4

Composite Materials

Contents

4.1 Introduction to Composites

In addition to metals, ceramics, and polymers, a fourth material category can be distinguished: composites. A composite material is a material system composed of two or more physically distinct phases whose combination produces aggregate properties that are different from those of its constituents. In certain respects, composites are the most interesting of the engineering materials because their structure is more complex than the other three types. The technological and commercial interest in composite materials derives from the fact that their properties are not just different from their components but are often far superior.

- Composites can be designed that are very strong and stiff, yet very light in weight, giving them strength-to-weight and stiffness-to-weight ratios several times greater than steel or aluminum.
- These properties are highly desirable in applications ranging from commercial aircraft to sports equipment.
- Fatigue properties are generally better than for the common engineering metals. Toughness is often greater, too.
- Composites can be designed that do not corrode like steel; this is important in automotive and other applications.
- With composite materials, it is possible to achieve combinations of properties not attainable with metals, ceramics, or polymers alone.
- Better appearance and control of surface smoothness are possible with certain composite materials.

Along with the advantages, there are disadvantages and limitations associated with composite materials.

- Properties of many important composites are anisotropic, which means the properties differ depending on the direction in which they are measured;
- Many of the polymer-based composites are subject to attack by chemicals or solvents, just as the polymers themselves are susceptible to attack;
- Composite materials are generally expensive, although prices may drop as volume increases; and
- Certain of the manufacturing methods for shaping composite materials are slow and costly.

There are five basic types of composite materials: Fiber, particle, flake, laminar or layered and filled composites.

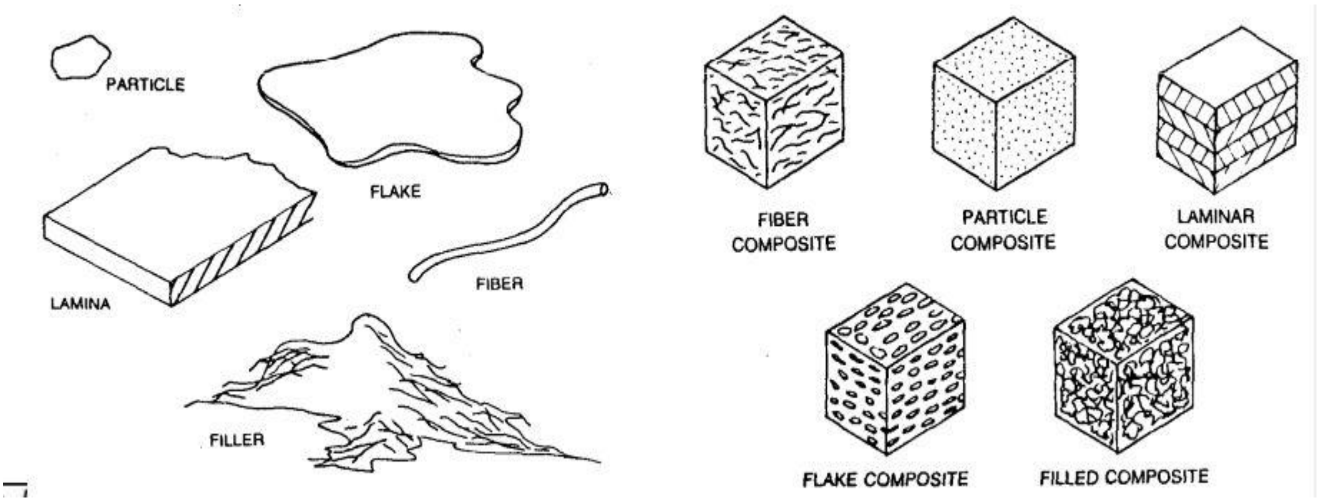

Fig.4.1 Various types of Composite Material

4.2 Classification of Composite Materials

As noted in the definition, a composite material consists of two or more distinct phases. The term phase indicates a homogeneous material, such as a metal or ceramic in which all of the grains have the same crystal structure, or a polymer with no fillers.

By combining the phases, using methods yet to be described, a new material is created with aggregate performance exceeding that of its parts. The effect is synergistic.

Composite materials can be classified in various ways. One possible classification distinguishes between (1) traditional and (2) synthetic composites.

