Composite Materials

Module I - Introduction **Lectures 1 to 2**

Introduction

Composite materials have changed the world of materials revealing materials which are different from common heterogeneous materials. A composite material is a structural material that consists of two or more combined constituents which are combined at macroscopic level and are not soluble in each other. It should be understood that the aforesaid composite material is not the by-product of any chemical reaction between two or more of its constituents. One of its constituents is called the reinforcing phase and the other one, in which the reinforcing phase material is embedded, is called the matrix. The reinforcing phase material may be in the form of fibers, particles, or flakes (e.g. Glass fibers). The matrix phase materials are generally continuous (e.g. Epoxy resin). The matrix phase is light but weak. The reinforcing phase is strong and hard and may not be light in weight.

For example, in concrete reinforced with steel the matrix phase is concrete and the reinforcing phase is steel. In graphite/epoxy composites the graphite fibers are the reinforcing phase and the epoxy resin is the matrix phase.

A material shall be considered as a composite material if it satisfies the following conditions:

1. It is manufactured i.e., excluding naturally available composites.
2. It consists of two or more physically and/or chemically distinct, suitably arranged or distributed phases with an interface separating them.
3. It has characteristics that are not the replica of any of the components taken individually.

What can be achieved by forming a composite material:

The following properties can be improved by forming a composite material:

- Strength (Stress at which a material fails)
- Stiffness (Resistance of a material to deformation)

- Wear & Corrosion resistance
- Fatigue life (long life due to repeated load)
- Thermal conductivity & Acoustical insulation
- Attractiveness and Weight reduction

What are the roles of the constituents of composite material:

(i) Role of Reinforcements: Reinforcements give high strength, stiffness and other improved mechanical properties to the composites. Also their contribution to other properties such as the co-efficient of thermal expansion , conductivity etc is remarkable.

(ii) Role of Matrices: Even though having inferior properties than that of reinforcements, its physical presence is must;

- to give shape to the composite part
- to keep the fibers in place
- to transfer stresses to the fibers
- to protect the reinforcement from the environment, such as chemicals & moisture
- to protect the surface of the fibers from mechanical degradation
- to act as shielding from damage due to handling

Terminology:

The following terms are frequently used in composite materials and hence it is necessary to know these terms.

- Staple fiber **:** Represents discontinuous fiber
- Filament **:** Represents a single continuous fiber (Refer figure 1.1)
- Strand **:** Represents a collection of untwisted fibers (filament) approximately 100 to 200 in numbers.
- Tow **:** Represents bundle of untwisted filaments in large numbers, say 2000 to 12000 filaments
- Yarn **:** Represents bundle of twisted fibers

- Sizes : Represents a thin coating of chemical applied on filament surface to protect the fibers from damage and environmental effects (e.g., polyvinyle acetane)
- Coupling agents : Used to get good bonding between fiber and matrix (e.g.,chrome complexes, silanes and titanes)

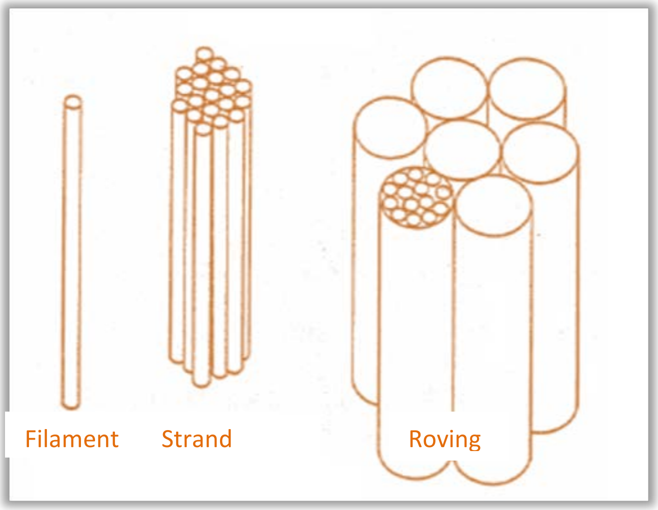

Figure 1.1 Fibers

Factors that contribute to the mechanical performance of the composites:

As is mentioned earlier, the characteristics of the composite materials depend on the properties of both reinforcing phase as well as matrix phase. Therefore it is important to know the factors of the constituents of composite materials, which contribute to the performance of the composite materials.

