Experiments/
Demonstrations
Composites
Composites

Introduction

A composite material is a combination of two or more separate materials that has characteristics not shown by either of the materials separately. An automobile tire, for instance—an example of a composite material—is made of rubber reinforced by one or more types of fibers, such as nylon, rayon, steel, glass, or Kevlar. The rubber does a fine job of keeping the pressurized air inside, but would not survive the stresses imposed on it by the car as it is driven. The fibers are strong and tough, but it would be impossible for a structure made only from the fibers to hold air. Together, the materials form a composite structure that both holds air and resists stresses.

Looking more closely at the composition and structure of the tire tread, we can see that it too is a composite. The rubber provides a high friction force, very handy to have in the case of a car. A pure rubber tire wouldn’t last very long, because the material is not very strong and becomes gummy when heated. Tiny balls of carbon known as carbon black reinforce the rubber and give it resistance to wear. Tire rubber compounds represent a trade-off between friction and durability, these factors being adjusted by the relative amounts of rubber and carbon black.

Composite materials have been around for a long time. Wood, a natural composite, is composed of cells made from cellulose fibers and bound together with a natural glue called lignin. If dried wood is examined under a microscope, the cellular arrangement becomes obvious. Although wood can be split parallel to these long cells, it is strong with the grain. The air spaces provided inside the cells of dried wood make it light in weight. This arrangement contributes to high strength at low weight and to toughness.

In the thirteenth century, the Mongols made composite bows from combinations of wood, animal tendons, silk, and adhesives. Even before that time, the Hebrew people added straw to their clay bricks to increase their durability.

Concrete is another example of a composite, and it has been made since Roman times. The rocks and sand are the reinforcement part of this composite, and the cement provides the cohesion that binds the structure/material together.

In addition to these “old” composites, the drive for stronger, stiffer, and lighter materials has produced many more modern composites of even higher performance such as tennis racquets, fishing poles, aircraft, space and automobile parts, and hulls of boats.
At the heart of any composite, a strong fibrous material bears the load. The fiber is constrained by the second material in the composite (the matrix) such that it takes the desired shape. Modern fishing rods are almost universally made from composites, whether the reinforcing fibers are glass, graphite, boron, or a mixture of these materials. The fibers, although strong, are not very stiff because they are very small in diameter, less than one-thousandth of an inch. By adding a matrix material, which is usually some type of epoxy in the case of the fishing rod, the fibers are tied together so that stress can be transferred from one fiber to another and so the fibers share the load. To further lighten the rod, it is made with a hollow core and is tapered so that the handle is thicker than the tip.

Most composites are used to make “things” that require high values of mechanical properties such as strength (resistance to breakage) or stiffness (resistance to bending) at a minimum weight. In these roles, composites can be made superior to structures made from any single material.

Modern composites use started with fiberglass in 1930, which is made from fine glass fibers bonded in most cases by polyester resin. The glass fibers are very strong in tension, and the resin helps to define the shape, bonds well to the fibers, and prevents the fibers from damaging each other by rubbing against their neighbors. Currently, many different types of fibers are available; the fibers are often quite expensive but are worth the price when the alternatives are considered. As more and more composite materials are used, the price will drop or become more compatible. Example: Some racquets, when they first came out, were $280 and now sell for $35.

A few years ago, composites were used only in parts of airplanes where their complete failure would have caused no serious problems. As confidence and reliability continues to increase, composites are being used in increasingly critical applications. Currently, several critical parts of passenger airliners are made from composites; some military airplanes are made largely from composites. Building the Voyager, the airplane that flew around the world without refueling in 1986, would have been impossible without modern composite materials.
Making Concrete
Instructor Notes

Reliability
This lab is designed to be experimental with lots of room for making mistakes and changes and testing the effects these cause. The success rate is determined by the care used in measuring and mixing ingredients.

Teacher Tips
1. Concrete is a composite material made from sand, rocks (aggregate), and cement. Students are familiar with this material but many have never made concrete and may not know how it cements itself together. Thousands of different kinds of concrete are used for many different applications. It would take much study to understand the many different compositions, reactions, and applications of this material.

2. Portland cement forms hydration bonds as it is setting in the concrete matrix. This means that the water added to the cement takes part in a reaction with the cement particles. The water forms a strong bond with the cement, and the cement particles are locked together in an intertwining matrix. Cement does not dry, it cures. Another way to put it is that the water does not evaporate, it becomes part of the concrete composite. Once concrete is formed it is very difficult to break and impossible to reverse the process back to the original materials. Hydration in concrete forms very strong bonds.

3. This lab is divided into two parts: First, have all students make cement so they become familiar with the material. Second, allow students to vary compositions to determine how these changes affect the concrete. Students can begin by making a common concrete from Portland cement. The composition of concrete made from Portland cement can vary also, so first try a common composition of 40/60 weight percent sand to rock ratio and a 45/55 weight percent water to cement ratio.

4. Once students have learned how to work with concrete, they can do some scientific exploration. By altering the composition of concrete, the properties of the material will also be altered. Testing and evaluating these changes is part of the work of a scientist. Encouraging students to follow the scientific process will help them learn, explore, evaluate, and be creative as they work with materials.
5. Test the samples following a test procedure, such as the one described on the following page (see Testing Materials) and record both the procedure used and the test results.

**Suggested Questions**

6. What strengthens this material?

7. Are there other materials which could be added to concrete to strengthen it? Try your theory by making and testing it.

8. Is there a better way to test concrete?

9. What is the best use for concrete materials?
Activity: Making Concrete

Student Learning Objectives
At the end of the activity students will be able to:
• describe a composite material
• explain why a composite might be chosen to replace more conventional materials
• participate in making concrete materials
• describe the process used in the experiment
• identify several composite materials used commonly in our lives.

