What are Composites?

Jean Frank
Associate Professor of Industrial Technology & Mechatronics
Thomas Nelson Community College
Hampton, VA 23666
frankj@tncc.edu

Abstract:
This module introduces basic concepts of composites and composite applications to students in middle school or high school technology courses. This module will explain what composites are, and why composites are becoming an essential part of today's materials. Instructors should use the accompanying PowerPoint presentation along with the text in presenting this module to the class.

The author recommends that this module be followed by the modules:
Keeping a Lab Journal, by Jean Frank
Table-top Composite Panel Fabrication Lab, by Craig Johnson
These modules are available under resources on www.materialseducation.org and are at the same level as the rest of this module.

Module Objectives:
The primary goal of this module is to introduce the basic concepts of composites, advantages and disadvantages compared to metals, and to familiarize the students to various manufacturing uses and processing methods.

Student Learning Objectives:
● Provide an introductory understanding of composite materials and their manufacturing processes
● Introduce common types of fibers and matrices
● Explain the advantages and disadvantages of composites
● Provide an understanding of composite material selection, practical uses and performance

MatEdU 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, fiber reinforcement, matrix, resin

**Type of Module:** Introductory

**Time Required:** (2) 45 min discussion periods, to accompany the PowerPoints:

**Pre-requisites:** Some fundamental knowledge of material science

**Target Grade Level:** Grades 8 – 14, especially high school technology courses

---

**Instructor Notes and background Information**

These instructor notes are meant for the use of the instructor when accompanying the PowerPoint slides noted above.

The module is divided into three sections:

- **Section A** - Composite definition and description; advantages and disadvantages
- **Section B** - Material configuration and types.
- **Section C** – Example – sandwich panel materials

The instructor should note that the design of composites varies, using a combination of varying materials and fabrication processes for many different industries. Instructor can introduce a few examples of composites and how they have improved an industry or product. Example: golf clubs, baseball bats, artificial limbs – composites are lighter, stronger, more durable than wooden bats and clubs.

Students at this level have probably never studied or reviewed strengths of material singularly or when combined. It is important that students understand the fundamental purpose of composites and their use. The intention of composites is that when different materials are combined, the intent is to create a composite material with more desirable properties than the individual constituents; the individual materials don’t lose their distinct properties – they combine and contribute to improve the resulting final product. These reinforced materials are widely used because of their performance and engineered properties - such as added strength to weight ratios, increased productivity or durability, etc.

**Section A: Composite Definition and Evolution (slides 1 – 7); Advantages and Disadvantages (slides 8 - 11) in the accompanying PowerPoint presentation**

The basic concept of composites is defined as two or more materials – reinforcement + matrix, that are combined to form a structure that has more desirable properties than the individual materials by themselves. Composites are tailor-made, by man, to meet unique design requirements through an unusual combination of properties for a given application. They can be considered multiphase materials.

**Examples:**
Laminates are made of multiple “sheets” of material – wood, paper, glass, etc. – that are layered and fixed together. Layering is typically done because a single “sheet” of material isn’t strong enough to withstand load by itself. Laminates are often designed to increase strength and decrease cost and can even reduce weight of the resulting product.

- **Wood** – plywood - instructor can use a piece of plywood to show that the wood – reinforcement material, and the glue as the resin, or:

- **Glass** – windshields, bulletproof glass – are layers of glass and sometimes plastic Typically bulletproof glass is made up of several layers of laminated glass. When weight reduction is crucial to the application, a thin plastic (polycarbonate) layer is incorporated onto the “exit” side of the glass.

- **Straw** (reinforcement) and mud (matrix) to make bricks

Composites often allows for designing materials with properties better than those of conventional materials. The chart below shows relative elastic strength (Elastic Modulus or “Young’s Modulus”) for a variety of materials with composite materials highlighted.

Young’s modulus varies from material to material due to differences in sample composition and test method. The rate of deformation has the greatest impact on the data collected, especially in polymers. The values here are approximate and only meant for relative comparison.

