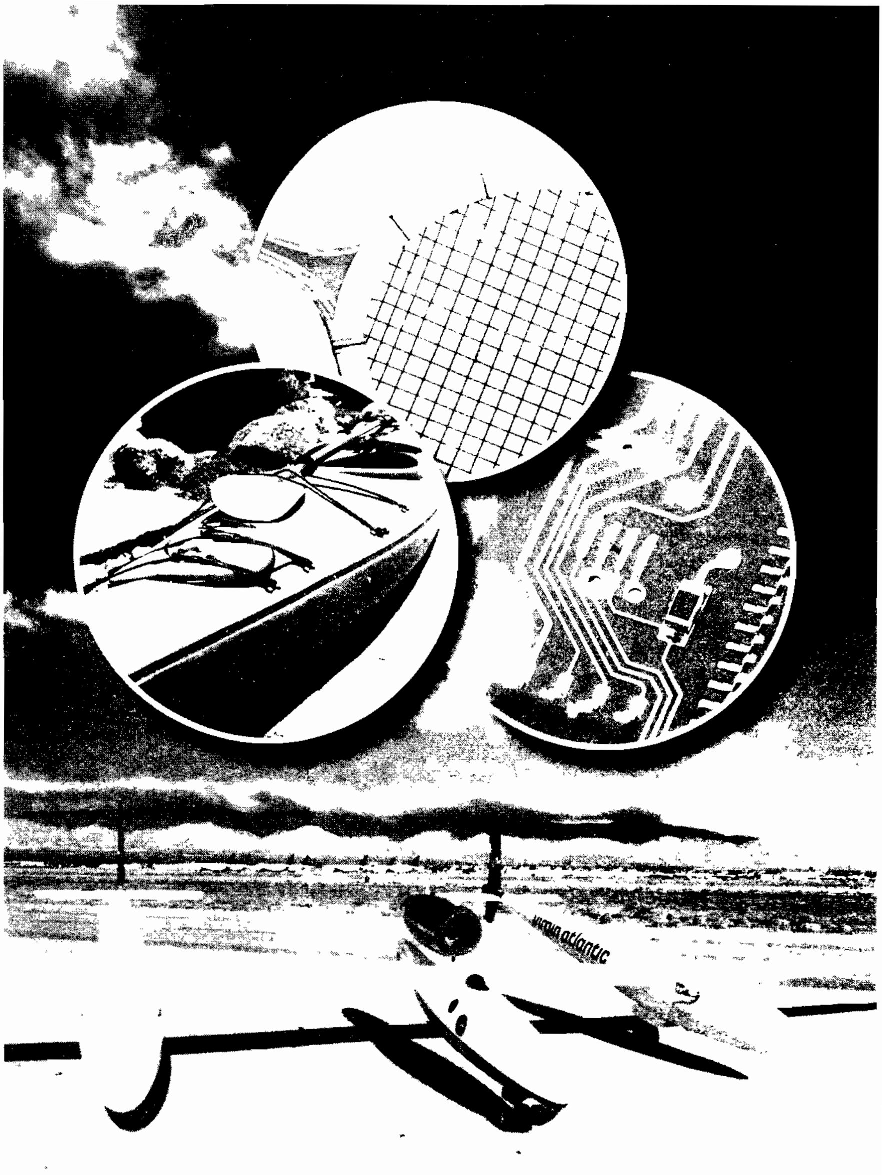
COMPOSITE MATERIALS

On our cover: **The small, round windows on SpaceShipOne help minimize its weight and structure load and allow the pilot to view the horizon while in-flight.**

BOY SCOUTS OF AMERICA
IRVING, TEXAS



33252
ISBN 0-8395-2165-0

2006 Second Printing

Requirements

1. Do the following:
   a. Explain the precautions that must be taken when handling, storing, and disposing of resins, reinforcements, and other materials used in composites. Include in your discussion the importance of health, safety, and environmental responsibility and awareness.
   b. Describe what a material safety data sheet (MSDS) is and tell why it is used.
2. Do the following:
   a. Explain what composite materials are. Include a brief history of composites and how they have developed.
   b. Compare the similarities and differences between composites and wood, aluminum, copper, and steel. Describe the physical, electrical, mechanical, corrosive, flammability, cost, and other such properties. For each of these raw materials, give one example of how it can be shaped and used for a specific application.
3. Describe how composite materials are made. Then do the following:
   a. Discuss three different composite reinforcement materials, their positive and negative characteristics, and their uses. Obtain the MSDS for each one and discuss the toxicity, disposal, and safe-handling sections for these materials.
   b. Discuss three different resins used in composites, their positive and negative characteristics, and their uses. Obtain the MSDS for each one and discuss the toxicity, disposal, and safe-handling sections for these materials. Include thermoset resins and thermoplastic resins in your discussion.

c. For each of the three resins you chose for requirement 3b, think of a new application that might be worth developing.

4. With your parent's permission and your counselor's approval, do ONE of the following:

   a. Visit a company that manufactures or repairs products made with composites. Discuss what you learn with your counselor.

   b. Find three composites-related Web sites. Share and discuss what you learn with your counselor.

5. Do the following:

   a. Use composite materials to complete two projects, at least one of which must come from the *Composite Materials* merit badge pamphlet. The second project may come from the pamphlet OR may be one you select on your own that has been approved by your counselor in advance.

   b. With your counselor's assistance, find an appropriate site where the projects can be safely completed under your counselor's supervision and/or the supervision of an adult approved by your counselor who is knowledgeable about composites.

   c. With your counselor, determine how the finished projects will be evaluated. Using those guidelines, evaluate the completed projects with your counselor.

6. Find out about three career opportunities in composite materials. Pick one and find out the education, training, and experience required for this profession. Discuss this with your counselor, and explain why this profession might interest you.

Note to the Counselor

Many useful, everyday products are made of composite materials. Earning the Composite Materials merit badge gives Scouts a chance to learn about composites: what they are, how they are made, and how they are used. Scouts have the opportunity to put their new knowledge into practice as they create items using composite materials.

This opportunity poses some inherent safety and health concerns. A Scout working on the Composite Materials merit badge will be exposed to hazardous materials. The risk must not be taken lightly, but neither should the Scout be afraid of learning to work with hazardous materials. This merit badge can be earned safely and without harm to participants' health. Be sure the Scout receives proper instruction in the use and handling of composite materials from a competent and responsible adult who is knowledgeable about composites.

Encourage all Scouts to use material safety data sheets (MSDS) to learn how to protect themselves from harm. Simply reading an MSDS, however, may not fully prepare a Scout to handle the health and safety concerns of working with a particular hazardous material. You, as the counselor, must be thoroughly familiar with all the hazardous materials used in the projects the Scout selects, and ensure that he fully understands those hazards.

These materials have a powerful smell. To protect Scouts from overexposure to chemical vapors, make sure all projects are done outdoors in a large open area to prevent a buildup of chemical vapors. Solvents, such as acetone, are flammable and must be kept away from all potential sources of ignition, such as electrical tools, fans, flames, and sparks.

It is highly recommended that all composite materials–related activities are carried out in groups of two or three Scouts. Conduct the projects outdoors, where there is plenty of fresh air.

Be sure all participants have the appropriate personal protective equipment, including body, hand, and eye/face protection and foot coverings. Protective clothing not only prevents exposure to hands, eyes, and face, but also keeps hazardous materials from contaminating street clothes.

It is highly recommended that Scouts work in small groups of two or three on their projects. As with all merit badge projects, work for this merit badge must be done under qualified adult supervision to ensure that Scouts take a careful, disciplined approach. With the proper care, precautions, and supervision, Scouts can safely enjoy learning a new skill.

SpaceShipOne during initial assembly, *far right*. The project, which was funded solely by Microsoft cofounder Paul G. Allen, led to the world's first privately piloted spacecraft to fly beyond Earth's atmosphere.

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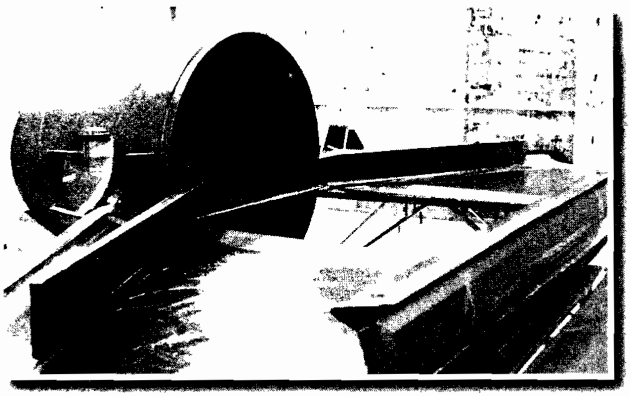
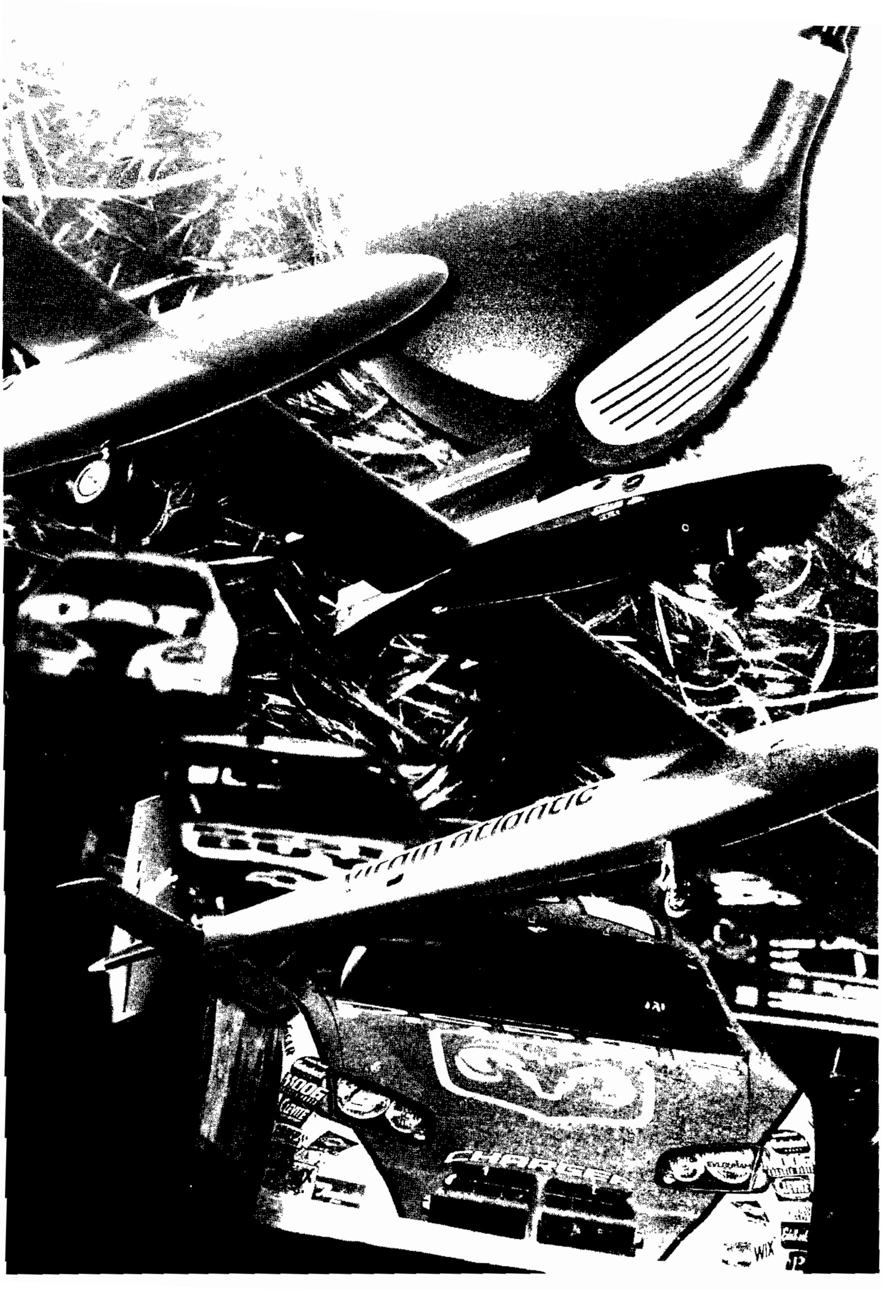


SpaceShipOne photos courtesy ©2004 Mojave Aerospace Ventures LLC, by David M. Moore. SpaceShipOne is a Paul G. Allen Project.


CHARGER
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What Are Composite Materials?

Definitions of words shown in **bold print** appear in the glossary at the back of this pamphlet.

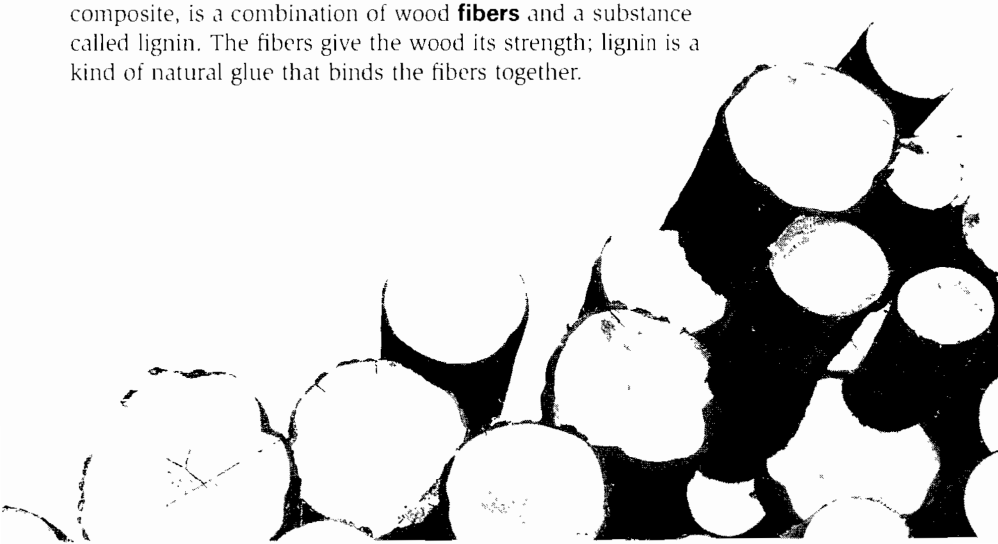
Composite materials are all around you, though you probably don't call them that. Composites make bicycles and skis lighter, kayaks and canoes stronger, houses warmer, and helmets tougher. You can find composites just about everywhere: in airplanes and sports cars, golf clubs and guitars, boats and baseball bats, bathtubs and circuit boards, and even bridges.

So what *are* composites?

Generally speaking, a *composite* is a combination of different components or elements. In photography, for example, combining many individual photographs into one picture creates a *composite photograph*. In the movie business, a film with the picture and the soundtrack side by side on the same strand of film is a *composite print*.

For your work on the Composite Materials merit badge, however, think of a **composite** as a material made from two or more different materials that, when combined, are stronger than those individual materials by themselves.

Composites can be natural or synthetic. Wood, a natural composite, is a combination of wood **fibers** and a substance called lignin. The fibers give the wood its strength; lignin is a kind of natural glue that binds the fibers together.

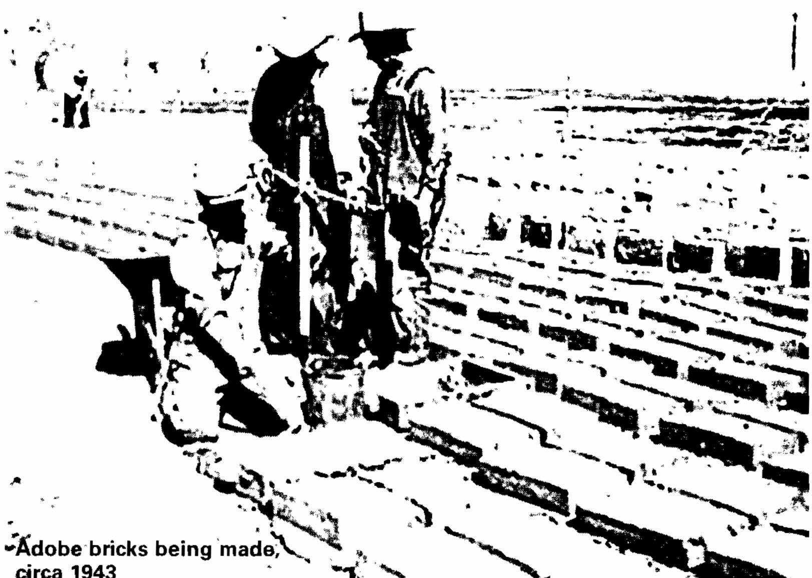


The adobe bricks used to build walls in some ancient civilizations were one of the first composite materials.

When Scout troops travel to the Philmont Scout Ranch in northern New Mexico, they sometimes stop by the Taos Pueblo, about 50 miles away. The Pueblo Indians began constructing their settlement's main buildings out of adobe between A.D. 1000 and 1450, long before Christopher Columbus arrived in America. Those buildings still stand today.