Materials
• Portland cement
• Water
• Sand
• Gravel or small rock

Equipment
• 1- to 2-gallon plastic container
• Mold or dam (see #1 of procedure in Making Concrete or #1 under Testing Materials)
• Scale
• Stirring stick (strong wooden dowel would work)
• Clamp for securing concrete for testing
• Weights for testing strength of concrete

Procedure
1. Make a mold or dam into which the concrete can be poured. A dam could be as simple as placing 2- x 4-in. pieces of wood together to create a 4- x 4-in. square. A rectangle of larger dimensions also could be made. An appropriate mold could be a plastic glove or a silicone mold for shaping a part.
2. In a 1- to 2-gallon plastic container, thoroughly mix 258 g of sand, 404 g of rock, 93 g of water, and 118 g Portland cement.
3. Pour the mixture into the mold or dam.
4. Let the concrete cure over night before handling it.
Project: Varying Concrete Components and Testing New Materials

In this project you get to experiment with different compositions of materials to make concrete and then test the concrete samples you create.

Procedure

Other concrete components—like sand or cement—can be varied, tested and the results compared. More sophisticated tests can be made by adding two component variables such as water and sand to the matrix.

1. Using the composition from step 2 in Making Concrete, change a single component in the composition, and test and evaluate how this variable will affect the material. An example would be to add 5% more water to a concrete batch. Try another sample with an additional 5% water, and analyze the material. A suggested test for your samples is found below (see Testing Materials).

2. Now reverse the process, and see how less water (5% and 10% less) affects the concrete. Test and record these results in your journal. Can the strength of these materials be evaluated from the results of these tests?

3. Another variation to the composition would be to replace rock with other materials, and investigate the results. Our garbage landfills are rapidly filling up. Are there some materials that could take the place of rock? Try ground-up milk jug parts or pieces of metal or ground automobile tires, and test the results of these concretes.

Testing Materials

1. To establish consistency in the data, you must establish a standard method to test each concrete sample. An example would be to make a standard size mold (i.e., a wood mold 1 x 1 x 10 in.). Each concrete sample could then be poured into the mold and cured for the same length of time (i.e., 3 days or maybe 7 days—just be consistent). A simple procedure for testing the strength of concrete could be applied as follows. The set up is shown in Figure 8.1.

2. Secure each sample with a “C” clamp 2 in. in from the edge of a table. On the end of the sample suspended over the edge of the table, add a device (basket or hanger) from which weights can be added.

3. Obtain weights of approximately the same mass. Weights could be small blocks of concrete you can make and weigh or blocks of metal weighing approximately the same.
4. Add weights one at a time to the basket until the sample breaks.
5. In your journal, record the weight necessary for failure to occur.
Composite Experiments
Instructor Notes

Reliability
All these experiments work well. Some experiments may require several trials if they have never been tried before.

Teacher Tips
1. These experiments help familiarize students with the processes and materials used to make common composites.

2. The experiments demonstrate the relationship among materials, weight, design of structure, and cost by taking students through building and testing different materials, doing a simple and crude strength-to-weight comparison, or a cost analysis of material types.

3. The experiments can also be highly detailed exercises in building and testing several identically sized test samples exposed to identical test conditions (See Young’s Modulus Testing of Beams). Students can observe vastly differing results because of different material characteristics, even though objects are built to the same design. To accurately test materials this way, it is important that dimensions of each sample be identical.

4. Good examples exist of cross-linkage, types of fiber orientation, matrix formation, and stress/strain matrix curves in the Jacobs’ textbook.

5. Epoxy curing time can be decreased by heating the epoxy in a furnace. Do not overheat the epoxy; it will burn. A suggested temperature of 50°C will dramatically decrease the curing time.

6. Fantastic household cleaner is an excellent substitute for cleaning sticky epoxy messes. We recommend this product (over acetone) because acetone has some health hazards associated with it.

7. Honeycomb is a difficult product to obtain. Boeing Surplus in Seattle, Washington, has been the main supply source. Contact a mentor teacher or PNL staff if additional material is needed.

8. Kevlar is made from fibers that are strong and thin. Special ceramic scissors from Jensen Tools, Inc. (See Vendor List in Appendix) are needed to effectively cut the fabric. These scissors are quite spendy. Use only as directed by manufacturer.

9. Tacky tape (zinc chromate) for the honeycomb composite project (#4) is supplied by Schnee-Morehead, Inc. (See Vendor List in Appendix). Some teachers have used molding clay with success.
Suggestions for Conducting Introduction to Composite Experiments: Projects 1-4

The following four experiments are identical except that a material or process has been changed in each project.

As a manageable means to conduct the experiments and allow the students maximum exposure to a variety of composite materials without doing all the experiments, small work groups with separate composite activities may work best. A suggested way would be to divide the class into four groups. One group could hand laminate the epoxy resin items while another group works with the epoxy resin items on the hydraulic press (see Table 8.1 for sample group assignments).

When the groups complete the activity, each group reports their observations, which have been written in their journals, to the entire class. Strength tests can then be conducted on the materials to further study properties of these composites.

Table 8.1. Sample Groupings for Composite Experiments

<table>
<thead>
<tr>
<th>Group A</th>
<th>1a Fiberglass cloth with epoxy resin</th>
<th>hand laminated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1b Fiberglass mat with epoxy resin</td>
<td>hand laminated</td>
</tr>
<tr>
<td></td>
<td>1c Fiberglass cloth with epoxy resin</td>
<td>vacuum bagged</td>
</tr>
<tr>
<td></td>
<td>1d Fiberglass mat with epoxy resin</td>
<td>vacuum bagged</td>
</tr>
<tr>
<td></td>
<td>1e Fiberglass cloth with epoxy resin</td>
<td>hydraulic press</td>
</tr>
<tr>
<td></td>
<td>1f Fiberglass mat with epoxy resin</td>
<td>hydraulic press</td>
</tr>
<tr>
<td>Group B</td>
<td>2b Kevlar with epoxy resin</td>
<td>hand laminated</td>
</tr>
<tr>
<td></td>
<td>2b Kevlar with epoxy resin</td>
<td>vacuum bagged</td>
</tr>
<tr>
<td></td>
<td>2c Kevlar with epoxy resin</td>
<td>hydraulic press</td>
</tr>
<tr>
<td>Group C</td>
<td>3a Honeycombed composite with glass cloth</td>
<td>hand laminated</td>
</tr>
<tr>
<td></td>
<td>3b Honeycombed composite with glass cloth</td>
<td>vacuum bagged</td>
</tr>
<tr>
<td></td>
<td>3c Honeycombed composite with glass cloth</td>
<td>hydraulic press</td>
</tr>
<tr>
<td>Group D</td>
<td>4a Honeycombed composite with Kevlar cloth</td>
<td>hand laminated</td>
</tr>
<tr>
<td></td>
<td>4b Honeycombed composite with Kevlar cloth</td>
<td>vacuum bagged</td>
</tr>
<tr>
<td></td>
<td>4c Honeycombed composite with Kevlar cloth</td>
<td>hydraulic press</td>
</tr>
</tbody>
</table>
Project 1: Fiberglass Hand Laminating Process

Student Learning Objectives
At the end of the activity students will be able to:
• make a composite to apply and test the concept of combining two or more different materials to obtain a new material. The new material will exhibit new and improved properties than the original materials.

