

## Composite Manufacturing Processes

Jean Frank

Associate Professor of Industrial Technology & Mechatronics

Thomas Nelson Community College

Hampton, VA 23666

[frankj@tncc.edu](mailto:frankj@tncc.edu)

### **Abstract:**

This module aims to provide students with a survey of methods of manufacturing fiber composite materials. This knowledge is needed for the understanding of the different types of matrix and reinforcement classifications and the materials used. Also included is how composites are considered, selected and designed for a certain application, and why a certain manufacturing processes are chosen for each application.

### **Student Learning Objectives:**

- Describe the use of different types of fabrics and the importance of the fiber direction
- Describe the different types of matrix phases upon which composites are based
- Describe the function of the primary and secondary phase in a composite material
- Describe the characteristics and manufacturing of composite laminates
- Describe the properties and design factors which determines composite materials end-use/application
- Identify some important manufacturing techniques for composites
- Demonstrate understanding of selecting a composite manufacturing method
- Consider further the advantages and disadvantages of using composites

### **MatEd Core Competencies Covered:**

- 7C Describe the general nature of composite materials
- 11A Describe the structure and advantages of composite materials
- 11B Explain basic processing procedures for composite materials

**Key Words:** Composites, materials, manufacturing processes, fibers, reinforcement, resin, matrix., methods

**Type of Module:** Intermediate level introduction to composite manufacturing processes discussion with accompanying PowerPoint

**Time Required:** One 50 min. discussion session

**Pre-requisites:** Completion of introductory composites modules and an intermediate level knowledge of materials science

**Target Grade Level:** Grades 9 – 12, and introductory courses for Community College

### **Instructor Notes and Slide Information:**

This module develops background understanding for students to be able to actually manufacture a simple composite. It is meant for grades 9 – 12 and can also be used as an introductory course for a

college composite class. Lecture notes are included for the instructor for use with the accompanying PowerPoint presentation, which describes some of the basic composite processes used in industry today, with an explanation of each, and some examples of industry uses. This knowledge, plus the module on Composite Manufacturing Healthy and Safety, is needed before undertaking a basic composite manufacturing exercise such as the module Composite Layup Lab.

### **Composite Manufacturing Processes (slide 1 – 22)**

Instructor should note that composite methods for manufacturing have two basic types of categories for composite processes:

- Open molding – resin is impregnated into the fibers and they are placed in an open mold, where they cure or harden.
  - Relatively low cost due to little to no tooling (the mold)
  - Allow for rapid product development cycles for prototyping – design changes are easily made
  - Wide part size potential
  - Secondary finishing processes needed as only one side of the finished part will have a good surface finish (the side that was against the mold)
  - Best for low volume production (<1,500 parts per year) as well as large and complex part geometries
- Closed molding - composite materials are placed in a two-sided mold, closed to the atmosphere
  - Allows for more complex part geometries
  - Produces better parts faster and more consistently than open molding processes
  - Less waste produced
  - More expensive due to tooling (mold) requirements

### **Open Molding Process – (slides 3 – 10)**

There are three main methods for impregnating matrices/resins into reinforcement/fibers: hand or spray method, and filament winding.

- Hand Layup – (slide 3 – 4) – fibers are layered and oriented onto a one sided mold. Resin is then poured onto the fiber/fabric surface and brushed on or rolled out using a hand roller. This manual rolling/brushing motion removes entrapped air, ensures complete wet out of the fabric, and densifies the composite. A catalyst can be used to initiate curing (hardening) of the resin system so the product can cure/dry without external heat. This is the simplest and easiest method. Hand layup is typically used in low-volume production of usually larger structures such as components for wind turbines.
  - Students should understand that by layering and arranging the reinforcement and matrix into different orientations, added strength and stiffness can result, that metal cannot duplicate with the same weight savings.
  - Students need to understand the different curing (drying/setting) methods: room temperature, applying heat – oven, or applying pressure.
  - Several curing (drying) methods are available:
    - cure at room temperature for several hours with use of an initiator/accelerator to the resin system
  - The cure can be accelerated by applying heat:
    - typically, an oven

- or with pressure - vacuum bagging or autoclave
  - Examples - wind turbine blades, aircraft parts, car panels, and architectural moldings.
- Spray up - (slide 5 – 6) – Similar to hand layup but uses a chopper/spray gun to deposit chopped fibers and room temperature curing resins on a low cost open mold. Manual rolling is then used, just as in hand layup, to remove entrapped air, etc. This method is typically used for molds with greater complexity than those used in hand layup and results in faster production. Ideal for producing larger parts such as bath tubs/shower units and vent hoods. The fibers are short, which compromises strength, and since resin is sprayed – low viscosity, strength and thermal, properties are also compromised.
  - Examples: showers and bathtubs
- Filament winding – (slide 7 - 8) – Used to produce round-form products that have a high degree of structural integrity (tanks, pipes, pressure vessels, etc.). A rotating mandrel is used as the mold and is automated. The rotating mandrel spins as fibers impregnated with resin are wound around the mandrel (mold) into predetermined geometric pattern. Many fiber/resin systems can be used in this process. Ensure students understand the advantages and disadvantages. Advantages is that it is a very fast method, resin content is controlled, makes high weight to strength laminates, can obtain high fiber weight percentages, and can achieve controlled fiber orientation that gives directional strength characteristics. Disadvantages is that the shape is limited to circular and oval products, mandrel may be expensive, and poor external surface finish that may affect aerodynamics in some applications (thus needs a finishing process, machining/sanding of exterior surface).
  - Examples: sail boat masts, cement mixers, aircraft fuselages, tanks, chemical storage tanks, gas and pressure cylinders.