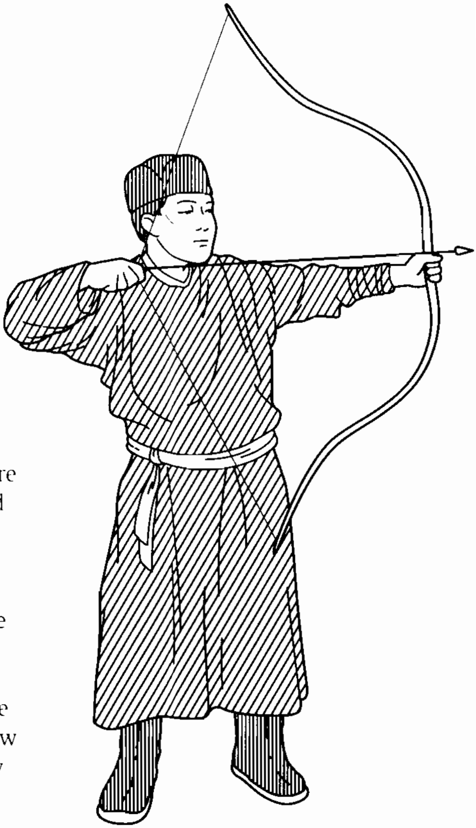
Other composites are synthetic (artificial or made by humans), and many of those have been around for thousands of years. Ancient peoples around the globe made adobe bricks, combining straw and mud to form a composite that is stronger than either the straw or the mud by itself. Modern builders may use steel and concrete—a combination that makes building materials strong and stiff.

The composite materials you will learn about for this merit badge are combinations of fibers and "glue," basically similar to wood or adobe brick. Modern composites, however, have unique and valuable properties that put them far ahead of historical versions. This pamphlet will introduce you to those properties or qualities, show you where and how composites are used, and take you through the steps to make your own composites products.



Adobe bricks being made, circa 1943

The History of Composites



Mongol warrior with his bow drawn

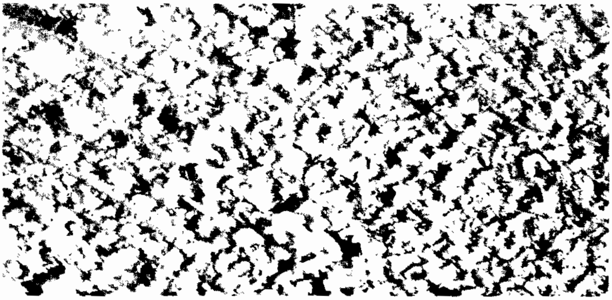
Thousands of years ago, the ancient Egyptians combined mud and straw to make adobe bricks. Mongol warriors in the 12th century A.D. made archery bows of composite materials. Over a core of bamboo, animal tendons were placed on the tension side (the outer surface), and horn on the compression side (the inner surface). This lay-up was tightly wrapped with silk, and the entire bow sealed with pine resin. With these superior bows, archers could hit targets from 490 yards (the length of nearly five football fields). Some of these bows, now more than 900 years old, were tested by a museum and found to be almost as strong as modern composite bows.

Modern Composites

Leo Baekeland, a chemist, introduced the modern era of composites in 1907 with his creation of Bakelite, one of the first synthetic **resins.** The resin itself was very brittle. However, Dr. Baekeland found that combining cellulose with Bakelite created a substance that was stronger and less brittle. The first commercial use of this new composite was to make gearshift knobs for the 1917 Rolls Royce automobile.

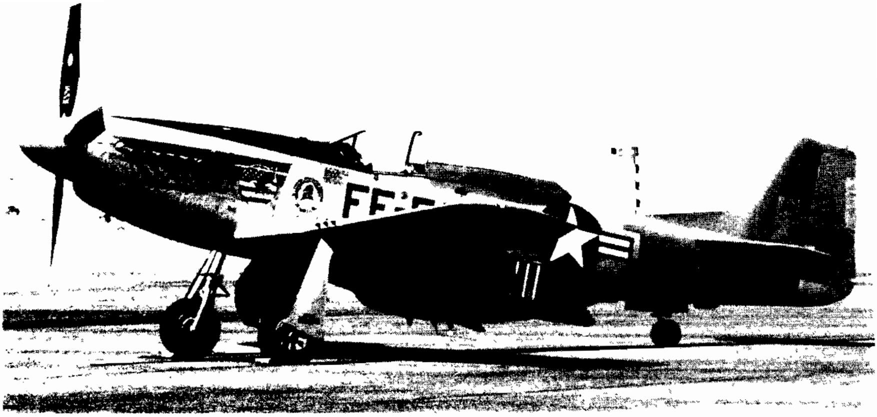
Cellulose is a substance that strengthens the stems and leaves of trees and other plants. Wood is about half cellulose. All fruits and vegetables contain cellulose. The stiff stalks of celery, for example, are rich in cellulose.

Resins act as the glue that holds composites together. A natural resin that you probably know is pine resin. Different types of resins that are used in composite materials are covered in the "How Are Composites Made?" chapter.



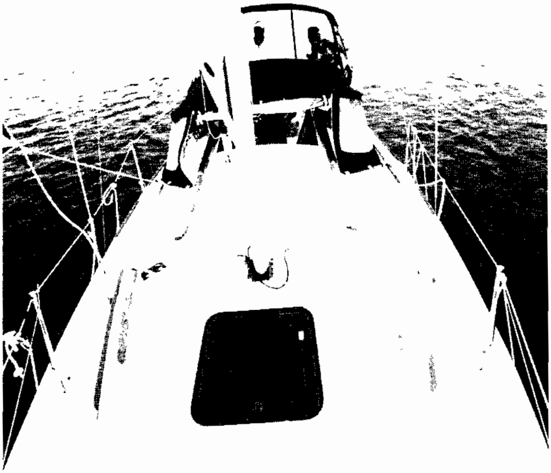
During the 1920s and 1930s, new and better resins were created. Then, in the late 1930s, the Owens-Illinois company developed a process for drawing glass into thin strands or fibers. These new glass fibers, when combined with the newer synthetic (polyester) resins, produced strong and lightweight composites. One of the first products to be made with these new composites was a boat hull, manufactured in the 1930s using fiberglass fabric and polyester resin.

Glass fibers



The new composites industry developed further during World War II. The military was looking for any material that could reduce weight while improving strength and offering good resistance to weather and the corrosive effects of salt air and water. The U.S. Air Force and Navy made good use of these properties of composites in many aircraft and watercraft.

After the war, the use of composites grew quickly. Boats, trucks, sports cars, storage tanks, pipes, and ducts—almost anything imaginable—were built using composites. The processes developed during this period are still used today, with some minor improvements or modifications.



Fishing poles made with modern composites are extremely flexible and durable.

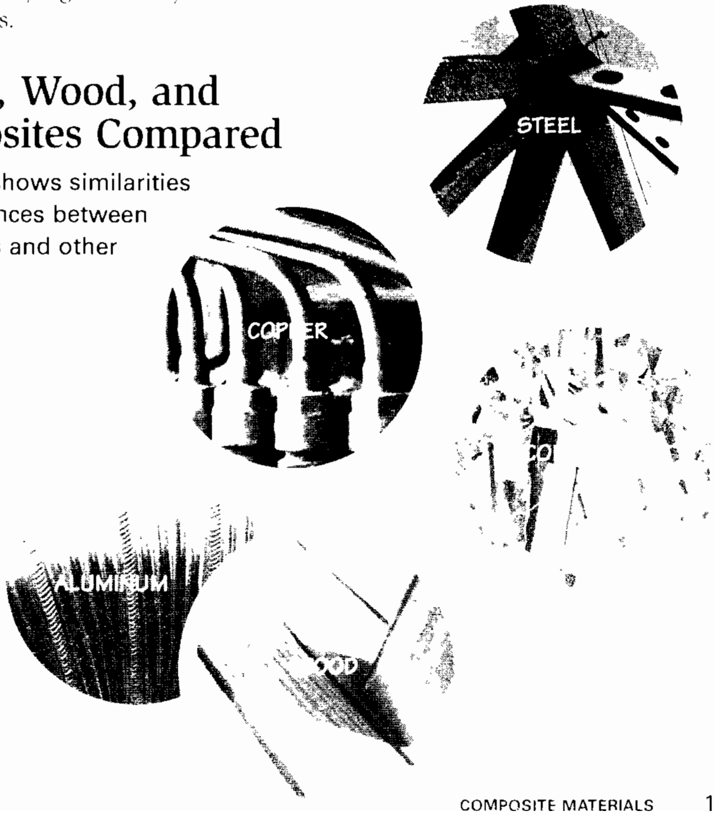
Why Use Composites?

Modern composites are often used as strong, lightweight replacements for traditional materials such as metal and wood. In many ways, wood is a great building material. It is strong, abundant, and relatively light. But it has some disadvantages. It is much stronger along the grain than across. It can twist and warp. And it swells and shrinks as humidity changes.

Wood can rot, and metal can rust or corrode. Metal can also suffer from *fatigue*—it may weaken or fail under repeated stress.

Metals, Wood, and Composites Compared

This chart shows similarities and differences between composites and other materials.



Material	Aluminum	Copper	Steel	Wood	Composites
Physical and Mechanical Properties	• Soft and weak in pure form; can be strong as steel when mixed with copper, zinc, magnesium, and other elements to form alloys • Lightweight—a third the weight of steel • Very good strength-to-weight ratio • Easily formed and shaped • Easily drawn into wires • Heats and cools quickly and evenly • Nonmagnetic	• Soft and weak in pure form; stronger when mixed with zinc (to make brass) and tin (to make bronze) • About three times heavier than aluminum • Low strength-to-weight ratio • Easily formed and shaped • Easily drawn into wires • Excellent conductor of heat • Nonmagnetic	• Strong, hard, durable • Heavy • Can be brittle unless properly hardened • Good strength-to-weight ratio • Can be cast, rolled, forged, and otherwise shaped • Average conductor of heat • Magnetic	• Soft and weak to hard and strong, depending on species • Lightweight (balsa, pine) to heavy (oak, ash) depending on species • Elastic, flexible • Low to good strength-to-weight ratio • Can be shaped by cutting, chiseling, planing, etc., not routinely cast or molded • Poor conductor of heat • Nonmagnetic	• Strong, tough, durable; can be made stronger in a specific direction (unlike metals, which have equal strength in all directions) • Lightweight • Stiff, crush-resistant, stable • Highest strength-to-weight ratios • Can be molded into complex shapes • Can be shaped with standard carpentry tools • Poor conductor of heat (insulator) • Nonmagnetic

Material	Aluminum	Copper	Steel	Wood	Composites
Electrical Properties	Good conductor of electricity	Excellent conductor of electricity	Conductive	Nonconductive	Nonconductive (can be made conductive in some applications)
Corrosion Resistance	• Does not tarnish or rust • Resists corrosion in salt water	Does not rust; weathering gives a green patina that protects against further corrosion	Rusts unless given a corrosion-resistant finish or coating	Rots, splits, warps; vulnerable to insects unless treated	Resists weathering and chemical corrosion
Flammability	• Noncombustible • Does not produce sparks when struck • Does not emit hazardous fumes when heated	• Noncombustible • Does not produce sparks when struck • Does not emit hazardous fumes when heated	• Noncombustible • Produces sparks when struck • Does not emit hazardous fumes when heated	• Combustible • Emits hazardous fumes and smoke when burned	• Combustible • Emits hazardous fumes and smoke when burned • Some composite materials are resistant to fire, or chemical additives are used in the materials to lower the effects of smoke and flame spread.

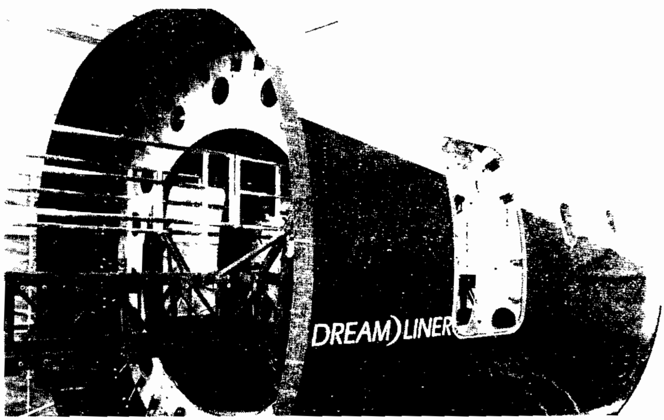
Material	Aluminum	Copper	Steel	Wood	Composites
Cost	Relatively high, compared with steel	Relatively high, compared with steel	Relatively low to high, depending on grade of steel	Low to high, depending on species	Low to high, depending on types of materials used and the application
Other Properties	Easily recycled	Easily recycled	Recyclable	Renewable resource	• Thermoplastic composites can be recycled. • Some composites use natural fibers or sources for resin that could be recycled. • Composites require low consumption of energy to produce materials and products.

Material	Aluminum	Copper	Steel	Wood	Composites
Typical Uses	• Beverage cans, bottle caps, foil pouches and wrappers • Aircraft, automobiles, trucks, railcars • Saucepans, cookware • Long-distance high-voltage power lines • Outdoor products (aluminum siding, roofing, storm windows, rain gutters, lawn furniture, license plates)	• Electrical and telephone wiring in homes, factories, offices • Motors, generators • Plumbing pipes, gas lines, electrical conduits, radiators • Cookware • Roofing • Decorative objects, jewelry	• Vehicles, machinery, tools • Structural beams, girders • Railroad rails • Bridges • Ship hulls • Storage tanks • Cookware, flatware • Surgical instruments • Nails, bolts, screws	• Building construction • Railroad ties • Telephone poles • Furniture, cabinets, trim • Tool handles • Musical instruments • Sports equipment, oars, paddles • Picture frames • Crafts, carvings	• Aircraft • Utility poles • Automotive parts • Tool handles • Recreational watercraft • Storage tanks • Sports equipment • Pipe • Building construction • Doors • Tubs, showers • Wind turbine blades • Helmets, protective gear • Circuit boards • Bulletproof panels • Artificial limbs • Satellites • Theme park rides • Military equipment • Pools • Bridge decks

Composites can be manufactured to have properties different from other materials, properties that can offer advantages over traditional materials. Here are examples of those properties.

LIGHT WEIGHT

Composites are light in weight, compared with most woods and metals. Their lightness is important in automobiles and aircraft, for example, where less weight in cars better [illegible] and better fuel efficiency (more miles to the gallon). People who design airplanes are greatly concerned with weight, since reducing a craft's weight reduces the amount of fuel it needs and increases the speeds it can reach. Some modern airplanes are built with more composites than metal.



Metals are **isotropic,** meaning they have uniform properties in all directions. Composites are **anisotropic,** having different properties in different directions.

HIGH STRENGTH AND STIFFNESS

Composites can be designed to be far stronger than aluminum or steel. Metals are equally strong in all directions. But composites can be engineered and designed to be strong in a specific direction. For the same weight, composites can be four to six times stronger than steel. Because of the ability to design stiffness into composites, they can be made lighter than many metal structures and still not bend under loads.

Composites can be made to resist bending in one direction, for example. When something is built with metal, and greater strength is needed in one direction, the material usually must be made thicker, which adds weight. A composite can be strong without being heavy. Composites have the highest *strength-to-weight ratios* in structures today.

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. Other materials can be strong and light, such as bamboo poles. 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.

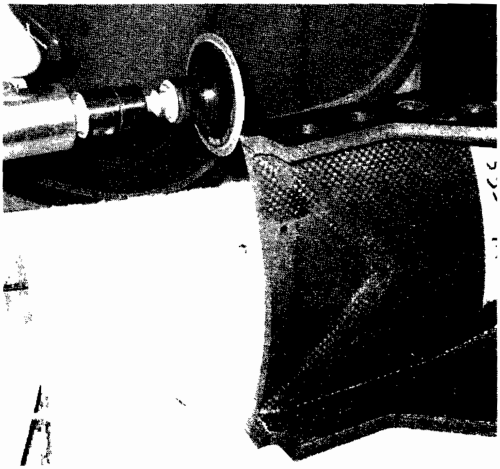
HIGH-IMPACT STRENGTH

Composites can be made to absorb impacts—the sudden wallop of a bullet, for instance, or the blast from an explosion. Because of this property, composites are used in bulletproof vests and panels and to shield airplanes, buildings, and military vehicles from explosions.

Bulletproof vest

CORROSION RESISTANCE

Because they do not rust or corrode, composites resist damage from the weather and from harsh chemicals that can eat away at other materials. They are good choices to use where chemicals are handled or stored. Outdoors, they stand up to severe weather and wide changes in temperature.



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. Most recreational boats today, for example, are built from fiberglass composites because these materials can easily be molded into complex shapes, which improve boat design while lowering costs. The surface of composites can also be molded to mimic any surface finish or texture, from smooth to pebbly.

PART CONSOLIDATION

A single piece made of composite materials can replace an entire assembly of metal parts. Reducing the number of parts in an automobile or a structure saves time and cuts down on the maintenance needed over the life of the item.