Materials
• Fiberglass
• Epoxy resin (two-part kit)
• Paper measuring cup, 4-6 oz
• Brush (1 in.)
• Polyethylene, 8 x 36 in. (clear plastic bags)
• Acetone or Fantastic
• Tongue depressor or disposable stirring sticks
• Eye dropper
• Plastic gloves
• Wax paper or plastic for table cover

Procedure
1. Cut five to six 3- to 4-cm x 30- to 40-cm fiberglass strips (mats) with scissors. Weigh the batch of strips to be used in the composite.
2. Approximately 2 oz of epoxy resin is needed for this experiment. Follow the directions on the back of the resin can, measuring the ingredients into a paper cup. Thoroughly mix contents with tongue depressor for 3-5 min.
3. Place polyethylene sheet on table top to protect the table.
4. Pour a small amount of resin onto the polyethylene surface. Note: resin does not stick to polyethylene. Spread to 4- x 40-cm area with brush.
5. Place one fiberglass 3 to 4-cm x 30 to 40-cm mat onto the resin.
6. Dip brush into resin. Paint the resin into the fiberglass mat by gently stroking the brush over the fiberglass. Begin brushing in the middle, and stroke toward the outer edges. The fiberglass will absorb the previously poured resin. Apply only enough resin with the brush to saturate the fiberglass.

7. Place second fiberglass mat (dull side up) onto the first layer. Apply resin with brush, working from the center out to prevent air bubbles. Add only enough resin with the brush to wet or saturate the fiberglass.

8. Repeat process with each additional fiberglass laminate.

9. Upon completion, place brush into empty cup.

10. Cover the fiberglass laminate with a polyethylene sheet. Apply a flat weight (i.e., books, wood, or metal slab).

11. Observe the contents of the cup and brush to verify that the resin is curing. The cup will feel warm from an exothermic reaction that is taking place. An odor will be increasingly noticeable as a chemical reaction occurs.

12. Clean the brush with acetone or Fantastic. Discard the cup and clean the table top if necessary.

13. Let the composite cure until rigid.

14. Take a final weight of the composite.

**Extension Activities**

1. Test the sample by breaking it. Determine the force necessary for the composite to break.

2. Make additional samples of this same composite using more epoxy. Be sure to weigh the fiberglass before and after making the sample. Test the sample as in 1 above. Record observations and test results in your journal. Also be sure to record any differences in processing the materials (i.e., change in size of fiberglass mats, seepage of epoxy from mat, etc.). Does additional epoxy strengthen the composite?
Project 2: Kevlar Hand Laminating Process

Materials

• Kevlar
• Epoxy resin (two-part kit)
• Paper measuring cup, 4-6 oz
• Brush, 1 in.
• Ceramic blade scissors
• Polyethylene 8 x 36 in. (clear plastic bags)
• Acetone or Fantastic
• Tongue depressor or disposable stirring stick
• Eye dropper
• Plastic gloves
• Wax paper or plastic for table top cover

Procedure

1. Follow the same procedure used in Project 1, but use Kevlar instead of fiberglass.
2. Kevlar is very difficult to cut with conventional scissors. Ask your teacher for ceramic scissors to cut the Kevlar fabric.
Project 3: Press Laminating Process Using Fiberglass

Materials

- Fiberglass
- Epoxy resin (two-part kit)
- Hydraulic press with a minimum 3-in. x 12-in. pressure loading surface area
- Paper measuring cup, 4-6 oz
- Brush, 1 in.
- Polyethylene, 8 x 36 in. (clear plastic bags)
- Acetone or Fantastic
- Tongue depressor or disposable stir stick
- Eye dropper
- Plastic gloves
- Wax paper or plastic for table cover

Procedure

1. Prepare mats as in Project 1, using fiberglass and epoxy resin. Be sure to weigh the batch of mats before applying the epoxy.

2. Cover the laminate (your composite matrix) with a polyethylene sheet. Place the laminate on a 3-in. x 12-in. metal plate and cover with a matching metal plate.

3. Place the plates in the hydraulic press and apply enough pressure to force the excess resin from the composite. It would be wise to have a catch basin of aluminum foil or plastic to catch any resin that might run over the edge of the pressure plates as the resin is extruded by the pressure.

4. Let the composite cure.

5. Clean the brush with acetone or Fantastic. Discard the cup and clean the table top if necessary.

6. Trim excess resin from the edges of the composite.

7. Weigh the composite after it has been peeled from the polyethylene cover.

8. A comparison can be made at this point of the amount of resin it takes to make a hand-laminated composite versus a pressure-compressed composite.
Project 4: Honeycomb Composite Using Vacuum Bag Process

Student Learning Objectives
At the end of the activity students will be able to:

• construct, apply a vacuum, and observe curing a hand lay-up honeycomb core composite.

Materials

• 3-5 mil polyethylene sheet (20 x 20 in.)
• Zinc chromate tape (tacky tape) or clay
• Honeycomb
• Fiberglass cloth
• Epoxy resin (two-part kit)
• Osnamburg-bleeder cloth (throw-away fabric to absorb excess resin)
• Paper cup
• Stir stick
• Paint brush, 1 in. wide
• Perforated Teflon or perforated polyethylene
• Silicone mold release

Equipment

• Aluminum vacuum plate
• Vacuum pump

Note

1. Use a minimum of the epoxy resin on the fiberglass as the resin will bleed out as a vacuum is applied.
2. Cover vacuum hole in aluminum plate with a gauze pad or folded bleeder cloth to prevent resin from plugging vacuum pump/line.