Traditional composites are those that occur in nature or have been produced by civilizations for many years. Wood is a naturally occurring composite material, while concrete (Portland cement plus sand or gravel) and asphalt mixed with gravel are traditional composites used in construction.

Synthetic composites are modern material systems normally associated with the manufacturing industries, in which the components are first produced separately and then combined in a controlled way to achieve the desired structure, properties, and part geometry. These synthetic materials are the composites normally thought of in the context of engineered products.

The classification system for composite materials used in this book is based on the matrix phase.

Metal Matrix Composites (MMCs) include mixtures of ceramics and metals, such as cemented carbides and other cermets, as well as aluminum or magnesium reinforced by strong, high stiffness fibers.

Ceramic Matrix Composites (CMCs) are the least common category. Aluminum oxide and silicon carbide are materials that can be imbedded with fibers for improved properties, especially in high temperature applications.

Polymer Matrix Composites (PMCs) Thermosetting resins are the most widely used polymers in PMCs. Epoxy and polyester are commonly mixed with fiber reinforcement, and phenolic is mixed with powders. Thermoplastic molding compounds are often reinforced, usually with powders.

The classification can be applied to traditional composites as well as synthetics. Concrete is a ceramic matrix composite, while asphalt and wood are polymer matrix composites.

The matrix material serves several functions in the composite. First, it provides the bulk form of the part or product made of the composite material. Second, it holds the imbedded phase in place, usually enclosing and often concealing it. Third, when a load is applied, the matrix shares the load with the secondary phase, in some cases deforming so that the stress is essentially born by the reinforcing agent.

Fig.4.2 Possible physical shapes of imbedded phases in composite materials: (a) fiber, (b) particle (c) flake.

4.3 Mathods of Manufacturing

- Open Mold Processes- some of the original FRP manual procedures for laying resins and fibers onto forms
- Closed Mold Processes- much the same as those used in plastic molding
- Filament Winding - continuous filaments are dipped in liquid resin and wrapped around a rotating mandrel, producing a rigid, hollow, cylindrical shape
- Pultrusion Processes- similar to extrusion only adapted to include continuous fiber reinforcement
- Other PMC Shaping Processes.

4.3.1 Hand Layup Method

- Open mold shaping method in which successive layers of resin and reinforcement are manually applied to an open mold to build the laminated FRP composite structure
- Labor-intensive • Finished molding must usually be trimmed with a power Finished molding must usually be trimmed with a power saw to size outside edges
    - Oldest open mold method for FRP laminates, dating to the 1940s when it was first used for boat hulls
    - Hand lay–up, or contact molding, is the oldest and simplest way of making fiberglass–resin composites. Applications are standard wind turbine blades, boats, etc.)