DIMENSIONAL STABILITY

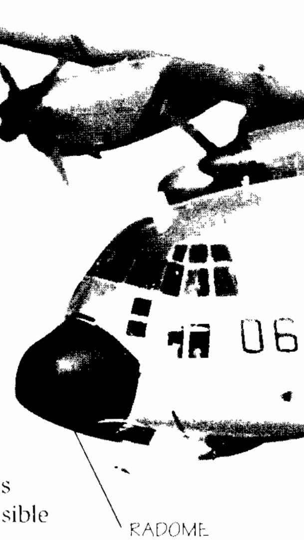
Composites retain their shape and size when they are hot or cool, wet or dry. Wood, on the other hand, swells and shrinks as the humidity changes. Composites can be a better choice in situations demanding tight fits that do not vary. They are used in aircraft wings, for example, so that the wing shape and size do not change as the plane gains or loses altitude.

CONDUCTIVITY

Composites are **nonconductive,** meaning they do not conduct electricity. This property makes them suitable for such items as electrical utility poles and the circuit boards in electronics. If electrical conductivity is needed, it is possible to make some composites **conductive.**

MAGNETISM

Most composites contain no metals and, therefore, are not magnetic. They can be used around sensitive electronic equipment. The lack of magnetic interference also lets the large magnets used in hospital MRI (magnetic resonance imaging) equipment perform better with composites. MRIs produce computer images of organs and tissues inside the patient's body, allowing doctors to see inside without surgery.



RADAR TRANSPARENCY

Radar signals pass right through composites, a property that makes composites ideal materials for use anywhere radar equipment is operating, whether on the ground or in the air. Composites play a key role in stealth aircraft, such as the U.S. Air Force's B-2 stealth bomber, which is nearly invisible to radar.

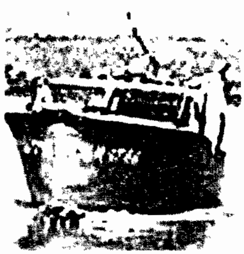
Composites are good materials for building radomes (radar domes), which are the bubbles or nose cones that enclose airborne or ground-based radar equipment.

LOW THERMAL CONDUCTIVITY

Composites are good insulators—they do not easily conduct heat or cold. They are used in buildings for doors, panels, and windows where extra protection is needed from extreme temperatures.

DURABILITY

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.

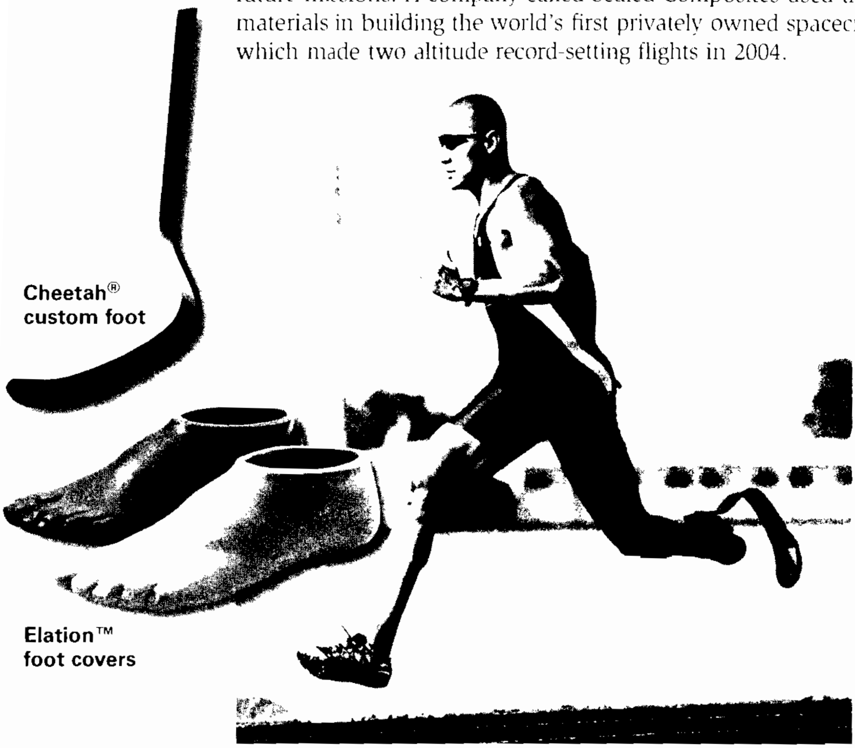


In 1947, the U.S. Coast Guard built 40-foot patrol boats using fiberglass composite materials. These boats were used until the early 1970s, when they were taken out of service because the design was outdated. After the boats were decommissioned, the composites were thoroughly tested and found to have lost only 2 to 3 percent of their original strength during 25 years of hard service.

Where Are Composites Used?

You have seen some of the ways that composites are used. Here are more examples, several of which you might find surprising.

Aircraft and spacecraft. Composite materials are used in new experimental planes and military drones (unmanned aircraft). In space, composites were used in oxygen tanks for Skylab, the first U.S. space station. NASA is exploring new uses for composites in future missions. A company called Scaled Composites used the materials in building the world's first privately owned spacecraft, which made two altitude record-setting flights in 2004.



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Artificial limbs made of composite materials can be formed to closely resemble their human counterparts or to improve function, such as this runner's foot. Pictured here, Marlon Shirley is the Paralympic world record holder in the 100m run.

Bicycles. Bicycles made with composite materials are much lighter than bikes that have metal frames. The road bikes ridden in racing events such as the Tour de France weigh as little as 15 pounds—the minimum the rules allow.

Boats. The most prevalent use of composites has been in the marine industry. Composites have replaced wood and aluminum in many of today's recreational watercraft. In military applications, ships are being designed with composites to give them stealth qualities. Other marine applications of composites include minesweepers, sonar domes, and even personal watercraft.

Buildings. Doors, window frames, countertops, tubs, showers, domes, towers, and other structures are made of composites. Used on the outside of buildings, composite materials may be made to look like stone, concrete, or even wood.

Cars. In sports cars and other vehicles, composites are found in fenders, wheel wells, hoods, and floors. Used in body panels and truck beds, and even under the hood, composites reduce the number of individual parts and make vehicles lighter, which makes them more fuel efficient. Top fuel dragsters, funny cars, and other race cars have strong, light composite bodies.

Communications satellites. Satellites in space undergo huge shifts in temperature, from searing heat to subzero cold, which can cause materials to expand and contract. Rather than use a material like aluminum for antenna parts, manufacturers use composites that do not expand and contract as much.

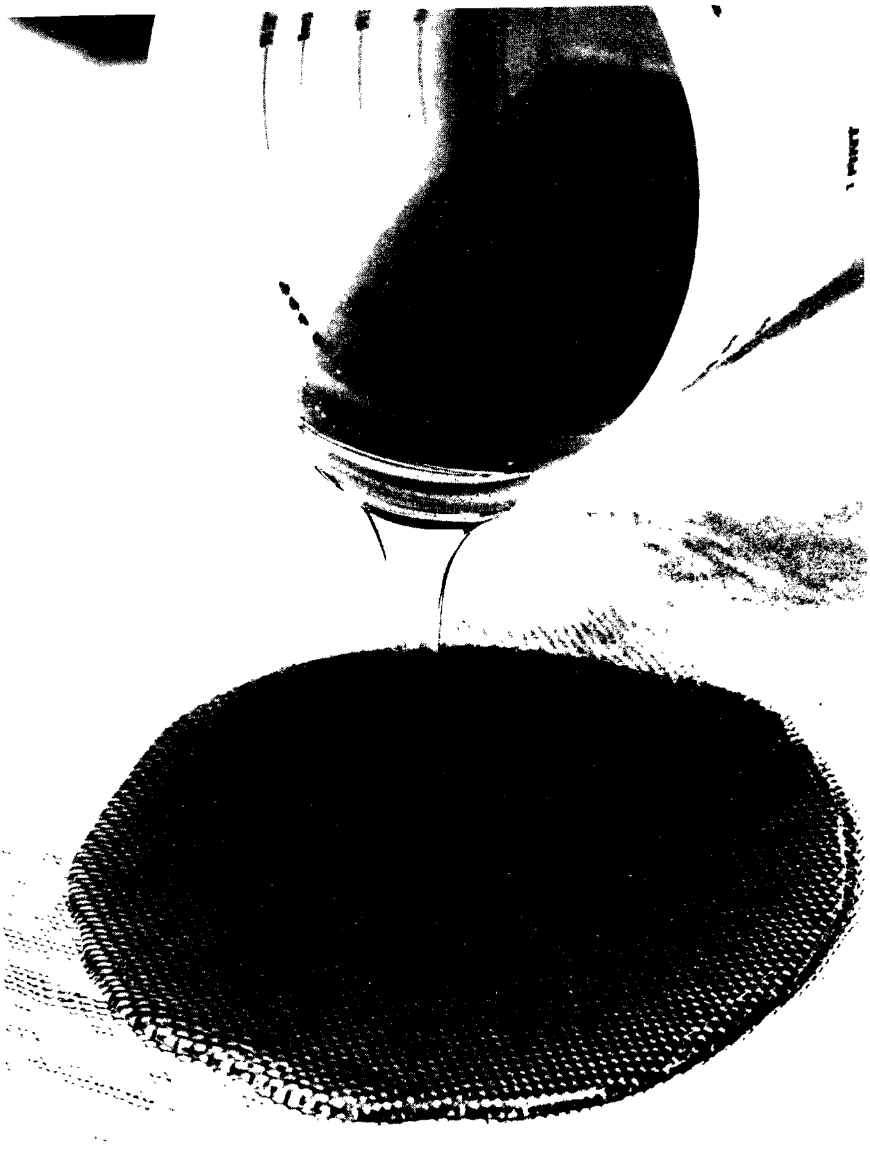
Musical instruments. Traditional wooden guitars can shrink or swell as the humidity changes. Guitars made of composites can avoid this problem and still mimic the sound qualities of wooden guitars.

Racing helmets. Race-car drivers wear helmets made of tough, shatterproof, lightweight composites. The excellent **impact strength** of composites (along with a lot of other safety gear) helps drivers to survive crashes at 200 mph.

Sports equipment. Composites are replacing wood and metal in fishing rods, tennis rackets, kayak paddles, windsurfing masts and boards, hockey sticks, baseball and softball bats, golf clubs, archery compound bows, and many other kinds of sports gear. Olympic athletes use equipment made of composites for their lightweight and strength qualities.

The first Chevrolet Corvette in 1953 had a fiberglass body. Today's models continue to use composites extensively, using carbon-fiber front fenders, wheel wells, and hoods.

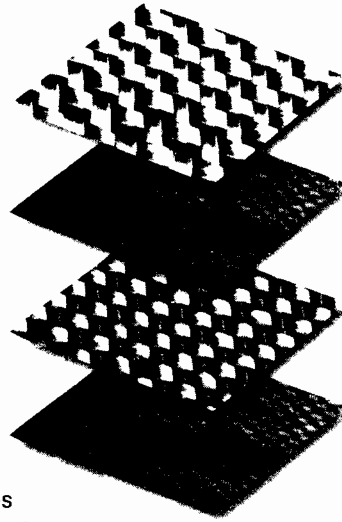
Composites are used in the shell of this replica motocross helmet.



How Are Composites Made?

Composites are made from three basic ingredients or components:

- **Fibers**—the **reinforcements** that carry loads and give composites their strength
- **Resins**—the polymer (plastic) or glue that holds the fiber reinforcements and the composite together, protects the fibers from the environment, and transfers loads between the fibers
- **Fillers** and **additives**—ingredients that give composite materials special properties

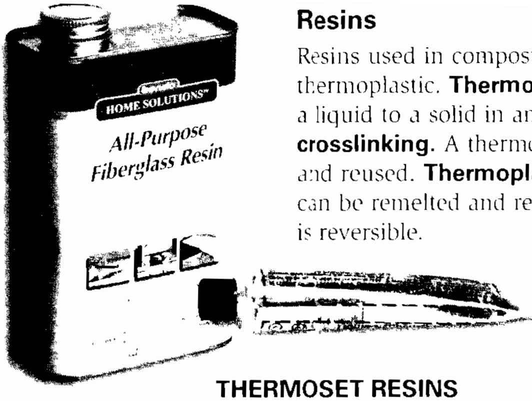


Fiberglass cloth

For this merit badge, we define *composites* as "a material that is made up of two or more materials that, when combined, are stronger than the individual materials." Another term for composites is *reinforced plastics.* The composites industry uses a more specific term: **fiber-reinforced polymer (FRP)** composites. A *polymer* is a chemical compound made of many identical components linked together in a chain. "Polymer" and "resin" are interchangeable terms, so in this pamphlet we use the more familiar word, *resin.*

Composites are shaped in or on **molds.** A common technique is to **laminate** (layer) resin and reinforcements onto a lightweight core material such as balsa wood.

Engineers and designers can choose from many types of resins and fibers to create composites with specific properties for specific uses. Let's take a closer look at each of these ingredients, then at the methods for molding them.



Resins

Resins used in composites can be either thermoset or thermoplastic. **Thermoset** resins are changed from a liquid to a solid in an irreversible process called **crosslinking.** A thermoset resin cannot be melted and reused. **Thermoplastic** resins, on the other hand, can be remelted and recycled; the hardening process is reversible.

THERMOSET RESINS

Thermoset resins are used to make most composites. Common thermoset resins include polyester, **vinyl ester,** and **epoxy.** Each of these has different properties.

Polyester resins are the most commonly used because they are low in cost and are suitable for many products. They are tough and resistant to most **solvents** (liquids such as acetone that can dissolve substances), but polyester resins can be damaged by certain solvents and by ultraviolet light.

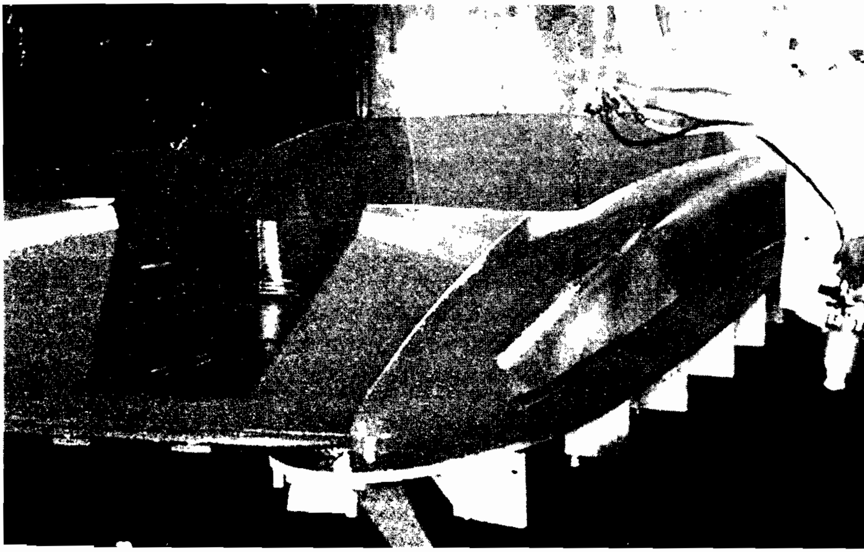
Epoxy resin is tough, nonconductive, resistant to chemicals, and dimensionally stable. Exposure to sunlight can degrade it. Epoxies are more expensive than polyester and vinyl ester resins and are more difficult to produce.

Vinyl esters are chemically similar to polyester and epoxy resins. They are a sort of compromise between the two, combining polyester's low cost and ease of use with epoxy resin's toughness and other desirable properties. Vinyl ester resin might be used if a product needs to resist corrosion. Like polyester, vinyl ester is used mainly in glass fiber–reinforced composites.

THERMOPLASTIC RESINS

Thermoplastics are the typical plastics that surround you at home and school, including toys, plastic containers of all types, and hundreds of common items we use every day.

Common thermoplastic resins include polypropylene and polyethylene. Thermoplastic composites have excellent impact strength. Polyethylene typically is used in packaging and communications equipment, and polypropylene in automotive parts and appliances.



GEL COATS

A special resin called **gel coat** is a form of polyester or vinyl ester resin that is used as a coating that protects the laminate from sun and water and provides a smooth, glossy finish to some composite products. If you look at the outside of a boat, the smooth, shiny, and sometimes colorful surface is the gel coat.

If you were to use composite materials to replace a traditional camp gadget—a kitchen rack, for instance—that is made of wood, you could choose an inexpensive polyester resin. Can you think of other outdoor gear or useful items (they need not be Scouting-related) that might perform better or last longer if made of composite materials? Which resins might do the job best?

Fibers

Fiber reinforcements can be natural or synthetic. Natural fibers include hemp, flax, and cotton. Most reinforcements used in composites are synthetic. Common synthetic fibers are **glass, carbon,** and **aramid.** When several layers of reinforcements are bonded together with resin, they form a **laminate.** Laminates are the building blocks of composites.

High-performance composites that use superior fibers like carbon are referred to as **advanced composites.**

GLASS FIBER

Glass fiber is the least expensive of all reinforcements. Glass fiber (also called fiberglass) is used in more than 90 percent of manufactured composites. Composites made of polyester resins and glass fibers are so common, in fact, the term "fiberglass" is often used for the composite material itself. Glass fibers, however, are only one part of a composite—they do the reinforcing.

The next time you hear a boat called a "fiberglass boat," you will know that is only part of the story. The glass fibers have been combined with a resin to form the composite material from which that boat was made.