(I) Factors that control the properties of fibers

(a) Length: The fibers can be long or short. Long, continuous fibers are easy to orient and process, but short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers. These include high strength, impact resistance, low shrinkage, improved surface finish, and dimensional stability. However, short fibers provide low cost, easy to work with, and have fast cycle time fabrication procedures. Moreover using randomly oriented short fibers the isotropy behaviour may be achieved and uni directional composites exhibit non-isotropic material properties.

(b) Orientation: Fibers oriented in one direction give very high stiffness and strength in that direction. If the fibers are oriented in more than one direction, such as in a mat, there will be high stiffness and strength in the directions of the fiber orientations. Hence the fibers are usually oriented in directions where high stiffness and strength are required.

(c) Shape: Due to easiness in handling and manufacturing fibers, the most common shape of fibers is circular. But fibers are available in the form of square and rectangle also.

(d) Material: The material of the fiber directly influences the mechanical performance of a composite. Fibers are generally expected to have high elastic moduli and strength than the matrix materials. The fibers will also good functional properties like, high thermal resistance, fatigue resistance and impact resistance.

(ii) Matrix factors

Matrix materials have low mechanical properties compared to those of fibers. Yet the matrix influences many mechanical properties of the composite. These properties include

- ✓ Transverse modulus and strength
- ✓ Shear modulus and strength
- ✓ Compressive strength
- ✓ Inter-laminar shear strength
- ✓ Thermal expansion coefficient
- ✓ Thermal resistance and
- ✓ Fatigue strength

(iii) Fiber-matrix interface

When the load is applied on a composite material, the load is directly carried by the matrix and it is transferred to the fibers from the matrix through fiber–matrix interface. So, it is clear that the load-transfer from the matrix to the fiber depends on the fiber-matrix interface. This interface may be formed by chemical, mechanical, and reaction bonding. In most cases, more than one type of bonding occurs.

(a) Chemical bonding: It is formed between the fiber surface and the matrix. Some fibers bond naturally to the matrix and others do not. Coupling agents are often added to form a chemical bond. Coupling agents are compounds applied to fiber surfaces to improve the bond between the fiber and the matrix.

(b) Mechanical bonding: Every material has some natural roughness on its surface. In composite materials, the roughness on the fiber surface causes interlocking between the fiber and the matrix leading to the formation a mechanical bond.

(c) Reaction bonding: It happens when molecules of the fiber and the matrix diffuse into each other only at the interface. Due to this inter-diffusion, a distinct interfacial layer, called the inter-phase, is created with different properties from that of the fiber or the matrix. Even though this thin interfacial layer helps to form a reaction bonding, it also develops microcracks in the fiber. These microcracks reduce the strength of the fiber and consequently that of the composite.

Fillers:

In composite materials fillers are introduced for reducing the cost, for improving the physical or functional properties or to aid processing. Fillers are solid materials which are introduced on the matrix material for improving a specific property. Normally, fillers increase the modulus but reduces the strength and hence there must be always an optimal filler content. Fillers do not react with the matrix material, develop adequate bond with the matrix and do not absorb water or any other liquid. Normally, fillers are not used in most advanced composite structures, because fillers bring down the strength of the composite materials. Some of the fillers which are very commonly used in polyester resin and epoxy resins are given below.

Calcium carbonate, Silica powder, Talc, Clay are used in polyester resin to reduce the cost and for processing in SMC (Sheet molding compounds).

Sand and aggregates are used in polyester resin for making polymer concretes and marble chips are used to make artificial marbles. Titanium dioxide and carbon blacks are used in Polyester resin to give white and black colour respectively when used for gel coat.