Procedure

1. Apply silicone mold release to an aluminum plate (see Figure 8.2). Rub or spray on silicone, and gently wipe off excess. Silicone prevents the composite from sticking to the plate.
2. Cut polyethylene sheet at least 2 in. larger than the honeycomb piece to be made or processed.
3. Cut four pieces of fiberglass 1 in. larger than the honeycomb piece.
4. Mix resin and catalyst at appropriate ratio, as instructions direct.
5. Place fiberglass cloth onto polyethylene sheet, and carefully work resin into cloth with a 1-in. brush, from the center to outer edges.
6. Repeat for second layer of fiberglass, working resin in with brush.
7. Place honeycomb onto fiberglass.
8. Place next layer of fiberglass cloth on top of the honeycomb.
9. Repeat steps 5 and 6, working resin into fiberglass.
10. Lay perforated plastic or Teflon on top of final fiberglass layer.
11. Place bleeder cloth over the composite laminate.
12. Apply zinc chromate tape (tacky tape) around outer edge of aluminum vacuum plate. This creates an air-tight barrier.
13. Cover with polyethylene sheet being careful that a seal is formed as the polyethylene contacts the tacky tape.
14. Pull a vacuum of 20 in. of mercury on the vacuum plate until laminate has cured.
15. Shut off the vacuum, and unwrap composite from vacuum apparatus. You now have a honeycomb composite material.
16. Discard materials that cannot be reused.
17. Check for defects where epoxy did not laminate the honeycomb and fiberglass skin. It may take several tries to obtain a well-laminated composite.
Simple Stressed-Skin Composite

Instructor Notes

Reliability

These demonstrations work well.

Teacher Tips

1. The experiment outlined is designed for minimal expense per concept learned. If students are interested in exploring the capabilities of different reinforcement fibers, such materials as Fiberglass cloth, woven Kevlar, or woven graphite fibers can all be used to make additional beams that can be evaluated by the cantilever beam test (see Young’s Modulus Testing of Beams). Additionally, other fabrication techniques such as vacuum bagging may be used to achieve better bonding while using even less epoxy. To save on supplies and time, the instructor may wish to prepare demonstration beams using the more exotic materials rather than having each student make all the beams. These demo beams may then be measured nondestructively for stiffness using the cantilever beam apparatus.

Prerequisite: The student should understand the concept of Young’s modulus of elasticity, a measure of a material’s stiffness. The Jacob’s textbook is a reference for this information.

Demonstration

The following two demonstrations are a lead-in to the next activity.

Procedure

Demonstration 1:

1. With a dark ink marker, draw on one face of a foam-rubber beam evenly spaced (i.e., 1 cm) lines (Figure 8.3).

2. Demonstrate by bending the foam rubber beam that the initially parallel lines get farther apart on one side (the tensile side) and closer together on the other side (the compressive side, see Figure 1).

3. Introduce the concept of stressed-skin composites by stating that a strong and stiff material, if attached to these faces, will provide substantial reinforcement to the structure by resisting such tensile or compressive forces.
Demonstration 2:

Bend precut pieces of polyurethane foam insulation (8 cm x 8 cm x 30-40 cm) with vertical lines 1-cm apart on all 8-cm faces. Students will soon note that the beam is not very stiff and will not bend very far before breaking.

Figure 8.3. Foam-Rubber Beam Used to Illustrate Tensile and Compressive Forces Resulting From Bending
Activity: Simple Stressed-Skin Composites Using Paper Reinforcement

Student Learning Objectives
At the end of the activity students will be able to:

• demonstrate the composite reinforcement concept using readily available materials
• demonstrate the consequences of certain defects in these structures.
• quantify the gains made by engineered composite construction, using a simple measurement of Young’s modulus of elasticity.

Materials

• Foam rubber beam about 8 cm x 8 cm x 30 cm, with vertical lines on all of the 8-cm faces
• Polystyrene or polyurethane insulating foam, cut into 3 x 3 x 18 cm strips
• Heavy paper such as construction paper
• Waxed paper or polyethylene
• Slow-setting (>3 h) non-allergenic epoxy resin, curable at room temperature

Equipment

• Cantilever beam-loading device (See Young’s Modulus Testing of Beams in this section)
• Known weights of about 100 g
• Dial-gauge indicator capable of measuring to 0.025 mm (although most will measure in thousandths of an inch)
• Calculator

Procedure

1. Prepare stressed-skin composites as follows: leave one beam as is; bond one 3 x 18 cm face of a second beam with construction paper; bond both 3 x 18 cm faces of a third beam with construction paper; make the fourth beam the same as the third, but make an intentional disbond by placing a piece of waxed paper or polyethylene 3 cm x 6 cm at the midpoint of one of its paper-reinforced faces. To achieve the best possible bond, use minimal epoxy, but be certain of complete coverage. Weight the beams
with books, wood, or bricks to push materials together or to compress them during the curing process. Use waxed paper or polyethylene to separate the composites from surfaces such as tabletops where bonding is not desired.

2. To test the beams, weigh them after any necessary trimming, then record the weight gains (relative to a nonreinforced beam) for reference. Bend the non-reinforced beams again for calibration purposes. Then bend the single-sided beam with the non-reinforced face first on the tensile side; the beam should be bent only slightly, taking care not to break it. Note that this one-sided reinforcement does not have much effect on the stiffness. Finally, bend the beam, so that the nonreinforced face is on the compressive side until it breaks. Note that the foam collapses on the compressive side. This is because the reinforcement has made the beam much stronger on the tensile side.

3. Now bend the two-faced reinforced beam without the intentional debond; it is noticeably stiffer than either of the two preceding beams (See Figure 8.4). You may want to break some of these beams to observe whether failure occurs on the tensile or compressive face. Next, bend the defected beam, but not to the breaking point, with the defect on the tensile side. Note that the defect has essentially no effect. Finally, bend the defected beam with the defect on the compressive side until it fails. Note that the nonbonded paper pops away from the foam in what is known as buckling. Buckling is a fairly common failure mode for this kind of composite and can be avoided by close attention to complete epoxy coverage as the composite is being constructed.