Glass fibers come in several varieties, designated S-, A-, C-, or E-glass. Each variety has special characteristics. *S-glass* is exceptionally strong. *C-glass* is extremely resistant to corrosion and chemical attack. *A-glass* has good resistance to chemicals. *E-glass* does not conduct electricity.

Though economical, glass fiber is relatively heavy. Of the common synthetic reinforcements, it has the least efficient strength-to-weight ratio.

CARBON FIBER

Super-strong carbon fiber is extremely stiff, and it is lighter in weight than glass fiber. Carbon fibers come in several varieties and strengths and are the most expensive kind of fiber reinforcements. They are typically used to strengthen airplanes and spacecraft. Carbon-reinforced composites are also used in products such as bicycle frames, tennis rackets, skis, and golf club shafts.

This carbon fiber bicycle frame is the same model used by world-class cyclist Lance Armstrong when he competed in the 2005 Tour de France.

ARAMID FIBER

Aramid fiber resists impact. It is used extensively in bulletproof vests and body armor. Racing drivers wear aramid suits that help protect them from burns in fiery, high-speed crashes. Aramid is commonly known by its trademark name, Kevlar. In cost, aramid fibers fall between glass and carbon. Aramid is more difficult to work with than glass and has a tendency to absorb moisture.

Synthetic fibers include glass, carbon, and aramid. Glass is typically white, carbon fiber is black, and aramid is yellow. For more about fibers, see the *Textile* merit badge pamphlet.

A firefighter's protective jacket is made of aramid fiber to help withstand extreme heat. His helmet is made of composite materials, too.

COMBINATIONS AND SPECIAL FIBERS

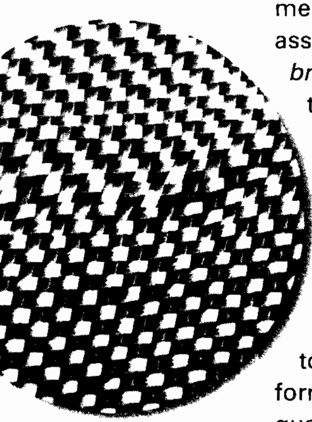
Different fibers can be combined to make a composite cost less or perform better. Composites that are made of more than one fiber are called **hybrid composites.**

Fibers with special characteristics are used when a composite must be exceptionally strong or heat-resistant—for high-performance military aircraft, for instance, or aerospace applications. These materials are quite expensive. Examples include boron (an extremely hard natural element) and ceramics (hard, manufactured materials that can withstand high heat and harsh chemicals).

Assembling Fibers

Fiber reinforcements can be used in two ways: chopped and randomly mixed with resin or bundled together in patterns.

In most composite products, the fiber reinforcements are bundled together for strength. Fibers are assembled in various patterns called *fabrics*. In the *braid* pattern, for example, fibers are woven into a tube shape. A *veil* is an ultrathin reinforcement used for smoothness on the outer surfaces of some composites. Other patterns include *stitched, mat, knit,* and *unidirectional.* For the Composite Materials merit badge, clothlike *woven* reinforcements will be the most common and simplest to use.



Because each pattern carries loads differently, how the fibers are placed or assembled is important to engineers and designers. The cost of each of these forms also varies, depending on the amount and the quality of the fiber used.

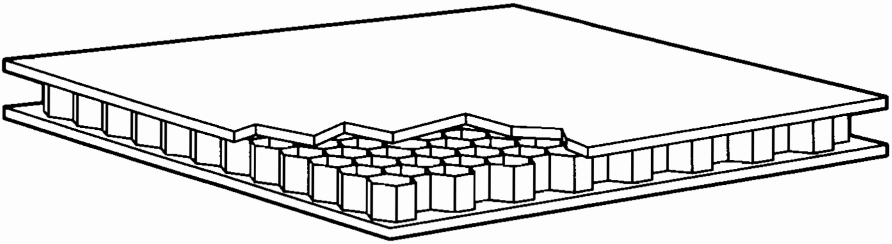
Fillers and Additives

Fillers are added to resins, not just to replace some resin and thus reduce a composite's cost, but often to improve the finished product in some way. Fillers can improve mechanical properties—the way a material reacts to fire and smoke, for instance. Also, filled resins (those with fillers added) will shrink less than unfilled resins (those without fillers). Parts molded from filled resins, therefore, will keep their proper shape and size. Other important properties that fillers provide include stiffness, surface smoothness, and resistance to water, weathering, and high temperatures or extreme changes in temperature.

Additives and other modifiers expand the usefulness of resins, aid in the manufacturing process, or make products more durable. While additives and modifiers often raise the cost of the basic materials, these substances always improve the performance of the finished product. Additives are commonly used in resins to improve fire resistance, to enhance electrical conductivity (composites are usually nonconductive), and to add color.

Core Reinforcement

Core materials are widely used in composites to make stiff, lightweight products. Typical core materials include balsa (wood from the balsa tree), polyurethane foam and PVC (polyvinyl chloride) foam (both manufactured in chemical processes), and **honeycomb.** These materials are lightweight and strong.



Honeycomb **is a core material made from sheets of resin-soaked material shaped into cells (openings) like those of a beehive's honeycomb. This structural material is strong, lightweight, and used in sandwich construction.**

Using **sandwich construction,** a core material is placed between two outside surfaces (called "face skins") of fiber reinforcements. This sandwich is bonded together with an adhesive or glue. The thicker the core, the stiffer the sandwich. To create a strong, lightweight floor for an aircraft, for example, engineers select honeycomb with glass-fiber face skins saturated with a polyester resin. The resulting floor panel is strong, stiff, and economical.

Many methods are used to manufacture composites. Selecting the best method depends on several factors, such as the size of the part to be made, the part's shape and surface finish, how many individual parts will be made, how quickly they will be needed, and how much money is available to invest in equipment.

Composites Manufacturing Methods

Due to the higher cost of equipment and tools, the closed-molding processes will not be explored for this merit badge.

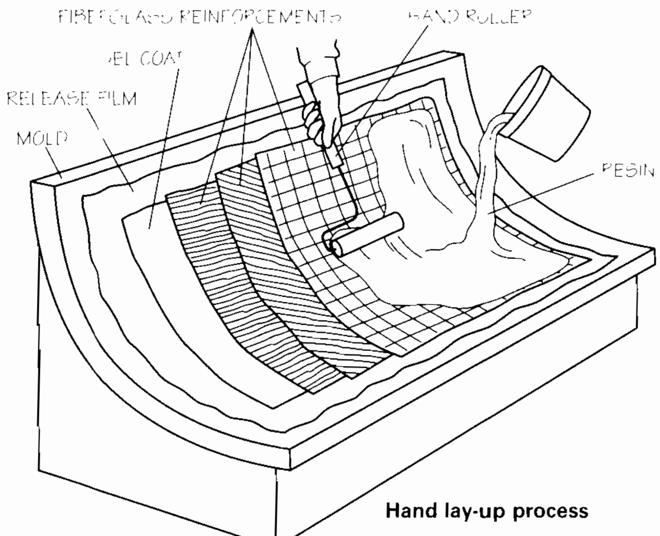
To manufacture a product made of composites, a mold is used to form the part. The two major divisions of manufacturing processes are open molding and closed molding.

- In **open molding,** the raw materials (resin and fibers) are placed in a mold and allowed to **cure** (harden) while exposed to the atmosphere.
- In **closed molding,** the raw materials are placed in one half of a two-surface mold. The mold halves are shut and the materials cure inside the mold, closed to the atmosphere.

Open-Molding Processes

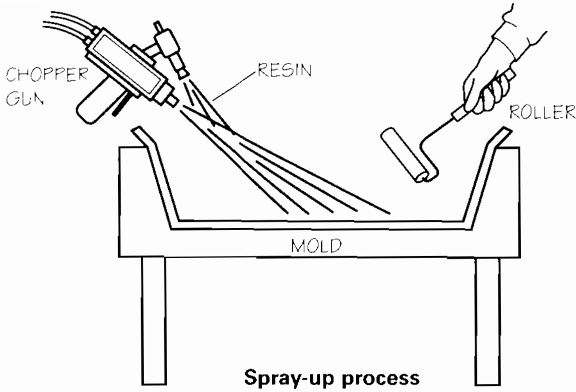
In open molding, the various processes include **hand lay-up, spray-up, casting,** and **filament winding.** Hand lay-up is the most common and least expensive manufacturing process because little equipment is needed.

Hand lay-up requires manual labor to mix the resin, saturate the fiber reinforcements, and place the materials in a mold. This manual method can be used to make products ranging in size from small to quite large: boats, storage tanks, tubs and showers, and architectural items such as domes used in buildings. It's a good method when small quantities are needed, and it is the method used for projects in this merit badge pamphlet.



Hand lay-up process

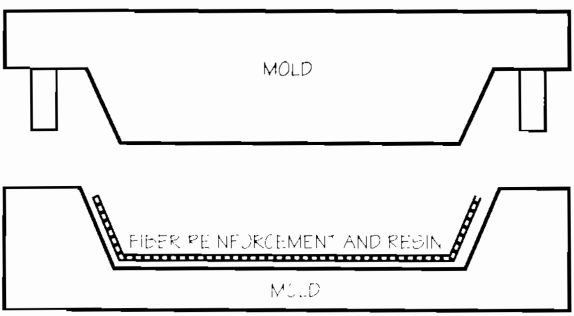
Spray-up is similar to hand lay-up, but special equipment is needed. A chopper gun is used to chop the fiber reinforcements into small pieces, which are then mixed in the air with the resin stream and sprayed on a mold. Spray-up is more automated than hand lay-up and is suitable for large quantities. Many boats and swimming pools are made using the spray-up method.



Spray-up process

Closed-Molding Processes

Closed-molding processes are usually automated, require expensive tools and equipment, and are best suited for manufacturing plants where large quantities of parts are produced. Typically, closed molding is for high-volume production ranging from 1,000 to more than 500,000 parts per year.



Closed-molding process

Closed-molding processes include **compression molding, pultrusion, resin transfer molding, vacuum bag molding,** centrifugal casting, and continuous lamination. The major differences between these methods (see the glossary) are how the raw materials are placed in or on the molds and how they are cured.

A Manufacturing Example

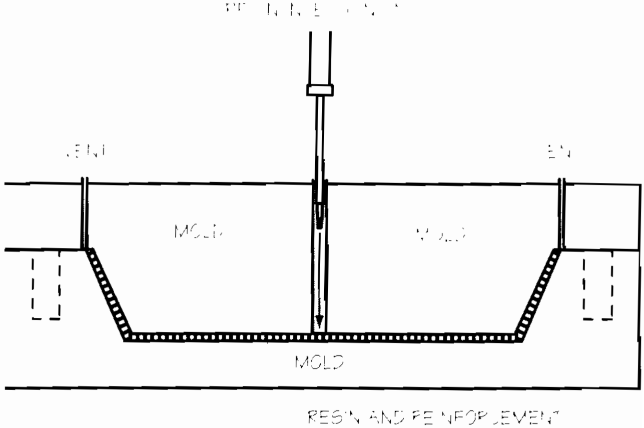
Suppose you wanted to make a hood for a sports car. The hood could be made by hand lay-up, spray-up, resin transfer molding, or compression molding. Which process do you select?

To hand lay-up a hood, start with a mold that is very smooth. After cleaning and polishing the mold surface, apply a layer of gel coat. Once the gel coat cures, place fiberglass reinforcement in the mold on top of the gel coat. When you have the correct amount of fiber reinforcement in position, manually apply polyester resin. Pour the resin on the fiberglass, working it with brushes, hand rollers, and/or squeegees until all the fibers are saturated or **wet-out.** (If you were using the spray-up method, the fiberglass and the resin would be deposited in the mold at the same time, using a chopper gun.)

Allow the laminate to cure at room temperature. After the hood is cured, carefully remove it from the mold and sand smooth all rough edges. The part then goes through various operations (drilling holes, adding hardware for hinge attachments and latches) for final assembly on the car. Before you can use the mold again, you must clean and polish it.

For hand lay-up, the equipment cost is low, but the cost of labor is high. Producing a single car hood using the hand lay-up method takes at least three hours.

Using resin transfer molding, the time can be cut to an hour. This method requires two molds. Gel coat is applied on one of the molds, then the reinforcement is placed in the mold, similar to hand lay-up. Once the reinforcement has been posi-



Resin transfer molding processes

tioned, hardware can be inserted and the two halves of the mold are clamped together. Resin is pumped in until the closed mold is full. The resin is allowed to cure. Then the molds are separated and the hood is carefully removed. All rough edges are sanded smooth.

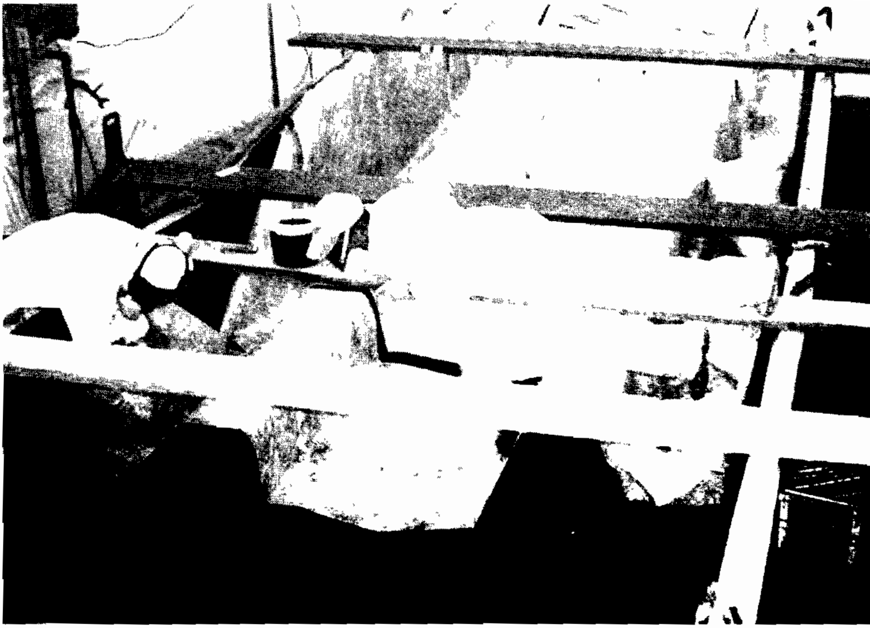
What about compression molding? This method needs no gel coat or cleaning of the mold surfaces. The two mold halves are made from high-quality steel, their surfaces treated for long wear and smoothness. A large, heated press is used to push the molds together. The composite material is a fiberglass reinforcement that is soaked with resin in a sheet called a **prepreg** (short for "preimpregnated," meaning saturated beforehand). The material is compressed under high pressure and heat until the part cures; the heat speeds the curing. A timer on the press opens the molds exactly when the part has cured. A normal molding cycle (position the material, cure the part, and unload it) takes only two minutes. The part requires little finishing when removed from the press and is ready for final assembly. Using compression molding, structural features can be molded into a car hood instead of adding hardware later.

Compression molding can produce parts in large quantities—hundreds of finished parts each day, compared to only a few parts per day using the other methods we have considered. Compression molding, however, is expensive. The labor cost is low, but the equipment cost is high. The high-quality molds needed for this method cost almost 50 times as much as a simple hand lay-up mold.

Which method is best? If you need only one or a few sports-car hoods, then hand lay-up is the right choice. If you are producing large quantities of hoods, then compression molding is the better alternative.

Visiting a Composites Manufacturer

For requirement 4a, you may choose to visit a company that makes or repairs composites products. Work with your merit badge counselor to locate a company in your area and arrange a visit to or a tour of a manufacturing plant. Check the local phone book under "Fiberglass." You will likely find listings for companies that design, fabricate, or repair all sorts of fiberglass products, from tubs and showers to camper toppers, boats, tanks, and pools. Under "Boat Repair," too, you will find companies that specialize in fiberglass.



Before the visit or tour, do some homework to find out what kinds of composite products the company manufactures. This will help you develop a list of questions to ask. Visiting a company that manufactures or works with composites is your chance to cover any questions or concerns that have cropped up in your work on the Composite Materials merit badge. Here are sample questions to get you started.

- What Manufacturing processes are used (open molding, closed molding)?
- What molds are used, and how are they used?
- What are the properties of the resins used in the products? Are the resins thermoplastic or thermoset?
- Are the fiber reinforcements being used natural or synthetic? What properties of the fibers make them right for the products being made?

You could also ask about any core materials (balsa, varieties of foam, honeycomb), fillers or additives, and gel coats that are used.

Before touring a composites manufacturing facility, be sure to review the "Safety and Environmental Awareness" section of this pamphlet. Ask about the safety and control measures the manufacturer uses.

- What hazardous materials does the company use? What are the safety and environmental concerns associated with these materials?
- How are hazardous materials handled? Stored? Disposed of?
- How are work spaces ventilated?
- What protective gear do workers wear?

This worker completes additional graphite/epoxy lay-ups inside the nitrous tank used in SpaceShipOne.


roop 5
austin, tx

Safety and Environmental Awareness

Handling, storing, and disposing of substances used in composite materials can create safety and environmental hazards. By taking proper precautions, you can reduce these hazards and safely use these materials.

