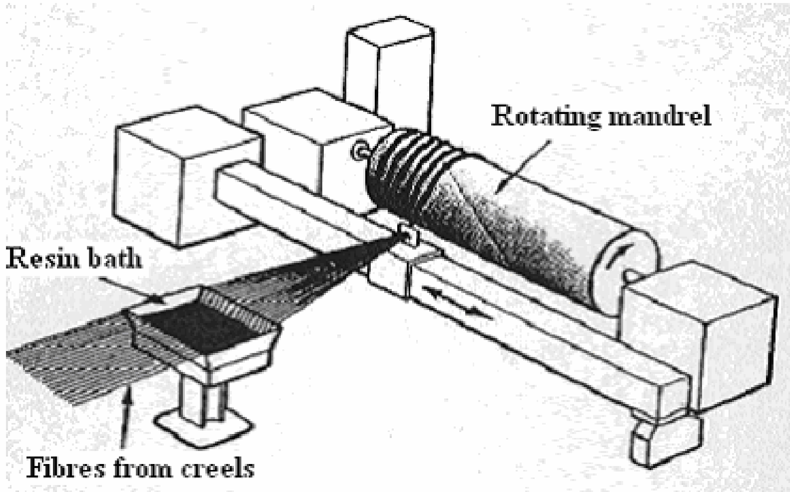

Fig. 9 Filment winding of fibre composites

(b) Centrifugal Casting: This method is used for cylindrical products which can be rotated about their longitudinal axis. Resin and fibres are introduced into the rotating mould/mandrel and are thrown out against the mould surface. The method is particularly suited to long tubular structures which can have a slight taper e.g. street light columns, telegraph poles, pylons, etc.

(c) Pultrusion: This is a continuous production method similar in concept to extrusion. Woven fibre mats and/or rovings are drawn through a resin bath and then through a die to form some desired shape (for example a 'plank' as illustrated in Fig. 10). The profiled shape emerges from the die and then passes through a tunnel oven to accelerate the curing of the resin. The pultruded composite is eventually cut to length for storage. A wide range of pultruded shapes may be produced - U channels, I beams, aerofoil shapes, etc.

(d) Injection Moulding: The injection moulding process can also be used for fibre reinforced thermoplastics and thermosets, for example DMC materials. This offers considerable advantages over compression moulding due to the higher production speeds, more accurate metering and lower product costs which can be achieved.

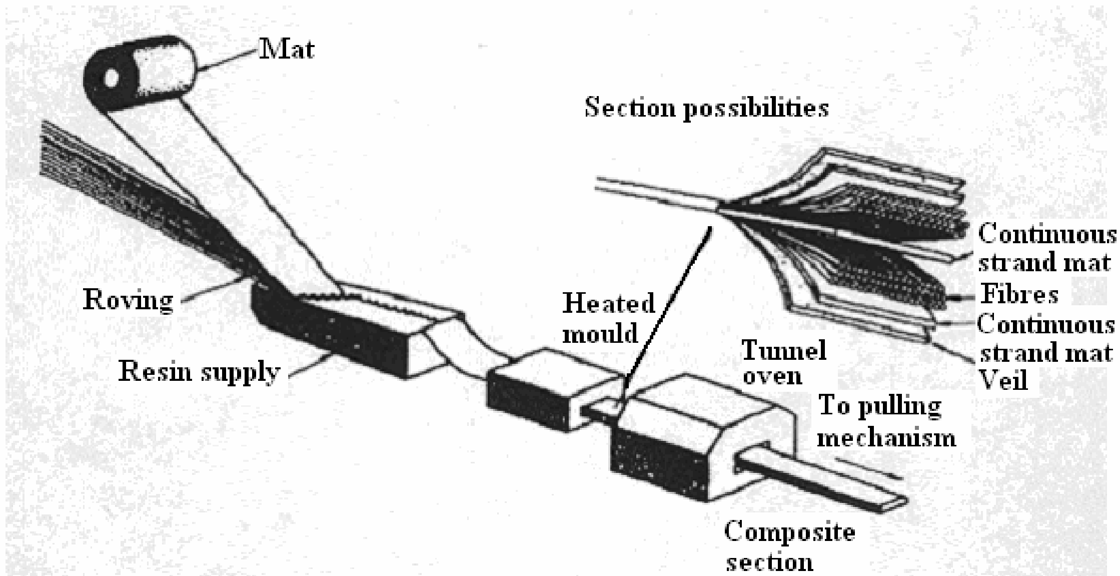

Fig. 10 Pultrusion process