<u>Typical examples of thermoplastics</u> include polyethylene, polystyrene, polyether–ether–ketone (PEEK), and polyphenylene sulfide (PPS).

Thermoplastic Advantages:

- Highly recyclable
- High-Impact resistance
- Reshaping capabilities
- Chemical resistant
- Aesthetically superior finishes
- Hard crystalline or rubbery surface options

Thermoplastic Disadvantages:

- Expensive
- Can melt if heated.

What are Current Manufacturing Methods of Polymer Matrix Composites?

1) Hand Lay-up Technique:

Hand layup is an oldest open-mold process used for the composite manufacturing. This process is simple, and it is a low-volume and labor-intensive process. Large components, such as boat hulls, can be prepared by this technique. Reinforcing mat or woven fabric or roving is placed manually in the open mold, and resin is poured, brushed, or sprayed over and into the glass plies. Squeegees or rollers are used to remove the entrapped air manually to complete the laminated structure as shown in Fig.1.3. The most commonly used matrixes are polyesters and epoxies that can be cured at room temperature. The time of curing depends on the type of polymer used for composite processing. For example, for epoxy-based system, normal curing time at room temperature is 24–48 h. A catalyst and accelerator are added to the resin, which enables room-temperature curing of the resin. In order to get high quality part surface, a pigmented gel layer is first applied on the mold surface. Hand layup is the most commonly preferred process for the manufacture of polymeric composites. Composites were basically manufactured by hand lay-up process, using a fiber-to-resin ratio of 40:60 (w:w).

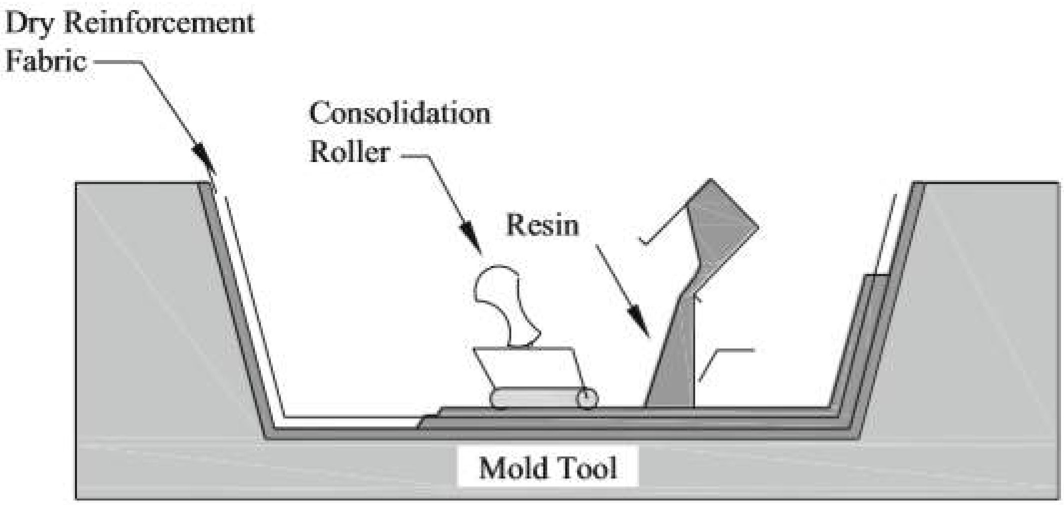

Fig. 1.3 Schematic of hand layup

2) Vacuum Bag Molding

In vacuum bag molding, the entrapped air and excess resin are removed using vacuum. After fabrication of the lay-up, a perforated release film or peel ply is placed over the laminate. The bleeder ply, which is placed above the peel ply, is made of fiber glass cloth, nonwoven nylon, polyester cloth, or other material that absorbs excess resin from the laminate, followed by a breather ply of a nonwoven fabric. The vacuum bag is placed over the entire assembly and sealed at the mold flange as shown in Fig. 1.4.

