ADVANCED Composites

FOURTH EDITION

Cindy Foreman

AVOTEK® INFORMATION RESOURCES

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Preface

Since the first edition of this textbook, many advances have been made in materials and the manufacture and use of composite components. Fewer advances have been made in the field of composite aircraft repair. Advances in composite repair is largely dependent on the manufacturers to include these new techniques into the structural repair manuals.

People have many misconceptions about what is involved in composite maintenance and repair. Working with composites falls into three categories, manufacturing, remanufacturing, and repair.

Manufacturing composites differs greatly from maintaining composites, yet many believe the techniques used in manufacturing are also used in maintenance. When composite components are manufactured, several procedures are used. Most components that can be repaired are manufactured by laying pre-impregnated fabric onto a mold, many times with a core structure. To cure the part, it is put into an oven or an autoclave to apply extra pressure and heat.

The second category, remanufacturing or rebuilding a component, is when very large damage has occurred that is outside the limits of the structural repair manual. To remanufacture a part, molds, vacuum bags, ovens, or autoclaves are also used.

The third category is the repair to composites where the damage is within the limits of the structural repair manual. This type of damage is what is covered in this book. Frequently, the component can be repaired on the aircraft. Repairs such as these differ from remanufacturing. The part is usually cured by vacuum bagging and using hot bonding equipment. These parts are not cured in an oven or autoclave. Many people tend to think that to repair a composite, you need all the equipment that a manufacturer uses. This is completely false.

People also have misconceptions of how strong composites are. When I was first learning about composites, I went to a trade show for manufacturers and engineers. There was a beautiful filament wound tail rotor on display. I asked the representative, "How are you going to repair it?" He replied "It's made of Kevlar, sweetie, it won't break."

Kevlar does break, hence, this book on composite repair.

In the 30 years of training technicians in advanced composite repair, I have found that with proper training, composites are not hard to work with; they are just different. Learning this simple fact is the primary purpose of this textbook.

A Note From Avotek. Textbooks must be of a general nature in their coverage of subject areas. The aircraft manufacturer is the sole source of operation, maintenance, repair, and overhaul information. The manufacturer manuals are approved by the FAA and must always be followed. Do not use any material presented in this textbook as a manual for actual operation, maintenance, or repairs.

The author and other individuals and companies who contributed to this textbook have done so in the spirit of cooperation for the good of the industry. To the best of their abilities, they have tried to present the material with accuracy, honesty, and pertinence. As with all human endeavors, errors and omissions can show up in the most unexpected places. If any exist, they are unintentional. Please bring them to our attention.

Email us at comments@avotek.com for comments or suggestions.

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Introduction to Composites

Composites are materials that are used in structural applications in almost all types of aircraft, including homebuilts, gliders, passenger airliners, business jets, fighter planes, and spacecraft.

In recent years, many manufacturers, working with grants from the government, have made major advancements in the field of structural science. The resulting new developments in materials technology have made it possible to design and build aircraft that perform better and operate more efficiently than previously thought possible.

Aviation composites technology has advanced to the point that it is strong enough to be used in primary airframe components. In some cases, whole airframe assemblies are constructed of advanced composite materials. As more manufacturers equip their aircraft with composite parts, the need for trained aviation technicians to fabricate, inspect, and maintain these aircraft also increases.

Using composite materials for aircraft manufacturing has elicited a variety of reactions from members of the aviation community.

- Aircraft manufacturers hail composites as a very durable, highly manufacturable material.
- Aircraft owners regard the new composite aircraft as lightweight and more cost-effective than their metal counterparts, affording them to transport more people, baggage, or fuel.
- Aircraft technicians sometimes regard composites as either another name for traditional fiberglass or as a mystery material that only engineers can understand.

Learning Objectives

REVIEW
- History of composites

DESCRIBE
- Elements of composites
- Advantages and disadvantages
- Who may repair composites

EXPLAIN
- How composites can be light and strong
- Where composites are used in various aircraft

Left: Engine cowlings and structural components are manufactured with advanced composite materials.

Composite materials are recognized as the most advanced substance for making aircraft parts. Composite structures are made from a combination of fabrics, fibers, foams, and honeycomb materials bonded by a matrix or resin system.

Section 1

What Is a Composite Structure?

The term *composite* is used to describe two or more materials that are combined to form a structure that is much stronger than the individual components. The simplest composite is composed of two elements: a matrix that serves as a bonding substance, and a reinforcing material.

Before combination, the matrix is generally in liquid form and the reinforcing material is a solid. Many times a core material is also added. All these materials are combined and cured to make a structure that is stronger than each was individually.

History of Composites

The concept of composite materials is not new. The oldest manufactured building material, adobe, is a composite formula (Figure 1-1-1).

Figure 1-1-1. The centuries old ruins of the Anasazi Indians in southwestern Colorado bear eloquent testimony to the durability of this simple composite material.

Adobe is produced by combining two dissimilar components, such as mud and straw, to form building bricks. After the bricks are cured in the sun, the resulting block is substantially stronger and more durable than the original components were alone.

A more contemporary example of composite material is in the traditional dope and fabric airplane. In this instance, nitrate or butyrate dope is combined (Figure 1-1-2) in proper proportions with grade-A cotton fabric, producing a strong, lightweight skin covering. The strength and simplicity of the dope and fabric airplane has endured through the years and is still a favorite airframe material for handcrafted classic and high-performance aerobatic airplanes. The smooth lines and meticulous workmanship of the dope and fabric airplane can be seen in such high-performance airplanes as the Stinson, Beech Stagger wing (Figure 1-1-3), and the Christen Eagle, all of which perform at summer air shows throughout the world.

World War II fighter airplanes and early airliners, such as the DC-3, used dope and fabric materials on control surfaces such as elevators, rudders, and ailerons.

The technology of composite materials progressed with the introduction of butyrate dope, fiberglass, and polyester resins. In the 1940s and 1950s, fiberglass fabric was impregnated with polyester resin and used for fairings, radomes, and other nonstructural components. In the 1950s, epoxy resins were introduced and have been used very successfully with fiberglass reinforcing materials.

Fiberglass parts reduce the aircraft weight considerably when used to replace their metal counterparts. The success of these lightweight parts lead to the increased use of composites on newer airplane model. For example, the 747 has more than 10,000 surface square feet of fiberglass composite structure.

When carbon/graphite was introduced as a reinforcing material in the early 1960s, a minor resurgence in using new composites occurred. Carbon/graphite composites (Figure 1-1-4) were used experimentally and on military aircraft in the 1960s and 1970s. Carbon fibers have advanced in their strength and technology since then, and now it is a very common advanced composite building material.

Kevlar®, an aramid fiber material, was first produced in the 1970s and is now found extensively in many aircraft. When developing new reinforcing materials, companies were also creating new chemical bonding formulas, which improved matrix materials.

Figure 1-1-2. Dope and fabric is a type of composite material that is still in use today.

Figure 1-1-3. Dope and fabric cover the Beech Staggerwing fuselage and wings.

Advanced composites have been created as a result of combining developments in chemical bonding formulas with new or existing forms of solid structural materials to form the high-strength, lightweight components used structurally in aircraft. These components are sometimes referred to as a fiber reinforced plastic (FRP). This term is not widely used outside the composites industry, because people do not like the idea of flying in plastic airplanes. Plastic, of which the resin matrix is actually made, is sometimes thought of as cheap toys that break into millions of pieces. Because of this, the terms *composite* or *advanced composite* are used.

Advanced Composite Repairs

A common misconception of advanced composites is that they can be repaired in the same way as the older fiberglass structures are repaired. A very dangerous temptation in the industry has been to relegate composite repairs to the fiberglass shop. Fiberglass, in the past, has been used mostly for nonstructural components such as fairings, spinners, and so on.

It is cost-effective to repair a composite component instead of scrapping it, even if the damage is substantial. The damage might be so extensive that it exceeds the limits stated in the structural repair manual, but to send it out to a remanufacturing facility saves money over purchasing a new component. If you compare the cost of repairing the damage against the cost of materials and labor involved in fabricating a new component, it is usually more economical to repair the component.

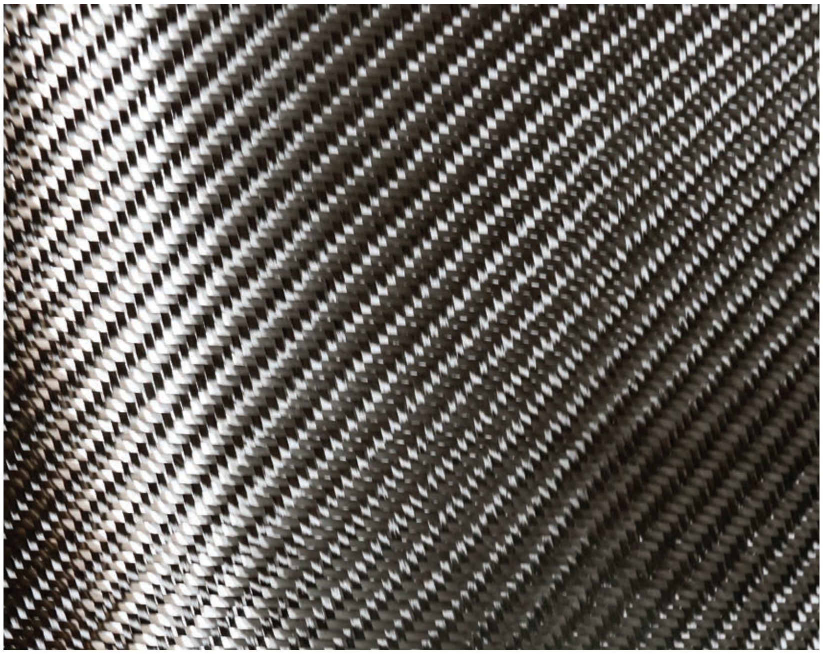


Figure 1-1-4. Carbon fiber fabric.

The newer, advanced composites use stronger fabrics and resin matrices that cannot be repaired in the same way as fiberglass and still produce the greatest strength. To repair an advanced composite part using the materials and techniques that have traditionally been used for fiberglass repairs can result in an unairworthy repair because such traditional repairs have excessive weight, increased susceptibility to material fatigue, and decreased flexibility.

Advanced composites are being used structurally because of their strength and adaptability to withstand stresses. These composites' repair procedures are different because the part must replace the structural integrity of the component. Excessive weight should not be added by applying excessive resin material, and drilling holes into a composite structure can weaken the fibers' load-carrying characteristics. The fabric type, weave, and positioning of the fabric patches are extremely important in distributing the stresses imposed on a repair.

Proper training and a strong understanding of the type of structure you are working with are very important. Follow all manufacturers' instructions carefully, using the proper materials and procedures.

Advantages

The greatest advantage of using composites is the high strength-to-weight ratio. In aircraft construction, saving weight is one of the key considerations for using any material, and designers are continuously trying to improve the lift-to-weight ratio. The more weight that can be saved, the higher the useful payload, which means more cargo, fuel, or passengers can be carried, increasing profits.

A composite part can be designed as strong as a metal part, but with considerable weight savings. Typically, 20 to 40 percent weight reductions are achieved when aluminum parts are replaced with composite structures.

When designing with composite materials, the weight savings are the primary pursuit. However, the composites also lend themselves well to forming complex, aerodynamically contoured shapes. The parts do not have to be flat but can have smooth, sweeping contours that would be difficult and expensive to fabricate from sheet metal. The reduced drag produced by these contoured shapes, in combination with the weight savings, enables an aircraft's range to be extended significantly.

The number of parts and fasteners can be reduced by using composites, simplifying construction and reducing cost. In some cases, very large structures can be manufactured in one piece, eliminating the riveting and seams.

Composites can be designed to be very flexible, resisting vibrations, thus eliminating the problem of stress fatigue found in metal structures.

Composite materials do not corrode as sheet metal does. The material does not oxidize or rust as metal does. Some composite fabrics can cause certain metals to corrode if they come in contact, but practices have been developed to avoid this.

Reduced wear is another advantage of using advanced composites. Depending on the fiber used, some composites will flex in flight without producing stress cracks like metal can. For example, helicopter rotor blades in flight have many stresses imposed on them. When made of composites, the wear is less, because the fibers can take the bending and twisting forces without developing metal fatigue.

In short, composites are years ahead of traditional aluminum alloy and are the closest thing yet to an ideal aircraft material. However, composites have their advantages and disadvantages, just as metal does, and is a long way from replacing all metal in aircraft.

Disadvantages

Composites do not corrode like metal does. However, they do have their own problems. Many people talk as if composites are indestructible. If this were the case, a book on composites repair would not have to be written because they would never fail or break.

Carbon fiber composites, when in contact with aluminum, can cause a galvanic potential, which causes the aluminum to corrode. This and other concerns are addressed in later chapters.

Moisture is a problem for some composite fabrics, such as Kevlar or aramid fabrics, if they are not fully enclosed in the resin. Exposed fibers can wick in moisture, causing the composite to fail.

Many companies claim that composite materials can be built many times stronger than a metal part. This is true, but when working with aircraft components, weight is also a very big factor. If the part has as sufficient strength as a metal component, the composite part can be made with the same strength and save considerable weight.

If you are using composite materials to build something other than an aircraft, such as a bridge, weight would not be an issue, and the component could be made many times stronger than metal. The strength of the composite depends on the type of fibers used, the bonding materials used, and how the part is engineered to take specific stresses.

Composites are more expensive if only a few parts are manufactured. It is expensive to design and manufacture the custom molds. As more composites are used structurally, they are becoming increasingly cost-effective as materials and manufacturing technologies mature.

Uses

Composites today are being used throughout the world on many aircraft. Helicopters, military, commercial, corporate, and personal aircraft all incorporate composites to some degree. Composites are being used in the power plants and the airframe designs. This book concentrates on the airframe uses of composites. European and other foreign aircraft manufacturers have been using more composite materials in their designs in the past than American manufacturers. This difference in design philosophy could be, in part, because of the more conservative policies of the Federal Aviation Administration (FAA). As the FAA proofs the strength and structural integrity of composite structures, it is more widely accepting of composites.

Section 2

Uses in Military Aircraft

The military has been using composites in aviation longer than the civilian market. Military aircraft has been a testing ground for composite design and now for their sustainability. For years, military helicopters and aircraft used composite components. Since the 1960s, carbon and boron composites were common materials used in many military applications (Table 1-2-1).

Helicopters

In the 1970s, the objectives of the U.S. Army's Advanced Composites Airframe program (ACAP) were to achieve a 22 percent weight reduction and a 17 percent cost reduction using an all-composite airframe on U.S. Army helicopters. Under ACAP, many designs of composite fuselages by different manufacturers were submitted for stringent testing.

Component		Manufacturer	Metal equivalent	Weight savings (%)	Status
F-15 horizontal and vertical stabilizers boron epoxy		McDonnell-Douglas Mitsubishi Heavy industries	Titanium	22 (estimated)	Production
F-14 horizontal stabilizer boron epoxy		Grumman Aerospace Corp.	Titanium	19	Production
B-1B reinforced longeron boron epoxy		Rockwell International	Steel-titanium	44	Production

Table 1-2-1. In the 1970s, manufacturers used boron in constructing military aircraft, many years before composites were used in production aircraft.

Bell D-292. Bell Helicopter's D-292 was a successful example using carbon/graphite for the forward roof, bulkheads, cowlings, frame, and beam caps. Kevlar was used in the fuselage shell and outside skins. A hybrid of carbon/graphite and Kevlar was used to construct the nose, canopy, vertical fin, horizontal stabilizer, fuel compartment, bulkheads, and floors. Fiberglass was used for the tail boom skin and cargo floor.

Sikorsky UH-60. The Sikorsky UH-60, (Figure 1-2-1) or the Blackhawk, uses 400 lbs. of Kevlar/carbon. It has a composite rear fuselage, carbon main rotor blades, and a composite rotor head.

Bell 222. The Bell Helicopter Model 222 main rotor is made of fiberglass/Nomex.

Figure 1-2-1. Composites are used extensively to build the Sikorsky UH-60.

Figure 1-2-2. The S-76 horizontal stabilizer is made of Kevlar and Nomex honeycomb.

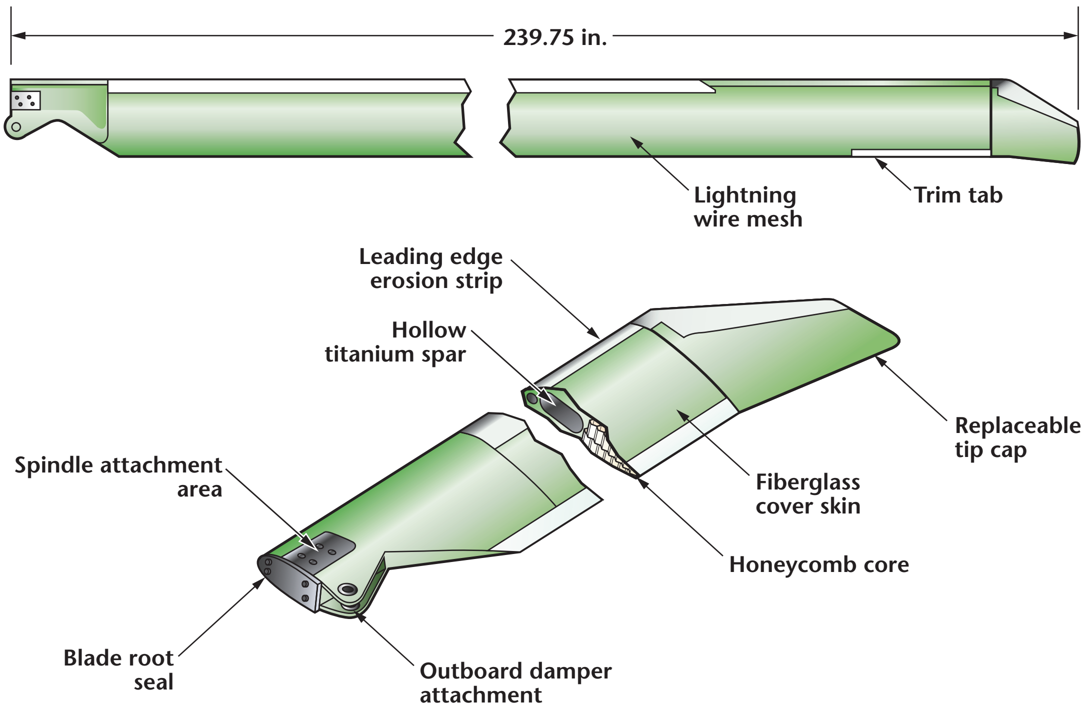


Figure 1-2-3. S-76 blade construction.

By refitting the CH-53 Super Stallion with composites, a 40 percent cost reduction was possible. Using composite materials eliminated approximately 10,000 fasteners.

Sikorsky S-75. Sikorsky also submitted a design for the ACAP with its S-75 helicopter. It successfully completed a 50-hour evaluation and exceeded the weight and cost-saving criteria. Sikorsky learned much about fabricating and producing composite materials, which was incorporated into much of its later designs.

Sikorsky S-76. Sikorsky S-76 (Figure 1-2-2) was the civilian model of the S-75. The horizontal stabilizer of the S-76 was the first all-composite component that the FAA certified for civilian use. Sikorsky used Kevlar and Nomex honeycomb to build the horizontal stabilizer. By using a thermoset matrix around extensive amounts of Kevlar sheet and Kevlar honeycomb, it conserved weight and had vibration dampening effect.

On today's latest models of the S-76, 60 percent of the total airframe is considered composite. The main and tail rotors (Figure 1-2-3) are made of fiberglass with a honeycomb core and are considered bearingless rotors.

Sikorsky CH-53. Sikorsky's CH-53, a heavy-lift helicopter, was first flying in the 1960s. Since then, it has gone through many model changes. In 1967 the main rotor blades of the CH-53E were changed to include the first titanium-fiberglass composite blades. The new design of the CH-53K (Figure 1-2-4) includes advanced rotor blades with a span of 35 feet and a chord of almost 3 feet. The rotor blades are fiberglass skins, honeycomb core and 30-ft.-long carbon spars. The new design has more than 75 percent composites; the CH-53E used 10 percent. The fuselage is made mostly of carbon fiber and a toughened epoxy resin over a new aramid-reinforced honeycomb core. In 2015 the CH-53K took its maiden flight; it was introduced in 2018.

Military Airplanes

Grumman X-29

In the 1980s, Grumman's X-29 forward swept wing design required extraordinary rigidity and torsion resistance. This was met by using 156 layers of unidirectional carbon/graphite filament in a complex fiber pattern. In flight, the X-29's forward swept wing design had aerodynamic forces that tended to twist upward on the leading edge. The orientation of the fibers limits the twist and allows the wing to return to its original configuration once the load is removed (Figure 1-2-5). If made of traditional sheet metal, the wing could not withstand the imposed stresses. Although it is a thin wing, the composite design produces a very strong structure that has a very low profile.

AV-8B Harrier

Another classic military aircraft is the AV-8B, known as the Harrier, started as a joint effort between Hawker Siddeley and McDonnell Douglas aircraft companies in the 1970s. It was designed as a vertical or short take off and landing (V/STOL). After the British withdrawal from the project, McDonnell Douglas redesigned the wing, fuselage and some aerodynamic features.

Figure 1-2-4. The Sikorsky CH53K has a 70 percent composite airframe.

Figure 1-2-5. The composites used in the forward-swept wing design of the X-29 withstand extraordinary stresses. Courtesy of NASA

Figure 1-2-6. The Harrier is still in use today.

The Harrier was made of 26 percent (by weight) carbon/graphite and epoxy materials. The Harrier was the first military aircraft with an all-composite wing (Figure 1-2-6). The later versions of the Harrier were used by the military in the Iraq and Afghanistan conflicts since 2001, and some are expected to be in service until 2025.

B-2

Northrop Grumman's B-2 Advanced Technology bomber (Figure 1-2-7), known as the Stealth Bomber, had its first flight in 1993. The B-2 is designed for minimum radar detectbility. It incorporates a *flying wing* construction. Throughout the years, it has gone under extensive upgrades and changes. It is believed that the frame and skin are composed of carbon/graphite fiber with high temperature epoxy resin to form the composite material which helps absorb radar energy. It is coated with a radar-absorbing spray to help with the stealth characteristics. It is expected to stay in service until 2056.

Figure 1-2-7. The B-2 incorporates the flying wing construction to help in its stealth capabilities.

Section 3

Uses in Regional Airliners

The rise of the commuter or regional airlines in the 1990s and 2000s has made two manufacturers stand out. Bombardier with the CRJ series, and Embraer with its ERJ series. The regional jets are cost-effective aircraft, linking hundreds of smaller airports to the global hubs.

Bombardier/Airbus

In 1996 Bombardier introduced the CRJ 200, which was based on the Canadair Challenger business jet, a 36-seat aircraft. A larger CRJ 700 was developed in the late 1990s with a new wing design and stretched and widened fuselage that seated 70-78 passengers. Composite materials are used in the aircraft secondary structures such as the radome, winglets, belly fairings, landing gear doors and empennage top fairings.

The new *C Series* jetliner, is a larger aircraft, with 100-149 seats (Figure 1-3-1). The newest C series aircraft use a high proportion of composite materials, about 46 percent of the total weight. Bombardier is the first commercial aircraft manufacturer to use *dry* fiber rather than pre-preg materials in manufacturing the carbon composite wings. Resin infusion has been used in military and other industries, but it is new to the commercial aviation sector. Airbus acquired Bombardier in the summer of 2018, but many of the structural repair manuals might still reflect the Bombardier name.

Embraer

Embraer, a Brazilian aircraft company, offers regional airlines with a range of 15-49 passenger load with the ERJ series (Figure 1-3-2), which took off in the United States as the number one regional aircraft in the late 1990s.

Embraer used aramid composites on leading edges of wings, carbon skins with honeycomb control surfaces (Figure 1-3-3). In the 2000s, Embraer introduced its line of E-Jet family. In 2011 Embraer updated the E-jet series to be called the E-jet-E2. These are much larger aircraft capable of carrying between 120 and 146 passengers.

Figure 1-3-1. Bombardier's C series (A220). Courtesy of Bombardier

Figure 1-3-2. One of Embraer's new E-jet-E2 series of aircraft. Courtesy of Embraer

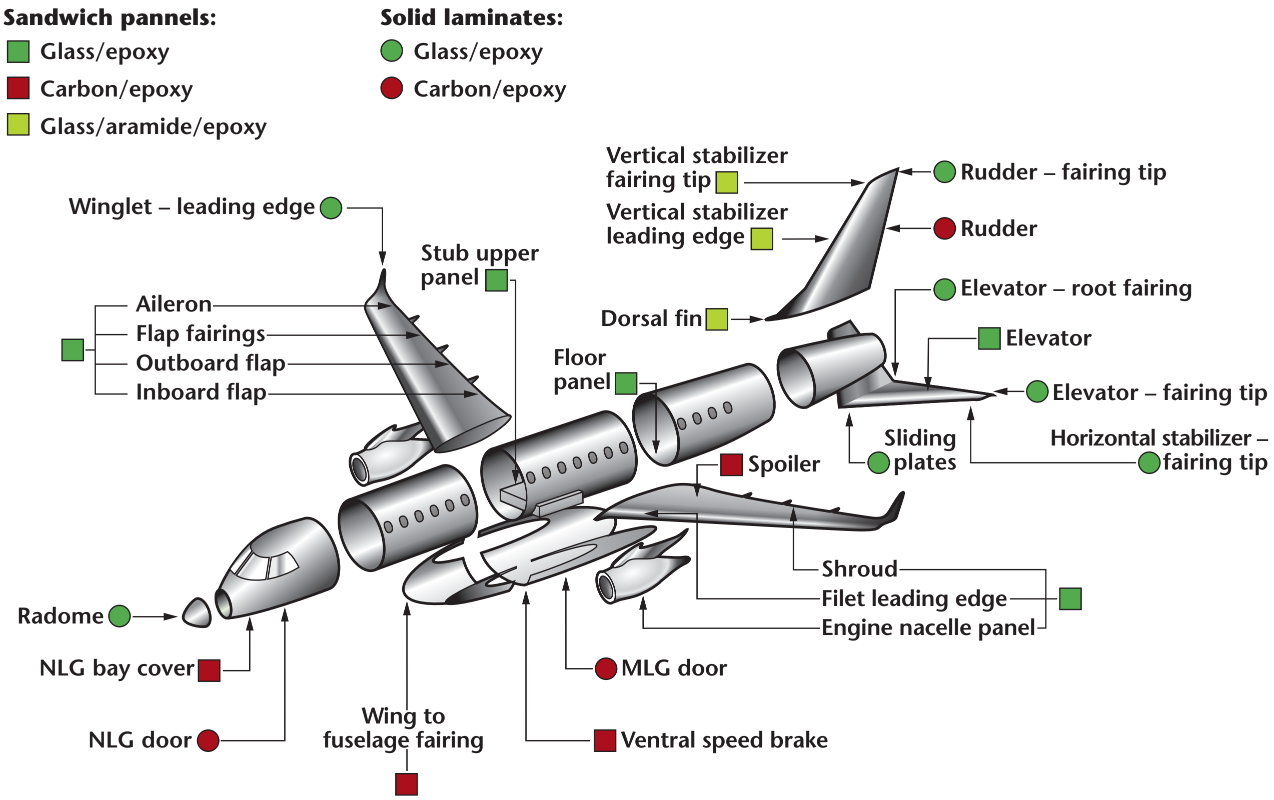


Figure 1-3-3. EMB 170 aircraft composite construction.

Section 4
Uses in Large Airliners

An early application of using composites in large transport aircraft was on Lockheed's L-1011, which consisted of 1,300 lbs. of woven fabric for the fairings, ailerons, vertical stabilizer, leading edges of the wings, and other components.

Lockheed succeeded in recognizing substantial weight savings in the L-1011 by using composites to fabricate the vertical fin. NASA designed a test to rebuild the vertical fin in 1984, using composite materials to compare it to its metal counterpart. The composite part reduced the weight by 28 percent over the metal counterpart, and a lower cost was achieved by reducing the number of internal ribs and fasteners (Table 1-4-1).

	Aluminum fin	Composite fin
Weight (lbs.)	858	622 (28% lighter)
Number of ribs	17	11
Number of parts	716	191
Number of fasteners	40,371	6,311

Table 1-4-1. The L-1011 composite vertical fin compared to an aluminum fin. The composite fin uses fewer parts, is easier to assemble, and is lighter than the aluminum fin.

Boeing

Boeing's use of composites in the past has been mainly with ailerons, elevators, rudders, and spoilers. Boeing is now using carbon/graphite, hybrid mixtures, and Kevlar for most of its newer applications. Boeing was the first to use a carbon spoiler and the first to use Nomex® honeycomb on its aircraft.

Boeing 757

The Boeing 757 uses composite materials in almost all its secondary structural components, which has increased fuel efficiency dramatically. Graphite/epoxy is used on primary control surfaces and spoilers. Hybrids of graphite/Kevlar are used on the access panels, undercarriage doors, wing/fuselage fairings, and cowlings.

The 757's design saved 1,000 lbs by using advanced composite components. Substantial amounts of composite material are used structurally as a replacement for aluminum.

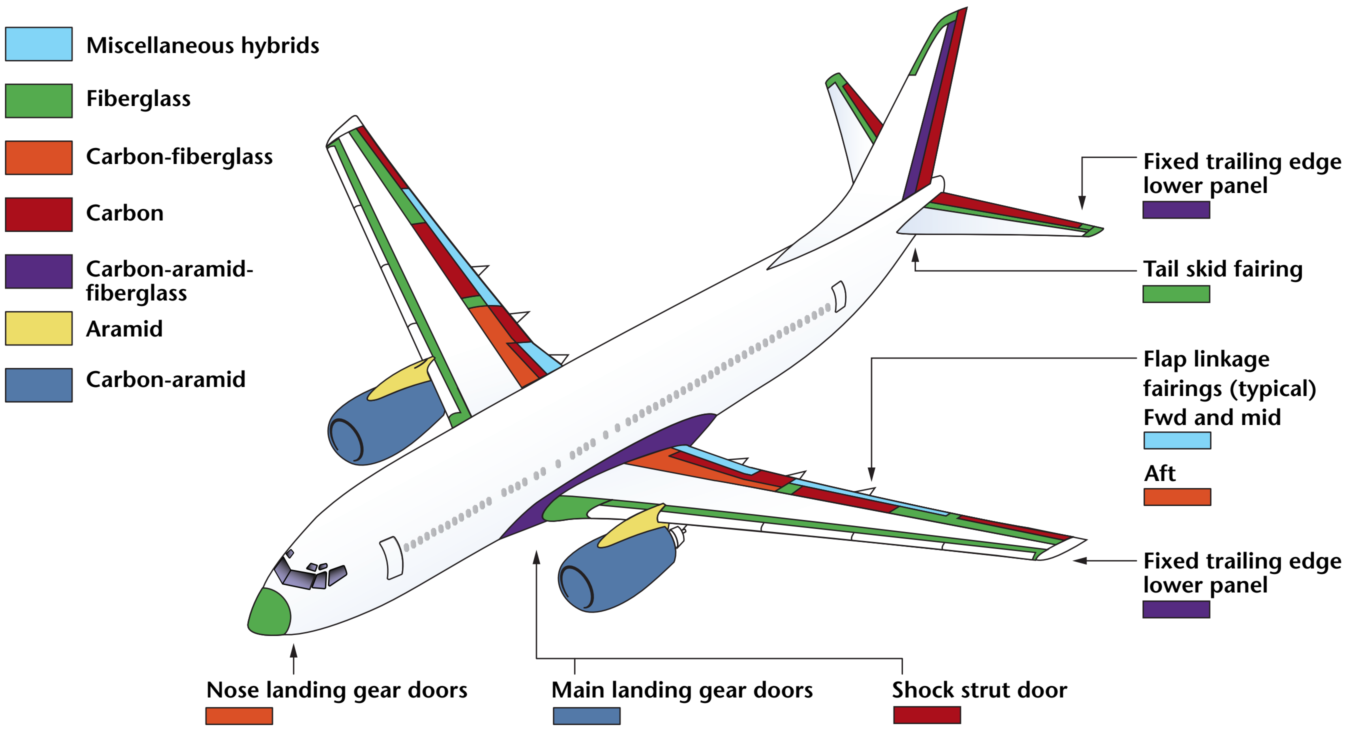


Figure 1-4-1. Graphite/epoxy use on the Boeing 767.

Boeing 767

The Boeing 767 demonstrates further use of composite structures in the aircraft construction: Kevlar, carbon (and combinations of both), and fiberglass. Carbon composites are used for the primary flight control structures. Fiberglass-reinforced plastics are used on the main deck floor panels, radome, and the fixed leading-edge panels. Fiberglass is used for its light weight, sonic and buffet resistance, and corrosion resistance (Figure 1-4-1).

Boeing 777

The 777 entered service in 1995. It uses composites for 20 percent of its structural weight as compared to about 3 percent on previous Boeing jets (Figure 1-4-2). The 777 has a 43-ft.-tall composite vertical fin box made of carbon and fiberglass. The wing's fixed leading edge, trailing-edge paels, flaps and flaperons, spoilers, outboard aileron, floor beams, and landing-gear doors are all made of composite materials. The engine cowlings are made of carbon fiber and epoxy skins covering a core of Nomex honeycomb. Using composite materials reduced the weight by 1,500 lbs.

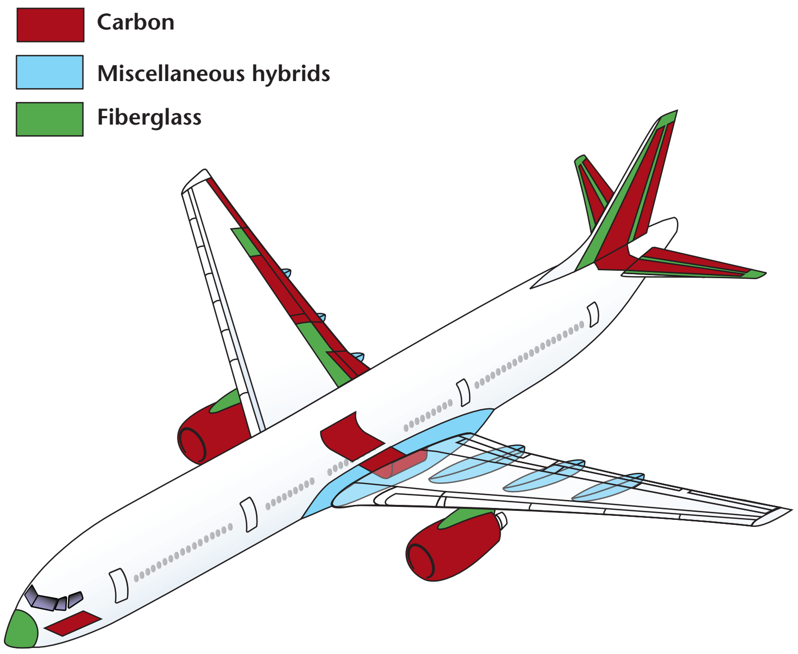


Figure 1-4-2. Composite material use in the Boeing 777-200.

Boeing 787 Dreamliner

The Boeing 787 entered service in 2011 (Figure 1-4-3). Along with many new features on this aircraft, composite use on the fuselage is the biggest advantage. The fuselage is built as a one-piece composite barrel sections that are bonded and bolted together. An estimated 50,000 fasteners were eliminated as compared to a metal aircraft construction. It is intended to replace the 767, and because of the amount of composite materials used, it is 20 percent more fuel efficient. Composite materials by weight are 53 percent of the airframe, or 80 percent composite by volume.

Repairs to the 787 consist of standard bonded repairs to the carbon sandwich sections, but newer repairs are planned on the fuselage and will be addressed later in this book.

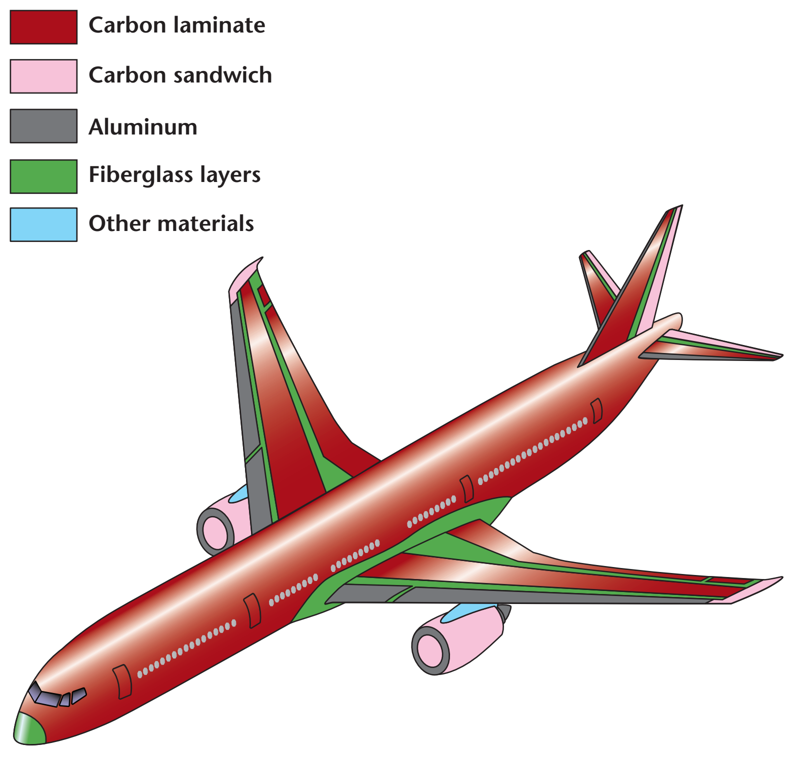


Figure 1-4-3. Composites used in the Boeing 787.

Boeing 777X-8 and 777X-9

Boeing's new 777X will be the largest and most efficient twin engine in the world. Most of the airframe of the new Boeing 777X is the same as the old 777 design; however, it has an updated composite wing (Figure 1-4-4). The new design adds a wing that is larger than any other Boeing model, and to operate at existing airports, the 777X features a folding wing tip. Boeing's 777X-8 and the 777X-9 are also enormous. Instead of requiring airport expansion, Boeing made considerations to accommodate the existing size of airports by designing the tips of the wings so they fold up.

With the new larger wing, the 777X will consist of about 30 percent composite airframe.

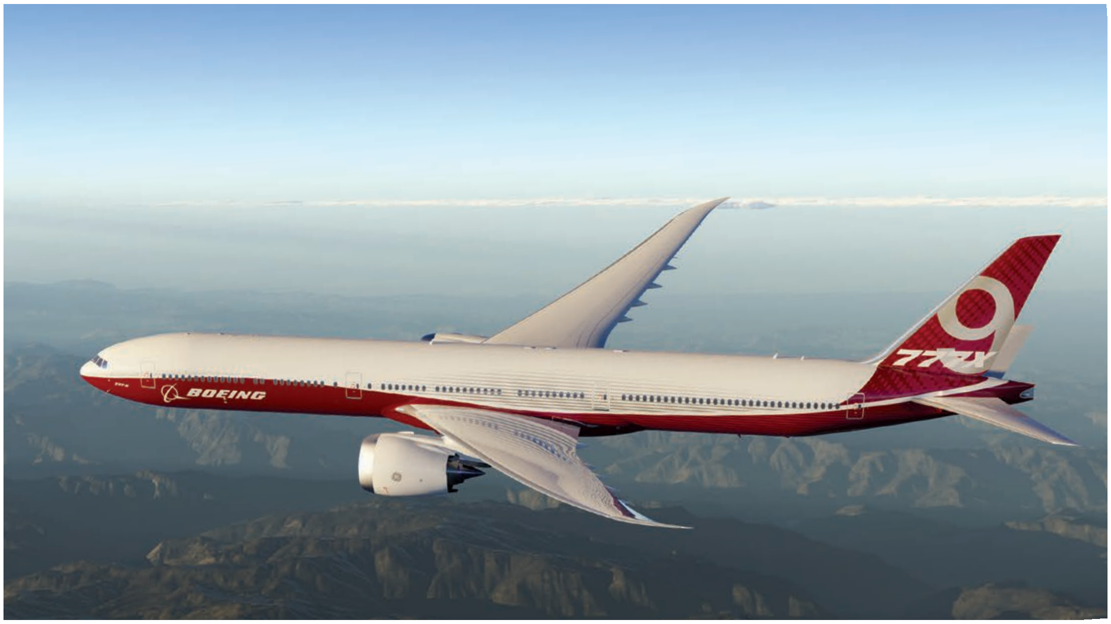


Figure 1-4-4. The Boeing 777X has an updated composite wing. Courtesy of Boeing

The wing itself is estimated to have as much carbon fiber reinforced plastics as the total 787. The larger aircraft will compete with the Airbus A380, and the Boeing 747. It is in production now and is scheduled for release in 2020.

Boeing 797

In the works, Boeing 797, a midsize aircraft to close the gap between the smaller 737, and the 787. The fabrication and manufacturing is under review and could include new out-of-autoclave resin infusion methods.

Airbus

The Airbus A300, A310, and A320 are a joint effort of British Aerospace and Aerospatiale. Extensive amounts of Nomex, carbon, and Kevlar are used on the control surfaces and other components.

Airbus first introduced composites on its aircraft by using fiberglass reinforced plastic components. In 1978 it tested carbon fiber components on the A399, then removed them for extensive testing and evaluation. This led to Airbus using carbon fiber on its aircraft.

Aramid and carbon are used extensively on the A310-200. All new Airbus models now include an all-carbon-fiber vertical fin (Figure 1-4-5)t. The A300-600 uses composites on the radome, nose landing gear doors, outer wing trailing edge, and other traditional areas such as the rudder, airbrakes and spoilers, main landing gear doors, thrust reversers, and fan cowl.

Airbus A350 XWB

The newer A350 is built to compete with Boeing 787 and the 777. The original version of the A350 was very much like the A330, but the new wing design (Figure 1-4-6), new engines, a new horizontal stabilizer, and more composite material use make the A350 a totally different aircraft. The large composite panels are bolted and bonded to a metal frame for the fuselage—a more conventional approach that make repairs easier than on the barrel type of fuselage used by other manufacturers.

Airbus A380

The Airbus A380 is the world's largest passenger aircraft flying today. It has been nicknamed the superjumbo. Because of the aircraft's size and weight, some airports had to be expanded to accommodate it. About 20 percent of the A380 fuselage is made with composite materials and the rest of aluminum alloy. The type of materials used include carbon fiber, fiberglass, and a material known as GLARE. These materials are used extensively in wings, fuselage sections, tail surfaces, and doors.

The A380 is the first commercial airliner to have a central wing box made of carbon fiber. It is also the first to have a smoothly contoured wing cross section instead of span-wise to reduce aerodynamic drag. GLARE is a composite material made of aluminum sheets bonded to fiberglass and is used in the upper fuselage and on the stabilizers' leading edges. GLARE is lighter and has better corrosion and impact resistance than conventional aluminum alloy.

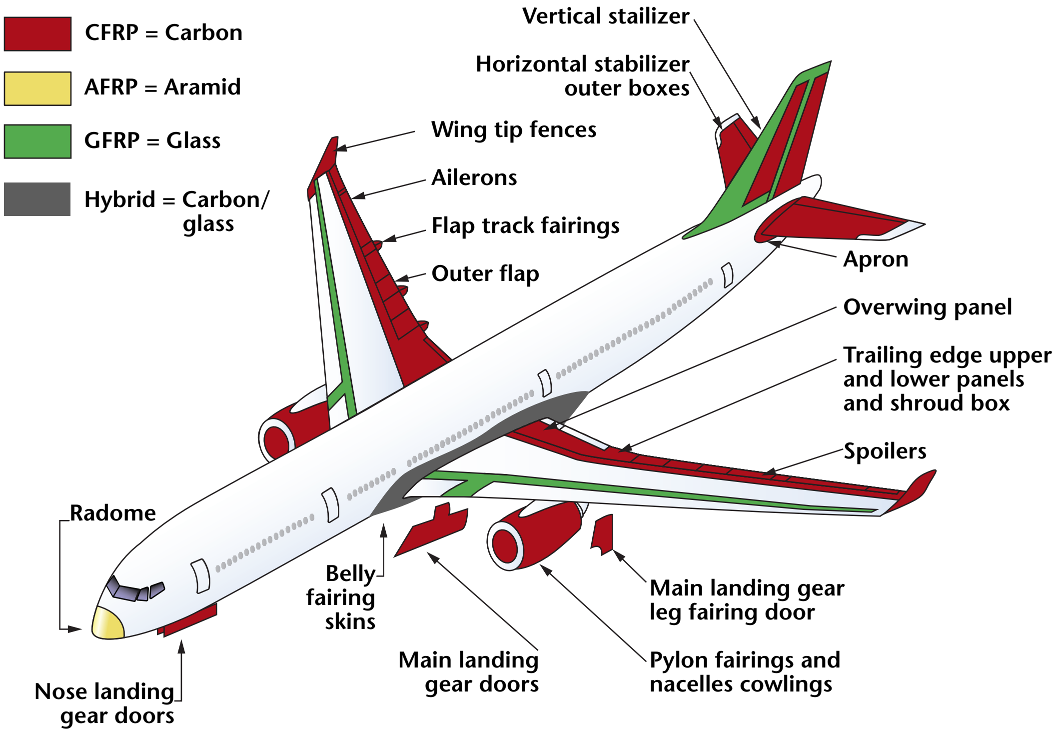


Figure 1-4-5. Airbus A330 composites.

Section 5

Uses in General Aviation

Many other aircraft are manufactured today that use composite components structucturally. As companies increasingly recognize composites as strong, lightweight and cost-effective materials to use in manufacturing, they will develop more advanced designs. Aircraft are special machines, the fastest and most complicated, and maintenance technicians need to keep up with the new developments to maintain their integrity for the safety of the public.

Cirrus SR20/22. This all-composite airframe aircraft has been in production since the late 1990s and continues to see expanded use as a civilian trainer, private aircraft, and small business aircraft. The U.S. Air Force Academy uses these as its primary trainers (Figure 1-5-1).

Figure 1-4-6. The blended winglets of the A350 are a new design.

Figure 1-5-1. Cirrus T53A (also SR20/22) flight trainer.

2

Reinforcing Fibers

When combined with a matrix, the reinforcing fibers give the primary strength to the composite structure. Three common types of reinforcing fibers are used: fiberglass, aramid, and carbon/graphite. Other fibers that are not quite as common include ceramic and boron. These fibers can all be used in combination with one another (hybrids), woven in specific patterns (fiber science), in combination with other materials such as rigid foams (sandwich structures), or simply in combination with various matrix materials. Each composite combination provides specific advantages. This chapter details each of the common types of reinforcing fibers and their characteristics (*Left*) along with some specialty fibers you might encounter when working with composites.

Learning Objectives

REVIEW
- Fiber terminology

DESCRIBE
- Materials used as reinforcing fibers
- Fabric weaves
- Fabric hybrids

EXPLAIN
- Fiber use and placement in composites
- How fiber orientation affects a component's performance

APPLY
- Determine which fibers are best for some situations

Left: Each reinforcing fiber comes in a variety of weaves and can be used in combination with other materials to produce the desired result. Aramid, fiberglass, and carbon are the most common.

Section 1

Fiberglass (Glass Cloth)

Fiberglass is made from small strands of molten silica glass (at about 2,300°F) that are spun together and woven into cloth. Glass fibers are somewhat fragile, so a sizing that lubricates the threads is used as a protective shield during the weaving process. *Sizing* is a treatment of a fabric or other surface with a gelatinous or glutinous substance usually made from glue, wax, or clay and used as a glaze or filler. After the fiberglass fabric is woven, the sizing must be removed by baking the fabric, and then a finish is applied. The finish makes the fibers more compatible with the matrix or resin system to be used. Many different weaves of fiberglass are available, depending on the application. Its widespread availability and low cost make fiberglass one of the most popular reinforcing fibers (Figure 2-1-1).

Fiberglass weighs more and has less strength than most other composite fibers. In the past, fiberglass was used for nonstructural applications; the weave was heavy and polyester resins were used, making the part brittle. Recently, however, newly developed matrix formulas have increased the benefits of using fiberglass.

The three common types of fiberglass are E-glass, S-glass (S2-glass), and C-glass. In aircraft structural applications, E-glass and S-glass are the most common.

- E-glass, also known as *electric glass* for its high electrical resistance, is a borosilicate glass commonly used for reinforcement because of its low cost and good strength characteristics.
- S-glass is a magnesia-alumina-silicate glass that is up to 40 percent stronger than E-glass and retains its strength characteristics at higher temperatures. S-glass is used where a very high-tensile-strength fiberglass is needed.
- C-glass is used in materials that require chemical resistance.

When used with the newer types of matrices and with the proper use of fiber sciences, fiberglass is one of the best reinforcing fibers used in today's advanced composite applications. Some of the new fiberglass composites' strength-to-weight ratio compares favorably with traditional aluminum materials. By using clever methods of combining fiberglass with other, more expensive fibers, such as aramid or carbon/graphite, a hybrid material can be produced that is low cost and strong. Producing hybrids is an exacting science that allows little room for error.

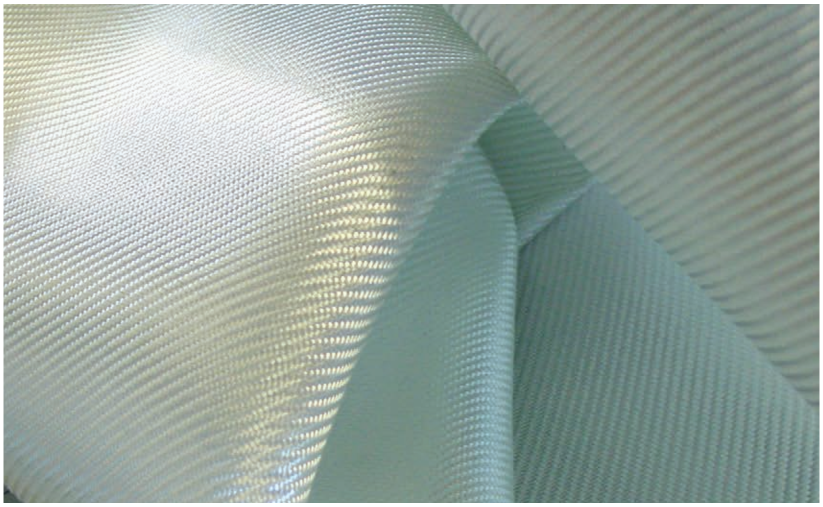


Figure 2-1-1. Fiberglass can be recognized as a white gleaming cloth. It is considered to be the most economic reinforcing fiber of advanced composites.

Section 2

Aramid

An *aramid*, or aromatic polyamide fiber, is usually characterized by its yellow color, light weight, high tensile strength, and remarkable flexibility. Kevlar® is a registered trademark of EI DuPont and is the best-known and most widely used aramid. Aramid ordinarily stretches a great deal before it breaks. The tensile strength of alloyed aluminum is about 65,000 pounds per square inch (p.s.i.), or about one-fourth that of aramid composite. However, the objective in aviation is not necessarily to have a stronger part but to have a part that weighs much less. By using a aramid reinforcing fiber, a component can be made with the strength of a metal counterpart at a fraction of the weight (Figure 2-2-1).

As with most reinforcing fibers, Kevlar and other aramids comes in various grades and weaves for different uses. The aircraft structural grade of Kevlar fiber is known as Kevlar 49. Kevlar 29 is used for boats, and Kevlar 129 is bulletproof material. A common misconception about Kevlar is that if Kevlar fabric is bulletproof, and an aircraft is made with Kevlar, the aircraft is bulletproof. However, bulletproof vests made with Kevlar are typically made of a different weave, weight, and process than aircraft-grade Kevlar. A bulletproof vest also has no matrix, which makes a part more brittle, and the vest has multiple layers of Kevlar fabric, which stretches as a bullet impacts the fabric, preventing penetration.

Aramid is an ideal material for use in aircraft parts that are subject to high stress and vibration. For example, some advanced helicopter designs use aramid to fabricate main rotor blades and hub assemblies. The flexibility of the aramid fabric allows the blade to bend and twist in flight, absorbing much of the stress. In contrast, a blade made of metal develops fatigue and stress cracks more frequently under the same conditions.

Aramid materials also have their drawbacks. Aramid stretches because of its high tensile strength, which can cause problems when it is cut. Drilling aramid, for example, can be a problem when the drill bit grabs a fiber and stretches it to the breaking point instead of cutting it. This makes the material look fuzzy (Figure 2-2-2). If the fuzzy material around fastener holes or seams is not sealed, it can act as a wick and absorb moisture. The moisture, in the form of water, oil, fuel, or hydraulic fluid, probably will not damage the aramid fibers, but the resin system can deteriorate, resulting in the layers of laminates separating. The fuzzy edge around

Figure 2-2-1. Aramid fibers can be woven by different weavers, but DuPont's Kevlar is probably the most well known because DuPont was the first to manufacture it. It has a tensile strength roughly four times that of aluminum alloy.

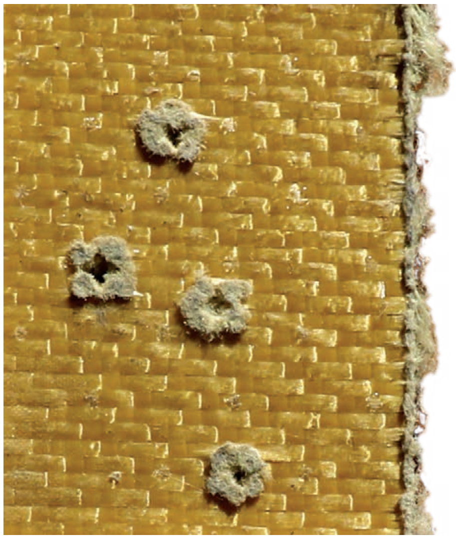


Figure 2-2-2. Cutting or drilling aramid can leave a fuzzy edge, which can lead to problems.

the drilled hole can also prevent a fastener from seating properly, which can cause the fastened joint to fail. This is explained in more detail in chapter 9, Machining Composites.

To combat any extra moisture in the fabric, the raw fabric can be vacuum bagged to dry out any excess moisture before applying the resin.

Although aramid exhibits great tensile strength, it does not have as much compressive strength as carbon/graphite composites.

Section 3

Carbon/Graphite

Carbon fiber, also known as graphite fiber, is a very strong, stiff reinforcement material (Figure 2-3-1). For many years, American manufacturers used the term graphite, and European manufacturers used the term carbon. *Carbon* correctly describes the fiber because it contains no graphite structure. Regardless of what you call it, you order it by number. If you order carbon #584 you get the same weight and weave as if you order graphite #584. It is the same material. Some structural repair manuals (SRM) might call for carbon #584 in one area, and graphite #584 in another. Recently, carbon has become the favored term by both American and European manufacturers. Many SRMs, however, still use the term graphite, so understanding that this material can be referred to in either way is still important to the maintenance technician.

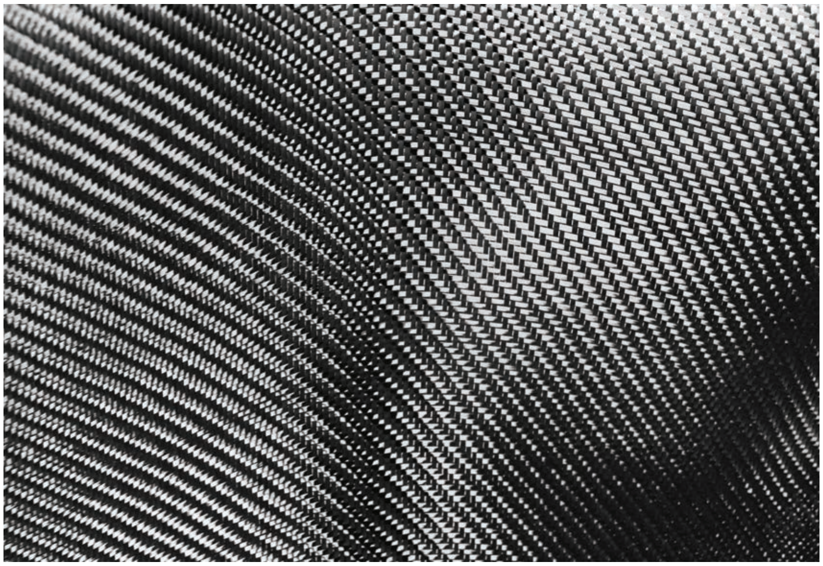


Figure 2-3-1. A fabric made of carbon/graphite fibers. The accurate name is carbon, but it is often referred to as graphite. Some publications even mix the terms. Regardless of the name used, it is the same material.

The carbon/graphite black fiber is very strong, stiff, and used for its rigid strength characteristics. These fiber composites are used to fabricate primary structural components, such as ribs and wing skins. Even very large aircraft can be designed with fewer reinforcing bulkheads, ribs, and stringers because of the high strength and high rigidity of carbon fiber composites. Carbon is stronger in compressive strength than aramid, but it is more brittle.

Carbon/graphite fibers are electrically conductive, have low thermal expansion coefficients, and have high fatigue resistance. Carbon fibers have less impact resistance than some other composite materials, and they can splinter or crack with high impact.

At one time, because of its conductivity, manufacturers did not require lightning or static protection on the carbon fiber components. However, after many problems, the carbon components used today incorporate some kind of lightning protection. More information on this is in chapter 12.

Carbon/graphite is corrosive when bonded to aluminum; that is, it causes the aluminum to corrode. Special corrosion-control techniques are used when carbon materials are in contact with aluminum components. Usually, a layer of fiberglass is used as a barrier, and the aluminum is anodized, primed, and painted before assembly.

Section 4

Specialty Fibers

Some fibers are used in specialty applications where extreme strength, stiffness, hardness, or heat resistance are needed. In such cases, boron or ceramic fibers can be used.

Boron Fibers

Boron fibers are made by depositing the element boron onto a thin filament of tungsten. The resulting fiber is about 0.004 inch in diameter, has excellent compressive strength and stiffness, and is extremely hard. Because boron can be hazardous to work with and is expensive, it is not used in civil aviation. Boron fibers were first used in the early 1960s for military aircraft: F-14, F-15, and B-1. Today they are still used only in military aircraft. As safety became more important and with the start of the Occupational Safety and Health Administration in the 1970s, protective equipment like gloves and dust masks are required when working with boron.

Boron was invented in the 1960s and was used because it has both the tensile strength of aramid fibers (not quite as good) and the compressive strength of carbon. Today, manufacturers use a combination of Kevlar and carbon to give both of these characteristics to the composite. See the Interply and Intraply Hybrids sections later in this chapter.

Boron fibers usually come in a unidirectional pre-impregnated (pre-preg) material. Boron composites have very high strength and stiffness in tension, compression, and bending stresses. The extent of these strengths, however, depends on the type of fiber science designed into the part.

In the 1990s, boron fibers were tested to see if they could extend the life of the aging aircraft fleet. When aluminum wing skins developed tiny stress cracks, boron patches were bonded to the aluminum to prevent further cracking. It was found that boron did not offer improved performance over fiberglass or carbon. Therefore, in designing a composite component that needs both strength and stiffness associated with boron, many civil aviation manufacturers are using hybrid composite materials of aramid and carbon, instead of boron.

Ceramic Fibers

Ceramic fibers are used in high-temperature applications. This form of composite retains most of its strength and flexibility at temperatures up to 2,200°F. The tiles on the space shuttle, for example, are made of a special ceramic composite that is heat resistant and dissipates heat quickly. Firewalls in aircraft are often made of ceramic fiber composites to dissipate the heat. Ceramic fibers are often also used with a metal matrix in turbine engine blades to help dissipate the heat, prolonging the life of the blade.

Section 5

Fiber Use

As composite materials gain use, new reinforcing fibers could be developed. The most commonly used reinforcing fibers are fiberglass, aramid, and carbon. When performing a composite repair, always use the materials that are specified in the SRM.

Table 2-5-1 details the different types of materials and their uses, historically, and currently. Notice that boron is the only fiber that is declining in use.

Category	1987	1992	2000	2015
Aircraft/aerospace	16,879	34,900	85,500	181,660
Types of fibers				
Carbon	4,953	10,800	47,530	105,359
Aramid	4,716	8,670	18,780	28,000
Boron	15	10	8	8

Table 2-5-1. U.S. demand for advanced composite fibers and materials (in thousands of pounds).

Section 6

Fiber Placement

The strength of a reinforcing material in a matrix depends on the weave of the material, the wetting process (how the matrix is applied), filament tensile strength, and the design of the part.

Many books and articles report the tensile strengths of fabrics, but these numbers represent the raw fabric without the resin that is added in the wetting process. Because the aviation community uses composites that contain a resin material, the tensile strength decreases because the resins make the structure more brittle, causing it to break at a lower tensile strength.

To find the amount of strength in a laminate that is 50 percent fiber and 50 percent resin, add the tensile strength of the fibers to the tensile strength of the resin, and divide by two. For example, if we have a composite part that is made up of carbon fiber with a compressive strength of 275,000 p.s.i., added to the compressive strength of the epoxy resin (20,000 p.s.i.), and divided by 2 gives us the compressive strength of 147,500 p.s.i. This calculation is shown in the below equation:

$$\frac{275{,}000 + 20{,}000}{2} = 147{,}500 \text{ p.s.i.}$$

This information would change as the type, weave, weight of the fabric, and the type of resin used change. As a technician, you might not need this information, but it gives you an idea how strong the part can become.

Section 7

Fiber Science

The selective placement of fibers needed to obtain the most strength in various applications is known as *fiber science*. The strength and stiffness of a composite depend on the orientation of the plies in relation to the load direction. In comparison, a sheet metal component has the same strength regardless of which direction it is loaded.

For example, if a wing in flight bends up and twists, the part can be manufactured so one layer of major fibers runs the length of the wing at 0°, reducing the bending tendency, and another layer with the major fibers running at 30° to the first, prevents a twisting motion (Figure 2-7-1). Many layers can be added to strengthen the part in the many directions, making a part that is unique to the forces applied on it. The manufacturer always designates what is 0° and specifies how to place each layer at different degrees.

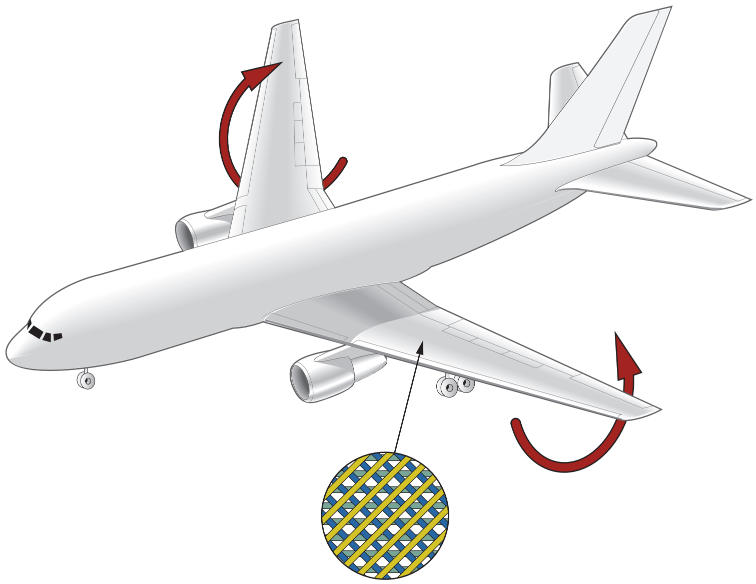


Figure 2-7-1. In flight, the structure tends to bend and twist. The fiber layers are laid in a way to limit the forces, thereby customizing a part to the type of stresses encountered.

Fiber Orientation

Fiber orientation is placing the fiber threads in a direction that enhances the strength or characteristic of the part for each aircraft part. Some terminology about fabric is required to explain how the fabric is placed in the correct position, with the weave going in the proper direction (Figure 2-7-2). These fabric characteristics—warp, weft, selvage edge, and bias—are discussed next.

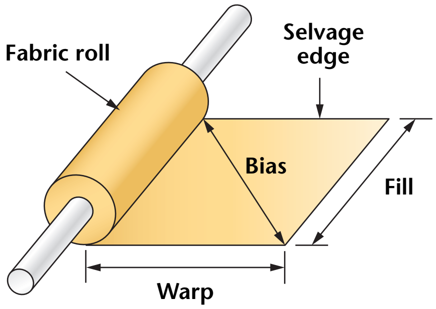


Figure 2-7-2. All design, manufacturing, and repair work begins with the orientation of the fabric.