### Approximate Young's modulus for composite and common materials

<table>
<thead>
<tr>
<th>Material</th>
<th>GPa</th>
<th>Mpsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (along grain)</td>
<td>11[4]</td>
<td>1.60</td>
</tr>
<tr>
<td>Human Cortical Bone</td>
<td>14</td>
<td>2.03</td>
</tr>
<tr>
<td>Glass-reinforced (Fiberglass)</td>
<td>17.2</td>
<td>2.49</td>
</tr>
<tr>
<td>High-strength concrete</td>
<td>30</td>
<td>4.35</td>
</tr>
<tr>
<td>Carbon fiber reinforced plastic (50/50 fiber/matrix, biaxial fabric)</td>
<td>30–50</td>
<td>4.35–7.25</td>
</tr>
<tr>
<td>Aluminum</td>
<td>69</td>
<td>10</td>
</tr>
<tr>
<td>Aramid Kevlar</td>
<td>70.5–112.4</td>
<td>10.2–16.3</td>
</tr>
<tr>
<td>Titanium (Ti)</td>
<td>110.3</td>
<td>16</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>117</td>
<td>17</td>
</tr>
</tbody>
</table>
### Approximate Young's modulus for composite and common materials

<table>
<thead>
<tr>
<th>Material</th>
<th>GPa</th>
<th>Mpsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon fiber reinforced plastic (70/30 fiber/matrix, unidirectional, along fiber)</td>
<td>181</td>
<td>26.3</td>
</tr>
<tr>
<td>Wrought iron</td>
<td>190–210</td>
<td>27.6–30.5</td>
</tr>
<tr>
<td>Steel (ASTM-A36)</td>
<td>200</td>
<td>29</td>
</tr>
</tbody>
</table>

(https://en.wikipedia.org/wiki/Young%27s_modulus)

### History of Composites

#### Industrial use

While many industries use composites, instructor can talk about why and bring in examples to show class – stress the lightweight and durability of the item:
- bring in a bat of wood and metal to show the difference; or a tennis racquet and mention how composites have good vibration dampening, hence less “tennis elbow” with composite racquets as compared to older wooden ones
- golf club – shaft of wood, and composite

#### Industrial and component manufacturing:

- **Aerospace industry** – lighter, stronger, temperature & wear resistance, smart structures (HIGH cost for materials and manufacturing)
  - Examples: aircraft components, rockets & missiles, satellites ...(Boeing 787 Dreamliner)
- **Sporting goods** – lighter, stronger, toughness, better damping capabilities (thus more comfortable for athletes), better aesthetics
  - Examples: tennis, golf – golf clubs, baseball bats, bicycles, boats, hockey, surf and skate boards ...
- **Automotive** – lighter, stronger, toughness, improved fuel efficiency (by weight reductions or aerodynamic design)
  - Fenders, bumpers, vehicle interiors – floors and doors, truck beds, BMW i3 (currently most intensive use of composites in an automobile) passenger cell
- **Construction** – lighter, stronger, toughness
  - Examples: bridges, buildings, dams, railway

#### Timeline

Refer to dates in power point for evolution of use and designing. Note that composite industry continues to evolve and transform major industries: marine, automotive, aerospace and manufacturing applications and uses.

#### Industrial uses

Ask students to give examples of industries that manufacture composites.
One of the earliest examples of composites is the brick – made from mud and straw.

- Mongol warriors in 12th century A.D. crafted archery bows from tendons from cattle and pine resin.
- 1800’s – man-made resins were developed by a chemical process called polymerization.
- 1930’s – Owens Glass Company developed a process for drawing glass into thin strands and began weaving them into fabric (i.e. glass fiber, fiberglass)
- 1942 – a dinghy is made from fiberglass and polyester resin.
- 1940’s – aviation industry searched for materials that were lighter, stronger, and resistant to weather and corrosion.
- 1950’s – Corvette automobile was developed with fiberglass panels
- 1950’s-1960’s – manufacturing methods were developed; pultrusion, vacuum bag molding, and filament winding. Filament winding became the basis for large-scale rockets.
- 1990’s and present – Nano technology and 3D printing.

