Composite Materials & Manufacturing

Training Objective

After watching the program and reviewing this printed material, the viewer will gain knowledge and understanding of the nature of composite materials and the ways in which these materials are transformed into a wide variety of manufactured products.

- The physical nature of composites are explained
- The function of the various types of reinforcements are outlined
- Numerous composite manufacturing processes are examined
- Composite fabrication and assembly methods are detailed

Composites consist of two distinct materials, which together improve product performance and/or lower production costs. Composite materials typically include plated, clad, or coated metals, however the term 'composites' has evolved to mean a material containing a matrix, or base substance, and a reinforcement material.

The matrix acts as a binder for the reinforcement while controlling the physical shape and dimensions of the part. Its primary purpose however is to transfer the load, or stress, applied to the part to the reinforcement. The matrix also protects the reinforcement from adverse environmental effects.

The reinforcement's function is to enhance the mechanical properties of the composite and is typically the main load bearing element. Reinforcements are usually in the form of either fibers or particles. Matrix and reinforcement materials can be polymers, metals, ceramics, or carbon. The most widely used composite materials are fiber-reinforced thermosetting polymers.

Thermosets require specific curing times to develop their full mechanical properties. Once set, thermosets cannot be reprocessed or reused in any way. Some of the common thermoset matrix materials include:

- Polyesters
- Epoxies
- Bismaleimides
- Phenolics
- Polyimides

The polyester materials, while less costly, have lower strength characteristics and are less heat and weather resistant. As such though, they are the most widely used in commercial products. The epoxy, bismaleimide, phenolic, and polyimide matrix materials exhibit superior mechanical properties and heat resistance qualities.

The reinforcement material can significantly improve the mechanical properties of the matrix. This is particularly true when the reinforcement is in the form of long oriented fibers. Physical properties are also influenced by the reinforcement, including:

- Density, or Weight per Unit Volume
- Thermal Expansion
- Electrical Conductivity
- Thermal Conductivity
- Vibration Dampening

Commonly used reinforcement fibers are E-glass, aramid, and carbon, which is also referred to as graphite. Some of the many forms of such fibers include strand, tow, filaments, fabrics, pre-impregnated tapes, and pre-forms. Several of these fiber materials can be used in the manufacture of a single part. The application of a fiber reinforcement can be in a single direction, varied angularly or varied randomly throughout the part.

Composite Manufacturing

The primary manufacturing methods used to produce composites include:

- Manual Lay-Up
- Automated Lay-Up
- Spray-Up
- Filament Winding
- Pultrusion
- Resin Transfer Molding

Manual lay-up involves cutting the reinforcement material to size using a variety of hand and power-operated devices. These cut pieces are then impregnated with wet matrix material, and laid over a mold surface that has been coated with a release agent and then typically a resin gel-coat. The impregnated reinforcement material is then hand-rolled to ensure uniform distribution and to remove trapped air. More reinforcement material is added until the required part thickness has been built-up. Manual lay-up can also be performed using preimpregnated reinforcement material, called 'prepreg'. The use of prepreg material eliminates separate handling of the reinforcement and resin, and can improve part quality by providing more consistent control of reinforcement and resin contents. Prepreg must be kept refrigerated prior to use, however, to prevent premature curing.

The productivity of the manual lay-up can be automated using CNC machines. These machines are used for both prepreg tape-laying and prepreg fiber-placement primarily in the aerospace industry. There is virtually no limit to the size of the work that can be tape-rolled, but the shape has to be relatively flat to butt each successive row without gaps, overlaps or wrinkles. Automatic, multi-axis fiber placement machines overcome this limitation by dispensing numerous, narrow individual tapes of material which are collimated as they are laid on the mold surface.

In spray-up, resin is sprayed onto a prepared mold surface using a specially designed spray gun. This gun simultaneously chops continuous reinforcement into suitable lengths as it sprays the resin.

After lay-up, the composite parts must be cured. Curing can take place at room temperature, often with heated air assist. Ovens, heated-platen presses, and autoclaves may also be used. Curing times may range from a single hour to one-half day or longer. Curing is also accomplished with vacuum bag molding. Here a non-adhering plastic film, usually polyester, is sealed around the lay-up material and mold plate. A vacuum is slowly created under the bag forcing it against the lay-up. This draws out entrapped air and excess resin. Vacuum bag molding is effective in producing large, complex shaped parts.