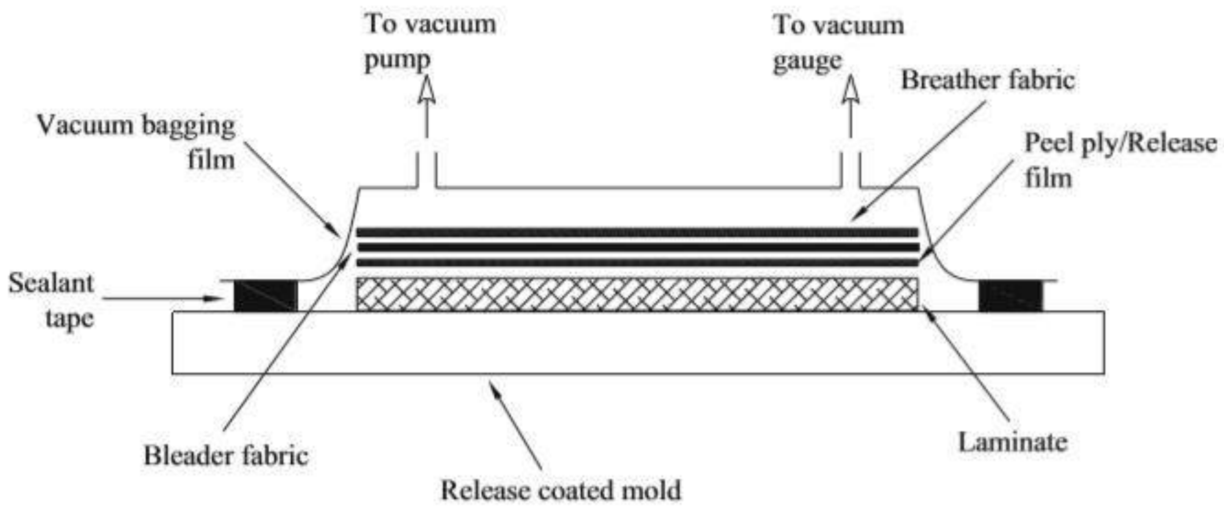

Fig. 1.4 Schematic of vacuum bag molding

A vacuum is created under the bag, and thus the laminate can be merged by applying a pressure up to one atmosphere. This process provides a high reinforcement, improved adhesion between layers, and great control of fiber volume percent compared to the hand lay-up.

Major advantages of vacuum bag molding are higher fiber content in the laminate, lower void content, better fiber wet-out, and reduced volatile emissions as compared to the hand layup. Large cruising boats and racing car components can be manufactured by vacuum bag molding. Disadvantages of vacuum bag molding include expensive and disposable bagging materials, labor intensive, inconsistent performance, trapped air/volatiles, wrinkles, loss of seal, and requirement of higher level of operator skills.

3) Pressure Bag Molding (or Autoclave)

Pressure bag molding or autoclave is identical to the vacuum bag molding except that the pressure, usually provided by compressed air or water, is applied to the flexible bag that covers the prepreg composite. The application of pressure forces out the entrapped air, vapors, and excess resin. It also facilitates better wetting of fibers.

Autoclaves are basically heated pressure vessels. These are usually provided with the vacuum systems. The bagged lay-up is cured inside the autoclave as shown in Fig.1.5.