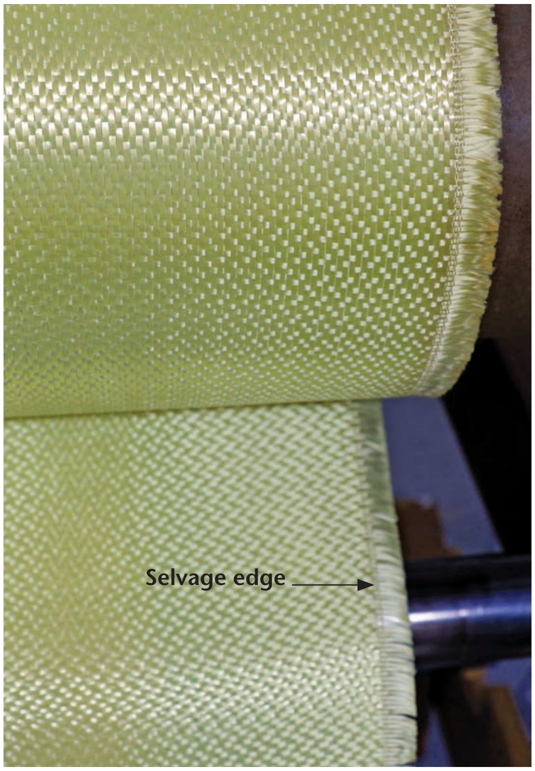


Figure 2-7-3. The selvage edge is the manufactured edge that is used to identify the warp threads, and is cut off before use.

Warp

The threads that run the length of the fabric as it comes off the bolt are referred to as the warp. The warp direction is designated at 0°. In a woven application, typically more threads are woven into the warp than the fill direction. Ultimately, a material is stronger in the warp direction than in the weft (fill) direction.

Because the warp direction is often critical in fabricating or repairing composites, it can be identified by inserting another type of thread at periodic intervals. The plastic backing on the underside of materials that are pre-pregs can also be marked to identify the warp threads.

Weft (Fill)

Weft, or fill, threads are those that run perpendicular to the warp fibers. They are designated as 90°. These threads are ones that interweave with the warp threads.

Selvage Edge

The manufactured edge produced by the weaver to prevent the edges from raveling is referred to as the selvage edge. It is parallel to the warp threads. When trying to align the warp threads of the raw fabric with the existing part, the selvage edge is used to find the warp threads, usually designated as 0°. The selvage edge is removed for all fabrication and repair work because the weave is different from the body of the fabric and would not give the same strength as the rest of the fabric (Figure 2-7-3).

Bias

The bias is at a 45° angle to the warp threads. Fabric can be formed into contoured shapes by using the bias. Fabrics can often be stretched along the bias but seldom stretched along the warp or weft. This is important to keep in mind when it is necessary to wrap a fabric around a contoured shape. When positioning the fabric over a compound curve, the warp threads cannot stretch around the curve, and excess fabric would have to be cut out (Figure 2-7-4, left). If the fabric is positioned with the bias along the curve, the fabric contours much better, and would not have to be cut (Figure 2-7-4, right). The engineers design this into the part, and it would be noted as a ± 45 degrees.

Fabric Orientation Examples

Design engineers can customize fiber direction for the type of stress placed on the part. A helicopter rotor blade has high stress along its

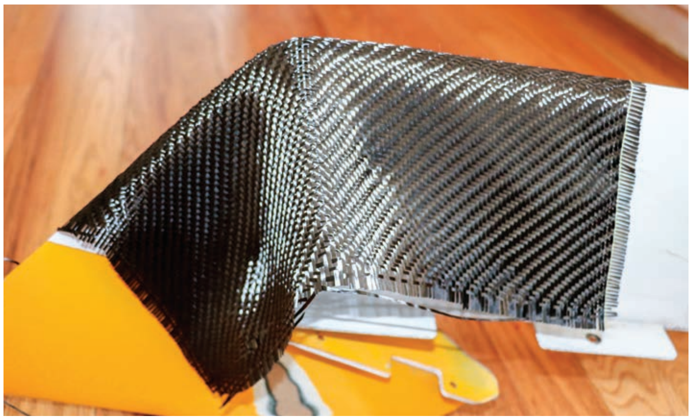



Figure 2-7-4. The warp direction of fabric over a compound curve (left) and bias direction (right).

length because of centripetal forces. If the blade is made of metal, the strength is the same in all directions, giving strength in directions that are not needed. If the blade is made of composites, however, it could have the majority of the fibers running through its length to give more strength in the direction in which the most stress is concentrated.

These vectors of strength can be referred to as 0° plies as directed by the manufacturer and shown in the SRM as warp threads. Placing the warp threads at 0° reinforces the axial loads like those to which a rotor blade is subjected. The next layer places the warp threads at a 45° angle to the 0° to react to shear vectors. A third ply could have the warp threads running at 90° angle to the 0° plies to react to side loads and limit the twist. Each layer can have the major fibers running in a different direction. The strength of the fibers is parallel to the direction the threads run. This is how designers can customize fiber direction for the type of stress the part might encounter.

Another example, the X-29 (Figure 2-7-5) forward-swept wing experimental jet fighter, required extremely strong wings to withstand the aerodynamic forces that caused wing failure on similar all-metal aircraft. To withstand these multidirectional stresses, the wings were produced with 156 layers of unidirectional carbon and designed to use multidirectional fiber orientation.

Figure 2-7-5. The X-29 was constructed with composite materials in the wings.
Courtesy of NASA

Section 8

Fiber Terminology

Fiber manufacturers use various terms or designations to describe their products. These characteristics include how heavy the fibers are and how they are constructed.

Fiberglass Yarn

Manufacturers use numbers about the glass fibers to designate how the yarn is made. The strand count designates how many hundreds of yards of glass strand are in a pound. The second number, often a fraction, designates the number of strands that are twisted and plied together to make up the yarn, which is then woven into a style. An example of a yarn count might be 450 1/2. This is pronounced as "four hundred fifty, one, two." The first number 450 means that the strand count of each strand is 450 × 100 yards, or 45,000 yards per pound. The 1/ indicates that there is just one strand, and the /2 indicates that two of these groups are plied together to make the final yarn. So, 1/2 indicates a yarn made of two single strands that have been twisted together to make a yarn. Manufacturers also use number designations to indicate the fabric style and weave. These are discussed later in this chapter.

Aramid (Kevlar®) Yarn

Aramid, or Kevlar, yarns are designated by the yarn denier (de). The denier is a numbering system that designates how many grams 9,000 meters of yarn weighs. Kevlar 49 yarn, which is aircraft quality, can have a designation of 1140de, which means that 9,000 meters of the Kevlar 49 yarn weighs 1,140 grams. Aramid yarns are not twisted and plied as fiberglass yarns are.

Figure 2-8-1. A bundle of carbon fiber filaments make a tow.

Carbon/Graphite Tows

Carbon/graphite yarns are designated in tows (Figure 2-8-1). A tow is a bundle of continuous carbon fiber filaments. Carbon-fiber tows are designated by the number of continuous filaments that make up the fiber bundle. A 3K tow means that 3,000 carbon fiber filaments make up the tow. Carbon fiber tows usually do not have twist.

Section 9

Fabric Styles

Materials used in aircraft construction are commonly found in three styles: a nonwoven unidirectional fabric, woven fabric, or a mat.

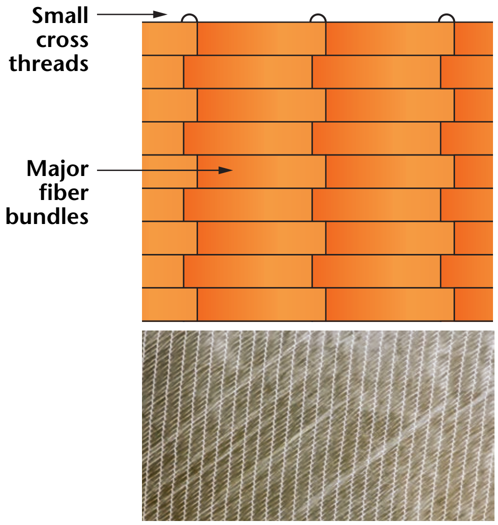


Figure 2-9-1. Unidirectional materials are constructed with the major fibers running in one, uniform direction.

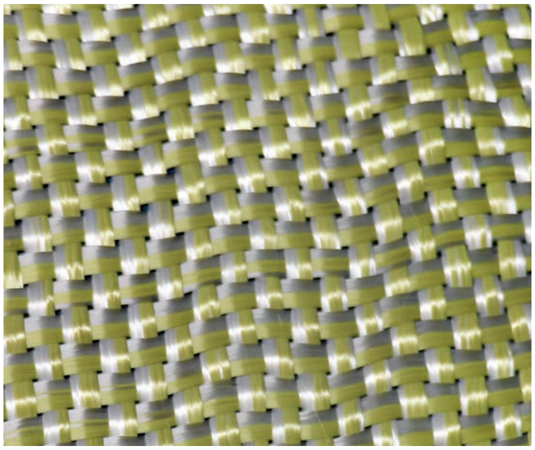


Figure 2-9-2. The major fiber bundles in bidirectional/multidirectional fabrics are woven in two or more directions. This example is a plain weave, where the warp and the fill threads alternate over one, under one.

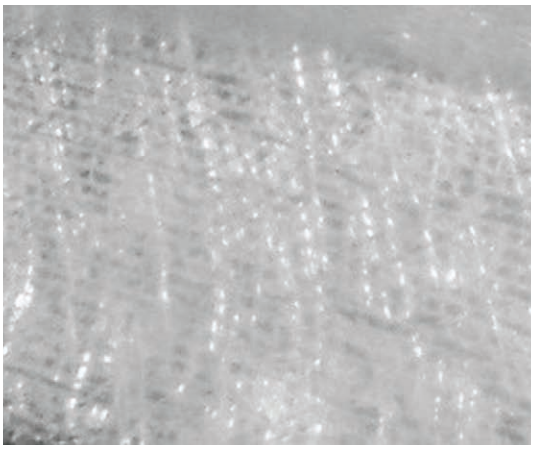


Figure 2-9-3. Matted fibers compressed together are used as a single layer to build up molds. They are typically made of fiberglass and not used for structural use.

Unidirectional Fabric

Fiber orientation in which all the major fibers run in one direction, giving strength in that direction, are known as unidirectional (Figure 2-9-1). This type of fabric is not woven together. In other words, there is no weft. Sometimes, small cross threads are used to hold the major fiber bundles in place, but they are not considered structural. Most of the time, these fabrics come in pre-preg form, and the resin/curing agent holds the fibers in place. Occasionally, you might see a strand of a different type of fiber along with the major fiber. This fiber is used to maintain the correct fiber alignment. Unidirectional fabrics can be laminated together with the fibers of each layer running in a different direction from the first layer. The component's greatest strength is parallel to the fiber direction.

Unidirectional tapes are available for repair work. They come in smaller widths and create a smoother surface. Unidirectional tapes are usually pre-preg, because unidirectional materials are difficult to saturate with resin manually. Unidirectional materials used in manufacturing are sometimes replaced with fabrics for repair work. When repairing a part, always follow the SRM.

Bidirectional or Multidirectional Fabric

This type of fiber orientation calls for fibers to run in two or more directions (bidirectional). A plain weave is common to most people, where the weave alternates one over, one under. Besides the plain weave in Figure 2-9-2, many patterns are woven together and can be seen in many different weaves. Sometimes, the warp threads have more fibers woven together than the weft, so it is important to line up the warp threads when doing a repair. In this arrangement, the fabric's warp direction is usually stronger than the fill.

Mats

Chopped fibers (usually fiberglass) that are compressed together and bound by a starch are often called mats (Figure 2-9-3). These mats typically are used to build up bulk in a mold. They are not typically used in aircraft parts, except in some older fiberglass fairings. The mat layer is usually used in combination with other woven or unidirectional layers of fabric to make the final finish smooth. A mat is not very strong, because the strands are not continuous and cannot carry the load throughout the part as in woven or unidirectional fabrics.

Section 10

Woven Fabric Weaves

Fabrics are woven together in several weaves and weights. Compared to unidirectional material, fabrics are more resistant to fiber breakout, delamination, and are more damage tolerant. Several types of fabric weaves are shown in Figure 2-10-1.

Note that the fabric weaves can be confusing. When choosing a fabric and weave to use for a repair, see the SRM. Unless you are an expert in composites, you should not be choosing the weaves yourself.

The most common weaves used in advanced composite aircraft construction are the plain and satin weaves. The plain weave (view A in Figure 2-10-1) is a simple pattern in which the warp and fill yarns alternate over and under each other. Plain weave fabrics are popular for wet lay-up because they are easy to impregnate with resin. A basket weave is a type of plain weave (view A) but with multiple yarns and thicker strands woven together as one. A 4 x 4 basket weave uses four yarns bundled together and woven with four yarns bundled together. This makes a heavier, stable fabric.

Satin weaves are very common for repair applications. They are made by floating warp yarns over several fill yarns and under one fill yarn in a repeating pattern. It is called a satin weave because it produces a satiny finish by exposing more warp threads on the front side of the fabric. Satin weave fabrics contour better around a complex curve than a plain weave fabric. The eight-harness satin weave is woven by interlacing a thread over seven threads and under one thread, as shown in Figure 2-10-1 view C. Some typical styles of fiberglass satin weaves for repair operations include the 7781, the 181, and the 1581. All have a 57 warp and 54 fill with a thickness of 0.009 inch. The difference in these fabrics is in the number of yarns used to produce the thread. The 7781 has 75 yarns warp and fill, the 1581 has 150 yarns warp and fill, and the 181 has 225 yarns warp and fill.

The four-harness satin or crowfoot weave (view B in Figure 2-10-1) interlaces a thread over three threads and then under one. The style 120 has a 60 thread warp, 58 thread fill, with 450 yarns warp and fill, and a thickness of 0.004 inch.

The style 120 for Kevlar and fiberglass, and the 3K-70-PW for carbon/graphite, are tight weaves, which makes them more resistant to moisture penetration (view A in Figure 2-10-1). Because of this, they are often found in the

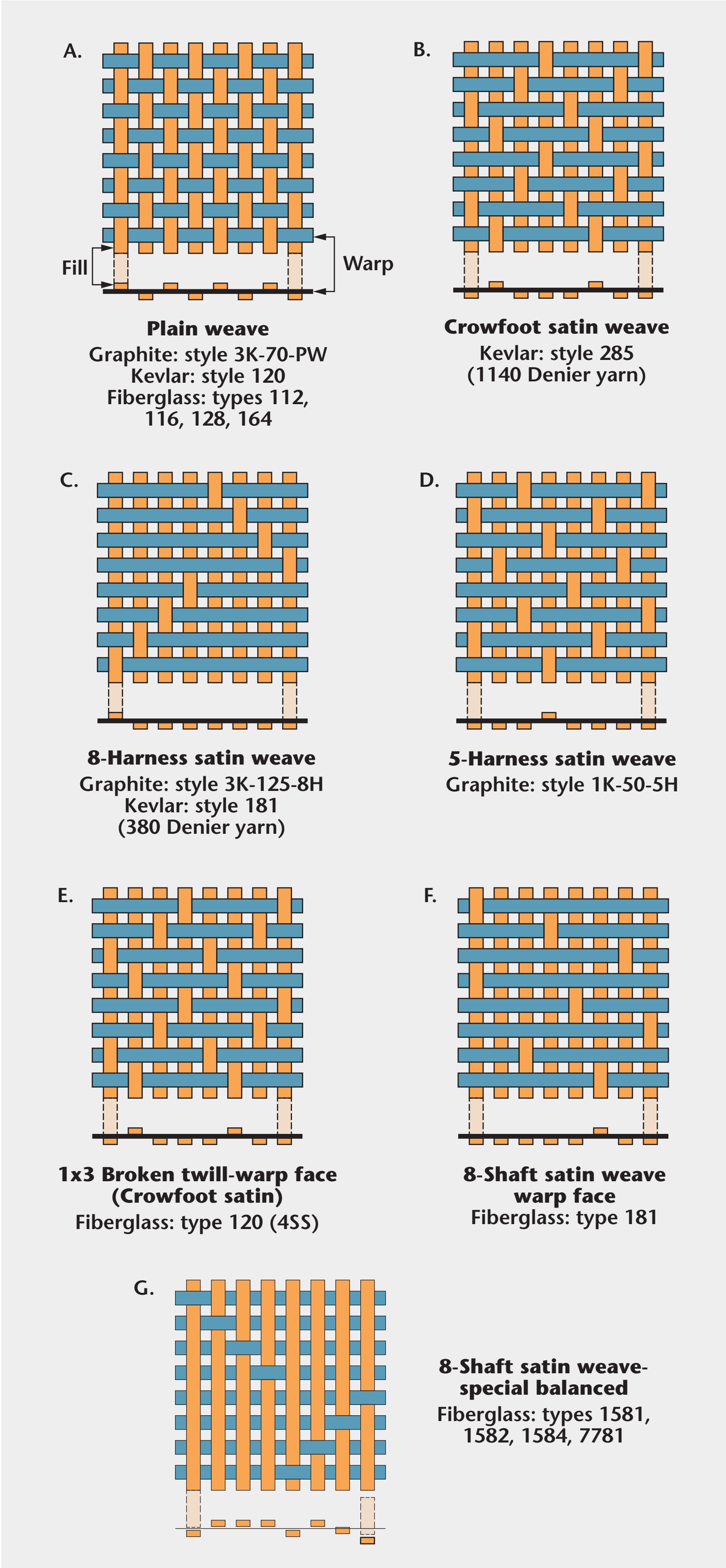


Figure 2-10-1. Each fabric is produced in different weaves to provide specific structural properties. Notice that some weaves are not over one, under one as the plain weave; instead, they go over three and under one, as in the crowfoot satin weave.

top final layer of a part, making the part more moisture resistant and with a very smooth finish. The eight harness and crowfoot satin weaves are looser weaves that drape easily around contours. When laid on the bias, they can contour around a leading edge without seams. The 1K-50-5H carbon/graphite weave (Figure 2-10-1 view D) is a thin fabric with good draping characteristics, especially when used on the bias.

Each type of material (aramid, fiberglass, carbon/graphite) is made in various weaves. Make sure you are using the correct type of material, in the proper form (bidirectional, unidirectional, mats), and in the proper weight and weave for each application. The SRM specifies these. Some common fabric styles and their data are listed in Table 2-10-1.

Fabric styles are characterized by the yarn construction, count, weight, thickness, and weave. The yarn construction is the yield or denier, twist and ply level. The count is the number of yarns per inch of width in the warp and fill directions. The fabric's weight is measured in ounces per square yard or grams per square meter. The thickness is measured in thousandths of an inch or in millimeters. The weave style is plain, satin, crowfoot, and so on.

Section 11

Finishes

Some fabrics have a finish to protect them during the weaving process or to help bond the fibers and resins together. Fabrics have different finishes. On fiberglass, the manufacturer might use a type of lubricant, called sizing, to protect the fibers during the weaving process. This is burned off, and another type of finish can be applied to the fabric. Volan and Silane finishes are common on fiberglass. Aramid does not need a lubricant during the weaving process, and it is cleaned by a process known as scouring. Scouring helps the resin flow through the fibers. No other type of finish is used with aramid, but the mechanical properties in a laminate are higher if the material has been scoured because the resin flows through the individual fibers, causing greater fiber to resin penetration. Carbon fabrics also do not have any type of finish on them. All the materials discussed here are compatible with epoxy resin systems.

Section 12

Hybrids

A manufacturer can design a part by using different types of fiber combinations (hybrid) to tailor a part for strength or to reduce cost. This can be done in several ways. The different materials are combined to give the characteristics of each different fiber. For example, aramid can be combined with carbon/graphite to produce a structure that combines the flexibility of aramid with the stiffness of carbon/graphite. Another example is a combination of aramid and fiberglass to produce a less-expensive, high-strength material. Three common types of hybrid structures are used in aviation today: intraply hybrid, interply hybrid, and selective placement.

Intraply Hybrids

Intraply hybrids use reinforcing material that is woven from two or more different fibers. The strength of the final structure can be designed

Fabric style	Weave	Weight (oz/sq yard)	Thickness (mils)	Count (warp × fill)	Yarn warp	Yarn fill
Fiberglass						
120	Crowfoot	3.2	3.5	60 × 58	450 1/2	450 1/2
7781	8-HS	.9	9.0	57 × 54	75 1/0	75 1/0
Kevlar						
120	Plain	1.7	4.5	34 × 34	195 de	195 de
285	Crowfoot	5.0	10.0	17 × 17	1,140 de	1,140 de
Carbon						
584	8-HS	10.7	13.5	24 × 24	3K	3K
Note: de = denier; HS = harness satin; K = thousands of fiber filaments making up the tow						

Table 2-10-1. The SRM often includes charts to indicate the style of fabric to use for repair work.

by adjusting the proportions of each fiber used (Figure 2-12-1).

Interply Hybrids

An *interply hybrid* uses two or more layers of different reinforcing material that are laminated together. Each layer, in addition to being a different material, can be used in the form of unidirectional or bidirectional fabric (Figure 2-12-2).

GLARE. GLARE stands for Glass Laminate Aluminum Reinforced Epoxy and is a type of interply hybrid. It was used in the 1960s to 1980s, but with the new composites available, it was not used as much. In manufacturing the A380, GLARE has resurfaced as a structural material again. S-glass is bonded to thin (0.2 mm to 0.5 mm) layers of aluminum (Figure 2-12-3). GLARE can be made with three layers of aluminum, with two layers of glass bonded between them. This thin hybrid gives the strength of 2024-T3 aluminum, without the cracking potential. The fiberglass and epoxy bonded between the layers help prevent cracks in the aluminum and combat corrosion. One of the problems with the old GLARE material is that it had to be manufactured in an autoclave. Now with resin transfer molding (see the Manufacturing chapter), it can be manufactured at a lower cost, in less time, and in larger pieces.

Selective Placement

Fibers can be selectively placed to give greater strength, more flexibility, or reduce cost. For example, the I-beam shown in Figure 2-12-4 uses carbon/graphite if stiffness is desired; fiberglass is blended in to reduce the cost of the structure.

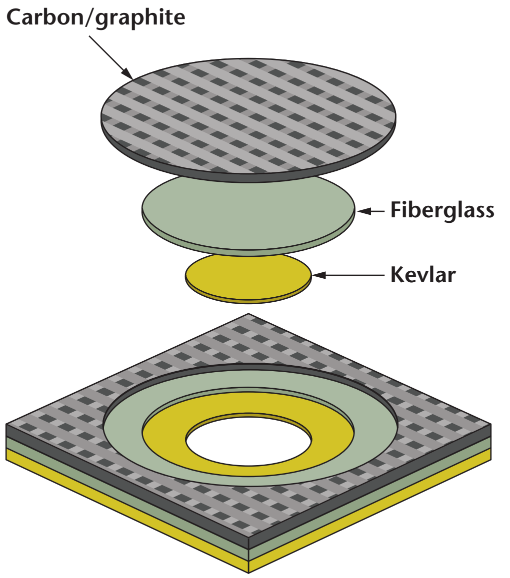


Figure 2-12-2. Interply hybrid—two or more layers of different reinforcing material that are laminated together. Each layer is a different material.

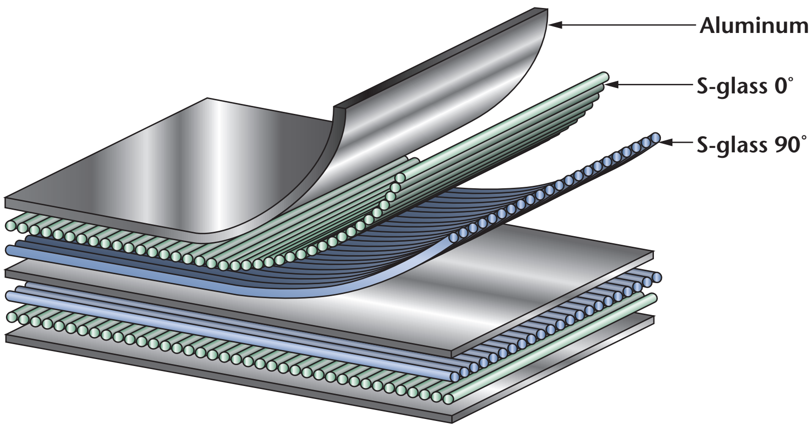


Figure 2-12-3. GLARE is made of glass between layers of aluminum.

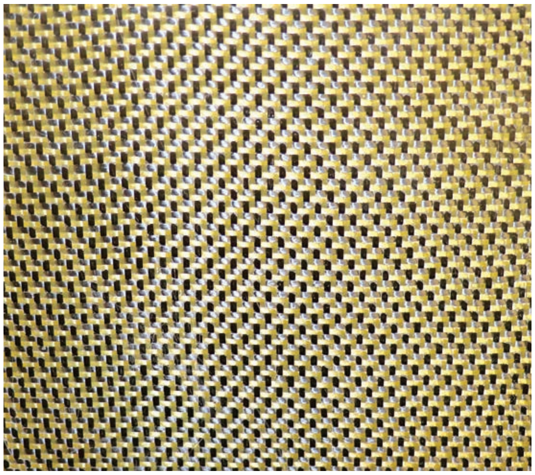


Figure 2-12-1. Intraply hybrid—two or more types of reinforcing fibers woven together to produce cloth. Here carbon is woven with aramid.

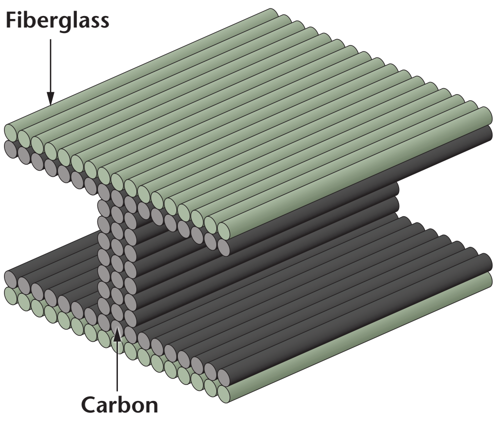
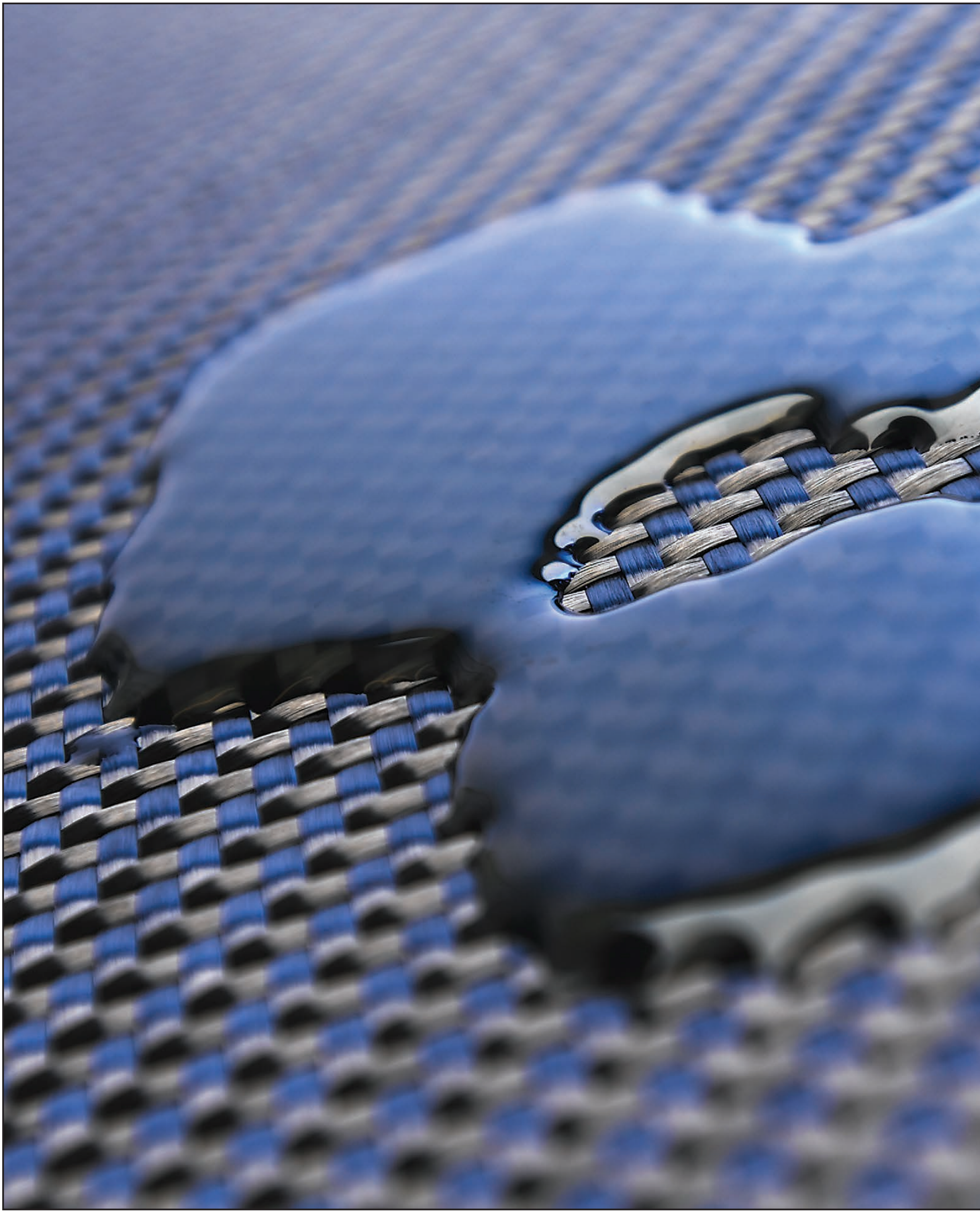
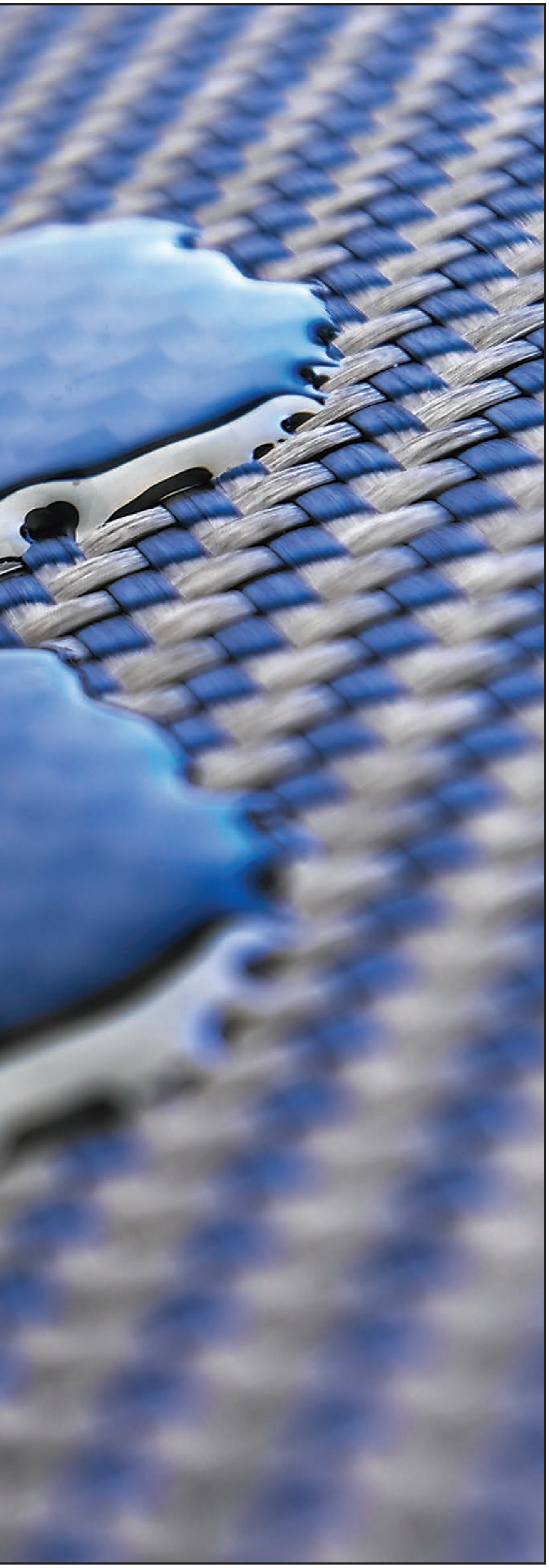


Figure 2-12-4. This I-beam uses carbon/graphite for stiffness and fiberglass for reduced cost.





Left: The matrix bonds with the fabric to produce strength characteristics in the composite that neither exhibited before combining. Courtesy Gurit, photo by Nick Cross. Creative Commons license.

3

Matrix Materials

The matrix is a bonding material that completely surrounds the fiber, giving it extra strength. The strength of a composite lies in the ability of the matrix to transfer stress to the reinforcing fibers. An advanced composite uses various manufacturing techniques and newer matrix formulas with newer reinforcing fabrics.

Polyester resin is an example of an early matrix formula used with fiberglass for making many nonstructural applications such as fairings, spinners, and trim. The old polyester/fiberglass formulas did not offer sufficient strength to be used to make primary structural members; they can be somewhat brittle. The newer matrix materials display remarkably improved stress-distributing characteristics, heat resistance, chemical resistance, and durability. Most of the newer matrix formulas for aircraft are epoxy resins.

Resin matrixes are a two-part system consisting of a resin and a catalyst, or hardener, which acts as a curing agent. The term *resin* often means both parts together, not just the resin. For simplicity, this book uses the term resin to mean both parts together. Many times a maintenance manual might use the term *catalyzed resin*, meaning that the resin and the curing agent or hardener have been mixed but not necessarily cured.

Learning Objectives

REVIEW

- Importance of the SRM

DESCRIBE

- What a matrix system is
- Why a matrix is used in composites
- What materials are used in a matrix
- Pre-pregs and their advantages and disadvantages

EXPLAIN

- How to mix a matrix
- Why adhesives are used
- Why fillers are used

APPLY

- Calculate proper parameters when working with given matrices

Section 1

Matrix Systems

Resin matrix systems are a type of plastic. Some companies refer to composites as fiber-reinforced plastics. Two general categories of plastics are made: *thermoplastic* and *thermoset.*

By themselves, these resins do not have sufficient strength for use in structural applications; however, when used as a matrix and reinforced with other materials, such as a fabric, they form the high-strength, lightweight structural composites used in aircraft today (Figure 3-1-1).

Thermoplastic

Thermoplastic resins use heat to form the part into the desired shape; one that is not necessarily permanent. If a thermoplastic is heated a second time, it flows to form another shape.

Thermoplastic resins can be found in overhead storage bins and nonstructural applications. However, with the advancements being made in composite science, thermoplastic resins are finding their way into the structural airframe applications, too. High-temperature thermoplastic resins can be used in more places. They are originally manufactured at around 750°F. These high-temperature composites can be used in normal operating environment, but the temperatures cannot exceed 750°F or the thermoplastic starts to flow again.

Thermoplastic composites are usually repaired with epoxy resins at 250°F because the underlying structure might start to flow if repaired at 750°F, damaging the structure further. Much research is occurring on expanding thermoplastics for structural use. As an aviation maintenance technician, you could be working on thermoplastic composites in the future.

Figure 3-1-1. When the resin is mixed with a catalyst or hardener, it is in a liquid form. After curing, it is a solid plastic. In composite use, the mixed resin is combined with a fiber reinforcement to form a fiber-reinforced plastic.

Thermosets

Thermosets use heat to form and set the part's shape permanently. The plastic, once cured, cannot be reformed even if it is reheated. Most modern structural airframe applications are constructed of thermoset resins.

Polyester Resin Systems

Polyester resins were developed in the 1930s by a chemist named Carleton Ellis. He patented the first process for making polyester resins in 1936. A year later, Ellis improved the basic design of polyester resin when he discovered what is still used today—combining unsaturated polyester alkyd with vinyl acetate or styrene, and curing it with a peroxide catalyst. The new formula is less viscous than the original, and it cures faster and more completely. The process for the new polyester resin system was patented in 1941.

Polyester resin was one of the core product advancements that launched the modern plastics industry. Polyester resins were first used with fiberglass to make boats. In World War II, when metal was scarce, manufacturers used other materials such as fiberglass to construct aircraft for the military.

Chemistry of Polyester Resins

The reasons for the widespread use of polyester resins are many. Polyester resins are very stable at room temperature and can be stored for years without affecting the quality of the materials. The resins cure at room temperature in just a few minutes when an inexpensive peroxide catalyst is added. Plus, no by-products are released, and the curing process actually produces additional heat, thus enhancing the curing process. Polyester resins are low cost and very versatile. They are not very resistant to alkali, however, nor are they strong enough to use as matrix material for structural components. Polyester resins will melt Styrofoam cores. Therefore, epoxy thermoset resins are more suited for use when a foam core is used.

Different curing agents can be mixed with the basic polyester resins to provide different pot life and cure times. Furthermore, accelerators combined with curing agents enhance the curing process. By varying the concentrations of the curing agent and accelerator, the rate of the cure process can be varied.

Epoxy Resin Systems

Epoxies are a type of thermosetting plastic resin well known for their outstanding adhesion, strength, and resistance to moisture and chemicals. They are useful for bonding nonporous and dissimilar materials, such as a metal part to a composite component, and can be used with all types of foam (Figure 3-1-2).

Figure 3-1-2. This cutaway of a rotor blade uses fiberglass with epoxy resin skins, bonded to a urethane core with metal bonded into the leading edge.

In 1946 an innovative company named Ciba introduced a new product at the Swiss Industries Fair called Araldite® (now a Huntsman product). This was the first formal introduction of epoxy resin to the manufacturing industry. Since then, epoxy resins have become one of the most widely used resin formulas in the world. Araldite is still widely used in manufacturing.

Epoxy resins are among the most common matrix systems used in composite fabrication and repair because of the following:

1. Epoxy resins are extremely flexible in terms of where they are applied. More specifically, they can be formulated to provide rigid or flexible strength, to perform at high or low temperatures, or to provide a combination of these characteristics.
2. Epoxy resins exhibit good adhesive characteristics when used with a broad range of cloth reinforcing materials, fillers, and substrates. They exhibit an extraordinary ability to completely wet a wide variety of materials and to adhere a variety of dissimilar materials.
3. After being cured, epoxy resins are resistant to deterioration by water, acids, bases, many chemical solvents, and ultraviolet (UV) light. They are so durable that they present a problem for disposal. It has been suggested that discarded epoxy-based composite material be ground up and mixed with asphalt to make roadways that are more durable while also using up an almost indestructible material.
4. Epoxy resins are easily cured at room temperature or at slightly elevated temperatures, and they do not require exotic equipment to process. The cure process emits no volatiles or water and represents a comparatively safe material to work with in terms of toxicity. These characteristics make epoxy material suitable for wet layup, pre-impregnating (pre-preg) fabrics or tapes, or wet filament winding.
5. Epoxy resins are very dimensionally stable—they shrink very little during the curing process and are good for use as structural parts, mold fabrication material, or tooling fabrication material. Epoxy resins are used in many instances to mold parts in mass production to very close tolerances.
6. Epoxy resins exhibit the strongest adhesive characteristics of any known polymeric material. For this reason alone, they are ideal for making lightweight structural materials for aircraft and space vehicles.
7. Although epoxy resins are initially more expensive than some other matrix material, in the long run, their superior strength, long shelf life, and ease of use make them more economical to use for fabrication and repairs than other matrix materials.

The quality of obtainable bonds depends on how joints are designed and the surfaces are prepared. They can be designed for different uses: high temperature, low temperature, rigidity, flexibility, fast cure, slow cure, or other characteristics. Each system is designed for a specific purpose. For example, a cowling might use an epoxy resin system that withstands high temperatures from the engine. The skin of an aileron might use an epoxy resin system made to withstand bending stresses, such as shown in Figure 3-1-3 of the Boeing 787 wing. Both parts are made of advanced composites, but they are used for different purposes. Both use epoxy resin systems but are very different in their chemical makeup, thus producing structures with different characteristics.

Just because it is an epoxy does not mean it is always suitable for use in all areas of the aircraft. Make sure you are using the type of epoxy resin the application calls for. For example, two-part epoxy resins are available at hardware stores. Such epoxy resins are not used on aircraft because they might not exhibit

Figure 3-1-3. The wing on a Boeing 787 uses a flexible type of epoxy resin reinforced with carbon fiber to be flexible in flight.

the strength, flexibility, or moisture resistance that is needed.

Resins can be compatible with many different curing agents, depending on the component's requirements. Many types of epoxy resins and many curing agents are made, each with its own advantages. Use the correct catalyst or curing agent and the correct resin. The most important rule a technician can follow is to use exactly the type of resin and catalyst specified in the structural repair manual (SRM).

Catalysts, hardeners, and curing agents. Catalysts are added to the resin in small amounts and initiate a reaction that causes the epoxy to polymerize or go through its chemical reaction to cure. Some epoxies can polymerize without the inclusion of the curing agent over a long time. This is why the shelf life is important. The epoxy is more rapidly cured by using the curing agent to facilitate the chemical reaction.

Figure 3-1-4. Radomes house radar equipment and are made of polybutadiene resin composites.

Another specialty type of epoxy resin use is for radomes. The curing agent is a polybutadiene mixed with the resin for making pre-preg materials for use in radomes (Figure 3-1-4). Radar system operations in aircraft and marine environments have contradictory requirements. The radome structure must be very thin to ensure the maximum efficiency of the radar. At the same time, the radome must be very strong to endure the severe impacts that occur, for example, on an aircraft during a hailstorm. The radome must be stable over a wide range of temperatures so it does not expand or contract significantly to cause mechanical problems or distort the radar signals. The radome must also be resistant to exposure to UV light and the corrosive action of water.

Section 2

Working with Resins and Catalysts

Resin and catalysts or hardeners come in many formats. When you are working with resins and catalysts or curing agents, always follow the procedures specified in the SRM. It is important to mix the resin system properly.

Improperly mixed resins do not provide adequate strength. Each part of the resin system is weighed before mixing—weigh resins out, do not mix them by volume. Always mix resin and hardener before adding any fillers.

If the resin system requires refrigerated storage, allow each part to warm up to room temperature before weighing and mixing. A cold resin is heavier than the same amount of a room temperature resin. Use a calibrated scale or balance to weigh the two parts of the resin to produce the proper mix. The scale surfaces or balance should always be clean (Figure 3-2-1).

Figure 3-2-1. Scales are used to accurately measure the mix ratio for a resin system.

Use the Exact Mixing Ratio

When working with resins and catalysts, it is important that you mix them in the proper ratios. The matrix formula for most advanced composites is very exacting. A slightly improper mix ratio can make a tremendous difference in the strength of the final composite. This mixing requirement is in the aircraft's SRM. An example specification is given in Table 3-2-1. It gives the type of resin system to be used in a specific repair area, such as resin B. In this table, resin system B is the Epon 828 resin, and the Epicure 3140 curing agent. The pot life of the mixture is 75 minutes and can be cured in either 7 days at room temperature or 90 minutes at 149°F (65°C). The mixing ratio for the B reference is 100 parts of resin to 33 parts of catalyst. This means you could measure out 100 grams of resin to 33 grams of catalyst. If less is needed, you could use 50 grams to 16.5 grams. If more is needed, use 150 grams to 49.5.

Notice in the table that the resin Epon 828 shows two different curing agents for different properties. The SRM directs you to which one to use for a repair. This table is only one example; be sure to use the correct chart in the manufacturer's SRM for the aircraft you are working on.

Mix resin systems together in a wax-free container. If you use a waxed container, the solvents in the resin and curing agents dissolve any wax on the inside of the container, causing it to be mixed in with the resin. This can cause the repair to cure incorrectly or possibly not cure at all. A thorough mixing action helps to achieve maximum strength.

Homebuilt aircraft are made with the same resin system throughout the entire aircraft. For convenience, pumps are made to dispense

		Parts by weight			Curing times	
Base resin	Curing agent	Resin	Catalyst	Pot life (min.)	Room temp.	Heated
A. Epon 828	DTA	100	10	15-30	24 hours	1 hour at 149°F (65°C)
B. Epon 828	Epicure 3140	100	33	75	7 days	90 minutes at 149°F (65°C)
C. Epocast 50A	Epocast 50/9816	100	15	50	24 hours	1 hour at 149°F (65°C)
D. Redux 410-A	Redux 410-B	100	40	60	5 days	1 hour at 248°F (120°C)

Table 3-2-1. An example resin mixing specification that might be in an SRM.

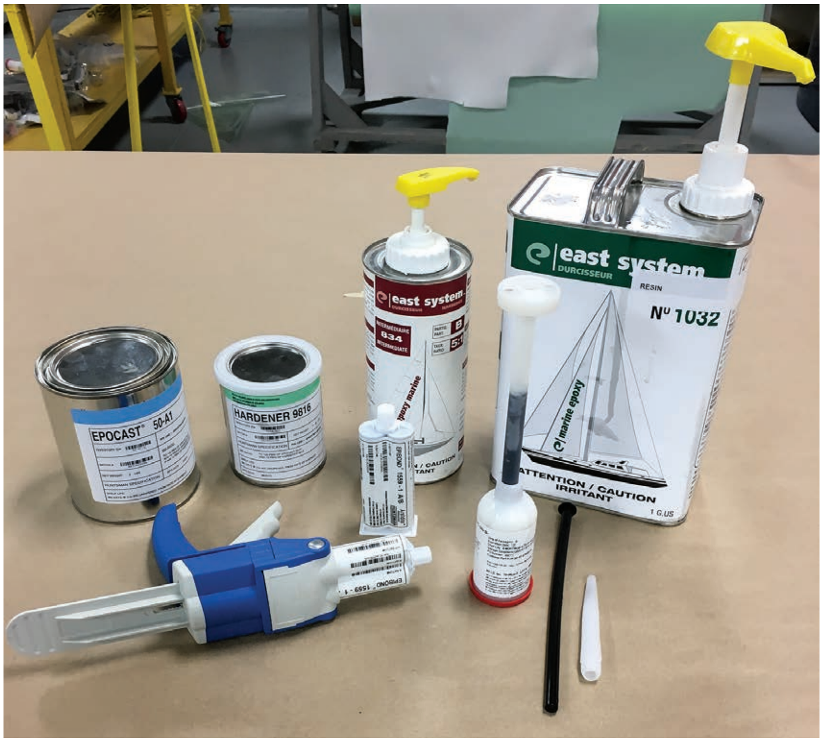


Figure 3-2-2. Resin systems can come in different types of packaging.

just the right amount of resin, and catalyst. This type of measurement is not used on production aircraft because many different types of resin are used throughout the aircraft, and the pumps dispense only one ratio.

Use the Proper Mixing Time

When working with resins, it is important that you mix them for the proper time. Three to five minutes is usually required to completely mix the components. Resins that are not mixed properly do not cure to the maximum strength obtainable. Do not mix the resins too fast. If they are mixed quickly, small bubbles could rise into the air and get on your skin or in your hair. Do not be concerned if you have bubbles in the cup because they will be worked out later in the layup with a squeegee. Vacuum bagging further ensures that no bubbles are trapped in the final composite.

Large volumes of resin and curing agent accelerate the chemical reaction. When this happens, it starts to cure in the mixing cup, possibly becoming too thick to work completely into the fabric. The pot life, or amount of time you have to work with the resins, is also reduced with large volumes. A few smaller quantity mixes are easier to work with.

An example of this is if a technician is making a homebuilt wing, and the instructions suggest mixing only 500 grams at a time. The technician knows that that is not enough to cover the whole wing, so he or she mixes an entire gallon at once. Because the amount of the mixture is so large, the chemical reaction is quick to the point of curing in the gallon container before it can be worked into the fabric. Smaller batches would have prevented this.

All resins cure by chemical reaction, but some generate their own heat, thus accelerating the cure. It is important to consider how long it will take to use the amount of resin that has been prepared. If too much is initially prepared and the work is extensive and takes a long time, you might not be able to use it all before the resin is too hard to work with.

Factors that Affect Mixing

Before mixing the resin and catalyst, you should be aware of a mixture's pot life, shelf life, and mixing ratio. These all determine whether the final composite performs as needed.

Pot Life

Before starting to work with a resin, be sure to know its *pot life*, which is the time that the resin/hardener mixture remains liquid enough to work into the fabric. The longer the pot life, the longer you have to work the resin in. Depending on the type of resin/hardener mixture, it can be as short as 10 minutes or as long as 3 hours.

Pot life is not necessarily the time it is usable in the cup. The resin and fabric should be in place before the actual curing takes place. If a resin with a short pot life is used to impregnate fabric, the patches must be in place on the surface before the resin starts to cure. If the patches are allowed to sit too long, they start their chemical reaction and become stiffer. Subsequently, when the patches are in place and vacuum bagged to cure, the chemical reaction of the resin and the fibers might not take place as it should. The patches will have cured separately and might not stick properly to each other or the part. Be sure to follow the mixing procedure correctly and use the mixture before the pot life has expired.

Shelf Life

The shelf life is the time the product is good in an unopened container. The shelf life varies by product. If the shelf life is exceeded, the resin or catalyst must be discarded because the two components do not produce the desired chemical reaction, and the cure of the part might not achieve sufficient strength. The shelf life of pre-preg materials is very important. Always dispose of expired materials properly.

Fiber-to-Resin Ratio

If too much resin is used, the part is called *resin rich*. Unlike traditional fiberglass work, advanced composite work is for structural applications. In this case, excessive resin is not desirable. This affects the strength of the composite by making the part brittle. It also adds extra weight, which is opposite of the reason for using composites in aircraft in the first place.

A resin-starved or *resin-lean* part is one in which too little resin is used, causing the part to be weak because the matrix cannot transfer the stresses to the fibers. Areas with more resin can appear glossy, and resin-lean areas have a whitish surface.

The correct amount of fiber-to-resin ratio is important to get the desired strength. In advanced composite work, a 50:50 ratio is good, but a 60:40 fiber-to-resin ratio is better. Remember, the fibers provide the strength, not the resin.

When working the resin into the fibers, be sure not to distort the weave of the fabric. If you apply too much pressure when using a brush or squeegee, the fibers could pull apart, changing the fabric's strength characteristic.

Prepackaged Mixtures

Resins and curing agents can be purchased in cans that hold the recommended amount of each component to be weighed and thoroughly mixed before use. They can also come in convenient prepackaged forms. For technicians, these packages eliminate the weighing process and expedite the repair. The packages are often designed to comply with a manufacturer's repair instructions for a certain type of repair (Figure 3-2-2). Be sure to check the cartridge part number, expiration date, and any special instructions.

The correct amount of resin and catalyst can be divided into convenient plastic packages that are divided by a clip. When ready for use, you remove the partition that separates the resin from the catalyst. Still within the package, the resin/catalyst mixture can be mixed together thoroughly. When completely mixed, the corner can be cut with scissors and the resin dispensed. This saves on weighing and handling the resins and can prevent accidents. A disposable cartridge that stores, mixes, and applies two component materials is available and convenient to use.

Figure 3-2-3. Dispensing the mixed resin through a syringe.

Cartridges come in many sizes and mixtures of resins/catalysts that can be tailored to a specific use. To use the cartridge, press a plunger that breaks the seal that separates the two components. Continue moving the plunger with twisting, up and down motions to mix the two components. The label states how many strokes are required to give a thorough mix. You can install a needle or syringe onto the end and dispense the resin through it (Figure 3-2-3).

The packages are often designed to comply with a manufacturer's repair instructions for a specific type of repair. Be sure and check the cartridge part number, expiration date, and any special instructions.

Section 3

Pre-Impregnated Materials

Materials that have the resin system already impregnated into the fabric are called *pre-pregs*, short for pre-impregnated. Because many epoxy resins are thick (i.e., have a high viscosity), it is often difficult to mix and work the resin system into the fabric and encapsulate the fibers. Pre-pregs eliminate the need for mixing, so you do not have to worry about whether the proper mix ratio was used or if you applied the proper amount of resin into the fabric.

Pre-Preg Types

Fabric

Pre-preg fabrics are manufactured by dipping the woven fabric into a resin solution. The resin solution has the proper amount of resin and curing agent weighed and mixed together. This fabric then goes onto a drying tower that removes any excess resin. Then a parting film can be added to one or both sides to prevent the fabric from sticking when rolled. Pre-pregs come on a roll that is usually refrigerated and ready to use (Figure 3-3-1). The chemical reaction of the resin/catalyst begins when the fabric reaches room temperature. Final curing does not occur until an elevated temperature is applied to the part. It usually cures at 250°F to 350°F for repairs.

Unidirectional

Pre-pregs can also be made in unidirectional material instead of a woven fabric. In such a case, the fibers come directly from spools of thread and are placed in the correct orientation. They are then heated on one surface while a paper with resin on it is applied to the other surface. The heat melts the resin from the paper and impregnates the threads. The paper and the threads are then squeezed together to impregnate the threads more thoroughly. The pre-preg is rolled and ready to be used. This material should be stored properly, because the two parts of the resin and hardener have already been mixed together (Figure 3-3-2).

Pre-Preg Characteristics

Backing

The plastic backing on the pre-preg material typically has a diamond pattern on the backside. This diamond is longer in one direction than the other. The long direction of the diamond indicates the fabric's warp. When cutting a piece from the roll and the selvage edge is not showing, you can easily see the warp direction by looking for the long diamonds on the plastic backing (Figure 3-3-3).

Pre-Preg Advantages

Pre-preg materials offer many conveniences over raw fabrics.

1. The pre-preg contains the proper amount of matrix. It does not produce a resin-rich or resin-lean component if cured properly. The pre-preg contains about 50 percent resin before curing. During the curing process, some of this resin bleeds out of the reinforcing fibers, thus producing a structure that contains about 40 percent resin and 60 percent fibers by weight.
2. The reinforcing fibers are completely encapsulated with the matrix. During

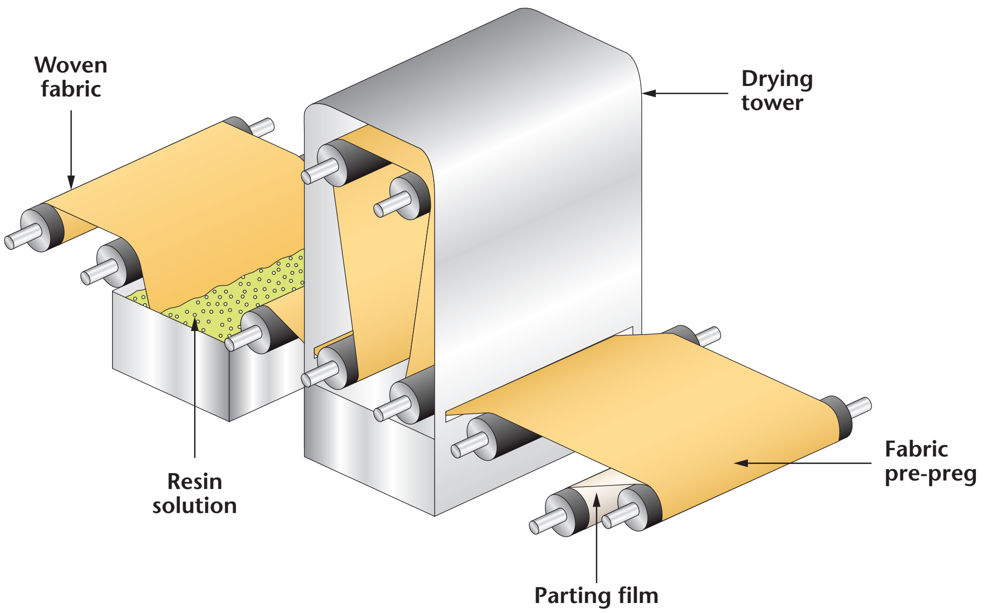


Figure 3-3-1. Pre-preg fabrics require a special manufacturing technique to ensure that the resin is mixed correctly and applied to the fabric so that the fibers are completely encapsulated. Parting film can be applied to one side or both.

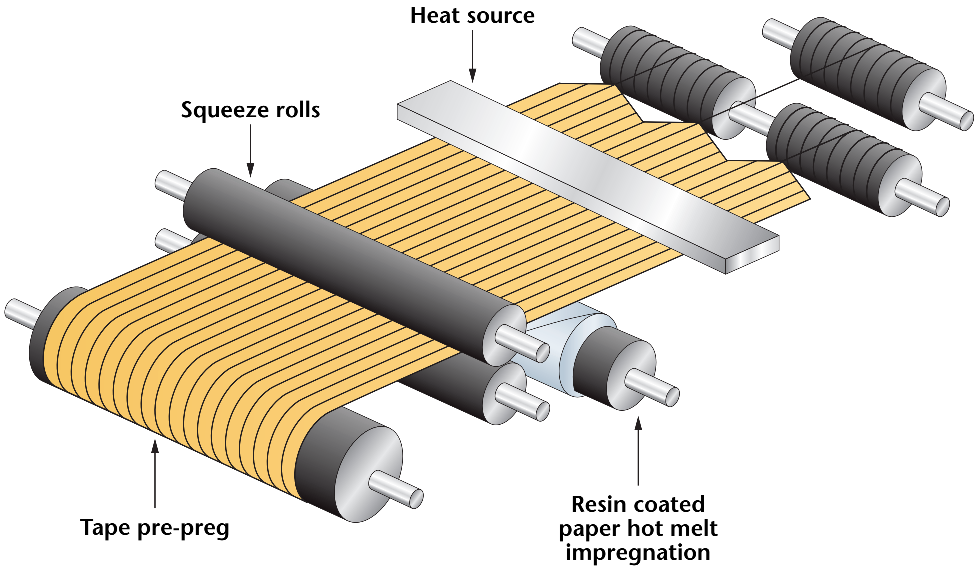


Figure 3-3-2. Unidirectional pre-preg fabric material is woven at the same time it is impregnated. The proper size and number of strands are fed from spools to form the proper width, instead of being pre-woven like fabric is.

hand layup, if a resin system is very thick, it is sometimes difficult to get the resin into and around each fiber to produce the strongest cure. This is not a problem with the pre-preg fabrics. You do not have to worry about distorting the fabric weave while working the resin into the fabric.

3. Pre-pregs eliminate the need to manually weigh and mix components. In hand layup, you must properly weigh the resin and curing agent. If they are not weighed properly, too much resin or curing agent could result in a part that does not cure properly, causing a part that is not airworthy.

4. In many cases, pre-pregs produce a stronger component or repair. This is because just the right amount of matrix-to-fabric ratio has been applied and it has been mixed properly. However, the strength of a composite repair also varies greatly depending on the how the repair is made and how it is cured.

Pre-pregs were invented for aircraft manufacturers to reduce the problems associated with completely wetting out the fabric with resin. It also saves time and reduces the problems associated with weighing and mixing the resins.

Pre-Preg Disadvantages

Pre-preg fabrics also have disadvantages:

1. The shelf life imposes limits. Most pre-pregs must be stored in a freezer. If pre-pregs are allowed to remain at room temperature for even a few hours, the resins/catalysts start their chemical reaction and begin to cure. The term *out-of-freezer life* is the time that the material is actually out of the freezer and is being cut or transported. During this time, the resins are warming up to room temperature and starting to cure. While in the freezer, this chemical reaction is slowed down to allow a longer shelf life. Pre-pregs usually

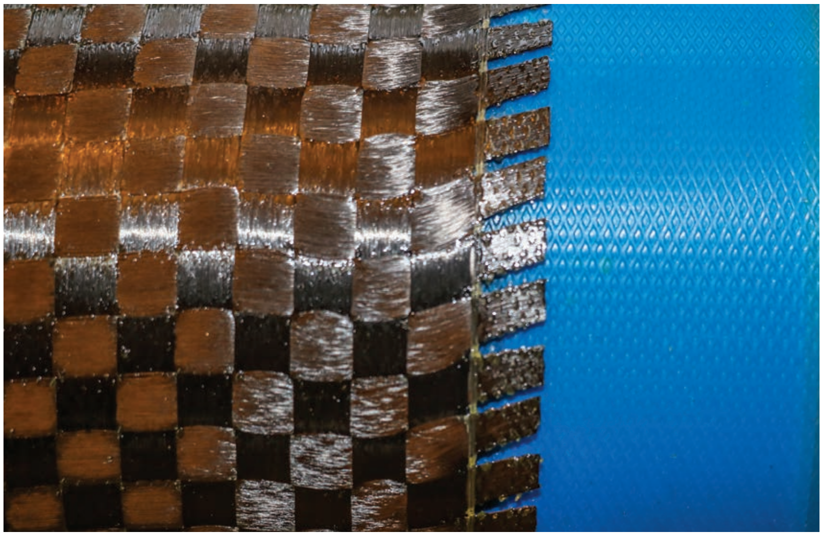


Figure 3-3-3. Pre-preg materials are pre-impregnated with resin and stored in a freezer to minimize curing. When you take a pre-preg out of the freezer, allow it to warm to room temperature before using. Note the direction of the warp threads, which are parallel to the selvage edge, and the long direction of the diamonds printed on the plastic backing, which also indicate the warp threads.

have a limited shelf life even if kept in the freezer. Some pre-pregs must also be shipped in cold storage overnight, which adds to the expense.

The amount of time out of the freezer should be carefully recorded and kept to a minimum; the allowable out-of-freezer time could be only a few hours. For example, if a roll of pre-preg fabric is taken out of the freezer to cut one yard of fabric, the time that the entire bolt of fabric is exposed to room temperature must be recorded, even if it is only 10 minutes. Each time the bolt is out of the freezer, the time must be recorded and added to the rest of the out-of-freezer time. If the manufacturer has designated a 5-hour out-of-freezer life, once the accumulated time that the material has been out of the freezer totals 5 hours, the fabric will no longer cure sufficiently in a repair to give the proper strength.

The shelf life of pre-preg materials is very important. The pre-preg material already has the resin mixed with the curing agent, and if the shelf life is exceeded, the material has gone through a chemical curing process, even in the freezer. If an overtime pre-preg material is used in the repair work, the patches will not stick to the structure or to other patches. The final cured repair could be torn off the part easily. This would be an unairworthy situation.

2. Many companies do not want to sell small quantities of a pre-preg with a specific weave and resin system, so a shop must purchase a full roll. For shops that do not work with large quantities of these materials, this is not cost effective. For example, a shop purchases a bolt of 100 yards of pre-preg with a freezer shelf life of one year. If the shop makes only a few repairs, the bolt could be only partially used before the shop must discard it at the end of that year. When the pre-preg material expires at the end of that year, it cannot be used to repair composite aircraft.
3. Pre-preg material is much more expensive than raw fabric that can be impregnated with the same type of resin system. This is especially true if the material exceeds its shelf life and must be discarded.
4. Composite components and materials have not yet been standardized. When working with metal aircraft, any manufacturer can call for 2024-T3, and you would know what type of metal to use. For composites, manufacturers use different weaves, different types of fibers, different resins, different core materials, different adhesives, and they use them in different areas of an aircraft. If you are in charge of the composite repairs to two different aircraft with composite components, you might find that the materials specified for the ailerons are completely different from a cowling. To order a whole roll of pre-preg material in one weave with one type of matrix on it would be wasteful unless many repairs are to be made on the one part that uses that type of fabric and matrix.

Using Pre-Pregs for Repairs vs. Manufacturing

A manufacturer originally makes a part using pre-preg materials and cures it at 350°F or higher for manufacturing, but substitutes a 250°F cure material for the part's repair. This is because the resin material gets brittle if it is heated to the higher temperature. This causes micro-cracking of the adjacent area to the repair.

To use the proper repair material and practice, consult the SRM, not the manufacturing materials listed in the engineering reference materials. The materials noted in the manufacturing manual for a repair might actually be the material that was used in manufacturing the aircraft, not those that are used as the repair pre-preg material.

The pre-preg system used in manufacturing could be an autoclave type of pre-preg, which means it produces a very strong, lightweight structure when cured in an autoclave. However, to repair damaged components with the same type of materials as originally used in manufacturing can lead to problems.

The autoclave cure is not used very widely in the repair procedure. Hot bond with vacuum bagging techniques are used more commonly. The resin system in these pre-pregs might not have the same strength when cured with hot bond techniques. The pre-preg materials are not experiencing as much vacuum with the hot bond as an autoclave could produce. The plies of the repair, although they are cured, can be easily peeled from the surface. This could have dangerous consequences if failure occurred in flight.

Always use the materials specified in the manufacturer's SRM and not necessarily the materials used in the original manufacturing. Wet lay-up repairs are very common to repair pre-preg manufactured parts.

Section 4
Adhesives

Resins come in different forms. Some resins are made for laminating, so they are generally thinner and can be worked into the fibers. Other resins are used for bonding and are generally known as adhesives because they stick parts together.

Adhesives are available in individual cans that are weighed and mixed together, in cartridges, or in convenient plastic bags. Two other common forms of adhesives used in composite work are film adhesives and foam adhesives.

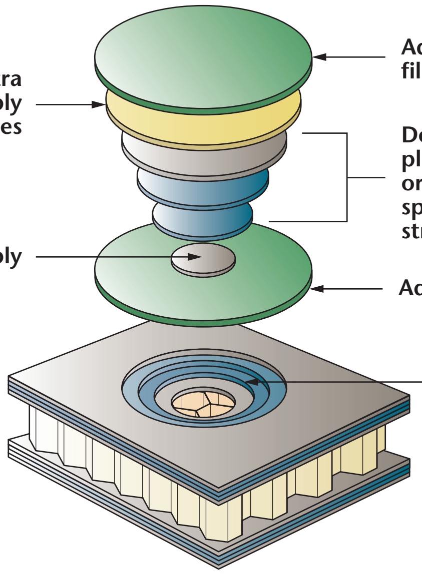


Figure 3-4-1. When performing a repair to a composite structure, an adhesive film is used with the pre-preg fabrics to help bond the patches.