Just as you take responsibility for your own safety in day-to-day tasks, you also must take responsibility for your safety—and that of others around you—when you work with composites. Working on projects for this merit badge is similar to work you have done for other badges involving tools, paints, and coatings or other chemicals. However, some specific safety requirements apply when you are using composite materials.

You must be knowledgeable about the materials and tools you will use for your projects. Be prepared. Understand the proper methods for safely handling the materials.

As a Scout, you are probably more aware of safety than many other people are. Safety is a way of thinking, a way of acting, and a way of being prepared.

Observe two important rules when working with composites for this merit badge:

- **Never work alone. Always work under qualified adult supervision.**
- **Work in a well-ventilated outdoor space that is free of other chemicals and away from heat sources such as open flames and electrical equipment that could spark and cause a fire.**

Never remove labels or put hazardous materials in unmarked containers.

Safety With Chemicals

Before you open a container or begin mixing any chemicals, make sure you read and understand the instructions and safety labels on the product. Resins, initiators, solvents, and other substances have safety information included in their packages. Carefully study this information—as well as **material safety data sheets**—before starting to work. A material's label and MSDS will indicate whether the material is flammable, corrosive, irritating, or hazardous.

It is required that you seek assistance and guidance from a responsible adult who is familiar with composite materials before you start your project.

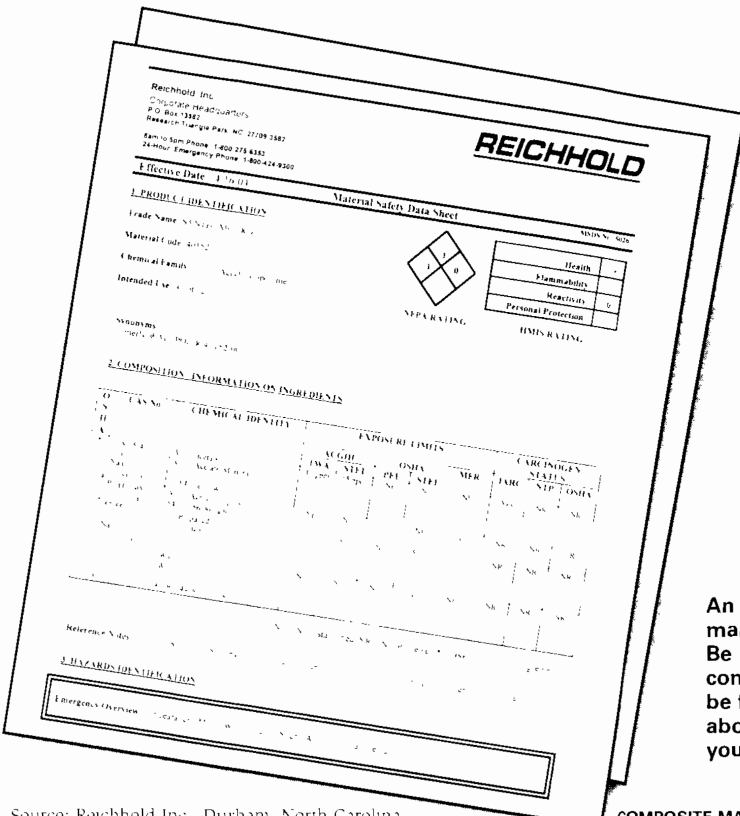
You will use some type of resin, and probably an **initiator,** in your composites projects. (Initiators are substances—usually peroxides—that start the curing of a resin.) Identify these materials and read the information carefully. If you are not completely sure of what you have read, seek help before continuing with your project.

When working with these chemicals, you will almost certainly spill or drop small amounts. It's not much different from pouring paint out of a can into a tray or dipping a paintbrush into a can: things can get a little messy. The important point to remember is to always clean up your spills immediately and dispose of spills and contaminated supplies such as gloves, protective clothing, and brushes in an approved manner, both for safety and to protect the environment.

Contact your local authorities for information about disposing of hazardous materials and soiled clothing, tools, or equipment.

Material Safety Data Sheets

Material safety data sheets (MSDS) give the proper procedures for working with, handling, and storing materials, and alert the user to any hazardous substances. The format of the documents may vary, but by U.S. law all must include certain information presented in eight specific sections. Some internationally formatted sheets will have 16 sections.


Reichhold Inc.
Corporate Headquarters
P.O. Box 13582
Research Triangle Park, NC 27709-3582
8am to 5pm Phone: 1-800-275-6353
24-Hour Emergency Phone: 1-800-424-9300

REICHHOLD

Effective Date

Material Safety Data Sheet

MSDS No.

1. PRODUCT IDENTIFICATION

Trade Name

Material Code

Chemical Family

Intended Use

Synonyms

NFPA RATING

Health

Flammability

Reactivity

Personal Protection

HMIS RATING

2. COMPOSITION, INFORMATION ON INGREDIENTS

CAS No.

CHEMICAL IDENTITY

EXPOSURE LIMITS

ACGIH

TWA

STEL

OSHA

PEL

STEL

MFR

CARCINOGEN STATUS

IARC

NTP

OSHA

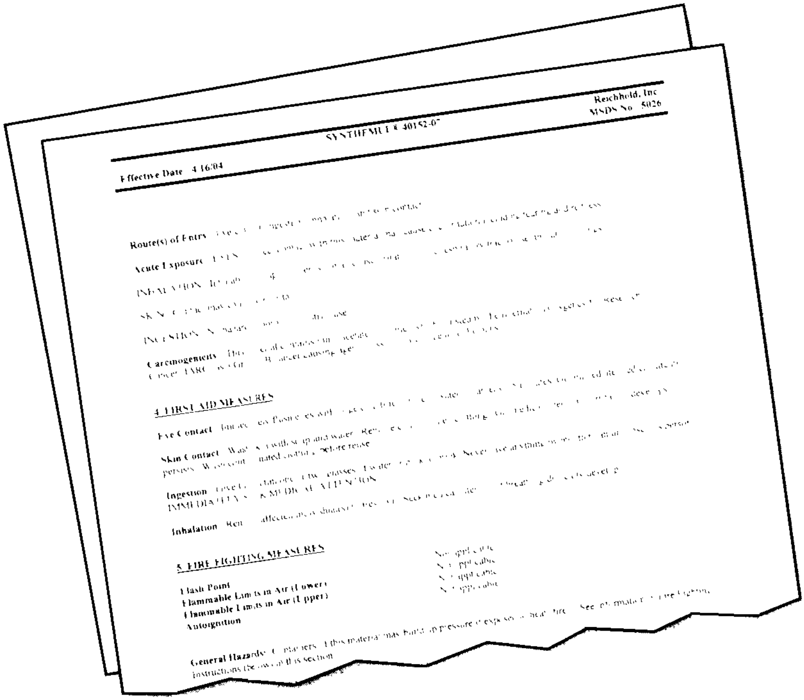
Reference Notes

3. HAZARDS IDENTIFICATION

Emergency Overview

Source: Reichhold Inc., Durham, North Carolina

An MSDS can be many pages long. Be sure to read the complete MSDS to be fully informed about the product you are using.



Flash point refers to the temperature at which vapors of a material can ignite if exposed to a direct ignition source. The lower the flash point, the more highly flammable a material is.

Here are the eight required sections.

Manufacturer Information. Identifies the material and lists the manufacturer's name, address, and emergency telephone number.

Hazardous Ingredients. Lists the hazardous ingredients in the material and some of the *exposure limits.* (See *PEL*—permissible exposure limits—in the list of MSDS abbreviations on the following page.)

Physical and Chemical Characteristics. Tells what the material will look and smell like and what will cause it to react.

Fire and Explosion Hazards. Tells whether the material is flammable and lists the flash point, firefighting materials and methods, and any unusual burning characteristics.

Reactivity. Tells how other chemicals will react with the material.

Health Hazards. Lists known routes of entry into the human body and the health risks from each, and lists any cancer research that may have been done on the material. Describes how to recognize and treat overexposure.

Precautions for Safe Handling and Use. Lists procedures to use in case of accidental spills and gives information about proper disposal.

Control Measures. Lists ways to avoid making contact with the material, such as using respirators, wearing gloves, and working in a well-ventilated area.

MSDS Abbreviations

You will often find these important abbreviations in material safety data sheets.

LEL: Lower explosive limit. The lowest concentration at which the substance will catch fire when an ignition source is present; below this level, the material becomes too "lean" (too diluted) to burn.

PEL: Permissible exposure limit. A regulatory limit on the amount or concentration of the material in the air that you can safely be exposed to without suffering undue harm.

UEL: Upper explosive limit. The highest concentration at which the substance will catch fire when an ignition source is present; above this level, the material becomes too "rich" to burn.

TLV: Threshold limit value. Similar to PEL.

TWA: Time-weighted average. The amount of the material to which the average human can safely be exposed over an eight-hour workday.

Icons like these often appear on chemical containers. They tell you if a chemical is corrosive *(top)*, a biohazard *(center)*, or flammable *(bottom)*.

Personal Safety

You can be seriously harmed if you inhale, touch, or swallow hazardous chemicals or get them in your eyes. When working with composites, take precautions against exposure to chemicals and wear the appropriate personal protective equipment.

Hazardous materials are capable of causing death or serious harm. Fiber reinforcements are nontoxic, but they can irritate your skin. Resins, initiators, and solvents, however, can be highly hazardous. Breathing high concentrations of their vapors can affect your health. Skin and eye contact from some chemicals can cause burns and tissue damage. These substances may be fatal if swallowed. Read and follow label precautions, carefully review the MSDS, and know the proper first-aid measures.

AVOID INHALATION

Avoid breathing vapors. Always work in a well-ventilated outdoor area. Avoid using household fans to provide better ventilation, because electricity in the presence of flammable solvents such as acetone can cause an explosion and fire.

Wear a respirator if the manufacturer recommends one. The MSDS or other information about the materials you are using will indicate whether a respirator is required. Generally, if you are working in a well-ventilated area, you will not need a respirator. If you are sanding or creating dust, you may choose to wear a dust mask similar to what drywall installers use.

AVOID SKIN CONTACT

Always wear gloves when mixing chemicals and handling reinforcements. Gloves are made of various materials. Latex and vinyl are common. Different gloves may be required, depending on the resin used and the type of cleanup solvents. The MSDS will specify the type of gloves to be worn. If you do not have the MSDS, check the product label—it might describe the appropriate type of gloves to use.

To protect your skin from resins and solvents, **wear nonabsorbent protective clothing.** Ensure that all areas of exposed skin are covered, including wearing gloves to protect your hands. A special type of disposable work clothes made from fabrics like Tyvek are used to keep industrial workers safe from contact with chemicals. These clothes can be obtained from composites industry manufacturing equipment suppliers or in some specialty hardware or paint stores. Booties also can be used to cover and protect shoes from dripping resin. Do not use plastic bags or throwaway rain gear to cover your clothing, because solvents will degrade the material.

If you do not wear foot coverings while working with composite materials, be sure to wear sturdy old shoes that you (and your parent) do not mind ruining with dripped resin.

AVOID EYE CONTACT

Always wear safety glasses or goggles when working on your composites projects. Take special care not to splash chemicals on your face or get them in your eyes.

AVOID INGESTION

Thoroughly wash your hands before handling food, eating, or drinking. Keep chemicals completely away from dining areas or anywhere food is prepared or eaten.

You may dispose of fiberglass scraps in ordinary household trash.

Handling Reinforcements

Glass-fiber reinforcements can cause your skin to itch. The protection used for handling reinforcements should be the same as used for handling resins and other chemicals. It is important to wear protective clothing, gloves, and goggles. Here are some other tips for handling reinforcements.

- Wash your work clothes separately from other laundry to avoid contaminating other clothes with fiber particles.
- If fibers irritate your skin, wash with mild soap and running water to relieve itching and redness. Wash hands thoroughly before eating or drinking.
- If you get fibers in your eyes, flush them gently but thoroughly with plenty of plain water. Seek medical attention.

Before starting your projects, discuss and plan how you will respond to emergencies. You must have an emergency plan. Begin by knowing and understanding the materials you will use. Ask yourself how and where something could go wrong, and plan your action to correct it. Have a fire extinguisher and/or other firefighting tools handy, as directed in the MSDS. If you are using electric tools, know where the power shutoff switches are. Identify the exits in advance, in case you need to get out of your work area quickly.

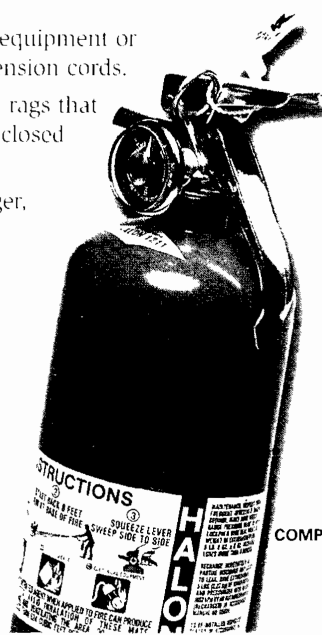
Fire Safety

Just as you must be careful when you refuel a power mower, you must take care when handling chemicals for making composites.

HANDLING FLAMMABLE MATERIALS

The chemicals used in making composites can react with various materials, and if spilled, dropped, or leaked they must be cleaned up immediately to avoid accidents and prevent a fire hazard. When handling flammable solvents or other flammable materials, take these special precautions.

- Avoid open flames, sparks, and static discharges. Do not allow smoking in an area where resins or other flammable materials are used or stored.
- Avoid contact with electrical equipment or devices such as fans and extension cords.
- Keep flammable solvents and rags that are saturated with solvent in closed metal safety containers.
- If they are five gallons or larger, electrically ground metal containers when transferring material between them.



As you know from your Scouting activities, fires cannot occur without three things present: fuel, oxygen, and heat. Without any one of these elements, a fire cannot start or be sustained.

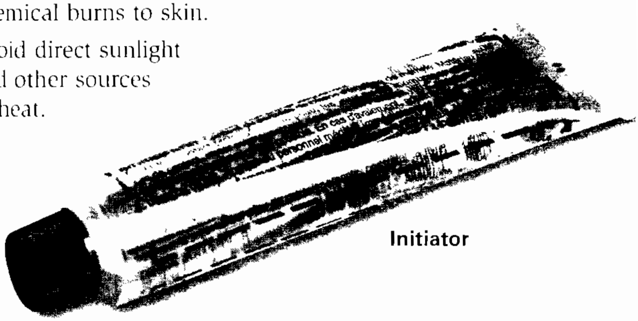
SAFELY CURING RESINS

If your project uses polyester resin, you will add an initiator to the resin to cure it. This will cause the mix to generate heat—one of the requirements for fire. The heat generated is a normal reaction but potentially hazardous. The materials must be handled safely. In your work area, follow these simple guidelines.

- Do not allow smoking or open flames.
- Use only equipment rated for use with flammable materials.
- Maintain your equipment in good condition.
- Clean up spills immediately.
- Properly dispose of excess curing resin. Initiate the resin with the proper amount of peroxide. (Follow the manufacturer's instructions.) Then fill the container with water and place it in a safe outside area, away from ignition sources, until the mixture cools to room temperature. Permit excess resin and scrap material to fully cure *and cool* before disposing of them.
- Use only the proper amount of initiator with the resin.

Special precautions are needed for handling initiators. Follow the manufacturer's instructions. In general:

- Avoid spills, because spontaneous combustion (self-ignition through chemical reactions) can occur when initiators combine with certain materials.
- Avoid contact with metal.
- Avoid splashing to prevent possible chemical burns to skin.
- Avoid direct sunlight and other sources of heat.



Initiator

When large quantities of resin are mixed, smoking "hot pots" can occur. The curing resin generates so much heat that it makes smoke. This is both a fire hazard and a health hazard. Take care not to breathe the smoke or fumes. Avoid this situation by mixing only the quantity of resin you need.

Environmental Responsibility

When working with composite materials and related chemicals and substances, you must take care at every step to avoid contaminating the air, water, or soil. Without proper disposal, materials like resins, initiators, and solvents can cause problems.

You must follow MSDS instructions, as well as state and federal regulations, when disposing of any materials used in making composites. Local, state, and federal regulations apply to hazardous material disposal, so ask your merit badge counselor about regulations that may affect your work on your composites projects. The local Environmental Protection Agency office (look in the blue pages of the phone book) can tell you about environmental regulations in your area.

Material Storage and Disposal

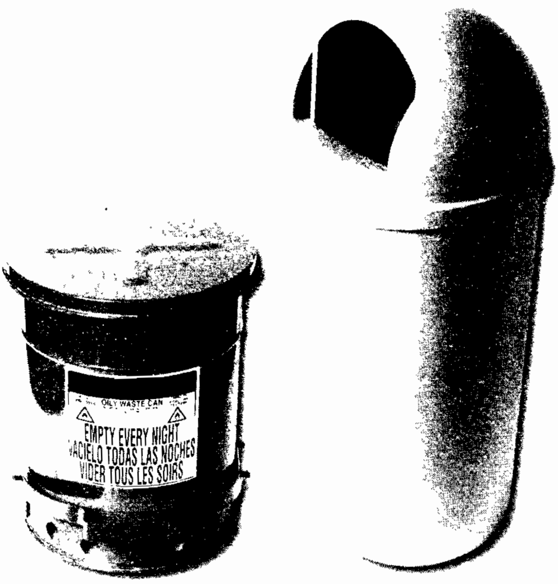
Because manufacturers in the composites industry handle large quantities of chemicals, the plants have designated areas and use special fireproof storage cabinets and containers for storing chemicals.