4. See Young’s Modulus Testing of Beams activity in this section.

5. Follow the same procedure with the one-sided and two-sided reinforced beams. The deflection should be at least 0.25 mm; if not, apply more weight until it is. You will note that the beam reinforced on one side is not much stiffer than the one without reinforcement, just as was learned by hand bending. Similarly, the two-sided reinforcement produces impressive gains in stiffness. Some students may want to relate the stiffness gains to the weight gains involved in the various reinforcements. Although the stiffness of the foam beams has been increased greatly by using only paper reinforcement, the resulting composites are not very stiff when compared with other materials. However, the density of the foam beams is very low compared with other solid materials. The following values of Young’s modulus for some common materials may be useful for comparison:

<table>
<thead>
<tr>
<th>Material</th>
<th>$E$, GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>69</td>
</tr>
<tr>
<td>Steel</td>
<td>207</td>
</tr>
<tr>
<td>Many solid polymers</td>
<td>3</td>
</tr>
<tr>
<td>Glass</td>
<td>69</td>
</tr>
</tbody>
</table>

Note: 1 GPa = $10^9$ Pa.
**Activity: Young’s Modulus Testing of Beams**

**Student Learning Objectives**
At the end of the activity students will be able to:
- set up a sample beam of material for testing
- test the sample beam or material
- calculate Young’s Modulus.

**Materials**
- Prepared sample or beam

**Equipment**
- Apparatus for testing Young’s Modulus (Figure 8.5)
- Dial indicator
- Support for dial indicator
- Weights
- Calculator

**Procedure**
1. Clamp material (test specimen or sample) to be tested to the upright 2 x 4 in. wood beam.
2. Adjust the dial indicator so it just touches the bottom of the specimen or sample.
3. Zero the dial indicator.
4. Place 50-g weight into paper cup placed on top of the specimen (see Figure 8.5).
5. Record deflection of dial indicator.
6. Continue adding weights if desired to get measurable deflection.
7. Calculate Young’s Modulus using the following equation:
   
   \[
   \text{Young’s Modulus (in Pascals, Pa) = } 4(98) \frac{WL^3}{DBH^3}
   \]
   
   where \(W\) = weight in g; \(L\) = unsupported length of sample in cm; \(D\) = deflection of unsupported sample in cm; \(B\) = width of sample in cm; \(H\) = height of sample in cm; and 98 = conversion factor to change g/cm² to Pascals, the international unit for elastic modulus.
Figure 8.5. Apparatus Used to Evaluate Stiffness of Composite Beams by Measuring Deflection of a Cantilever Beam in Bending
Airfoils
Instructor Notes

Reliability

This experiment will work well. The airfoils produced will have measurable lift and give measurable differences in weight to strength ratios for the various airfoil designs.

Teacher Tips

1. Balsa sheets are available from hobby supply stores and some scientific supply catalogs. Total cost for this activity is approximately $200.00 for a class of 25 students.

2. Transparent polyester (monokote) is available from model airplane hobby shops.

3. The glue to bond the balsa is cyanoacrylate (Superglue). Common brands used in model airplane building are Zap and Hot Stuff.

4. The special iron designed for use in model construction and the high-temperature heat gun used in model construction are available from hobby stores.

5. The various parts of the wing are illustrated and labeled for orientation in Figure 8.6. Figure 8.7 gives the actual size for the airfoil used in the project. If you wish to do a larger or smaller version of the airfoil, it can be enlarged or reduced on a photocopier.

6. In testing the airfoil, the free-end length needs to be carefully measured as load deflection is a cube function. Figure 8.8 shows a possible test system.

7. When students are testing airfoils for failure, it is wise to check the approximate distance they have placed their weighing container from the floor: If the container is placed more than 5 cm from the supporting surface, the airfoil will be totally destroyed when it fails.

Caution: Avoid breathing the fumes of reacting cyanoacrylate. Be careful not to bond fingers together as cyanoacrylate adheres quickly and tenaciously to skin. If this should happen, use the debonding chemical available at hobby shops, or wait 10 min before slowly rolling the bonded surfaces apart. Do not pull fingers directly apart or use sharp blades to cut the skin surfaces apart. Take extra care to avoid getting glue in your eyes.
8. In discussing cause(s) for failure, students should speculate on what could have been done differently during construction. All the wings tested so far have failed at the point of attachment to the clamp and the test apparatus. Failure occurs under compression at the interface between the wing and the clamp.

9. Students could now build a second modified wing that remedies the problem, or they could build an identical wing with different materials (say a wing made from polystyrene insulating foam covered with balsa—which makes impressive gains in mechanical strength). They should stay within the weight limits; keep weight to a minimum.

10. Keep these results to build a data base as other classes conduct this project.
Project: Constructing and Testing a Composite Airfoil

Student Learning Objectives

At the end of the activity students will be able to:

• test a constructed airfoil to determine its relative stiffness and point of destruction
• graph results of different designs to determine the best construction.

Materials

• Balsa wood, sheet 1/16 in. x 3 in. x 36 in. (36)
• Balsa wood leading edge 3/8 in. x 5/16 in. x 36 in. (18)
• Balsa trailing edge 1/8 in. x 3/4 in. x 36 in. (16)
• Balsa 1/8 in. x 1/4 in. x 36 in. (12)
• Spruce 1/8 in. x 1/4 in. x 36 in. (9)
• Bicarbonate of soda, Na₂HCO₃ (baking soda)
• Transparent polyester covering material, Monokote or equivalent (2 sq yd)
• Glue, cyanoacrylate (Zap or Hot Stuff)
• Wax paper
• Sand paper, 150 grit
• Strong string or duct tape

Equipment

• T head pins (1 box)
• Heat gun (high temperature) used in model construction
• Electric iron, designed for model construction
• Plastic or cloth bag (or plastic pail)
• Meter stick
• Steel templates, cut to Clark Y airfoil shape, with notches for spars
• X-Acto knives or equivalent hobby knives with straight point blades
• 60 x 120 cm fibrous ceiling tile, flat finish (building board)
• Trays (6), approximately 5 x 15 cm long for sodium carbonate
• Vacuum cleaner with brush
Procedure

1. Use Table 8.2 to select the balsa and/or spruce your group will use to construct the airfoil. Cut the pieces slightly larger than the templates from the 1.6 mm (1/16 in.) sheets of balsa. Drill holes in the balsa to accommodate the posts of the template.