Film Adhesives

One of the most unique forms of adhesive is a film. Film adhesives have both the resin and catalyst pre-blended and cast onto a thin film of plastic. The film must be stored in a freezer because at room temperature, the two parts slowly start to cure. In the freezer, the curing process is slowed down, giving the film a longer shelf life. Film adhesives are used, in many cases, to help bond a pre-preg patch to a repair area. It is sometimes used when the patch covers an exposed core area and fibers.

Film adhesives add another layer of resin so the resin in the pre-preg patches does not get wicked into the dry surrounding fibers, which could create a resin-lean repair. The film adhesive is cut to the desired shape, and placed into the repair area. Room temperature heat causes the resin and catalyst mixture to start curing, and the backing could be hard to remove. To make it easier to remove the backing, place the piece back in the freezer for a short time (15 seconds), then try to remove the plastic. The pre-preg patches are then laid over the adhesive film in the proper places, vacuum bagged, and cured with heat and pressure. The second part to be bonded is placed over the adhesive and cured with heat and pressure (Figure 3-4-1).

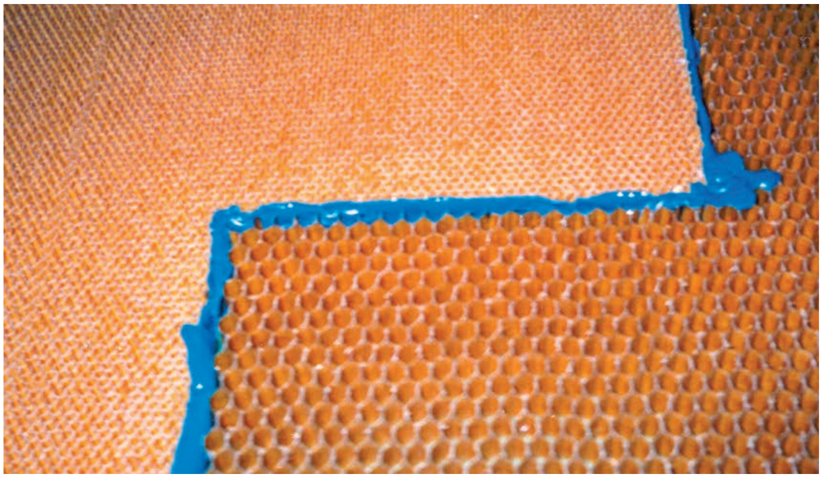


Figure 3-4-2. A foaming adhesive is placed between two types of honeycomb to bond them together. The color usually designates the foaming adhesive's curing temperature. As heat is applied, the foaming adhesive expands into the open crevices of the honeycomb.

Foaming Adhesives

Foaming adhesives are another type of bonding agent used with pre-preg materials. When heat is applied to these adhesives, they foam up and expand. These are often used to splice replacement honeycomb core segments to existing honeycomb cores (Figure 3-4-2). The foaming adhesive fills up the edges of the honeycomb, creating a larger surface area to which bonding occurs. Similarly, when installing fasteners, foaming adhesives can be used around the area of the fastener to create more area for bonding. The adhesives come either in a roll or a sheet and are stored in a freezer. These are primarily used with pre-preg repairs because they require higher temperatures to cure.

The repair is often done in two cure cycles. When replacing a core, it is wrapped with the foaming adhesive and inserted down into the routed out area, then cured. The foaming adhesive could also foam up into the crevices of the honeycomb causing the top surface to be uneven. The extra foaming adhesive is sanded off the top surface, cleaned, and pre-preg patches are placed over the core as prescribed in the SRM. The part is then vacuum bagged and cured again.

Section 5
Fillers

Fillers are materials that are added to mixed resins to control viscosity and weight, to increase pot life and strength, and to make it easier to apply the resin. When filler is used as a thixotropic agent, it increases the volume of the resin, making it less dense, less susceptible to cracking, and makes it a lighter material.

Fillers are inert and do not chemically react with the resin. Fillers are added to resin systems that have already been properly weighed and mixed together. The fillers are added as a percent of the total weight of the mixed epoxy resin and catalyst. The method by which the resin and fillers should be mixed is specified in each aircraft's SRM.

Filler material can be in the form of microballoons, chopped fibers, or flox.

Microballoons. Microballoons are small spheres of plastic or glass. If plastic spheres are used, they must be mixed with a compatible resin system that does not dissolve the plastic from which they are made. Glass microballoons are more common because the solvent action of the matrix does not affect them. Microballoons are used primarily as a thixotropic agent. Microballoons do not add strength the way chopped fibers or flox do.

Chopped fibers. Chopped fibers can also be used as a filler material. Chopped fibers can be any type of fiber cut to a certain length (one-quarter to one-half inch are common).

Flox. Flox is made of the fuzzy fibers taken from the fabric strands. As a filler, the flox is added to the mixed resin system when added strength is desired. For example, if a hole is accidentally drilled in the wrong place in a composite structure, the hole can be repaired by filling it with a mixture of resin and fibers. The mixture gives more strength than pure resin in the final repair. If the hole is filled with pure epoxy resin, it might be too brittle and add weight. Before filling any holes, consult the SRM to determine the appropriate repair for the type of part being worked on (Figure 3-5-1).

In the example of the data sheet in Figure 3-5-1, the resin and catalyst are weighed and combined at the proper ratio, mixed together, and then the glass flox is added. The note at the bottom to not mix more than 500 grams at once is given because the chemical reaction is quicker with more material and drastically reduces the pot life (working time). In this case, it would be shorter than the 30-minute pot life listed.

Section 6
Metal Matrix Composites

The matrix material in composites does not always have to be made of plastic or resin; it can be metal (Figure 3-6-1). The metal can be aluminum, titanium, or steel. The composite is formed when chopped fibers or fiber strands are mixed into the molten metal. The mixture is then formed, molded, rolled, or extruded

GLASS FLOX EPOXIDE MIX

This data sheet gives details of the mixing amounts for glass flox epoxide mixture.

MIXTURE

Epikote 162 resin — 100 parts by weight

Epikure 113 hardener — 38 parts by weight

Glass flox — 50 - 70 parts by weight depending on desired thickness.

Do not mix more than 500 gms. at once. Use within 30 minutes of mixing.

Cure time = 24 hours at 70 °F.

Figure 3-5-1. An example data sheet from an SRM.

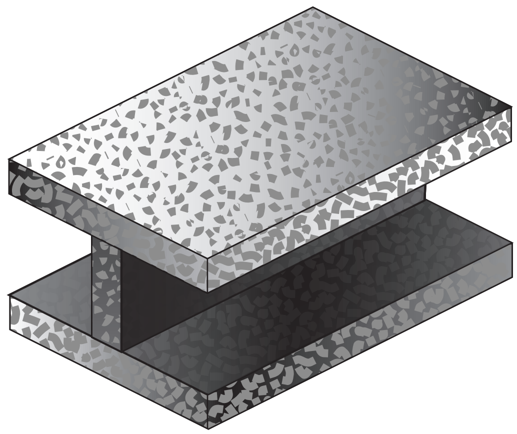


Figure 3-6-1. In a metal matrix, chopped fibers are added to a molten metal solution that is later forged or extruded.

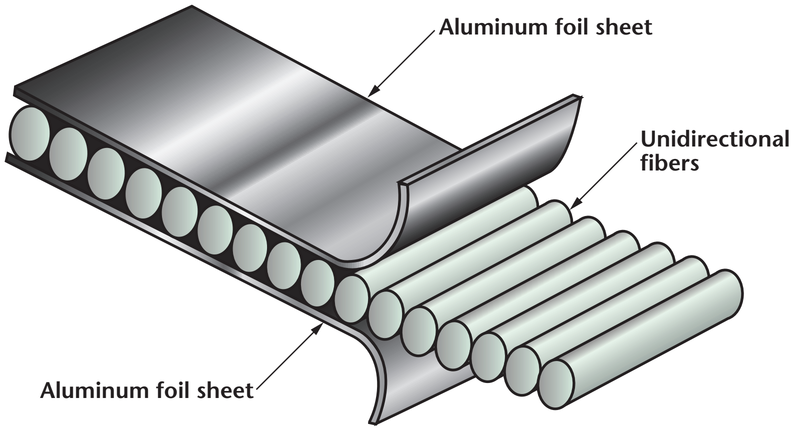


Figure 3-6-2. Thin aluminum or other metal foil compressed with fibers. These metal sheets are then rolled together in the manufacturing process to produce a lightweight composite sheet.

as usual. The fibers give extra reinforcement to the metal, lending more strength without adding weight. The fibers can dissipate heat more quickly, thus causing less wear in the part. The fibers can also make the part more flexible.

Another example of metal used with composites is with unidirectional fibers sandwiched between layers of metal foil (Figure 3-6-2). These metal sheets are then rolled together in the manufacturing process to produce a lightweight, composite sheet.

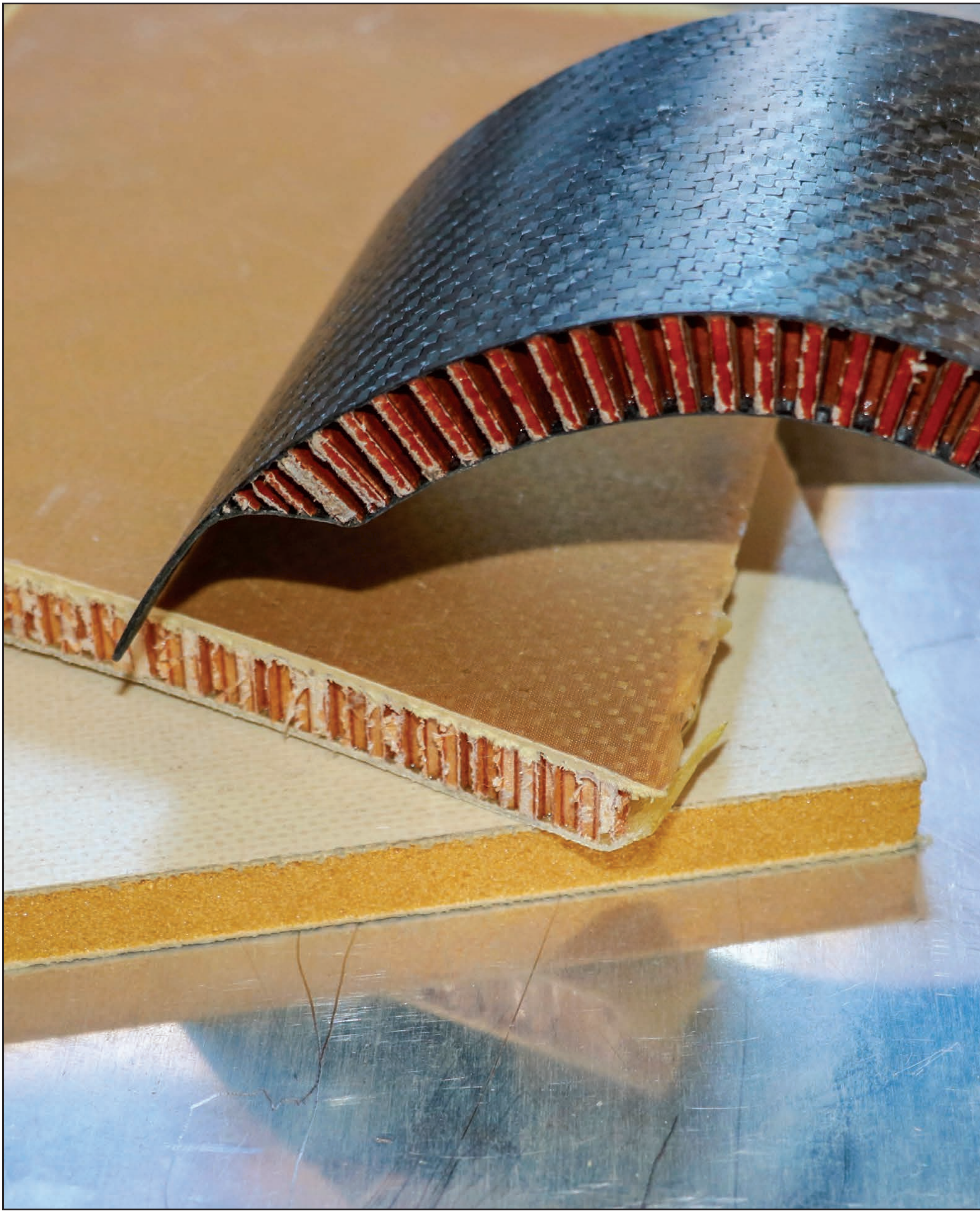
Metal matrix composites are still in the experimental stage and are not yet used in structural airframe parts. However, these structures will probably be seen in the near future. Some powerplants are being made with ceramic fibers mixed with metals. Turbine engine blades, for example, are made with ceramic fibers and metal to allow heat to dissipate quicker, which reduces the blades' elongation and distortion. On reciprocating engines, ceramics are being mixed with metals used for cylinder walls, which improves heat dissipation and reduces wear.

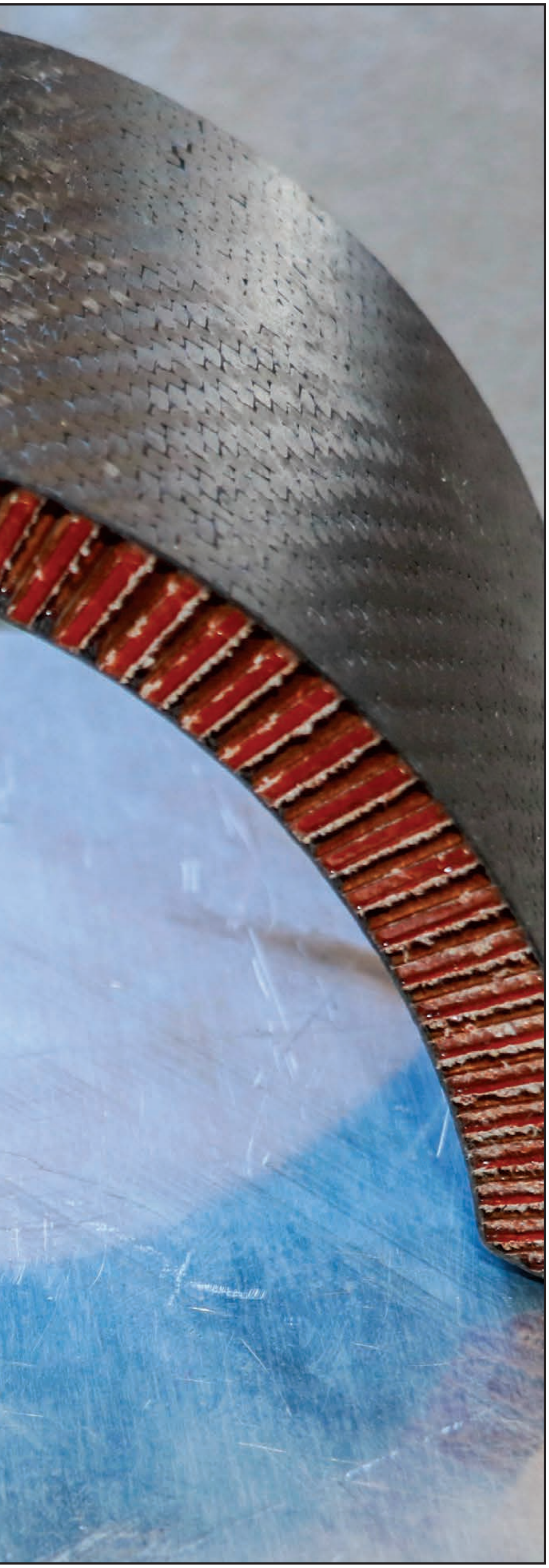
Section 7

Troubleshooting Matrix Problems

If a composite component or part does not function properly or fails early because the composite did not bond as expected, you should be aware of what could have caused the problems. The following factors can reduce the bonding of resins and parts:

- Not weighing out the resins correctly.
- Not mixing the resins thoroughly.
- Not cleaning the bonding area thoroughly. This can include sanding, removing paint, washing with an unapproved solvent, and using a dirty, oily rag to clean the part. If the part is metal, proper cleaning can involve some etching of the metal before bonding.
- Using overtime materials or leaving them outside the freezer too long, and they have lost their adhesive properties.





4

Core Materials

Section 1

Introduction to Core Materials

Core material is the central member of an advanced composite assembly. When bonded between two thin face sheets, it provides a rigid, lightweight component (Figure 4-1-1). Such composite structures are sometimes referred to as a sandwich construction. Two common core structures are honeycomb and foam.

Honeycomb has the greatest strength-to-weight ratio, but foam is usually more forgiving. If a foam core is damaged, its inherent resiliency causes it to have what is called a *memory*, which returns it to about 80 percent of its original strength. Most honeycomb cores have little resiliency.

Honeycomb cores can be rigid or flexible, depending on the cell shape. An elongated cell shape can be bent to form a part, as shown in the curved piece to the left. Aerospace-grade honeycomb can be made with aramid, Nomex®, aluminum or fiberglass, and coated with a heat-resistant phenolic resin. Foams cannot flex in this way and must be cut to fit a similar shape.

Core materials can also be made of *balsa wood* or laminations of hard wood bonded to laminates of high-strength materials. Some older composite rotor blades were manufactured this way. Balsa wood has a high aspect ratio and withstands stress when the grain is aligned in the direction of the stress.

The skins that are laminated to honeycomb, foam, and wood cores could be metal or composite skins.

Learning Objectives

REVIEW

- Types of core materials
- Core materials' benefits

DESCRIBE

- Honeycomb construction
- The types of foam core used

EXPLAIN

- How to identify a honeycomb ribbon's direction
- How to cut honeycomb core
- How to work with different foam types

APPLY

- Match a honeycomb ribbon direction to an existing part

Left: Most core materials today are foam and honeycomb. Balsa wood is still used in some situations.

Figures 4-1-1 through 4-2-2

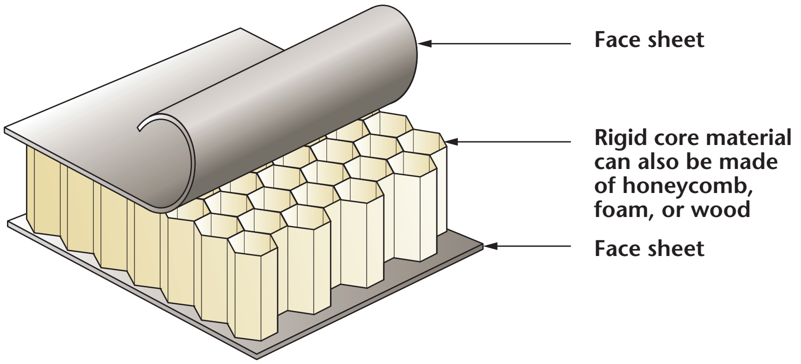


Figure 4-1-1. A core material can dramatically increase a structure's strength without adding significant weight.

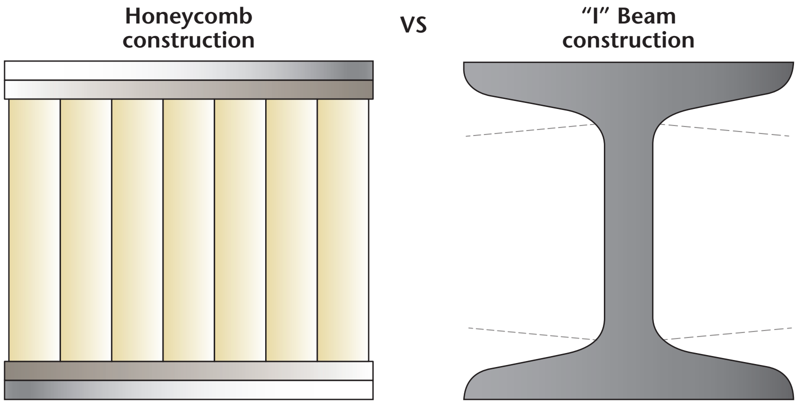


Figure 4-1-3. Bending and flexing compared for a solid core material and a spar I-beam.

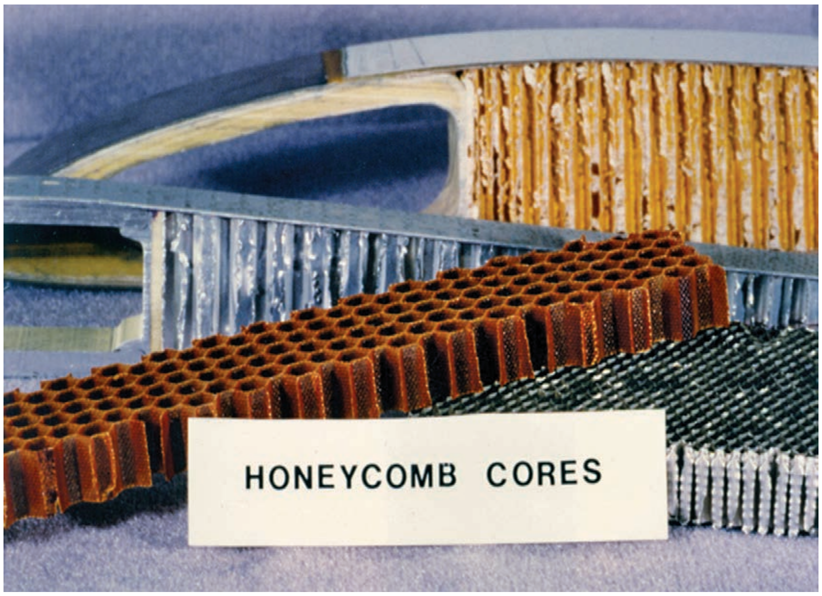


Figure 4-2-1. Typically, honeycomb cores used in aircraft construction are made of aluminum or Nomex.

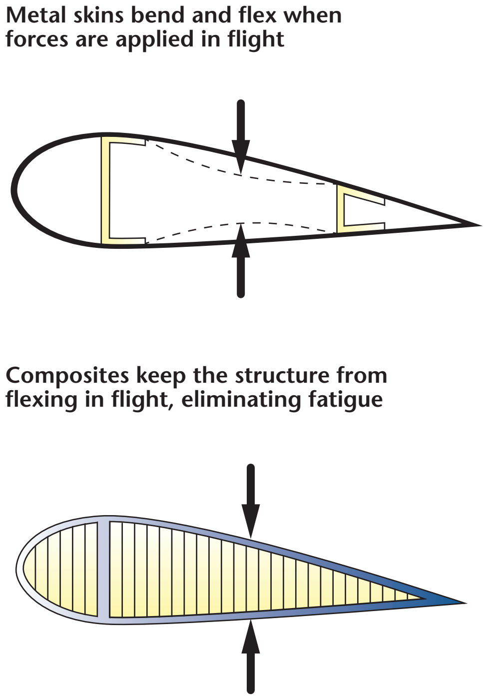


Figure 4-1-2. Stress comparisons of an aluminum (top) and solid core composite (bottom) airfoil.

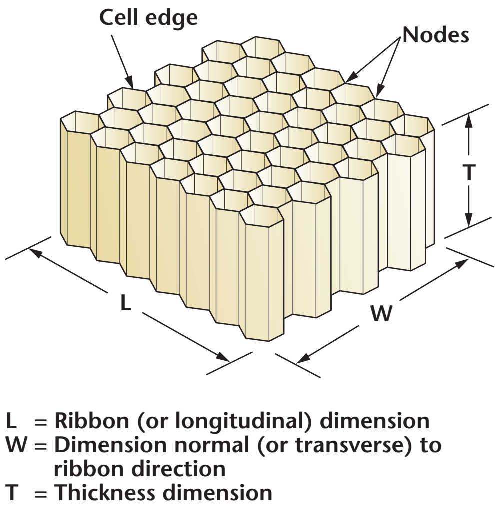


Figure 4-2-2. Honeycomb is made in a variety of core configurations, thicknesses, and densities. The ribbon direction is important to note when repairing a composite. The new core ribbon direction must be aligned with the existing ribbon direction.

The core material gives a great deal of compressive strength to a structure. For example, the sheet metal skin on a rotor blade tends to flex in flight as stress is applied (Figure 4-1-2 top). This constant flexing causes metal fatigue. A composite blade with a central foam or honeycomb core eliminates most flexing of the skin because the core is uniformly stiff throughout the blade (Figure 4-1-2 bottom).

If skins are made of sheet metal with metal ribs, the skins twist and flex where there is no support. The solid core resists the bending and flexing, greatly increasing its lifespan. The honeycomb and foam cores perform about the same. Another example is how the flanges of an I-beam spar bend and flex; however, with a solid core material, the tendency to bend is eliminated (Figure 4-1-3).

Section 2

Honeycomb Cores

A honeycomb type of core structure has the shape of natural honeycomb cells and has a very high strength-to-weight ratio. Honeycomb cores, when used in sandwich core construction, have a high strength-to-weight ratio, a high compression strength, a uniform distribution of stress, rigidity, thermal and acoustical insulation, and are fire resistant.

Honeycomb core can be made of aluminum, Kevlar®, carbon, fiberglass, paper, Nomex, or steel. The most common types of honeycomb used in aviation manufacturing are aluminum and Nomex. Nomex, manufactured by DuPont, is widely used as an advanced composite core material. Aluminum honeycomb, which might or might not be considered a composite by the manufacturer, is usually found with aluminum skins (Figure 4-2-1).

Honeycomb Construction

Honeycomb cores are made by crimping the core material into place. The pattern has what is known as a ribbon direction (Figures 4-2-2 and 4-2-3). The ribbon direction can be found by attempting to tear along one side of the honeycomb. If you are tearing in the ribbon direction, the honeycomb separates into strands, and the direction of the tear is parallel to the direction of the ribbon. The honeycomb does not tear except in the ribbon direction. When doing a repair, it is important to line up the ribbon direction of the replacement honeycomb core with the ribbon direction of the original part.

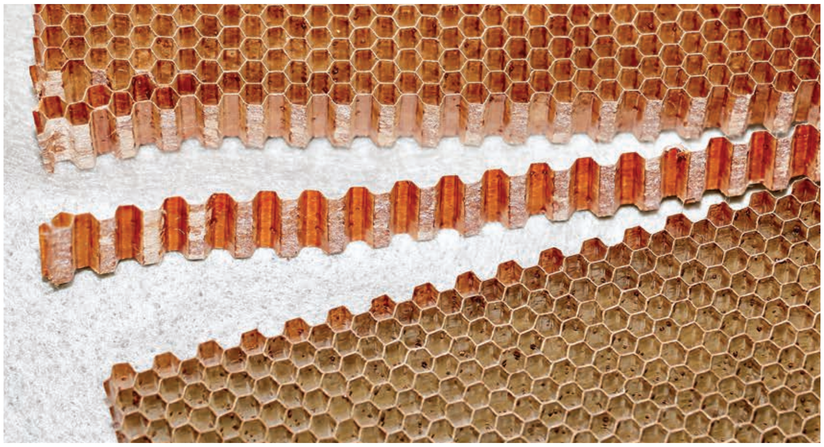


Figure 4-2-3. A traditional honeycomb cell shape with a tear along the ribbon direction. In the middle is a single ribbon.

Honeycomb Repairs

When using honeycomb for a repair, the same type of honeycomb that was used in the original structure should be used for the replacement material. Identify the honeycomb by the type (aluminum, Nomex) in a certain grade (aerospace), cell size in inches (1/16, 1/8), the density in pounds per cubic foot (2.0, 3.0), the thickness in inches (1/2, 1), and the cell shape (hexagon, overexpanded). The aircraft's structural repair manual should specify these under the types of materials to be used for a repair.

Cell Shape

Different cell shapes are used in honeycomb, although the hexagon shape is the most common for flat or slightly curved areas. An overexpanded cell shape (Figure 4-2-4) is longer on one side of the cell and is used to bend around single curves. A cell that has a hat shape is used when the material is to be formed around compound curves. To maintain the component strength, always use the correct type of honeycomb cell shape in the repair.

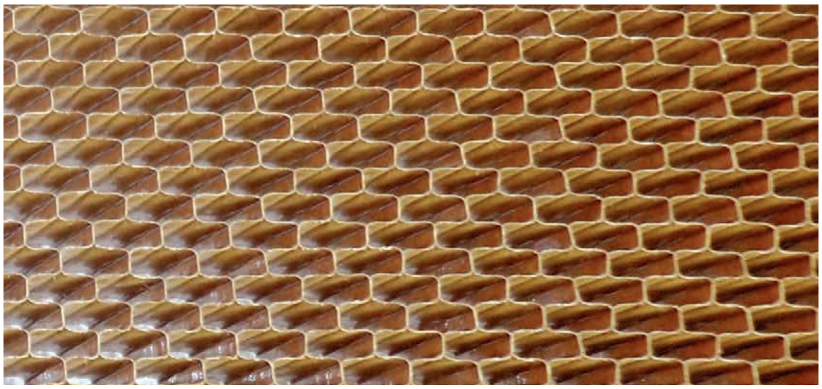


Figure 4-2-4. Overexpanded honeycomb is used where the honeycomb needs to bend around a curve, as in a leading edge.

Working with Honeycomb

Honeycomb tends to bend and flex when it is being cut. To keep it stiff for cutting, wrap a piece of masking tape around the cutting area. If you need to shape a thicker piece down to a taper, for a trailing edge for example, place the honeycomb in a container filled with water and freeze it. Next, take the iced honeycomb out of the container and cut it on a band saw. The ice holds the honeycomb rigid while cutting the shape. After the piece is cut, melt off the ice and completely dry the core before using it in the repair.

Honeycomb can be joined together with a foam adhesive, usually in the form of a tape. The foam adhesive is laid between the parts to be joined and heated to cure. During the curing process, the foam expands into the crevices of the honeycomb core.

Section 3

Foam Cores

Many types of foams are available for making an advanced composite core, depending on the application. Foams with different densities and types are used for high-temperature applications, fire resistance, repair, structural applications, and so on. When using foams in a repair operation, it is important to use the proper type and density (Figure 4-3-1). Even though they are easily shaped, foams can provide much greater strength and stiffness than plain laminates.

Figure 4-3-1. Foam cores for sandwich construction can be Styrofoam, urethane, polyvinyl chloride, or Strux (cellulose acetate).

Figure 4-3-2 illustrates the advantages of a sandwich structure. Compare the four layers of solid fiberglass laminate to a foam core sandwich structure that is four times as thick. This part has two layers of fiberglass on top and two layers of fiberglass on the bottom of the foam. The part becomes 37 times stiffer than the laminate and 10 times stronger, with only a 6 percent increase in weight. This is not a great amount of added weight in exchange for the amount of strength and stiffness gained by using the foam core.

Styrofoam

Styrofoam®, or extruded polystyrene foam (XPS), is commonly used in homebuilt aircraft and should be used only with epoxy resin. Polyester resin dissolves the Styrofoam.

Aircraft-quality Styrofoam is not the same as the type used to make Styrofoam cups. The Styrofoam used in cups has a large cell configuration and cannot be used for structural applications. This is known as a closed cell and cannot be wire cut with the same smoothness as an open cell. The type of Styrofoam used to make aircraft components is much stronger and is known as open cell.

To form a shape, Styrofoam can be cut with a hot wire cutter, a tool that uses a heated wire to cut material. The tool is typically homemade and used in constructing homebuilt aircraft. To make a cut, attach a template to each end of the foam stock. The wire is then heated and run around the template (Figure 4-3-3). Because the wire is held against the template, hot wire cutting is ideal for making smooth, curved surfaces.

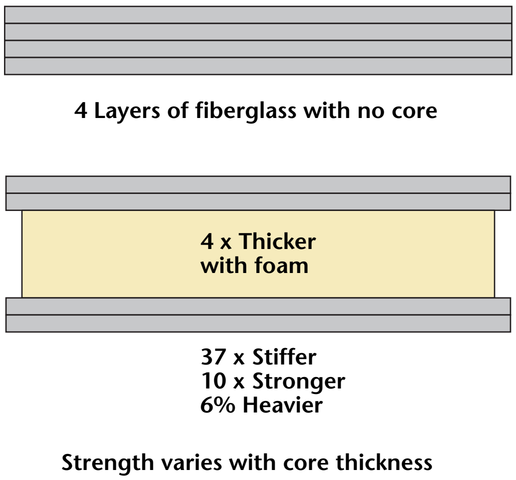


Figure 4-3-2. Strength-to-weight advantages of sandwich construction.

Polyurethane and Polyvinyl Chloride (PVC) Foams

In the past, polyurethane was used for structural applications, but problems existed. They are now technically a combination of polyvinyl chloride (PVC) and polyurethane, and are referred to as PVC foams. These newer types of closed-cell foams have a good resistance to water absorption, are chemical resistant, and are made with special fire retardants.

Polyurethane foam (Figure 4-3-4) can be used with either epoxy or polyester resin. The older polyurethane cannot be cut with a hot wire cutter in the way Styrofoam is cut because when urethane is subjected to high temperatures, it creates a hazardous gas. Instead of using a hot wire cutter, urethane can be cut with common tools. Knives can be used to get the rough shape, which can then be sanded with another piece of foam to the desired size and shape.

PVC foam is used with either polyester or epoxy resins. It is safe to cut this material with a hot wire cutter. PVC is found throughout the aircraft, including interiors. PVC can be used in nonstructural parts. Aircraft interiors, cabin sidewalls, luggage bins, and seat shells are some of the components often manufactured by PVC foam. Typical PVC products include the Herex®, Divinycell®, Klegecell®, and Termanto® and are used for some structural applications and interiors.

PMI and SAN Foams

Newer foams like polymethacrylimide (PMI) foams have the highest overall strength and stiffnesses of foam cores. PMI foams are a closed-cell structure with a high fatigue life, and they can be cured and used at elevated temperatures. Because they do not need to be coated with resin before manufacturing with pre-pregs, the cost to manufacture with them is less than with polyurethane foams. ROHACELL® is a PMI foam used for its strength and stability, for high-performance components such as helicopter rotor blades, control surfaces, and pressure bulkheads.

Styrene acrylonitrile (SAN) foams behave in a similar way to toughened, cross-linked PVC foams. They have most of the properties of PVC cores but are considered tougher and able to absorb impacts that would fracture some PVC cores. The SAN foams have a higher temperature performance and can be manufactured with higher temperature pre-pregs.

ROHACELL HERO is a SAN foam that is lightweight, durable, and less expensive to produce, making it desirable for manufacturers.

Figure 4-3-3. Using a hot wire cutter around a template to shape Styrofoam.

Figure 4-3-4. Polyurethane foam cores used with fiberglass skins shown in a cross section of Bell 49 helicopter blades.

Sandwich panels made with ROHACELL HERO cores are easier to detect impact damage visibly in aircraft inspections. The damage does not propagate out from the impact area, making the repair easier. Water cannot penetrate the foam, which is advantageous over honeycomb structures. It can also be cured at a higher temperature.

It is being used in structures for aircraft wings, landing gear doors, radomes, vertical and horizontal stabilizers, ailerons, and other areas subject to surface impact damage. When repairing foam cores, always use the type and density of foam that is required by the structural repair manual.

5

Composite Manufacturing

This chapter on composite manufacturing techniques is not a comprehensive treatment of the subject. Many books are available on the subject of composite manufacturing and engineering. Here, we cover basic information on composite manufacturing so that when a repair is needed, you can use some of the same techniques to restore a good measure of the original structural integrity.

From the manufacturers' perspective, composites represent cost effectiveness. Many case histories show an average 20 percent cost reduction when composite assemblies are used to replace a metal counterpart. The key word in this comparison is *assemblies*.

Three primary factors are considered when analyzing manufacturing costs:

- Materials costs
- Fabrication time
- Assembly time

Advanced composite materials cost five to ten times more than aluminum. Fabrication time—the time required to form the final shape—is about the same for aluminum and composites. In some cases, composites require more fabrication time.

Another large difference between composites and aluminum is the assembly time. Composite structures can be made into very complicated shapes. Consequently, stiffeners, ribs, lugs, beams, and such can be molded together as part of the fabrication process. Although this can lengthen the fabrication time, it almost eliminates the assembly time. Because assembly time typically is four to five times more with aluminum fabrication time, the net result is a major savings in time. In addition, an

Learning Objectives

REVIEW

- Roles of heat and pressure in manufacturing with composites

DESCRIBE

- Methods used to manufacture with composites
- Steps for molding a new part
- Steps for making a mold of an existing part
- Role of vacuum in various manufacturing processes

EXPLAIN

- Coefficient of thermal expansion

APPLY

- Identify lightning protection used in a part

Left: Airbus A310 vertical stabilizer being manufactured using filament winding equipment.
Photo by W. Schroll; courtesy of Airbus.

integrated fabrication requires substantially fewer fasteners such as rivets, nuts and bolts than the assembled aluminum counterpart.

The same characteristics that make composites advantageous to use in manufacturing also require a more precise repair procedure when they are damaged. A part that is made of many metal subassemblies, such as a wing, can be repaired by removing and replacing discrete subassemblies such as skin panels and ribs. Because the composite counterpart can be molded as a single unit, with few or no subassemblies, damage must be corrected with a true repair rather than replacing subassemblies.

Composites are becoming more cost effective as the materials and manufacturing technologies mature.

When designing with composite materials, the weight savings are the primary pursuit. However, the composites also lend themselves well to forming complex, aerodynamically contoured shapes. The parts do not have to be flat but can be smooth, sweeping contours that would be difficult and expensive to fabricate from sheet metal, but not from composite materials.

Section 1

Heat and Pressure

Most manufacturers of composite structures augment the strength of the finished product by applying heat and pressure to the matrix/fiber mix as it cures. This does the following:

1. The heat and pressure help ensure that the fiber material is completely saturated.

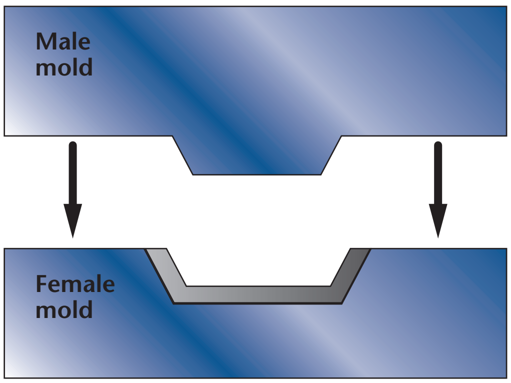


Figure 5-2-1. Compression molding is normally used to manufacture many precision formed parts.

2. The pressure squeezes out excess resin from the reinforcing fibers so that a more even blend of fiber and matrix is produced.
3. The pressure eliminates air pockets between fabric layers or in the matrix. In the past, high-quality parts were made by laying up the fibers into a mold, vacuum bagging the mold, then applying additional pressure in an autoclave. Today, out-of-autoclave (OOA) manufacturing is being used very successfully and could become the standard in the future.
4. The heat accelerates the matrix curing process. In some cases, a high temperature is required to effect a cure of the matrix formula.

Section 2

Manufacturing Methods

Compression Molding

Compression molding is a manufacturing process that uses a male and female mold. The reinforcement fabric is wetted with a matrix or a preimpregnated (pre-preg) material. It is laid into a female mold and a male mold is used to form the shape of the part. If a core material is used, the fabric is wrapped around the core of the desired shape. Again, the two sides of the molds are used to apply pressure and give the part its final shape (Figure 5-2-1).

The component cures when the molds are heated to a set temperature for a specified time. Two commonly used heating methods with compression molding are by circulating heated oil through the mold or using electric filaments that are imbedded into the mold. Another option is to place the entire mold assembly into an oven. The objective is to

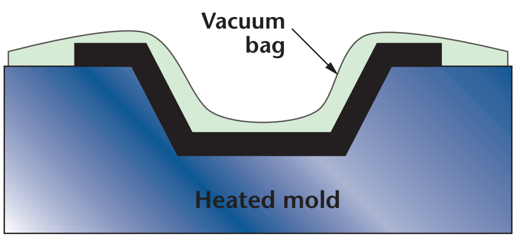


Figure 5-2-2. Vacuum bag molding can apply pressure to both very large and very complicated shapes. It is used in both manufacturing and repairing composites.

apply evenly distributed and carefully controlled heat.

Because composites start out as reinforcing fibers (cloth) and a liquid (uncured matrix material), the only limitations on the shape of a molded component are the limitations associated with the mold itself. Once a mold has been made, it can be reused to economically produce many precision-formed parts.

Vacuum Bagging

With vacuum bagging, the object that is to be cured is placed into a mold, with a plastic covering over the part (Figure 5-2-2). The air is then withdrawn by using a vacuum source and creating a vacuum against the part. When the air is evacuated, pressure is applied to the component by the surrounding atmosphere. A good vacuum source for composites pulls about 28 inches of mercury (in. Hg) at sea level, which results in nearly 14 pounds per square inch pressure being applied to the surface.

The vacuum bag technique can be used in combination with molds, wet layup, filament winding, resin transfer molding and autoclave curing (Figure 5-2-3). This method applies a very uniform pressure to somewhat complicated shapes and can accommodate moderately large objects. Vacuum bagging is the most commonly used method to apply pressure for composite repairs. Chapter 7 fully describes the vacuum bagging process and materials.

Both compression molding and vacuum molding have the advantage of distributing the matrix evenly throughout the reinforcement. This helps to eliminate air bubbles and results in a seamless structure. It is easier to fabricate and is usually stronger than a metallic counterpart.

Filament Winding

Another manufacturing method that produces incredibly strong structures is filament winding. Filament winding is widely used because of the manufacturing benefits of low-cost materials, accuracy, automation, and repeatability. In filament winding, the reinforcing fiber is wound as a continuous thread around a mandrel of the desired shape (Figure 5-2-4).

To provide the precision required in placing this thread, a filament winding machine or robot is used. Some filament wound parts use pre-preg threads, and others dip the threads into a resin bath and use a drying area to dry off extra resin. Once the filament has been

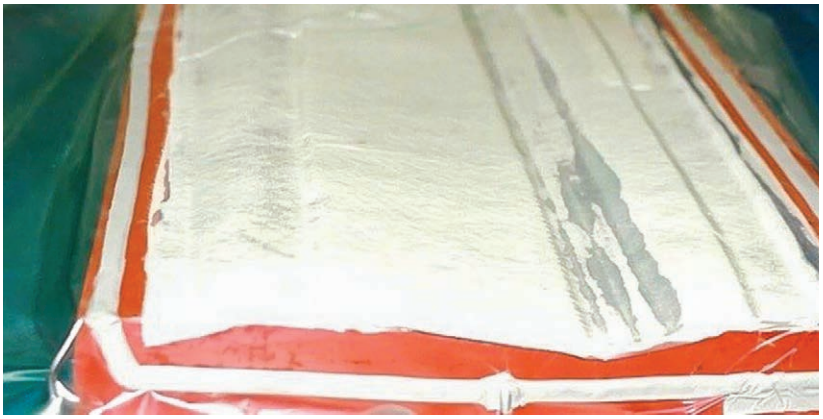


Figure 5-2-3. The part is vacuum bagged into the mold (red component) and cured.

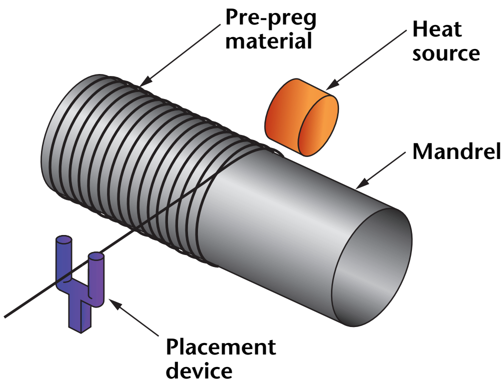


Figure 5-2-4. When performing basic filament winding, the placement device goes back and forth as the mandrel turns.

wound in the desired pattern, the composite mixture is cured. The part is usually vacuum bagged and cured in an autoclave to further compact the fibers. After the cure, the mandrel can stay in place, or it can be washed out using a solvent wash or with a mandrel extractor. Sometimes the fabric is wrapped around the mandrel dry, with no resin on it. It is then used as a base for another form of manufacturing such as resin transfer molding (RTM).

The filament winding manufacturing method has been used to produce some of the strongest composite structures known. It is used in making helicopter rotor blades, propellers, and even an entire fuselage.

Very few repairs have been approved for use on filament-wound parts. This is because if the damage is a dent and a few of the filament strands are broken, the repair should not be cut out. Sanding the layers out, as done on most repairs, cuts through more of the continuous fibers, which weakens the structure more after the repair than it was with the dent or damage.

Fiber Placement and Tape Laying

Fiber placement and tape laying is an automated process in which tapes (unidirectional pre-pregs) are laid over a mandrel and compressed into place. The difference between this and the filament winding process is that the tapes can be cut at the ends, and very intricate shapes can be formed. This can be a very expensive manufacturing process.

Resin Transfer Molding (RTM)

RTM is a manufacturing method that uses a two-part mold with the dry fabric laid into the mold. The two molds are matched together, and a system of resin and catalyst is pumped into the mold through injection ports. The resin follows a path through the mold. The part inside the mold can be heated and cured. The major advantage to this process is in the time savings over hand layup because of the layup and vacuum bagging time. RTM fabrications do not need to be autoclaved to cure. The major cost of this type of manufacturing method is in the molds. They can be quite intricate and, unless used many times, they might not be very cost effective.

The resins used in the RTM process must have a very low viscosity. New advancements have been made in RTM applications. These include the resin and curing agent premixed, and this is called a one-part system.

Out of Autoclave (OOA)

Composite manufacturers have been searching for an alternative to autoclave curing and have a few new innovations. The OOA methods use less energy, have shorter cycle times, and have less equipment investments, thus lowering the cost of the part. One of the problems that has been encountered is that it is difficult to control the amount of trapped air and moisture in the vacuumed part.

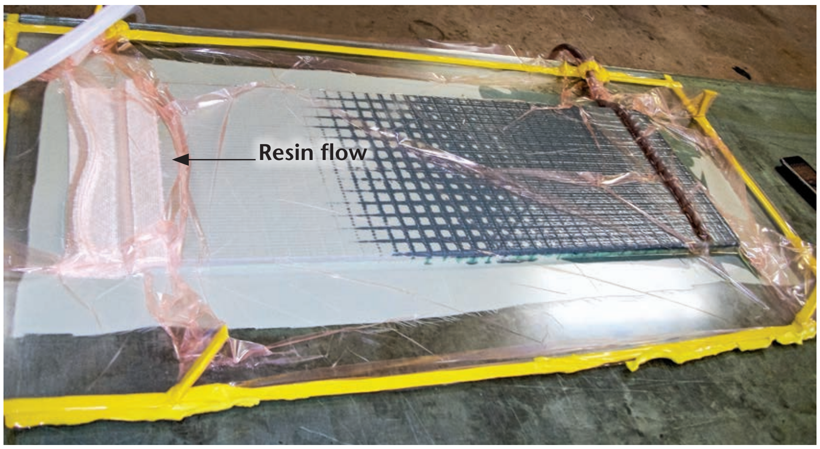


Figure 5-2-5. A panel manufactured by vacuum resin infusion. The vacuum bagged component incorporates vacuum lines that draw the resin throughout the part. The type of resin used is a room-temperature cure that also creates its own heat by means of chemical reaction.

Vacuum Resin Infusion

Vacuum resin infusion is a process that produces parts OOA and without an oven. The panel shown in Figure 5-2-5 is made of two layers of fiberglass on top and two on bottom with a foam core. The vacuum is applied on the left, and resin is flowing from the right to the left. The foam facilitates the resin flow with channels and holes. Very large components can be made efficiently with vacuum infusion.

The part can be made to include spars and cores so they do not have to be bonded on later. The spar is usually a foam that sits at a 90° angle to the part (Figure 5-2-6).

With vacuum resin infusion, layers of dry fabric are laid into a mold with peel ply and a plastic mesh, which is applied to help the resin flow. The entire mold is vacuum bagged. Bleeder is not used, because the excess resin should flow to dry areas of the part. A vacuum pot is attached to the main vacuum source to hold vacuum pressure. Vacuum lines are attached to the pot. When the vacuum source is turned on, vacuum pulls air from the part. To evacuate all the excess air and air pockets between the layers of fabric, the vacuum is usually held for at least 20 minutes before the resin is introduced. This is referred to as debulking (Figure 5-2-7).

Next, a very low-viscosity (very thin) resin/catalyst mixture is drawn into the part by the vacuum, wetting out the fibers, and surrounding any cores until the fabric is totally encapsulated. Excess resin flows into the vacuum pot which is a resin trap, protecting the vacuum source.

Depending on the type of resin used, it can generate its own heat by exothermic reaction to cure, or it can be moved into a heated area to accelerate the curing.

Newly developed pre-pregs that have a higher flow resin system and a longer out-of-storage life are being used for vacuum infusion molding. Such pre-pregs enable the parts to be debulked (vacuum bagged for long times to evacuate the air) and then cured with the higher flow resin systems so that fewer voids are possible. The pre-pregs can be used with filament winding, or woven and placed into molds, vacuum bagged, and cured in an oven.

Figure 5-2-6. Fabric is laid into the mold, a 6-in. spar is placed at a 90° angle, followed by the final layers of fabric over the entire structure. Peel ply is draped over the entire structure. This part will be vacuum bagged.

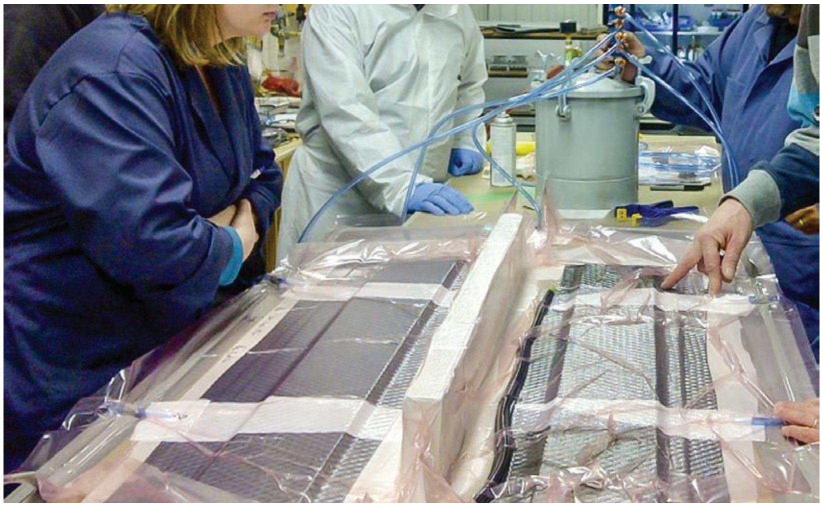


Figure 5-2-7. The part is vacuum bagged and attached to the vacuum pot.

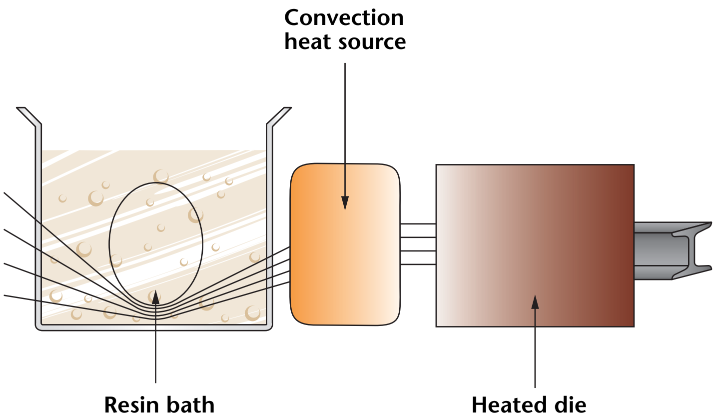


Figure 5-2-8. Pultrusion uses a large, heated die to form and cure the part.

Double Vacuum Bagging

In a practice called double vacuum bagging, a second vacuum bag is placed over the part and first vacuum bag to apply more vacuum to the evacuated part. As the resin flows into the pot, it is pulling resin into the dry fibers. Once the fibers have been saturated, the resin hoses are closed off, and excess resin is drawn into the vacuum pot. Sometimes these hoses are clogged with cured resin (from the exothermic reaction), or air, and another vacuum bag is needed to press out the resin. This is done by placing a breather cloth over the evacuating vacuum bag, and adding another vacuum bag over the top. This provides atmospheric pressure to help evacuate the resins from the part.

Pultrusion

Pultrusion is a relatively simple, low-cost, automated method of manufacturing composite components. The reinforcing fibers are dipped into a resin bath (or pre-preg fibers are used) and pulled into a die that is the shape of the part (Figure 5-2-8). The material moves through the die as it is heated and cured. The finished part comes out the end of the die. This heated die can be very long. As the part is pulled through, the die compresses the fibers into the final shape of the part. The parts do not require vacuum bagging or an autoclave to cure.

Wet Layup or Hand Layup

Hand layup is a manufacturing technique that involves laying pre-preg material by hand into a mold. The mold is usually vacuum bagged and, if heat is required to cure the part, placed into an autoclave or oven to cure. Some parts are cured in room temperature under vacuum pressure.

If pre-pregs are not used and the fabric is impregnated with resin by hand, the process is known as a *wet layup*. In this case, the fabric can be impregnated outside the mold and laid in as with a pre-preg, or it can be impregnated in the mold. The parts are then vacuum bagged and cured. Depending on the resin system used, heat might or might not be applied. If the resin is a room temperature cure material, it can be cured with just vacuum pressure at room temperature. If elevated heat is needed, heat lamps or an oven can be used.

In the homebuilt world, many times a core is covered with fabric and then the resin is applied to the fabric. This is also known as wet layup. The parts are not vacuum bagged because the resin system cures very quickly, and there is no time to vacuum bag the part. Heat is not used because there is no need to accelerate the cure.

Although this technique is less precise than other manufacturing methods, it is the most flexible procedure available. The simplicity and flexibility of the wet layup has made this technique a favorite of home aircraft builders. Furthermore, the materials and processes used with wet layup are the same as those that are often used to make repairs to composite structures (Figure 5-2-9).

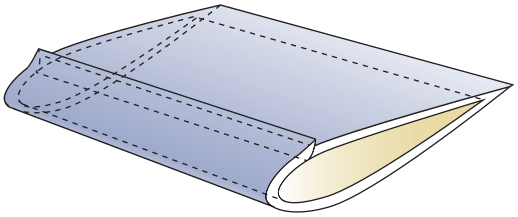


Figure 5-2-9. Although wet layup or hand layup is the least precise method for manufacturing, it is the most flexible and most frequently used in repair procedures.

Section 3

Molds or Tooling

Molding means to pull one or more parts from a mold. Each part is identical. The molds that are used in manufacturing composites are referred to as the *tooling*. No one material is considered the material for advanced composite tooling. The major reason for this is the problem of the coefficient of thermal expansion (CTE) between the parts and the tool. This means that if a tool is made of fiberglass and the part to be made in the tool is carbon, the carbon and fiberglass expand at different rates under heat, causing the tool or the part to warp. To reduce warpage, use compatible materials and resin system temperature cures.

For higher temperature manufacturing methods, or if the part is to be cured in an autoclave, the materials used to make the mold could include carbon/epoxy, ceramics, hybrids, and metals. Steel and aluminum molds are cheaper to make, and the materials are readily available, but the problems of the different CTEs must be addressed when used with advanced composites.

The composite type of tooling has its own set of problems as well. Composites sometimes require several stages in their manufacturing and can result in many types of errors. One advantage of such tooling is that heating elements can be placed inside the tool for curing the composite without using an oven. A tool that is manufactured in this way must be used many times for it to be cost effective.

You can use simpler methods of manufacturing molds, including building up your own composite mold with either epoxy or polyester resin. Although it is very time consuming, it is a lower-cost method that is used in many facilities. Again, multiple parts are usually made from these molds, reducing the unit cost.

Building a Part from a Simple Mold

Molding begins with creating a plug that is the same size and shape as the part being duplicated. Plugs can be made of an inexpensive material such as foam, fiberglass, and plaster. The plug is then waxed and prepared for creating the mold. Building a mold allows you to make numerous identical parts. The mold itself is typically much heavier and thicker than the part that is made.

For purposes of discussion, assume we are making a mold in an airfoil shape. The materials of the component are a carbon fiber skin with a lightweight sandwich core, in this case honeycomb, then vacuum bagged in the curing process (Figure 5-3-1). The next sections describe the steps used.

STEP 1

Create the plug. The *plug* is a model of the part being duplicated. Sculpt the plug of aircraft Styrofoam® and fiberglass skins to the exact size and shape using the manufacturer's blueprint.

- Make a template from masonite or other similar material that is the same as a cross section size of the part.
- Attach the template to the foam with small nails. Using a hot wire cutter, go around the template, cutting the foam (Figure 5-3-2). Try not to have lags in the wire that make indentations in the foam.
- Lay raw fiberglass over the foam and brush or squeegee the mixed epoxy resin into the fibers. In this example, a layer of coarse fiberglass weave is put on first, followed by a layer of fine weave on the outside (Figure 5-3-3).
- When the fiberglass has cured, sand the plug to exactly match the component size.
- To build up low areas, use fillers and primers, and then sand them down to get the exact dimensions desired.
- The plug must have a prepared surface. This is very important because it affects the entire remaining process. Spray the plug with a primer coat. When the primer

is dry, sand the surface with several kinds of sandpaper, starting with 200 grit, then 400 grit, and finishing with a wet sanding with 800 grit. Ending with such a very fine paper leaves a perfectly smooth finish.

STEP 2

Construct the parting board with the plug. A parting board is a box type of tool used to hold the plug on the centerline, which makes it easier to remove from the mold. Mount the plug to expose just half of the component at the centerline.

- Construct a box using four boards (2 x 4s) nailed together for the base of the box. The box must be taller than half the plug. Nail a piece of masonite to the top of the box.
- To make the parting board, outline the plug on a piece of masonite.
- Cut along the line with a saw. When cutting, it is better to make the parting board bigger than too small. It is possible to fill in gaps between the plug and the parting board with clay.
- Wax the plug and the parting board with a high-temperature mold release or wax made from carnauba oil with paper towels. You can apply the wax much like waxing a car.
- Allow each coat of wax to haze, then buff it and let it stand for 1 hour before applying the next coat. Apply four coats of wax.
- After waxing, the plug is ready to be mounted in the mounting board (Figure 5-3-4).
- Draw the centerline on the plug with a marker.
- Build braces for the box so that the plug fits down and rests at the centerline.
- Fill in the gaps around the plug using non-drying, oil-based clay. The clay and release agent must be compatible.
- Smooth the clay down into the edges and remove any excess.
- Wax the plug again including the clay and the board. Do not change the position of the plug on the board. Buff the mold to a haze.
- Apply a light mist of liquid polyvinyl alcohol (PVA) release agent. Usually three light mist layers is enough, allowing 10 minutes between coats. Excess PVA can cause problems; apply only a light mist per coat. After the third layer of PVA, wait 2 to 3 hours for it to dry.

Figure 5-3-1. This photo shows a sample plug (white), mold (red), and a finished component (black).

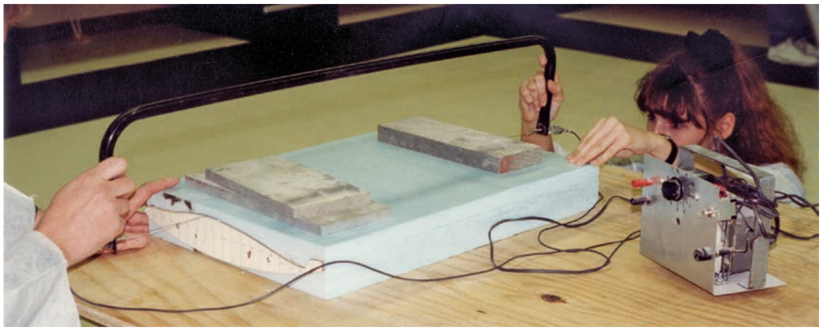


Figure 5-3-2. Using a hot wire cutter to cut around the template.

Figure 5-3-3. Two layers of fiberglass are placed on the foam to make a plug.

Figure 5-3-4. Building the parting board around the plug. The mold is made in two parts on the top side and the bottom side of the plug.

STEP 3

Making the mold. For this example, we will be using an epoxy resin and fiberglass to construct the mold.

- The first layer to apply is the surface coat. Because this is an epoxy mold, we selected an epoxy surface coat. The surface coat creates the smooth outer surface from which the parts are pulled.
- Brush on the surface coat. Doing this leaves brush marks that eventually flow out smooth. Surface coat in the corner and all around the edge of the mold. Use a 1-in. brush to make the lip of the mold. If you want the mold big enough to vacuum bag, use a 3-in. lip all around the edges. Be sure to cover all areas.
- After the proper surface coat curing time (about 1 hour), do a brush test to see if a mild impression is left in the surface coat. It should be dry enough that no brush strokes show.
- Apply a second layer of resin with a fresh batch of surface coat.
- After drying again for 1 hour, lay the fiberglass into the resin.
- While the part is drying, this is a good time to precut the fabric reinforcement to fit the part.
- Our example is using four layers of 2-oz. fabric, and eight layers of 6-oz. fabric. To figure out how much material is needed, use at least enough material to make the mold three times thicker than the part pulled from it.
- Mix epoxy resin, catalyst, and microballoons to make a paste. Measure by weight.
- Apply this paste into corners and tight edges where fabric could pull away.

Figure 5-3-5. Laying coarse fiberglass over the plug, and working the resin in. The red color is the epoxy surface coat.

- Smooth off to even out the edges and corners.
- Mix the base coat of resin by weight. Some types of resin do not allow a very long working time, so you might have to work quickly.
- Brush a base coat of resin over the entire surface, being careful not to disturb the paste.
- Lay the fiberglass into the resin, wetting out the fibers. Add additional layers, wetting out as you go. Be sure to add enough fabric to include the lip of the mold (Figure 5-3-5).
- Get out all the air bubbles with a brush or roller; work out any wrinkles in the fabric with a brush or your fingers. Cut out any excess fabric and fold over to make the fabric smooth next to the plug.
- If the type of resin used is a quick cure, you might need to make a fresh batch of resin.
- Let the mold cure about 30 minutes to a partially cured state, but soft enough to be cut by a razor knife.
- Trim the fiberglass all around, leaving about a 1-in. lip to join the halves together. Cut down with the razor knife against the box.
- After trimming, cure for 24 hours before removing the mold from the parting board.

STEP 4

Release the mold from the plug. Releasing the mold from the plug can be very difficult. If the mold sticks to the plug, you must repair the mold surface before using it to create any parts. Plastic release wedges are available in various sizes, and several wedges might be required to release the mold.

- Insert the wedge into the crack between the molds. Push the wedge around the edge to get it apart. After one side is off, squeeze gently on the plug or use a wedge between the plug and mold. Be careful not to damage the mold.
- Wash the mold with dish soap to remove all clay and PVA. Do not use solvents to remove all clay and PVA.
- Inspect the surface for areas that might need repair.
- If a repair is necessary, be sure not to alter the geometry of the mold.
- When a mold is released, a small amount of flash remains around the edges. Flash is the extra extruded resin that needs to be removed. Use a Dremel tool or sander to grind down the edge.

- As a last step, sand and polish the mold surface. A very smooth surface is the best. Use 400 grit sandpaper, then 600 grit, and then polish to achieve the smoothest surface possible. Before proceeding, wash and dry the mold.

STEP 5

Prepare the mold for making the part. Prepare the surface of the mold in the same way as you prepared the plug for release.

- Apply wax in three layers, buffing out when hazed and allowing 1 hour between coats.
- Apply three light coats of PVA, allowing about 10 minutes between coats. After the final coat, allow it to dry for 2 to 3 hours.

STEP 6

Lay up the part. Because timing is important, before you begin gather the materials and tools that you will need to finish the part lay up.

- Precut the fabric to the correct size and shape, with all material orientation figured out in advance.
- Mix a small batch of resin and catalyst and brush on a surface coat of resin into the mold. If the part is made with pre-preg material, a film adhesive could be used.
- Lay the material into the mold (Figure 5-3-6).
- Allow the material to partially cure, then trim it flush. If pre-preg material is used, you can cut it after it is laid into the mold.
- Add core material, reinforcement for the spar at this time (Figure 5-3-7).
- Add additional layers of reinforcement fabric over the core material.
- The part can now be vacuum bagged (Figure 5-3-8), using standard vacuum bagging materials and procedures (chapter 7).
- Before removing the part from the mold, cure it for the required time.
- Release the finished part by using wedges. Be careful not to damage the mold or the part.
- After the part has released from the mold, inspect the surface for imperfections that might require repair, such as air bubbles.
- Wash off the PVA mold release, sand off the excess seam flash, and trim the part.
- The mold should be in good condition and can be used again and again.

Figure 5-3-6. Laying fabric into the mold.

Figure 5-3-7. Any honeycomb is added, then another final piece of the fabric is added over the honeycomb.

Figure 5-3-8. Vacuum bagging the part into the mold.

Making a Mold from an Existing Part (Splash)

A two-part molding compound can be used against an existing damaged part to make a mold. The damage on the existing part should be removed and the part sanded smooth. The area must be clean of dirt and grease. The area of the existing part should be waxed with mold release. If the damage extends all the way through the skin, a backup can be made with two-part potting compound. The potting compound is mixed and put into the hole and cured. Sand down the potting compound until it has the same contour as the original part. Seal the area with a coat of resin. Cure the resin, and sand lightly.

Apply mold release over the entire structure. Mix the two parts of the molding compound together, following manufacturer instructions. Apply the molding compound to the existing part over the damaged area. After the molding compound has cured, remove the part and sand the inside of the mold to create a very smooth surface.