For small projects and work areas, where you are not likely to have these special cabinets and containers, follow these general guidelines for material storage and disposal.

- Keep bottles and tubes of resin, epoxy, and other materials tightly capped.
- Do not store materials for long periods. See the manufacturer's instructions.
- Do not dispose of initiators in normal household waste.
- Make sure all resins and scrap composites are fully cured and cooled down before disposing of them. Once the materials are fully cured and have become solid, they may be disposed of with the household trash.
- Properly dispose of materials according to the manufacturer's instructions. Be sure to contact your city or other authority for any special instructions about disposal.

Unmixed resin, hardener, or other liquid chemicals are considered hazardous waste. If the MSDS does not offer specific advice on disposal, ask the local waste-hauling authority for the proper procedure for disposing of small quantities of hazardous materials. Dispose of any chemical material according to the manufacturer's instructions and local laws.

Unused leftover fiberglass cloth can be disposed of in household trash. Before disposing of mixed resin, allow the resin to fully cure, cool down, and become solid. Dispose of in a separate bag. You may then throw it away like ordinary trash.




times for flats

Your Composites Projects

For requirement 5, you will make two projects using composite materials. A project can involve laminating onto a core material, the same technique that is used for creating surfboards, skate-boards, and snowboards. Or you might use a mold to form your project—creating a small boat using an existing toy as your mold, for example.

Composites lamination works best in warmer temperatures.

Preparing Your Project Area

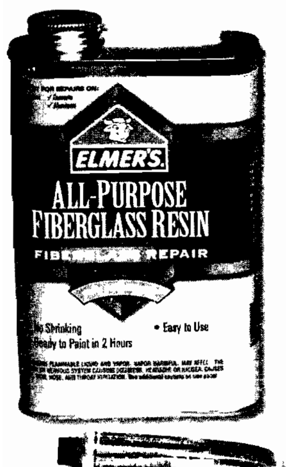
Select a well-ventilated work area outside—a concrete driveway is a good space. Remember to spread newspaper on the working surface for easy cleanup. When you are ready to begin using the resin and other chemicals, remember to put on your protective gear and clothing (such as a Tyvek uniform). These items will keep solvents and other chemicals off your clothes and skin.

Basics of Hand Lay-Up Laminating

As you have read, composites products can be manufactured in several different ways depending on the size of the part, the quantity to be made, and the final cost of the product. In the composites industry, nothing is more basic than hand lay-up lamination. In making your projects, you will use the hand lay-up process. The other manufacturing methods are simply too costly and are geared more toward large-scale commercial production.

As you learn and practice the basic techniques of lamination, you and your buddies should work with a responsible adult who is experienced in handling resin and the other materials used in composites manufacturing. The simple explanation provided in this pamphlet is meant only as an introduction to the process. It is not a substitute for the hands-on demonstration and supervision given by someone familiar with the materials and techniques.

In your work for this merit badge, you will use fiberglass reinforcement and resins, most likely polyester or epoxy. These materials are readily available. You can buy them at specialty stores such as boat repair shops, auto repair or parts stores, large hardware stores, or hobby shops.



Steps in Hand Lay-Up

You can use hand lay-up to make a part in a mold or to make a sandwich construction using a core material that acts as the mold. The following explanation assumes that you will make a part in (or on) a mold that has the shape of the final product. The laminating process includes these steps:

Step 1—Prepare the mold.

Step 2—Mix the resin.

Step 3—Place and distribute the saturated fiberglass reinforcement on the mold.

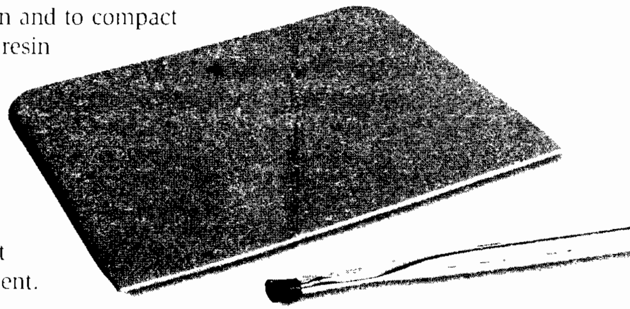
Step 4—Saturate (wet-out) the reinforcement with the right amount of resin to achieve the proper resin-to-reinforcement ratio. Add resin as necessary to any dry spots.

Step 5—Remove trapped air and compact the laminate.

Step 6—Allow the laminate to cure completely.

Tools for Laminating

For hand lay-up laminating, you need two basic tools:



- **Squeegee**—to spread resin and to compact the laminate. As you pour resin onto the fiberglass reinforcement, you use a curving or S-shaped motion of the squeegee with just enough pressure to make a good laminate surface that has the correct ratio of resin to reinforcement.
- **Stiff brush**—to work resin into the reinforcement and to remove excess resin.

If you are making a sandwich construction, omit the mold-preparation step.

PREPARING THE MOLD

The mold must be clean and smooth. To be sure the part you make will come out of the mold, first apply a wax coating to the mold surface. The easiest way to do this is to apply carnauba furniture wax to the surface and pretend you are waxing your parent's car. Once you have coated the mold, you are ready to begin.

If your mold has a slope, it's best to wet-out the reinforcement before you put it in the mold.

MIXING THE RESIN

Carefully read the instructions on the container of the resin you are using. Properly mixing the resin and the initiator (hardener) is key to good work. Each resin uses ingredients that are specifically made for that product.

Follow the manufacturer's instructions and *do not mix and match ingredients*. Determine the amount of resin you need, and pour it into a suitable container for mixing. Measure the correct amount of initiator in a polyethylene measuring cup—not a metal container. Pour the initiator into the resin and mix thoroughly.

The temperature outside will affect the amount of initiator that will be required. Use less initiator in hot weather and more in cold weather, but read the instructions first so you do not use more or less than the indicated range. Using too much or too little initiator will cause the laminate to cure improperly.

PLACING THE REINFORCEMENT

One way to place the reinforcement is to pull an ample piece of the fiberglass material directly from the roll or package, lay it into the mold, and trim it to shape using hand shears or heavy-duty scissors. You will need to cut the outside edges, corners, pleats, and other shapes necessary to make the fiberglass conform to the shape of the mold.

A second method is to cut a pattern. You precut the material to a specific shape, then place it in the mold. Cutting a pattern has advantages: You save time during laminating and avoid trimming the material in the mold.

Make sure to mix only enough resin to finish the project. Mixing too little resin will stop your lay-up process and damage your project, but mixing too much could result in a smoking hot pot.

SATURATING THE FIBERGLASS REINFORCEMENT

A good laminate has no dry spots on the reinforcement. The individual glass fibers are thoroughly saturated—wet-out—with resin.

How much time and effort it takes to completely wet-out a laminate depends on several factors, including the type of resin, the temperature, and the type of fiber reinforcement.

The *resin-to-glass ratio* is simply the amount of resin in the laminate compared to the amount of fiberglass. This is usually determined by the weights of the resin and the glass. The proper amount of resin is important for a quality product. Too much resin gives a resin-rich result Too little, and your final product is resin-starved.

- If resin-rich, the product will be weak and too heavy, and will look sloppy. A resin-rich surface appears glossy or wet, and individual fibers cannot be seen.
- If resin-starved, the product will also be weak and look sloppy, and it will not cure properly. A resin-starved surface appears whitish with transparent, air-filled areas.

You can determine the resin-to-glass ratio by looking. A laminate with the proper amount of resin should have a dull surface appearance with a distinct fiber pattern showing.

Making Overlaps and Seams

In large composites projects, several pieces of fiberglass reinforcement might be necessary to cover the surface.

When you join pieces of fiberglass reinforcement to form a seam, overlap the pieces by 1 to 3 inches. This ensures that the structural properties of the laminate are not weakened. If you use more than one layer of reinforcement, be sure to stagger or space out the overlaps to avoid thick buildups that also can create weak areas.

REMOVING AIR BUBBLES AND COMPACTING THE LAMINATE

When you saturate the fiberglass reinforcement with resin, air can be trapped in the laminate, creating *voids*. Air voids are simply bubbles, which when trapped in the cured laminate can cause problems ranging from poor appearance to structural failure. To remove air bubbles, use a squeegee or a paint roller to push the saturated glass reinforcement evenly down to the mold surface, squeezing air voids out of the laminate.

CURING THE LAMINATE

Temperature is important in properly curing resins. The warmer the weather, the faster the resin will cure. Polyester and particularly vinyl ester resins do not cure well at low temperatures. The minimum temperature for laminating, therefore, is 60 degrees. Check the manufacturer's instructions and be sure you are working within the recommended temperature range at all times.

The mixture's thickness also affects cure time. Thinner laminates cure more slowly and thicker ones cure more quickly.

Remember that your projects for this merit badge must be completed under the direct supervision of your merit badge counselor or another responsible adult who is knowledgeable about composites.

Resin curing too quickly? In hot weather, you may find that the "pot life" or working time of the resin you are using is too short. The speed of curing may be slowed with a different mix of resin ingredients. Follow the manufacturer's instructions or ask your counselor's advice.

FINISHING

Once the resin has cured, you can remove the part or product from the mold. Take care not to damage the product or the mold. Use heavy-duty scissors (or a small saw if necessary) to remove excess resin and fiberglass from the product's edges. Clean the edges with sandpaper or a file. If the mold was not smooth, the product's surface may be rough. Lightly sandpaper the surface smooth. Finish with paint, if desired.

Project Ideas

Now that you are familiar with the basics of hand lay-up, you can proceed with your own projects. Here are some ideas.

Model Airplane

This project is a composite of polystyrene foam, paper, and glue.

Materials

- ☐ Polystyrene foam glider kit (available from a craft store)
- ☐ Tissue paper or lightweight wrapping paper, nonwaxed, not coated
- ☐ White glue
- ☐ Small paintbrush
- ☐ Ice-cream sticks (5)
- ☐ Sandpaper
- ☐ Paint and brushes to decorate the finished piece
- ☐ Newspaper to protect work surface
- ☐ Water for cleanup

Step 1—Assemble the model airplane according to the manufacturer's instructions.

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Prevent the glue from drying before the paper is applied by working only in small areas.

Step 2—Apply a light coat of white glue to a small spot on the surface of the model.

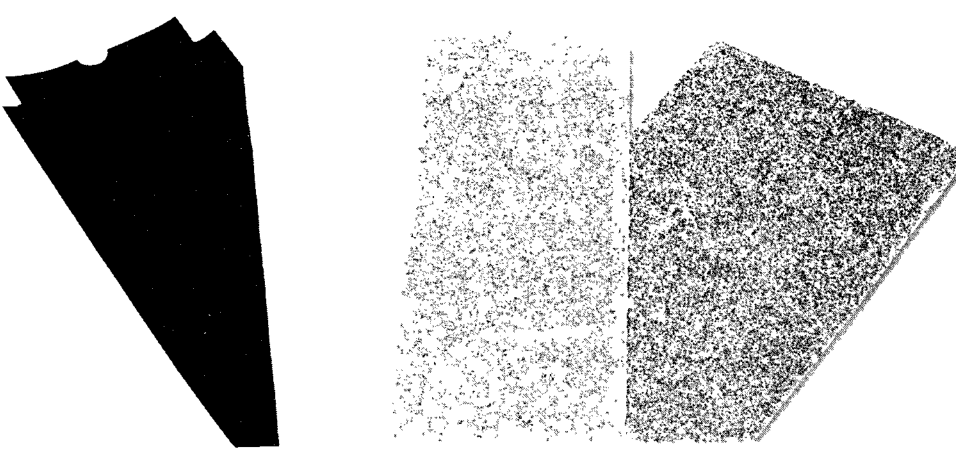
Step 3—Apply tissue paper or lightweight wrapping paper to the model, making sure to saturate (wet-out) all areas with the glue. If needed, apply more glue until the paper is thoroughly saturated. Try to avoid wrinkles in the paper.

Step 4—Work out any air bubbles by pushing the glue toward the edge of the paper using the paintbrush or ice-cream stick.

Step 5—Wipe or squeegee off excess glue using the straight edge of an ice-cream stick.

Step 6—Repeat steps 2 through 5 on all exposed surfaces of the model so that no polystyrene foam is exposed. Allow the model to dry overnight.

Step 7—Lightly sand the model with sandpaper to prepare the surface for painting, then paint it as you like.

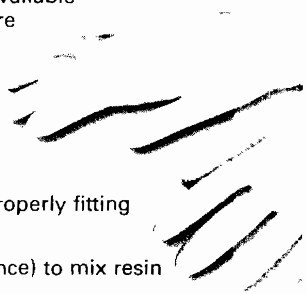


Decorative Birdhouse

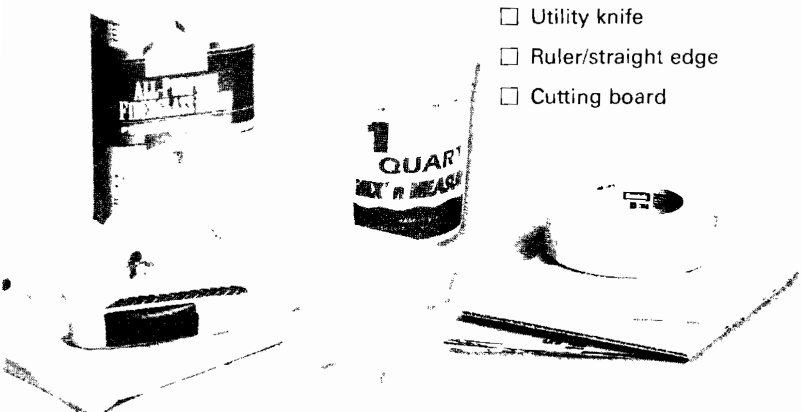
This project is a composite of glass-fiber reinforcement, polyester resin, and cardboard (core material). Optional core material could be balsa wood or urethane foam (not polystyrene foam).

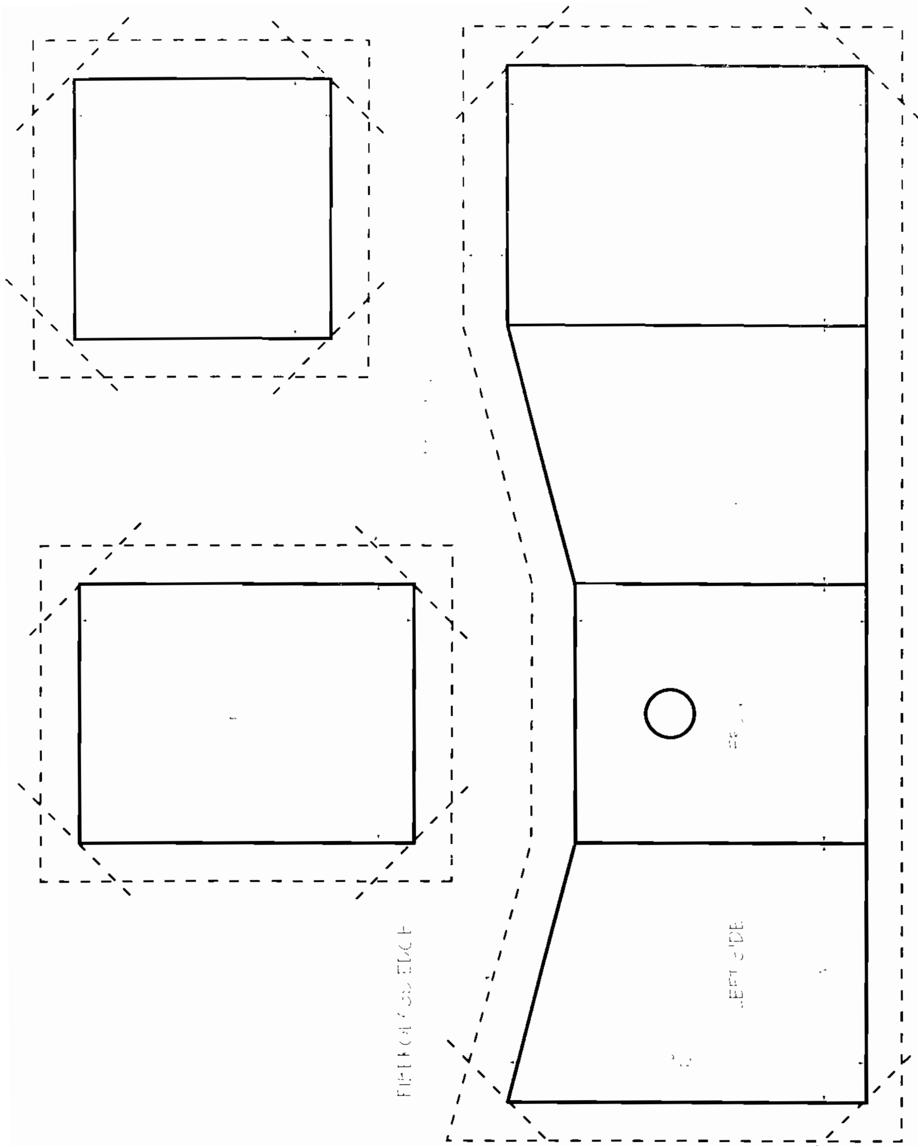
Always read manufacturers' instructions and precautions before working with resins, initiators, or other chemicals.