Steps Hand Layup Method

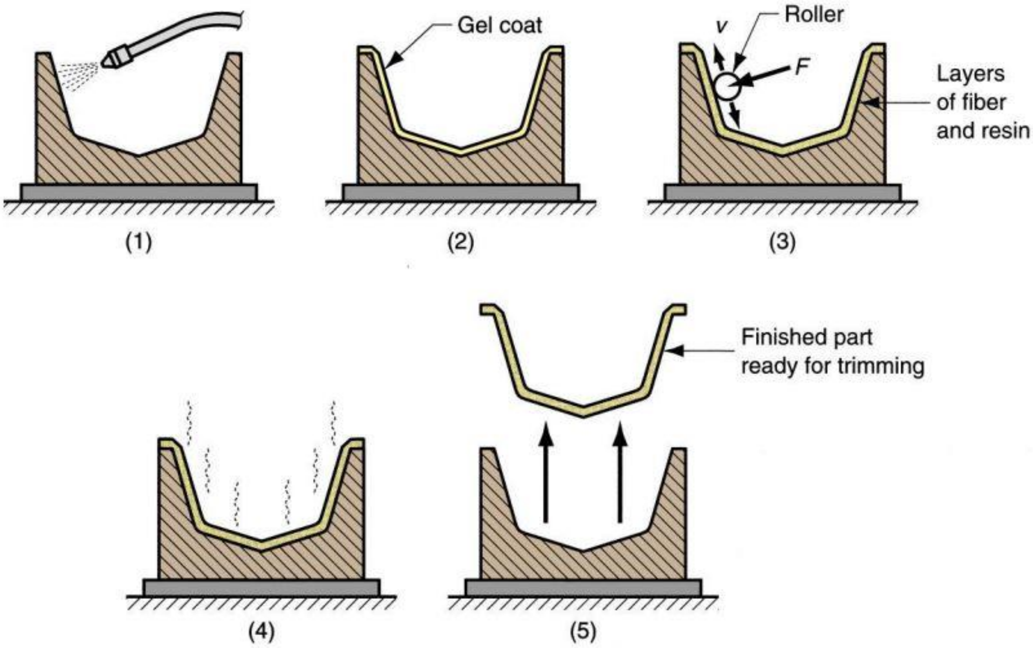

Fig.4.3 Hand Layup Method

1. mold is treated with mold release agent;
2. thin gel coat (resin) is applied, to the outside surface of molding;
3. when gel coat has partially set, layers of resin and fiber are applied, the fiber is in the form of mat or cloth; each layer is rolled to impregnate the fiber with resin and remove air;
4. part is cured;
5. fully hardened part is removed from mold.

Applications

Generally large in size but low in production quantity - not economical for high production

- Boat hulls
- Swimming pools
- Large container tanks
- Movie and stage props
- Other formed sheets
- The largest molding ever made was ship hulls for the British Royal Navy: 85 m (280 ft) long

4.3.2 Spray up Method

- Liquid resin and chopped fibers are sprayed onto an open mold to build successive FRP laminations
- Attempt to mechanize application of resin-fiber layers and reduce lay-up time
- Alternative for step (3) in the hand lay -up procedure

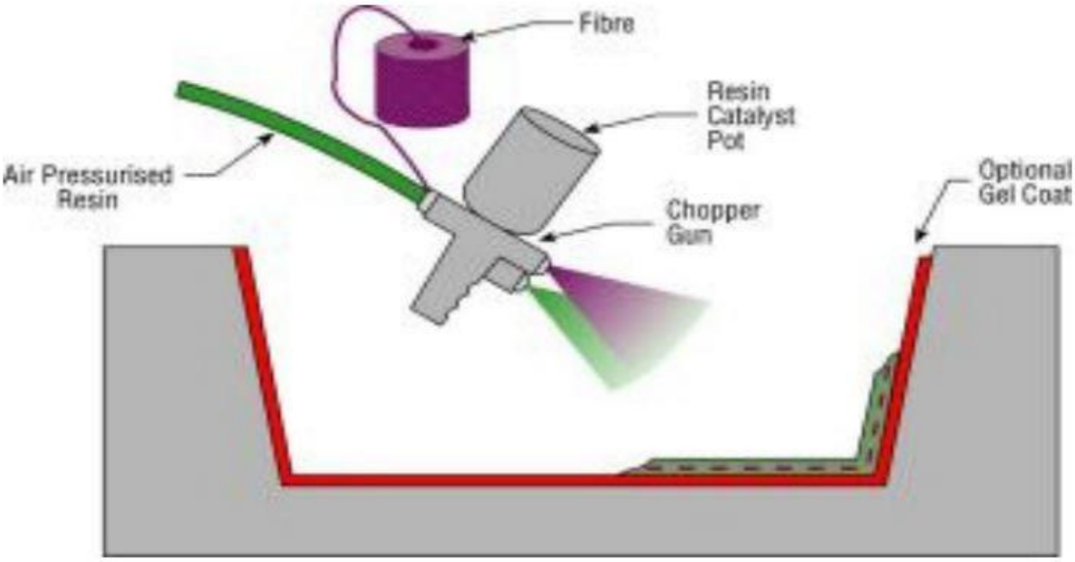

Fig.4.4 Sprayup Method

- In Spray–up process, chopped fibers and resins are sprayed simultaneously into or onto the mold. Applications are lightly loaded structural panels, e.g. caravan bodies, truck fairings, bathtubes, small boats, etc.

4.3.3 Vaccume Bagging Method

- The vacuum–bag process was developed for making a variety of components, including relatively large parts with complex shapes.
- Applications are large cruising boats, racecar components, etc.