The mold is ready to be used to make the part. Fabric and core materials can now be laid into the mold and vacuum bagged and cured. The manufacturer specifies the type of fabric and resin materials to use when you get an approval to do this type of manufacturing.

Section 4

Lightning Protection

In the manufacturing process, some form of lightning protection must be built in to the advanced composite structure. As a technician, you must be able to identify the type of protection used and able to repair the component with the lightning protection intact. Aircraft require electrical contact between all metallic and composite parts to prevent arcing or fiber damage.

Aluminum or copper is used to provide a conductive path for dissipating the electrical energy. The aluminum can be provided in several ways depending on the aircraft's manufacturer. Regardless of whether an aircraft is made of aluminum or composites, when lightning hits the aircraft, it needs a path for the electricity to flow through (Figure 5-4-1). On an aluminum skin, the electricity flows through the skin and discharges out the static wicks.

Composites do not conduct electricity, so lightning protection must be built in to the component. If lightning protection is not in the composite and the lightning exits through the composite component, the resins in the composite evaporate, leaving bare cloth.

Carbon/graphite composite was at first believed to conduct enough electricity to dissipate the electrical charge, but this was later found not to be true. Aluminum or copper lightning protection can be found in carbon/graphite parts. A barrier, such as a layer of fiberglass, should be used to prevent a galvanic potential between the carbon/graphite and aluminum. The barrier prevents the metal's corrosion.

Section 5

Electrical Bonding

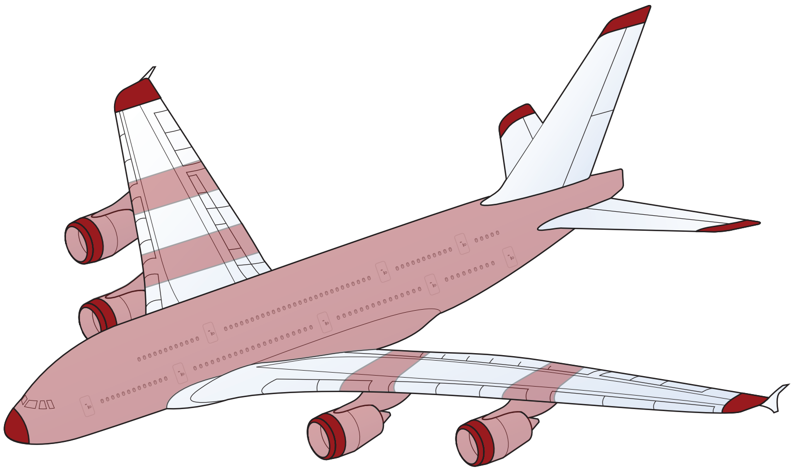
Manufacturers use different methods to dissipate the electrical charge on composite structures. The following are a few of the methods:

1. Aluminum wires can be woven into the top layer of composite fabric. Fiberglass or Kevlar® are usually used rather than carbon/graphite. Carbon/graphite usually is not used with aluminum wires because of the galvanic potential between the aluminum and the carbon. Copper wires could be used.
2. A fine mesh screen can be laminated under the top layer of fabric (Figure 5-5-1). If this method is used on a carbon/graphite component, it is usually sandwiched between two layers of fiberglass to prevent a galvanic potential, or a copper mesh is used. The barrier prevents the metal's corrosion. Copper does not have the galvanic potential when next to carbon, as aluminum does.
3. A thin aluminum foil sheet can be bonded to the outer layer of composite during the manufacturing process.
4. Aluminum can be flame sprayed onto the component. This is molten aluminum that is sprayed on like a paint. Some companies just paint the component with an aluminized paint.
5. In some structures, a piece of metal is bonded to the composite to allow the electrical charge to dissipate out to another metal component or static wick.

Section 6

Painting the Composite Part

After manufacturing a part, the part is painted to seal the surface from moisture and for cosmetic purposes. For most aircraft, the same type of paint that is used for the metal portions of the aircraft is suitable for use on the composites. Some companies, such as Boeing, use a layer of Tedlar on the composite before painting. Tedlar is a plastic coating that serves as an additional moisture barrier.



ZONE 1: Initial lightning attachment area

ZONE 2: Swept stroke attachment area

ZONE 3: All remaining areas

Figure 5-4-1. Areas on an aircraft that are most susceptible to lightning strikes.

Gel Coats

A gel coat is a polyester resin that is used when manufacturing the part. The manufacturing mold is coated with a color coat of polyester resin. The plies are laid down into the surface of the colored gel coat and impregnated with an epoxy resin. After curing, the gel coat is on the outside surface and provides a smooth finish. The plies of fibers that are embedded with the epoxy matrix are the structural part of the aircraft. The gel coating is not structural; it is more like a paint coat.

Gel coats were used on gliders extensively in the 1970s and 1980s. Gel coats have several disadvantages. Because they are made of polyester resin, they are not as strong or flexible as the epoxy matrix. If the aircraft is stored outside and exposed to the sun and weather, the gel coat can become brittle and crack. Because of the parts' bending and flexing in flight, this cracking of the gel coat must be inspected. The inspection is to see if the structural fibers themselves are cracked and not just the gel coat. If only the gel coat is cracked, there is no structural damage. However, if the fibers are cracked, the structure must be repaired.

Gel coats cannot be rejuvenated as dope and fabric aircraft can. The gel coat must be sanded off and reapplied. Many aircraft owners who have had problems with the gel coat cracking, sand off the gel coat surface and paint the surface with one of the new generation types of paint (usually an epoxy) that are very flexible and can withstand the weather. When sanding off the gel coat, be careful not to sand through the fibers because the fibers were manufactured into the wet gel coat and are not perfectly even.

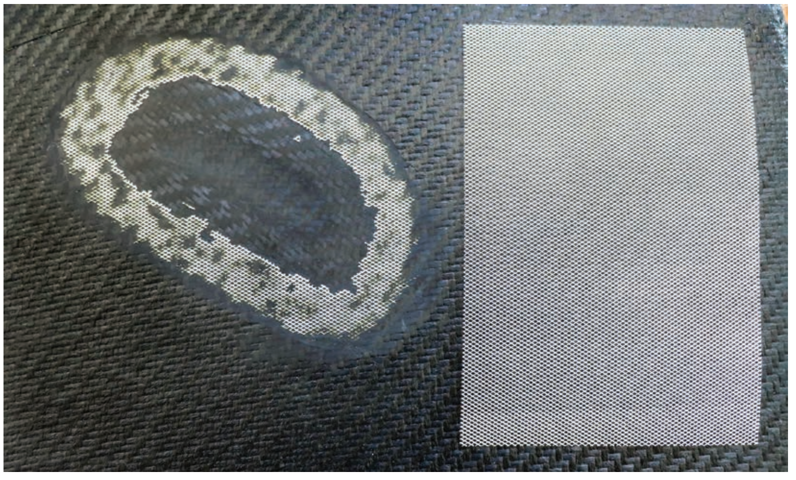


Figure 5-5-1. After sanding off the top layer of carbon, a fine mesh screen can be seen. Next to it is the screen that will be used in the repair to replace the removed screen.

Epoxy Paints

Fill primers can be used over a repair but, again, do not add too much weight to the repair or you will negate the whole reason for using composite parts on the aircraft. Light weight and high strength are the keys to doing proper composite repair work.

The new generation epoxy-based paints are used on composites just as on aluminum parts. The flexibility and wear resistance of the paint does not deteriorate as some gel coats do. The component is primed and painted in the same manner as an aluminum part.

6

Composite Safety

Left: Proper safety environment is important for both the technician's health, and the reliability of the aircraft repair.

Courtesy of USAF

Safety is always of utmost importance around an aircraft. It is no different when working with composite materials. Even if there is no apparent danger, personnel must observe proper safety precautions at all times to prevent injury or aircraft damage. Most accidents dealing with composite materials occur because of improper use and handling. All personnel should be aware of the hazards associated with using these materials in a shop, and they should be taught how to minimize these hazards.

In addition to the safety precautions detailed in this chapter, technicians must make sure the materials used for composite repair procedures are confined in a designated work area. Eating, drinking, or smoking in the work area should not be allowed.

Learning Objectives

REVIEW

- Importance of safety when working with composites

DESCRIBE

- An SDS
- How to properly handle matrix materials
- Precautions to take when machining composites

EXPLAIN

- Possible dangers in composites work
- What compressed air can do to composites

APPLY

- Determine if a material is expired or may be used
- Identify and demonstrate how to wear the proper protective equipment

Section 1

Safety Data Sheets

Before working with composite resins, solvents, or fabrics, it is important to know exactly what type of material you will be handling. Before any work, obtain and read the safety data sheet (SDS) for the material. An SDS is a document that identifies a hazardous material. These were formerly known as MSDSs, or material safety data sheets, but the name was shorted to encompass more than just materials. The SDS contains information on health precautions, flammability of material, ventilation requirements, and information for health professionals in case of an accident. An example SDS is provided in Figure 6-1-1. You can get the SDS through the material's supplier or manufacturer.

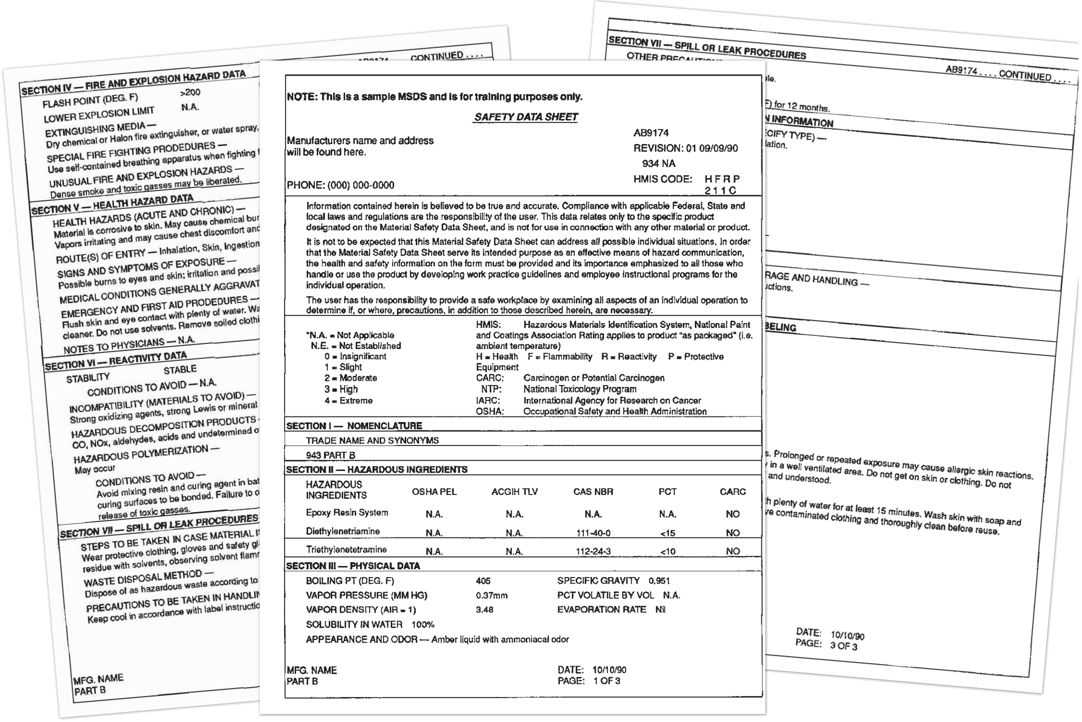


Figure 6-1-1. A sample SDS.

All personnel should know where the sheets are kept in the shop. As a technician, you might not be directly involved with the SDS when the material is delivered because the SDS could be kept in the tool crib area, in a notebook, or on the shelf next to the product. The SDSs could also kept in the doctor's or nurse's office of the company, or your boss or secretary might have them filed for safe keeping.

By law, the SDSs for all hazardous materials used in the shop must be available to the people working with the materials (Figure 6-1-2).

Figure 6-1-2. SDS must be available in the workplace.

To maintain the highest level of safety in the shop, you must know where your company keeps the SDSs. If something happens to you while working with hazardous chemicals, it is important that you take the SDS to the doctor with you. A doctor cannot be expected to know every chemical, so if you bring an SDS with you, the doctor can treat you appropriately and, in many cases, more quickly.

Section 2

Personal Safety with Chemicals and Matrices

The best way to work safely with composites is to wear personal protective equipment (Figure 6-2-1) for your skin, eyes and face, and to protect against inhalation.

Skin Protection

The proper skin protection required for a material is listed in the material's SDS. Certain materials can cause allergic reactions when they contact the skin. Some people are more sensitive to these materials than others. Using rubber gloves is the most effective way to provide skin protection from these chemicals. The gloves should be replaced after heavy use.

Figure 6-2-1. Safety gloves, goggles, respirator, and dust masks are required when working with composites.

Shop coats should be worn to prevent clothing contamination and subsequent skin contact. Clothes saturated with epoxy resins should be removed immediately. If contaminated clothing is allowed to stay next to your skin, it can be highly irritating. Remove any splashed resin from your skin immediately. Wash your hands thoroughly before and after work, before eating or smoking, and before putting on gloves.

Always wash your hands before using the restroom. Many of the chemicals are potential carcinogens and can cause serious irritation and possible cancer in the technician and with a sex partner.

Special epoxy cleaners are available that break down the resins without drying out the skin. Do not use excessively strong solvents to clean your skin because they dry out the natural oils in your skin and cause allergic reactions that can cause your skin to peel (a form of dermatitis).

Respiration and Ingestion

You must have proper ventilation when working with any resins or solvents. Also, some resins are sufficiently toxic as to require you to wear a respirator when working with them. To alleviate respiratory issues, some shops provide a ventilated mixing booth. However, once the chemicals have been mixed, it is often necessary to apply the resin in an unventilated area or otherwise expose yourself to the chemical fumes. In such cases, it is important that you use a respirator once the mixed resins are removed from the mixing booth.

Keep contaminated gloves, clothing, and material away from your hands and mouth. Some of the composite materials are very toxic and have no known antidote. If you ingest them, you are as good as dead. It is imperative that you wash your hands with soap and water before eating, smoking or drinking, and before and after using the toilet facilities. Special soaps and cleansers are available that remove epoxies without harming your skin as solvents do.

Eye and Face Protection

Some resins, hardeners, and solvents can make you go blind. Some solvents and matrix components can cause permanent blindness within a few seconds after contact with the eye. Goggles that can be worn alone or in combination with prescription glasses provide complete eye protection against front and side impacts, chemical liquid splashes, and dust. If you splash any epoxy resin or solvents in your eye, rinse out the eye immediately at an eyewash station (Figure 6-2-2), report the accident to your supervisor, and seek medical help.

The Occupational Safety and Health Administration (OSHA) requires that an approved eyewash station be available in workplaces. They should be cleaned and maintained regularly. All approaches to the station should *always* be unobstructed.

Very serious eye accidents have occurred when people did not take the warnings seriously. If you get any substance in your eye, immediately seek medical attention. If the substance is left in

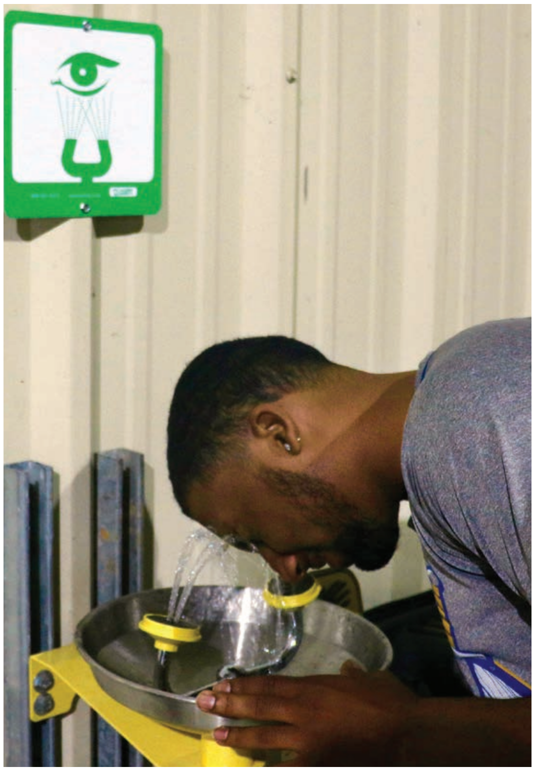


Figure 6-2-2. An OSHA-approved eyewash station is required and extremely important!

the eye for a prolonged time or overnight, the damage to the eye can become more severe. Do not take chances. Tell your supervisor and seek medical help immediately.

Face shields also offer good protection when working with resins. However, if you have an updraft table, face shields should not be used. Updraft tables, as their name implies, pulls fumes up through an exhaust vent. If a face shield is being worn, the fumes are pulled up under the shield and have no place to exit. This can cause respiratory problems and injure the eyes.

> **CAUTION:** Plastic contact lenses can craze from resin fumes. When plastic comes in contact with the fumes of solvents or resins, white lines appear on the surface of the plastic. This is known as crazing. If possible, wear glasses instead of contact lenses, and always wear goggles.

Section 3

Solvent Types and Safety

Many types of solvents are used when working with or repairing composites.

Solvent Types

Some of the most common solvents used with composites are acetone, methyl-ethyl keytone (MEK), and denatured alcohol.

Acetone. Acetone is a very good solvent, with less health risk associated with it than others. It is used for general cleaning of tools, equipment, and for cleaning composite components during the repair operation.

MEK. MEK has been used for cleaning dust, grease, and mold release agents from composite components. Depending on the structural repair manual or local laws, MEK could be banned where you work. MEK is considered toxic in some states or countries and might not be available for use.

Denatured alcohol. Denatured alcohol is used as a pre-bond prep to clean the composite parts after sanding.

Safety Guidelines for Using Solvents

When working with with all solvents and matrices, follow these safety guidelines:

- Eliminate flame and spark sources. All solvents are flammable, so when solvents are being used, do not smoke. A strict, no-smoking policy should be in effect. Do not use solvents in the vicinity of sanding because sparks could create a fire hazard. Also, do not have solvents nearby when bagging films and peel ply materials are unrolled. They can create a static charge.
- Use solvents neatly. Do not pour any solvent directly onto the part. A clean, soft cloth moistened with the solvent is usually adequate.
- Use solvents in a well-ventilated area and avoid breathing the vapors for prolonged times.
- Wear gloves when applying solvents to protect the skin from drying out.
- Never use solvents to clean skin. Use more suitable epoxy cleaners that are less dangerous to your health.
- Wear goggles when pouring solvents.
- Keep solvents in the original containers.

Section 4

Handling and Storing Matrix Materials

For safety, when handling and storing composite materials, read and closely follow the manufacturer's instructions (Figure 6-4-1). Read the labels on containers for all information on handling, storage, and safety precautions. This includes mixing and safety instructions. When working with any materials you are not familiar with, consult the SDS. Improperly stored adhesives, resins, or preimpregnated materials (pre-pregs) can result in structurally unsafe aircraft components.

- Follow all manufacturers' instructions for mixing components. If you do not mix resins properly, the maximum cured strength will not be achieved. The two parts of the resin system must be weighed properly to get the proper mixture. Use a scale to mix to the proper ratio specified. Fortunately, some resins and adhesives come prepackaged and already have the proper amounts in the two parts of the package.
- Always store the matrix materials properly. Some resins and catalysts require special storage temperatures (Figure 6-4-2). Three

storage temperature ranges are common: room temperature of 75°F to 80°F, refrigeration of about 40°F, and freezer temperatures of 32°F or less. Follow the manufacturer's instructions carefully.

- Keep records on refrigerated storage to ensure that materials that are placed first-in are the first-out for use.
- Keep refrigerated materials sealed to prevent moisture from entering them. An identification label must accompany the material.
- Record accumulated time out of refrigerated storage. Some pre-preg fabrics have an *in-freezer* storage life and an *out-of-freezer* storage life, because when the pre-preg is out of the freezer while cutting, the resins are slowly warming up to room temperature, starting their cure cycle. If they stay out of the freezer for too long, they cure too much and do not have adequate strength when needed.
- Allow components to warm to room temperature before weighing and mixing.
- Discard all materials that exceed the storage life, shelf life, or *limitation date*, which is calculated from the date of manufacture or date of shipment receipt (whichever is applicable). For example, if an item has a manufacturing or shipment date of 9/2018, and a six-month storage life, its limitation date can be stamped 3/2019 and should not be used after that.

  To discard the materials properly, consult the SDS. Many materials may not be thrown away. Instead, they might have to be mixed and cured before disposal because they could be toxic waste if left unmixed.

  Pre-preg materials are considered toxic waste and may not be thrown out in the trash. They must be cured first. If small scraps exist from cutting out patches, cure them at the same time as the repair. If the entire roll has exceeded its storage life, many facilities cure it in an oven to make it nontoxic. Instead, consider donating that material to a local maintenance training class to be used for training and not used on in-service aircraft.

- Handle materials with gloves to maintain cleanliness.
- Never use brushes contaminated with another type of resin.
- Store dry fabric and bagging materials in a clean, dry area. Be sure not to distort the fabric weave.

Figure 6-4-1. All instructions supplied by the materials' manufacturer and the structural repair manual must be followed exactly.

Figure 6-4-2. Some materials require specific storage temperatures. Note that the packaging statement, "Store at -40°F. or colder upon receipt," actually means below 40° and not 40 below 0°.

- Post materials certification papers close to the storage area. Make sure the certification in paper form matches the batch of the lot printed on the material labels (Figure 6-4-3).
- Do not allow protective hand creams to come in contact with the resins or bond lines. They can create an un-bondable surface.
- Do not remove the backing on pre-preg materials until the material is used.
- Store honeycomb and foams in the original packing box.
- Clean rooms are not required for making composite repairs, however, it is nice if you have a separate area for sanding and one for laying up the patches. This helps prevent dust particles created in the sand-

ing operation from getting into the repair. If your shop does not have separate areas to do the composite repair work, before attempting to bond patches, you should clean the area thoroughly and vacuum up any dust, then do a solvent wash.

Minimizing Fire Hazards

Many of the solvents and resin materials used are flammable; keep them away from heat and open flame. To minimize or eliminate the danger of fire, be sure to meet the following requirements:

- Eliminate all flames, smoking, sparks, and other sources of ignition from areas where solvents are used.
- Use tools that do not produce sparks.
- Ensure that all electrical equipment meets the applicable building and fire codes.
- Keep flammable solvents in closed containers.
- Provide adequate ventilation to prevent vapors from building up.
- Statically ground the aircraft and any repair carts.
- Never unroll bagging films or peel ply near solvents. Doing so can produce static electricity.
- Never have solvents in the area when sanding. The possibility of sparks during the sanding operation is a fire hazard when solvent fumes are present.

Section 5

Personal Safety while Machining

Sanding, drilling, and trimming operations on composite structures produce very fine dust particles that can become airborne, thus contaminating the air. To help alleviate health risks, you must wear a respirator. A dust collector or downdraft table also is very desirable to use while sanding or machining (Figure 6-5-1) because it pulls the fine particles out of the air. However, do not rely solely on a dust collector or downdraft table. Use such equipment with a respirator.

Some composites decompose when being trimmed or drilled at high speeds. Because

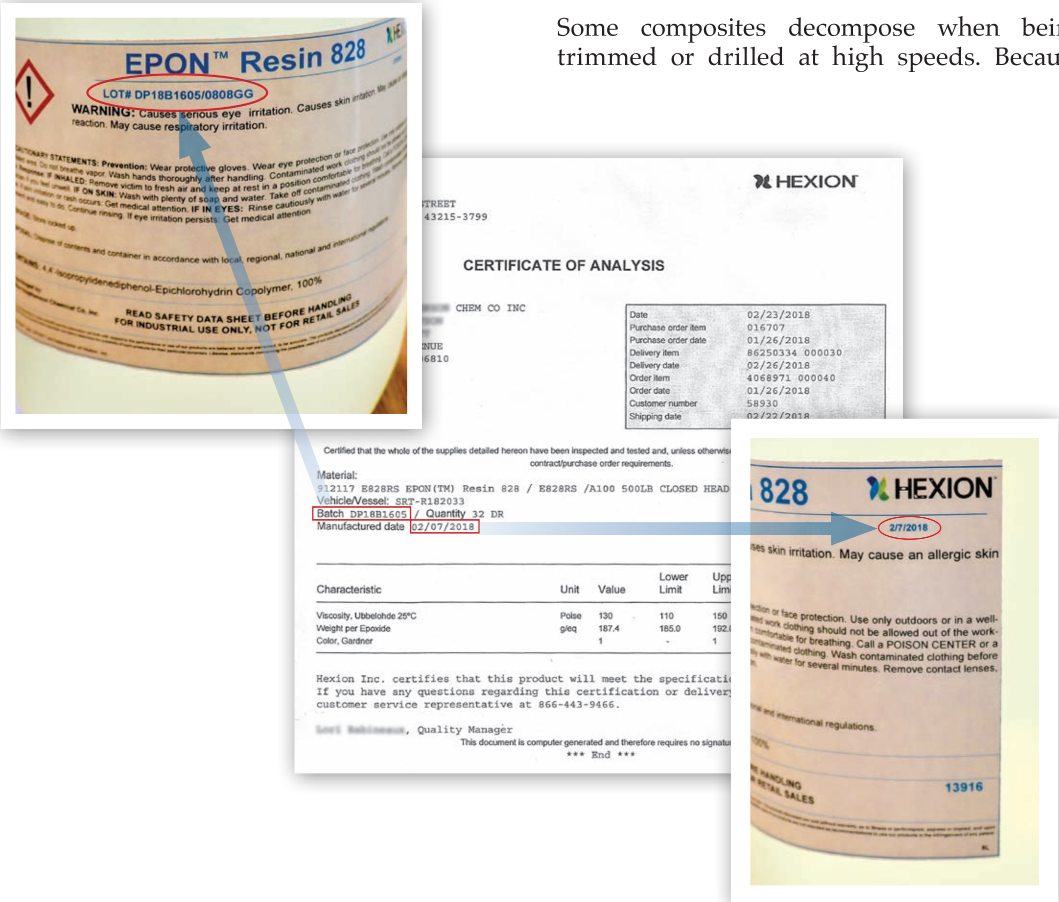


Figure 6-4-3. Make sure the certification batch and date numbers match on the materials' labels and the certification paperwork. You should keep the certification paperwork near the material storage area.

of the friction generated, the process is burning away various materials and creating toxic fumes. Composites vary in their toxicity, so you should consider all composites equally hazardous and observe appropriate safety precautions while working with any of them.

To minimize the possibility of particles entering the pores of the skin, wear protective clothing, such as a shop coat that does not have loose-fitting sleeves. After working with composites, take a shower to flush particles from the skin and hair.

Tool Safety

Working with composites almost always involves using tools. To protect yourself and others and to prevent damage to things in the work area, follow these guidelines:

- Before changing cutters in pneumatic power tools, disconnect the air supply from the tool.
- Never hold small parts in your hands while drilling or cutting.
- Always use a backup on the opposite side of the component to help prevent injury or damage.
- Because carbon chips can be corrosive to aluminum parts and hazardous to electrical components, you might have to remove carbon composite parts from the aircraft before working on them.
- Always point the exhaust from pneumatic power tools away from other people. You must wear safety goggles when drilling, sanding, routing, or grinding.
- Never use compressed air to blow dust from a part that has been sanded. The excessive air pressure could cause an area of the laminate to disbond, causing further damage. To remove the dust, use a vacuum, followed by a solvent wash.

Working Environment

Good housekeeping is an important aspect of the profession. It directly affects an individual's safety and general work. Because of the materials used in composite repair, good housekeeping is a must. Following are good housekeeping practices to use in your working area:

- Do not block access to any safety equipment.
- Keep storage areas neat and orderly.
- Properly dispose of mixing containers.
- Keep fabric remnants swept up.
- Wipe up any spills and keep tools clean.
- Make sure container labeling is legible and that the lids are intact.
- Empty the trash receptacle.
- Keep bagging materials on rolls with covered storage.
- Keep sanding operations away from any lay-up area.
- When sanding and machining composites, use respirators along with downdraft tables or dust collectors.
- Ensure that proper ventilation is available while working with resins.

Figure 6-5-1. Machining or sanding composite structures on a downdraft table reduces airborne particles.

7

Applying Pressure

Pressure should be applied to the surface during the curing operation until the component is fully cured. Applying mechanical pressure achieves the following:

1. Removes excess resin from the components, ensuring the proper ratio of resin-to-fiber reinforcement. As the resins cure, they start to flow. The pressure squeezes out some of this excess resin.
2. Removes air trapped between composite layers.
3. Maintains the contour of the repair relative to the original part.
4. Holds the repair securely, preventing the patches from shifting in the curing process.
5. Compacts the fiber layers together.

Learning Objectives

REVIEW

- Importance of pressure in curing composites
- Methods of applying pressure

DESCRIBE

- Desirable properties when choosing vacuum bagging materials
- Tools used in vacuum bagging
- Where pressure comes from in vacuum bagging

EXPLAIN

- Role of bleeders and breathers
- Role of pleats
- How to check for leaks

APPLY

- Determine the materials for which to supply a conformity report
- Determine what is causing a vacuum bag leak

Left: Using a stethoscope tube to amplify the hissing sound, which indicates a leak.

Section 1

Methods of Applying Pressure

Various types of tools and equipment are used to apply mechanical pressure. The pressure should also hold the patches in place during the curing process so they do not shift. Vacuum bagging is the most widely used and recognized method of applying pressure on advanced composites. A repair is vacuum bagged for most of the curing methods, including ovens and autoclaves. In the past, vacuum bagging materials and equipment were not available, and other methods were used to provide pressure, such as shot bags.

Shot Bags

Shot bags were used in the past to apply pressure to a part for repairs (Figure 7-1-1). This method is effective when working on large, contoured surfaces that do not require heat to cure the resins. A shot bag is a bag filled with shot, sand, or other heavy material. The bag's weight provides the pressure. To prevent the shot bag from sticking to the repair, place a plastic sheet of film on the repair before placing the shot bag on it. Unfortunately, because of the laws of gravity, shot bags cannot apply pressure to the underside of an aircraft part, such as a landing gear door. In such a case, you must remove the part from the aircraft and turn it upside down to apply this type of pressure.

Shot bags do not produce the amount of pressure you can get with vacuum bagging. Other forms of pressure, like books, tool boxes, and so on, do not conform to the shape of the part. Most aircraft parts have a slight curve to them. If the weight does not conform to the curve, the repair will not have even pressure, and the part will be lumpy.

If heat is to be applied to the part for curing, the shot bag is not a good form of pressure to use. The shot bag absorbs the heat and deflects it away from the surface.

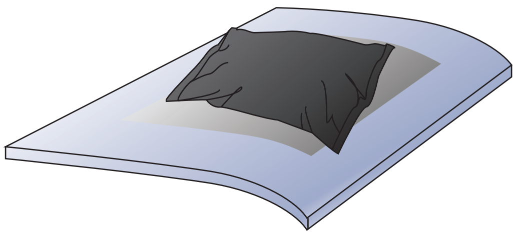


Figure 7-1-1. A shot bag applies pressure to the top of a repair.

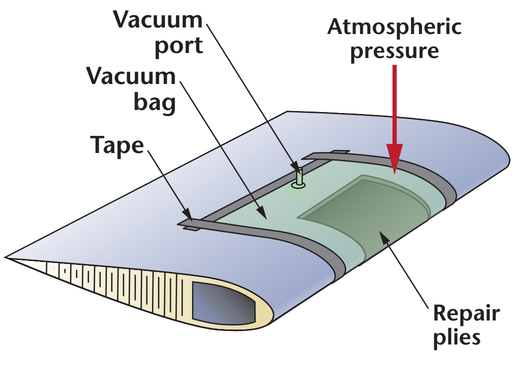


Figure 7-1-2. Vacuum bagging can conform to the part as a shot bag cannot. Vacuum bagging adds pressure to all sides under the vacuum.

Vacuum Bagging

Vacuum bagging is probably the most effective method of applying pressure to a repair and is recommended for use whenever possible. Vacuum bagging works by using atmospheric pressure to provide an even pressure over the surface of the repair (Figure 7-1-2). Once the air is evacuated inside the bag with a pump, atmospheric pressure pushes down on the part.

The pressure of the surrounding atmosphere is greater at lower elevations than it is at higher elevations. Consequently, the amount of pressure a vacuum bag repair creates at sea level is greater than the pressure created in a repair at a high mountain airport. The amount of pressure also varies according to the effectiveness of the vacuum seal and the amount of force drawn by the equipment used.

Theoretically, at sea level, in a vacuum, you can pull 30 inches (in.) of mercury, or 14.7 pounds (lbs.) per inch. If you have an area of 6 in. x 10 in., the size of a typical heat blanket, the pressure at sea level would be 60 in. x 14.7 = 887 lbs. on the repair. The higher the altitude, the less atmospheric pressure exists.

As an example, we have an aircraft scale that goes up to 3,000 lbs. and we vacuum bag it as shown in Figure 7-1-3. The scale size is 12 x 12 in. The weight on the scale shows the atmospheric pressure that is pulled on the part. In this case, 12 x 12 = 144 in. total pressure. If pulled at sea level, it would be 14.7 lbs. of pressure per square inch, or 14.7 x 144 = 2,116.8 lbs. of pressure on the scale. Figure 7-1-4 shows the scale at sea level. It actually shows 2,742 lbs. of pressure on the scale, which could be because extra area around the scale is being vacuumed.

Surface bagging is used on larger surfaces and for most repair work (Figure 7-1-5 top). With a surface bag, the part to be repaired serves as one side of the bag. On penetration repairs, the backside of the damaged area must be sealed to prevent air from flowing through the repair to the other side. In this case, the puncture is sealed on one side with vacuum bagging material, and the repair is vacuum bagged on the other side where the patches are curing. When one side of the puncture has cured, the other side of the repair can be completed. This repair is often done in separate steps.

Self-enclosed bagging material is used on small parts. Self-enclosed bagging material is a plastic tube that can be sealed on the ends (Figure 7-1-5 bottom). The self-enclosed tube vacuum bag can be used on a repair when the part is removed from the aircraft and is small enough to be placed inside the tube. The process places atmospheric pressure on all surfaces of the part. If the

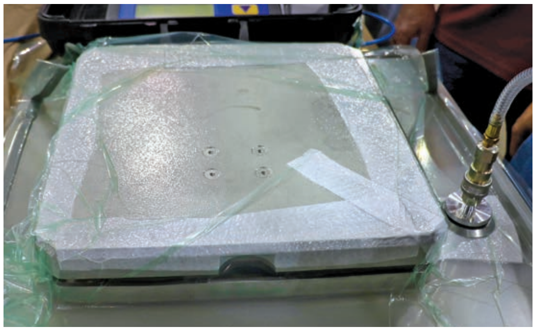


Figure 7-1-3. The aircraft scale is vacuum bagged (at sea level).

Figure 7-1-4. The scale shows a weight of 2,742 lbs. This is the weight on the part. Vacuum bagging gives a great amount of pressure.

part is hollow, the pressure can cause the part to collapse, especially in the area of the repair because it is not yet cured. In this situation, internal and external bagging should be used.

If you are working in an area with high humidity, vacuum bagging should always be used because high humidity can affect the cure of the resins. The vacuum bag system evacuates the air and the humidity.

Section 2

Vacuum Bagging Materials

The materials commonly used for vacuum bagging come in several types, depending on the manufacturer and how the repair is to be done. Vacuum bagging materials are not a permanent part of the repair. They are removed and disposed of after the cure. They are tools used to make the repair. They include peel ply, release film, bleeders, breathers, and sealant tape. Many types of vacuum bagging materials are available, and your decision about which ones to use could be based on the following properties:

- The material's ability to withstand the cure temperature. Bagging materials come with different temperature ratings. If a repair is to be made at 350°F, the vacuum bagging film, bleeders, breathers, peel plies, and sealant tapes should all be able to withstand this temperature.
- The material's cleanliness. Foreign materials are not desirable in a repair because they could become imbeded.
- The ability to pull the proper amount of vacuum. Pinholes in the bagging film and wrinkles around the pleats do not allow the proper vacuum to be pulled. If the bagging film is too dry and the moisture content of the film is too low, it can cause problems.
- If improper materials or too heavy of bleeder (10 oz.) are used, it could pull out too much resin, resulting in a dry repair.

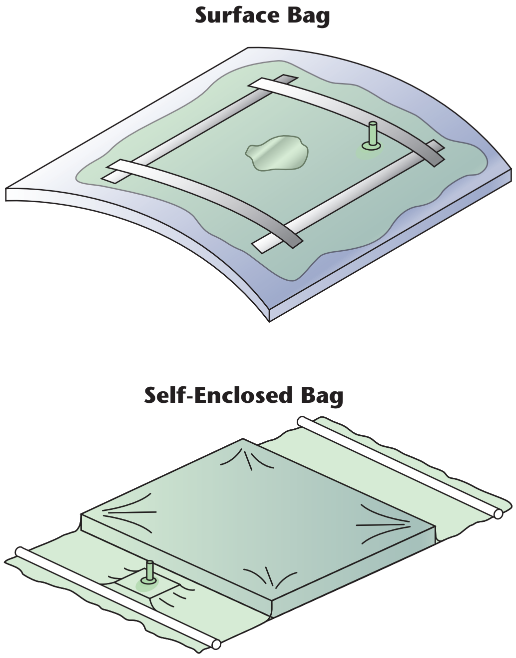


Figure 7-1-5. Surface bags (top) and self-enclosed bags (bottom) are basically the same in function.

Vacuum materials do not stay with the aircraft and are considered tools. After they are used, you can discard them. They can come with certification sheets but should not be included in the paperwork for materials used for the repair. Some vacuum bagging materials have shelf-life limitations that you must consider, but if you can pull the proper amount of vacuum required, you may still use them.

Although the materials can come with a conformity report, they are not required for the repair, again because the materials are tools. Only materials that remain on the aircraft need conformity reports. Examples of such materials include repair fabrics and resin systems.

Peel Ply and Release Films

Release fabrics and films are used as a barrier between the wet patches and the other vacuum bagging materials. Release fabrics are known as peel plies (Figure 7-2-1). Release films that are perforated are used in the same manner as peel plies. These release materials are placed over the wet resin surface, allowing excess matrix and air pockets to flow up through the material and up into the next layer. These hold the repair patches in place and keep the other materials from sticking to the repair. The peel ply layer is easily *peeled* off the surface when cured to provide a final rough surface that is slightly etched and suitable for painting.

Peel Ply

A nylon or polyester release fabric can be used next to the wet resin in the vacuum bagging operation to keep the patches in place, transfer excess resin and air pockets to the bleeder material without sticking to the part. After curing, the peel ply is peeled off the part, which causes a slightly rough surface. This is important if the part is to be repainted.

Peel plies come in different finishes; some are very smooth, and others are coarse. The more coarse the weave, the more *etched* the surface is. Most peel plies are white, unless treated with mold release (greenish tint), corona (bluish tint), or Teflon® (tan) to release easier from the cured surface.

Teflon peel ply is an excellent material because it releases from the repair area very cleanly. However, two types of Teflon peel plies are made: porous and nonporous. The porous material allows resin to flow through the fabric up into a bleeder material, and the nonporous release does not. The nonporous is used primarily in manufacturing against the side of a mold.

Peel plies are more desirable than release films for repair applications because they allow the resins to flow through more evenly and create the slightly etched surface. The peel ply used over a repair eliminates the need for sanding off the gloss or extra resin before painting. If the peel ply is left on over a repair, it keeps the part clean until it is ready to be painted.

Peel ply is not considered a means of applying pressure by itself; however, homebuilt aircraft plans often do not call for vacuum pressure. In such cases, peel ply can be applied over a seam where the materials overlap or when building up an area to be bonded to another part. After the resin is worked in to the material, the peel ply is applied to remove excess resin and air bubbles, prevent shifting, and feather-in the repaired area with the surrounding surfaces. If the part is to be bonded to another part or painted, a rough weave of peel ply is desirable. When the peel ply is removed, the surface is also rough, eliminating the need for sanding before bonding or painting the area.

Release Films

Release films come in two forms: perforated and nonperforated.

Perforated release film. Perforated release film is a plastic with holes that allow excess resin to flow into a bleeder, just as a peel ply material does. It is used in the same way as a peel ply is used. Perforated release films are usually used with preimpregnated (pre-preg) materials to prevent too much resin bleeding out. This type of film comes with holes in different sizes and spacing depending on how much excess resin needs to be bled away from the repair area. Perforated release films come in various temperature ratings depending on the cure temperature.

Some structural repair manuals recommend using a perforated release film instead of using a peel ply for pre-preg repairs. Like peel ply, this plastic is used over the wet repair surface but has small holes to allow resins to flow through to the bleeder. The amount of resin that bleeds out is limited by the size and number of holes in the material. A disadvantage to using the perforated release film is that after the part is cured, a resin-rich area remains on the repair that must be scuff sanded before painting. When sanding, be careful not to go through the top fibers of the part or repair plies. The bleeder material sometimes sticks to the wet resin in the holes, causing fuzzy spots (Figure 7-2-2). To prevent this problem, you can place a layer of peel ply between the perforated film and the bleeder.

Nonperforated release film. Nonperforated release film does not allow the excess resin to flow out. It is not used as the perforated release film is because doing so would not allow the resin to flow out, creating a brittle, heavy repair. The nonperforated release films are used when a barrier is needed between other parts of the vacuum bagging process. They are often used under a heat blanket over the bleeder material. This prevents the bleeder material and resins from coming in contact with and damaging the heat blanket. Vacuum bagging film can be used as a nonperforated release film.

The glossy surface that is created when the part is cured with a release film must be removed by hand sanding; otherwise, the paint might not adhere to the structure. Carefully sand off the glaze and do not sand into the fiber material.

Bleeders

Bleeders are cotton-like absorbent materials used to soak up excess resins (Figure 7-2-3). Some technicians use felt or other absorbent material but only for room temperature curing; otherwise, it could melt. Bleeders are temperature rated. Use the type according to the temperature at which the work is cured. Do not use the bleeder in contact with the repair. If you do not use a release fabric, peel ply, or release film with it, the bleeder material becomes a permanent part of the aircraft.

Place bleeder material on top of the peel ply to absorb the excess matrix. Bleeder material is simply an absorbent sheet. Different bleeder thicknesses and weights are available. The thicker types bleed more resin out of the repair. Use the type that best suits the lay-up you are using for a repair. If you are impregnating the patches with resin by hand, you probably need a heavier bleeder to soak up the excess resin. However, if you use a very dry lay-up, use a thinner bleeder. If using a pre-preg, a thinner bleeder material is the best option. Typical bleeder weights are 4 oz., 7 oz., and 10 oz.

Breathers

Breathers are cottony materials that allow air to flow over a part's surface throughout the vacuum-bagged area. A breather is the same material as a bleeder and can be used as a combination material called a bleeder/breather (Figure 7-2-4). If a breather is not used, the vacuum bag could seal itself by sticking to an area, and the rest of the vacuum bagged area would not receive a correct amount of vacuum pressure.

When you apply the vacuum hose, air must be able to flow to the vacuum port without restrictions. Use a breather over the repair area under the vacuum bagging film. On very contoured parts, breathers serve an important purpose of allowing the vacuum bag to conform to the contours. If the breathers do not cover the entire part, or if the breather under the vacuum valve does not touch the other materials, the air flow can be cut off and vacuum is pulled from around the valve, and not from the entire part as needed.

Place the breather material (usually the same material as the bleeder) over the total layup, including the heat blanket in the repair area to ensure that vacuum is pulled throughout the vacuum bag. Also place breather material on one side of the repair to allow air to flow through it and up through the vacuum valve.

Bleeders and breathers can be made of the same material and can be used interchangeably in many cases. Because of this, some manufacturers refer to it as a bleeder/breather.

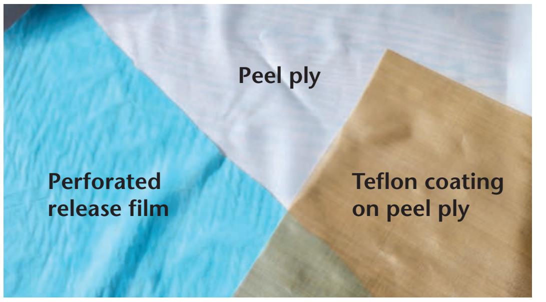


Figure 7-2-1. These materials all keep the wet resin patches in place, allow excess resin to flow through the material, into a bleeder, and make it easier to remove all the materials from the wet resin fabric after the cure.

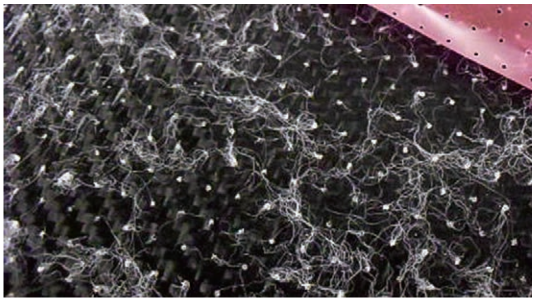


Figure 7-2-2. The fuzz of the bleeder stuck to the final part. This needs to be sanded out.

Figure 7-2-3. The 10-oz. bleeder (left) is very thick (1/4-in. thick) and will pull more resin out than the 4-oz. (right), which is thinner (1/8-in. thick).

Figure 7-2-4. The bleeder/breather material is placed over the peel ply to absorb extra resin and allow air to flow throughout the repair.

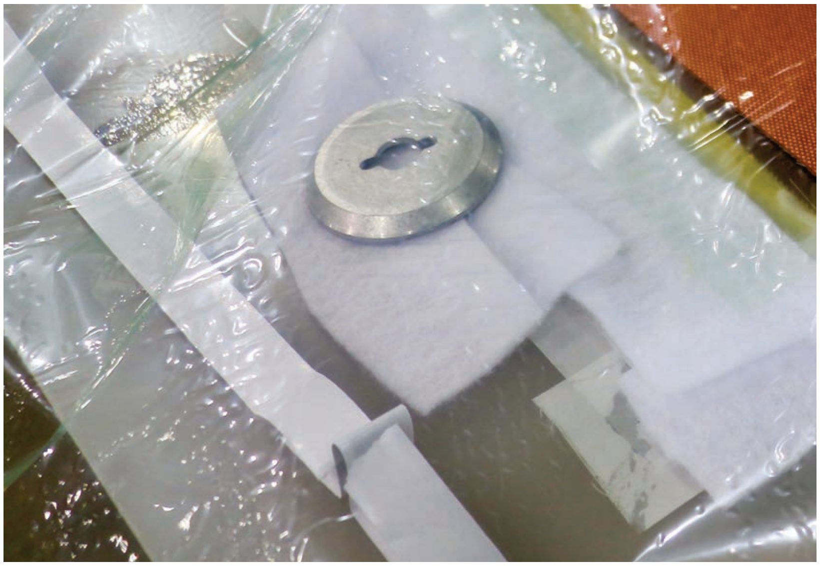


Figure 7-2-5. The vacuum valve base is placed over the bleeder away from the wet resin area. After the vacuum bagging film is stuck down to the sealant tape, make a small cut in the bagging film over the valve base, and connect the top of the valve to the base, making an airtight seal but allowing air to exit through the valve.

Figure 7-2-6. Applying sealant tape around the repair area. Overlap the ends to seal all air leaks.

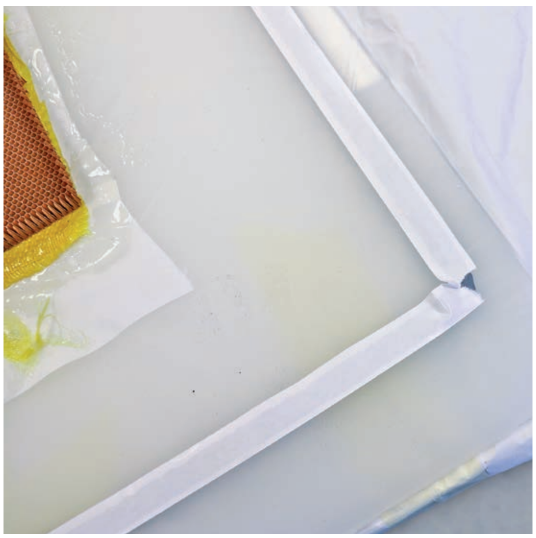


Figure 7-2-7. A closeup of a sealant tape corner.

Place the *vacuum valve* on top of the breather material to remove the air from inside the vacuum bag (Figure 7-2-5). It is important that you place the vacuum valve in an area that does not have wet resin under it. If you place the valve over the wet repair area, it sucks up the wet resin, which cures in the vacuum valve, causing it to be permanently clogged with resin.

After the entire vacuum bagging operation is done, attach the vacuum valve to a vacuum hose, which connects to the vacuum pump.

Sealant Tapes

Sealant tapes are used to maintain a positive seal between the surface of the original part and the bagging films. This seal must be complete and have no leaks so that maximum atmospheric pressure is held against the part. Some sealant tapes have a limited shelf life, so storage and labeling might be required. If the shelf life is exceeded, the seal will not be the standard quality, and the sealant tape might not be easily removed from the surface.

The tape should hold tight even if the bagging film shrinks in the curing process, and it should be able to withstand the temperatures of the cure.

Attach the sealant tape around the repair area as shown in Figure 7-2-6. When used in conjunction with the vacuum bagging film, sealant tape produces an airtight seal. After the repair is made, you can remove it from the aircraft surface without taking the paint off. Sealant tape comes on a roll with paper backing on one side. As the tape is laid onto the surface, leave the paper on the tape so that you can push it down onto the surface without it prematurely sticking to the bagging film (Figure 7-2-7). Remove the backing when you are ready to apply the vacuum bagging film. Afer the sealant tape is surrounding the part, you are ready to continue with the lay-up.

Section 3

Vacuum Bagging Process

Once the repair is made and the patches are in place, cover the area with several materials to facilitate the vacuum bagging process. Figure 7-3-1 shows the materials used for a vacuum bagged repair with pre-preg materials, and Figure 7-3-2 shows the layers for the wet lay-up materials. The paragraphs that follow describe the process in more detail.

Figures 7-3-1 through 7-3-2

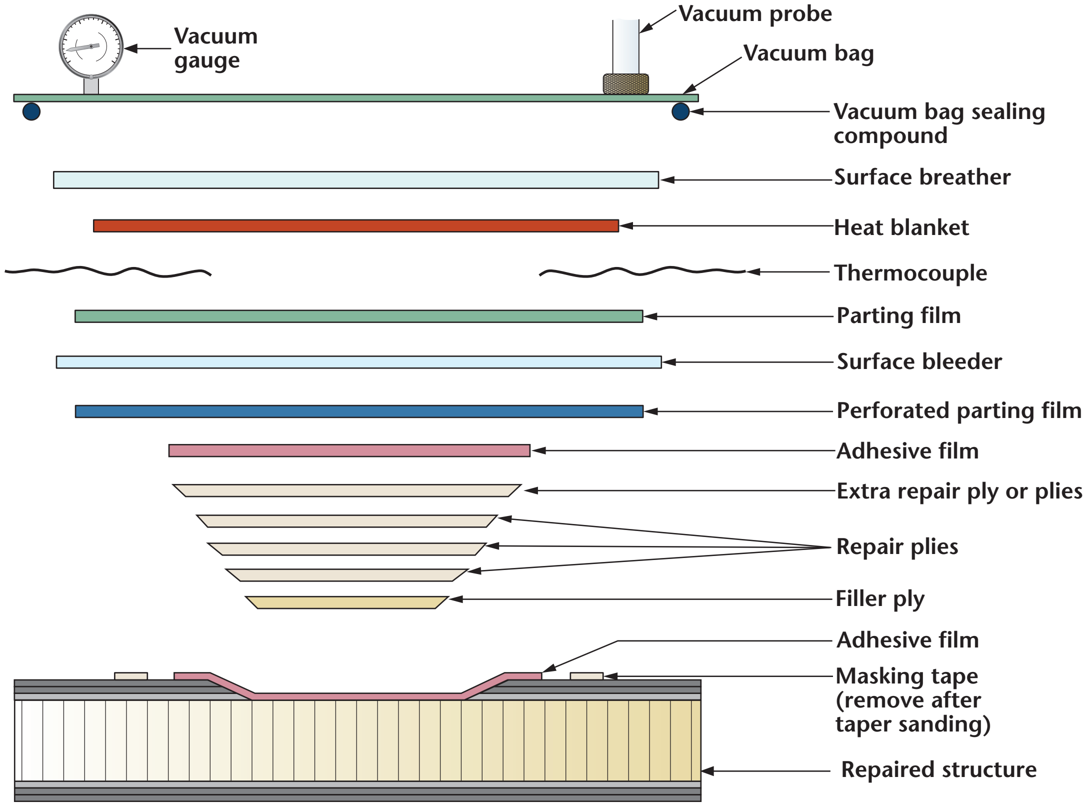


Figure 7-3-1. A cross-sectional view of a complete vacuum bagged surface repair for pre-preg materials.

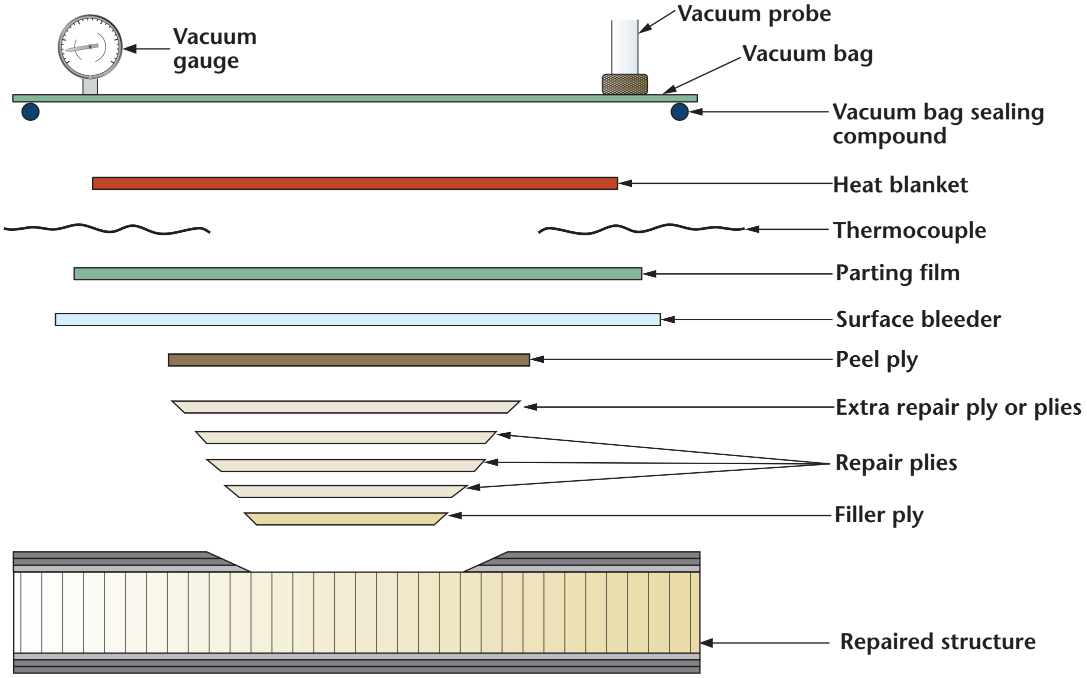


Figure 7-3-2. A cross-sectional view of a complete vacuum bagged surface repair for wet lay-up materials.

Beginning the Lay-Up

When using a heat blanket to cure the repair, lay a parting film over the bleeder material to prevent the heat blanket from sticking to it. In this case, the parting film can be a nonperforated release film or a piece of vacuum bagging material. It should be able to withstand the temperature of the cure because it is directly in contact with the heat blanket.

Place the heat blanket over the parting film so it covers the thermocouple tip. Lay the heat blanket cord into the sealant tape, and place another piece of sealant tape over the cord to prevent air from leaking around the cord (Figure 7-3-3). If the heat blanket has two wires, split them apart before laying the piece of sealant tape over the cord.

Adding a Thermocouple

When using a thermocouple or temperature-sensing device to monitor the temperature of the part while curing, lay it next to the repair area, preferably over the parting film over the bleeder. Just as with the heat blanket wire, seal the thermocouple wire into the sealant tape and then place another small strip of sealant tape over the thermocouple wire (Figure 7-3-4). This prevents air from leaking around the thermocouple wire. Depending on the type of equipment being used, the thermocouple could be a probe, or just the two thermocouple wires stripped and twisted together.

In the past, the twisted ends of the thermocouple wire were placed in the edges of the wet resin and were cut off after the cure. If this bit of twisted thermocouple wire was left in the repair, it created a stress point and was considered foreign object damage (FOD) in the repair.

Placing the Bagging Film

Lay vacuum bagging film over the repair and work the edges into the sealant tape to produce an airtight seal. The most commonly used bagging films are made of nylon because they resist tears and punctures, and they are rated at different temperatures. The most effective way to create a seal with the bagging material is to take the paper off the sealant tape on one side and lightly press the bagging film into the sealant tape.

Making Pleats

On a contoured part, you might need to add *pleats* to allow extra bagging film to conform to the shape of the part (Figure 7-3-5). Pleats allow extra room in the bagging film to conform to the shape of the part and achieve a good seal. If extra vacuum bagging material is not available in some places, or if extra material does not conform to the shape of the part, a bridging effect can occur, allowing the excess resin to flow into these areas in the curing process. If enough pleats are added around the vacuum bagging area, the excess material should easily conform to the shape of the part when the vacuum is applied.

The pleats are made from small pieces of sealant tape and folded together. These pieces are then positioned in the sealant tape that surrounds the edges of the repair. When the bagging film is applied, it is attached to all surfaces of the sealant tape, producing a pleat in the bagging film (Figure 7-3-6).

To make the pleats, cut a 3-in. to 4-in. piece of sealant tape. Pinch the middle of the sealant tape together and attach the ends to the sealant tape that has been placed around the part. To use a pleat, place it even with any edge or sharp contour to allow for the extra plastic where it is needed to provide a good seal. No more than half of the backing paper on the sealant tape should be removed before attaching the bagging film.

Sealing the Vacuum Bag Tightly

After the repair is laid up, you should lightly press the bagging film into the tape until it forms an airtight seal that covers the part. If it is necessary to readjust the bagging film, you can pick it up and reposition it. If the film is stuck to the tape too firmly, however, it is difficult to reposition. After the film is positioned correctly, you should then push it firmly into the tape to produce an airtight seal.

Applying Vacuum

Cut a slit into the bagging film over the vacuum base, insert the vacuum valve into the base, and then seal it so it is airtight. Avoid wrinkles in the bagging film around the valve because air can leak around it. If any wrinkles form, work them out to be smooth. The valve is now ready to be attached to a vacuum hose.

Connect the vacuum source to the vacuum hose and turn on the vacuum source. The vacuum pump evacuates all the air, and the vacuum bag should conform to the shape of the part.

Figures 7-3-3 through 7-3-6

Figure 7-3-3. Place the heat blanket wire over the sealant tape, and then place another small piece of sealant tape over the wire to prevent air from leaking around it.

Figure 7-3-4. Place the thermocouple under the heat blanket, place the wire over the sealant tape, and affix a second piece of sealant tape over the wire to prevent air from leaking around it.

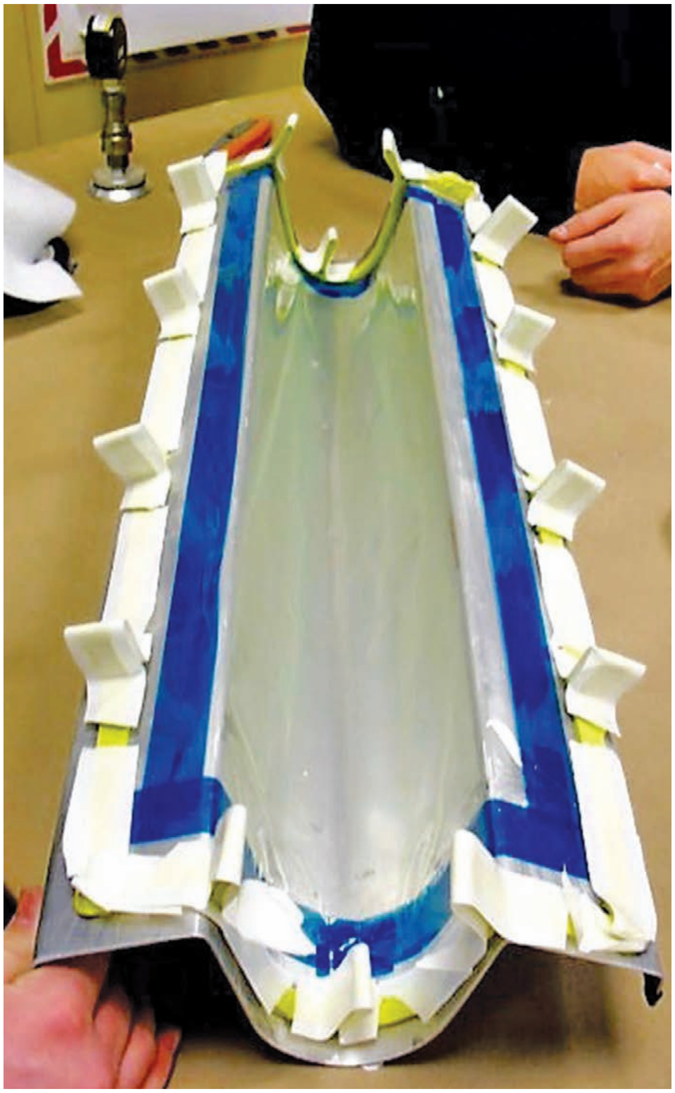


Figure 7-3-5. Create pleats around the structure to position extra film where needed to provide pressure on concave or convex surfaces.

Figure 7-3-6. The vacuum bag film goes up one side of the pleat and down the other.

Checking for Leaks

Check to see if any leaks are in the bagging film. You can detect a leak by the hissing sound it makes. If an area of the bagging film has a hissing sound, push down on it into the sealant tape until the hissing stops. The sound is caused by air is passing through a gap between the sealant tape and the vacuum bagging film.

Leaks usually occur where the tapes overlap, at pleats, or where wires pass through the sealant tape. As the leaks are plugged, the vacuum gauge on the equipment shows a rise in the inches of mercury. To detect a leak that cannot be found with regular hearing, or in a place where the surrounding area is loud, you can use special leak detectors. High-end ultrasonic leak detectors are available (Figure 7-3-7), but budget devices such as the end of a stethoscope (see page 7-1) or a funnel (Figure 7-3-8) also help you detect the leaks. Once all the leaks have been found, perform a vacuum leak check.

Figure 7-3-7. Here, an ultrasonic leak detector is used to find a leak in the vacuum bag. It amplifies the hissing sound in areas where loud noises are a problem.

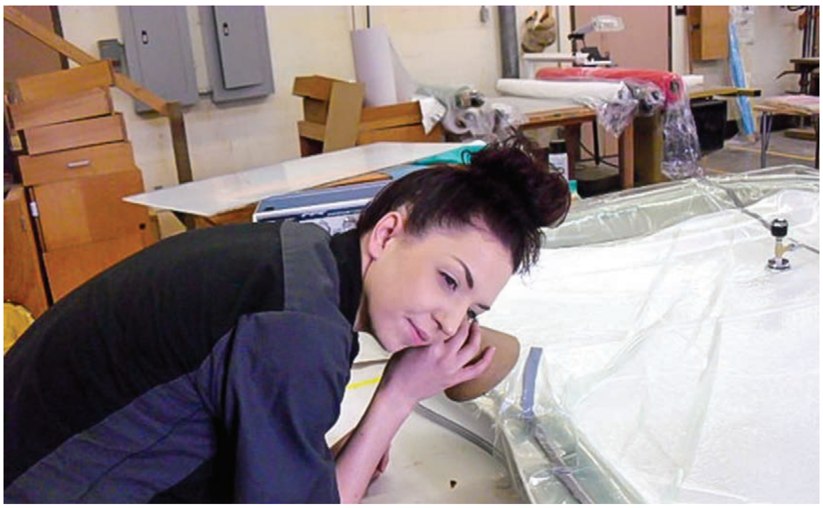


Figure 7-3-8. Here, a technician is using a funnel to find a leak.

To perform a vacuum leak test, you can use an additional vacuum valve fitted with a vacuum gauge as shown in Figure 7-3-9. A vacuum gauge is usually attached to the hot bond unit that could also be used.

After vacuum is drawn on a part, the vacuum hose is disconnected for about two minutes. With a vacuum gauge attached to another vacuum port, note the amount of mercury drop. A drop in mercury means that some leaks have not been sealed completely. Depending on the manufacturer's instructions, an allowable drop could be 1 in. to 4 in. of mercury in two minutes.

De-Bulking the Part

Before applying heat to the vacuum bagged part, let the part remain for a period with the vacuum on. This is called the *de-bulking* period. During this time, the layers are compacted, and extra air is evacuated from the part. This could be anywhere from 10 minutes for a repair and up to several hours for a manufacturing process. This is usually accounted for in the cure cycle. Once the heat is applied, the vacuum continues to pull air from the part. As the resin system goes through its chemical reaction, the resins start to flow out, and any air bubbles trapped in the part are pulled out. Some resins will gas during the cure, creating air bubbles. This is why the vacuum bagging should be left on during the entire cure.