Materials



- ☐ Fiberglass repair kit that includes polyester resin, fiberglass cloth or mat, and initiator (available at auto supply stores or in the hardware section of some stores)
- ☐ Cardboard from an old box
- ☐ Paper-based tape
- ☐ Newspaper
- ☐ Goggles, disposable dust mask, and properly fitting latex gloves for protection
- ☐ Disposable mixing cup or bowl (16-ounce) to mix resin
- ☐ Ice-cream sticks or tongue depressors
- ☐ Small paintbrush (no more than ½ inch wide) to spread the resin
- ☐ Acetone
- ☐ Sandpaper (medium and fine grit)
- ☐ Paint and paintbrush to decorate the finished piece
- ☐ Heavy-duty scissors
- ☐ Utility knife
- ☐ Ruler/straight edge
- ☐ Cutting board





Template for cardboard walls, floor, and roof, to be enlarged.
The fiberglass mat should be 1 inch wider than the cardboard.

Step 1—Using scissors or a utility knife, cut out cardboard shapes to form the walls and roof of the birdhouse.

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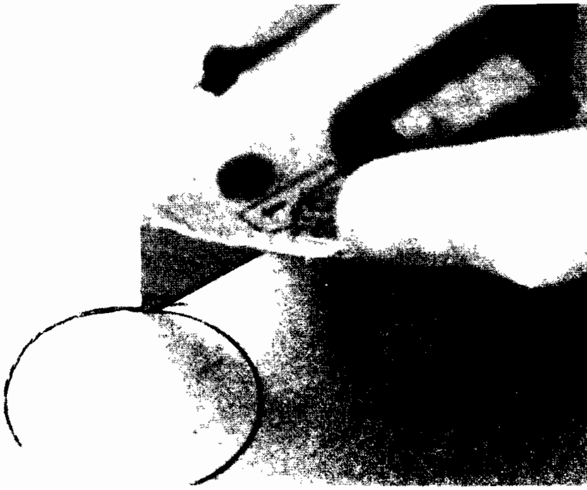

Step 2—Mark a 2-inch hole in the cardboard front wall as if for bird entry. Cut out the hole with a utility knife.

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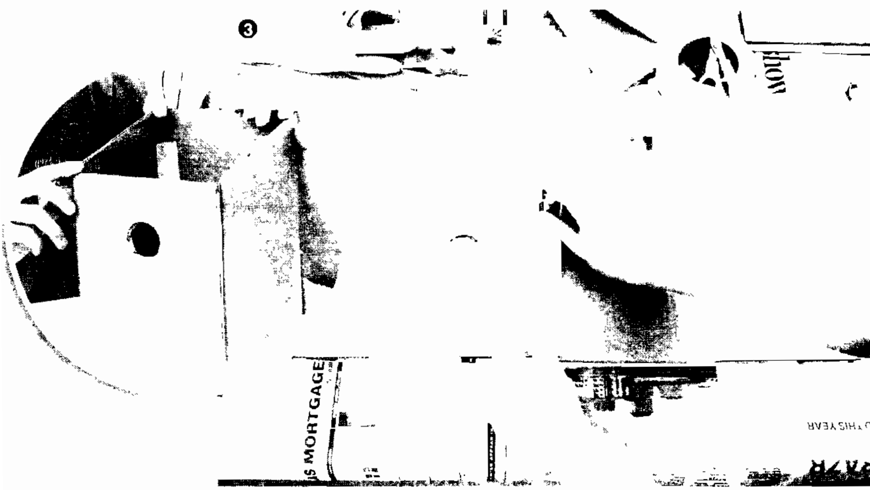
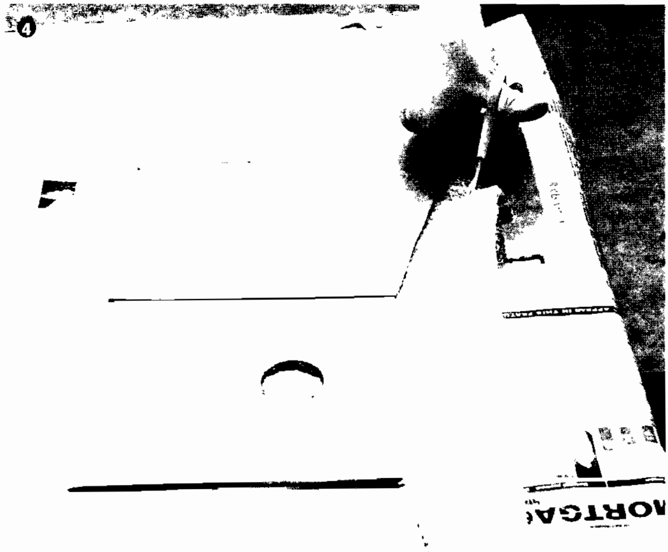


Step 3—Temporarily assemble house panels with paper tape. Before proceeding, examine the structure and make sure the house is what you want. Now is the time to make changes. Once the lamination process starts, it is too late.



Step 4—Cut the fiberglass mat for the walls and roof as shown in the pattern. There will be about 1 inch of overlap around the edges of the birdhouse.

Start Lamination

Step 1—Wearing latex gloves and eye protection, measure 12 ounces of resin into the disposable mixing cup. Then consult the manufacturer's instructions to determine how much initiator to add to the resin you have poured into the cup.

When mixing resin or laminating, wear latex gloves and goggles. Be careful not to spill or splash resin. Immediately clean up any spills. Use caution when weighing resin and initiator. Always add initiator to resin, not the other way around.

Once the initiator is added to the resin and you have mixed it well, you are working against the clock. The resin will begin to harden immediately, so you will need to work quickly and precisely. The "working time" is the period of time the resin can be manipulated before it hardens.

Step 2—Use an ice-cream stick or tongue depressor to thoroughly stir the resin and initiator mixture.

Step 3—Using the paintbrush, lightly coat the outside of the walls with resin.

Step 4—Carefully place the fiberglass mat on top of the resin, being careful to leave a 1-inch overlap around all the sides. Cut the entry hole out of the fiberglass.

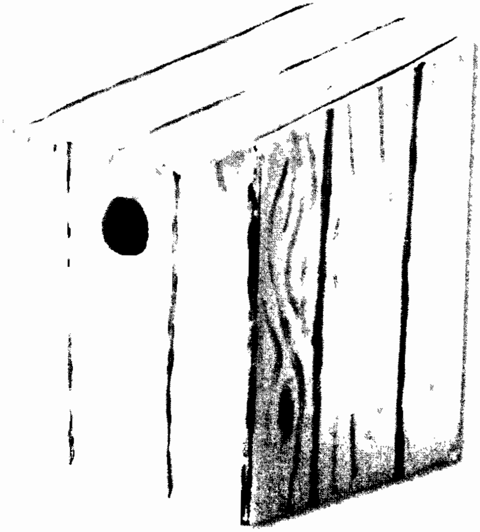
Step 5—Using the paintbrush, wet-out (saturate with resin) the fiberglass mat to the edges of the birdhouse walls. Remove air bubbles or wrinkles in the mat by applying pressure to the surface with the brush. Use sweeping motions from the center of the piece to the edges. If there are any dry spots, pour a small amount of additional resin onto the mat and work it in with the paintbrush. All areas of the fiberglass mat must be wet-out, but avoid using too much resin.

Step 6—Mix a smaller batch of resin as described in steps 1 and 2, and wet-out the overlaps on the fiberglass mat. Fold the flaps to the inside of the walls.

Step 7—Fold the walls of the birdhouse into shape, overlapping the fiberglass mat at the seam. Set the house aside in a well-ventilated outside area, and allow it to cure.

Step 8—While the birdhouse is curing, repeat the laminating process (steps 1 through 7) with the roof and the floor. Allow these to cure also.

Step 9—Attach the roof and floor to the house. The roof may be permanently attached or removable to make it easier to paint.



Finish

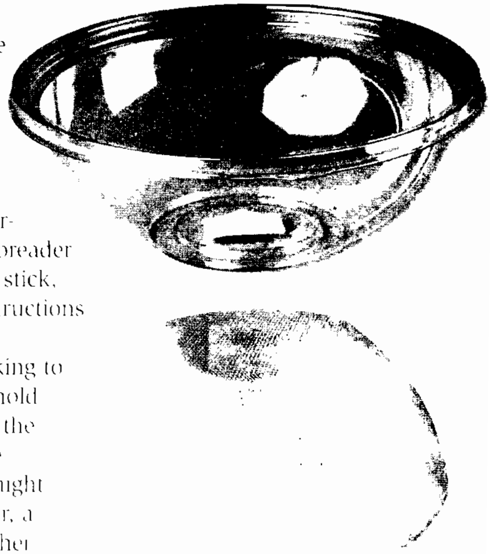
Step 1—Clean the tools you used with acetone.

Step 2—Allow all unused, initiated resin to harden.

Step 3—Properly dispose of used brushes, newspaper, and any hardened resin after it has cooled.

Step 4—Lightly sand the outside surface of the birdhouse to remove excess resin and rough edges. Paint as desired.

Decorative Molded Bowl



For a project using a mold, make a simple decorative bowl. You could use a fiberglass repair kit for boats that includes resin, initiator (hardener), fiberglass cloth, plastic spreader or squeegee, mixing stick, mixing tray, and instructions for use. To keep the composite from sticking to the bowl (or other mold you use), first cover the mold with a suitable mold release. This might be wax, waxed paper, a Mylar sheet, or another material. Be sure to use a mold release that will work well with the resin system you are using and will not harm the mold. If you are not sure what mold release to use, read the instructions that came with the fiberglass repair kit and ask your counselor's advice.

Project Ideas

Lots of fun and useful items can be made or repaired using the materials and techniques described in this chapter. Use your imagination to dream up something that strikes your fancy, but always follow all the safety precautions described in this pamphlet and specified by the manufacturers for the products that you use. Be sure you have your merit badge counselor's approval before you begin, and work with a responsible adult who is knowledgeable about composites. Here are a few possibilities for composites projects.

- Walking stick
- Model boat
- Skateboard
- Snowshoes
- Repair or reinforce a wooden tool handle
- Patrol kitchen box
- Camp signage
- Fire bucket

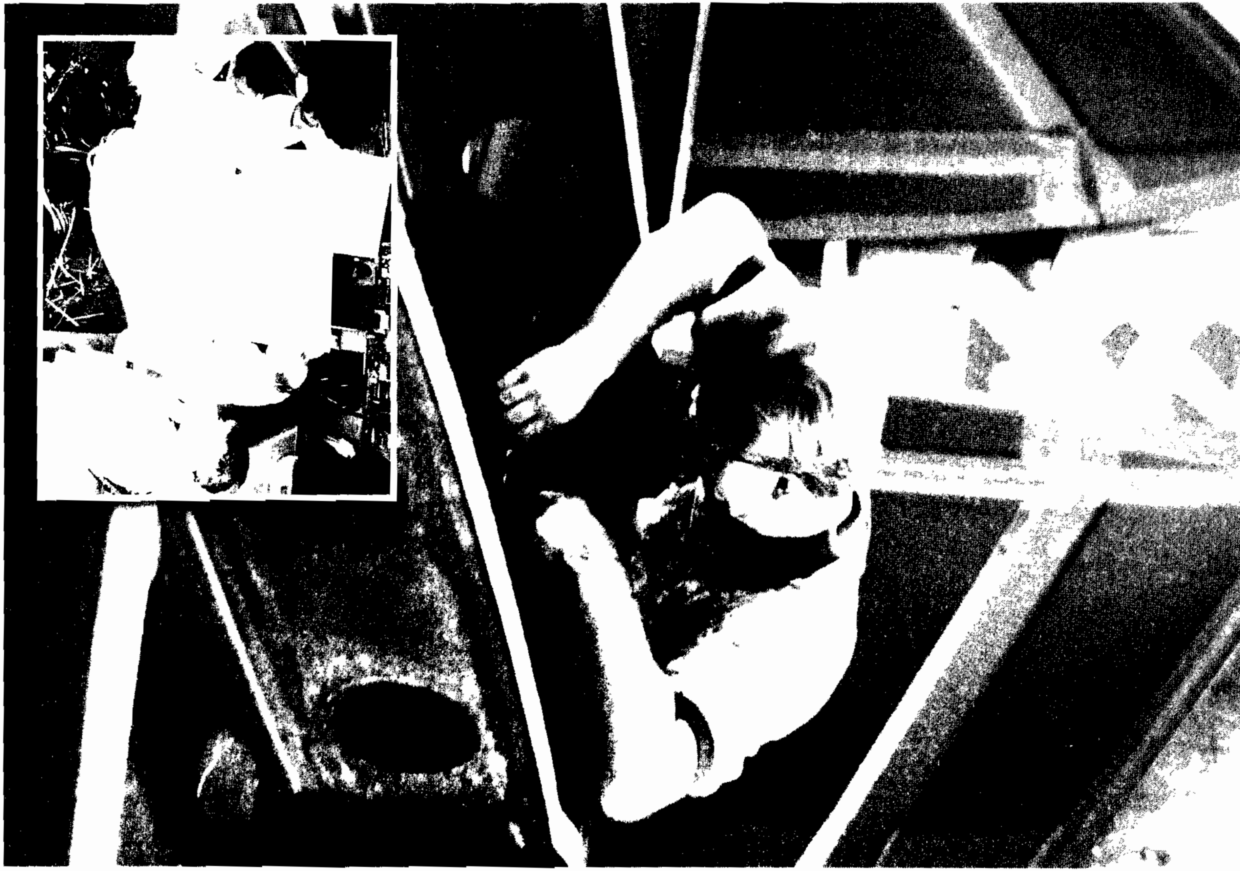
Evaluating the Finished Projects

For requirement 5c, you are to evaluate (judge) your completed projects with your counselor. What features or qualities do you think your finished projects should have? Do your projects meet your expectations for such qualities as those listed here? (You may use this list as a starting point for discussion, but tailor your evaluation to your own projects and to your personal goals and expectations.)

Are your finished products

- Useful and safe to use or display?
- Structurally sound and impact-resistant?
- Attractive and free of air voids?
- Not resin-rich or resin-starved?
- Well-proportioned, balanced, symmetrical, and even?
- Strong, stiff, and durable?
- Lightweight or buoyant (capable of floating)?
- Waterproof or weathertight?
- Rustproof?
- Not flammable?
- Nonconductive?

Did you have any construction or safety problems? How would you avoid them in the future?



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Careers in the Composites Industry

The composites industry offers many career opportunities. You might find a position with a company that produces the raw materials used in manufacturing composites, or a company that makes composite parts, or one that uses the parts. You might work at a university or in a laboratory doing research and development on new materials or processes. You might work in design, creating new applications for composite materials.

Wherever your career path may lead, it starts with a high school diploma and a good foundation in science and math. Opt for all of the general science, math, chemistry, physics, and English classes that you can.

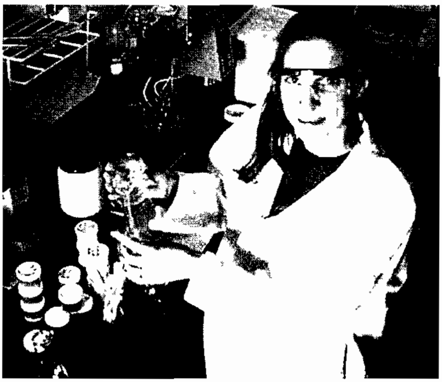
A high school graduate may qualify for a manufacturing position in a composites plant as a material technician, mold operator, toolmaker, painter, or general laborer, for example. Further education or training is necessary, however, for most opportunities in the composites industry.

Educational requirements beyond high school depend on the career path you choose. Some positions require a two-year technical or associate degree; others require a four-year bachelor's degree. For advanced positions, you might need a master's degree or doctorate. Chemistry and engineering are common majors.

Types of Career Opportunities

In composites-related industries you will find five major areas of career opportunities: research and development, production, marketing and sales, human relations, and finance. Some positions require degrees in business, accounting, finance, or marketing. In office positions, it is common to find people who have both engineering and business degrees.

Here are some typical professions in the composites industry



Chemists

Chemists develop formulas for the resins that go into various composites. Their work may take much time and many experiments. A chemist may work in a research laboratory, in a quality control department, or on the manufacturing "floor" (which is the area of a plant or factory where products are actually made, as opposed to the offices or labs). This is a problem-solving, inventive career. A chemist may solve problems in manufacturing, or—as a technical sales or service person—may help customers solve problems.

Chemists usually have at least a bachelor's degree in chemistry. Master's degrees and doctorates are common.