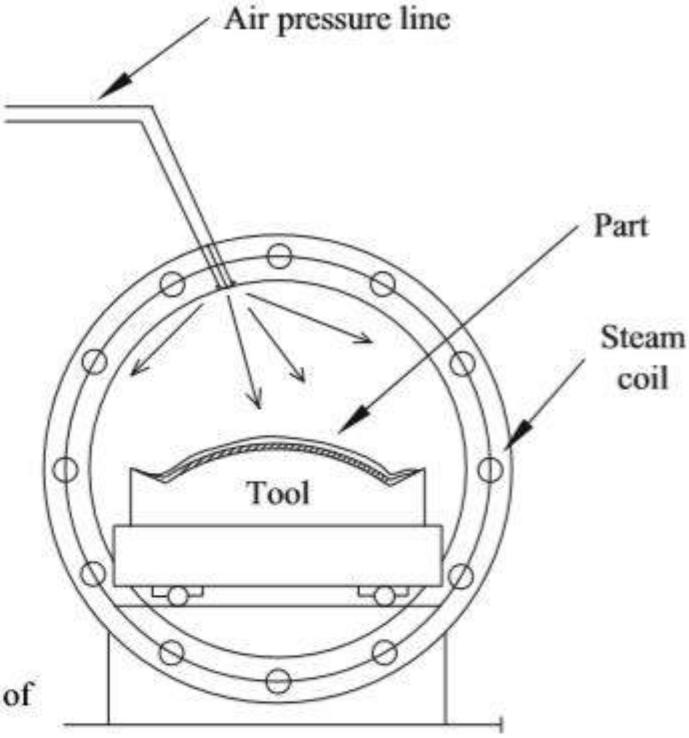

Fig. 1.5 Schematic of autoclave

The process of autoclave involves application of higher heat and uniform pressure on the component during curing, which results in a denser and low void percentage product. The autoclave equipment and tooling are expensive and it is only suitable for high-end applications. The pressures required for curing are typically in the range of one to six bars and takes several hours to complete the curing. This method accommodates higher temperature matrix resins having properties higher than the conventional resins, such as epoxies. Component size is limited by the autoclave size. It is mostly used in the aerospace industry to manufacture high-strength/weight ratio parts from pre-impregnated high-strength fibers for aircraft, spacecraft, and missiles.

4) Filament Winding

This process consists of a rotating mandrel on which pre-impregnated fibers or reinforcement is wound in the preset patterns. The method provides the best control of fiber placement.The wet method is shown in Fig. 1.6. Here,the fiber is allowed to pass through a bath containing low-viscosity resin. In the dry method, the pre-impregnated reinforcing layers are wound on the mandrel, and then the component is removed and postcured.