**Advantages and Disadvantages of Composite Materials**

Composite parts have both an advantage and disadvantage when compared to metal components. Compare metal to composites. Example: how metal corrodes and needs constant preventative maintenance: to be inspected, cleaned and painted. Composites resist environmental damages better. Disadvantage of composites, harder and more expensive at times to find delamination, and inspect and repair compared to metals.

**Advantages:**

- Light Weight - Composites are light in weight, compared to most metals.
- Strength Related to Weight - Strength-to-weight ratio is a material’s strength in relation to how much it weighs. Some materials are very strong and heavy, such as steel. Composite materials can be designed to be both strong and light. This property is why composites are used to build airplanes—which need a very high strength material at the lowest possible weight.
- Corrosion Resistance - Composites resist damage from the weather and from harsh chemicals that can eat away at other materials.
- Design Flexibility - Composites can be molded into complicated shapes more easily than most other materials. This gives designers the freedom to create almost any shape or form.
  - Part Consolidation - A single piece made of composite materials can replace an entire assembly of metal parts. Reducing the number of parts in a machine or a structure.
  - Dimensional Stability - Composites retain their shape and size when they are hot or cool, wet or dry.
  - Radar Transparent - Radar signals pass right through composites, a property that makes composites ideal materials for use anywhere radar equipment is operating.
• Durable - Structures made of composites have a long life and need little maintenance. We do not know how long composites last, because we have not come to the end of the life of many original composites. Many composites have been in service for half a century.

Disadvantages:

• Delamination - Since composites are often constructed of different ply layers into a laminate structure, they can "delaminate" between layers where they are weaker.
• High Cost - They are a relatively new material, and as such have a high cost.
• Complex Fabrication - The fabrication process is usually labor intensive and complex, which further increases cost.
• Damage inspection and repairs - Delamination and cracks in composites are mostly internal and hence require complicated inspection techniques for detection, and repairing criteria.
• Composite to metal joining - Metals expand and contract more on variations in temperature as compared to composites. This may cause an imbalance at joinery and may lead to failure.

Section B: Composite Material Configurations and Types. (slides 12 – 26)

Matrix and Reinforcement: How composites are formed and why

• Composites are composed of two main components: the matrix and its reinforcing materials
  • Composed of a polymer matrix (resin) that is reinforced with an engineered, man-made or a natural fiber (example: glass, carbon, or aramid), or other reinforcing material (particulates, etc.).
  • Three main types of composites depending on the shapes of the reinforcements: particulate (concrete mixture of cement and gravel), fiber (fiberglass panel), and laminar/laminates (plywood).
  • The matrix protects the fiber from mechanical and environmental damage, and transfers the load between the fibers. The fibers – reinforcement - provides the strength and stiffness to reinforce the matrix - resin. (This module will focus on fibrous composites)
  • The reinforcement fiber is embedded into the matrix resin.

Ensure students understand that Glass Fiber (fabric) is incredibly strong. However, fabric alone is not strong enough to support loading requirements. The fabric must be impregnated with some resin matrices:

• The primary function of resin is to transfer stress between the reinforcing fibers
• Acts as a glue to hold fibers together
• Protects fibers from mechanical and environmental damage

Instructor can introduce videos from YouTube:
Matrix (resins) –
This section will introduce to students that the basic function of the matrix is to hold reinforcement together, and transfer the load. Example: if a strand of fiber is broken, the surrounding matrix works to transfer that load to the next nearest fiber strand/bundle, which then continues to carry the load until failure.