<table>
<thead>
<tr>
<th>Variation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW</td>
<td>Ribs 6 cm apart, balsa spars</td>
</tr>
<tr>
<td>BN</td>
<td>Ribs 3 cm apart, balsa spars</td>
</tr>
<tr>
<td>BWS</td>
<td>Ribs 6 cm apart, balsa spars, shear webs</td>
</tr>
<tr>
<td>SW</td>
<td>Ribs 6 cm apart, spruce spars</td>
</tr>
<tr>
<td>SN</td>
<td>Ribs 3 cm apart, spruce spars</td>
</tr>
<tr>
<td>SWS</td>
<td>Ribs 6 cm apart, spruce spars, shear webs</td>
</tr>
</tbody>
</table>

BW = balsa with wide spars; BN = balsa with narrow spars; BWS = balsa with shear webs; SW = spruce with wide spars; SN = spruce with narrow spars; SWS = spruce with shear webs

2. Make a template-balsa sandwich using all rib pieces.

3. Carve and sand the balsa to match the templates; be careful not to sand the templates themselves.

4. To make notches for the spars, (see Figures 8.6 and 8.7) glue a 10-cm strip of 150-grit sandpaper to the 1/4 in. face of some scrap spruce spar wood. Sand the spar notches in the ribs, avoiding enlarging the notches in the templates.

5. Take a piece of wax paper large enough to cover the building board, and mark reference lines on it to guide the placement of the spar and ribs. Be sure the reference lines are spaced correctly for your airfoil ribs and are at right angles to the spar reference line.

6. Cover the building board with the wax paper. This will prevent the wing from becoming glued to the board as well as giving you a placement guide for the spar and ribs.

7. Pin the bottom spar in place on the building board.

8. Pour sodium bicarbonate (Na₂HCO₃) into a long narrow tray.

9. Dip the rib pieces into the sodium bicarbonate. The tiny amount of soda that sticks to the rib will accelerate the reaction of the cyanoacrylate and strengthen the bond.

10. Hold each rib perpendicular to the building board, making sure each closely follows the reference lines.
11. Apply the cyanoacrylate to the junction of the spar and rib. The bond will secure this junction in 2 to 3 seconds.

**Caution:** Avoid breathing the fumes of reacting cyanoacrylate. Be careful not to bond fingers together as cyanoacrylate adheres quickly and tenaciously to skin. If this should happen, use the debonding chemical available at hobby shops, or wait 10 min before slowly rolling the bonded surfaces apart. Do not pull fingers directly apart or use sharp blades to cut the skin surfaces apart. Take extra care to avoid getting glue into eyes.
12. Set the top spar securely in place, and apply cyanoacrylate to the joints.

13. Pin leading edge and trailing edge in place. Under the leading edge, use a 3-mm (1/8-in.) shim to hold it up, since the airfoil is not quite flat.

14. Bond with cyanoacrylate.

15. If shear webs are to be attached to the spars, cut the webs so the grain of the wood is perpendicular to the building board, then bond to the front and back surfaces of the top spar with cyanoacrylate.

16. Remove the wing, turn it over, and then bond the bottom spar and shear webs together with cyanoacrylate.

17. The outer ribs on each end of the wing need to be strengthened to prevent warpage as the wing-covering material shrinks. To strengthen each end rib, glue a piece of scrap spar material onto the outer ribs.

18. Carefully sand the wing as necessary. Use a vacuum cleaner with brush to remove dust. Set aside wing while you prepare the transparent polyester covering material.

19. Cut a piece of covering approximately 1 cm larger on all sides than the wing. Follow manufacture’s instructions for applying the covering, first tacking it in place using an iron, then use a heat gun to shrink the film.

**Testing**

1. Record the weight of each wing to be tested for strength and stiffness.

2. Using a clamp that fits the shape of the airfoil’s top profile, fasten the wing to the edge of the workbench, allowing approximately 35 cm of the airfoil to hang free like a cantilever (see Figure 8.8). Because the deflection under load is a cube function, the free length should be carefully controlled.

3. Suspend a container (plastic or cloth bag or small plastic pail) from the top spar using a strong string or duct tape. Weight will be added to the container that will cause deflection. This container should be about 5 cm from the floor. Can you think of a reason why?

4. Using a meter stick fixed to the base, measure the distance to the nearest millimeter from the lower wing surface to the floor.

5. Place weights in the suspended container until a deflection of 1 cm is attained.

6. Weigh the container and weights, and record the value in your journal.
7. Continue adding weight until failure occurs. Record the failure weight and the approximate deflection at failure in your journal.

8. Observe and describe the failure point and any characteristics that you saw during the loading process in your journal.

9. Plot class test results with the x-axis as the structure type and the y-axis as the weight to cause the 1 cm deflection (graph I) and the weight to cause failure (graph II).

10. Observe the graphs for any pattern or trends. Are the two graphs similar?
Making Paper
Instructor Notes

Reliability
This lab works very well with any plant material. However, it is not recommended that students use wood as it takes too long and can be hard on the blender. Leaves, straw, rice, and grasses work well. You may want to experiment and use cardboard, used paper, construction paper, or blue jeans in making paper.