Post-Curing Process

After the curing process, remove from the part all the layers of bagging film, sealant tapes, bleeders, breathers, and peel plies or release

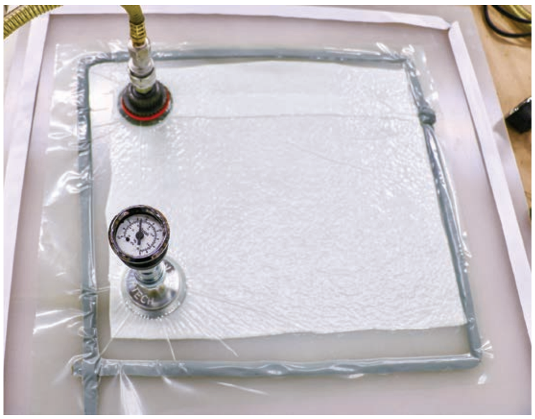


Figure 7-3-9. A leak test can be performed with a gauge attached to the vacuumed area. The vacuum hose is attached to a vacuum valve with a check valve in it. The gauge is connected to another vacuum valve. If a leak exists, when the vacuum hose is disconnected from the vacuum valve, the vacuum gauge drops.

films and dispose of them. These are considered tools used to provide a vacuum and do not stay with the aircraft. To keep the surface clean, you can leave the peel ply layer on the part until it is painted.

The rough surface of the peel ply is like a slight etch that allows the paint to adhere to the part better. If a perforated parting film was used, the surface must be scuff sanded to allow the paint to adhere. While sanding, be careful not to sand through the fabric.

Vacuum bagging can be used for parts that are cured with hot bonding units, heat blankets, heat guns, and heat lamps. The vacuum bagging process is used for repairing and manufacturing methods as in autoclaves, ovens, and against the molds.

Section 4

Composite Repair Materials

Some of the more commonly used materials for composite repair are discussed here.

Vacuum Bagging Films

Vacuum bagging films are used to cover the component and seal out air. They must be made with absolutely no voids or pin holes. If small holes exist in the film, air leaks through and less pressure is applied to the part while curing. Bagging films are made to be used in a variety of temperature ranges, from room temperature up to 750°F. It is important to use the correct temperature rating for the required cure temperature. The vacuum bagging film should remain flexible in high-temperature cures, especially around highly contoured shapes. If the bagging film becomes brittle, it can develop air leaks, which decreases the amount of atmospheric pressure applied to the part.

Selecting the appropriate bagging film depends on the method by which the part is cured and the required temperature of the cure. Bagging film is hydrophilic, or water sensitive, material. Moisture acts as a plasticizer. The higher the moisture content of the film, the more flexible and rubbery it becomes. During the vacuum bagging process, it is important that the film is as flexible as possible so it can be formed around any contoured shape.

It is extremely important to maintain the moisture content when storing this film. When the material is shipped, be sure it is enclosed in a plastic wrap. Cut only the amount to be used from the roll, and then store the rest of the roll in the original plastic wrapper. This is especially important in dry climates and in the winter when the moisture content can dry out and cause the film to become brittle. If the material becomes brittle, you can rehydrate it by placing it in a humid environment.

Calking Plate or Caul Plate

In some cases, a calking plate or pressure plate is used to add extra pressure that smoothes the contour of the part being cured. This is usually an optional piece made of wood, aluminum, or copper. If there is a slight curve in the part or component, the calking plate must also conform to the shape of the part. If it does not, a space between the part and the calking plate could collect resin and not cure properly.

Splash Mold

A splash mold is a mold that was created before the repair to give the exact contours of the part during the repair (Figure 7-3-10). This is like a caul plate that is made for a specific part. For more on how to make and use a splash mold, see chapter 11.

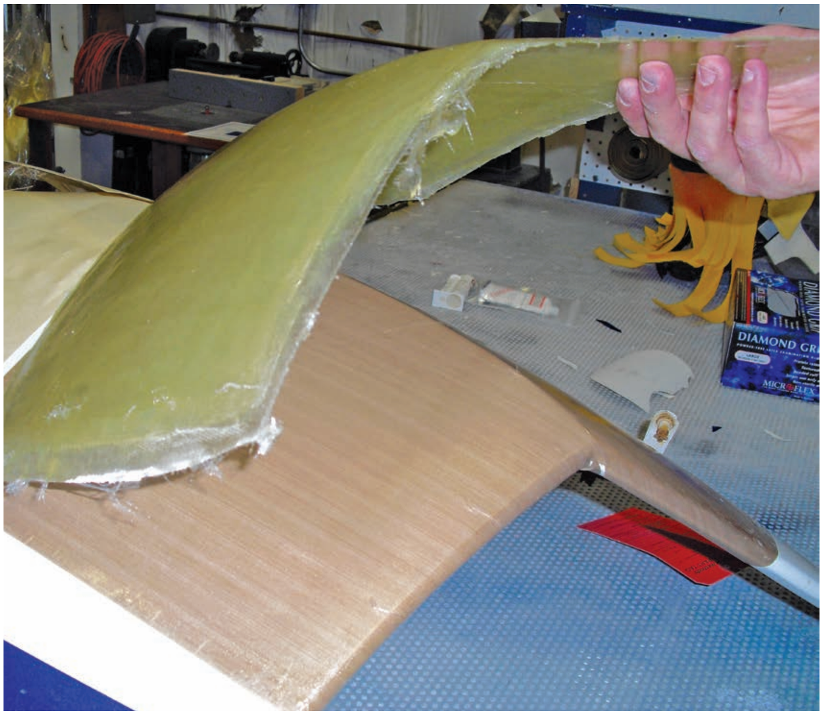


Figure 7-3-10. A caul plate, or in this case, a splash mold is used to help contour the repair.

Insulation Layers

Insulation can be added either outside the vacuum film or under the vacuum bagging film and over the heat blanket. It is used to minimize the amount of heat loss during the cure process. The insulation can be a few layers of fiberglass or a sewn blanket with many layers. If the repair work is done in a very cold environment, the heat blanket can lose heat around the edges and cause incomplete curing in some areas. An insulation blanket can prevent this from happening. Insulation is considered optional because if the thermocouple is directly under the heat blanket, the controller keeps adding heat to keep the blanket at the desired temperature.

Section 5

Vacuum Bagging Examples

Below are a few examples that illustrate the vacuum bagging process.

Self-Enclosed Bagging

When a part has multiple repair areas that need vacuum to be applied for curing, instead of vacuum bagging each area separately, one bag can be applied over the entire part. A large bag is made about three times the size of the part, allowing the bagging film to go inside and outside the part, thereby preventing the part from collapsing.

Cut a large sheet of vacuum bagging material and fold it in half. Seal two sides with sealant tape but leave the end open. On the open end, apply sealant tape to one side of the bagging film, but leave on the paper backing so the bag does not yet seal. Place the part inside the bag with all the proper bagging materials. Add a breather at this point because it allows air to flow completely throughout the bag.

Connect the air valve to the bag, and seal the bag on the prepared edge. Connect the vacuum hose and remove the air. It takes time to make sure all the areas are being covered in pressure and that no bridges are forming for resin to build up into. It is best if the bagging film is smooth over the areas of the repair. This reduces the chance of a resin buildup over the repair. If a resin ridge does form, you can remove it by sanding, being careful not to damage the new repair. The part is then cured (Figure 7-5-1).

Bagging on Both Sides of a Tight Radius

In the repair shown in Figure 7-5-2 the leading edge has a very tight radius. This requires that pressure is applied on both sides of the repair, inside and outside the leading edge.

To bag this part, place a line of sealant tape inside the leading edge and around the repair area shaped as a square. Place another line of sealant tape over the outside of the leading edge, so that the two lines meet on the edges. Be sure that a longer piece of sealant tape extends past the edge. Place a piece of bagging film over the top of the leading edge and press it into the sealant tape. Place another piece of bagging film on the inside and seal it to the sealant tape. Then, seal the open edge with another piece of sealant tape. Evacuate the air and check for leaks.

The most common place for air leaks to occur is on the inside of the curve of the leading edge. Much pressure might be needed to press the sealant tape into the part to produce a good seal. A very clean part is required to get the tape to stick to the surface.

The vacuum bagging operation can be done around a corner or over an edge, as illustrated in Figure 7-5-3. Trailing edges can also be vacuum bagged in this manner. If the repair is done to both sides of the edge, a calking plate should be used in the vacuum bag to prevent the repair plies from bending up or down as the air evacuates the repair.

Bagging with Access to Only One Side of the Part with Damage Extending through the Part

When damage extends through the skin but there is no access to the other side, use a very lightweight potting compound to fill any voids from the back and seal it. To do this, after the damage is removed and step sanded, fill the hole to seal off the backside. Mix the two-part potting compound and place it inside the hole, sealing all the edges of the hole, then allow it to cure.

Once the potting compound has cured, sand it to the contour of the hole. Place the new repair plies over the hole and then vacuum bag the part from the topside without drawing air up through the repair. Such a repair can add weight to the component and must be approved before performing the work. If weight has been added and it is a control surface, a weight check or balancing of the component is required.

Figures 7-5-1 through 7-5-3

Figure 7-5-1. To prevent the part from collapsing in any area, the entire part is put into a self-enclosing bag. The bag must be made about three times larger than the part to allow extra bagging film to contour around the part on the inside and outside, giving the proper amount of pressure on both sides of the part.

Figure 7-5-2. The part is bagged on the inside and outside with sealant tape and bagging film. The top bagging film is brought over the top of the repair and sealed to the bagging film attached to the inside of the part.

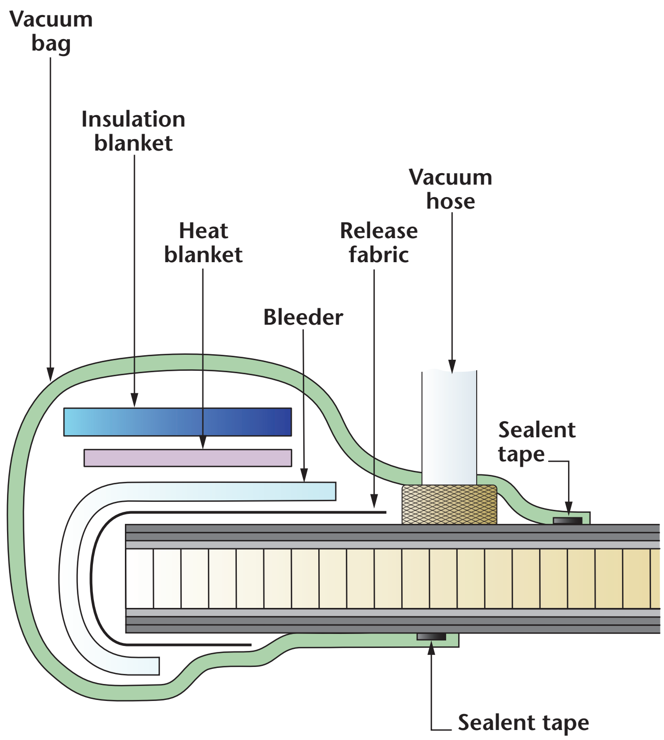


Figure 7-5-3. Stack-up of heat being applied to the edge of a piece of honeycomb panel.

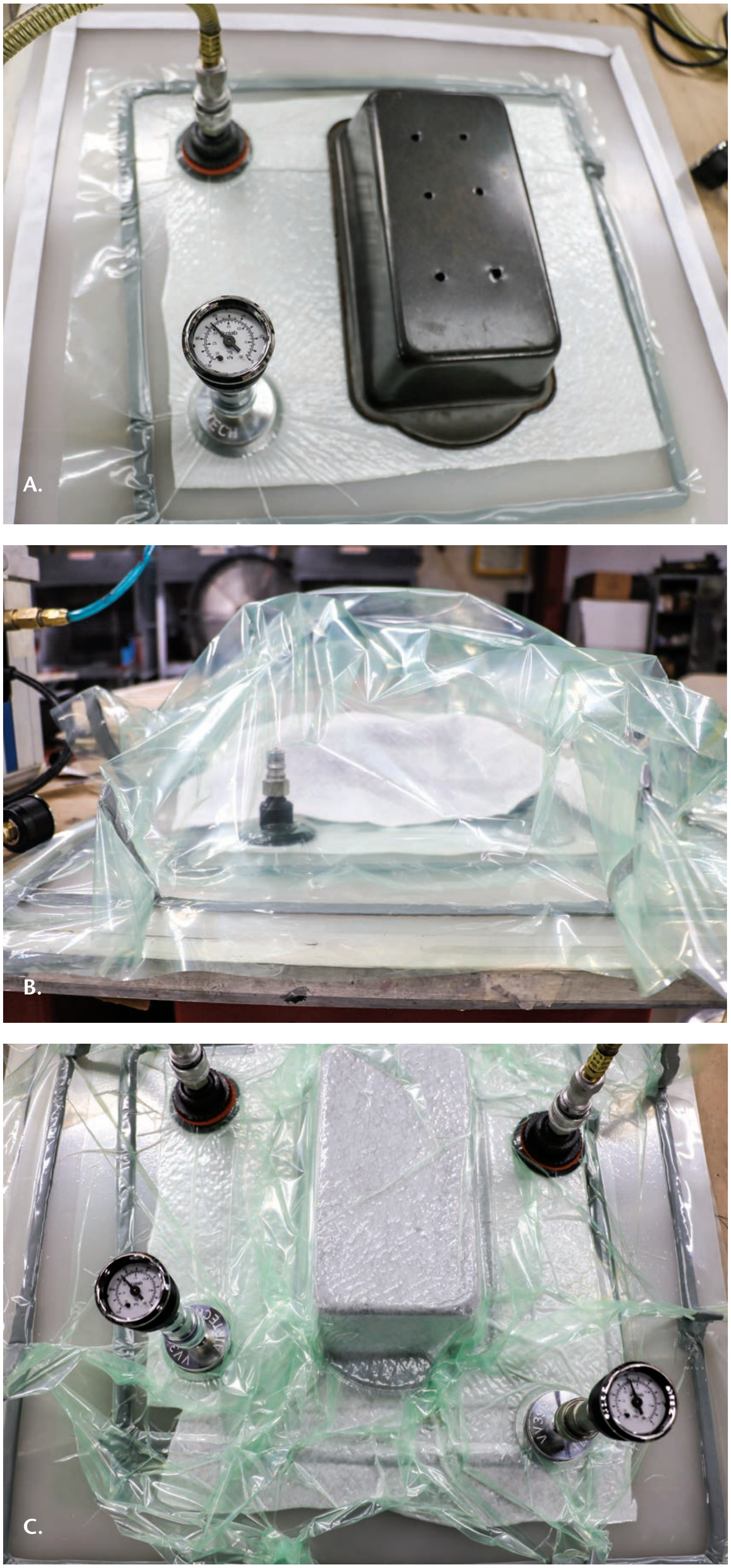


Figure 7-5-4. (A) The part is vacuum bagged, and a metal cage is placed over the part. (B) Breather material and a second vacuum bag are added. (C) Vacuum is pulled on the inside vacuum bag and the outside vacuum bag. No additional vacuum is gained.

Double Vacuum Bagging

Double vacuum bagging is used in vacuum resin infusion manufacturing (see chapter 5) where curing with an autoclave is desired but is not available or feasible. It does not apply any more vacuum than a single vacuum bag. However, it is used to vacuum the part after the resin is drawn through the fibers.

In this approach, the part is bagged as normal, then a steel, perforated box is placed over the area (Figure 7-5-4A). Breather material is placed over the box to allow air to flow, followed by a second vacuum bag on top of the box (Figure 7-5-4B). Vacuum is then applied to both the inside and outside vacuum bags (Figure 7-5-4C).

It is a myth that double vacuum bagging creates more vacuum. The vacuum applied is one atmosphere of pressure. Adding a second bag over the top does not create any more pressure on the part, because there is no more atmospheric pressure to apply. The air is already evacuated, and the pressure is the same. If more pressure is needed, such as when vacuum bagging at a high altitude, the best thing to do is to add shot bags to the top of the vacuumed part.

Section 6

Vacuum Bagging Troubleshooting

Leaks can prevent the optimal seal from forming in the vacuum bag. A good seal is required so that sufficient pressure is placed on the part and ensuring a good cure. To see if any leaks exist in a vacuum bagging setup, perform a vacuum leak check.

A simple way to check for leaks is to listen around the edges of the sealant tape with a stethoscope tube. If there is a hissing sound, it is an indication of a leak. You can also use a funnel with the large part next to your ear. An ultrasonic leak detector is available if you do very large repairs or in a loud area where hissing sounds are hard to detect.

The following problems can cause leaks in a vacuum bag setup.

Gaps in the sealant tape. The sealant tape is used to give a tight seal to the surface of the part. If a gap exists between the tape and the part, or between the tape and the bagging film, it will leak air. Check the most common areas first. Push tightly wherever the sealant tape is attached to the surface. Then check areas such as pleats or areas where the sealant tape overlaps. Areas that have a thermocouple wire or heat blanket cord can leak if not tightly sealed.

Fabric through the sealant tape. Sometimes in the vacuum bagging process, an edge of peel ply or bleeder material might overlap the sealant tape. The air will flow through this area. Take the vacuum pressure off, and reposition the material. Apply vacuum again to see if the leak is gone.

Cuts in the bagging material. In the bagging operation, it is common practice to use scissors and razor knives. If the vacuum bag is cut accidentally, causes a hissing noise. If the cut is small, a piece of sealant tape is sufficient to seal it. However, if the cut is larger, a smaller vacuum bag might have to be made and placed over the cut area. Line the cut area with more sealant tape and place a piece of bagging film over the area (Figure 7-6-1). Apply vacuum pressure again and the air is removed from the smaller bag at the same time as the original bag.

Dirty surface. If the area around the repair was not cleaned properly, the sealant tape might not adhere to the surface. It is important to keep the area around the repair clean. Place solvent on a clean cloth and wipe the area to clean away any grease or dirt that might be on the surface.

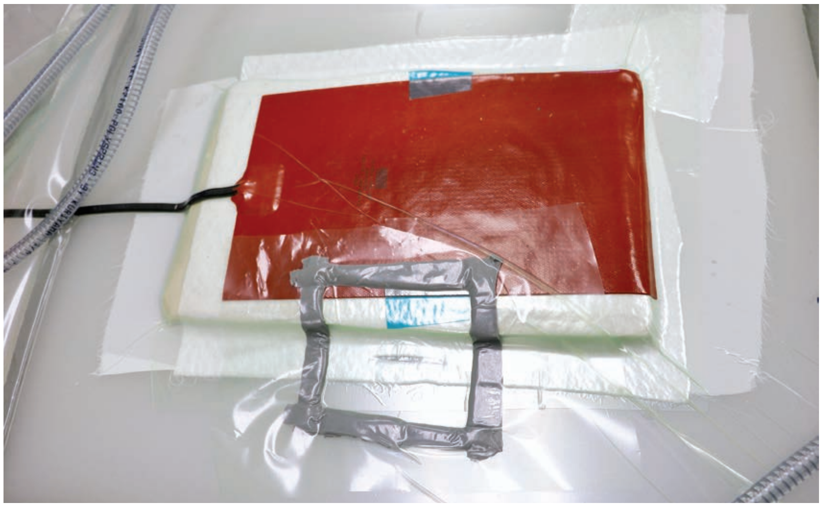


Figure 7-6-1. Repairing damage to the vacuum bag by adding a smaller vacuum bag around the cut surface.

Old tape and film. Very old sealant tape might not stick to the surface properly. If you cannot pull the minimum vacuum that is required, try using newer sealant tape. Dry, crunchy vacuum bagging film does not conform well to the part and could have tiny leaks in it.

Dirty valve. Make sure the vacuum valve does not have cured resin in it that might have been cured into it from a previous use.

8

Methods of Curing

Composite matrix systems cure through chemical reaction between a resin and catalyst or hardener. Some matrix systems require heat to cure the composite to achieve maximum strength; others cure at room temperature but can be accelerated by applying external heat.

Improper curing or handling during the cure has a direct effect on the strength of the repair. Failure to follow the proper curing requirements or improperly using curing equipment can cause defects that can, in turn, cause the repair to be rejected. For example, if the cure temperature is too high, the resins could evaporate out too much, and create a *dry* repair.

This chapter describes both room-temperature and heated methods for curing composite repairs and the equipment used in doing so.

Learning Objectives

REVIEW

- Importance of heat and pressure in curing composites

DESCRIBE

- Equipment used in heat curing processes
- Curing methods used with composites
- A ramp soak curing process

EXPLAIN

- Where to place a thermocouple when curing with a heat blanket
- Types of repairs autoclaves are used to make

APPLY

- Be able to understand composite repair instructions in an SRM

Left: Vacuum bagging the part before curing in an autoclave.

Section 1

Room-Temperature Curing

Some repairs can be cured at room temperature (65°F to 80°F) over a timespan of 8 to 24 hours, depending on the type of resin system used. The curing process can be accelerated by applying low heat (140°F to 160°F) to some room temperature resin systems. Check the material's documentation for the applicable cure time.

Full cure strength usually is not achieved until after five to seven days. If the repair calls for a resin system that can be cured at room temperature, it would be for parts used in areas with no exposure to high operating temperatures (usually above 160°F).

Room-temperature cures normally are performed on composite parts that are used on lightly loaded or nonstructural parts.

Section 2

Heat Curing

The most widely accepted method of curing structural composites uses resins that cure only at higher temperatures. These adhesives and resins require elevated temperatures to develop full strength and to reduce the brittleness of the cured resin. The high heat also shortens the curing time.

When a part is manufactured at a high temperature, the repair patches used in its repair might need to be cured at the same temperature to restore the original strength. These resins usually cure at a temperature of 250°F to 750°F. When making the repair, you should hold constant the amount of applied heat. You can do this by using a thermocouple to monitor the surface temperature of the repair area.

Although curing by applying heat, in some cases, produces a stronger repair, overheating can cause extensive damage to the component. If too much heat is applied, the matrix can vaporize (or gas) and cause bubbles to form on the surface. A dry area is also an indication of excessive heat.

For a preimpregnated material (pre-preg) repair, some aircraft manufacturers specify in the structural repair manual (SRM) that technicians can repair a part using less heat for a longer time than was used when the part was manufactured. For example, if a part was originally cured at 350°F for 1.5 hours, the repair can be done using the same materials and cure at 250°F for 2.5 hours. Repairing a part this way prevents the area around the repair from overheating. If the undamaged area surrounding the repair is placed under high heat a second time, micro-cracking (tiny cracks in the resin and fibers that are not visible) could develop and weaken the structure. This is one reason repairs are not cured in an oven or autoclave; instead, the heat is applied just to the area of the repair.

Although the fibers can withstand higher temperatures than the matrix, do not exceed the recommended curing temperature. Staying within the recommended temperatures reduces material disintegration or further delamination of the existing structure around the repair. Because some SRMs do not specify Celsius (C) or Fahrenheit (F) in the cure temperature information, technicians must know if the proper temperature is in degrees Celsius or Fahrenheit. For example, if a pre-preg material comes from Europe, the cure temperatures are stated in degrees Celsius. So if the manual states that the material cures at 180°, but a technician uses 180°F, the part will not cure in the set time (180°C = 350°F).

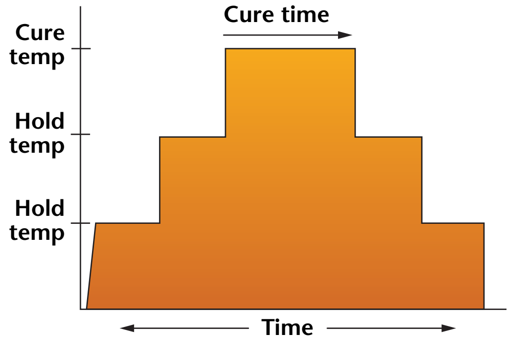


Figure 8-2-1. The step curing process is used where a technician adjusts the manually operated controller. The technician must watch the time and temperature closely.

When a part needs heat to cure, it is not enough to simply apply heat at the final cure temperature. It is important to allow a slow rate of temperature increase, known as a *ramp up*, so the resins have enough time to flow out of the fabric and into the bleeder material before going through the curing process. If this does not occur, a resin-rich area can result.

It is also important to allow a repair to cool at the proper rate. Composites gain much of their cure strength while cooling. A gradual cooling is desirable but not usually possible unless a controller is available. A controller is a device that regulates the temperature. Hot bond equipment includes the controller and a vacuum source for composite repair.

The step cure and ramp and soak heating methods are probably the most commonly used for composite repair because they ensure a slow rate of temperature rise and decline.

Step Curing

Step curing requires the technician to make heat adjustments at certain time intervals with a manually operated controller. The simplest thing that a controller does is maintain a selected temperature (called a *setpoint*). When used in this way, it is referred to as a setpoint controller. If the technician selects a setpoint above the current temperature, the controller applies heat to change the temperature as rapidly as possible to the new value. If a setpoint is selected below the current temperature, the controller turns off the heat to cool down to the setpoint as rapidly as possible.

Step curing is the process of bringing up the temperature slowly by raising the temperature to one point and holding it there, then bringing it up again and holding it there and repeating this process until the cure temperature is reached. This allows the heat to build slowly, allowing the resins to flow before reaching the cure temperature. The cure temperature is specified in the SRM and held for a time that is also specified in the SRM. After the cure time has elapsed, the temperature can be stepped down by reducing the temperature slightly and holding it there, then bringing it down slowly again and holding it there until room temperature is reached. This slow cooling down gives the component a stronger final cure (Figure 8-2-1).

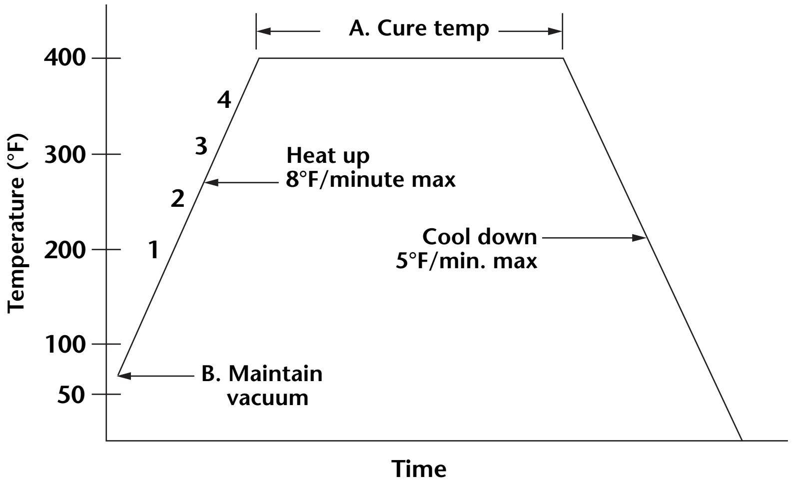
Ramp and Soak Curing

A programmable controller produces a more sophisticated and accurate curing than the step curing process. For this method, a controller is programmed in a ramp and soak mode that heats or cools a repair at a set rate. For example, Figure 8-2-2 shows a repair that needs to be heated at a slow, constant increase from room temperature to 400°F at 8° per minute. If room temperature is 70°, it takes about 41 minutes to reach the 400° mark (that is, 400° – 70° = 330°; 330° ÷ 8° each minute = 41.25 minutes). This heating process is called the ramp.

Once the repair has been heated to 400°F, the SRM might require this temperature to be held for a set time. In this example, the temperature is held for 2 hours. When the controller operates during these 2 hours it is referred to as the *soak*.

The SRM might specify that the temperature be ramped down to room temperature at a set rate after the soak. In our example, a 5° per minute cooldown rate takes 1 hour and 6 minutes (400°F – 70°F = 330°F; 330°F ÷ 5°F each minute = 66 minutes). Both heating and cooling cycles are combined to graphically show a ramp and soak profile, as shown in Figure 8-2-2.

SRMs typically do not give the ramp up and ramp down times because the starting temperatures might not always be the same. In the example shown in Figure 8-2-3, the outside temperature is 30°F and the final cure temperature is 250°F. In this scenario, the ramp up is longer than the warm climate line shown, which starts with a warmer temperature of 105°F.



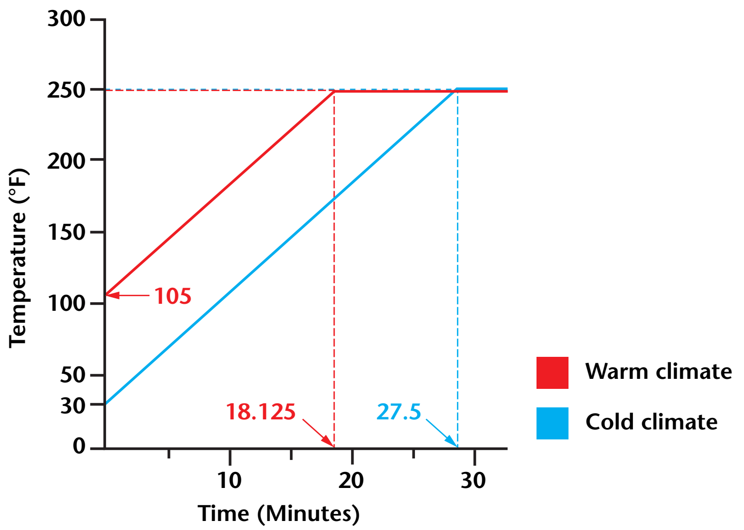
A. Refer to the component repair for the required cure temperature and time.

Examples:

1. **Cure at 200°F ±10 and hold for 220 minutes**
2. **Cure at 250°F ±10 and hold for 155 minutes**
3. **Cure at 300°F ±10 and hold for 130 minutes**
4. **Cure at 350°F ±10 and hold for 120 minutes**

B. Maintain 22 in. of vacuum minimum during entire cure cycle

Figure 8-2-2. Profile for a ramp and soak cure.



Warm Climate

If the cure is to be done in a warm climate where the temperature outdoors is 105°F, the cure ramp up time is to be at 8°F per minute.

Therefore, 250° – 105° = 145° ÷ 8° = 18.125 minutes to climb to the cure temperature of 250°F at a rate of 8°F per minute.

Cold Climate

If the cure is to be done in a cold climate where the temperature outdoors is 30°F, the cure ramp up time is to be 8°F per minute.

Therefore, 250°F – 30°F = 220°F ÷ 8° = 27.5 minutes to climb to the cure temperature of 250°F at a rate of 8°F per minute.

Figure 8-2-3. Ramp up times differ between cold and warm climates.

Section 3

Equipment Used for Heat Curing

Equipment is available for many types of heat curing processes, whether for a mobile repair or in a shop; for manually controlled or programmed curing cycles; and for heating by blanket, lamp, oven, or autoclave. Equipment is also made that records the temperatures used in a curing cycle so you can verify that the cycle matches what an SRM specifies for a repair.

Hot Patch Bonding Machine

A hot patch bonding machine performs two functions:

- It applies atmospheric pressure using a vacuum pump (*vacuum bagging*).
- It applies and controls the heat.

Originally, hot bond units were designed for repairing composite components when an oven or autoclave was not available. A portable unit was needed to complete the work. Hot bond units are portable, and it has become apparent that they are ideal for repairs that do not require remanufacturing, such as those typically called for in the SRM (Figure 8-3-1).

The simplicity of these units makes repairs easier and more affordable for maintenance facilities. They are small, portable units that can easily be carried to the repair site. Components do not necessarily have to be removed from the aircraft, which saves time and money.

Figure 8-3-1. Hot patch bonding is done with a heat blanket and is normally used with a vacuum bag. Controller devices are used, and the temperatures and times should be recorded.

Hot patch bonding machines use heat blankets that have electrical coils bonded into a rubber pad or blanket. These blankets can heat up quickly unless they have a monitoring unit attached to control the temperature and its rise or fall. More details are in the Heat Blankets section later.

A monitor or controller is a device that works with the hot patch bonding equipment to maintain a constant temperature or changes the temperature at a specific rate. In working with composites, the temperature must be controlled both at a constant and specific rate of change. To achieve professional results, it is critical to perform these functions with minimum effort and maximum efficiency. The simplest function the controller does is to maintain a temperature for the repair. The specified temperature is called the setpoint of the repair. When the controller is working in this mode, it is called a setpoint controller.

Another function the controller might be able to perform is the *ramp and soak*. The controller allows the temperature to slowly rise at a specific rate, then holds the temperature constant, and then allows a slow decline of temperature at a specific rate.

Some companies require that a permanent record of the cure cycle be included in the log of the aircraft repairs. Recording the temperatures of the curing process can be done by using a temperature recording unit. Some hot bond units include a recorder in the unit; in others it is a separate unit. More details are in the Temperature Recording Units section later.

> **WARNING:** Do not become dependent on the recording unit to ensure that the part is repaired correctly. Many aspects of a repair require close monitoring. Just because the repair was cured at the proper temperature does not mean the repair is airworthy.

Controllers in the hot patch bond unit use thermocouples—placed beside the repaired area, under a heat blanket, and under the bagging film—to sense what temperature is being delivered to the part. The thermocouple sends the temperature information to the controller, which then applies heat or stops heating depending on how the controller is set. More details are in the Thermocouples section later.

If the repair is over a spar or a *heat sink*, the temperature in that part of the repair could be significantly lower than in areas not over the spar. In this case, a fiberglass insulator (two or three layers of fiberglass) can be laid over the spar area to hold in the heat. Place it over the vacuum bagging area, and if it gets too hot, remove it. Monitoring the area with a temperature sensor also works well.

Figure 8-3-2. Controllers are actually fairly simple in their operation. Settings are straightforward, indicators are clearly represented, and programming is not complicated.

Many shops and FAA officials think that the thermocouple recording is to show that the repair was done correctly. Some recordings do not have the time and date on the recording, so it could have been done on any repair, at any time, not necessarily on the part being repaired. Many things can happen during the repair: the improper type of repair materials used, patches placed with the warp threads going in the wrong direction, oil or water on the surface, or incorrect cleaning, improper bagging, improperly sanding, or many other reasons. Any of these could cause the repair to fail. It is not the number of thermocouples or recording of the temperature that ensures a correct repair, it is the workmanship of the technician.

If a recording is to be used, it should have the time and date stamp on it and, if possible, the aircraft part number being repaired to identify it as the printout for the part actually being repaired.

In Figure 8-3-2, the controller face setpoint is 148°F. In this example, if the thermocouple is sensing only 144°F, it applies heat with the heat blanket or heat gun until the thermocouple senses 148°F. If the controller is in the cooling down process and is set to 100°F, the controller stops applying heat until the temperature drops below 100°F.

Ramping up the temperature to its final cure temperature too quickly does not allow enough time for the resins to flow properly before they reach the curing temperature (soak). This could result in a resin-rich area. For example, if 250°F is the final cure temperature and the controller applies heat too soon, it will reach the 250°F mark as soon as it can (usually within 30 seconds). The resin and catalyst mixtures need time to slowly start their chemical reaction and bleed out excess resin and air pockets before the final cure temperature is reached.

It is also important that the heat be allowed to decrease slowly so the part does not cool too quickly. Composites gain much of their strength in the cooling process, and cooling slowly prevents the part from becoming brittle. Slow temperature rise and fall is desirable but can usually be done only by using a monitor or controller.

A graph of a technician operating a setpoint controller might look like Figure 8-3-3. Here, the temperature climbs quickly from room temperature (T1) to the setpoint temperature (T2). A controller can be used in many ways.

Heat Blankets

Heat blankets are used with a thermocouple and a controller or a hot bonding machine to regulate the heat. Heat blankets are probably the most widely accepted form of applying heat to a composite component for repair work. They heat the repair area uniformly without heating an area that is larger than necessary. They can be used in a vacuum bagging setup to hold the heat directly onto the surface.

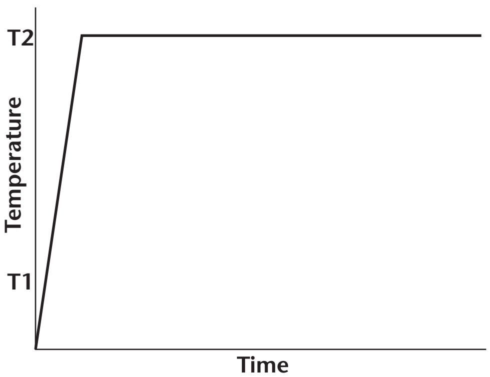


Figure 8-3-3. A controller will advance very quickly to the next setpoint, unless it is programmed for a slow ramp rate.

Heat blankets are made of a flexible silicon and come in a variety of forms and sizes. A thermocouple is used under the blanket to monitor the heat. A controller or regulating unit powers heating coils in the blanket (Figure 8-3-4) to keep the temperature at the desired setting.

Most manufacturers recommend using a heat blanket for curing repairs because of its ability to evenly heat the part. The ramp and soak method of heating is easily done with the heat blanket method and results in a stronger cure. The heat blanket must cover the repair completely and usually is an inch or two larger than the largest size patch. However, if the heat blanket is too large, the heat can damage surrounding areas of the part.

The heat blanket is placed in a vacuum bag over the repair area so no matter where the repair is being done, the heat blanket is over the patches being cured. For example, if the underside of a wing is to be repaired, the vacuum bagging film with vacuum applied holds the heat blanket tightly to the patches as they cure.

Some heat blankets are very flexible and can bend around curved surfaces, such as a leading edge; others are made for flat use only. A flat heat blanket should not be used on a curved surface because bending it breaks the wires in the heat blanket. Customized heat blankets made to the shape of a part can be used if the part is sharply contoured. This is most commonly used if the same type and size of part is repaired repeatedly.

Figure 8-3-5 shows a typical bagging operation with a heat blanket.

Limitations of Heat Blankets. To make the best use of heat blankets, in addition to being careful not to flex a flat blanket too much, you should be aware of their limitations.

- Using an oversized heat blanket can draw too much current for the machine to handle. Find out what maximum size heat blanket your machine can run. For example, the instructions might say, "Do not use heat blankets that exceed 3,000 watts of power." If the heat blanket you have uses 5 watts per square inch, the largest size blankets that could be used would be around 24 × 24 inches, or 10 × 60 inches, or 40 × 15 inches.

Figure 8-3-4. Fine wires are imbedded in the heat blanket and are controlled by a hot bond unit.

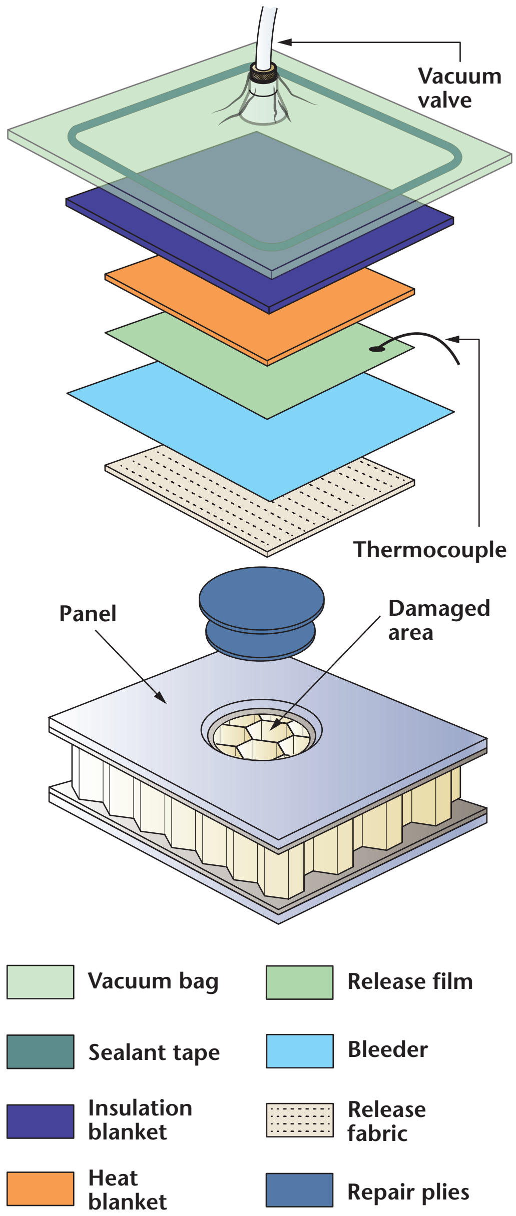


Figure 8-3-5. A typical bagging operation with a heat blanket. Make sure there is a release film (vacuum bagging film works great) over the bleeder. The thermocouple goes on top of the release film. If the thermocouple is in direct contact with the bleeder, resin will stick to the thermocouple, possibly ruining the thermocouple.

- Some hot bond equipment allows you to use more than one heat blanket on the same ramp and soak. However, the controller functions are based on only one thermocouple input, so there will be master and slave heat blankets. The position of the thermocouple determines the master. When using more than one heat blanket, exercise the following precautions:
  - Use heat blankets that are the same size and use the same amount of wattage per square inch.
  - Continually monitor the process temperature of the heat blanket that does not have the thermocouple. You can do this with a digital thermometer, a solid state recorder, or any other suitable temperature-measuring device. Touch each blanket briefly to determine if one is substantially hotter or cooler than the other.
  - As much as possible, use heat blankets in combination with the same type of materials and environment. Different materials and shapes absorb and dissipate heat at different rates. For example, if a repair is done on a work table, make sure that all heat blankets are on the same table with the same insulating materials above and below them.
  - Never leave the repair process unattended.
  - Use thermostatically controlled heat blankets for failsafe temperature limitations. These types of heat blankets open a fuse when the temperature reaches a certain point, stopping the heat from burning a part. For example, for a repair that cures at 350°F, a blanket with a rating of 400°F could be used. If the temperature goes beyond 350°F, it can only rise to 400°F before the fuse opens, saving the part.
  - Never use a heat gun and a heat blanket together in the same repair process run.

Heat Guns

If the shape of the part to be cured is sharply contoured, a heat blanket might not be flexible enough to conform to the shape of the part. If this is the case, you can build a structure to hold in heat, then use a heat gun with a hot bonding machine to apply the heat.

Heat Gun Structures

Structures used to hold in heat are the tent and the box.

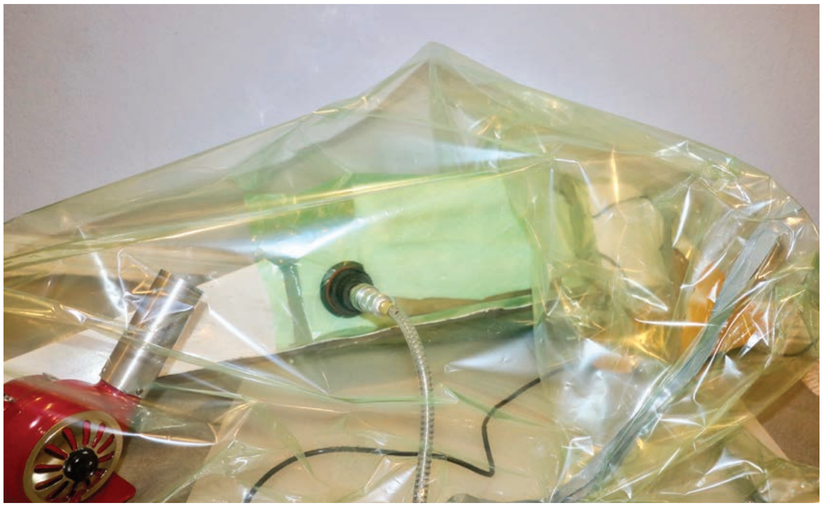


Figure 8-3-6. The repair is vacuum bagged, then an outer bag is placed around the repair area. This forms the tent to hold in the hot air. The heat gun blows air up toward the top of the bag. There is a thermocouple at the repair site, and the heat gun is plugged into the controller. With the ramp and soak feature, the heat gun follows the program.

Heat gun tent. First, place the part in a vacuum bag, then make another tent of bagging film over the part to hold the heat in around the component with sealant tape. This tent over the repair uses many large pleats to contain the hot air from the heat gun. To prevent excessive curing, be sure the heat gun is not pointed directly at the part. If the cure temperature of the part is 250°F, the bagging film used for the tent should be able to withstand a high heat range (Figure 8-3-6).

Heat gun box. An alternative to using vacuum bagging film is to construct a box of foam insulation boards that are lined with aluminum, which hold in the heat. If needed, you can modify a cardboard box (Figure 8-3-7) if you do not exceed 150°F.

CAUTION: Do not cure at temperatures higher than 150°F with a cardboard heat gun box.

Figure 8-3-7. A heat gun is used with a controller to cure a curved part to which a heat blanket cannot conform to the shape. Here, a box is used to keep the heat in (150°F max for cardboard).

Using a Heat Gun

The heat gun is monitored with a thermocouple and the controller of the hot bonding controller unit. When using a heat gun to cure a composite part, it must be controlled with a monitor. A typical heat gun can generate temperatures of 500°F to 750°F when it is left on constantly. If the cure temperature is 180°F and a heat gun is used to cure the component, you should monitor the heat gun with a controller to maintain a constant temperature.

To control a heat gun, use a thermocouple with the controlling unit to keep the temperature constant. The controller allows the heat gun to reach the desired temperature, and then the thermocouple senses this and shuts off the heat gun. The heat gun cycles on and off around this temperature to hold the temperature fairly constant.

Problems can occur if the heat gun is focused on one place of the repair. The heat gun nozzle should not point directly at the surface, because excessive evaporation of the resins in one spot can leave dry areas, which are grounds to reject the repair. The objective is to create an oven environment just around the part.

Heat guns can present a fire hazard and should never be left unattended during the cure process.

Heat Lamps

For many years heat lamps have been used to cure composite parts. However, with the availability of precision heating equipment, heat lamps are generally no longer recommended for structural repairs. On the other hand, if no other heating equipment is available, heat lamps can be used satisfactorily to accelerate room temperature resin cures (Figure 8-3-8).

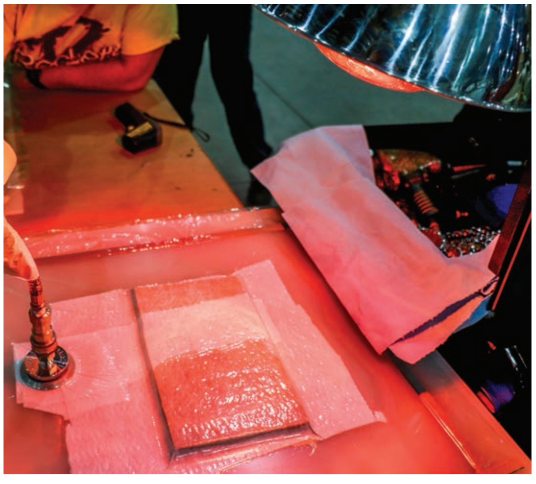


Figure 8-3-8. Heat lamps can be used to accelerate a room temperature cure on nonstructural parts.

Heat lamps should not be used on resins that must be cured at a very high temperature, such as pre-pregs. They are also not the most reliable heat source because the temperature cannot be accurately controlled and the heat can localize in one spot. If the heat lamp is too close or is left on too long, the part can be scorched or blister.

Drafts in the work area can also affect the amount of heat delivered by a heat lamp. The light of the lamp must hit all areas of the part. If there is a shadow on any area, it will not cure at the same rate as a part with the light shining on it.

To help monitor the temperature, use a high-accuracy, noncontact infrared temperature gun with a digital thermometer. Always hold the gun the same distance from the part to compare readings from different areas. To control the temperature, raise or lower the heat lamp. The closer the lamp is to the part, the hotter it gets. Monitor the lamp frequently to avoid an overheating condition.

Ovens

Ovens offer controlled, uniform temperature over all surfaces. The oven must have vacuum ports installed to provide vacuum pressure while curing. Manufacturers frequently use oven curing (Figure 8-3-9). Ovens used to cure composites must be certified for that purpose. When using an oven for repair work, the part must be removed from the aircraft and the part must be small enough to fit in the oven.

If an aircraft part has metal hardware attached, do not cure it in an oven because the metal heats up at a faster rate than the composite material. This is called the coefficient of thermal expansion. The metal expands at a different rate than the composites at a high temperature and could deteriorate the adhesives under the metal, causing it to break away from the composite and cause bond failure. In these parts, fasteners, lightning protection, and any metal bonded to the structure can fail.

Ovens can also present a problem by heating up the entire part, not just the repair area. The areas that are not being repaired are subjected to very high temperatures and can deteriorate the existing structure with micro-cracking. Micro-cracking is very fine cracks forming in the resin and the fibers; these cracks cannot be seen with the naked eye.

Using a localized heat source such as a heat blanket is the preferred method for repairs.

If the damage is very large, the metal components are removed and the part can be put in a mold and can be repaired or remanufactured.

Autoclaves

Autoclaves are used in manufacturing to produce very strong, compressed components. An autoclave (Figure 8-3-10) cures by applying heat and substantially more pressure to a part—two, three, or even more atmospheres of additional pressure. In contrast, parts that are vacuum bagged are subject to one atmosphere of pressure. Autoclaves usually are used in manufacturing processes and not for repairs unless the part must be remanufactured.

If a large and extensive area of damage on a part needs to be repaired, it is best to send the part to a remanufacturing facility. Such facilities have the capabilities, molds, and an autoclave to handle these repairs. In this process, the part is placed into the original mold, vacuum bagged, and placed in the autoclave, which then heats to the curing temperature at a controlled rate and applies additional pressure. If an extensively damaged component is not cured with molds, high heat, and adequate pressure, the part might not regain its original strength.

When curing in an autoclave, thermal expansion is a problem, just as when using an oven. You must remove all metal from the part before curing in an autoclave. The metal expands at a different rate than the composites at a high temperature and could deteriorate the adhesives under the metal, causing it to break away from the composite and cause bond failure. So, fasteners, lightning protection, and any metal bonded to the structure can fail.

Use caution when operating an autoclave. They can be very dangerous if not operated properly. The seals in the autoclave should be inspected regularly to make sure nicks or cracks have not formed in the rubber and that the rubber has not deteriorated from time and extensive heat. If the seal fails, the internal pressure could cause a catastrophic explosion.

Thermocouples

A thermocouple senses the temperature of the part and relays the information to the controller or monitor (Figure 8-3-11). It should be used under the heat blanket, close to the repair, between the blanket and a release film. Do not place the thermocouple in the repair area or the wet resins will form to the shape of the thermocouple.

Figure 8-3-9. Oven curing is often used in the manufacturing process to cure many parts at the same time.

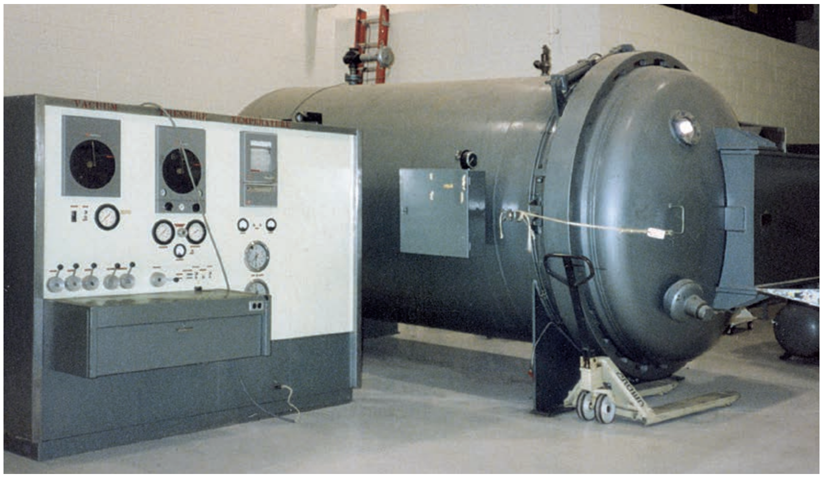


Figure 8-3-10. An autoclave provides both heat and pressure under extremely controlled conditions.

Figure 8-3-11. A thermocouple is placed under the heat blanket to sense the temperature. It is plugged into the controller that runs the heat blanket. It can also be used on top of the heat blanket if a layer of fiberglass is used as insulation between the blanket and the thermocouple.

Thermocouples are made of two types of wire—iron/constantan—twisted together to sense the temperature (Figure 8-3-12). The older style thermocouples are twisted on the ends, and many SRMs specify to put them directly into the wet resin of the repair. After curing, they would be imbedded into the repair. In the past, the ends were clipped off and the wires were left in the area of the repair. This had the undesirable effect of causing a stress concentration. Do not leave anything in the repaired area.

The wires of the thermocouple can get tangled and twisted anywhere along the wires' length. If a break exists in the wire, the thermocouple could be sensing the air temperature outside the repair area, which causes the heat blanket to heat up because the thermocouple is telling the controller there is not enough heat. This could be a very serious situation. The part could burn enough that it is destroyed. Make sure your thermocouple wires are in good condition and not kinked.

Newer thermocouples are encased in a flexible cable, so they are protected against kinking and breaking (Figure 8-3-13). The ends do not need to be twisted because they are bonded to a probe or flat end. The tip of the probe is the sensing device. Do not place the probe in the wet resin area. Instead, place it on top of the release film, under the heat blanket, and next to the repair area.

Another common problem associated with thermocouples is that they slip out of place during the vacuum bagging process. In the cure cycle, if the thermocouple does not sense the temperature under the blanket, it can cause problems. Make sure the heat blanket covers the tip of the thermocouple or probe. Use a piece of high-temperature flash tape to secure the thermocouple before the vacuum bagging is applied.

Some SRMs call for using multiple thermocouples in a repair. This usually is for one to control the hot bond unit, and other as a backup; if one thermocouple fails, the other can record the actual temperature around the repair. You can use multiple recording thermocouples depending on the area of the repair.

A common practice is to use a hot bond unit with several thermocouples to monitor the area of the repair. These are used to see if a hot spot exists anywhere in the repair area. A hot spot could be caused by metal taking the heat away from an area, and it does not heat up to the required temperature. Insulation blankets or a few layers of fiberglass can be used to allow more heat to stay in the area. Do not place the blanket inside the vacuum bag; if it is outside the vacuum bag and the temperature gets too hot in that area, you can remove a layer of fiberglass. If a recording of the repair is required, keep the record with the logs of the aircraft.

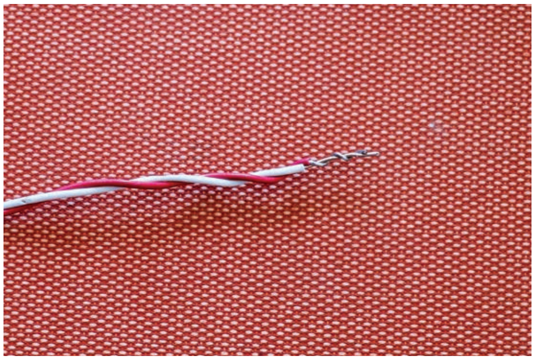


Figure 8-3-12. Iron and constantan wires are twisted together at the ends and used to sense the temperature of the component during curing.

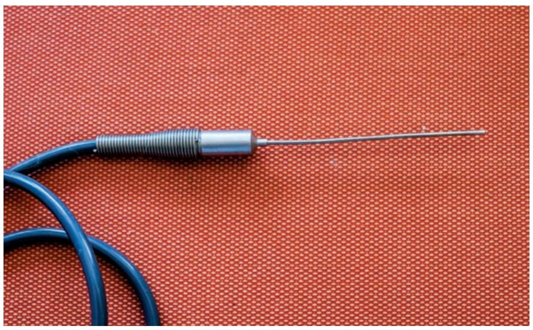


Figure 8-3-13. Iron and constantan wires are twisted together and potted into the probe area. The flexible outer cord prevents the wires from kinking and causing opens in the wire.

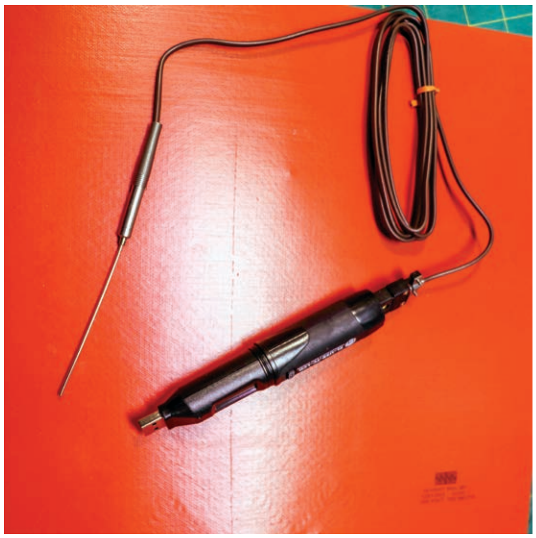


Figure 8-3-14. A temperature recording unit consists of a thermocouple and the recorder. The thermocouple is placed in the repair area, and the recorder is turned on. After the cure, the unit is plugged into a computer to generate the ramp and soak profile that was just completed.

Temperature Recording Units

A recorder is a unit that records what temperature the thermocouple is reporting for a time (Figures 8-3-14 and 8-3-15). If you are running a ramp and soak profile, the recorder senses the ramping up of the temperature, how long it takes to get to the cure temperature, how long it is held at the cure temperature, and what the temperature is during the ramp down. It also records how long it takes to cool to room temperature. The record provides a handy way to check that you have cured the repair for the required time at the correct temperatures.

Many people see the record as a way of checking that the repair was completed correctly, but it does not do that. Doing so can give the technician a false sense of security.

Many things can go wrong with a composite repair: the wrong resin type, incorrect mixing, out of date material, too little pressure applied, surface contamination, incorrect orientation of the plies, using the wrong type of repair, and not including some lightning protection. The list can go on and on. But if it was cured correctly and has a paper indicating so, it can give a false impression. Technicians must know about composites and their repair procedures and record everything that was done, not just the temperature at which it was cured.

If you are required to use a recorder, it should clearly mark the date and time of the recording. Some advanced recorders allow the information to be downloaded into a computer where the aircraft part number and other information about the repair can be recorded. This information can be used in a computer-based maintenance record.

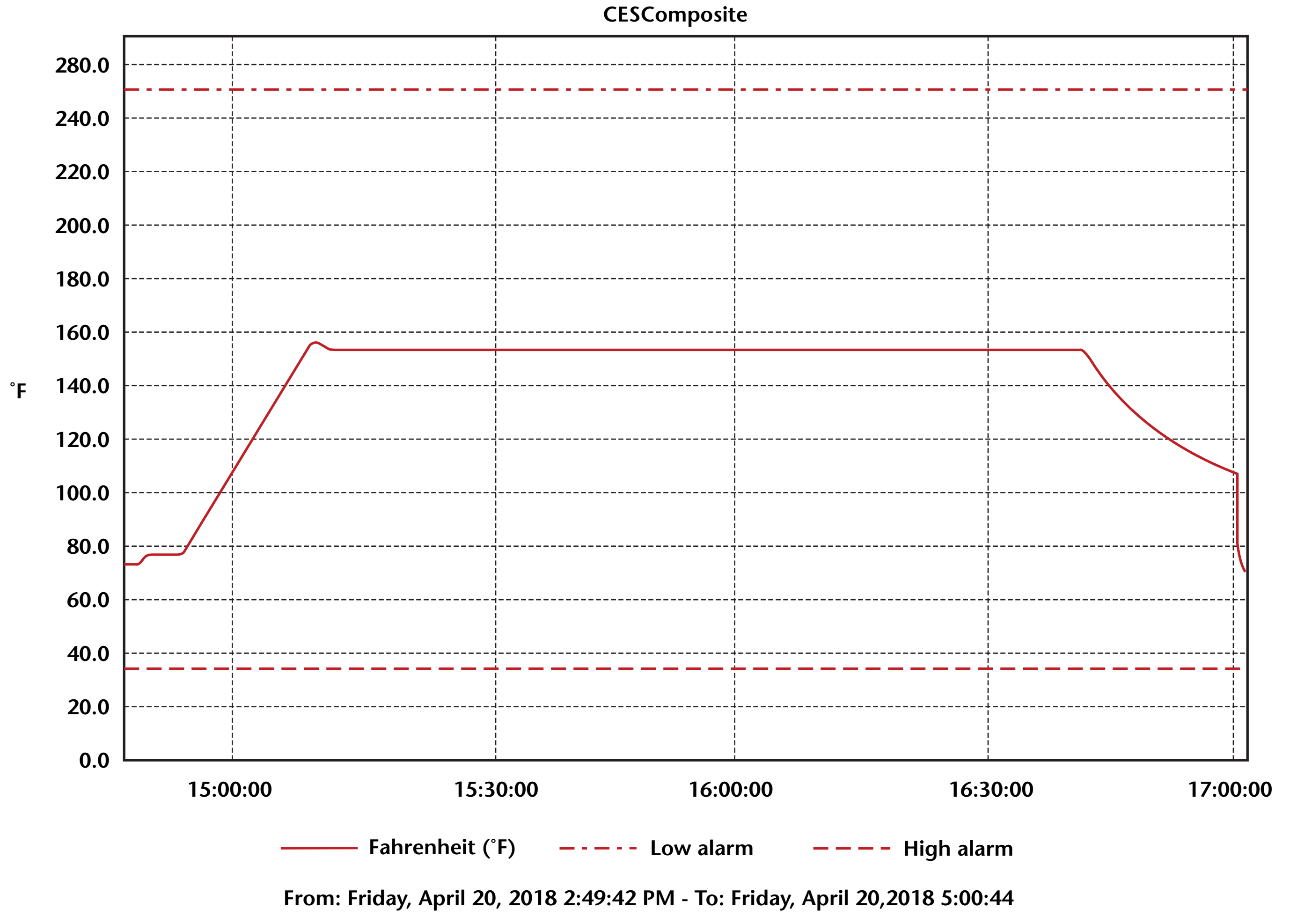
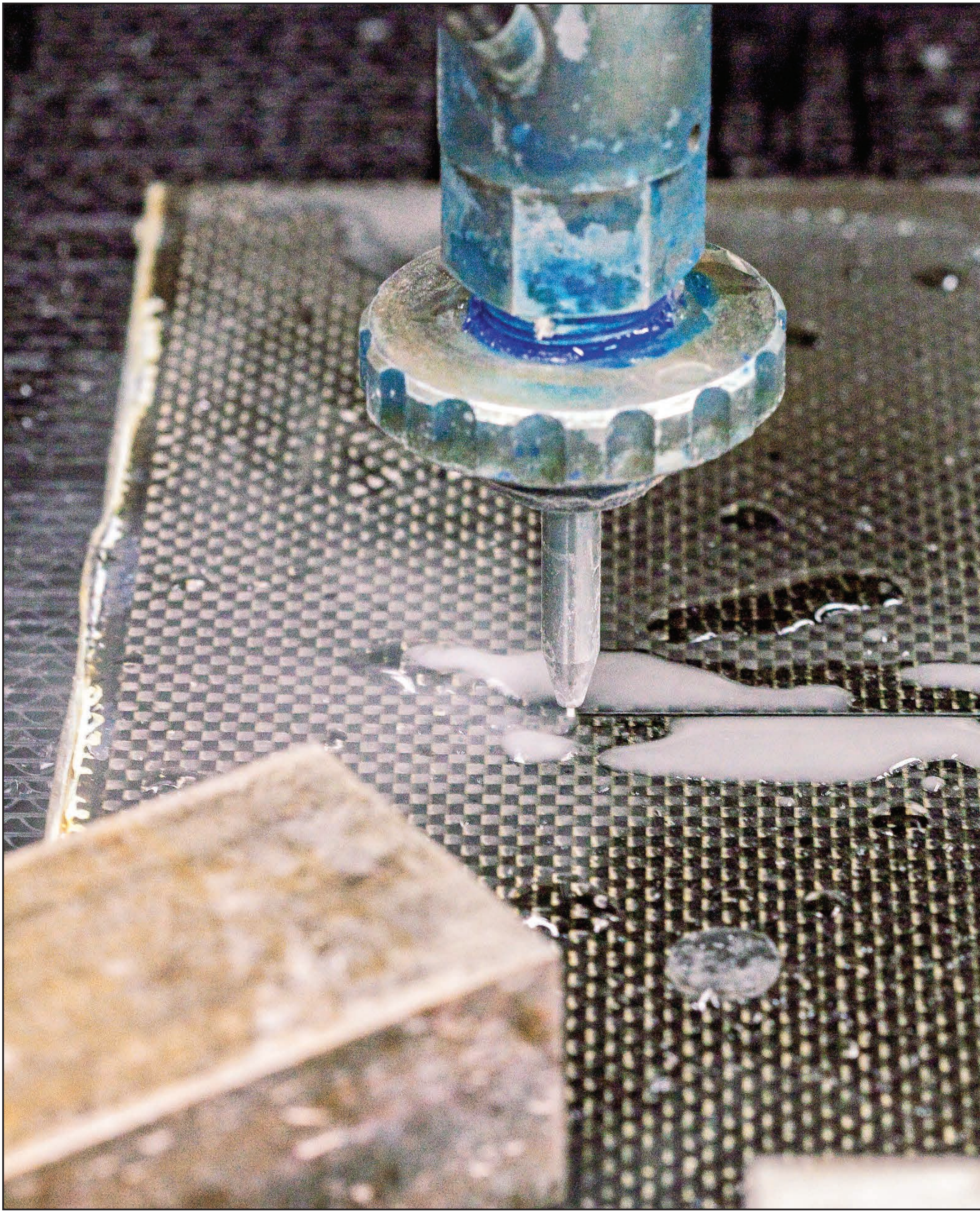
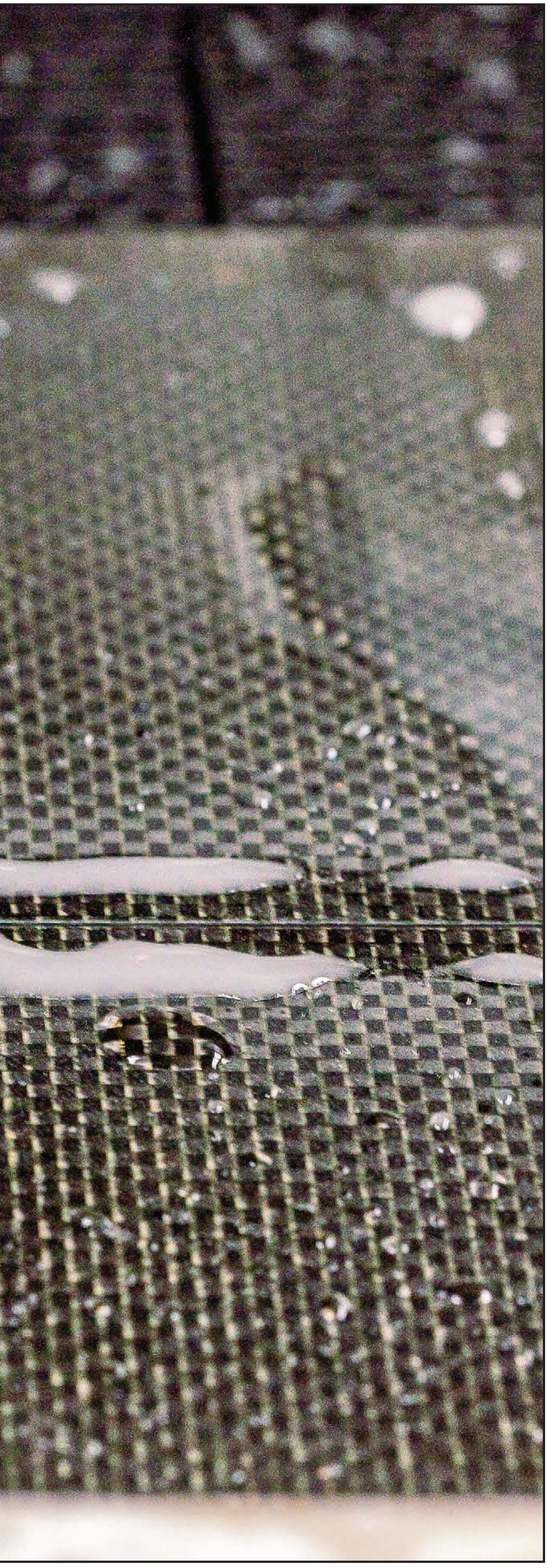


Figure 8-3-15. The recording is generated in a computer, and part numbers and additional information can be stored for an aircraft.