The schematic in slide 15 shows how the matrix protects fibers from mechanical damage, and how load is transferred between the fibers. The fibers provide the strength and stiffness to reinforce the matrix. The reinforcement fiber is embedded into the matrix. The matrix also protects the fibers from the environment, ex: water intrusion.

Resins for the matrix of the composites can be broken down into two major categories – thermosets and thermoplastics:

- **Thermosets** – must be mixed with a catalyst (i.e. hardener) – crosslinking the molecules, this chemical reaction that forms a solid – once hardened, cannot be remelted/reused. Include epoxy, polyester, phenolic, polyurethane and silicone (always two part, i.e. two part epoxy). Typically thermosets have superior properties to thermoplastics but their inability to be recycled makes them somewhat unattractive.
- **Thermoplastics** – not chemically crosslinked, meaning the resin can be repeatedly melted and reused, and no chemical changes occur.

How a material is used is determined by its properties. For example: if a material is hard, can it bend? Can it be shaped or molded? – why the matrix allows a form to be molded, and how fiber creates the shape.

Reinforcement (fiber) Slides 20 - 26

YouTube video:

https://youtu.be/jsAJIMKeoZQ (fibers)

Introduce to students that reinforcements can be engineered and formed to a designed shape, to provide certain properties in the direction of the load. Many materials with a variety of strength properties, can be used to reinforce matrices, ex: wood. Glass fibers are the most common for many industries, because they are relatively inexpensive to produce and have excellent strength to weight ratios. The most common fibers are: glass, carbon, and aramid fibers. Regardless of the material, reinforcements are available in many forms: continuous (long or short), particle, or flake. In some cases, fillers are just added to act as a resin stretcher – particle, flake. The materials are designed into a unique shape/form depending on product requirements and manufacturing processes.
In industry, several names are given to composites to help differentiate them from the materials used. Some general composite types:

- **FRP** – (Fiber reinforced Plastic)
- **GFRP** – (Glass Fiber Reinforced Plastic) – this is the most common and inexpensive, and is typically called fiberglass. Usually white.
  - Most common example – bathtub, boat
- **CFRP** – (Carbon Fiber Reinforced Plastic) – this is widely used in aerospace and automotive because of its excellent stiffness and strength as well as strength-to-weight ratios.
  - Auto parts – shocks, panels
- **AFRP** – (Aramid Fiber Reinforced Plastic) – this as some of the highest relative strength because of the fibers ability to stretch rather than break.
  - Most common example used in bullet proof vests.

The fibers provide the primary strength of the composite structure.

Reinforcements can be engineered and designed to provide certain properties in the direction of the load. Many materials with a variety of strength properties, can be used to reinforce matrices, ex: aluminum. Glass fibers are the most common for many industries, because they are relatively inexpensive to produce and have excellent strength to weight ratios. Carbon fiber (CF) has BETTER strength to weight ratios than glass fiber, but is more expensive and glass fiber is superior in its impact properties.

The most common fibers are: glass, carbon, and aramid fibers.

Regardless of the material, reinforcements are available in many forms: continuous (long or short), particle, or flake.

**Section C Example: Sandwich panel Materials (slides 27-32)**

This section discusses composite sandwich panel materials, appropriate because the experiments in Module 3.1.3 provide the students with the opportunity to make sandwich panels. Advantages of sandwich panels include

- High strength and very lightweight
- Thin but stiff outer skins, often aluminum or another material
- Lightweight core, including foam, honeycomb or balsa wood

**Student Evaluation**

1. What is a composite material?
2. What is the purpose of the reinforcement?
3. What is the purpose of the matrix?
4. Describe the purpose of the clock method when layering the reinforcement materials?
5. Describe one process to fabricate a composite component?
6. What are some of the advantages to using composites over metal components?
Bibliography:

1. http://coursenotes.mcmaster.ca/4T03/Lecture_1.pdf  
   a. Matrix and reinforcement figures  

This work is part of a larger project funded by the Advanced Technological Education Program of the National Science Foundation DUE #1400619