Teacher Tips
1. Using the borates for pulping is much safer than using sodium hydroxide. All work well however. Care should be taken when heating so the solution does not boil over. The solution is hot and caustic. If students get splashed, rinse off immediately.
2. Screen door screen works well for the deckle (screen). Do not use fiberglass screen as it is too flexible.
3. The size of the screen is not important. Use a size that will fit in the tray you will use to hold the pulp mixture.
4. Often the pulp sticks to screen a little, a gentle pry at a corner will release the pulp from the screen.
5. When ironing the paper, turn the cloth over to speed drying. The cloth will come off easier if the paper is not dried to a crisp.
6. Stopping at any point where indicated will not change the end results. This lab can be done over several weeks, if the need arises.
7. For students who want to go farther, they can add potassium alum to make the paper waterproof or add a piece of thin wire or thread to the screen before pressing to make water-marked paper.
8. To get a whiter paper, the pulp can be bleached with ordinary household bleach. Simply add about 50 mL of bleach to the mixture after boiling and before blending. Allow to set overnight. Rinse bleach out the next day, and then continue with the pulping operation.
9. Paper is made from cellulose fibers. Although many different types of plants are used to produce paper in the United States, most paper is made from trees.
10. The Egyptians used papyrus to create the first paper-like writing surface. Paper as we know it today was probably invented in China. Papermaking was for centuries a slow and difficult process. In the early 1800s, the continuous roll method of making paper was developed so paper could be mass produced.
11. Recycled paper is now being used to create “new” paper. Waste paper is dumped into a large mixing machine called a pulper pit. Here the paper is mixed with water, heated, and becomes “pulp.” The pulp is forced through screens of smaller and smaller mesh to remove foreign objects. To remove the ink the pulp goes through several tanks where it is bleached to form a white pulp. Paper that is not “de-inked” is considered “minimum impact paper”. The bleached, cleaned pulp is spread on large rolls of screen and is pressed and dried to form paper.

**Project: Making Paper**

**Student Learning Objectives**
At the end of the activity students will understand how to:
- make a cellulose pulp from plant material
- make paper from pulp.

**Materials**
For making pulp:
- Dried plant material
- Cheese cloth
- String
- Pulping chemical (borax or sodium borate, sodium pyroborate, sodium tetraborate, or sodium hydroxide)
- Red litmus

For making paper:
- Pulp
- Wire screen (screen door screen 10 cm x 10 cm or to fit tray)
- Masking tape or plastic tape
- Plastic tray (for wire screen to fit into)
- Cookie sheet
- Sponges
- Pieces of cloth (cotton is best)
- Blocks of wood to fit wire screen
- Micropipette
- Spatula
- Stirring rod
- Electric iron - to be shared
- Chemical goggles
**Equipment**

- Balance
- Scissors
- Hot plate or other source of heat
- 600 mL beaker or suitable container
- Blender

**Procedure**

1. *Preparing the plant material:* Cut two pieces of cheesecloth into 25-cm x 25-cm squares. Lay one piece of cheesecloth on the other. Cut the dried plant material into the center of the cheesecloth. Make the pieces less than 1 cm in length. Gather the cheesecloth to make a large “tea bag” with the cut plant material inside. Write your name on a tag and attach to a string to identify your tea bag.  

   (You may stop at this point if time runs out)

2. *Boiling:* Place your tea bag in the 600-mL beaker. Add enough warm water in 100-mL increments to cover your “tea bag.” Add 10 g of pulping chemical for each 100 mL of water you used. (Note if you are using sodium hydroxide use 5 g for each 100 mL of water used.) Place the beaker on the hot plate. Adjust heat to gently boil the contents for 45 min to 1 hour. Add hot water as the water in the beaker boils away. If time allows, boiling can continue for several hours. (Note: Boiling plant material in pulping chemical creates a smell some people find unpleasant. Do this activity in a well-ventilated area.)

   **Caution:** Use chemical goggles.

   (You may stop at this point if time runs out. Just leave the tea bag in the beaker with the pulping chemical. Turn off the heat!)

3. *Washing:* Carry the beaker carefully to a sink. Turn on the cold water, and empty the beaker into the sink. Note the color of the liquid. Fill the beaker with cold water and dip your “tea bag” in and out of the water several times. Empty the pot. Refill the beaker with water and repeat dipping process. Continue to wash your “tea bag” in this manner until the water rinse is uncolored. Test a few drops of this water with red litmus paper. Wash your “tea bag” until the rinse water will not turn red litmus blue. When the litmus stays red you have removed all the pulping chemical.

   (You can stop at this point. You can store your rinsed tea bag in a tightly sealed container at room temperature for a day or two. Refrigerate if storage is for a longer period.)
4. **Pulping:** Squeeze your "tea bag" to press out most of the water. Cut open the bag. Put a handful of your plant material into a food blender (save the rest in a covered container). Add 20 to 30 mL of water, and place the cover on the blender. Turn on the blender for about 10 sec. If the blender does not mix the material smoothly, turn it off. Add another 20 mL of water and try again. Continue adding water until the mixture blends smoothly. Blend for 1 min at medium speed. Stop the blender and look carefully at the pulp. Blend for another minute and look at the pulp again. Continue until the pulp stops changing in appearance. You now have pulp to make paper. Pour your pulp into a storage container; put a lid on it.

(You may stop here. Pulp can be stored at room temperature for a day or two or in the refrigerator for several weeks.)

5. **Making paper:**

A. **Making a screen**

There are several ways to add an edge to the screen. These edges make it easier to remove the paper from the screen later. Your screen can be used over and over again. The easiest way is to place masking tape all the way around the four edges of your screen.

B. **Loading the screen**

Soak the sponge and the pieces of cloth in water. Squeeze out as much water as you can, then place the sponge on the cookie sheet. Just before you begin, plug in the iron and turn it on medium heat. Pour 1 to 2 cm of water into the plastic tray. Add some of your pulp to the water. Stir the mixture well to separate the fibers of the pulp. Add pulp until the mixture is a little too thick to see through. Slide the wire screen into the pulp mixture from one end, and let it rest on the bottom. Do not drop the screen in the mixture as it will trap the fiber below the screen. Move the screen around and stir up the mixture to get an even layer of pulp above the screen. Lift the screen out of the pan, and place it on the damp sponge. The pulp side should be up. Use your finger to push any tufts of pulp that hang over the border of the screen onto the open meshwork. This will make it easier to pull the paper off the screen later. Check the pulp visually for bare spots. Use a micropipette to add a few drops of undiluted pulp to fill in any bare spots.

C. **Pressing the pulp**

Place a piece of damp cloth over the pulp on the screen. Place a block of wood over the cloth. Press down on the wood as hard as you can to squeeze most of the water out of the pulp. Lift off the block of wood, and set it aside. Lift the sandwich of cloth, pulp, and screen off the sponge. Turn the sandwich over so the screen is on top. Lift one corner of the screen so you can see the pulp. Use a thin spatula (or the blade of a knife) to peel the sheet of
pulp off the screen. Work slowly and carefully. Don’t worry if you tear the sheet of pulp. To repair tears, use a micropipette to put a few drops of pulp mixture over any tears.