Filament winding refers to wrapping a narrow fiber tow or band of tows of resin impregnated fiber around a mandrel of the shape to be produced. When the mandrel is removed, a hollow shape is the result. Uses for filament winding include pipe, tubing, pressure vessels, tanks and items of similar shape. Filament winding is typically applied using either hoop or helical winding. In hoop winding, the tow is almost perpendicular to the axis of the rotating mandrel. Each mandrel rotation advances the material-delivery supporting carriage one band width, butting the edge of one band next to the previous band. In helical winding, material is deposited in a helical path in one direction, then turns around on end and returns in a helical path in the opposite direction. Filament winding mandrels may be metallic or non-metallic and designed to either collapse to facilitate part removal or may be dissolvable after curing.

Pultrusion is a continuous process used primarily to produce long, straight shapes of constant cross-section. Pultrusion is similar to extrusion except that the composite material is pulled, rather than pushed, through a die. Pultrusions are produced using continuous reinforcing fibers called 'roving' that provide longitudinal reinforcement, and transverse reinforcement in the form of mat or cloth materials. These reinforcements are resin impregnated by drawing through a resin wet-out station; and generally shaped within a guiding, or preforming, system. They are then subsequently shaped and cured through a preheated die or set of dies.

Once cured, the pultrusion is saw-cut to length. Pultrusions can be hollow or solid, and applications include bar and rod, pipe, tubing, ladder rails and rungs, and supports of many kinds.

Resin transfer molding or 'RTM' produces large, complex items such as bath and shower enclosures, cabinets, aircraft parts, and automotive components. In this process, a set of mold halves are loaded with reinforcement material then clamped together. Resin is then pumped or gravity fed into the mold infusing the reinforcement material. Once the mold is filled with resin, it is plugged and allowed to cure. After curing, the mold halves are separated and the part removed for final trimming and finishing.

Composite Fabrication & Assembly

Cured composite parts may be machined, drilled, and sawed as needed to meet specifications. Tooling must be kept sharp, often being carbide or diamond tipped, as the composite material can be highly abrasive. A coolant is often used to prevent heat buildup during machining.

The two principle joining methods used for assembling composite parts are adhesive bonding and mechanical fastening.

Adhesive bonding produces strong, permanent joints. Proper preparation and cleanliness is critical. Typical joint configurations include lap, double lap, overlays, and scarf joints. Work pieces may be placed in a fixture and pressed together while setting and curing. Elevated temperatures may be required depending on the adhesive type used.

Mechanical fastening employs rivets, pins, bolts, and other fasteners. These may be either metallic or composite material fasteners. Careful and precise holemaking and accurate torquing are required to prevent distortion and cracking of the composite material during fastening.

Review Questions

1. The primary purpose of the matrix is to:
   a. act as a binder
   b. control the physical shape and dimensions of the part
   c. transfer the applied load, or stress, to the reinforcement
   d. protect the reinforcement from adverse environmental effects

2. The most widely used composites are:
   a. bismaleimides
   b. fiber-reinforced thermoplastic polymers
   c. fiber-reinforced thermosetting polymers
   d. phenolics

3. The least costly matrix materials are the:
   a. polyesters
   b. phenolics
   c. polyimides
   d. epoxies

4. The mechanical properties of composites are significantly increased with the use of reinforcement material that consists of:
   a. finely ground particles
   b. long oriented fibers
   c. random chopped fiberglass material
   d. graphite flakes

5. The first coating typically applied to the mold surface prior to beginning a manual lay-up is called the:
   a. gel-coat
   b. reinforcement-coat
   c. top-coat
   d. release-agent

6. Curing may be accomplished:
   a. at room temperatures
   b. in ovens
   c. with vacuum bag molding
   d. all of the above

7. Typical composite products produced by the resin transfer method are:
   a. machine components
   b. tubing and pipe
   c. ladder components
   d. tub and shower enclosures

8. Adhesive bonding of composite parts may require:
   a. elevated temperatures during curing
   b. refrigeration while setting
   c. vacuum chambers
   d. additional mechanical fastening

Answer Key

1. c
2. c
3. a
4. b
5. d
6. d
7. d
8. a