Curing layups - can be done by exposing to air, heat – oven, or by vacuum bagging (see next section).

### **Closed Molding Process – (slides 11 – 24)**

Fibers and resin cure inside a two-sided mold. Usually require automation and special equipment, for high volume manufacturing.

- Vacuum bagging – (slides 9 – 10)
  - a plastic film is placed over the wet hand layup, edges are sealed, and a vacuum is drawn. Other materials inside the bag are: release film placed over the laminate, followed by a bleeder ply to absorb the excess resin. A breather ply of non-woven fabric is placed over the bleeder, with the vacuum bag encasing the entire laminate area.
  - Vacuum uses a pump and atmospheric pressure to eliminate voids and force out excess resin.
  - Advantages to vacuum bagging allows better resin flow from applied pressure thus reducing voids (chances for premature part failure).
  - Disadvantages is labor costs and bagging material cost vs product curing in atmosphere, and skill level of technician.

- Vacuum infusion – (slide 11) - The reinforcement and core materials are laid-up dry in the mold by hand, then peel ply and vacuum bag materials cover the layup, it is encased by the mold and the vacuum bagging process begins and resin infuses the mold. Used to manufacture large structures. One side is finished. Sometimes referred to as Vacuum Assisted Resin Transfer Molding (VARTM) –
  - Uses vacuum pressure to drive resin into laminate.
  - Advantages are similar to the Resin Transfer Molding (RTM), except only one side has a good surface finish. Produces strong, lightweight laminates, and larger products can be produced.
  - Obtains high resin-to-fiber ratios and virtually no voids making it one of the strongest processes to fabricate a composite laminate.
  - Helps reduce harmful chemical emissions from resins.
  - Distinguishes itself in that it is the only closed mold process that uses only atmospheric pressure to push the resin into the mold cavity.
  - Lower tooling costs than other closed mold processes.
  - Disadvantages are that it has slower cycle times, highly dependent on viscosity of the resin, and higher consumables costs.
    - Examples: boats, large auto body panels and aviation components.
  
- Resin transfer molding (RTM) – (slide 12 - 13) – used when you want both sides to have superior surface finish. Layers of reinforcement are laid up in the tool cavity dry. The cavity determines part thickness. Used for large and small components. Selective reinforcement and accurate fiber management is achievable. Ability to build-in fiber volume fraction loadings up to 65%. Inserts may be incorporated into moldings. Advantages include high dimensional tolerances and stability, superior surface finishes, high production rates, high repeatability and lowest variability from part to part. Post machining is rarely needed. Disadvantages include higher tooling costs and longer times to make dimensionally precise tools.
  - Examples: auto and aviation components
  
- Compression molding – (slide 14 - 19) – Most common option for high volume production of composite parts. Matched metal dies (the tooling) are mounted in a hydraulic press and a charge (molten material made up of the matrix and reinforcement with no distinct shape) is placed into the dies and then closed under certain pressure and temperature for a certain amount of time (cycle time). This combination quickly cures the material.
  - A high volume, high pressure method.
  - The process can be automated, and enables design flexibility of components.
  - Produces high strength, complex parts in a broad range of sizes
  - Molds are pressed by hydraulics or mechanical means and heated. There are several types of compression molding:
    - SMC – sheet molding compound
    - BMC – bulk molding compound
    - TMC – thick molding compound
    - Wet layup compression molding
    - ECM—Extrusion compression molding
  
- Pultrusion – (slide 19 – 22) Continuous automated process and is adaptable to both simple and complex shapes with constant cross sections. Very cost effective in high production volume settings. Standard shapes are I-beams, channels, angles, beams, rods, bars, tubing, sheets, etc.

Continuous fibers are pulled from several spools or creels through a resin bath and then into a long heated die that has the desired end cross section shape. Upon exiting the die the material is cured and then cured cross sections are cut down the production line to appropriate lengths. High strengths are attainable. There are low labor costs involved as this system is majorly automated.

### **Follow-up:**

The knowledge of the various methods for composite manufacture, plus the **Module** Composite Manufacturing Healthy and Safety, is needed before undertaking a basic composite manufacturing exercise such as the **Module** Composite Layup Lab.

### **Student Evaluation**

1. How are the materials and structures manufactured?
2. Most widely used manufacturing method is?
3. How do fibers provide the primary strength of the composite structure?
4. Curing can be accomplished how?
5. Typical composite products produced by the pultrusion method are?

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