Basic Processing Steps

The major steps performed during the pultrusion process are described here. These steps are common in most pultrusion processes:

1. Spools of fiber yarns are kept on creels.
2. Several fiber yarns from the spool are taken and passed through the resin bath.
3. Hardener and resin systems are mixed in a container and then poured in the resin bath.
4. The die is heated to a specified temperature for the cure of resin.
5. Resin-impregnated fibers are then pulled at constant speed from the die, where resin gets compacted and solidified.
6. The pultruded part is then cut to the desired length.
7. The surface is prepared for painting. Surface preparation is an important element to perform finishing operations because the pultrusion process utilizes internal mold releases. These mold releases are a form of wax that form a film on the outer surface of the part. This film can be removed by solvent wiping, sanding, or sandblasting. Solvent wiping is the simplest method of surface preparation. Several solvents (e.g., toluene, xylene, methylene chloride, or acetone) can be used for this purpose.

Advantages of the Pultrusion Process

Pultrusion is an automated process with the following advantages:

1. It is a continuous process and can be completely automated to get the finished part. It is suitable for making high-volume composite parts. Typical production speeds are 2 to 10 ft/min.
2. It utilizes low-cost fiber and resin systems and thus provides production of low-cost commercial products.

Limitations of the Pultrusion Process

Pultruded components are used on a large scale in infrastructure, building, and consumer products because of lower product cost. However, pultrusion has the following limitations.

1. It is suitable for parts that have constant cross-sections along their length. Tapered and complex shapes cannot be produced.
2. Very high-tolerance parts on the inside and outside dimensions cannot be produced using the pultrusion process.
3. Thin wall parts cannot be produced.
4. Fiber angles on pultruded parts are limited to 0°. Fabrics are used to get bidirectional properties.

Limitations of the Filament Winding Process

Filament winding is highly suitable for making simple hollow shapes. However, the process has the following limitations.

1. It is limited to producing closed and convex structures. It is not suitable for making open structures such as bathtubs. In some applications, filament winding is used to make open structures such as leaf springs, where the filament wound laminate is cut into two halves and then compression molded.
2. Not all fiber angles are easily produced during the filament winding process. In general, a geodesic path is preferred for fiber stability. Low fiber angles (0 to 15°) are not easily produced.
3. The maximum fiber volume fraction attainable during this process is only 60%.
4. During the filament winding process, it is difficult to obtain uniform fiber distribution and resin content throughout the thickness of the laminate.

5. Pultrusion Process

The pultrusion process is a low-cost, high-volume manufacturing process inn which resin-impregnated fibers are pulled through a die to make the part. The process is similar to the metal extrusion process, with the difference being that instead of material being pushed through the die in the extrusion process, it is pulled through the die in a pultrusion process. Pultrusion creates parts of constant cross-section and continuous length. Pultrusion is a simple, low-cost, continuous, and automatic process. Figure (5) illustrates a typical pultrusion process in which resin-impregnated yarns are pulled through a heated die at constant speed. As the material passes through the heated die, it becomes partially or completely cured. Pultrusion yields smooth finished parts that usually do not require post-processing.

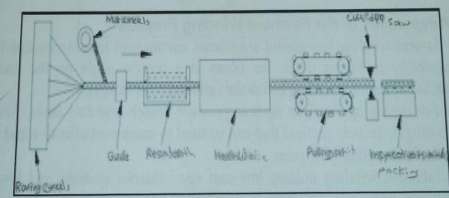

FIGURE (5) Illustration of a pultrusion process.

Basic Processing Steps

The steps during the RTM process are summarized below:

1. A thermoset resin and catalyst are placed in tanks A and B of the dispensing equipment.
2. A release agent is applied to the mold for easy removal of the part. Sometimes, a gel coat is applied for good surface finish.
3. The preform is placed inside the mold and the mold is clamped.
4. The mold is heated to a specified temperature.
5. Mixed resin is injected through inlet ports at selected temperature and pressure. Sometimes, a vacuum is created inside the mold to assist in resin flow as well as to remove air bubbles.
6. Resin is injected until the mold is completely filled. The vacuum is turned off and the outlet port is closed. The pressure inside the mold is increased to ensure that the remaining porosity is collapsed.
7. After curing for a certain time (6 to 20 min, depending on resin chemistry), the composite part is removed from the mold.