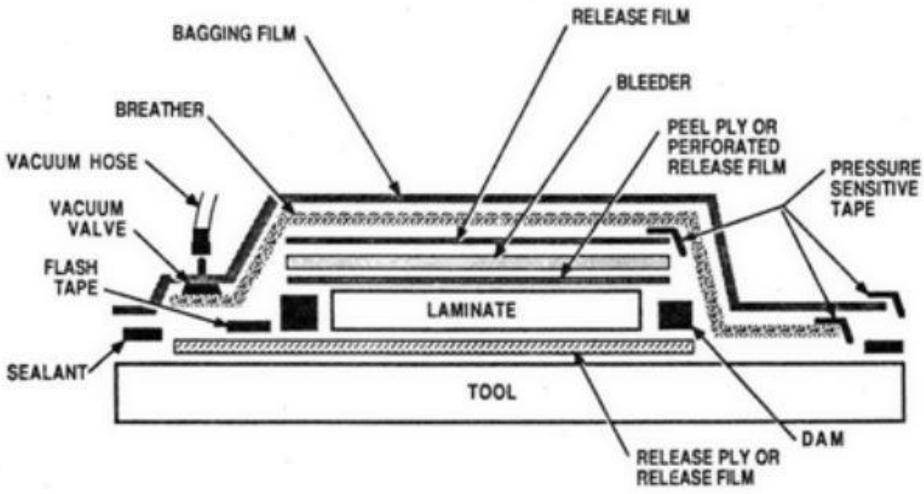

Fig.4.5 Vaccume Bagging Method

- Use atmospheric pressure to suck air from under vacuum bag, to compact composite layers down and make a high quality laminate
- Layers from bottom include: mold, mold release, composite, peel-ply, breather cloth, vacuum bag, also need vacuum valve, sealing tape.

4.3.4 Filament Winding

- Resin-impregnated continuous fibers are wrapped around a rotating mandrel that has the internal shape of the desired FRP product; the resin is then cured and the mandrel removed .
- The fiber rovings are pulled through a resin bath immediately before being wound in a helical pattern onto the mandrel.

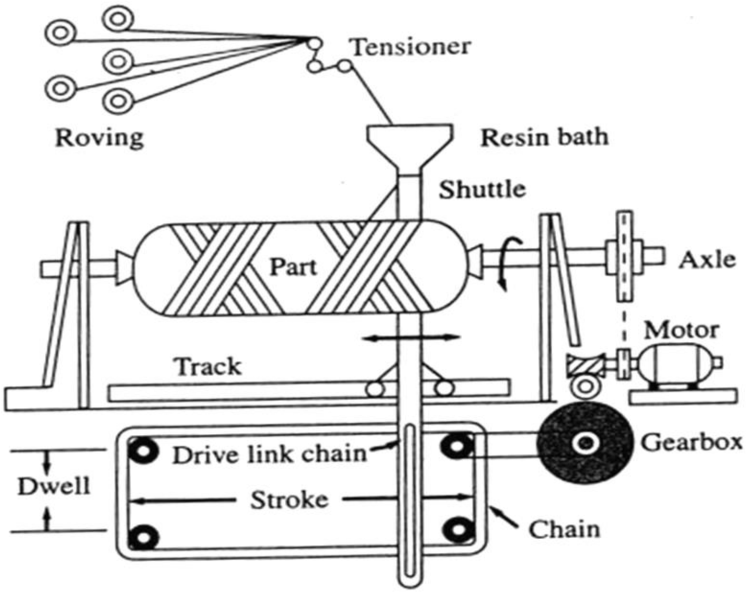

Fig.4.6 Filament Winding

- The operation is repeated to form additional layers, each having a criss-cross pattern with the previous, until the desired part thickness has been obtained.