Chemical Engineer

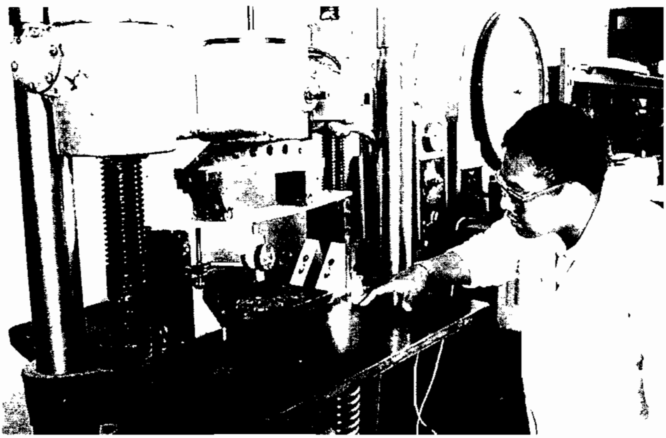
While chemists concentrate on resin formulas and processes, chemical engineers are mainly builders who draw on their chemical knowledge to design and plan facilities to manufacture resins, reinforcements, or composite products. In other words, chemical engineers use the basic knowledge developed by chemists to set up ways to apply composites technology to make materials and products.

To earn a bachelor's degree in chemical engineering, people study not only chemistry but also physical design, economics, and manufacturing. Many chemical engineers hold master's degrees.

Chemical Technician

Chemical technicians work for and with chemists and chemical engineers to develop new products, resin formulas, and new or improved processes to achieve specific purposes. They test resins and composites, set up equipment, conduct experiments, and install and operate machinery to make resins or composite products. Technicians work in manufacturing plants, research labs, and chemical production facilities.

This type of position requires knowledge of laboratory methods, test procedures, and using instruments. A technician often has two years of college chemistry or engineering and holds an associate degree.



Product Designer

Product designers find good ways to use composites for new purposes. They look at new and inventive ways to use composites to replace conventional materials such as glass, steel, concrete, and wood. They create products that look good, are strong, and have the desired physical characteristics.

A product designer needs a background in materials engineering, composites, structural engineering, and design, and needs to have an artistic flair. This position requires at least a bachelor's degree, typically in engineering.

Materials Engineer

Materials engineers must understand composites and how they perform and the advantages of composites over other materials. In some ways a materials engineer is much like a product designer who not only designs but also builds the composite. These professionals are becoming more important to the industry as composites are being used in new ways and new places. Some universities now offer bachelor's degrees in composite materials engineering.

Manufacturing or Production Engineer

A manufacturing engineer is well-trained in all manufacturing techniques. This person is responsible for taking the design and making sure it is built correctly. A manufacturing engineer must be a problem solver to make sure the production line is always moving. This person works with all production departments.

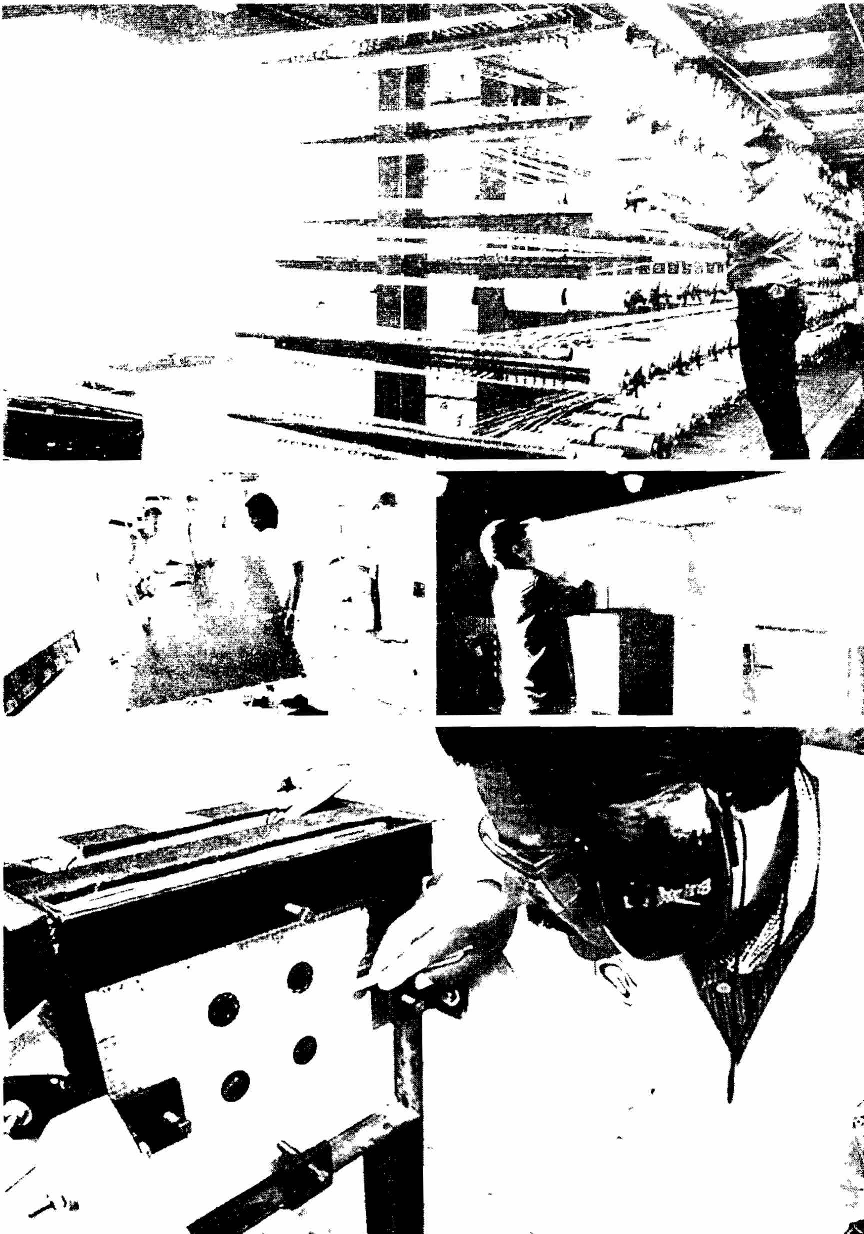
Quality Engineer

A quality engineer makes sure the parts and products are built as specified in the design. This engineer is well-trained in testing and inspection and often deals with customers.

Other Composites Manufacturing Positions

Many positions in composites manufacturing require a specialized skill or knowledge, including

- Production supervisor
- Pattern or tool maker
- Laminator
- Mold fabricator
- Press/mold setup technician
- Assembler
- Fixture, jig, or rigging fabricator
- Fluid-handling setup and maintenance worker
- Woodworker, metalworker, or electrician



Glossary

additive. A material added to a resin to enhance its performance. Additives include colorants and flame retardants.

advanced composite. A composite that is applied in high-performance applications, such as aircraft or military applications.

anisotropic. Materials having different strengths or properties in different directions; a quality of composites.

aramid fiber. A synthetic reinforcing fiber used in body-armor fabric and other applications; short for *aromatic polyamide*, commonly called Kevlar.

carbon fiber. A high-performance, synthetic reinforcing fiber known for its light weight, high strength, and high stiffness. It is produced by "baking" or "charring" rayon, pitch, or acrylic fibers at temperatures above 1,800 degrees Fahrenheit.

casting. A mixture of resin and fillers poured into a mold, usually without fiber reinforcement, and left to cure to form the final product.

closed-mold process. Manufacturing process where reinforcements and resins are closed to the atmosphere and processed in a two-sided mold or within a vacuum bag.

composite, or composite material. A material that is made up of two or more different materials that, when combined, are stronger than the individual materials; generally referred to as *composites*.

compression molding. A closed-mold manufacturing process in which composite materials are compressed between matched molds under high pressure and heat until the part cures. Used for molding large quantities of complex parts.

compressive strength. The ability of a material to resist a crushing or buckling force.

conductive. Capable of transferring electrical current.

crosslinking. The chemical bond that turns liquid resin into a solid material.

curing. The chemical process that converts a resin into a hardened state.

epoxy resin. A thermoset resin having excellent strength, adhesion, and corrosion protection.

exothermic. The quality of resin to give off heat when it cures.

fabric. Arrangement of fibers held together in two dimensions.

fiber. Slender, threadlike material that is much longer than it is round and is an individual strand in a fabric.

fiber-reinforced polymer (FRP) composite. Material in which a polymer resin contains reinforcing fibers providing greater strength and stiffness than either the resin or fiber alone. *FRP composite* is a more specific term than the general word, "composites." Sometimes referred to as *advanced composites.*

filament. A single element in a fiber; the smallest unit of a fibrous material.

filament winding. An open-mold manufacturing process that applies resin-saturated, continuous strands of fiber reinforcements over a rotating cylindrical mold; used for creating hollow products like rocket motor casings, pipes, and chemical storage tanks.

filler. A material added to resins to improve the appearance and performance of composites and lower the cost.

gel coat. The outermost surface layer of resin; a special polymer resin that enhances the surface appearance and performance of composites.

glass fiber. A fiber made from molten glass (silica, sand, limestone, and other minor ingredients), available in several types such as A-glass, E-glass, S-glass, and C-glass. Also called *fiberglass.*

hand lay-up. An open-mold manufacturing process in which a reinforcement is applied to the mold by hand and resin is applied with a brush or roller onto the reinforcement.

hardener. A chemical added to a thermoset resin to cause a curing reaction.

honeycomb. A manufactured core material of resin-saturated sheet material formed into six-sided cells or openings and used in sandwich construction.

hybrid composites. A composite laminate of two or more different fiber reinforcements, such as glass and carbon fiber, combined in a single structure.

impact strength. The ability of a material to resist an abrupt or shock load.

initiator. A hardener, sometimes called a *catalyst*, that causes the cure of a thermoset resin.

isotropic. Having uniform properties in all directions; a quality of metal.

laminate. Two or more layers of fiber reinforcement bonded together with a resin.

material safety data sheet (MSDS). A document that includes detailed information on a material, including health and physical hazards, exposure limits, and precautions.

mil. A unit of measurement that defines the diameter of glass fibers (1 mil = 0.001 inch).

mold. A tool for forming composite materials into the desired shapes or parts.

monomer. A single molecule that is a constituent of a polymer.

nonconductive. Incapable of transferring electrical current.

open-mold process. Manufacturing process where reinforcements and resins are exposed to the atmosphere.

ply. A term used to describe a single layer of reinforcement in composites.

polymer. A large molecule made up of many units that are linked together in a chain. Polymers can be naturally occurring, such as starch, or synthetic, such as polyester.

prepreg. A reinforcement that is saturated with resin and ready to use for molding; short for "preimpregnated," meaning the fibers have been presoaked with resin.

pultrusion. A closed-mold manufacturing process to form composites into long, consistent shapes like rods or bars. Continuous strands of reinforcement are pulled through a resin bath to saturate them, then pulled through heated steel molds that shape the composites into continuous lengths. Pultruded products include fishing rods and golf club shafts.

reinforcement. A term for fibers, particles, or "whiskers" (thin hairlike materials) used in composites. Fibers are the most common reinforcement in composites and greatly influence composites' properties.

resin. A polymer (plastic) that binds together reinforcing material in a composite.

resin transfer molding. A closed-mold manufacturing process in which reinforcement material is placed in a closed mold, into which resin is injected under pressure.

roving. A loose bundle of untwisted yarns or strands of a reinforcing material.

sandwich construction. Two relatively thin laminate sheets ("face skins") bonded to a lightweight core material such as honeycomb, balsa, or varieties of foam.

solvent. A liquid substance capable of dissolving or dispersing other substances. In working with polymer resins, solvents such as acetone are commonly used for cleanup.

spray-up. An open-mold manufacturing process in which a chopper gun is used to chop reinforcement material and add it to resin, which is then sprayed onto a mold. This process is used in boat manufacturing.

storage life. The period of time during which a liquid resin, initiator, or other chemical can be stored under specified temperatures and remain suitable for use. Also called *shelf life*.

strand. A bundle of filaments, normally untwisted.

tensile strength. The ability of a material to resist forces that stretch the material.

thermoplastic resins. Resins that are not crosslinked and so can be melted, formed, remelted, and re-formed.

thermoset resins. Resins that are converted from a liquid to a solid through irreversible crosslinking.

vacuum bag molding. A closed-mold manufacturing process in which a vacuum is created to force the laminate against a mold, thus removing trapped air and excess resin and compacting the laminate.

vinyl ester. A type of thermoset resin related to epoxy resin and commonly used in corrosion protection.

wet-out. The process of thoroughly saturating reinforcements with resin.

yarn. A twisted bundle of continuous filaments, fibers, or strands, used for weaving fabric reinforcements.

Composite Materials Resources

Before you surf the Web, be sure you have your parent's permission.

Your local library can be a valuable source of information about composite materials, although you may need to visit a university library for in-depth information. You can also find composites information on the World Wide Web. Just go to one of the popular search engines and type "composite materials" or "composites" in the search box.

Nearly any topic in the field of composites can be found on the Web. You can find general information, details on specific applications like carbon-fiber bicycle frames, and material safety data sheets on thousands of raw ingredients used to make composites.

Other important sources of composites information are the professional societies and trade organizations that relate to the industry. (See the partial list at the end of this chapter.) Many of these organizations publish information about themselves in their own printed publications, as well as on the Web.

Information technology is rapidly changing, including sources of composites information. When you read this, there may be additional sources not available at the time this pamphlet was written. Your librarian, teacher, or counselor may be able to help you find them.

Scouting Literature

Chemistry, Engineering, Model Design and Building, and *Space Exploration* merit badge pamphlets

Books

Aird, Forbes D. *Fiberglass and Composite Materials: An Enthusiast's Guide to High Performance Non-Metallic Materials for Automotive Racing and Marine Use.* HP Trade, 1996.

Composites Institute. *Introduction to Composites*, 4th ed. Technomic Publishing Co., 1998.

Du Plessis, Hugo. *Fiberglass Boats.* 3rd ed. International Marine/Ragged Mountain Press, 1997.

Edmunds, Arthur. *Building a Fiberglass Boat.* Bristol Fashion Publications, 1999.

Marshall, Andrew C. *Composites Basics*, 7th ed. Marshall Consulting Publishing, 2005.

Rutan, Burt. *Moldless Composite Sandwich Construction.* Rutan Aircraft, 1983.

Strong, A. Brent. *Fundamentals of Composites Manufacturing: Materials, Methods, and Applications.* Society of Manufacturing Engineers, 1989.

Periodicals

Composites Manufacturing

American Composites Manufacturers Association
1010 North Glebe Road, Suite 450
Arlington, VA 22201
Telephone: 703-525-0511
Web site: *http://www.cmmagazine.org*

Composites Technology

Ray Publishing Inc.
4891 Independence St., Suite 270
Wheat Ridge, CO 80033
Telephone: 303-467-1776
Web site: *http://www.compositesworld.com*

Organizations and Online Resources

American Composites Manufacturers Association
Web site: *http://www.acmanet.org*

American Society for Composites
Department of Civil Engineering
422 Kettering Laboratory
University of Dayton
300 College Park
Dayton, OH 45469-0243
Web site: *http://www.asc-composites.org*

Center for Composite Materials
201 Composites Manufacturing Science Laboratory
University of Delaware
Newark, DE 19716-3144
Telephone: 302-831-8149
Web site *http://www.ccm.udel.edu*

Composites World
Web site. *http://www.compositesworld.com*

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Grandville, MI 49418
Telephone: 616-243-4444
Web site: *http://www.e-composites.com*

NetComposites
Web site: *http://www.netcomposites.com*

Occupational Safety and Health Administration
200 Constitution Ave. NW
Washington, DC 20210
Toll-free telephone: 800-321-OSHA
Web site: *http://www.osha.gov*
Composites safety Web site:
http://www.osha.gov/SLTC/composites/index.html

Acknowledgments

The Boy Scouts of America is extremely grateful to the M. C. Gill Corporation, El Monte, California, for its generous gift to fund the development and production of this new Composite Materials merit badge and pamphlet. The M. C. Gill Corporation is a composites industry leader around the globe.

Thanks to the many individuals and groups involved with the development and production of the merit badge and pamphlet. In particular, thanks to the following: Merwyn C. "M. C." Gill, Stephen Gill, Matt Lowry, and Armond Beal, M. C. Gill Corporation; Phil Gill, Royal Plastic; John P. Busel, Larry Cox, Robert Lacovara, Andy Rusnak, and Missy Henriksen (former executive director), American Composites Manufacturers Association; Denny Fink, Jim Scholler, and Ken Weber, NORAC Inc.; Matthew Benson, Composites Technology Center, Winona (Minnesota) State University; Peter Joyce, U.S. Naval Academy at Annapolis; Charles Botsford, P.E., AeroVironment Inc., Steve Nutt, Ph.D., Merwyn C. Gill Composites Center, University of Southern California; Jack Beauchamp, Ph.D., California Institute of Technology; Donald Klosterman, Ph.D., Center for Basic and Applied Composites Research, University of Dayton (Ohio); Hilary Gregg, M.A., La Canada, California; John D. Tickle, Strongwell; Frank Moore, The Boeing Company; Terry Price, M.A., Cerritos Community College, Norwalk, California; and Sven Rundman.

Thanks to members of Troop 4 and Troop 5, Austin, Texas, for their assistance with photography.

ACMA
American Composites Manufacturers Association

The Boy Scouts of America gives special thanks to the American Composites Manufacturers Association for its assistance with the development and production of the *Composite Materials* merit badge pamphlet. For more information about composites, visit the ACMA's Web site at *http://www.acmanet.org.*

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