9

Machining Composites

Completing an airworthy repair of a composite structure is not any more difficult than conventional repairs, but the techniques, materials, and tools are different, demanding proper training and concentration. For example, composite materials act differently from traditional aluminum when machined. Each type of fabric machines differently from other types of fabrics. If you do not do a composite repair correctly, the repair does not develop the full-strength characteristics that are necessary in a composite structure. Before attempting a repair of a composite component, you should consult the manufacturer's structural repair manual (SRM).

Section 1

Cutting Uncured Fabrics

Fiberglass or carbon/graphite fabric in its raw state, meaning no resin has been applied, can be cut with conventional fabric scissors. On the other hand, to cut aramid fabric in its raw state, you will need scissors with special steel or ceramic blades and serrated edges. The serrated edges hold the fabric and cut without fraying the edges. Diamond-charged scissors are steel-bladed scissors that are heat treated with a fine diamond dust on the cutting edge. They are useful for cutting raw aramid fabric. These scissors cut through aramid with ease and last many times longer than conventional fabric scissors. Conventional scissors separate the weave and do not cut the fabric properly unless they are very sharp. If used to cut Kevlar® and other aramids, the scissors' edges also dull quickly and must be sharpened frequently.

Learning Objectives

REVIEW
- Safety precautions to take with composites
- Importance of the SRM when making any repairs
- Meaning of the term composite fastener

DESCRIBE
- How to cut uncured composite fabrics
- Cutting, machining, drilling, and countersinking cured composites

EXPLAIN
- Preventing fastener corrosion used with composites
- Why fasteners used in composites are different from those in metal
- Reasons to sand by hand

APPLY
- Choose proper tools for drilling and cutting composites

Left: Waterjets quickly and precisely cut composite fabrics.
Courtesy of Wichita State University, National Institute for Aviation Research

Scissors that are used to cut aramid should be used to cut only aramid, never fiberglass or carbon/graphite. The same applies to scissors made to cut fiberglass. They should never be used to cut carbon/graphite, and visa versa. Although fiberglass and carbon/graphite can be cut using the same type of scissors, they should not be used interchangeably. The different fabrics tend to dull the cutting surface in different ways.

Keeping your scissors and tools reserved for specific materials dramatically extends the tools' life. Make a mark with black, white, and yellow paint on the scissors' handles and other tools to identify the material they are used to cut. Yellow for aramid, black for carbon/fiber, and white for fiberglass. These match the colors of the fabric (Figure 9-1-1).

Figure 9-1-1. The scissors on the left (A and C) are standard fabric scissors marked with black and white paint. They also work well on any of the vacuum bagging materials. The scissors on the right (B and D) are for aramid only and are solid ceramic blades that are serrated. The black handled ones have "Aramid fiber only" engraved on them. The blunt tip scissors (D) are also serrated and marked with yellow paint.

Figure 9-1-2. Cutting pre-preg composites with a razor knife.

Preimpregnated (pre-preg) materials can be cut with a razor blade in a utility knife and with a template or straight edge (Figure 9-1-2). This is true of aramid and other fabrics. The resin tends to hold the pre-preg fibers in place while the razor edge cuts through the fiber.

Section 2

Machining Cured Composites

The high strength of cured composites requires different machining tools and techniques to be used than those used with metal structures. Aramid fibers can absorb cutting fluids if they are used, and if the wrong type of cutting fluid is used, the area might not bond properly. Typically, water is the only acceptable cutting fluid.

Machining characteristics of fiber-reinforced plastics or composites vary with the type of reinforcement fiber in it. Again, if a cutting tool is used with aramid, it should be used only on aramid. If that same tool is used on a carbon/graphite or fiberglass structure, it dulls the cutting surface differently than if used on aramid and will never cut aramid in the same manner again (Figure 9-2-1).

Some composites decompose when being trimmed or drilled at high speeds. The friction generated can burn away various materials, creating toxic fumes.

> **CAUTION:** Composites vary in their toxicity; you should treat all composites as equally hazardous and observe appropriate safety precautions when working with any of them.

Drilling and Countersinking

Drilling holes in composite materials presents different problems from those encountered in drilling metal. Composites are more susceptible than metal to material failures when machined, making hole quality important. Properly selecting and applying cutting tools can produce structurally sound holes.

Delamination, fracture, breakout, and separation are types of failures that can occur while drilling composites. Delamination most often occurs as the peeling away of the bottom layer as the force of the drill pushes the layers apart, rather than cutting through the last piece. A fracture occurs when a crack forms along one of the layers from the force of the drill. Breakout occurs when the bottom layer splinters as the drill completes the hole. Separation occurs when a gap opens between layers as the drill passes through the successive layers.

To combat these problems in drilling, use wood as a backing to the material being drilled or use a drill stop. When the drill bit is exiting the backside of a hole, use very light or no pressure. Use a very sharp drill to cut through the laminate, not push through. This prevents the last ply from delaminating.

When a blind fastener is to be used with the composite part and the backside is inaccessible, a wood backup is not possible. In this case, a drill stop is useful to limit how deep the drill goes through the composite structure. By limiting the depth of the drill passage, breaking the fibers on the backside can be eliminated.

Do not use a cutting coolant when drilling holes into bonded honeycomb or foam core structures—the coolant can seep into other areas and remain in the structure after a patch has been bonded over the repair. Also, if a coolant is used, the laminate fibers can absorb the cutting fluid and create an unbondable surface.

Solid carbide drill bits work on all types of composites and have a longer life than a standard steel drill bit. Diamond dust-charged cutters perform well on fiberglass and carbon; however, when used on aramid, they produce excessive fuzzing around the cut and should be avoided.

Drill motor speed is important. A high speed works best for most types of materials being drilled. However, do not use excessive pressure.

Drilling Aramid

The physical properties of aramid fibers are high in tensile strength, so if you are using a conventional sheet metal drill bit, the fabric tends to fuzz around the drilled holes. Because aramid fiber is flexible, the drill pulls a fiber to the point of breaking instead of cutting it. As each fiber is pulled before it is cut, a fuzzy appearance is produced around the edge of the drilled hole. This fuzzing of the fibers often makes the hole smaller than the drill that is used (Figure 9-2-2).

Figure 9-2-1. Bits are painted for the type of fabric they are used on. The yellow paint on the left bit is for aramid, the white, fiberglass, and the black for carbon. The bit on the right was originally used for carbon, but as it dulled, white paint was added to show it would be a good bit for hybrid carbon/fiberglass components.

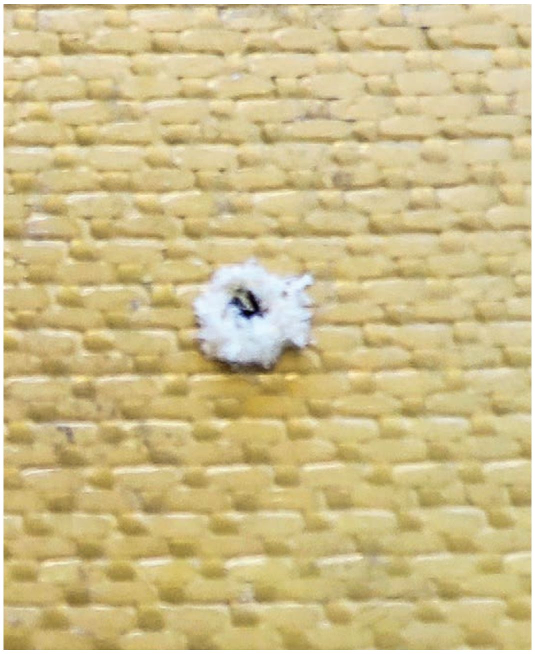


Figure 9-2-2. The fuzz around the hole is caused by the drill pulling the fibers and then cutting them with a traditional sheet metal drill.

The fuzzing around the hole might not be a problem in itself, but if a fastener is to be installed, it might not seat properly in the hole. Consequently, if the fastener does not seat properly, mechanical failure can occur when stresses are not properly distributed.

If an occasional hole is to be drilled, you can remove the fuzzing fibers by applying a quick-set epoxy to the fuzzed hole and then filing or sanding or filing them off (Figure 9-2-3).

If the area where the hole is to be drilled has just been cured and the peel ply or release fabric layer has not yet been removed, the hole can be drilled through the peel ply to eliminate the fuzzing around the hole.

If many holes are to be drilled, such as when a new part is to be installed, but it has no holes to line up with the existing part, special bits can be used that are made for use with aramid. These bits cut through the fibers without fraying the material. They last longer than conventional drill bits and usually produce a cleaner hole. Carbide bits last dramatically longer than conventional bits. If possible, use a drill bit made for aramid, and use it only on aramid.

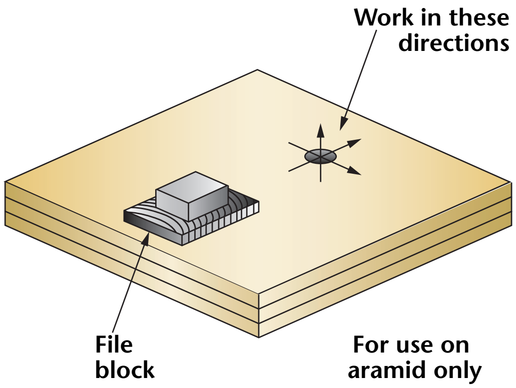


Figure 9-2-3. Fuzz around a hole drilled in aramid can be removed by applying a quick-set epoxy to the fuzzed area, and then filing it off after the epoxy has set.

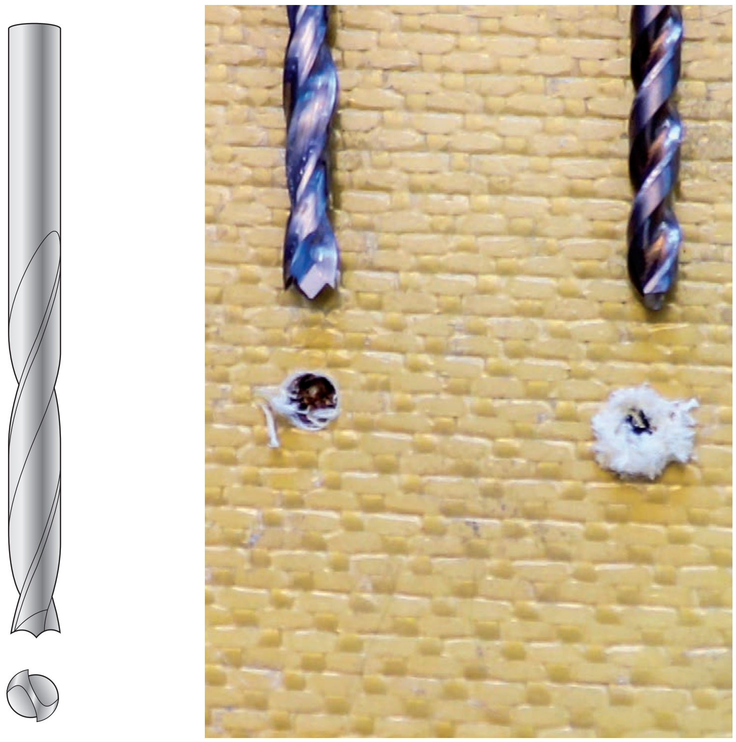


Figure 9-2-4. Special brad point drills are made for drilling aramid composites. The hole on the left is cut with a brad point bit, as compared to the hole on the right, cut with a standard sheet metal bit.

A brad point bit is designed for use with aramid fabric. It is produced with a C-shaped cutting edge (Figure 9-2-4). The edge of the bit holds the thread in tension as the C shape cuts through the fiber, without stretching it. A very sharp bit works best. Although they are designed for aramid composites, they also produce good holes in fiberglass and carbon/graphite.

Brad point bits are available at hardware stores for use with wood. They do not have the C-shape, and they can be used in aramid, but they usually do not produce as clean a hole as a brad point made for composite use and do not last as long.

Aramid fiber composites tend to absorb moisture, especially in areas that have been drilled or cut. No cutting fluid should be used except water. If water is used, be sure to thoroughly dry the fabric before bonding.

Aramid fibers and Kevlar should be drilled at a high speed. Using a very sharp drill bit produces a much better cut. The pressure on the drill should be light—the weight of the drill motor alone is usually sufficient. When the bit is exiting out the backside of the hole, reduce the pressure to prevent breakout. This problem can be eliminated if you use a drill stop that is set so that just the tip of the drill has clearance past the backside of the material.

Drilling Fiberglass or Carbon/ Graphite

Drilling fiberglass or carbon/graphite can be done with most conventional tools; however, the abrasiveness of these composite materials reduce the quality of the cutting edge and drastically shorten the life of the drill bit.

Carbide, diamond-charged, or carbide-coated tools yield better results and last longer. Diamond-charged tools are usually steel drill bits that have a coating of diamond dust to cut through the material. This type of drill bit works well on carbon/graphite and fiberglass components.

When cutting fiberglass, most fibers fracture at the cutting edge of the tool. Carbon/graphite fibers are stiffer and stronger and resist the cutting action of the tool. If a dull drill bit is used, the fiber could break inside the composite structure, causing the hole to be larger than that of the drill (Figure 9-2-5).

Holes drilled into carbon/graphite are often larger than the drill used. Dust chips allowed to remain in the holes during the drilling process also can cut, thus enlarging the hole more. This creates a problem in that the excessive hole size causes the fastener to wear in the hole, so it does not offer the required strength. An oversized fastener might have to be used if wear has taken place and the hole is too large.

For fiberglass or carbon/graphite drilling, a dagger or spade bit can be used (Figure 9-2-6). Using these bits reduces the tendency of the fibers to break rather than be cut. The dagger or spade bit has a single cutting edge. The best results for drilling and countersinking carbon/graphite materials are obtained when using a carbide dagger bit.

Uni-drills can be used to drill and ream carbon/graphite and fiberglass, but they do not produce an acceptable hole in aramid materials. Uni-drills fuzz the aramid fibers excessively.

Drilling with Hole Saws

Holes can also be cut by using a hole saw (Figure 9-2-7). However, the saw will tend to tear out the honeycomb core. A hole saw's teeth usually do not cut through the fibers of an aramid composite, but rather fray the edges, so they are not recommended for that material. For carbon/graphite cutting, the saw can be fitted with a blade that has diamond dust on the cutting edges, which tends to produce a cleaner cut.

Drilling Counterbores

When a larger hole is needed, counter bores can be used with all types of composite materials, except aramid. When used with aramid, it can create excessive fuzzing.

Countersinking Composites

Countersinking a fastener hole is as important in composites as it is in metal parts. A countersunk hole should be produced to the proper fastener angle, depth, and finish. The tendency of aramid fibers to fuzz around a drilled hole can be eliminated by using very sharp countersinks made for aramid composites. Again, the fastener must seat properly in the hole to produce the greatest strength. All the fuzzing around the hole should be removed to allow all the surfaces of the fastener to be in contact with all the surfaces of the composite.

A trick to countersinking aramid is to use a very sharp bit, start the countersink, then remove the fuzz from the bit, and try to countersink it again, this time going a little further down. To help cut the material as it is countersunk, you can add a quick-setting epoxy.

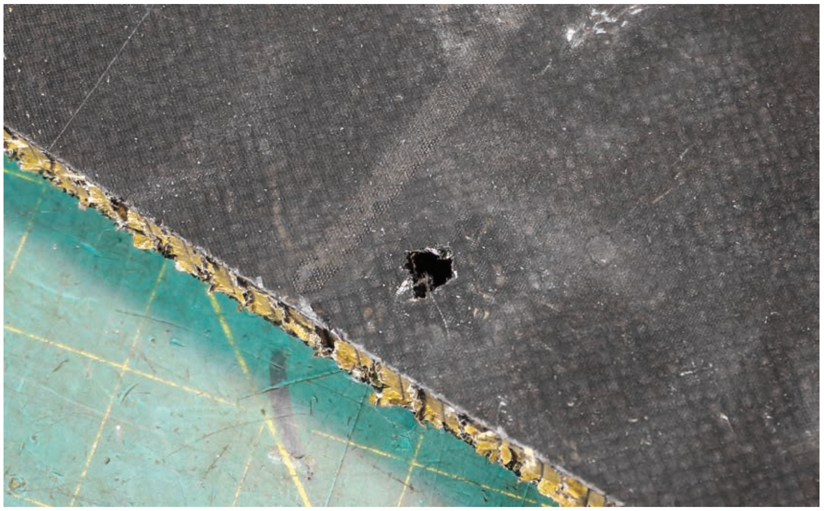


Figure 9-2-5. Carbon can break during drilling, causing the hole to be larger than that of the drill bit.

Figure 9-2-6. A spade bit cuts more with its outer edge; the inner portion mostly removes waste material. Traditional spade or dagger bits with an included angle of 118° are used in PLEXIGLAS® windshields. For composite work, the more pointed bit with an included angle of 60° is used.

Figure 9-2-7. A hole saw.

Sanding

Sanding is used to remove single layers of fabric during the repair operation. With composites, use silicon-carbide or carbide sandpaper. Do not use aluminum oxide for sanding carbon fibers. Small particles of aluminum from the sandpaper can become lodged in the fibers. Silicon-carbide or carbide sandpaper prevents deterioration from an electrolytic action.

> **CAUTION:** Standard composite safety procedures call for wearing a dust mask when sanding.

Figure 9-2-8. Composite layers are very thin, and hand sanding the paint away from the repair prevents going through the structural composite layers.

Figure 9-2-9. Mechanical sanding with a right angle sander gives more control. Sanding with too much pressure, or too coarse of grit sandpaper are common problems. It can be difficult to see where one layer stops and the next starts, resulting in damage to the core.

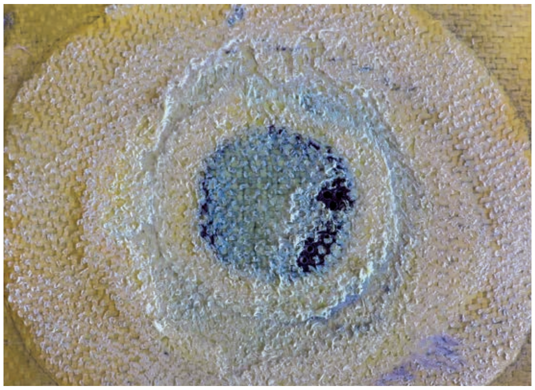


Figure 9-2-10. The honeycomb core can be seen as a result of sanding too much.

Hand Sanding

Hand sanding is used when you need to remove only one layer or a very thin coat of paint (Figure 9-2-8). The fabric layers of composites are very thin, and they can sand off very quickly using a grinder. Be careful not to sand through too many layers of fabric. If sanding a layer of paint, sand to the primer layer, and be careful not to sand into the top layer of fabric or an additional repair could be required.

Mechanical Sanding

CAUTION: If sanding a part on the aircraft, be sure the aircraft is grounded. Static electricity can cause combustion, and grounding the aircraft and the cart can prevent this.

Composite layers are very thin, so you must be careful when sanding off the paint and when sanding down the layers for a repair. If removing paint, use a course grit sand paper and then change to a finer grit when getting close to the composite material. When sanding laminates during a repair operation, use a right-angle sander or drill motor. The tool should be capable of 20,000 revolutions per minute (r.p.m.) and equipped with a 1-in., 2-in., or 3-in. sanding disc. The discs are made in many diameters, but a 1-in. or 2-in. disc gives you more control when step sanding or scarfing the composite structure.

Use a right-angle sander for scarfing and step cutting the repair (Figure 9-2-9). You have much more control with a right-angle sander than with a drill motor because your hand is closer to the work. Some sanders blow exhaust air out the front, others blow the exhaust out the back. If the air is out the front, composite dust blows away from the working area, which is the more desirable of the two.

CAUTION: Standard composite safety procedures call for wearing a dust mask when sanding.

When sanding carbon/graphite, do not allow the dust to blow away, because it can lodge on an aluminum surface and cause an electrolytic action. If a dust collector or downdraft table is available, use it. You should vacuum up the dust and dispose of it properly as often as possible. If you are repairing composites frequently, a right-angle sander will help you do a professional job.

All materials sand differently, and various techniques should be used with each material. When sanding aramid, for example, the material will likely fuzz. When the sanding is almost through the layer, you will see a lighter color of fuzz and spots of gloss might appear. In the sanding process, it is important to look carefully for a gloss area. When an area begins to gloss, one layer of laminate has been removed and the sander is just above the next layer.

Carbon/graphite material produces a very fine powder when it is sanded. It is usually easier to see the layers of carbon/graphite than with aramid.

Another way to tell if you have sanded through one layer is to look at the weave. Most composites are made with each layer's weave in different directions; therefore, if you see a change in weave direction, it is usually an indication of different layers.

The layers of a composite laminate are very thin, and a common problem is to sand with too much pressure, or too quickly, and go through two layers instead of one. This can present a problem if the laminate has only three over a core structure and the repair calls for sanding down to the core. If the first two layers are sanded down and counted as one layer, when the next layer is sanded down, the honeycomb core will be exposed, and there will not be enough surface area to laminate a new patch over the plies (Figure 9-12-10).

Trimming and Cutting

Standard machining equipment can be used to trim composites, but some modifications to the tooling might be necessary. All cutting surfaces should be carbide coated, if possible. Diamond-edged blades work well on carbon/graphite and fiberglass. The machining that can be performed on composites include trimming with routers, drilling with hole saws, cutting with band saws, waterjet cutting, drilling counterbores, hydraulic press cutting, and laser cutting.

Trimming with Routers

The most common types of routers operate at 25,000 to 30,000 r.p.m. They are used to trim composite laminates and to route out damaged core material (Figure 9-2-11). For routing Nomex honeycomb, carbon/graphite, or fiberglass laminates, a carbide-blade, diamond-cut, router bit works best.

A diamond-cut router bit does not refer to diamond chips or dust on the cutting surface; rather, it is the shape of the cut on the flutes (Figure 9-2-12).

Figure 9-2-11. Standard routers, or trim routers with speeds of 25,000 to 30,000 r.p.m., work well for cutting composites. Using special bits designed for specific materials normally produces good results to remove honeycomb cores.

A special router bit has been developed that meets the demands of the physical flexibility of aramid fibers. A herringbone router bit (Figure 9-2-13) works best on thick laminates of aramid because the flutes change direction. As the bit starts to pull out an aramid fiber, the flute changes direction to cut off the pulled out fiber, giving a clean cut. This works well on thick laminates of aramid without causing excessive fuzzing.

To route out damaged core material, a circular or oval area of the top laminate skin over the damaged core must first be routed, using a pointed router bit. If the damage penetrates one skin and the core, be careful not to route into the opposite laminate. Adjust the depth of the bit to go through just the top layers of fabric. Hold the router steadily over the area to be routed. The point of the bit will drill down and then can be guided around the hole with a template. A flush bit is then used to clean out the core material. A diamond cut works well to clean out the honeycomb core.

Readjust the depth of the bit to clean out the core material. If the damage requires all core material to be removed in this area, the depth of the bit should be to the top of the bottom layers of fabric.

To prevent the router from going into the bottom layers, adjust the depth so that some honeycomb can still be seen. This can later be removed by hand sanding.

Some repairs require only a portion of the honeycomb to be removed in the repair area. In this case, adjust the depth of the bit accordingly.

Figure 9-2-12. A diamond-cut router bit is used to clean out the honeycomb core without tearing the edges of the honeycomb.

Figure 9-2-13. A herringbone router bit.

Once the depth has been determined, again use the template to trace around the edges of the cut-out, then using a back and forth motion, remove any remaining honeycomb.

If the area to be routed is tapered, as a trailing edge, then the router template must have shims under it to produce the desired cut (Figure 9-2-14).

If the part is curved, the router depth should not go to the bottom skin. This extra precaution is to prevent laminates on the opposite side from being damaged. Any excess honeycomb in this area can be sanded away by hand.

If the damage penetrates both skins and the core, the router depth can be set to completely remove the damaged area.

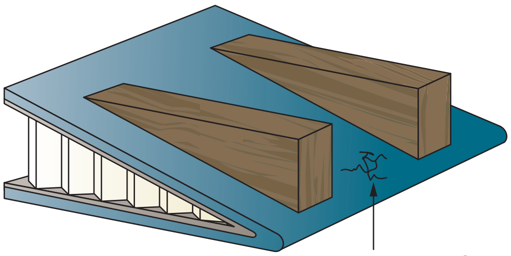


Figure 9-2-14. When removing the core from a tapered control surface, use tapered shims to hold the routing template parallel with the skin.

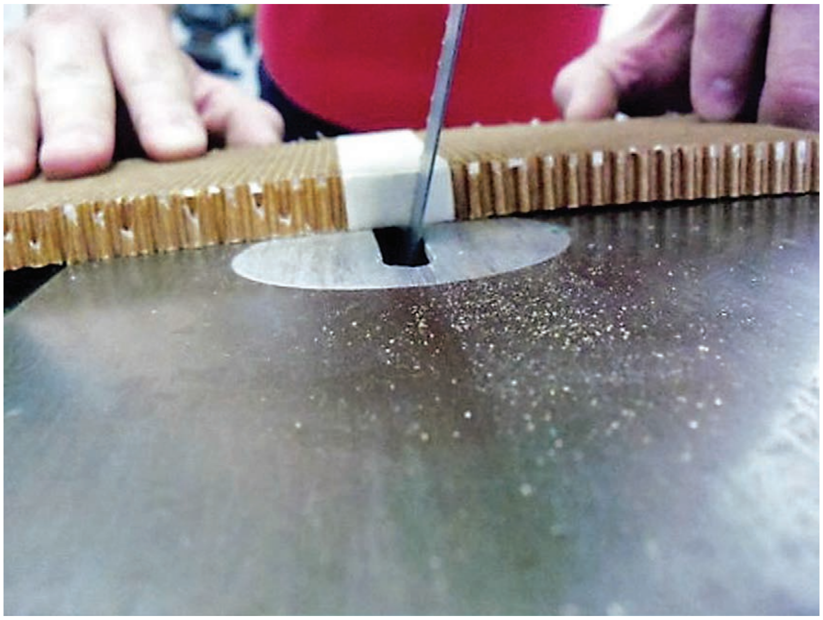


Figure 9-2-15. Special bandsaw blades are available for cutting carbon/graphite material. Some fuzzing is produced when cutting aramid, but it can be cleaned up by hand.

Cutting with Band Saws

A band saw can be used to trim composites if it has a fine-tooth blade with 12 to 14 teeth per inch. Blades made for composite sawing are available with carbide or diamond dust on the cutting edges for use when cutting carbon/graphite material. Band saw cutting produces some fuzzing on aramid, but this can be cleaned up by sanding the edges. A band saw does not produce as clean a cut as a waterjet. Honeycomb can be cut to an angle with a band saw. Tape the area with masking tape to hold the honeycomb in place while cutting (Figure 9-2-15).

A very thick piece of honeycomb might need further rigidity while cutting. You can add this rigidity by placing the core in a plastic container of water, and then freezing. After the honeycomb is frozen, it is easier to cut. Once cut, the water must be removed completely before using. To do this, place the honeycomb under a heat lamp, then vacuum bag it.

Waterjet Cutting

This cutting system uses a fine stream of water pumped at 30,000 p.s.i. to 50,000 p.s.i. through a pin hole nozzle to slice through composites (photo at the beginning of this chapter). Waterjet cutting does not produce dust or fumes and causes no delamination or fuzzing of aramid laminates.

Waterjet cutting is used most often in the manufacturing process and is not commonly used for infield repair applications. A waterjet knife uses such a fine spray of water that water wicking into aramid is not a problem. If some water is absorbed on the edges, you can quickly remove it by putting the part under a heat lamp to evaporate the water.

Hydraulic Press Cutting

During the manufacturing process, pre-preg fabric can be cut using a large hydraulic press. Pattern pieces are made using sharp, metal-cutting edges that stamp out the fabric piece. The hydraulic press works best on pre-preg fabric because the resin holds the pieces together to get a smooth edge.

Laser Cutting

Cutting out the parts with a laser is another manufacturing cutting practice. A laser uses a highly focused light beam to cut through composite materials. Laser cutting can be performed on both uncured and cured composite materials, and the pieces can be many layers thick, so many parts can be made with one cutting.

Section 3

Fasteners

The fasteners used on composites are different from those used on sheet metal. Hole filling rivets are not used in composites. If the metal of a rivet expands and completely fills a hole in a composite structure, it expands against the sides of the laminate and can delaminate the edges of the hole. The holes drilled into the composite can also cause material failure because each individual strand of the composite carries a load. Many holes drilled for a traditional sheet metal repair patch severely damage the structural integrity of a composite structure. That is why different types of repairs are used for composite components. The same is true of the fasteners used with composites.

Figure 9-3-1 shows a traditional hole-filling rivet used on sheet metal. If that same rivet is installed in composite materials, with many thinner layers, the rivet's lateral pressure can cause delamination and damage to the sides of the material (Figure 9-3-2). It is not very stable and can loosen over time.

When installing fasteners into a composite structure, use the following general rules:

- When using fasteners in carbon/graphite structures, they must be made of titanium or corrosion resistant steel. Do not use aluminum fasteners with carbon/graphite material because of the materials' tendency to corrode the aluminum.
- If an aluminum fitting is used in a carbon/graphite structure, make sure that the aluminum has a corrosion-protective coating.
- Do not use hole-filling fasteners like AN470 rivets in composites because they can damage the hole as they expand, causing the laminate layers to delaminate.
- Close-tolerance holes and fasteners ensure more equal load distribution.

Composite Fasteners

The term *composite fasteners* can be defined in two ways: fasteners made of composite material, or fasteners used to fasten composite materials together. To avoid confusion, a composite fastener in this discussion refers to fasteners used to fasten composite sheets or other composite materials together. The discussion includes fasteners made of both metal and composite materials.

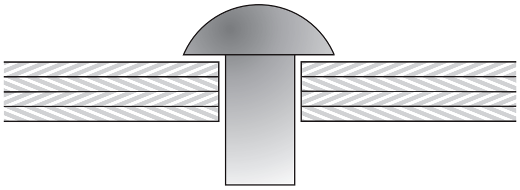


Figure 9-3-1. A rivet loosely fits inside the drilled hole.

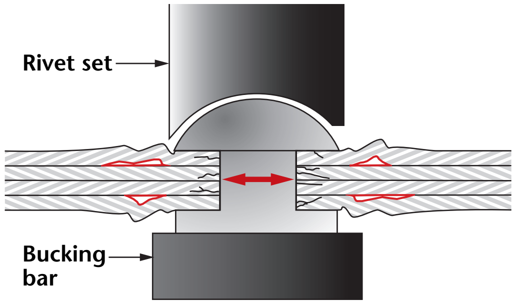


Figure 9-3-2. After bucking, the rivet's metal fills the hole, expanding outward on the sides of the material. It works fine in metal, but not on composites.

Composite materials in manufacturing reduce the need for fasteners in many applications. Making complex shapes from composites allows molds to be created that produce components in one piece. Another technique known as co-curing allows large or very complicated components to be assembled by curing the materials together, rather than using fasteners to hold the components together. This ability to manufacture components without so many mechanical fasteners is one of the great advantages that composite materials offer.

In producing primary, load-carrying structures from composite materials, however, the structures to be joined are too large to lend themselves to bonding or co-curing and require mechanical fasteners. Furthermore, some cases exist in which the shape of a component is complex enough to require mechanical fasteners to complete an assembly. Satisfactory fasteners must be used to securely assemble components that are made from advanced composite materials. Such new composites seldom work well with traditional fasteners such as aluminum rivets. Consequently, the aviation industry has had to reevaluate the materials technology and the mechanical engineering associated with aviation fasteners. The industry addressed the problems in three ways:

- Modified traditional sheet metal fasteners slightly for use with composites.
- Developed new fasteners for use with composite materials.

- Reconsidered part functionality, asking do fasteners need to actually penetrate through materials?

Sheet metal parts are made using a material that constantly exhibits the maximum strength possible. In other words, sheet metal is as stiff on an operating aircraft as it is in the sheet metal fabrication shop. This rigidity substantially affects the formability of the material: if the material is flexed too many times in the fabrication process, the metal is weakened because of work hardening. The sheet metal stretches and subsequently varies in thickness and strength as it is bent into the desired shape. This is why components that are complex in shape or that require multiple strength characteristics must be made as isolated components and then joined together to form the final design. The best way to join aircraft sheet metal together is to drill holes and install sheet metal rivets.

In contrast, composite materials usually start out as pre-preg fabric. Before being cured, the material is very flexible and is stored in rolls. The manufacturer builds a component from this material usually by laying the material into a mold and curing the pre-preg material with heat and pressure. The mold can be very complex in shape, as long as the part can be properly cured, and the finished component can be removed from the mold. By the means of fiber science—for example, multiple layers of similar or dissimilar fabric co-bonded together—a very complex and strong component can be engineered.

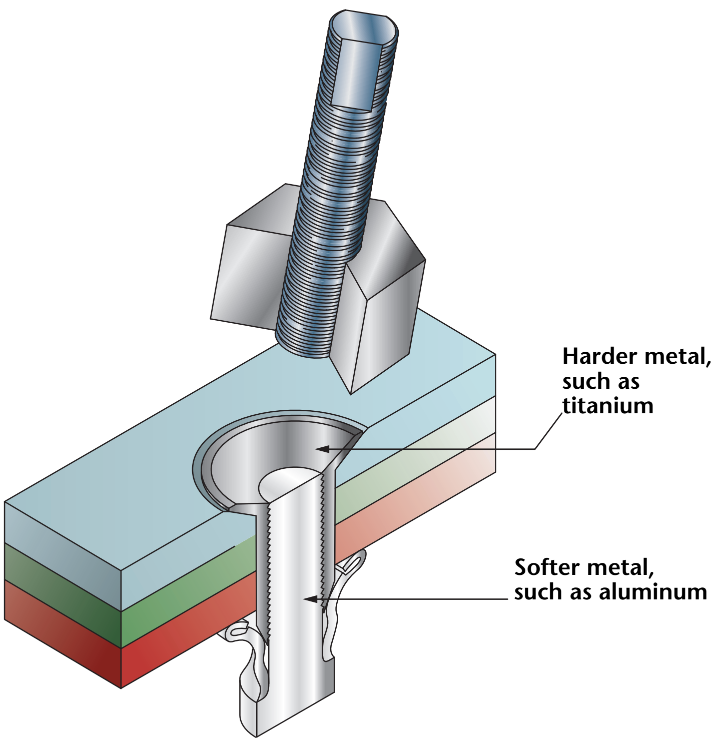


Figure 9-3-3. A bimetallic fastener used in composite components.

Metallic Fasteners

When advanced composites were increasingly used in military and civilian aircraft designs, the fastener industry was unprepared to meet the mechanical and chemical requirements of advanced composite materials. The most immediate solutions involved fasteners that were slight alterations of those originally designed for metallic structures. At the time, no alternatives existed for aeronautical engineers other than to use metallic fasteners on nonmetallic structures.

The progression of the bolts include a threaded insert that is compatible with the composite material. Composite fasteners are usually made out of a very strong outer material that does not have a corrosive effect on the composite material, such as steel or titanium. As the nut is turned, the softer metal on the inside deforms to form the flange on the bottom and holds the bolt in place. The bolt shears off when it is flush with the top of the surface (Figure 9-3-3).

Results of these short-term solutions of metallic fasteners demonstrated the problems associated with using incompatible materials. These problems include dissimilar electrical potentials, electrical problems, and mechanical problems.

Dissimilar Electrical Potentials

Most metals are not compatible with carbon composites because of dissimilarities in electrical or galvanic potentials that cause severe galvanic corrosion. This type of corrosion is especially evident in wet or corrosive environments. To address the galvanic incompatibility, manufacturers use two methods:

- Make the fasteners from metals that are compatible with the carbon materials. This includes metals such as titanium alloy, stainless steel, or inconel.
- Coat the metal fasteners with a dielectric protective layer that isolates noncompatible metal fasteners from the carbon materials in the composite. Such protective coatings are made of fiberglass or a potting compound.

Unfortunately, both of these approaches create new problems.

Electrical Problems

The biggest problem with using metallic fasteners in carbon composites is the cost of using exotic metals like titanium. Applying a protective dielectric coating on a fastener made of an incompatible metal (such as aluminum) prevents galvanic corrosion. This allows for using lighter, less expensive metals, and it keeps the mechanical aspects of the fastener more in line with those of the composite materials. However, the protective coating must remain completely intact to prevent what could be catastrophic failure from galvanic corrosion. If the dielectric coating cracks, wears off, or otherwise allows for electrolytic action between the fastener and the structure, the structure will ultimately fail. Applying or installing a protective coating adds expense and time to the manufacturing process.

Other problems are created by using a dielectric coating, such as reduced lightning strike protection. When lightning strikes a traditional, sheet metal aircraft, the electricity is conducted through the sheet metal to the static discharge wick. Ordinarily, this causes very little damage. In contrast, when lightning strikes an aircraft made of nonconductive composites, problems do occur.

The presence of an isolated metal conductor in a nonconductive composite aircraft can cause severe damage if struck by lightning. The lightning charges the fastener enough that it either arcs to another metal component, or if arcing is not possible, it explodes. Either way, the damage will be extensive and could be disastrous; this is unacceptable. Although the fastener might be mechanically compatible with a composite structure, the overall design is still susceptible to galvanic corrosion, is more expensive, and is subject to severe problems if lightning strikes.

Aircraft structures contain many nut plates and channels and, as with fasteners, these components are often made of titanium or stainless steel to be compatible with the composite structure.

Mechanical Problems

Mechanical problems arise when composite parts are assembled using blind or solid metal rivets. Standard rivets are designed to be used on metal materials. Consequently, the force required to upset the blind side of a rivet is meant for use with metal parts. When this same force is applied in the process of fastening two composite laminar structures, the composite is either crushed, or disbonds occur around the fastener. This problem is exacerbated by the small upset diameter of most metal rivets: their small footprint often causes the laminate to crumble. Also, the fastener can loosen because of the loss of preload as the laminate deforms.

When a composite structure is damaged when installing a rivet, the rivet must be drilled out, the damaged portion of the composite repaired, and an oversize rivet reinstalled. These are costly repairs in terms of time and materials. In an attempt to address this installation problem, a bimetallic rivet is used in which the upset side of the rivet is made of a softer material, such as columbium. The fastener shown in Figure 9-3-3 is bimetallic. However, one of the advantages of composite structures is the smooth aerodynamic surfaces that are possible and of special importance on control surfaces. If a bimetallic rivet is installed double flush on the trailing edge of a control surface, a shaving operation might be necessary to achieve the flush tolerance necessary to avoid turbulence. This tolerance could be between 0.000 and 0.010 in.

Fasteners designed to provide an interference fit were originally designed with metal in mind. An interference fit is of value where structural pieces require the longest possible fatigue life. When a traditional interference-fit fastener is installed in an advanced composite laminate, the laminate will separate because of the lateral forces that the fastener exerts. Such separations range from minor cracks to major delaminations.

One way to address this problem is to install a sleeve into which the fastener can be inserted. To install a sleeve, drill a smooth hole, install the sleeve, and fill the holes on the side with an adhesive (Figure 9-3-4). The adhesive fills the space around the sleeve and into a honeycomb structure, so there is solid contact between the sleeve and the honeycomb core.

Although this solves some of the problems of delamination, it adds parts and labor to the operation and adds weight to aircraft. As with any intrusive process, this also exposes the laminate to environmental degradation if the sleeve is not installed correctly. This is of spe-

Figure 9-3-4. Inserting a fastener into a sleeve like this reduces damage to the laminate.

cial concern when the laminate includes hydrophilic (wicking in of moisture) materials such as Kevlar; the sleeve can conceal fluid damage or exposed laminate that can occur in the manufacturing process. If the area is difficult to inspect, the damaged area can grow as water or other fluids are absorbed into the laminate materials.

Nonmetallic Fasteners

Nonmetallic fasteners are needed for composite materials for the following reasons to overcome the limits of metallic fasteners discussed earlier:

- They prevent galvanic corrosion.
- They provide material strength compatibility.
- They have reasonable costs for manufacturing.
- They are lightweight.
- They provide overall materials compatibility.

Fasteners Made of Composite Materials

In addition to offering very good strength-to-weight ratios, advanced composite materials are attractive to airplane manufacturers because of the low costs associated with manufacturing airplane parts. This major improvement in aircraft fabrication has eliminated the need to join so many components as with sheet metal fabrication. At the time of this writing, however, no one has yet devised a way of making a single-piece airplane. Although composite materials have reduced the number of fasteners needed, there is still a need to fasten composite materials to other composite components and to sheet metal components.

Materials for Composite Fasteners

Various composite materials have been evaluated for fasteners made of composite material. Some of the considerations for suitable materials are the following:

- Sheer strength
- Susceptibility to moisture absorption
- Resistance to chemicals
- Thermal stability
- Thermal conductivity
- Fatigue resistance
- Vacuum stability (off-gasing characteristics)
- Compressive strength
- Coefficient of thermal expansion
- Dielectric strength (conductivity)

The common practice to achieve an acceptable level of those characteristics is to mix a resin/curing agent with fiberglass, aramid, or carbon fibers. Each manufacturer has its own resin formulation and fiber specification. Mechanical strength is usually increased using long carbon fibers. Fasteners made of composite material prove to have very high strength-to-weight ratios: one-fifth the weight of steel and one-half the weight of aluminum is typical.

Adhesive Bonded Fasteners

An alternative to drilling into the skin of the aircraft is to install adhesive bonded fasteners. These fasteners are rivetless and require drilling only when a fastener needs to penetrate the composite. Composites carry loads through each individual strand. A hole drilled through an entire structure can weaken that structure where the fastener is installed. A fastener manufacturer, Click Bond®, designed fasteners for adhesive bonding to the structure. Its fasteners include nut plates, studs, cable tie mounts, standoffs, bushings, and insulation mounting systems. Its systems have been approved for many military and commercial airliners, helicopters, and other vehicles. The adhesive bonded fastener that seems most impressive is the nut plate (Figure 9-3-5).

On a typical metallic installation, the nut plate (Figure 9-3-6) has three holes drilled in a row. The two on the outer edge are for rivets to attach to the surface, and the middle hole is drilled for the fastener. When three holes are drilled closely together in a composite component, it can severely weaken the surface. With the adhesive bonded nut plate, only one hole is drilled through the component, and the fastener is attached with an adhesive to hold it in place.

To install an adhesive bonded fastener, the composite must be cleaned of all paint, and surface etched, then cleaned again using acetone or methyl-ethyl keytone (MEK) with a clean cloth. If you do not properly clean the surface, the fastener will not bond properly.

Using Fasteners

Common fasteners used with composite structures are the removable fasteners, such as those used around door edges. Probably the most common damage to these areas is from wear around the edges of the hole, causing the part to improperly transfer the structural load.

Figure 9-3-5. Adhesive fastened nut plates with one central hole drilled, designed for composite use.

Figure 9-3-6. A sheet metal nut plate with three holes drilled relatively close together, which would cause weakness in a composite component.

If the composite part fails because of worn holes, one solution is to use an oversized fastener. This solution might be only temporary because the same loads can recur, resulting in the same wear of the hole. A more permanent solution is to use a fastener with a liner and permanently installing it in the composite structure. The fastener can be removed, but the liner stays in place.

Fasteners can pull out of the edges of the composite if placed too close to an edge. Therefore, it is important to place fasteners well enough inside an edge to prevent excessive wear or pull out. The direction of the weave of the fabric is also very important to prevent the fastener from pulling out.

The material around a drilled hole is sealed to prevent the fabric from wicking moisture. One way to seal a hole is to use an insert coated with resin. The resin, in combination with the insert, permanently seals the hole against moisture.

In some aircraft, passenger seats are installed using a type of foam adhesive that expands and fills the holes of the honeycomb floor panel to make it possible to permanently attach the seat to the floor. To accommodate a removable passenger seat, a fastener can be used with a metal or plastic insert, making it possible to install or remove the passenger seat without causing damage to the honeycomb composite floor panel.

Where a blind fastener is needed, special fasteners that are very similar to a Hi-Lock fastener can be used. Some of these fasteners have a very small bearing surface with the composite part. This can allow the fastener to puncture through a thin sheet if too much pressure is imposed on it. If possible, it is best to use a composite fastener that has a large bearing area (Figure 9-3-3). To work properly, you must use the proper diameter and length of these fasteners.

When installing fasteners into a composite structure, follow these general rules:

- For fasteners used with carbon/graphite structures, they must be made of titanium or corrosion resistant steel.
- It is best not not use aluminum fasteners with carbon/graphite material because they tend to corrode the aluminum. If an aluminum fitting is used in a carbon/graphite structure, make sure that the aluminum has a corrosion protection coating.
- Do not use hole-filling fasteners like AN470 rivets in composites because they can damage the hole as they expand, causing the laminate layers to delaminate.
- Close-tolerance holes and fasteners ensure more equal load distribution.

Removing Fasteners

To drill out and remove a fastener, the softer metal center should first be drilled out. The outer rim can then be removed using a punch.

Composite Welding

Composite welding tools can be used to fasten thermoplastic composites, such as overhead storage compartments. As you might recall, thermoplastic composites can be reformed by applying heat. Composite welders apply heat and pressure, much like a heated rivet gun, to press the thermoplastic down and reform it.

Composite welders do not work on thermoset composites because heat applied to a cured thermoset part does not cause the resin to reflow. In manufacturing, composite welders can be used with thermoset resins that have not yet gone through their final curing stage. Once the thermoset has completely cured, it cannot be reformed by reapplying heat. For repair work, composite welding would be ineffective.

Left: This sanding shop is equipped with dust collection and all safety gear.

10

Setting Up Shop

Learning Objectives

REVIEW

- Equipment for
  - Machining
  - Lay-up
  - Vacuum bagging
  - Curing

DESCRIBE

- Requirements for storing materials
- A good composites working environment
- Practices for storing materials in the freezer

EXPLAIN

- Costs involved in using composite materials
- Why specialized training is needed for working with composites
- FAA procedures related to composites

APPLY

- Determine if a material meets certification requirements

When trying to determine if it is feasible to set up a repair shop, be realistic about the cost-effectiveness of composite repairs. Not all companies need state-of-the-art autoclaves and other expensive machinery unless they intend to remanufacture the parts, which would require the original molds and curing equipment. The structural repair manual (SRM) is the most important place to find information on what type of equipment, tools, and materials that are used on an aircraft. Most SRMs keep the sizes of the repairs smaller than a remanufacturer, and the equipment needed could be as simple as a hot bond unit. Many companies are hesitant to set up a composite repair shop because they have the following concerns:

- Lack suitable facilities
- Lack proper equipment
- Lack experienced technicians
- Lack access for on-aircraft repairs
- Need for short downtime

Aircraft are profitable only when flying, so the downtime of the aircraft is very important. Repair facilities must figure out when to do the repair and when it is feasible to set up shop. When determining a repair, the facility personnel need to ask important questions.

- Can the damage be repaired in a reasonable time?
- Can the part be fixed at a reasonable cost?
- What will be the downtime of the aircraft? Would it be faster to do the repair in-house or send it to a repair station that specializes in composite work? If the part is sent away, it must be taken off the aircraft and replaced with another part. It can be very

expensive to have extra replacement parts on hand. How long will it take the company to fix it? Crating and shipping the part also adds time and expense.

- Are the proper facilities and equipment available? Suitable facilities for composite work could differ from existing facilities because some repairs require special equipment specifically created for composite work.
- Do the technicians have the appropriate skills? Certain skills are required to fix composite parts correctly. Special training needs to be provided for those who are to work on the composite components.
- Are all the materials available? Some composite materials are not readily available, and many require a minimum purchase amount. Typically, manufacturers require shops to purchase full rolls, which could contain anywhere from 100 yards to 1,000 yards of material (Figure 10-0-1). Honeycomb cores are usually purchased in 4- by 8-foot sheets and, in some cases, several sheets might be the minimum purchase amount. If few or small repairs are done, find a supplier that deals in small quantities.
- What type of special storage is required for some materials?
- What safety requirements must be met with composites?

In most instances, it makes sense to repair a composite component compared to scrapping it, even if the damage is very large. The damage could be so extensive that it exceeds the limits stated in the SRM, but sending it to a remanufacturing facility saves money compared to purchasing a new component. If you compare the costs of materials and labor involved in making a new component to repairing an existing one, it is usually more economical to repair it.

Figure 10-0-1. Most materials come from a supplier or weaver in very large quantities. This roll of peel ply has more than 700 yards on it.

Composite repair differs from manufacturing the composite component in that you do not have the molds, and many repairs are done without removing the component from the aircraft. Curing also is done differently, usually with hot bonding equipment. Materials for repair with certification might be harder to come by as well. The fabricators of preimpregnated (pre-preg) materials and resin systems are set up to sell very large quantities of materials to the aircraft manufacturers who use it within the 6 to 12 month shelf life. Most fabricators do not want to sell smaller quantities, so the amount of material you have to buy, compared to how much you will use, will probably result in the material going overtime before it is used.

If pre-pregs are hard to acquire in small quantities, the SRM might give repairs for both pre-preg and wet lay-up procedures.

Section 1

Facilities Required

Good housekeeping is an important aspect of a repair shop because it directly affects the technician's safety and the equality of work. Because of the materials used in composite repair, good housekeeping is a must on the work floor, and in and around the storage areas for the materials.

Storing Materials

When working with composites, special storage facilities might be required depending on the type of work performed and the materials used. Composite material storage, such as fabrics, resins, and foam, could require special storage temperatures to ensure the quality of the material. Three storage temperature ranges are common: room temperature of 75°F to 80°F, refrigeration of about 40°F, and freezer temperatures of 0°F or lower.

Freezer space must be available for most structural grade pre-pregs and adhesives. If improperly stored, the adhesives, resins, or pre-pregs that are used for the repair can result in structurally unsafe aircraft components.

Some pre-preg fabrics have both an in-freezer storage life and an out-of-freezer storage life because the resins slowly warm up to room temperature and start their cure cycle immediately when removed from the freezer. If they are allowed to stay out of the freezer too long, they cure too much and do not have adequate strength for the repair.

The time spent out of the freezer must be tracked. Figure 10-1-1 shows a sample log report used to track out-of-freezer time. In this example, the roll was received on 10/12/2018, and the first entry was on 10/22. The time that the roll was taken out of the freezer was 11:17, put back in the freezer at 11:33, so 16 minutes out of the freezer. Each entry is added together so on 12/14, it was out for 23 minutes, but the roll total is 1 hour and 38 minutes.

To store materials properly, every repair shop should do the following:

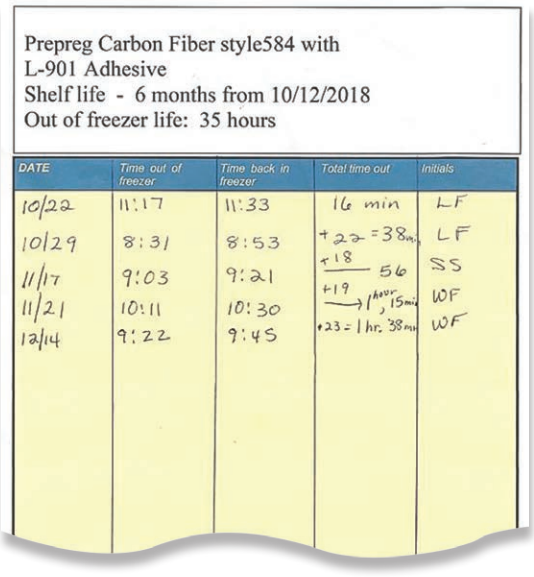
- Keep records on refrigerated storage to ensure the first materials in are the first out for use (first in/first out).
- Seal refrigerated materials properly to prevent moisture from entering.
- Ensure that an identification label always stays with the material.
- Record accumulated time out of refrigerated storage.

Discarding all materials that exceed their storage life is another important aspect of good housekeeping. Many containers have a limitation date that is calculated from the date of maufacture or date of shipment receipt (whichever is applicable). If an item has a manufacturing or shipment date of 1/18, and a 6-month storage life, its limitation date could be stamped 7/18 and should not be used after then.

To discard the materials properly, consult the safety data sheet (SDS). Many resins, catalysts, and pre-preg materials are considered hazardous waste if disposed of without curing, so the two parts might have to be mixed and cured before throwing them away. Pre-preg materials can be cured in an oven or donated to your local Airframe and Powerplant (A&P) school for training purposes. Once the material is cured, it is no longer considered toxic.

A chest freezer is preferred over an upright because the resin system on an upright freezer can tend to slowly flow down because of gravity. That makes some areas of the roll much more resin rich than others. Turning the rolls every week solves this problem, and it is much easier to do in a chest freezer (Figure 10-1-2).

Obviously, the most important factor about a freezer is that it keeps the materials at the required temperature. If power is lost and the freezer warms, record the fact and label the materials as time out of the freezer. The best way of monitoring the freezer is to use a thermometer that records the high and low temperatures in the freezer. If you notice that the high temperature is outside the range, you should subtract the amount of time it was since someone last checked the freezer temperature. Other recording devices are available, including ones that are similar to those used under the heat blankets to record a cure.



Prepreg Carbon Fiber style584 with
L-901 Adhesive
Shelf life - 6 months from 10/12/2018
Out of freezer life: 35 hours

DATE	Time out of freezer	Time back in freezer	Total time out	Initials
10/22	11:17	11:33	16 min	LF
10/29	8:31	8:53	+22 = 38min	LF
11/17	9:03	9:21	+18 56	SS
11/21	10:11	10:30	+19 → 1 hour, 15 min	WF
12/14	9:22	9:45	+23 = 1 hr. 38 min	WF

Figure 10-1-1. A log report is usually made when the roll is received; use it to record time out of the freezer.

Figure 10-1-2. A chest freezer, on the left, is used for storing pre-preg materials, and a refrigerator for storing some adhesives and chemicals is on the right.

All composite fabrics and vacuum bagging materials should be kept on rolls in a covered, clean, and dry storage area away from contamination (Figure 10-1-3). Remember, vacuum bagging materials have a specific moisture content that keeps the material flexible. Vacuum bagging film should be stored in a plastic casing or bag that can be sealed to prevent the film from becoming brittle. Kevlar, on the other hand, wicks in moisture or humidity and therefore should also be protected in plastic.

Store honeycomb and foams in the original packing box away from the working area where dust and other contaminates could damage the material.

Resins, catalysts, hardeners and solvents might or might not require refrigerated storage. If not, they must be stored in a cabinet marked "Flammable." All SDS and certifications should be stored nearby (Figure 10-1-4).

Working Environment

Safety is vitally important when working with composites because of the danger to the technicians, the repairs, and the machinery. Safety equipment must always be available to the technician working on the composite structure. Dust masks or respirators that filter to 5 microns are required when sanding, drilling, or trimming some composite structures. When working around a composite sanding environment, it is nice to have a dust mask on even if it is not required to have one that filters down to fiber microns. Cancer of the sinuses is becoming more common among people who worked with fiberglass in the 1960s, when safety was not taken seriously, and masks were not worn.

A clean environment is desirable when making composite repairs, however a *clean room* is not required except in manufacturing. To maintain cleanliness, maintain separate areas of the shop for the sanding and machining operations and laying up fabric patches. This eliminates repair contamination and provides a cleaner and safer work area. If you do not have separate areas for composite repair, clean the area very well and vacuum up any sanding dust before bonding patches.

The FAA may inspect for the following items in a clean room environment:

1. Temperature and humidity control.
2. Air filtration and pressurization capable of providing slight, positive over-pressure.
3. Room designed to minimize dirt traps (recessed lights, sealed floors and no ledges). Regular cleaning must be scheduled.
4. Clean and filtered compressed air when used in the clean room.
5. Contamination restrictions in cutting layup, and bonding areas must prohibit the use of uncontrolled sprays, exposure to dust, handling contamination fumes, oily vapors, and the presence of other particulate or chemical matter that could adversely affect the repair or alteration process.
6. No eating or smoking in these areas.

Figure 10-1-3. Composite fabrics and vacuum bagging materials stored on a rack help maintain cleanliness and safety.

Figure 10-1-4. Storage locker marked *Flammable* for resins, catalysts, and solvents. SDS and certifications should be stored next to the locker.

Figure 10-1-5. An updraft table pulls hazardous fumes from the work area.

Adequate ventilation also must be available while working with any solvents, resins, catalysts, and adhesives. Check the SDS for each type of chemical used to see what is required. An updraft table (Figure 10-1-5) can be used to pull hazardous fumes from the air.

In cases where the resins used are very toxic, use an updraft table while you are impregnating the resin into the fabric, pulling hazardous chemicals away from the working area. Once the fabric has been impregnated, the repair patches are cut to the correct size, noting the weave direction. These can then be taken to the area of the repair, possibly on the aircraft itself. As you peel off the plastic backing, again, you could be exposed to the toxic fumes. To filter out the fumes, wear a respirator. Keep others away from the area, until it has been vacuum bagged, so they do not feel the effects of the fumes. If you do not have access to an updraft table, when doing any work while using very toxic resins, you should wear a respirator that filters out the fumes.

A downdraft table or dust collector must be capable of filtering down to 5 microns. Dust masks must be used at the same time, and cleanup is required after use. A vacuum system incorporated in the cutting head of the tool is also acceptable.

Figure 10-1-6. Downdraft tables are used to pull the fine dust from the air.

During the sanding and drilling process, use a dust collector or downdraft table to keep the fine sanding particles from contaminating the air.

A downdraft table is a table that pulls air down and pulls small particles away (Figure 10-1-6). A dust collector, which should be able to filter down to 5 microns, is more portable and can be taken to the aircraft if a repair is being made while the part is attached to the aircraft.

An eyewash and first aid station must be available near any repair station and kept unobstructed.

Many of the solvents and resin materials are flammable and must be kept away from heat and open flame when in use. Meeting the following requirements minimizes or eliminates the danger of fire and subsequent destruction of life and property:

- Eliminate all flames, smoking, sparks, and other sources of ignition from areas where solvents are used.
- Provide adequate ventilation when working with any resins or solvents.
- Perform any sanding operation away from any area where flammable materials are used. Sanding can cause sparks, which are an ignition source.
- Do not have solvents nearby when bagging films and peel ply materials are unrolled because they can create a static charge.
- Meet all storage requirements.

Section 2

Composite Materials

The fabric materials used in advanced composite structures come in a variety of weaves and weights. The SRM designates which weave and style to use for various repairs. Typically, fabrics come with a description printed on the paper that details the type of weave and style to show that it conforms to a specific requirement. This description could also contain information on what type of fiber was used in the weaving, whether there is a finish on the fabric, the roll and lot numbers, and other data that would help track exactly where and when the fabric was woven. The materials used in composites cost about 3 to 5 times more than aluminum. Because of this high cost, repairs must be done correctly to maintain a cost-effective workshop.

If the material is a pre-preg, it will also have information of storage temperatures, shelf life, and so on. This information is required to be on file for all fabrics. This information could be on the tube the fabric is rolled onto. If the data is not on the paper or on the tube when you receive the fabric, put this information on the cardboard tube.

Raw, woven fabric (non-pre-preg) is usually stored on storage racks and covered with plastic to prevent dust accumulation. It should also be kept out of the sunlight and protected from high humidity. Some of the fabrics can wick in humidity and be affected by sunlight.

A common problem with these materials is that they cannot be purchased in small quantities. Shops that work exclusively on repairs might not want to buy large quantities and then have their shelf life expire—this can become quite expensive. Some companies supply small quantities of composite materials, but as composite materials become more commonly used, more companies might offer these materials in small quantities.

Vacuum Bag Materials

Many types of bagging materials are available for composite work; however, many of them are for high-performance use in manufacturing at very high temperatures and pressures. This high-performance capability adds to their cost. For most repairs, lower temperatures are used for curing, allowing a wide variety of less costly bagging materials to be used. It might be hard to find small quantities of these materials, but some suppliers break full rolls.

Vacuum bagging materials do not require all the material certification that the composite materials do. These materials are used as tools with the composite repair. They facilitate the vacuum bagging and curing of the repair, and they are taken off the repair when completed. Because they are removed, these materials do not become a permanent part of the aircraft and, therefore, do not require certification. This is contrary to the belief of some officials that might tell you that the vacuum bagging material requires certification. Although conformity can be verified by contacting the manufacturer of the material, it should not be required. A good argument for this situation is to ask if your ball peen hammer also requires certification.

Section 3

Tools and Equipment

Some of the tools and equipment used for composite work are the same as those used with sheet metal. Drills, grinders, and saws are generally the same. What is different are the parts used with some of these tools. For example, special drills and sanding discs of various grits are required to complete fabrication and repair work. Vacuum bagging and hot bonding equipment are also special tools needed with composites. Many hot bond equipment models are available and range from simple to operate to very complex.

The following sections provide an idea of what might be appropriate for different size shops.

Machining Equipment

When working with machining tools, use non-spark-producing tools that are designed to be used with composite materials. Traditional drills can be used, but special drill bits produce cleaner holes in aramid and carbon/graphite. Brad point and dagger drill bits are commonly used. Additional machining information is in chapter 9.

Bandsaws equipped with fine-tooth blades work on all types of composite materials; however, they can produce a slight fuzzing on aramid fabrics. These edges must then be cleaned up by wet sanding with fine grit sandpaper to smoothe out the rough edges made by the bandsaw.

When sanding, a right-angle sander is a good choice. It offers more control because the disc is close to the area being sanded. Drills fitted with a small sanding disk can also be used, but they do not offer as much control for very fine work.

Other machining tools that might be desirable, but not necessarily required, are routers, waterjet cutters, counter bores, hole saws, and hot wire cutters. For details on these, see chapter 9.

Vacuum Bagging Equipment

Vacuum pumps are used to vacuum bag a component. They are available in various configurations. Many conventional vacuum pumps are driven by electricity, but the noise level is very high and they can generate heat, which can make them less acceptable in certain shops.

Other vacuum systems work with compressed air (Figure 10-3-1). Because the vacuum equipment is driven by compressed air, it does not generate heat, and it is quiet if it includes a muffler. Therefore, these all improve the working environment.

Vacuum equipment is usually incorporated with hot patch bonding system that also includes a heat source.

Vacuum Hoses

Different types of hoses are to be used depending on if you are curing in an oven or an autoclave, or with heat blankets, heat guns, or heat lamps. If the hose is enclosed in the heating environment, such as in ovens or autoclaves, the hose must be able to withstand the high heat.