Highly automated

– low manufacturing costs if high throughput

– e.g., Glass fiber pipe, sailboard masts

4.3.5 Pultrusion Process

- Similar to extrusion (hence the name similarity) but workpiece is pulled through die (so prefix "pul-" in place of "ex-")
- Like extrusion, pultrusion produces continuous straight sections of constant cross section
- Developed around 1950 for making fishing rods of glass fiber reinforced polymer (GFRP)
- A related process, called pulforming, is used to make parts that are curved and which may have variations in cross section throughout their lengths

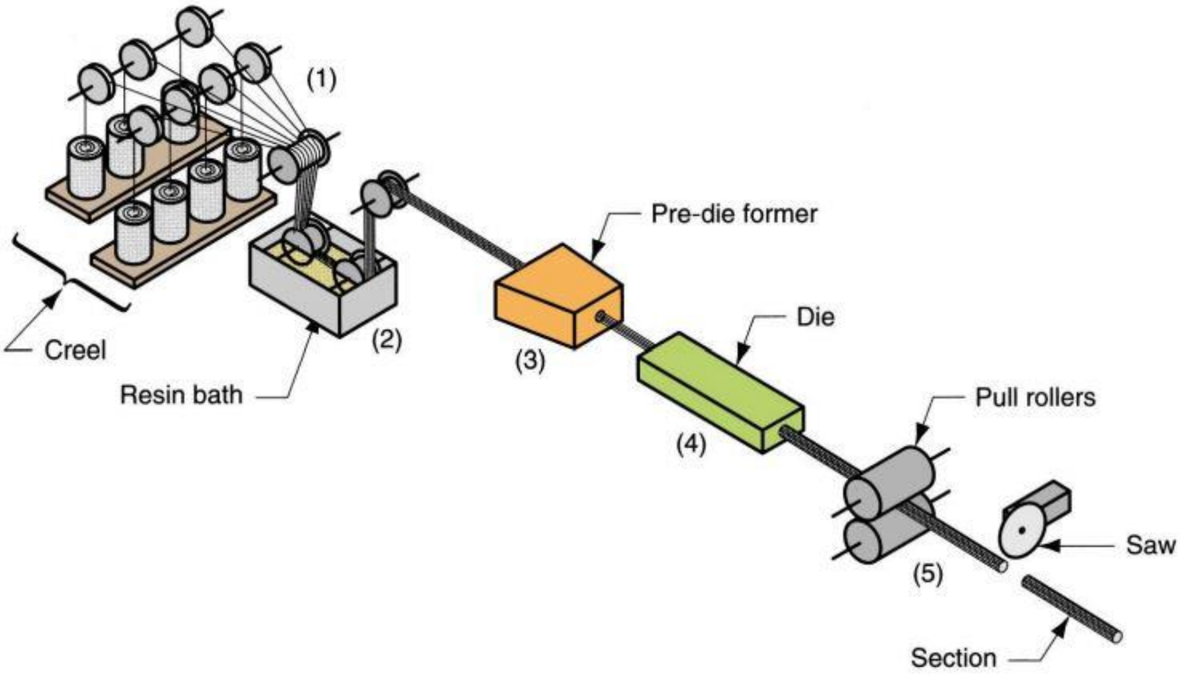

Fig.4.7 Pultrusion Process

- Continuous fiber rovings are dipped into a resin bath and pulled through a shaping die where the impregnated resin cures.
- The sections produced are reinforced throughout their length by continuous fibers
- Like extrusion, the pieces have a constant cross section, whose profile is determined by the shape of the die opening
- The cured product is cut into long straight sections

4.3.6 Resin Transfer Moulding Process

- In 1976, Osborne Industries, Inc., originated and initiated the closed-mold molding process that was later known in the plastics industry as resin transfer molding, or RTM.
- The resin transfer molding process has been in use ever since. RTM is one of the best methods for mass production of composite parts.
- It is primarily used to mold components with large surface areas, complex shapes and smooth finishes.
- The automotive, industrial equipment and agriculture industries have used the resin transfer molding process for decades for these reasons.
- Below we discuss a more detailed step-by-step of the resin transfer molding process and its advantages.

CREATING THE PREFORM

- The preform, or contoured fiberglass reinforcement, is the matrix, already in the shape of the finished product, into which the resin will be injected.