Advantages of the Resin Transfer Molding Process

Recently, RTM has gained importance in the composites industry because of its potential to make small to large complex structures in a cost-effective manner. RTM provides opportunities to use continuous fibers for the manufacture of structural components in low- to medium-volume environments. Some of its major advantages over other composites manufacturing techniques include:

1. Initial investment cost is low because of reduced tooling costs and operating expenses as compared to compression molding and injection molding. For this reason, prototypes are easily made for market evaluation. For example, the dish antenna was first made using an RTM process to validate the design features before capital investment was made for compression molding of SMC parts.
2. Moldings can be manufactured close to dimensional tolerances.
3. RTM processing can make complex parts at intermediate volume rates. This feature allows limited production runs in a cost-effective manner. This lends benefits to the automotive market, in which there is a growing need toward lower production volumes per car model and quicker changes to appeal to more niche markets.
4. RTM provides for the manufacture of parts that have a good surface finish on both sides. Sides can have similar or dissimilar surface finishes.

5. Structures requiring complex loading cannot be produced using this process because the properties are mostly limited to the axial direction.

6. Resin Transfer Molding Process

The resin transfer molding (RTM) process is also known as a liquid transfer molding process. Although injection molding and compression molding processes have gained popularity as high-volume production methods, their use is mostly limited to nonstructural applications because of the use of molding compounds (short fiber composites). In contrast to these molding processes, the RTM process offers production of cost-effective structural parts in medium-volume quantities using low-cost tooling. RTM offers the fabrication of near-net-shape complex parts with controlled fiber directions. Continuous fibers are usually used in the RTM process. In the RTM process, a preform is placed into the mold cavity. A matching mold half is mated to the first half and the two are clamped together. Then, using dispensing equipment, a pressurized mixture of thermoset resin, a catalyst, color, filler, etc., is pumped into the mold using single or multiple ports in the mold. After curing for 6 to 30 min, depending on the cure kinetics of the mixture, the part is then removed from the mold. Thus, RTM results in the production of structural parts with good surface finish on both sides of the part. The main issues in the RTM process are resin flow, curing, and heat transfer in porous media. The process involves injecting a precatalyzed thermosetting resin under pressure into a heated mold cavity that contains a porous fiber preform. During mold filling, the resin flows into the mold and experiences exothermic curing reactions, causing its viscosity to increase over time and finally solidification. After the fiber preform is completely saturated with resin, cure reactions continue past the gel-point to form a cross-linked polymer. The RTM process is a closed mold operation in which a dry fiber perform is placed inside a mold and then the thermoset resin is injected through an inlet port until the mold is filled with resin. The resin is then cured and the part is removed from the mold. Figure (6) shows Schematics of the RTM process.

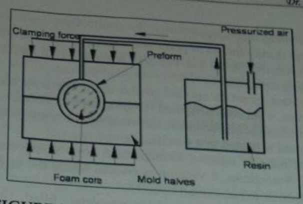

FIGURE (6) Schematics of the RTM process

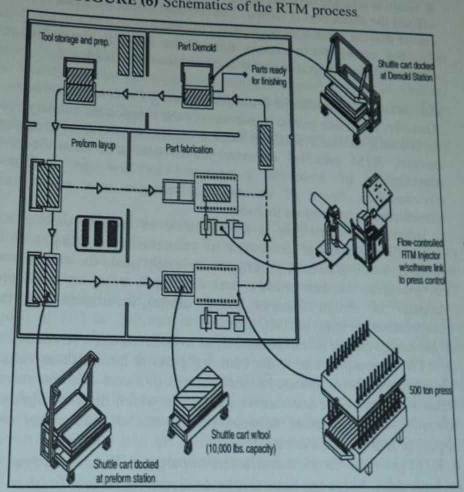

FIGURE (7) A typical production flow diagram during the RTM process.