If you apply heat by another method, plastic hoses can be used as long as they are equipped with an internal wire to keep them from collapsing (Figure 10-3-2).

Vacuum hoses are usually included with the hot bonding system.

Vacuum Valves

The valves used in the vacuum bagging operation must be able to withstand the temperatures and the vacuum being pulled. Again, if the part is to be cured in an oven or autoclave, the valve must be made of metal to withstand the heat.

If you are applying heat with a heat blanket and the valve is not in direct contact with the heat, you can use a less expensive plastic valve. Most vacuum valves incorporate a channel in the base to allow easier airflow through it and prevent the valve from sealing to the part when a vacuum is drawn on it. The vacuum valves are usually included with the hot bonding equipment.

Figure 10-3-1. Vacuum is created by using compressed air through a series of venturi tubes.

Figure 10-3-2. Vacuum hose used for vacuuming in an area where the temperature does not go above room temperature, the internal wires to prevent collapsing can be seen in the clear tubing. The vacuum valve is a quick connect style.

Acoustical Leak Tester

To check for leaks around the vacuum bagging seal and to locate any pinholes in the plastic, an acoustical leak tester can be used. A probe is pointed anywhere a leak is suspected, the hissing sound is amplified and heard through earphones. A funnel is a simpler version that can be used. The large end is pointed at the areas suspected of leaking, and your ear is next to the small end. This magnifies the hissing sound. A simple stethoscope with the end cut off, so just a tube is pointed at the areas suspected of leaking, can also be used. These two alternatives are cost-effective ways to listen for leaks.

Lay-Up Tools

Use a balance or scale to mix the two parts of the resin system to the desired weight. A digital scale is the most accurate. Do not mix by volume; always mix by weight.

Homebuilt aircraft designers have made a quick and easy pump for measuring the resins and catalyst to the correct ratio for homebuilt aircraft. This device is not used in the repair field because many types of resins are available with different ratios for mixing. A scale is much more versatile.

Scissors to cut various materials are required. Carbon/graphite and fiberglass can be cut with conventional fabric scissors. The scissors should be made of metal, without plastic handles. The solvents used to clean up these scissors after working with them could melt the plastic handles.

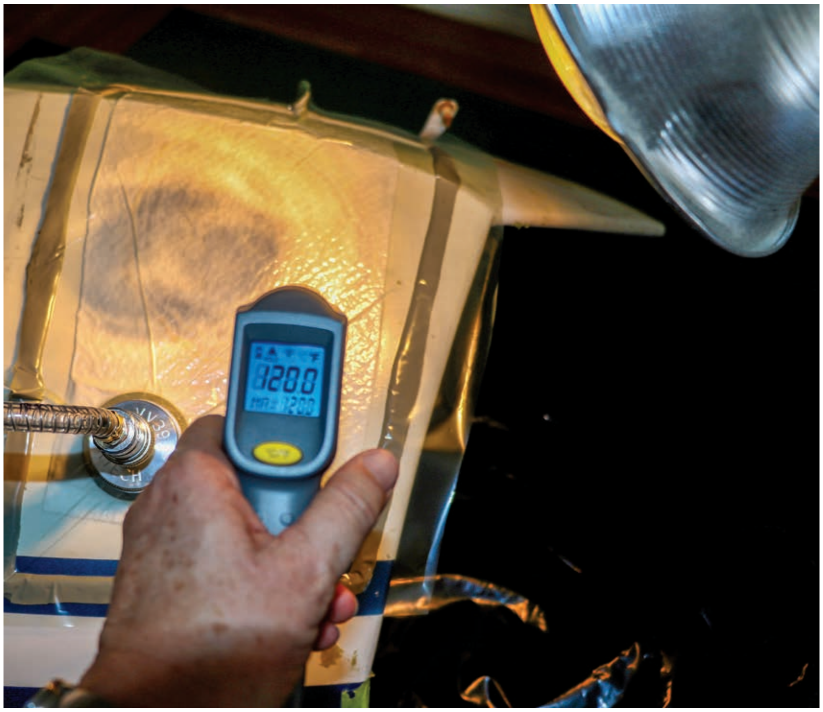


Figure 10-3-3. Surface temperature can be checked with a laser thermometer when using heat lamps to accelerate the cure.

Aramid fabric should be cut with special scissors that cut the fibers without fraying. If a lot of aramid cutting is to be done, these special scissors are very desirable.

Squeegees come in various types depending on what the user prefers. Some are soft and flexible; others are a hard plastic. This is just a matter of preference.

Curing Equipment

Structural repairs require equipment to heat the repair. Several ways can be used to cure the composite repair with heat. Failure to follow the proper curing requirements, or improper use of curing equipment could be reason to reject the repair

As mentioned earlier, some resin systems can be cured at room temperature (65°F–80°F) in 8 to 24 hours depending on the type of resin system used. Using heat with some room temperature curing matrix systems can accelerate the curing process. However, most structural composite parts are manufactured at a high heat, and the repair must also be cured at high heat.

The most widely accepted method of curing structural composites is by using resins that cure at high temperatures. The adhesives and matrix systems used for repairs require elevated temperatures during their cure to develop full strength. This heat also reduces the brittleness of the resins. The cure temperature can range anywhere from 150°F to 750°F. The amount of heat applied should be held constant by monitoring the surface temperature of the repair.

Heat Lamps

Using heat lamps to cure advanced composite parts is not recommended. The temperature cannot be accurately controlled and heat lamps can localize the heat in one spot. They can used as an economical alternative to heat blankets; however, the temperature cannot be monitored as well. A breeze across the surface can lower the temperature by 10 degrees. Because of these difficulties, use heat lamps only as a way to accelerate the cure time for room-temperature cure resins (Figure 10-3-3).

Heat Guns

When a heat gun is used to cure a composite part, it must be controlled with a temperature monitor. This is necessary because a typical heat gun can generate temperatures of up to 750°F when it is left on continuously. If, for example, the cure temperature is 350°F, the heat gun should be monitored with a controller. Problems can occur if the heat gun is pointed to one place on the repair; the excessive curing in that spot could evaporate the resins, leaving dry areas that are cause to reject the repair.

Oven Curing

Ovens offer controlled and uniform heating of all repair surfaces. Some ovens have vacuum ports to provide vacuum pressure while curing. One problem associated with using an oven to cure repairs is that the part must be removed from the aircraft and must be small enough to fit into the oven. Manufacturers frequently use oven curing to produce a part. Ovens used to cure composites must be certified for that purpose.

Autoclaves

Autoclaves are customarily used in manufacturing composites rather than in repair procedures. An exception to this is when the damage is very extensive; the part must be put into the original mold and cured with heat and extra pressure. A composite part repaired to this extent is more accurately referred to as a remanufactured part.

In remanufacturing, the part is placed back into its original mold used during manufacturing, then vacuum bagged and heated up to the curing temperature at a controlled rate while more pressure is applied.

Hot Bond Use with Heat Blankets

Flexible silicon heating blankets come in a variety of forms and sizes. This is the preferred method of curing repairs for most composites because of the controlled, even heating of the part. Most hot bond equipment comes with all the vacuum valves, vacuum hoses, thermocouples, and heat blankets required to start working with the unit. Other sizes of heat blankets can be ordered later as the technician sees the need for various sizes.

Hot Patch Bonding Equipment

Composite hot patch bonding equipment is most often used to repair composite components in the field or when the damage is small enough not to require remanufacturing of the part. They offer many advantages over autoclave and oven curing. They include both the controller for heat application by a heat blanket or heat gun, and the vacuum pump for applying pressure.

Figure 10-3-4. This composite hot patch bonding unit has both vacuum and heat capabilities.

For example, CES Composites—a firm that provides advanced composites supplies and equipment—offers a composite hot patch bonding system that incorporates a heat control unit and a vacuum source to complete composite repairs. This portable unit is very lightweight and ideal for use in shop repairs (Figure 10-3-4).

The 100 percent solid-state heat control unit works as a setpoint controller and a ramp-and-soak controller, depending on the type of repairs being performed. The digital display panel is easy to read and can be programmed up to 99 hours long with a maximum of eight steps. The vacuum unit provides up to 27 in. Hg at 58 p.s.i. It converts standard shop air into vacuum pressure.

This machine also comes with all heat blankets, vacuum hoses and valves, thermocouples, gauges, and instructions. A solid-state recorder or a strip chart recorder is also available that can be used with this controller.

Section 4

Training

Composite materials are seeing increased use in the aviation industry because of the high strength and lightweight structures they produce. One of the most significant drawbacks to using composites is the lack of trained technicians who are capable of making acceptable repairs to damaged composite structures. Such repairs must be done properly to restore the structural integrity of the damaged part. The techniques required to properly complete composite repairs are not commonly known.

Technicians, inspectors, maintenance managers, and critical maintenance personnel must achieve a level of technical expertise to work on the advanced composite components. Training is needed to provide practical information about common field repairs, tools, materials, and techniques. After completing the training, a technician should be able to easily translate the manufacturer's instructions into airworthy repairs using the skills and knowledge gained.

FAA Concerns

Inspecting shops that manufacturer or repair composite components must be addressed by the FAA and the shops. Following proper procedures is a must when repairing composite structures, for the safety of the aircraft.

Many Advisory Circulars (AC) provide information and guidance concerning the compliance with the *Code of Federal Regulations* (CFR). The ACs are used in combination with the manufacturer's SRM.

Material Specifications

When material specifications are called out in the repair or alteration drawings or other documents, the materials used must meet the qualification requirements in the material specifications.

Receiving Procedures

When the materials are received, the shop personnel must ensure the that conformity of the materials received meet the materials specifications. Then the receiving personnel must ensure that the materials are protected from contamination, temperature deviations, and other storage requirements and that these changes did not occur during transport, handling, and storage that could affect its strength.

If the materials shipped are pre-pregs, resins, core splice, or film adhesives that require refrigeration, the amount of time should be recorded that it was "out of the freezer" during the transport time. Other materials received that do not affect the repair do not need a controlling specification. These materials include bagging film, bleeder cloth, and sealant tape. They are used as *tools* and do not stay with the aircraft after they have been used. They are consumable items.

Supplier Quality Control Testing

The supplier is responsible for supplier quality control (QC) testing on each batch of material. Copies of the original material manufacturer and supplier laboratory test reports showing actual test results, if applicable, must accompany each batch of material received for the purchaser's review and approval. The FAA may inspect these records.

Storing Materials

Proper storage and handling of the materials is important to maintain the structural integrity of the finished part. Whenever the material is taken out of the freezer for cutting and processing, the accumulated time must be tracked. The FAA may check for storage temperatures, shelf-life records, and records that show accumulated time out of freezer.

The support of the material is important. Even in the freezer, the rolls must be supported to prevent flat spots. Stacking of rolls on top of one another is not allowed. Raw materials must not be folded, which could break or damage the fibers.

FAA requires the following practices for materials stored in the freezer:

1. Using frost-free cold storage equipment.
2. Using a temperature gauge or thermometer, which should be calibrated.
3. Identifying which materials must be stored in the freezer.
4. Placing a tag or record on each roll or container showing the batch number, lot number, roll number, shelf life ending date, and the total, allowable, and accumulated out life. Be sure to have room available on the label to add more accumulated out time.
5. Specifying the highest allowable freezer storage temperature.
6. Regularly monitoring freezer storage temperature.
7. Requiring that the material be stored in moisture-tight bags or containers in the freezer to prevent moisture absorption.
8. Specifying that the material is to thaw within the container or bag until the condensation of the exterior of the container has dissipated. This is to prevent atmospheric moisture from condensing on the material.

9. Retain the batch number, lot number, roll number, shelf life, and out time records for a specified time. Recommended time is minimum of 2 years after the material is depleted or disposed of.
10. Materials that have exceeded their shelf life or out time limit must be scrapped or recertified.

The FAA has been concerned with the conformity and documentation of parts since the "bogus parts" problems came to the forefront.

Fabric has no material designation printed on it. The industry could take a lesson from the days of dope and fabric aircraft. The weavers of the fabric would print the spec number on the selvage edge of the material every 3 feet because the FAA required it. As it is now, rolls of fabric are sent out to manufacturers in large quantities (sometimes around of 500 yards to a roll) with a sticker pasted to the inside of the roll. The sticker tag should include the weave of the fabric, and the weaver of the fabric. However, this is not always the case, as shown in Figure 10-4-1. The sticker does not say whether it has passed quality control or is first quality, but the number on the sticker should match up with a paper that has the same number. The Certificate of Compliance paper should state, "We Certify that this material meets the requisites of..."

In some cases, the sticker is on the outside of the roll, but it does not reference the material. It might have only a bar code that corresponds to the paperwork included with the fabric (Figure 10-4-2).

Certification of the materials is printed on paper sheets and included with the roll to show that the material passes quality control, and it conforms to the standard of the weave. This is fine for manufacturers but not for repair stations or airlines.

Certifications include the name of the weaver, customer order number, date of the sale, date it was manufactured, style of fabric, width, lot number, weave, warp, fill, and if this material meets the requirements for first quality.

A detailed shop record must accompany every part for repair.

Some repair stations and smaller commuter airlines might do only a few repairs a year, and do not require the large rolls of 500 yards of certified material, which is very expensive, especially if multiple fabrics are required for a repair. Buying certified fabrics in small quantities has been a struggle for many maintenance shops. A smaller company might buy the full roll, and re-roll a smaller amount. The original paper certifications are copied, and a second conformity sheet is sent with the material saying that the shop bought 10 yards of a certain weave, and it conforms to the spec needed. This increases the cost for many ethical small-quantity distributors because there is no part designation on the fabric. It also requires the shop to have certifications in a notebook next to the rack where the fabric is stored.

Some composite companies sell materials that have no certificates at all, but they still sell them as the designated weave. **These may not be used on aircraft.** They might not have passed quality control for aviation, they could be seconds or materials with a slight material flaw, or they might not even be the type of material you require. You can buy carbon fiber fabric weaves that do not even have carbon in them. They are dyed fiberglass.

If the material is certified, the information is not always sent with the materials and must be requested separately.

Figure 10-4-1. A sticker might be on the inside of the roll that corresponds to paperwork that is sent with the fabric.

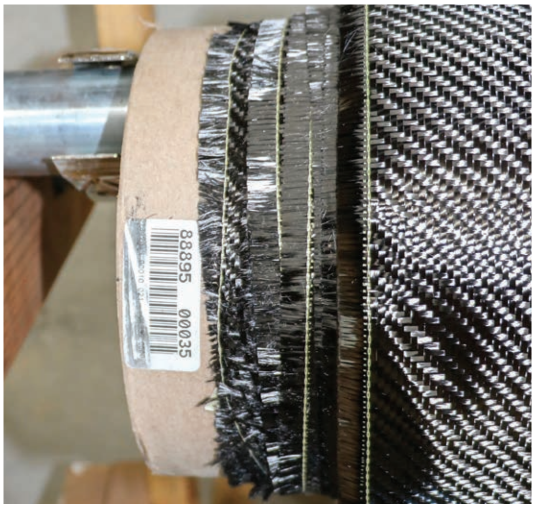


Figure 10-4-2. A sticker on the outside of the roll.

Photo: This WP-3D Orion's radome was repaired. Before starting a repair, check the damage repair limits.
Courtesy of NOAA

11

Assessment and Repair

The task of repair begins when a technician determines the structure has been damaged to the extent that it requires a repair. It is important to evaluate the damage to determine the type, depth, size, and location of the defect. Some defects can be more serious to the performance of the part, and this information must be considered seriously so the best method of repair can be determined.

Learning Objectives

REVIEW

- Lightning protection measures

DESCRIBE

- Types of damage to composites
- Methods of nondestructive inspecting
- Steps for repairing composite damage
- Adhesives used with installing a core

EXPLAIN

- Procedure for step cutting
- Importance of fabric and core direction
- Procedure for impregnating raw fabric
- Process for painting composites
- What could give a false reading in a tap test

APPLY

- Plan a repair and mark an area for different damage scenarios

Section 1

Classifying Damage

Damage is placed in one of three classifications: negligible, repairable, or non-repairable. Although all manufacturer definitions vary slightly, negligible damage is described as any damage that can be corrected by a simple procedure with no restrictions on flight operation. Repairable damage is damage to the skin, bond, or core that places restrictions on the aircraft or part. All permanent repairs must be structural load-carrying repairs that meet aerodynamic smoothness requirements.

A non-repairable part is one that is damaged beyond established repair limits. If a composite part has been damaged beyond the specified repairable limitations, it should be removed and replaced. In some cases, however, the part can be remanufactured if the manufacturer approves. The part should be crated and sent to the original manufacturer or an authorized repair station that is equipped to perform the remanufacturing operations.

There are definite engineering reasons for establishing repair limits for critical airframe com-

Repair Area A — Laminated Carbon/Epoxy Structural Skins		
Type of Damage	Negligible Damage (Note 8)	Repairable Damage
Scratches	Glass Ply Damage (Note 5)	0.010 to 0.030 inch in depth and less than 3.25 inches in diameter or length without Carbon failure. (Note 1)
Dents (Note 1)	Less than 0.010 inch in depth (Note 6)	
Panel Edge Damage	Less than 0.125 inch wide by 6.0 inches in length and less than depth of skin. (Note 1)	None
Surface Damage	Not defined	Less than 1.0 inch diameter and less that 0.085 inch deep.
		Greater than 1.0 inch diameter but less than 3.25 inch diameter and less than 0.035 inch deep.
		Greater than 1.0 inch diameter and .035 inch deep but less than 3.25 inch diameter and .085 inch deep.
Surface Damage and Holes	Not Defined	Greater than hole limits set in Fig. 3-15 (55-32-01) but less than 6.0 inches in diameter.
Holes (Note 9)	None	Holes through skin after clean-up that are within limits set forth in Fig. 3-15 (55-32-

Repair Area B —Bonded Carbon/Epoxy Skins to Honeycomb Sandwich Structure		
Type of Damage	Negligible Damage (Note 8)	Repairable Damage
Scratches	Does not penetrate beyond protective glass ply into Carbon composite	Penetrates one or more Carbon plies but not through more than 1.0 inch.
		Penetrates one or more Carbon plies but through skin and not longer than 3.25 inches.
Dents (Notes 1 and 3)	Less than .010 inch in depth (Note 6)	.010 to .030 inch in depth and less than 1.0 inch in diameter. (Note 1)
Panel Edge Member Damage	Less than .125 inch wide and 6.0 inches in length and less than depth of skin (Note 1)	None
Holes and/or cracks through one skin	Not Defined	1.0 inch diameter hole or less (Note 1)
		1.0 inch to 3.0 inch diameter hole (Note 1)
Holes and/or cracks through both skins	Not Defined	1.0 inch diameter hole or less on either side (Note 1)
		1.0 inch to 3.0 inch diameter hole on either side (Note 1)
Skin to core voids	Less than .50 inch diameter in area	Greater than .50 inch but less than 2.50 inches in diameter or no greater than .70 inch wide by 4.0 inches long.
Leading or Trailing Edge Damage	Less than .25 inch deep (Note 3)	Greater than .25 inch deep but less than .380 inch beyond .008 inch stainless steel leading edge and 3.0 inches in length (Note 1)

NOTES: EXAMPLE DAMAGE CLASSIFICATION

1. Any dent damage causing delamination, breaking and/or creasing of the skin must be considered as a fracture and must be repaired accordingly.
2. The repair adhesives do not adhere well if are not properly bonded initially.
3. It is permissible to straighten out dents in the .008 gauge vee edge that are confined to within .25" of edge. Use three-ounce hammer and backup bar. Care must be taken to avoid debonding.
4. Surface damage is defined as cuts, deep scratches, abrasions, and dents with broken fibers that do not penetrate the skin.
5. Surface damages such as scratches and abrasions that damage paint and/or protective fiberglass outer ply but do not scratch or abrade the carbon laminate fibers underneath are classified as negligible damages.
6. Dents in skin that are stable and are not accompanied with delaminations or broken fibers are classified as negligible damage.
7. Sum of void dimensions in any direction shall not exceed 20% of maximum dimensions in that direction.
8. There are no restrictions on size, locations, or number of negligible repairs.
9. Repairable holes in vertical stabilizer box skin are limited to holes that do not extend into the internal structure before or after cleanup.
10. This table is taken from Structural Repair Manual. It is not to be used while making a repair.

Figure 11-1-1. Example of a typical damage classification chart. A picture of the aircraft is usually included, outlining Repair Areas A and B.

ponents. Standard repair procedures cannot always replace 100 percent of the damaged composite part's strength. Therefore, it is imperative that technicians do not exceed the manufacturer's specified repair limits during field repairs.

Many times the damage is a combination of two types of damage. For example, a part might have a hole and be delaminated. For a component, the delamination could be within the repairable limits, and the hole, alone, could be within the repairable limits. However, a delamination with a hole might not be within limits. When determining the reparability of a component, read the entire section of the structural repair manual (SRM).

Repair methods and damage classification have not yet been standardized in the aviation industry. Each manufacturing engineer can develop a method of classifying damage with an appropriate repair procedure for an area of the aircraft. Figure 11-1-1 is an example of a damage classification chart that might be found in the SRM for the aircraft component. The repair procedures that are presented in this textbook are intended to give the technician some background as to the most commonly used procedures. This example should not be used for any aircraft, except the one for which it was designed.

Section 2

Types of Damage

Damage to a composite can be from various things. Overflexing the part could show cracks. Impact damage from hail, hangar rash, towing, baggage handling can all cause problems. Typically the damage is done on the ground and not in flight. Figure 11-2-1 shows several common types of damage.

The types of damage are cosmetic, impact, delamination, cracks, and holes.

Cosmetic Defects

A cosmetic defect is a defect on the outer surface that does not involve damage to the structural reinforcing fibers. Cosmetic damage is often caused by chipping or scratching during handling. It does not affect the part's strength and usually is repaired for aesthetic reasons. If damage is done to a top fiberglass layer of structural components made of either aramid or carbon/graphite, it can be considered negligible or cosmetic damage because this outer layer is not considered structural.

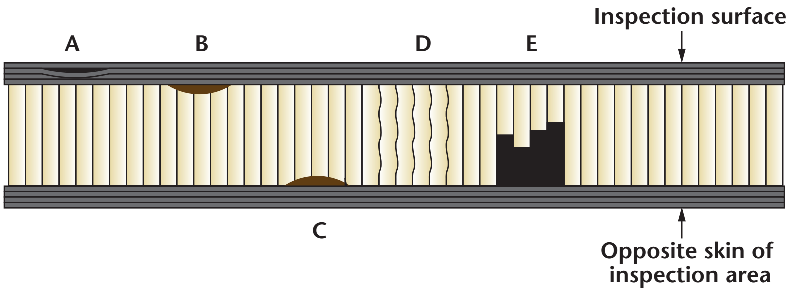


Figure 11-2-1. Typical damage to advanced composite parts. A shows delamination between the layers of fabric, B and C show delamination between the skin and core, D is a crushed core, and E is water in the core.

Impact Damage

Impact damage occurs when a foreign object strikes the part. The degree of damage can range from slight to severe. The most common cause of impact damage is careless handling during transportation, storage, or standing parts on their edge without adequate protection.

The thin face sheets on a sandwich panel are very susceptible to impact damage. An area that has been subjected to impact damage should also be inspected for delamination around the impacted area.

Nicking, chipping, cracking, or breaking away pieces of the edge or corner can also be caused from improper handling.

Delamination

Delamination is the separation of fabric layers of material in a laminate (Figure 11-2-2). Delamination can occur with no visible indications from the outer skin. To compound the problem, delamination often accompanies other types of damage, especially impact damage. This damage has several causes, including impact, moisture in the fabric, or lightning strikes. Another type of delamination is an unbond, or as it is sometimes called, a *disbond*. A disbond occurs when the skin of a sandwich structure becomes separated from the core.

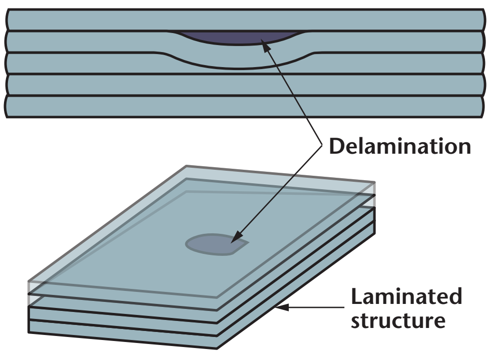


Figure 11-2-2. Delamination of fabric layers.

Figure 11-2-3. Areas that show cracks should be inspected more thoroughly to see if the cracks are only in the paint or have propagated into the fiber materials.

In cases in which damage is visible, it is best to assume the damage has radiated into areas that exhibit no visual damage.

An air pocket between layers of fabric could also be the result of improper bonding of the composite. This can occur during manufacturing or during a repair operation by any of the following:

- Improper resin/catalyst
- Improper mixing or weighing of the two matrix components
- Inadequate pressure or heat during the cure cycle
- Improperly cleaning off dirt, grease, or foreign materials from the surface to be bonded

Cracks

Cracks can occur in advanced composite structures just as in metallic ones. Sometimes they can be detected visually; other times they might require more advanced methods of nondestructive inspection (NDI). A crack can be just in the top paint or matrix layer and not penetrate into the fiber material at all. The paint can be sanded off, and a portable microscope can be used to see if the cracks actually go into the structure or just in the paint or gel coat.

A crack could also extend into the fiber material and into the core yet appear to be just in the top surface. A thorough inspection should be made to determine the extent of each crack (Figure 11-2-3). This can be done by sanding down the paint and looking closely at the fibers with a handheld microscope.

Hole Damage

Holes can result from impact damage, overtorquing fasteners, or from fasteners pulling through. Holes drilled in the wrong location, wrong size, or wrong number of holes drilled can also be classified as hole damage.

Holes caused by a lightning strike can burn off resins, leaving bare cloth.

Tiny holes, known as *pin holes*, in the skin surface are not easily detected, however, they could lead to more extensive damage. If moisture is allowed to get into the core structure, along with the airflow over the part, it can cause a small delamination, which can grow into a very large delamination.

Section 3

Inspection Methodology

Areas on the aircraft that are susceptible to damage, such as leading edges made of thin face sheets over a honeycomb panel, should be inspected more often than areas that are more protected, such as the vertical stabilizer. These areas should be visually inspected periodically; more in-depth inspection should be done at regular overhaul intervals.

Many times, to be inspected correctly, the inspection method requires that the component be removed from the aircraft. This type of inspection is usually done at the time of the aircraft's overhaul. Between overhaul inspections, visual inspection usually is adequate. Each manufacturer calls for a specific test method depending on the location and type of structure.

With the 787 being mostly composite airframe, Boeing is designing and testing composite hardware so that inspections are mainly visual. This reduces the need for ultrasonic and other nonvisual inspection methods, saving time and money.

This section discusses the inspection methods used to check for damage: visual, the coin tap test and other types of NDI.

Visual Inspection

Visual inspection is used to detect cracks, surface irregularities (from an internal flaw), and surface defects such as delamination and blistering. A good visual inspection usually detects surface flaws. A light and a magnifying glass are useful in detecting cracked or broken fibers. A small microscope is also helpful in determining whether the fibers in a cracked surface are broken or if the crack affects only the resin or paint.

Delaminations can sometimes be found by visually inspecting the area at an angle with a bright light shown on the surface. The delaminated area can appear to be a bubble or an indentation in the surface. Use a coin tap test if you suspect an area of delamination.

Coin Tap Test

One of the most important methods used to detect internal flaws or delaminations is a coin tap test. Use a coin or rounded-edge steel washer (Figure 11-3-1) to tap lightly along a bond line or area suspected of having a flaw. Listen for variations in the tapping sound.

Figure 11-3-1. Coin tapping a part around areas suspected of delamination. The circled area is larger than the hole because delamination was detected.

A sharp solid sound indicates a good bond. A dull thud indicates bond separation. However, changes in the thickness of the part, reinforcements, fasteners, and previous repairs can give false readings. Whenever damage is found visually, coin tap around the area to find damage such as a delamination that cannot be seen. In many cases, if there is a hole, crack, or other damage, there is also delamination around the area. This type of test works only on one side of the component at a time. The opposite side of the component must also be coin tapped to find delaminations.

Some companies suggest a tap hammer, which works well for some technicians. Technicians usually have several methods that work for them. After developing a tap test method that works for you, and after much tapping, you will be more experienced with different materials. As an example, at a major airline shop, the technicians were using the tapping method, which seemed odd because they had all kinds of NDI equipment available in the shop. The technicians reported that they were just as good at finding debonds with tapping as with the NDI equipment, and tapping is much cheaper to operate. The technicians were within 1/8 inch of the damage recorded on their NDI equipment.

Coin tapping on edges, around holes, and internal structures that might include spars will all have a different sound. Do not think that if the sound is different, something is wrong with the part. The sound can change for many reasons. Trailing edges are tapered down, so that the structure is not as thick in some areas; this gives a different sound. Edges of a panel give a different sound than an area that is solid. Drilled holes with fasteners inserted, or not, also give a different sound than a solid area. If the component's composition is different, such as a change in the type or thickness of honeycomb, or a metal part internally bonded in, you will also hear a change in the tapping sound. This is how the part is made, which you can tell by looking at the SRM. You should expect a difference in the sound, and there might be nothing wrong with the part. To be more certain that the sound change is normal, coin tap in an area of the same configuration that you do not suspect for delamination, and compare the sound.

NDI Equipment

A technician who has had training in NDI and on the equipment being used, is the one who performs the inspection. Once the results of the test are available, the repair can be performed and retested, if needed, after the repair.

Many NDI methods can be used. In this section, we provide an overview of ultrasonic, thermography, laser holography, radiography, and dye penetrant. Table 11-3-1 indicates defects that various inspection methods can locate.

	Service-incurred defects						
Inspection	Impact	Delaminations (disbonds)	Cracks	Hole damage	Water	Lightning strike	Burns and overheating
Visual	X		X	X		X	X
Radiographic (X-ray)	X		X	X	X	X	
Ultrasonic		X	X		X	X	
Thermographic	X	X		X	X	X	
Tap testing	X	X		X		X	
Dye penetrant	Do not use on composite materials.						

Table 11-3-1. Defects that can be revealed by various inspection methods.

Ultrasonic Inspection

For internal damage inspection an ultrasonic tester can be used. Ultrasonic testing uses a high-frequency sound wave as a means of detecting flaws in a part by beaming a high-frequency wave through the part and viewing the echo pattern (pip) on an oscilloscope. By examining the variations of a response, you can detect delaminations, flaws, or other conditions.

Some ultrasonic equipment cannot differentiate between a honeycomb cell and a void, resulting in an unreliable reading. New ultrasonic equipment has been recently developed to detect flaws in skins over honeycomb cores. This equipment works on carbon/graphite and fiberglass by using special probes, but it does not work on materials such as aramid. Ultrasonic equipment can be ineffective for detecting some types of damage on some composite structures, so make sure the equipment you are using can be used on the type of component you are testing.

Three types of ultrasonic testers are commonly used: A-SCAN, B-SCAN, and C-SCAN. An A-SCAN is a time-versus-amplitude display that is read from left to right. A known reference must be scanned first. Then the height of the specimen pip is compared to the height of the pip on the reference. A B-SCAN takes a cross-sectional view of the material being tested and uses an oscilloscope screen to compare the sample. C-SCAN imaging equipment shows the shape, size, and location of the damage, but it does not show the depth.

To ensure reliable results for ultrasonic inspection, technicians must receive specialized training in NDI and the equipment.

Thermographic Inspection

Thermography locates flaws by temperature variations at the surface of a damaged part. Heat is applied to the part, then the temperature gradients are measured using an infrared camera or film (Figure 11-3-2). On the film, a material's thickness varies and shows up as different colors because of the heat buildup in different areas of the material. Thermography requires knowledge of the thermal conductivity of the test specimen and a reference standard for comparison purposes.

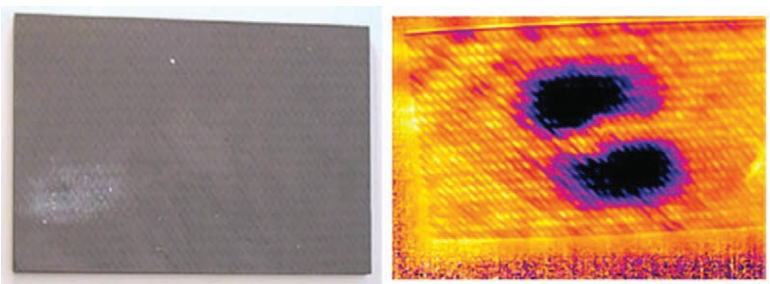


Figure 11-3-2 . The panel on the left appears to have no damage, but the thermography image on the right shows impact damage.

Courtesy of MoviTHERM

Laser Holography Inspection

Laser holography calls for the suspect part to be heated and then photographed using a laser light source and a special infrared camera film system. It is used to detect disbonds or water in honeycomb and impact damage. Laser holography is quite expensive to use; at this time, only manufacturers and very large airline maintenance facilities use the process.

Radiographic Inspection

Radiography can be used to detect cracks both internally and externally that cannot be seen. Radiography also detects water inside the honeycomb core cells. It is useful for detecting the extent of the damage that cannot be seen. Like laser holography, because of the expense this type of testing is used only by manufacturers and large airlines. Such companies test the manufactured components to see if the ply orientation is correct and that matrix cracks, delaminations, subsurface damage, resin content (resin rich or starved), and porosity can all be seen. This is helpful to the manufacturers so they can adjust their methods of manufacturing to produce the perfect part.

Dye Penetrant Inspection

Dye penetrant is used successfully for detecting cracks in metallic surfaces; however, it *should not* be used with advanced composites. If the dye penetrant is allowed to sit on the surface, the wicking action of the fibers can pull the dye penetrant into any cracks or broken fibers and would no longer bond to new material. The entire affected area would have to be removed before new patches could be applied. This, in effect, could extend the damage to a size that would make the part non-repairable.

Section 4

Repair Operation

It is not necessarily difficult to complete an airworthy repair to a composite structure. However, the techniques, materials, and tools that are used are different from those used on conventional repairs. If technicians do not take care to do a composite repair correctly, the repair will not develop the full strength characteristics that are desirable in a composite structure.

The question in the aviation industry is no longer, "Will the composite work?" Rather, the most relevant composites-related question that is now asked in the aviation industry is, "How do you fix it?"

Aeronautical and materials engineers have designed composites to perform in the air, but the most common types of damage to composite structures occur during ground handling. Aircraft damage most commonly occurs when the aircraft is being serviced, stored, and maintained, or during landing and takeoff.

Composites that use very thin laminates over cores are susceptible to impact damage that can occur from a dropped tool, mishandling by tugs or other ground support equipment, or in the case of a component part, simply by being dropped on a hard surface.

If the part is subject to continuous loading and unloading of stress, the resins can develop very tiny cracks. These cracks can eventually prevent the resin from transfering the stress loads to the fibers. The fibers themselves will probably not crack and fail, but the damage to the resin can seriously weaken the part's structural integrity.

Aviation composites are designed to be strong, light, and durable. These components are usually very expensive parts because they are made in one piece, often including stiffeners and internal components in one part. A composite repair must be made correctly because the cost of replacing the part is often not feasible. The technician's responsibility then is to be able to complete the repair with sufficient expertise so as to restore the original structural strength. Engineers and manufacturers are testing many new repair techniques to help technicians achieve these goals.

This is a new technology, and new repairs are expected to be introduced periodically. The FAA guidelines for structural repair state that the design strength and remaining service life of the part must be restored. All the repair procedures found in this textbook, although not specific, are typically found in SRMs.

Traditional Fiberglass Repairs vs. Advanced Composite Repairs

The older type of fiberglass repairs cannot be used on the advanced composite structures of today, because the advanced composites are often used for structural applications. The fiberglass structures of the past were typically used for nonstructural applications. Consequently, the old style fiberglass repair methods were not necessarily intended to restore full structural strength to a part.

Many fiberglass repairs were done with polyester resins and cured at room temperature. The resins were often applied very thick and were not bled out of the fabric during the cure process. Fabric weaves and ply direction were not considered, and many times the patches were bonded on without removing the damaged area. When a part is used structurally, it must deliver the same characteristics in flight as the original part.

Section 5

Repair Procedures

Some procedures are common to many types of advanced composite repair. This section is presented only as an example typical repair situation. For an actual repair, the technician must consult the manufacturer's SRM for such information as operating environment, damage size limits, repair proximity limits, and other information pertaining to the repair.

> **NOTE:** The information in this book is for training purposes only. Consult the appropriate SRM.

Determine Damage

To determine the type and scope of a part's damage, do the following:

1. Visually examine the part for the extent of the damage.
2. Check in the vicinity of damaged area for entry of water, oil, fuel, dirt, or other foreign matter.
3. Check for delamination around the damage by coin tapping or other technique.
4. Check in the applicable section of the manufacturer's SRM to determine whether the damage is within the repairable damage limits.

Surface Preparation/Paint Removal

If the part is reparable, prepare the surface for the repair process. Remove surface contaminants such as exhaust residue, hydraulic fluid, and surface film by using a suitable soap and water solution, followed by a solvent wash of MEK or acetone. The repair zone should be masked off with masking tape about 2 inches beyond the largest area patch to be replaced.

> **NOTE:** MEK is considered by many to be harmful to people and the environment. In some states, it is illegal to use. Usually an SRM offers a choice of using MEK or acetone. Denatured alcohol can be used in some cases.

The paint also must be removed from around the repair area to promote adhesion of the repair materials. This is done mechanically (Figure 11-5-1). Usually a small right-angle grinder fitted with 100 grit sandpaper, or a scouring pad is used to remove the paint down to a primer level, if used, or the last layer of paint. To remove the final bit of paint, a finer grit paper is used, sometimes with hand sanding.

Do not use paint strippers on composite structures. The problem is that because paint strippers are designed to remove epoxy-based paint, and because the resin systems used on most composites are epoxy based, the paint stripper deteriorates the resins in the component.

> **CAUTION:** Never use paint strippers of any type on any composite structure. Strippers can remove surface layers of resin and expose fabric. Some fabrics can absorb the stripper and create a surface that does not bond to another surface or paint.

When using a power sander to remove paint, take great care. Most larger power sanders are not recommended for paint removal because they do not provide sufficient operator control. If the top layer of composite fibers is sanded through, more extensive repairs could be required. Composite plies might not be perfectly even. In such a case, sanding the top layer in one area would be fine, but in another area the same depth of sanding could result in sanding through to the core material. This is especially prevalent in composites that were manufactured using a gel coating on the outside.

11-5-1. Remove the paint from the part, being careful not to damage the structural layers.

Abrasive particulate blasting. Over the years, abrasives have been blasted in an area to remove the paint. Different abrasives have proven to be acceptable. Plastic bead blasting has proven to work on some composite designs. It is used just to chip off the paint and not go into the repair. Other manufacturers do not want it to be used, because it is so abrasive that it goes down into the fiber layers.

Take care not to damage the plies that surround the repair area. If surrounding plies are damaged in the paint removal operation, the repair area might have to be enlarged. If this happens, it might not fall within the repair limits, and some manufacturers limit the number of repairs in a certain area. If two repairs are being made, they might be too close together and the part could become non-repairable.

Figure 11-5-2 presents an example scenario. The tape shows the area of the repair. The paint is removed from within the taped area. If, while removing the paint, you go into the structural plies, you would have to make your repair larger. Depending on how deep into the repair plies the damage is, the final repair patch might be enough to cover the area. Once the paint has been removed from the area surrounding the damage, you should clean the part with an appropriate solvent.

Removing Moisture from a Damaged Area

During the paint removal, moisture could be detected in the form of water, oil, or even hydraulic fluid in the part. It is important to remove the moisture. Moisture in the composite component can be very dangerous if it is allowed to remain in the structure during the repair and after the repair is completed, especially when the moisture is in a honeycomb structure. Water that is trapped in a structure expands when heated, building up pressure, which can cause further delamination. If the trapped water is allowed to freeze, it expands, also causing delamination. The water can also act as a plasticizer, reducing the composite structures' strength characteristics.

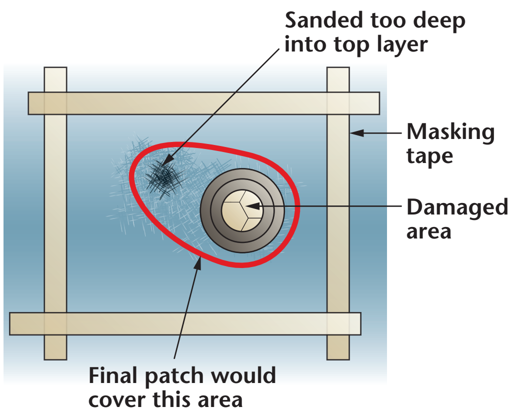


Figure 11-5-2. Masking off the repair area is used in the area around the actual damage where the paint needs to be removed.

If the moisture is not removed before bonding the patches, blisters can form, or the patches will not bond at all.

Water or moisture can enter edges that are not properly sealed and around holes not properly sealed that were drilled to accept hardware. The part can gather moisture from humidity or from rain and snow that soaks into the edges.

When the part has been damaged, it is important to bring the part into a dry area to avoid excessive moisture from wicking into the part. If the part has been properly sealed with paint or sealant after manufacturing or repairing, moisture should not be a problem.

Radiography and laser holography are good methods of detecting moisture in a composite structure. An ohmmeter is another way to detect moisture; if the ohmmeter indicates continuity when the two probes are placed on the suspect surface, moisture is probably present in the material.

Once moisture has been detected, it must be removed. To remove water from a composite component, use the following steps:

1. Remove any standing water with a wet/dry vacuum cleaner. If oil is present, use towels soaked in solvent to thin the oil and help remove it. It should look fairly clean.
2. Vacuum bag the surface using a vacuum unit to pull out water. Use a screen with a heat blanket to evaporate the water. As the vacuum unit is connected, the reduced pressure pulls out most of the water, the bleeder helps absorb the water, and the heat blanket with the screen evaporates any remaining water (Figure 11-5-3).
3. An alternative method is to apply heat with a heat lamp to dry out the component.
4. During the repair process when curing patches, a slower temperature rise reduces the probability of blisters and voids forming, but this is true only if a small quantity of moisture is present.

If all the contaminants cannot satisfactorily be removed by using the above methods, the affected part must be removed and replaced.

After a repair is finished, it must be protected from moisture. Paint and edge sealant can be used to help prevent moisture from entering the structure. Some manufacturers recommend using a layer of plastic moisture barrier (a polyvinyl fluoride film known as Tedlar®) to prevent moisture from entering through the fibers.

Marking the Repair Area

This portion of the repair procedure defines the area that is to be cut and stepped to accommodate the patch. To mark the proper amount of space for each cut, use the following procedures:

1. Outline the entire damaged area that must be cut out and removed.
2. Expand the repair radius (assuming the repair is a circle) by one-half inch for each ply that must be repaired.
3. If an overlap patch is used, the extended radius is typically an additional inch. Place the masking tape along the lines where the repair is to be made.

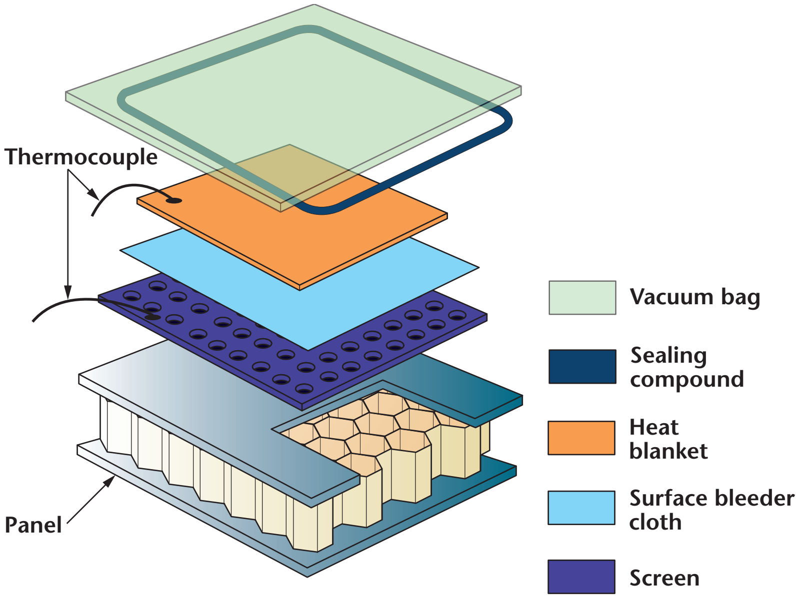


Figure 11-5-3. Vacuum bag setup used to draw moisture from the area being repaired.

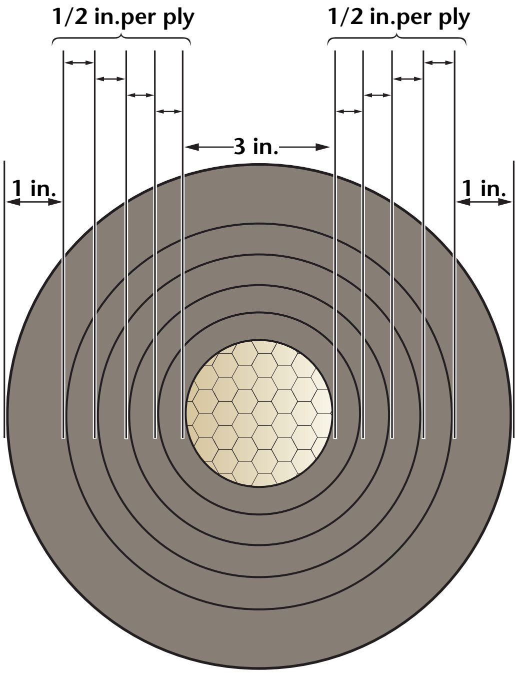


Figure 11-5-4. Example repair: the total size of the repair would be 9 inches in diameter.

Figure 11-5-5. Repairs are not always circular. The half inch per ply around the edges is still required. This part was repaired using a splash mold.

For example, if the damage to the skin and core is 3 inches in diameter, and it has five surface plies, the 3-inch diameter area should be routed out (Figure 11-5-4). Then a one-half inch wide area per ply is sanded around with an overlap layer of 1 inch. The total size of the repair is as follows:

3 + (8 x 1/2) + 1 + 1 = 9 inches in diameter

Sometimes, the repair area is irregular and not circular (Figure 11-5-5). The damage might not be perfectly circular, but the same half inch per ply step is used. On an edge, the patches are one-half inch per ply step, but they can be straight on one side.

Removing Core Damage

If damage has occurred to the core material of a sandwich structure, the damaged area must be removed first, before sanding the laminate.

For this example of core removal, the top fiber layers could show some damage that penetrates to the core. However, the bottom sandwich layers for this discussion are undamaged.

Use a suitable marking device to outline the area where the core must be removed. A trim router, or a right-angle grinder fitted with a router bit, is usually used to remove the damaged core material. The first cut should be made with a pointed router bit to outline the plug in the damaged core. This top laminate layer plug should then be removed with a pair of pliers. If the surface to be routed is flat, simply set and lock the depth of the cut on the router base. Determine the depth by referring to the SRM. When routing to a partial depth, support the router on a flat template so the core surface is flat. Remember, it is better to route to a partial depth than it is to route through the opposite layer of laminate (Figure 11-5-6).

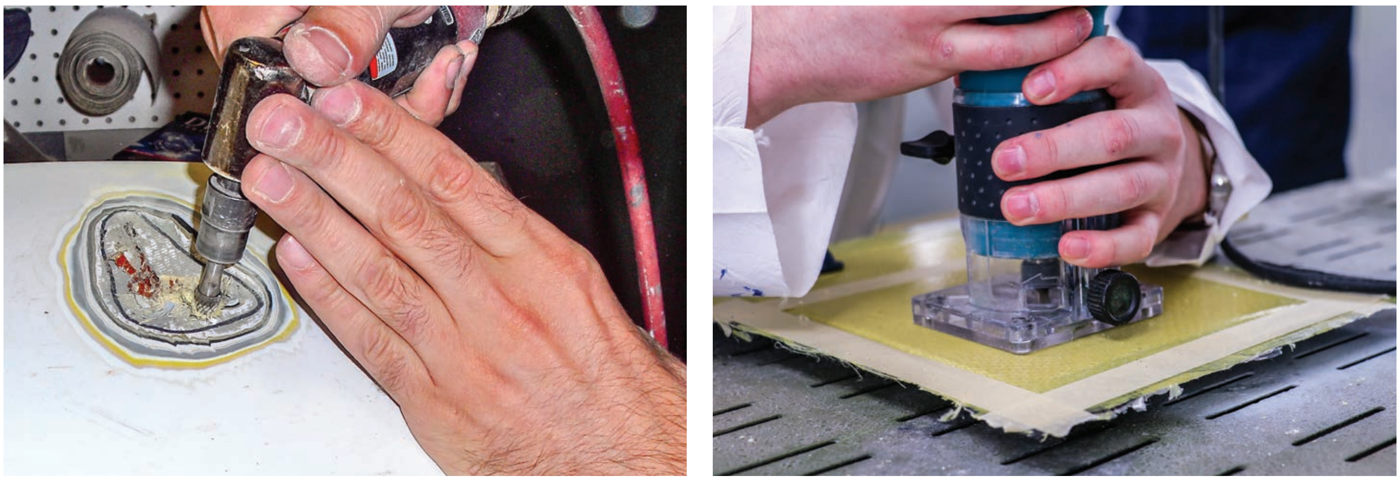


Figure 11-5-6. A right-angle grinder (left) fitted with a router bit can be used to clean out the damaged honeycomb core. A trim router (right) is used to remove the core with a flush bit. A diamond cut bit is used to prevent damage to the honeycomb while routing.

The second cut is made by a flush bit to route out the entire honeycomb area. Again, be cautious to route only to the surface of the opposing laminate. As a precaution, leave about 1/16 inch of the honeycomb showing—this can then be hand sanded down to the opposite layer. Route the honeycomb out to the top of the opposite face sheet. If the router damages the opposing laminate, to repair it you must sand it and add repair plies.

If the repair surface is sloped (such as on a trailing edge) or curved (such as on a leading edge), it might be necessary to use a wedged template to ensure the router is held at the correct relative depth of cut.

Figure 11-5-7. Sanding is the method that is usually used to remove the plies with the most control.

Laminate Step Cutting and Scarfing

To create the proper step cuts in the laminate, each successive layer of fiber and matrix must be removed without damaging the underlying layer. In this portion of the repair procedure, take great care to avoid damaging the fibers surrounding the area being removed. Sanding is the best method of removing the plies because it offers the most control.

Manual sanding offers a great deal of control, but it is tedious and takes time. Mechanical sanding is faster and easier, but it is also more likely to cause additional damage by sanding away too much material. One of the best tools for mechanically sanding composites is a small pneumatic right angle sander. If this is not available, you can use a drill with a sanding disc attachment. Patience and experience are the best ways to achieve adequate control of the sanding operation (Figure 11-5-7).

When sanding materials such as Kevlar, which produces fuzzing, you will likely achieve better results by using a finer-grit sandpaper such as a 220 grit. Carbon and fiberglass does well with 180 grit; the type of sandpaper used entirely up to you as maintenance technician to produce the perfect sanding.

Sand down each layer about one-half inch all the way around the damaged area. The idea is to sand one-half inch-wide concentric circles (assuming a round repair) that progressively step down to the core material. Start sanding at the outermost mark and work down, toward the center, removing one layer at a time.

If using an overlap patch, do not taper or step sand into the top ply in this area because this weakens the repair. The component's structural strength is reduced if sanding on the top layer exposes or damages the fibers in the unsanded area. The more accurately you make the sanding cuts, the more easily it is to shape the replacement plies and accurately place them into the repair. The sanding operation can be done by step cutting or by scarfing.

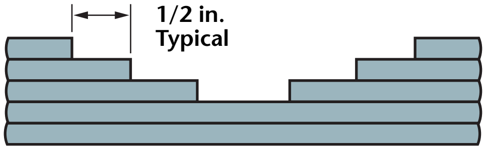


Figure 11-5-8. Step cut sanding.

WARNING: Sanding composite structures produces dust that can cause skin irritations. Breathing excessive amounts of this dust can be irritating to your lungs. Observe proper safety precautions.

NOTE: Finer-grit sandpaper usually keeps the fuzzing down when sanding aramid fabric. The finer grit also removes the material slowly, giving more time to find the individual plies.

Step Cutting

The step effect is achieved by sanding away about one-half inch of each layer as you taper down to the center of the repair. Initially, the aramid fuzzes and the carbon/graphite produces a fine powder as each layer is being sanded through. Eventually, the materials show a glossy area for each removed ply. As the fiber/matrix is being sanded, watch for a slight glossing of the work area. The glossing indicates that one layer of material has been removed and the top of the next layer has been exposed (Figure 11-5-8).

When you see the glossing effect, be cautious to stop sanding in that area or the next layer of material could be damaged. The layers are very thin, and an inexperienced technician could sand through into the next layer. However, with practice, you can master this portion of the repair technique.

Another way to detect if one layer has been sanded is to look for a change in major fiber direction. This is possible only when the warp direction of each layer has been manufactured in alternating positions. As the top ply is sanded away, the next layer produces the weave in a different orientation, signaling that one layer has been removed, exposing the top of the next layer (Figure 11-5-9).

The most difficult layer to sand is probably the second to the last layer, especially if it is over a core structure. Be careful not to sand through the last layer and expose the core during this sanding operation. Do not use excessive pressure on the sander or excessive speed. These rings will make the replacement plies easier to cut and easier to place into the repair area more accurately.

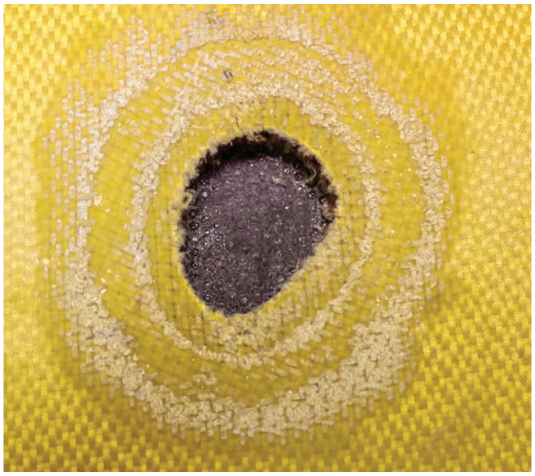


Figure 11-5-9. Step sanding is when each layer is sanded away to show the lower layer. Look for the changes in the weave pattern.

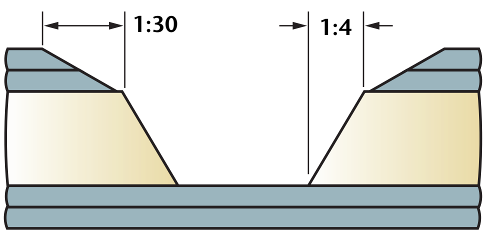


Figure 11-5-10. Scarf sanding.

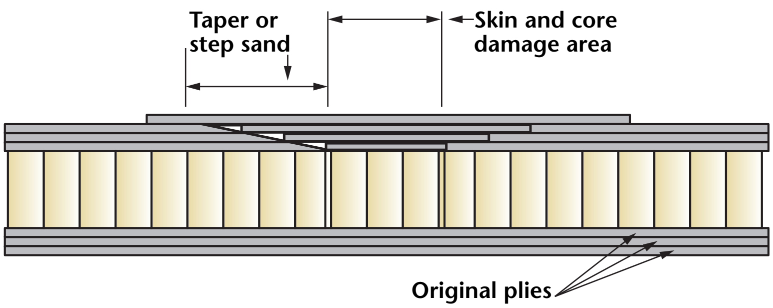


Figure 11-5-11. A stack-up of sanded scarf skin repair.

Scarfing

Use scarf cutting to remove damaged material with a tapered cutout. The scarf dimensions are made using the ratio of the total height of the plies to a given length. The scarf should be an even taper down to the center of the repair. By shining a light on the surface of a scarf cut, you can identify the layer transitions (Figure 11-5-10).

A 1:30 ratio means the thickness of the skin is 1, the taper is 30. Cores can be scarfed at a different ratio than the laminates, 1:4 for example. It is important to read the repair manual carefully and fully understand how to make the appropriate cuts. Note that in some SRMs, the text might call for a scarf cut; however, the illustration could be of a step cut. As long as the patches have enough bonding area, either sanding operation might be correct (Figure 11-5-11).

Because composite repair science is still relatively new, there is much controversy as to which type of sanding operation is better, the step cut or the scarf. The type of sanding is controversial, and the order and the way the patches are laid into a sanded area are also controversial. You should follow what is presented in the SRM as closely as possible. Direct any questions you have to the manufacturer or a designated engineering representative.

Cleaning

All repairs must be cleaned after the sanding to create a suitable surface for the repair plies to structurally adhere. A bond's strength is directly related to the condition of the surfaces involved in the adhesion process. To remove the dust from sanding, the first step in cleaning the part is to thoroughly vacuum of the sanded material. Do NOT use compressed air to blow the dust away. This could add oil or water to the newly sanded area, and it could cause delaminations of fragile areas such as the thin layer of fabric under the area where the honeycomb core has been removed.

Many times during the sanding operations, the technician might touch the surface of the repair to see how the sanding is preceding and to see if the next ply has been exposed. The oils from a person's hands can contaminate the surface and must be removed before bonding any patches. To avoid the problem of oils seeping from the hands to the repair surface, many companies require that the technician use thin cotton gloves that allow the hands to feel the surface without leaving residue on the surface. If the surface is not properly cleaned, the patches cannot bond adequately.

To develop a strong bond between the patch and the existing part, the adhesive or resin must be in complete contact with both parts. The dust from sanding can be removed by using a vacuum cleaner. To clean away any residual oils, use a solvent wash of MEK, acetone, or butyl alcohol with a lint-free cloth, such as cheesecloth. Always allow the cleaning solvent to dry before proceeding with the repair. Aramid can require a longer drying time because of its wicking characteristic.

Once the part has been cleaned, it is important not to touch the surface or any of the repair materials with bare hands or the entire cleaning process must be repeated.

Do not use compressed air to blow away dust because this can cause delamination of the layers or cause the skin to delaminate from the bottom core.

Water Break Test

Before bonding, some manufacturers might require a water break test to detect oil or grease contamination. This test ensures that no contaminating surface oils are on the part. To perform the water break test, flush the repair surface with room temperature water. If the surface is not clean, the water film breaks into beads (Figure 11-5-12 left). If this occurs, the solvent cleaning process should be repeated until the water sheets off rather than beads (Figure 11-5-12 right).

Water sprayed on a freshly waxed aircraft beads up. If it has been a while since the aircraft was waxed, the water flows off and does not bead up. If the composite surface is clean, the water does not bead up, but rather flows off of the surface. The water introduced should be evaporated off by applying a heat lamp for a few minutes. If the part is not completely dry before bonding the patches, they will not adhere properly and be cause for rejecting the repair.

Materials Preparation

Gather the materials needed for the repair. The SRM lists the materials you need.

1. Cross-reference the area on the aircraft where the damage occurred with the manufacturer's description of the composite that was used to fabricate the part. The materials used should be identified by:
    - Material type, class, and style.
    - Number of plies, orientation, and stacking sequence.
    - Adhesive and matrix system.
    - Type of core, ribbon direction, core splicing adhesive, and potting compound.
2. Be sure all resins, adhesives, and prepregs are within their usable life.
3. Identify and understand all deviations from the original manufacturing materials. For example, in some cases, in making repairs to aramid material, technicians use fiberglass patches to prevent the blistering problems that are more apparent with aramid. Also, consider the availability of materials and storage facilities. See the caution below in, "A note about prepregs used in manufacturing."
4. Identify the manufacturer's recommended cure system and ensure the proper tools are available. These can include, for example, a hot patch bonding machine, heat blankets of the proper size, and vacuum bagging equipment and materials. Be sure to check if the material cure temperatures are in Celsius or Fahrenheit, and cure accordingly.
5. Use the proper resins, and weigh and mix the resins properly (Figure 11-5-13).

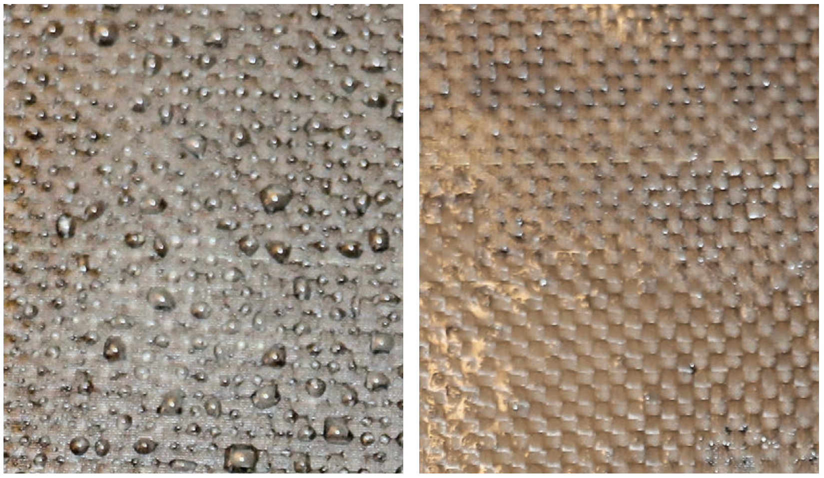


Figure 11-5-12. Beaded water (left) indicates that the surface is not clean. After cleaning with a solvent, the water is not beaded (right), indicating that the part is clean and ready for bonding.

Figure 11-5-13. Follow the manufacturer's instructions carefully to ensure resins are mixed properly.

Prepackaged resin systems. Some manufacturers recommend using Semkits, which are prepackaged two-part resins systems. Often the two-part resins are packaged so the chemicals can be mixed in a plastic bag without weighing or handling. This type of packaging usually provides the resin and the activator in two colors. The idea is to mix both colors together well enough that neither original color is seen in the mixture. This visual check ensures a complete blending of the two chemicals. When the resin and activator are thoroughly mixed, the corner of the plastic bag can simply be cut off to remove the matrix mixture.

Another type of packaging has the two parts of resin in a plastic tube with a foil separator to prevent the two parts from mixing accidentally. A stem is used to break the foil, then mixed with an up and down motion while turning the stem. The package instructions inform the technician as to how many strokes are required to mix the resin system properly.

Pot life. Pot life is not necessarily the time the mixture is usable in the cup. The resin and fabric should be in place before the actual curing takes place. If a resin with a short pot life is used to impregnate fabric, and the patches are cut to size, the patches must be in place on the sanded surface before the resin starts to cure. If the patches are allowed to sit too long in the plastic backing, the chemical reaction starts and the patches become stiffer. Subsequently, when they are in place and vacuum bagged to cure, the chemical cross-linking of the resin and the fibers might not take place as designed to do. The patches will have cured separately and might not stick to each other or to the part properly. Be sure to follow the mixing procedure correctly and use the mixture before the pot life has expired.

A note about pre-pregs used in manufacturing. Use caution when using the same pre-pregs as those used in manufacturing the aircraft. This may or may not be the correct repair pre-preg material to use because the pre-preg system used in manufacturing can be an autoclave type of pre-preg. This means it produces a very strong, light structure when cured in an autoclave. However, to repair damaged components with the same type of materials as originally used in manufacturing can lead to problems. The autoclave cure is not used very widely in the repair procedure; hot bond with vacuum bagging techniques are used more commonly. The resin system in these pre-pregs might not produce the same desired strength characteristics when cured with hot bond techniques. They are not getting as much vacuum as an autoclave could produce. The plies of the repair, although they are cured, can be easily peeled from the surface. This could have dangerous consequences if failure occurred in flight. Always follow the aircraft manufacturer's repair manual, not the manual for the manufacturing materials.

Honeycomb Ribbon Direction

Just as fabric has a warp direction, honeycomb also has a specific way it should be inserted into the repair. Figure 11-5-14 shows the ribbon of the honeycomb is the direction the honeycomb can be pulled apart. Notice the staggered cells that the ribbon creates. Then, 90° to the staggered cells, is a straight row of cells. The straight rows are easier to match up with the original honeycomb in the part. The ribbon of the repair plug must be oriented in the same direction as the ribbon of the original part.

To align the ribbon direction on the existing part to a new replacement part, place a piece of masking tape over the routed out part, and mark the area of the cutout on it (Figure 11-5-15).

Align the ribbon direction of the new piece of honeycomb to the existing honeycomb (Figure 11-5-16).

Cut out the new honeycomb core with a razor knife (Figure 11-5-17).

If the plug is a circle or whenever you are in doubt of the direction, lay it into the routed out area. Then, make a mark on one side of the core to match with a mark you made on the existing part (Figure 11-5-18).

Installing the Core

Once you know the core fits perfectly inside the routed out hole, use an adhesive on the bottom of the cutout and around the core. The manufacturer designates the type of adhesive to use. It could be an adhesive film, a foaming adhesive, or a mixture of resin/catalyst with micro balloons.