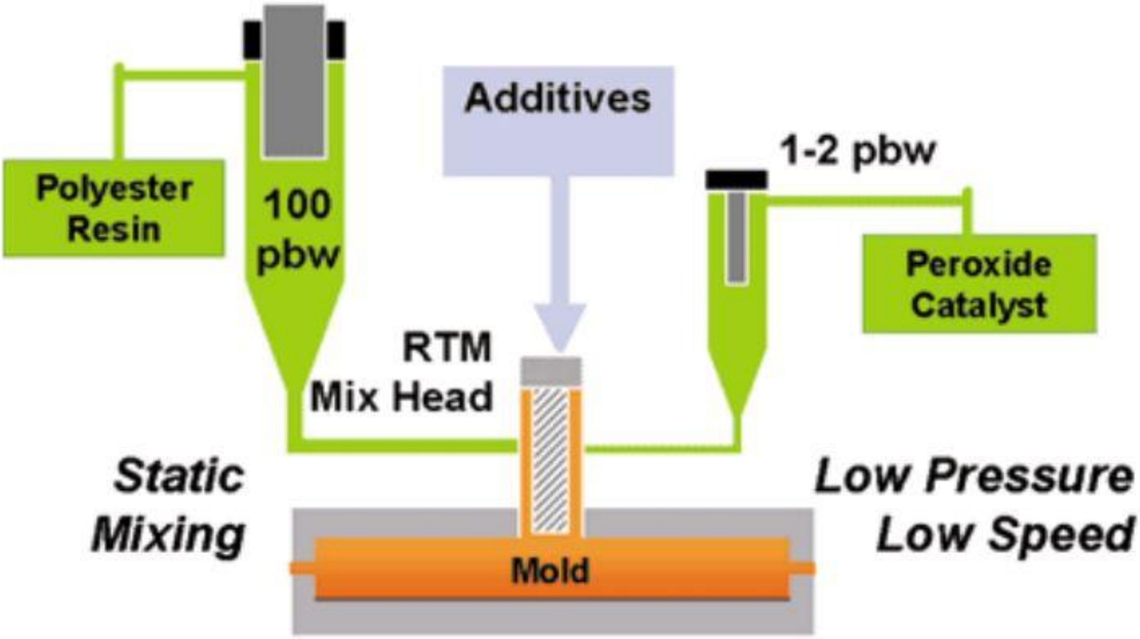

Fig.4.8 Resin Transfer Moulding Process

- First, the type of fiber must be defined. There are several different fiber types available for use in RTM composites, from random mats to two-dimensional woven rovings.

PREFORM LAYUP

- Once the preform or fiberglass reinforcement is created, it is packed into a mold cavity that has the shape of the desired part.

CLOSING MOLD

- The mold cavity is then closed and clamped. The mold cavity allows for precise control over part thickness and allows for a smooth finish on both the A and B sides of the part.
- Gel coats may be used inside the mold to provide a high-quality, durable finish.

INJECTION PHASE

- Catalyzed, low-viscosity resin is then pumped into the heated mold under pressure, displacing the air through vents , until the mold is filled.
- The injection phase must guarantee the complete impregnation of the preform.
- Bad impregnation of the fibers results in dry spot areas with missing adhesion between the layers.

CURING PHASE

- After the injection phase, the curing cycle starts, and the resin polymerizes to become rigid plastic.
- Curing time varies and is dependent on the mold temperature and chemistry of the resin being used.

ADVANTAGES OF RTM

- There are several benefits to using the resin transfer molding process over the alternative processes available. Some key benefits include:
- Good surface quality
- Wide range of reinforcements
- Large, complex shapes
- Dimensional tolerances
- Low capital investment
- Less material wastage
- Tooling flexibility
- Low environmental impact
- Labor savings
- Ability to add inserts and reinforcements at a point of infusion for greater strength
- Zero air entrapment within the product.
- Resin transfer molding continues to be an increasingly popular method of fabrication. Contact Osborne Industries today for further information on how we can assist in your next molding project.

4.3.7 Rsin Film Infusion

- Dry fabrics are laid up interleaved with layers of semi-solid resin film supplied on a release paper.
- The lay-up is vacuum bagged to remove air through the dry fabrics, and then heated to allow the resin to first melt and flow into the air-free fabrics, and then after a certain time, to cure.