D. Drying the paper

Cover the sheet of pulp with another sheet of damp cloth. Iron this sandwich (cloth, pulp, cloth) until it is completely dry. You may turn the sandwich over once or twice as you are ironing to speed drying. When the sandwich is completely dry, carefully peel the two pieces of cloth away from the paper. Examine the paper that you have made.

(You can make as many sheets of paper as time permits now. Just remember to add undiluted pulp as you remove more sheets of pulp.)

**Extension Activities**

1. Compare different types of paper (look at fibers under a microscope).
2. Research the current technology being used to recycle paper and produce “new” paper.
3. What is dioxin? Why is/could it be a problem? How is it used in papermaking?
4. What do wasps have to do with the topic of paper?
5. What is a watermark? Create your own paper that has your own watermark.
6. Investigate the history of rice paper.
7. Create masks using paper.
8. Use various materials to create paper, or add flowers or fabric to your pressed pulp to make designs.
Peanut Brittle
Instructor Notes

Reliability
This activity works well if directions are followed, but success will vary. It is an excellent activity before winter break.

Estimated Time for Activity
One class period.

Teacher Tips
1. This lab’s origin is unknown, but it is a well-known and much appreciated (delicious) experience.
2. It is important that you protect the students and yourself from harmful chemicals by
   • making sure the equipment is clean (beakers, thermometer, stirring rod). Purchase and dedicate the equipment for only this lab. You don’t want contamination. Washing and sterilizing equipment at the end of the lab and storing it for next year will help ensure cleanliness.
   • making sure the materials are new and fresh
     sucrose is table sugar
     glucose is corn syrup
     mixed esters are margarine
     protein pellets are peanuts
     sodium bicarbonate is baking soda
     4-hydroxy-3-methoxybenzaldehyde is vanilla
     (artificial OK, real is better)
3. Students may over heat the sugar solution and burn it (Yuk!).
4. When adding vanilla and baking soda, the beaker should be held with a hot pad.
5. It is recommended that raw spanish peanuts be used, but this is definitely not necessary. They cook as the brittle is formed.

Safety
1. Be careful of flames and hot surfaces, burns are possible.
2. If glass rods or thermometers break, discard the batch.
3. Do not use mercury thermometers.
**Activity: Peanut Brittle**

**Student Learning Objectives**

At the end of the activity students will be able to:

- investigate the formation of a delicious composite material by the infusion of CO\(_2\) into a mixture of protein inclusions and foamed saccharides
- Cooperate with other students in performing this activity in a small group because of time limitation
- understand this experiment is edible, cleanliness is absolutely necessary.

**Materials**

- Sucrose, 75 g
- Glucose, 3M, 60 g
- Water, 20 mL
- Mixed esters, 19 g
- Protein pellets, Spanish, 50 g
- Sodium bicarbonate, 4 g
- 4-hydroxy-3-methoxybenzaldehyde, 1.0 mL
- Paper towels, 30 cm x 30 cm
- Plastic cup (5), 3 oz.
- Aluminum foil, 30 cm x 30 cm

**Equipment**

- Safety glasses
- Beaker, 400 mL
- Beaker tongs
- Stirring rod
- Bunsen burner/hot plate
- Ring stand and ring
- Wire gauze (ceramic centered)
- Graduated cylinder, 25 mL
- Thermometer (candy)
- Scale/balance
**Procedure**

1. Clean laboratory. Wipe down balance/scale and areas surrounding it with a damp cloth. Wash any other surfaces that will be used for this experiment. Wash your hands too!

2. Keep an accurate record of the process you followed in your laboratory journal.

3. Weigh out 75 g of sucrose into a plastic cup.

4. Weigh out 60 g of 3M glucose solution into a plastic cup.

5. Measure out 20 mL of water into a plastic cup, using graduated cylinder.

6. To a 400-mL beaker add steps 1-3.

7. Heat this mixture of saccharides slowly. Stir constantly. Bring to a boil. Use as cool a flame or heat that will maintain boiling. Avoid burning the saccharides.

   **Note:** Never stir solution with your thermometer; always use a stirring rod.

8. Weigh out 7 g of solidified mixed esters in a plastic cup. Add 6 g of the solidified mixed esters to the boiling glucose-sucrose solution. Take the remaining 1 g of solidified mixed esters, and lightly coat a 30-cm square of aluminum foil.

9. Continue to heat and stir. Use beaker tongs to stabilize the beaker while stirring.

10. Weigh out 50 g of Spanish protein pellets on a piece of 30-cm-square paper towel.

11. When the temperature reaches 138°C, add the Spanish protein pellets (containing arachin, conarchin, and oleic-linoleic glycerides.)

12. Continue to stir.

13. Weigh out 4 g of NaHCO₃ into a plastic cup.

14. In a 25 mL graduated cylinder, put 1.0 mL of 4-hydroxy-3-methoxybenzaldehyde.

15. Prepare a pad by folding a paper towel into fourths.

16. When the temperature reaches 154°C, remove the beaker from the heat source. Place the beaker on the paper pad near the aluminum foil. Remove the thermometer.

17. While one partner holds the beaker and is prepared to stir, the other adds the 4-hydroxy-3-methoxybenzaldehyde and NaHCO₃.

18. Stir vigorously. When the rising mixture slows, pour the mixture on to the aluminum foil.
19. When the mixture has cooled, break up the new product, submit a small sample for judging, and consume the rest at will.

20. Thoroughly clean all equipment and the laboratory; remember, this experiment is edible, so make sure to clean all equipment so the next group can use it. Dispose of paper towel and plastic cups.

21. Finish writing observations in your journal. Write a summary report of this lab to include generic terms for ingredients and the product you made.
Vocabulary—Composites*

Advanced composites
Cermets
Composites
Curing
E-glass
Fatigue
Fiber
Filament
Carbon black
Epoxy
Laminated composites
Sandwich composites
Glass fibers
Kevlar
Laminate
Matrix
Nondestructive evaluation
Pre Preg
S-glass
Whisker
Specific stiffness

*Instructor may vary vocabulary to suit particular content presented.