Fused silica is used in epoxies to reduce coefficient of thermal expansion and mica is used to improve the thermal conductivity without affecting the electrical properties.

Aluminium trihydrate and Antimony trioxide are used in polyester and epoxies for improving fire retartant properties. Graphite is used to reduce the coefficient of friction and proving self lubricating property in these resins. Silicon carbide is used in these resins to increase the wear resistance by using them as a surface coat.

Additives:

Additives are added to the polymer matrix for aiding the processing technique or altering some properties. They are added in small quantity (less than 5%) and the additives do not affect the mechanical properties due to their small quantity.

Hydroquinons is used as an inhibitor to inhibit the cure and prolong the shelf life. Parafin vax is used to prevent the evaporation of styrene from the coating surface. This act an air inhibitor.Tinorin, Benzophenos and Benzotriazoles are used as an UV stabilizer, to improve the resistance of UV rays. Aerosil powder is used to reduce the viscosity of the resin. Magnesium oxide, Calcium Oxide and Magnesium hydroxide are used to increase the viscosity of the resin. They act as a thickener in making SMC and BMC.

Pigments:

Pigments are added to the resin to get composite products of different coloursIn wet lay up the pigment is added to the get coat and it is added to the moulding compound in compression moulding. The pigments readily mix in polyesters and in epoxies and phenolics these do not mix readily. There are organic and inorganic pigments. Inorganic pigments are fast and durable. The pigments are available in the form of pastes or powders. The paste form mixes faster than the powders.

Preprocessing of Composite materials:

FRP composites are prepared by the ingredients like, fibers, matrix, curing agents, fillers, pigments and additives, with different propositions. Some the ingredients are added in small quantity, which become cumbersome or time consuming while making large size products through wet moulding (Hand lay up) or through wet winding (filament winding process). To avoid this inconvenience, the raw materials are precomposed and brought in to an intermediate stage for further processing. There are several kind of precomposed materials and the details are given below.

Thermoset Moulding Compounds:

The physical mixure of all the raw materials in the uncured resin system is called moulding compound and it is tack free. This can be a premix compound like DMC(Dough Moulding Compound) or a chemically thickened compound like SMC (Sheet Moulding Compound). These compounds are mostly used in compression moulding. Injection moulding grades are also available.

Pre impregnated Sheets or Prepregs: These are tack free rovings,tapes, clothes or mats of the reinforcement of fibers and reinforced in resin system which is semi cured, with suitable proportion. These prepregs are used in compression moulding or in filament winding.

Reinforced thermoplastic pellets:

Short fibers or particulates are introduced in thermoplastic resins and pellets are prepared. The pellets are prepared by extruding the fibers and molten plastics by an extruder and chopped the extrudate in to short pellets. The pellets which are used for injection moulding will have the fiber length of 3 mm, which will pass through the nozzles of injection moulding or extruders easily. There special kinds of injection moulding machines to use the long short fibers (length between 8 to 15 mm), which are preferred for achieving high strength.

Cowoven and Comingled Fiber Fabrics:

The long reinforced and plastic are cowoven together to make thermoplastic prepregs of long length. During moulding process the plastic fibers melt and form the matrix. The disadvantage of this method is that when the adjacent fibers melt, there is larger gap between adjacent fibers and to avoid this fabrics made of comingled fiber bundles (have both the fibers) are used.

Thermoplastic Matrix Prepregs:

The composite sheets or tapes are made by reinforcing the fibers in a thermoplastic matrix. The reinforcements can be in the form of continuous woven or non woven fiber mats or short fibers. The thermoplastic sheets are made by melt impregnation, slurry deposition, solution impregnation and by film slacking.

In melt impregnation the thermoplastics is melted and is impregnated in the fiber and then cooled.

In slurry deposition, the fiber is impregnated with the slurry of polymer and the liquid is evaporated out.

The solution impregnation is same as slurry deposition but the solution of the matrix is made use of.

In film slacking, the matrix is made in the form of a film, which is stacked between the reinforcements and melted to fuse in to the reinforcements.