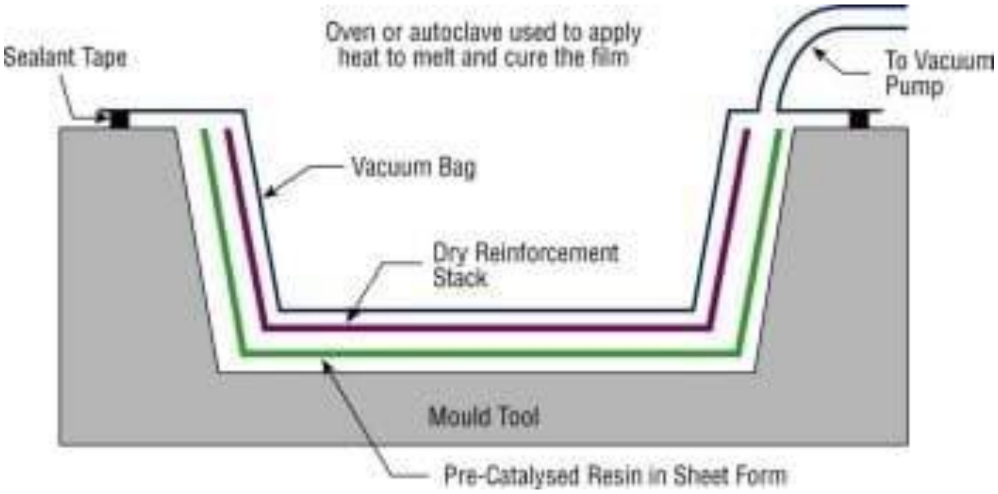

Fig.4.9 Tool Terminology

Materials Options

- Resins: Generally epoxy only.
  Fibres: Any.
  Cores: Most, although PVC foam needs special procedures due to the elevated temperatures involved in the process.

Main Advantages

- High fibre volumes can be accurately achieved with low void contents.
- Good health and safety and a clean lay-up, like prepreg.
- High resin mechanical properties due to solid state of initial polymer material and elevated temperature cure.
- Potentially lower cost than prepreg, with most of the advantages.

Main Disadvantages

- Not widely proven outside the aerospace industry.
- An oven and vacuum bagging system is required to cure the component as for prepreg, although the autoclave systems used by the aerospace industry are not always required.
- Tooling needs to be able to withstand the process temperatures of the resin film (which if using similar resin to those in low-temperature curing prepregs, is typically 60-100°C).
- Core materials need to be able to withstand the process temperatures and pressures.

Applications

- Aircraft radomes and submarine sonar domes.

4.4 Properties of Composite Material

The composite material is a kind of multi-phase material which is made of two or more kinds of materials, such as metal material, ceramic material or polymer material, through the composite process. The mutual complementarity of each material in properties makes the comprehensive performance of composite materials much better than the original single material to meet different requirements.

Compared with ordinary materials, composite materials have many characteristics, which can improve or overcome the weakness of a single material, give full play to the advantages of each material, and give new properties to the material; according to the structural and stress requirements of the component, give the reasonable matching performance of the predetermined distribution, and design the best performance of the material. The specific performance is as follows:

High specific strength and high specific modulus.

The outstanding advantages of composite materials are of high specific strength and specific modulus. For example, the specific modulus of carbon fibre reinforced resin composite is 5 times higher than that of steel and aluminium alloy, and its specific strength is 3 times higher than that of steel and aluminium alloy.

High fatigue resistance.

Fibre composite, especially resin matrix composite, is less sensitive to notch and stress concentration. Moreover, the interface between fibre and matrix can blunt or change the direction of the propagating crack tip, that is to say, it can prevent the rapid propagation of the crack. Therefore, the fatigue strength is relatively high. The fatigue limit of carbon fibre unsaturated polyester resin composite can reach 70% ~ 80% of its tensile strength, while only 40% ~ 50% % for metal materials.

Strong fracture resistance.

There are a large number of independent fibres in fibre composite materials. Generally, there are thousands to tens of thousands of fibres per square centimetre. They are combined into a whole by a tough matrix. When a small number of fibres are broken due to overload or other reasons, the load will be redistributed to other fibres that are not broken, so that the components will not be damaged suddenly in a short time. Therefore, the composites have high fracture toughness.

Good damping performance.

The natural frequency of the structure is related to the mass and shape of the structure itself and is proportional to the square root of the specific modulus of the material. If the natural frequency of the material is high, resonance and early damage can be avoided.

4.5 Reference

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