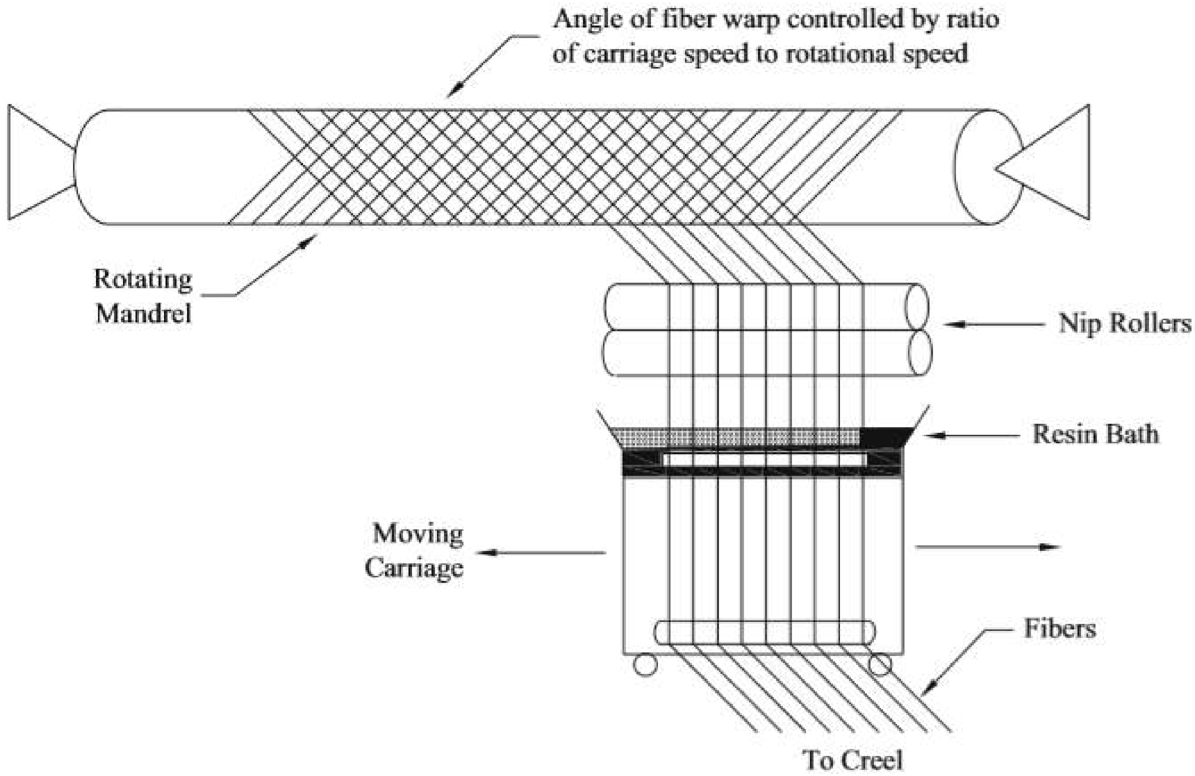

Fig. 1.6 Schematic of filament winding

Conventionally, this process is used to make pressure vessels, rocket motor cases, tanks, ducting, golf club shafts, and fishing rods. Recently, non-cylindrical and nonspherical composite parts are also produced by filament winding technology. Polyesters, vinyl esters, epoxies, and phenolics are the typical thermoset resins used in the filament wound parts. This process is best suited for parts with rotational symmetry, but it is possible to wind odd-shaped parts using a robotized winding. It requires special equipment and may result in variation in the part thickness in case of tapered parts. The tooling and setup cost is high and it is only suitable for a limited variety of components.

5) Resin Transfer Molding

Resin transfer molding (RTM) is a low-pressure closed molding process for moderate- and high-volume production. This process basically involves placement of the dry stack of reinforcement in the bottom part of the mold, and then the other half is clamped over the bottom mold. For complex shapes, preforms are used. After closing the mold, a low-viscosity resin containing catalyst is pumped in, which displace the air through strategically located vents. The resin/catalyst ratios are controlled by metered mixing equipment and injected into the mold port as shown in Fig. 1.8.

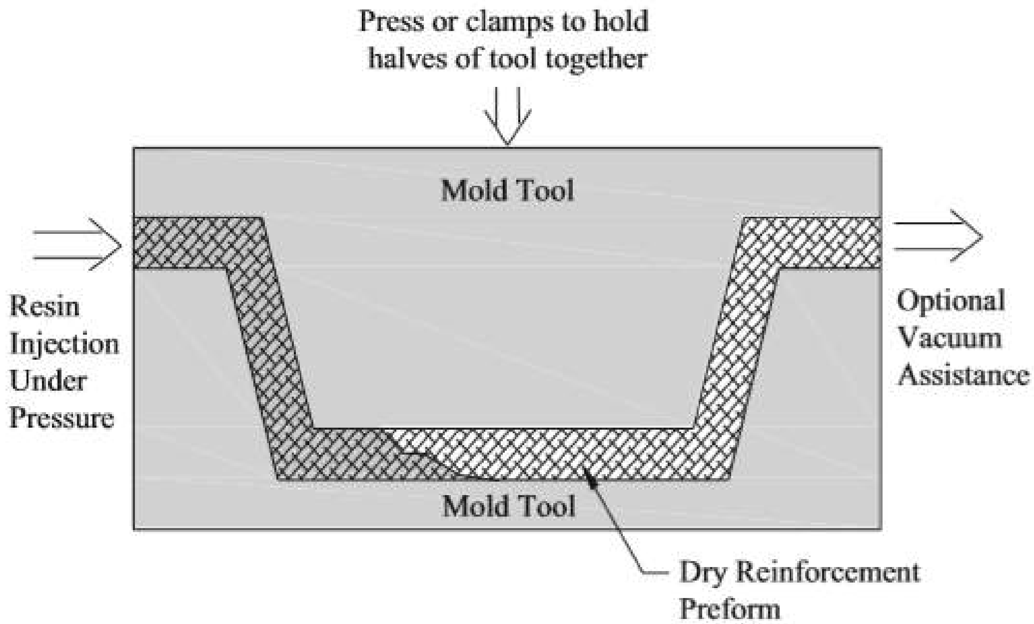

Fig. 1.8 Schematic of resin transfer molding

The commonly used matrix resins include polyester, vinyl ester, epoxy, and phenolics. Both injection and curing can take place at either ambient or elevated temperature. In order to have optimum surface finish, a gel coat is applied to the mold surface prior to molding. High-quality parts such as automotive body parts, bathtubs, and containers are produced by this method. The variation in injection pressure has no effect on the quality of moldings. A wide range of resin viscosities has been successfully molded by this technique (RTM). It can produce laminates having high fiber volume with very low void contents. It is safe for the health and environment due to the enveloping of resin. Component prepared by RTM has molded surface on both sides. The disadvantages of RTM process are need of heavy and expensive tooling to withstand pressures, limitation in size of the components, and very expensive scrap parts due to un-impregnated areas.