Film adhesive. Film adhesive is used for repairs with pre-preg material. When installing the honeycomb or foam plug into the cutout area using a film adhesive, before you insert the repair core, it is important that you remove the plastic backing from the adhesive. If not removed, the backing acts as a barrier and prevents the materials from bonding, resulting in a repair that is not airworthy. To use a film adhesive, the diameter of adhesive is cut to the same diameter of the replacement plug. It is inserted in the hole with the plastic backing still intact. If the film adhesive has come to room temperature, it can be difficult to remove the plastic backing. If the cutout piece can be placed back into the freezer for a short time,

Figures 11-5-14 through 11-5-18

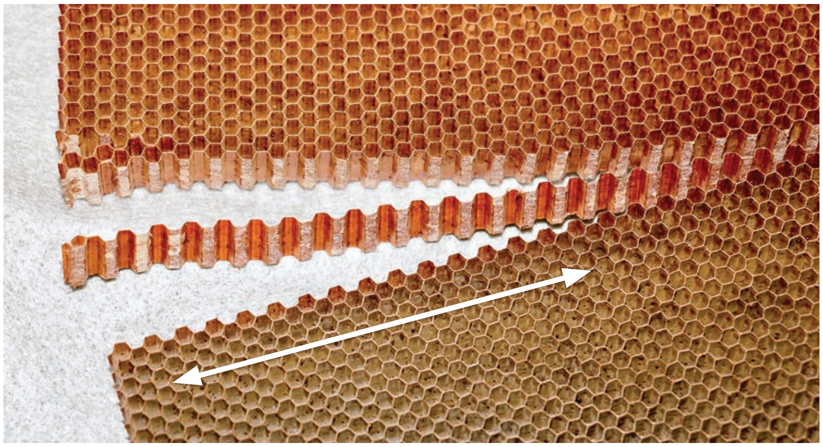


Figure 11-5-14. The ribbon direction of the honeycomb is the side where a ribbon can be pulled away from the honeycomb.

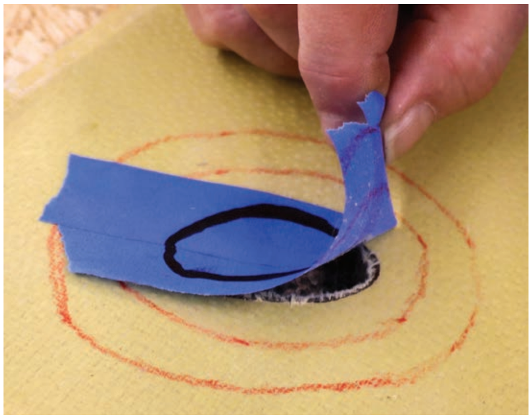


Figure 11-5-15. Mark the routed out area on the tape to get the size needed to replace the core.

Figure 11-5-17. Cutting out the new honeycomb plug.

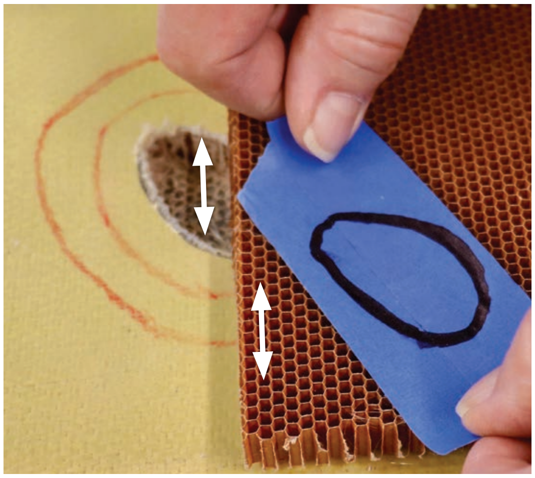


Figure 11-5-16. Notice the straight line of cells, matched up to the straight line of cells inside the cut out area. The tape is placed in the same direction as the cutout.

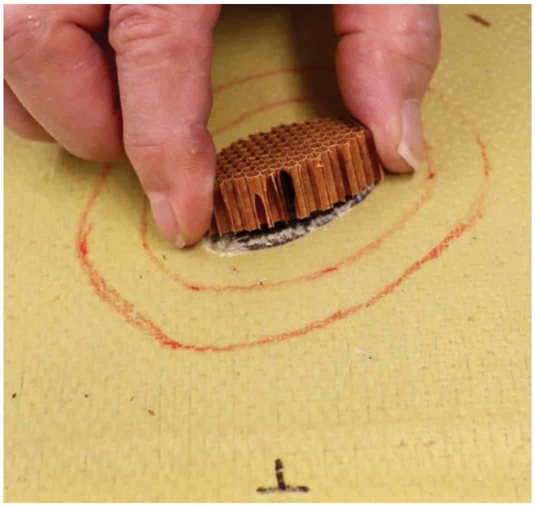


Figure 11-5-18. The mark on the core aligns with the mark on the part. In this case, a T is used to designate the top of the repair.

the plastic backing will release much easier. Lightly apply pressure with a squeegee, then remove the plastic and insert the core.

Expanding foam. An expanding foam adhesive is another method of installing the core if using pre-preg materials for the repair. The new core is cut 1/8 in. smaller than the cutout, to allow the foaming adhesive to expand into the core. An adhesive film is used in the bottom of the routed out area, then the new core's edges are wrapped with the adhesive and inserted into the routed-out hole. The part is typically vacuum bagged then cured at a high temperature, typically 250°F to 350°F. The foam adhesive around the edges of the core expands to fill the edges of the honeycomb plug and secures it to the internal edges of the part. If the foaming adhesive foams up higher than the top surface during the cure, it might need to be sanded down flush with the part before the patches can be applied to the repair (Figure 11-5-19).

Resin/catalyst with micro balloon mixture. Typically on a wet lay-up repair, the manufacturer might call for using a resin/catalyst and microballoon mixture. If using this, a light coat of the mixture is all that is needed. The micro balloon mixture can be spread over the bottom and on the sides of the core to hold a plug into place. Do not fill the honeycomb core with the resin mixture because the repair can become heavier and more susceptible to cracking. This mixture can also be used when repairing foam core structures.

Fiber Orientation

The patches made from the reinforcing material for the repair must carry the stress loads originally carried by the fibers that were manufactured into the part. Structural composite parts are engineered and manufactured to endure specific stress loads. Their ability to endure these stress loads is dependent, in great measure, to the way in which the fibers are oriented (Figure 11-5-20).

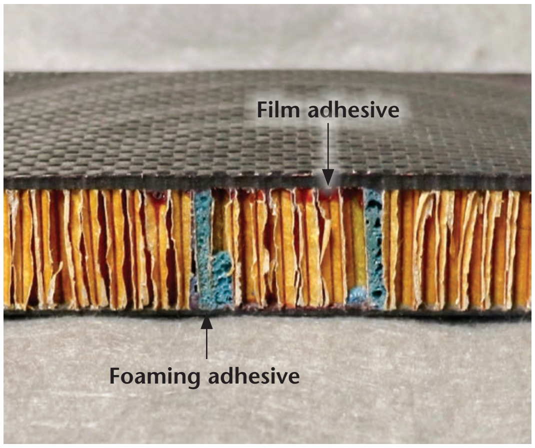


Figure 11-5-19. A film adhesive (pink) was used on the bottom and top of this core replacement, and a foaming adhesive (blue) was used around the core.

One fabric bonding patch ply of the same thickness and ply orientation should be used for each damaged ply removed.

The fiber orientation of the new patches must be in the same direction as those of the original structure, so any stress imposed on the part can flex through the repair as well as it does throughout the entire structure (Figure 11-5-21). If the fiber orientation is not correctly applied in a repair operation, the part's strength is dramatically reduced, which can cause the component to fail.

A warp compass is a tool used to reference the orientation of the warp of the fiber. The warp fibers are a reference for properly aligning the fabric of a patch with the original part. If a fabric weave is to have a stronger direction, it is usually on the warp threads.

For most composite repairs, the surface layer of the original part is considered the reference, or the zero warp angles, that corresponds with the warp of the fabric. The SRM supplies information on the ply direction of each layer of the part.

On a bolt of fabric, it is easy to determine the warp direction by looking at the direction of the selvage edge. On a finished part, the selvage edge is removed, making it more difficult to identify 0° or the direction of the warp. The SRM should define the 0° reference direction in relation to the part being repaired (longitudinally, chord wise, and so on) (Figure 11-5-20).

Notice in Figure 11-5-22 that all the arrows in the patches are going in the same direction to designate the warp weave of the repair fabric. The *T* on the top of the patches go in different directions and are later positioned so that the T is aligned to the area that the SRM designates as the top position, marked on the part. All the Ts will be lined up, and the arrows will be pointing in different directions because each layer has the warp in different directions.

Use the warp compass by placing the compass on the repair and aligning the warp direction of each successive patch in the same orientation as the corresponding laminate layer. An easy way to cut the replacement patches to the correct size and shape is as follows:

1. Lay the warp compass onto the repair.

Figures 11-5-20 through 11-5-22

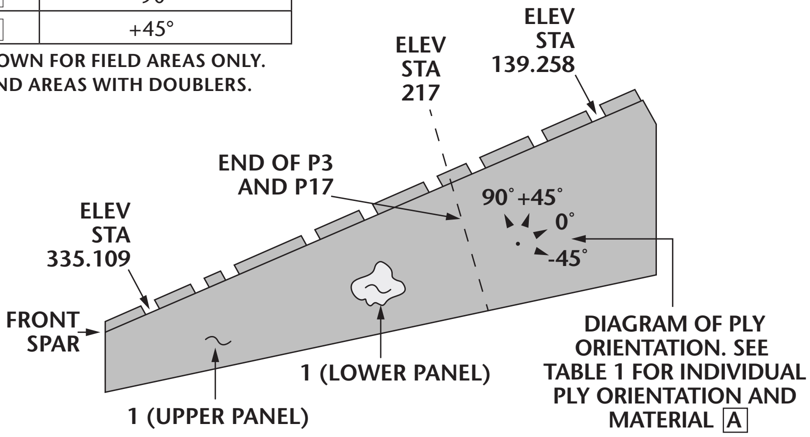
ITEM	DESCRIPTION	GAUGE	MATERIAL	EFFECTIVITY
1	ELEVATOR PANEL SKIN CORE		GRAPHITE/EPOXY HONEYCOMB SANDWICH SEE DETAIL 1 NON-METALLIC HONEYCOMB CORE	

LIST OF MATERIALS

ITEM	PLY NO.	MATERIAL	PLY ORIENTATION [A]
1	P1	[B]	+45°
	P2	[C]	90°
	P3	[C]	90°
	P4	[B]	+45°
	P16	[B]	+45°
	P17	[C]	90°
	P18	[C]	90°
	P19	[B]	+45°

MATERIAL AND PLY ORIENTATION SHOWN FOR FIELD AREAS ONLY.
SEE DRAWINGS FOR EDGE BANDS AND AREAS WITH DOUBLERS.

TABLE 1



OUTBOARD ELEVATOR

Figure 11-5-20. The SRM lists the materials you need, identifies each ply, and gives the ply orientation.

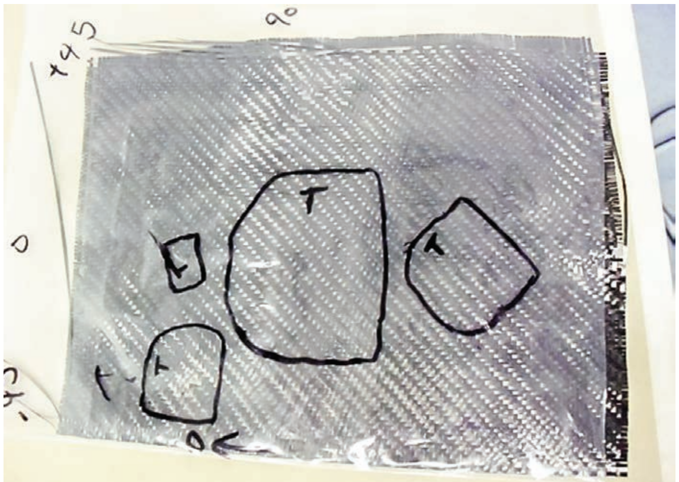


Figure 11-5-21. The fiber directions are different in these patches. The T indicates the top of the patch.

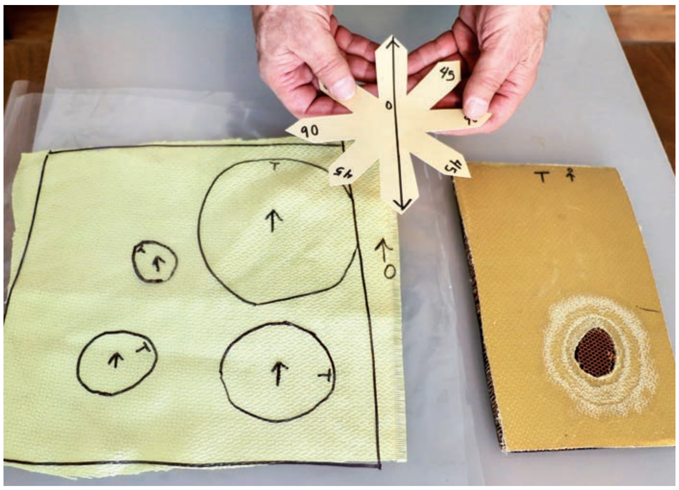


Figure 11-5-22. A warp compass is a tool that can be used to reference the orientation of the fiber's warp.

2. Orient the 0° reference mark on the compass with the 0° reference of the part.
3. Lay a clear piece of plastic material on top of the repair area.
4. Trace the shape of the repair cutout onto the plastic, starting with the bottom cut.
5. Note the warp orientation on the plastic for the layer being traced.
6. Remove the plastic from the repair and place it over the repair fabric, being careful to orient the warp in the correct direction.
7. After the fabric is impregnated with resin, cut the fabric to the correct shape using a sharp razor knife along the outline on the plastic.
8. As the patches are cut out, keep the plastic stuck onto the patch so you can easily recognize the fiber direction and you can lay the patches into the repair in the proper sequence.
9. Once the patches are cut out, remove the plastic backing, and lay the patches into the sanded area with the fiber direction in the correct direction.

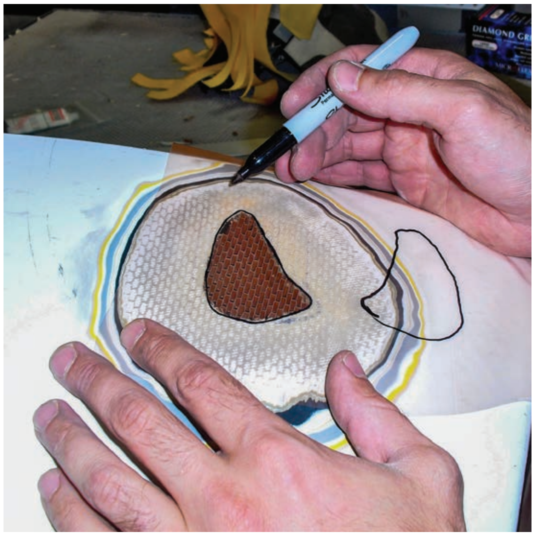


Figure 11-5-23. Use a sheet of clear plastic to note the shape of the patch.

Figure 11-5-24. Impregnating the fabric with catalyzed resin.

Bonding Patches

When replacing laminate plies over a repaired core in a sandwich structure, some manufacturers call for installing an extra ply of the same size as the core plug. This extra patch is placed on top of the core plug at either 0° or 90°. The purpose of the extra patch is to minimize the possibility of a surface depression forming in the finished repair.

To develop a strong bond between the new patch and the existing part, the adhesive or resin must be in complete contact with both parts. To ensure this contact, the surface of the existing part must be cleaned of grease or foreign material. The raw repair patch material should be clean and free of oil such as the natural oils that occur on a person's hands. For this reason, a technician should wear plastic or cotton gloves when handling the repair fabric. This applies to both pre-pregs and raw fabric.

Impregnating Raw Fabric

Some manufacturers call for using pre-preg materials in certain repairs; however, other repairs can be achieved by allowing the technician to fabricate and impregnate resin into raw fabric. Because pre-pregs might not be available for a repair, it is often necessary to impregnate the fabric at the time of the repair.

A sheet of clear plastic is placed over the routed and sanded out areas, and the patches are drawn onto the plastic in the shape of the patch. The direction of the fabric (the selvage edge), and the direction of the part should be noted on the plastic (Figure 11-5-23).

Once the shape of the bonding patches has been determined using a sheet of plastic and a warp compass, place the repair fabric on a suitably clean work surface, such as another sheet of plastic, so the resin can be worked into the fabric.

Be sure to weigh and mix the resins properly. Follow all manufacturers' instructions. Exercise the proper safety precautions.

The resins must fully permeate the fabric so that after curing, the resin and the fabric form a single, solid structure. When working with the squeegee, use caution: do not damage the fiber orientation or fray the fabric. The fabric/resin mixture should be about 60/40. A resin-rich repair is more susceptible to cracking because of a lack of adequate fiber support. A resin-starved repair is weak in areas where sufficient resin does not provide stiffness or because the fibers are not held together and supported as in a completely impregnated repair. Mix only enough resin to complete the repair.

To describe the scene shown in Figure 11-5-24, place the repair fabric between two pieces of plastic. The top piece of plastic should have the drawings you made of the patches that will fit perfectly into the sanded out area. Under the top piece of plastic, pour mixed resin in the areas of the patches, and put the plastic over the repair material. Using a squeegee, make sure that the patches are impregnated with the resin. Flip over the plastic to see if the resin has gone throughout the patch area, and that the back side is also impregnated.

Cut out the patches using a utility knife or scissors (Figure 11-5-25).

Find out how long the pot life, or working life, of the resin is. As discussed earlier, some resin systems have very short pot life (15 minutes); others have long pot life (4 hours). One of the misconceptions of pot life is that it is the time it is usable in the cup. Although this is true to a point, the resin and fabric should be in place before the curing takes place.

If a resin with a short pot life is used to impregnate fabric, and the patches are cut to size, the patches must be in place on the sanded and cleaned surface before the resin starts to cure. If the patches are allowed to sit too long in the plastic backing, they will start their chemical reaction and become stiffer. Subsequently, when the patches are in place and vacuum bagged to cure, the chemical cross-linking of the resin and the fibers might not take place as it is designed to do. The patches have cured separately and might not stick to each other properly. Be sure to follow the mixing procedure correctly, and use the mixture before the pot life has expired.

Installing the Patch

Once the repair patches have been impregnated with resin and cut to shape, the repair area can be prepared for the lay-up patch. To ensure that the surface is clean, perform a final wash with acetone and allow the part to dry. The plies of fabric can then be laid into the step cuts. Lay the patches over the sanded area and remove all plastic backing. Be sure to place them with the correct ply orientation and in the right sequence, following the SRM (Figures 1-5-26 and 1-5-27).

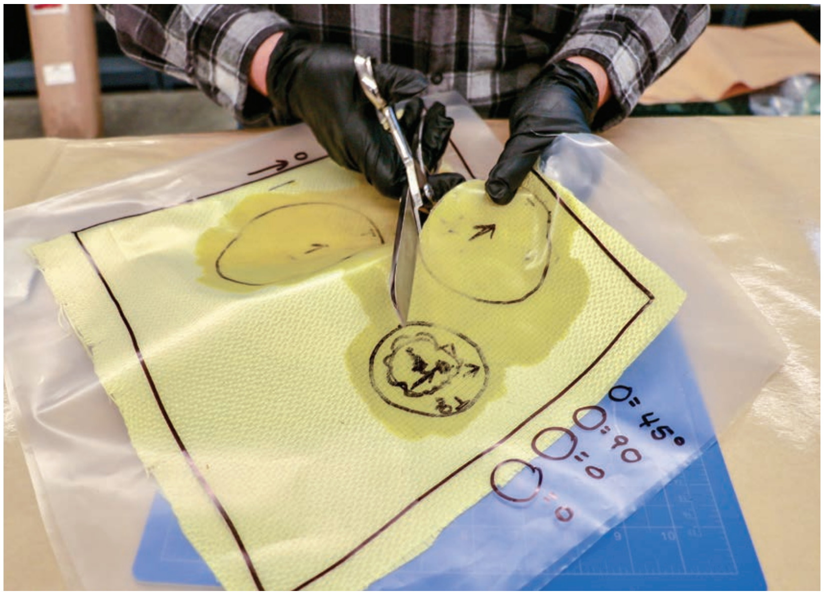


Figure 11-5-25. Once the fabric is impregnated with resin, cut out the patches with a utility knife or scissors along the lines marked on the plastic sheet.

Figure 11-5-26. Remove the back plastic and match the orientation of the fiber patch with the orientation designated in the SRM for each patch.

Figure 11-5-27. Once the patch is in place, carefully remove the plastic on the top of each patch. Use a tool such as a mixing stick to hold the patch in place while removing the plastic.

Do not squeegee each layer. Doing so could work the resin down into the core or disorient the fibers. Place a layer of peel ply or perforated release film over the final patch and then work out any air pockets using a squeegee. The peel ply holds the fibers in place and keeps the fibers from fraying.

Pre-Preg Patches

For some repairs, pre-pregs are required by the manufacturer.

Remove the pre-pregs from the freezer and cut off a sufficient amount. Then store the bolt of fabric in the freezer as quickly as possible. Take the plastic that outlines the patches and identifies the warp, place it over the pre-preg material, and cut it out with a razor knife.

A word of caution: Always follow the manufacture's SRM instructions and not those provided with the manufacturing materials. The materials stated in the manufacturing manual for a repair could actually be the material that was used in manufacturing the aircraft, not for the pre-preg repair material. The pre-preg system used in manufacturing could be an autoclave type, which means it produces a very strong, lightweight structure when cured in an autoclave. However, to repair damaged components with the same type of materials as originally used in manufacturing can lead to problems. The autoclave cure is not used very widely in the repair procedure. Hot bond with vacuum bagging techniques are more commonly used. The resin system in these pre-pregs might not produce the same desired strength characteristics when cured with hot bond techniques. They do not get as much vacuum as an autoclave could produce. The plies of the repair, although they are cured, can be easily peeled from the surface. This can have dangerous consequences if failure occurs in flight.

Pre-preg patches are cut much the same as for the wet lay up. Pre-pregs come from the manufacturer with a plastic backing already on the bottom side, and sometimes on the top. After using a clear piece of plastic to draw the repair patches, the clear plastic is laid over the prepreg material, lining up the selvage edge of the repair pre-preg material (Figure 11-5-28).

Figure 11-5-28. The clear plastic that was used to outline the size and orientation of the patches is placed over the pre-preg material, and cut out with a razor knife or scissors.

Some manufacturers call for an adhesive to be used over the sanded surface before the patches are applied. A thin layer of adhesive film or tape is sometimes used. In such a case, the adhesive is taken from the freezer storage and cut to size. The adhesive is cast onto a thin plastic film that must be removed before applying the patches.

Apply the adhesive film with the plastic backing to the sanded area with the adhesive side down. Use heat to soften the adhesive from the film. With light strokes from a squeegee, the plastic should soon separate from the adhesive. The fiber patches are ready to be laid into the repair area.

The pre-cut, pre-preg patches can now be laid into the repair area at the correct orientation. Be sure to remove any plastic backing from the patches. If the plastic is allowed to remain, the patches will not bond to the surface, resulting in a repair that is not airworthy. Pre-pregs can be squeegeed after each patch is applied. There is no danger of wet resin dripping into the core area. A perforated release film, or peel ply, can be added to prevent the patches from shifting in the vacuum bagging operation.

Once the repair patches are in place, place the vacuum bagging materials around and over the repair area. Apply heat to produce a proper cure. Follow all manufacturer's instructions when vacuum bagging and curing a composite repair.

Section 6

Lightning Protection

When lightning strikes traditional sheet metal aircraft, the electricity is conducted through the sheet metal to the static discharge wick. Ordinarily, a lightning strike to a metal aircraft causes very little damage. It looks about the size of a cigarette burn in the metal (Figure 11-6-1). When lightning strikes an aircraft made of nonconductive composites, however, problems do occur. The presence of an isolated metal conductor in a nonconductive composite aircraft can cause severe damage if struck by lightning. The lightning charges the fastener enough that it either arcs to another metal component or, if arcing is not possible, it explodes. Either way, the damage will be extensive and could be disastrous; these are unacceptable consequences.

Whether an aircraft is aluminum or composite, when lightning hits it, the aircraft needs a path through which the electricity can flow. Aircraft require electrical contact between all metallic and composite parts to prevent arcing or fiber damage. Aluminum is used to provide a conductive path for dissipating the electrical energy in materials such as Kevlar and fiberglass. Because aluminum is corrosive when used with carbon/graphite material, a copper mesh can be used instead of aluminum. This path is usually provided to static wicks (Figure 11-6-2).

Further describing the repair shown in Figure 11-6-2, the other layers are sanded down for the repair. When repairing this damage, the smaller layers are placed into position, and a layer of lightning protection is laid over the two repair plies. If it is a mesh, it must overlap the existing lightning protection by one-half inch. A layer is placed over the top layer, and then a final layer of repair patch extends one inch past the top layer that was sanded out. It can then be vacuum bagged, cured, and then tested for continuity.

Because composites do not conduct electricity, lightning protection must be built into the component. If no lightning protection exists in the composite and the lightning exits through the composite component, the resins in the composite vaporize, leaving bare cloth. Another indication of lightning damage is dark brown or black spots or smudges that appear to be heated. When doing a repair, it is important to replace any lightning protection that might have been removed during the repair operation.

The type of lightning protection needed can be one of the following:

- A top layer of material that has fiberglass and aluminum or copper wires woven together.

A top layer of very thin aluminum that is either bonded or flame sprayed onto the composite surface. If the structural composite material is carbon/graphite, a top layer of fiberglass can be bonded to the structure before the aluminum is applied. This gives a barrier between the aluminum and the carbon/graphite (Figure 11-6-2).

- A very fine screen or mesh made of either aluminum or copper is bonded under the top layer. In the case of carbon/graphite composites, the mesh can be protected by a layer of fiberglass against the carbon/graphite surface, then the mesh is placed down, followed by another layer of fiberglass. This is used to prevent corrosion between two dissimilar metals. More typically, a copper mesh is used instead of aluminum mesh because it does not present the problem of the galvanic potential caused by dissimilar metals.
- A bonding strap from the composite component to an aluminum structure.

Regardless of what type of lightning protection was used originally in manufacturing the aircraft, when the repair is made, the part must be restored to provide a path for dissipating an electrical charge.

If the metal wires are woven into the top layer or if a fine screen or mesh is just under the top layer, repair the part by laying all repair plies into the

Figure 11-6-1. Lightning strike damage.

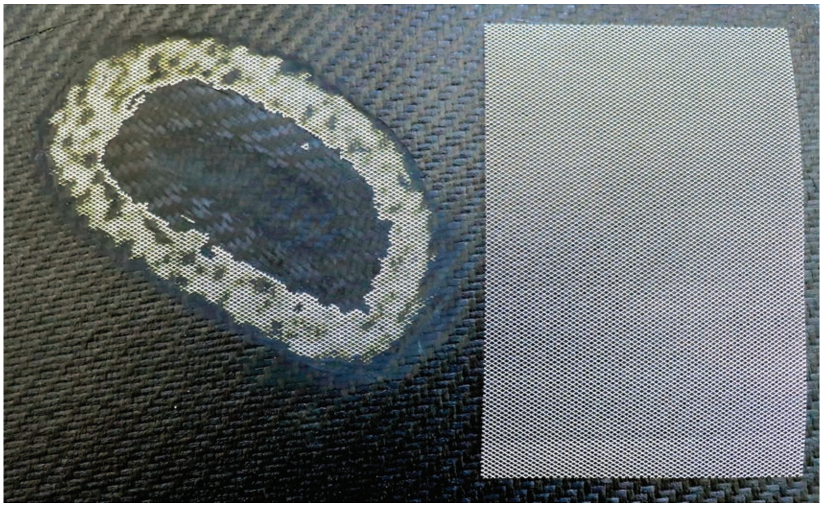


Figure 11-6-2. The top layer of fibers was removed to show the lightning protection under the top layer.

sanded area until the ply with the aluminum protection is reached. A fine screen of aluminum or copper mesh is then placed on top of the repair plies. Take care to overlap the wires, usually by one-half inch, so the new wires contact the wires in the original part. If the wires do not contact each other, no path exists for the electrical charge to follow and the charge will exit out the repair. Once the metal screen patch is installed, the fiber patch is put into the repair and cured into place.

After curing, test to see if continuity exists by scratching the surface of the original part and inserting an ohmmeter probe. The repair area is also scratched and the other probe of the ohmmeter is placed on it. Good conductance should exist between these areas. If good continuity is present between these areas, the lightning charge can flow through the structure and out to a static wick.

If a thin metal foil is used for lightning protection, it can be difficult to bond to the repair area. The resins cannot flow through the foil sheet, and the bottom repair plies could be resin rich. This type of metal film should be installed after the part has completely cured and is bonded on with an adhesive. If the part was originally flame sprayed with aluminum or painted with aluminized paint, be sure to apply it following manufacturer's instructions.

Section 7

Inspecting the Repair

Quality control inspection is performed to ensure that the proper steps are followed in the repair process and that the final repair meets the manufacturer's requirements.

After the part has been cured, remove and discard all peel ply, release film, bleeder, breather, sealant tape, and bagging film. Next, inspect the repair as follows:

1. Check to see if the repair has cured properly.
2. Check for delamination. Any delamination of the skin from the core is cause for rejection of the repair.
3. Ensure that there are no voids. Voids can be cause for rejection.
4. Check for any white areas that indicate excessive heat and could have caused the resins to bleed out, leaving only fabric.
5. Check to make sure there is no excessive foreign material in the repair. Many manufacturers give a maximum amount of foreign material that can be included and still be an airworthy repair.
6. Check for excessive resin on the edges. This is usually not allowed.
7. Look for blisters or white areas because they could be an indication of moisture in the composite during cure.
8. If lightning protection was installed during the layup, ensure that good electrical continuity exists. Check it with ohmmeter.
9. Check for brown spots on the part, which would indicate oil or grease contamination.
10. Inspect all repairs to the requirements of the manufacturer, which might or might not include NDI.
11. Lightly sand the edges to produce a feathered edge before painting.
12. Clean the part and prepare the surface for painting.
13. Paint the structure with the original type of paint in accordance with the manufacturer's specification. Painting instructions are in the next section.

If the repair is being made to a control surface, it must be rebalanced.

Section 8

Painting the Composite Part

After completing a repair, the part should be painted. Fill primers can sometimes be used over the repair, but do not add too much weight to the repair; doing so ruins the whole point of using composite parts on the aircraft in the first place. The fill primer is used to fill in any dips around the sanded area. Spray it on, allow it to cure, then sand it down again, before painting. Lightness and high strength are the keys to doing proper composite repair work.

Epoxy-based paint. For most aircraft, the same type of paint used for the metal portions of the aircraft is suitable for use on the composites. An epoxy-based paint is preferred over a gel coat. Epoxy-based paints are more flexible, stronger, and protect the underlying part from sun damage (Figure 11-8-1).

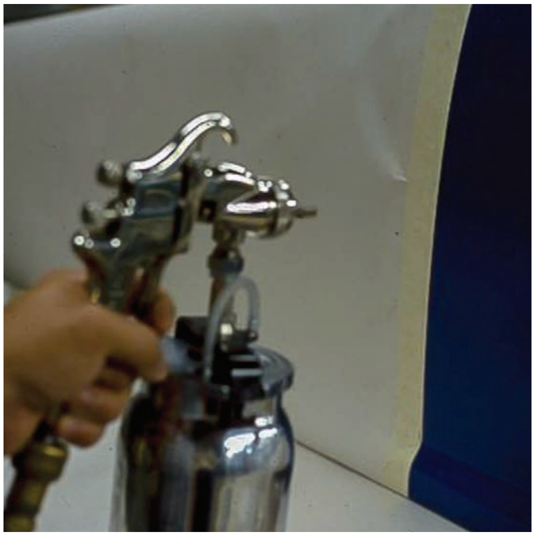


Figure 11-8-1. The painting equipment and application techniques used on composite parts are similar to those used for metallic parts.

Some companies, such as Boeing, use a layer of Tedlar on the composite before painting. Tedlar is a plastic coating that serves as a moisture barrier.

Gel Coats. A gel coat is a polyester resin used in manufacturing the part. The manufacturing mold is coated with a color coat of polyester resin. The plies are laid down onto the surface of the colored gel coat and impregnated with an epoxy resin.

After curing, the gel coat on the outside surface provides a smooth finish. The plies of fibers that are embedded with the epoxy are the structural part of the aircraft. The gel coating is not structural; it is more like a paint coat. Gel coats were used on gliders extensively in the 1970s and are not common today.

The problem with gel coats is that they are made of polyester resin, so they are not very strong or flexible. If the aircraft is parked outside in the sun and weather, the gel coat can crack. The aircraft must be inspected to see if the fibers themselves are cracked and not just the gel coat. If only the gel coat is cracked, there is no structural damage. However, if the fibers are cracked, the structure must be repaired.

Gel coats cannot be rejuvenated as dope on fabric can. The gel coat must be sanded off and reapplied. Many aircraft owners who have had problems with the gel coat will sand off the gel coat surface and paint the surface with one of the new generation of paints that are very flexible and can take the weather. Be careful when sanding the coat off—the fibers were manufactured into the wet gel coat and the gel coat thickness will not be perfectly even. Do not sand through the fibers.

Section 9

Recording Your Work

A log entry or FAA Form 337 must be prepared to show conformance to the recommended repair procedure. Include the following items in your records:

- Part identification: Part and serial number
- Conformance to repair requirements: Steps taken to restore the item to a serviceable condition, refer to the SRM.
- Material standards used: Cross-reference to the manufacturing record. Although, sometimes the materials that were used to manufacture are not the same material the SRM recommends for repair.
- Curing: Time, temperature, and pressure used in the repair cure cycle—might or might not require a recording of the cure cycle.
- Material traceability: Type of fabric material, matrix and adhesives, and core material used. Traceability of materials, such as a certification of conformity, or certification of materials, dates and batch numbers must be included to show airworthiness.
- Inspection of the repair: Identify any type of inspection used after the repair has been made.

12

Types of Repairs

Many composite repair methods for various parts of an aircraft are detailed in the appropriate structural repair manual (SRM). The repairs discussed in this chapter are only a sampling of the most common repairs, and many repairs are simplified for training purposes. A repair procedure described in this book might resemble a repair in an SRM, but depending on the aircraft and the manufacturer, different materials and resin systems might be used. If you understand the basics, and can apply the different materials called for in the SRM, you can master composite repairs. In any repair situation, before performing any repair procedures, consult the SRM for the aircraft. The procedures in the AC 43.13 section on composite repairs should not be used for advanced composite repairs, except fiberglass. As stated in the AC 43.13: "NOTE: These repairs are not to be used on radomes or advanced composite components, such as graphite (carbon fiber) or Kevlar."

Repairs fall into one of four types:

1. Bolted-on metal or cured composite patches
2. Bonded-on metal or cured composite patches
3. Resin injection
4. Laminating on new repair plies

The bolted-on and bonded-on surface patches are not preferred because the repair might not restore the part's original strength. A patch that is bolted or bonded above the surface of an external part also causes aerodynamic changes. If the part is a rotor blade, a surface repair could cause an undesirable flutter and concentrated load stresses. These induced stress loads could prematurely pull out the blind fasteners that attach the repair.

Learning Objectives

DESCRIBE

- Potted repair technique
- Repairs to laminate structures
- Repairs to sandwich structures

EXPLAIN

- Differences between laminate and core structures
- The importance of a splash mold
- Why a mechanically fastened repair is considered temporary

Left: After sanding off the paint, fiberglass, and Kevlar, this part is ready for the patches.

Bolted-on and bonded-on surface repairs could be useful for emergency field repairs where the proper equipment, tools, and materials are not available. Such repairs are many times considered to be only temporary.

Resin injection is used to fill holes or voids. This type of repair is done simply by using a needle and syringe to inject resin into the void of a damaged area. Most manufacturers use this type of repair only on nonstructural parts or parts that are not subject to a great deal of stress. The injected resin repair does not restore very much strength and, in some cases, might actually cause the delamination or damage to expand.

The most reliable type of repair is laminating on new repair plies. This involves removing the damaged plies and laminating on new plies of the correct material.

Section 1

Repair Failures

All repairs should be performed correctly according to the type of damage and the function of the part on the aircraft. Some of the most common reasons for a repair to fail are the following:

1. Poor surface preparation
2. Contaminated fabric or other materials
3. Incorrect measuring and mixing of the resin system
4. Incorrect cure time, incorrect temperature, or inappropriate temperature rise and drop
5. Inadequate pressure

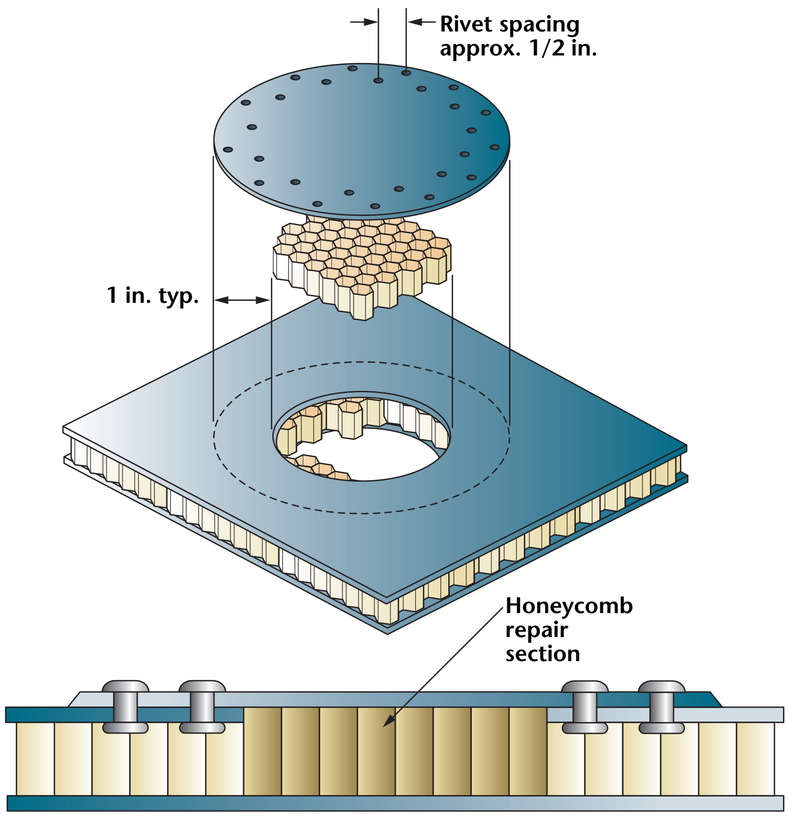


Figure 12-2-1. Patches using blind fasteners and a sheet metal plate or pre-cured patches are normally considered a temporary repair.

Section 2

Typical Repair Procedures

The following repair procedures are outlined to illustrate some of the various techniques and procedures commonly used for repairing composite structures.

> **NOTE:** All repair procedures in this book are for training purposes only. Before any repair is made to an aircraft, consult the SRM for the aircraft involved. The following repairs are example repairs only and are provided for training purposes only.

Mechanically Fastened Repairs with Pre-Cured Patches

When the proper facilities or curing and bagging equipment are not available for online work, a pre-cured patch inserted with blind fasteners can be used. This type of repair usually does not give the maximum strength. Because it is not a flush repair, it can cause vibration when performed on critical parts. This type of repair can be considered a temporary repair until the damage can be scarfed down and the patches correctly laminated on with heat and pressure.

Many times these repairs are performed with common repair materials such as sheet metal plates and rivets. If composite patches are required, kits with pre-cured patches might be available.

Pre-cured patches come in several sizes: 2, 3, and 4 inches wide. These patches are made to have the fibers of each layer in the correct orientation. Such a patch could have a peel ply layer that indicates the orientation in which it should be laid into the routed out repair.

Some manufacturers offer various sizes of core material that is bonded to pre-cured laminates. These pre-made patches are available so the technician can simply route out the damaged area and insert the core and laminate patch. This type of repair can have a type of adhesive preapplied to help it bond.

Usually the patch uses some type of mechanical blind fastener that is drilled through the patch into the surface of the original part to hold the patch in place while it is further stabilized with blind fasteners. The problem with using blind fasteners in a core structure is that they have a tendency to crush the core structure. This can cause the core to delaminate from the plies. Again, this type of repair can be considered a good temporary repair (Figure 12-2-1).

Composite Skin Repair at Rib Locations

This repair uses an aluminum doubler fastened with blind rivets to a composite skin for reinforcement over a damaged rib area. This is an interesting example of fastener use in composites. Figure 12-2-2 illustrates this repair.

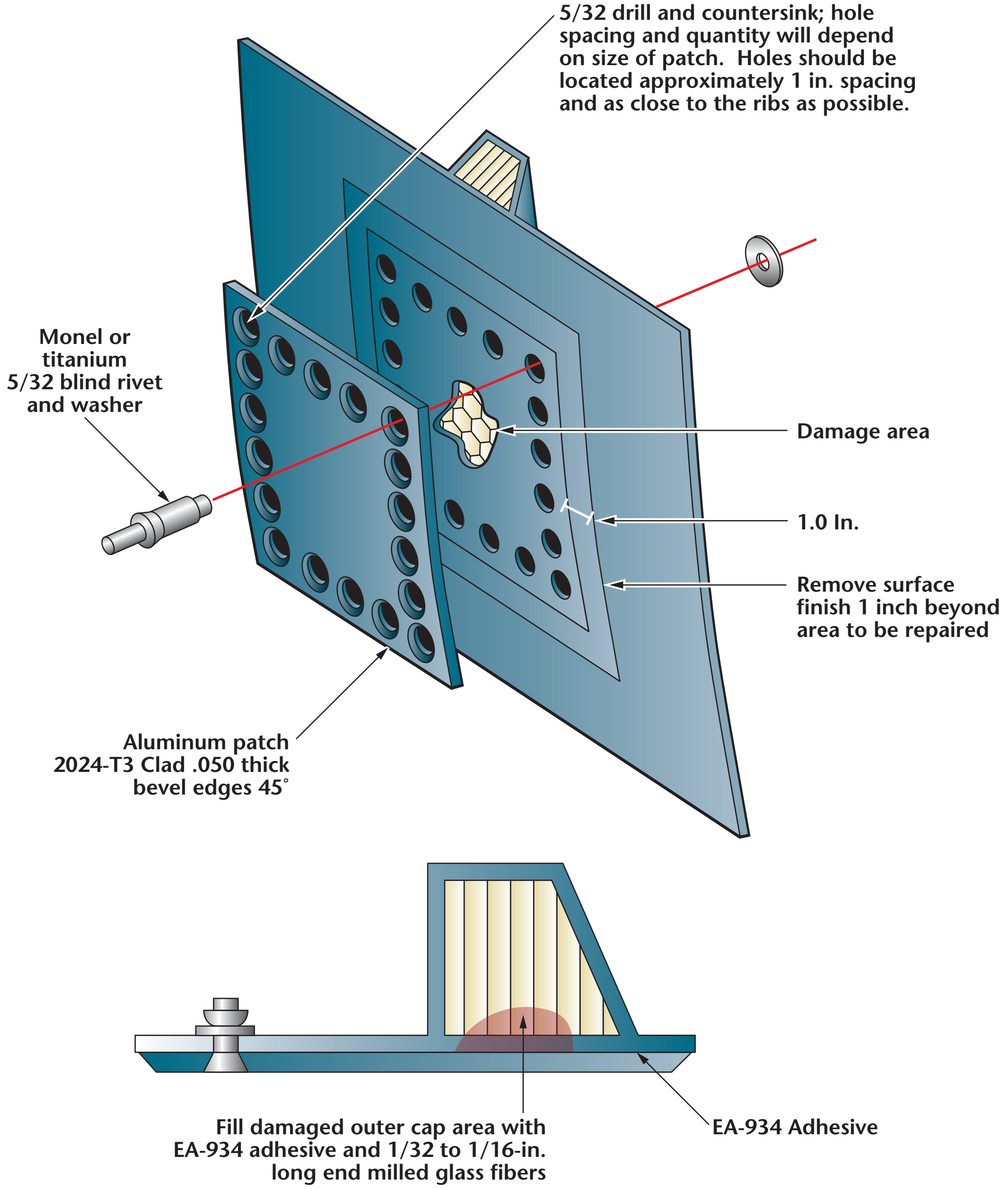


Figure 12-2-2. An aluminum patch installed, bonded, and fastened to the surface with a composite stiffener on the inside of the structure.

1. Remove the surface finish.
2. Remove as much of the damaged skin as possible, without causing further damage to the skin or rib.
3. Clean the area with solvent.
4. Fill in removed skin areas with a potting compound.
5. Use an aluminum doubler extending 2 inches past the edges of the damage. Form the aluminum doubler to conform to the shape of the part.
6. Drill rivet holes in aluminum sheet and countersink on one side. Rivet holes should be spaced evenly at about 1-inch spacing and close to the rib.
7. Abrade the surface of aluminum with a nonwoven aluminum oxide pad (such as Scotch-Brite™) for bonding to the composite.
8. Prepare the adhesive and apply to the composite skin and aluminum doubler.
9. Position the doubler over the damaged area and insert the fastener.
10. Clean up any excess adhesive that squeezes out around the doubler.
11. Cure the adhesive following the manufacturer's instructions.
12. Apply surface finish according to the manufacturer's instructions.

Potted Repair

Potted repairs do not give as much strength to the composite structure as refitting the hole with a new core. Filling the hole with a resin/microballoon mixture adds weight to the part and decreases the flexibility. Further flexing of the part can cause the potted plug to dislodge, but many SRMs still list this type of repair for advanced composite structures.

1. Clean the damaged area.
2. Sand out the delaminated area.
3. Fill the core area with a resin/microballoon mixture.
4. Prepare patches.
5. Apply pressure and cure.
6. Refinish.

Most potted repairs are appropriate for foam core sandwich structures. However, in some cases, it may be permissible to drill a small hole into the delaminated area and inject resin into a honeycomb disbonded area.

Damage to One Face and Core (Potted Repair)

The following type of repair is similar to an older type of fiberglass repair that calls for the damaged core to be routed at a vertical angle. This is a problem because the plug could pop out if the repaired part flexes during flight.

This is no problem if the repair is done to nonstructural parts. New advanced composites, however, are commonly used for structural applications. For example, if a plug repair should pop out of a control surface, it could cause aerodynamic flutter and a subsequent loss of control. Consequently, to prevent a catastrophic failure, it is critical that any repairs to structural parts be performed correctly.

One of the primary differences between the composite repair and the fiberglass repair is in the way the repair plug is retained in the routed hole in the core. The composite repair calls for the damaged core material to be undercut with respect to the surface laminate. In this way, the original laminate skin helps to retain the repair plug when the surface flexes. In addition, the composite repair uses an overlap patch to further strengthen the repair (Figure 12-2-3).

1. Open up the puncture with a drill or router to remove the ragged edges and broken fibers.
2. Clean out the crushed core and undercut core about 0.125 inch. Mark the outline of the overlap plies on the part.

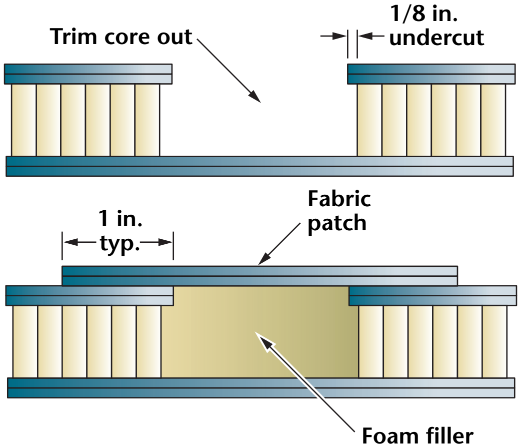


Figure 12-2-3. An undercut potted repair with the repair plies bonded to the surface.

3. Prepare the surface.
4. Clean out sanding dust and vacuum the hole.
5. Apply a foam filler by pouring or by using a spatula to fill up the hole. Agitate the foam to displace air pockets and fill the cavity. Allow the foam to cure.
6. Cut the repair patches to size, allowing an overlap in all directions beyond the edge of the hole.
7. Prepare the bonding patches.
8. Apply pressure and cure.
9. Refinish.

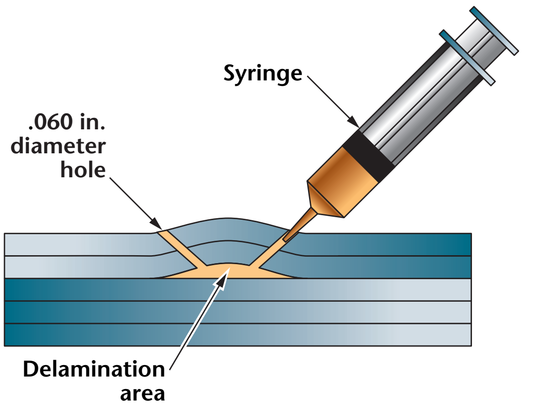


Figure 12-3-1. Resin injection repair to delaminated area.

Section 3

Delaminations

Delamination occurs when the laminate layers become separated or when the plies separate from the core material. Delamination is sometimes referred to as unbonding, or *disbonding*, of the plies. Sometimes a delamination can be detected by shining a light over the part and looking at the damaged area at an angle. The damage can be recognized as a bubble or an indentation.

Internal delamination is the separation of plies that do not extend to the edge or a drilled hole area.

It is important to properly assess the extent of an internal delamination using the appropriate nondestructive inspection (NDI) method. If the delamination is over a core area, the resin might fill up the core and not help seal the skin. In excessive cases, the skin might be delaminated even further because of resin injection. If you perform a resin injection, use a low-viscosity resin and apply pressure to the area so the skin attaches to the core.

> **NOTE:** This type of repair can be considered a temporary repair until a more permanent repair can be made to the structure. If this repair is not approved by the manufacturer because of the type of part, the size of damage, or the type of stress the part endures, a repair should be performed by removing the damaged plies by step cutting or scarf sanding and laying in new repair plies.

Delamination Injection Repair

If the internal delamination is sufficiently minor, it can sometimes be repaired by simply injecting resin into the cavity formed by the ply separation. Injecting resin fills the area and reattaches the skin (Figure 12-3-1).

1. Clean both surfaces of the part.
2. Drill a 0.060-inch diameter hole from one surface down to the delamination at each end of the delamination. Be careful not to drill through the part.
3. Clean the part again with acetone or methyl ethyl ketone (MEK) (if MEK's use is permitted).
4. Select and mix the resin and curing agent as required.
5. Load the mixed resin into a clean syringe with a needle attached. Inject the resin into one drilled hole until the resin comes out the other drilled hole.
6. Apply pressure and cure.
7. After the cure, remove clamps and vacuum bagging materials, then sand and refinish.

This type of repair might not be approved by the manufacturer because the delamination cavity is filled with resin, which adds weight. This would be of major significance if the damaged part is a primary control surface. Furthermore, the resin alone could be ineffective in restoring the strength and could cause brittleness. In flight, the extra resin in this area would not be as flexible and could cause further delamination in the damaged area.

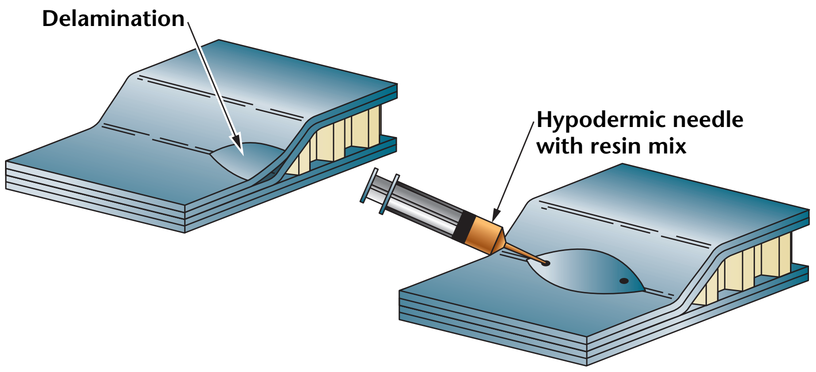


Figure 12-3-2. A resin injection repair for a small delaminated area.

Delamination at Honeycomb Core Edgeband

This simple repair does not need vacuum bagging and rarely is cured with heat. This resin-injection repair is illustrated in Figure 12-3-2.

1. Clean the surface with solvent.
2. Outline the void area and mark the two injection hole locations.
3. Using a 0.060-inch diameter drill, slowly drill into the disbonded area. Do not drill through the part.
4. Select and mix the resin and curing agent as required.
5. Load the mixed resin into a clean syringe with a needle attached. Inject the mixed resin into one hole, allowing air to escape through the other.
6. Clean any excess resin from the surface of the part.
7. Cure according to the manufacturer's instructions.

Mislocated Potting Compound in a Honeycomb Structure

In some cases, the manufacturer supplies a component with potting compound installed to accommodate a fastener (Figure 12-3-3). If this is not correctly positioned, it might need to be repositioned.

1. Locate the correct location of the fastener that requires the additional potting compound.
2. Drill a 1/8-inch hole at the correction through one skin only.
3. Insert a small Allen wrench through the hole and rotate 360° to break the honeycomb cell walls to a 1-inch radius around the drilled holes.
4. Vacuum out the debris.
5. Using a sealant gun, or syringe, force the potting compound through the drilled hole.
6. Cure in accordance with the manufacturer's instructions.

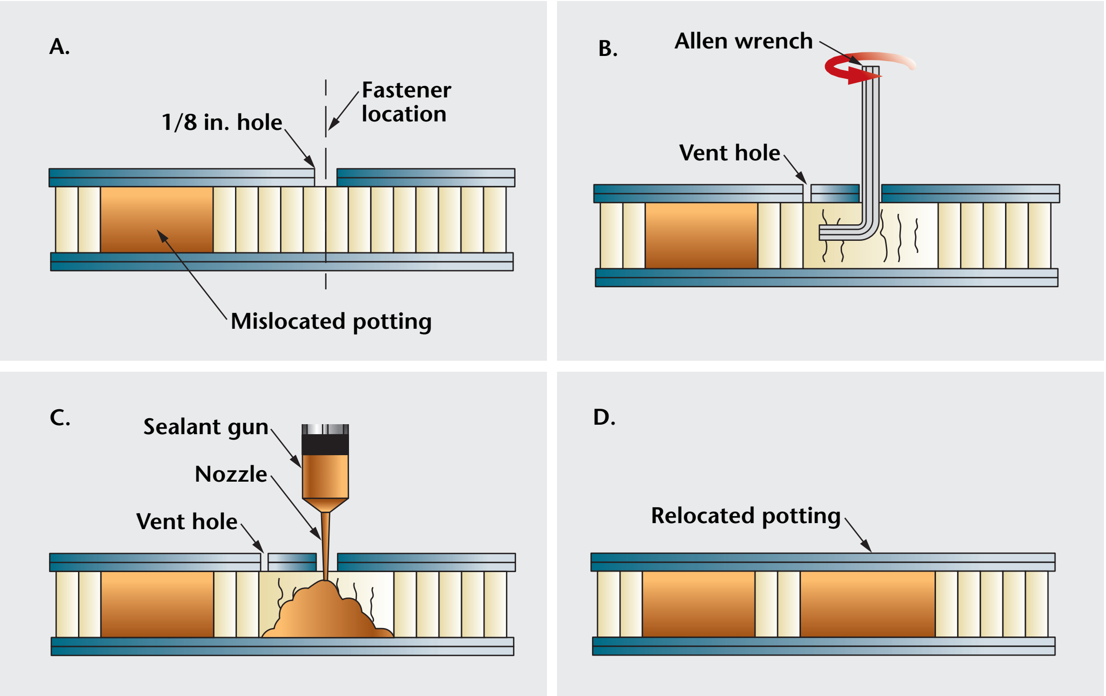


Figure 12-3-3. When the potting compound for a fastener location is mislocated, these steps are necessary to relocate the fastener.

7. Redrill the hole and install the fitting. Be sure to meet the manufacturer's requirements.

8. If the part failed because the fastener pulled out, filling the damaged hole and redrilling it might not be a good repair; it could pull out because the resin/filler mix does not provide adequate strength. An insert or grommet can be installed permanently with an adhesive. The fastener can then be used without causing further damage to the composite structure.

Section 4

Damage to Laminate Structures

Solid laminates are those structures that do not have a core. They require different repairs depending on how badly they are damaged, where the damage is, and how thick the laminate is. This section discusses the following types of repairs for solid laminate structures.

- Cosmetic defect
- Damage removal and ply replacement
- Laminate repair with access to one side
- Edge repair
- Edge delamination
- Holes in laminates with limited surface area

Cosmetic Defect

A cosmetic defect is a surface resin scratch that does not penetrate the first structural ply; that is, it has negligible damage.

1. Clean the area with MEK or acetone.
2. Sand the painted area around damage and feather the edges.
3. Scuff sand the damage, then clean it with solvent.
4. Mix the resin with filler or approved surfacing putty.
5. Fill the damaged area with resin-filler mixture. You can apply it with a squeegee, brush, or fairing tool.
6. Cure the repair.
7. Sand and refinish.

Damage Removal and Ply Replacement

This type of repair calls for removing the damaged laminate plies and then replacing the removed plies with new ones. The new impregnated and pre-cut patches are laid into the sanded-out area with the weave of the new patches in the same orientation as those of the original part. The replacement plies are cured with heat and pressure to restore the original composite strength.

An overlap patch usually is 1 inch larger than the last repair ply. It is used as a bridge between the repair and the original part. It might not be required. The overlap patch initially sits on top of the part, but with the heat and pressure that are applied during the cure cycle, it compresses it to be level with the surface. Several scenarios of this repair are covered below.

Damage to One Surface

Fiber damage to one side of the surface that does not completely penetrate the part can be repaired as follows (illustrated in Figure 12-4-1):

1. Prepare the surface by cleaning and removing paint.
2. Remove the damage by scarfing or step-cutting the plies.
3. Select and mix the proper resin and repair material.
4. Prepare the bonding patches, laying in each one successively.
5. Vacuum bag or apply pressure and cure.
6. Remove the vacuum bag materials, blend the edges, and refinish.

Alternative Ply Replacement

The step cut repair is probably the most common type of step cut repair; however, there are differing opinions as to how the plies should

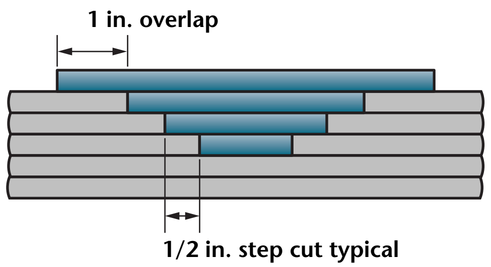


Figure 12-4-1. Step cut repair in which the damaged material is removed, and new reinforcing patches are applied.

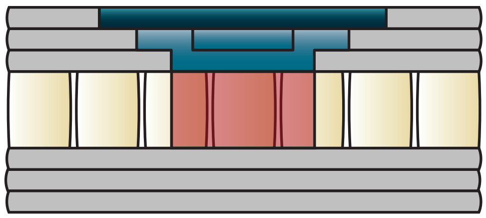


Figure 12-4-2. This variation of the step cut repair uses alternating plies.

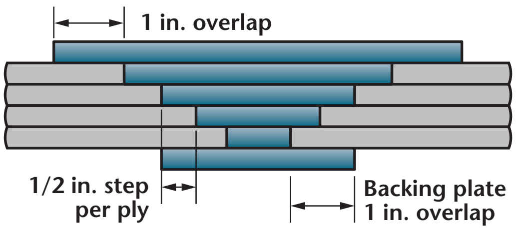


Figure 12-4-3. Repair to fiber damage that extends through the part on a thin laminate uses a step cut with a backing plate.

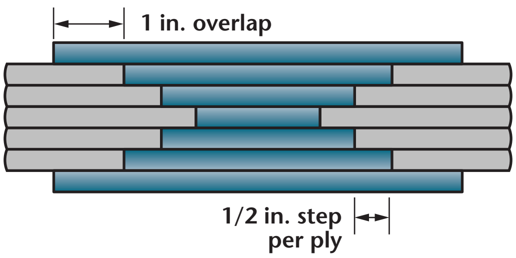


Figure 12-4-4. A thick laminate step cut is modified somewhat. The step goes in both directions.

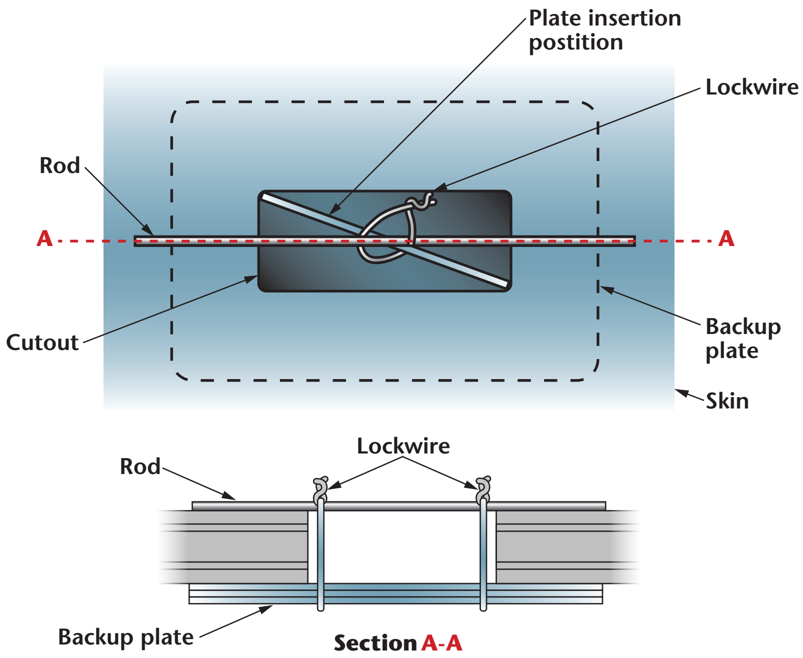


Figure 12-4-5. When one side is inaccessible, this repair involves installing and curing a backup plate.

be laid into the repair. Figure 12-4-2 shows the plies being laid in differently from the previous step cut example.

Some glider repair manuals call for this type of repair. The purpose for using this type of repair as opposed to the more traditional step cut repairs is to prevent the surface plies of the repair from delaminating and peeling off the surface of the skin in case of high impact. Too often the repair patch does not conform to the shape of the step cut area. This creates an air gap around the edges of the patch. If such an air gap occurs, the repair should not be considered airworthy.

Fiber Damage through the Part

Damage that affects all the laminate layers of a structure can be addressed in several ways depending on the following:

- The number of plies in the part
- The location of the damage
- The size of the damage

The steps to perform this repair are below and illustrated in Figure 12-4-3:

1. Prepare the surface.
2. Remove the damage by scarfing or step cutting the plies.
3. Select and mix the proper resin and repair material.
4. Prepare the bonding patches.
5. Use a backing plate, if desired, to support the structure from the backside.
6. Vacuum bag or apply pressure and cure.
7. Remove vacuum bagging materials, blend edges, and refinish.

When the laminate is very thick, instead of starting out to sand 1/2 inch per ply, which would make the repair very large, the repair can be sanded down from one side and up from the other. This makes the repair smaller but can be used only if access to the opposite side is available (Figure 12-4-4).

Laminate Repair with Access to One Side

If the damage extends through the laminate, but access to the opposite side is not available, a pre-cured patch is attached to the inside of the repair and repair plies built on it (Figure 12-4-5).

1. Clean the area to be repaired.
2. Cut out the damaged area in a rectangular shape with rounded corners. This allows the backup plate to pass through the cutout area to the back side. The backup plate should extend at least 1 inch beyond all edges of the cutout.
3. Working through the cutout area, lightly abrade the interior skin surface in a 1-inch area around the cutout.
4. Clean the sanded area with solvent.
5. Prepare a backup plate with the proper materials as described by the manufacturer. These can be made by impregnating the materials yourself or by using preimpregnated materials (pre-pregs).
6. Cut out the plies to make up the backup plate, and lay out a flat surface prepared with parting film.
7. Vacuum bag the patch and cure it with heat.
8. Drill two holes at each end of the cutout in the backup plates. These holes are used to retain the backup plate in place during installation.
9. Pass a short loop of lockwire through each pair of holes in the backup plate. Twist the wires together one turn to hold the backup plate in place.
10. Mix the proper adhesive and coat one side of the backup plate.
11. Pass the backup plate through the cutout and position it against the interior skin.
12. Place a wood or steel rod through the wire loops to bridge the cutout. Twist the wires against the rod until the backup plate is held firmly against the interior skin.
13. Cure with heat, following the manufacturer's instructions.
14. After it is cured, remove the lockwire and fill the holes with adhesive.
15. Prepare patches by impregnating the fabric or using pre-pregs, following the manufacturer's instructions.
16. Cut the required number of plies to fill the hole and for the repair plies, keeping in mind the orientation of each ply.
17. Lay the plies in place into the repair area. Place the final ply, sometimes called the sanding ply, over the entire area.
18. Apply pressure and cure the repair, following the manufacturer's instructions (Figure 12-4-6).

Edge Repair

Edges are usually damaged by either being crushed or punctured. The repair procedure follows:

1. Remove the damage using the specified scarf or step cuts.
2. Insert new plies and overlap the patch on both the top and bottom of the part.
3. The repair plies should extend beyond the edge of the existing structure.
4. Cure the repair.
5. Trim the repair plies to the correct length and shape.

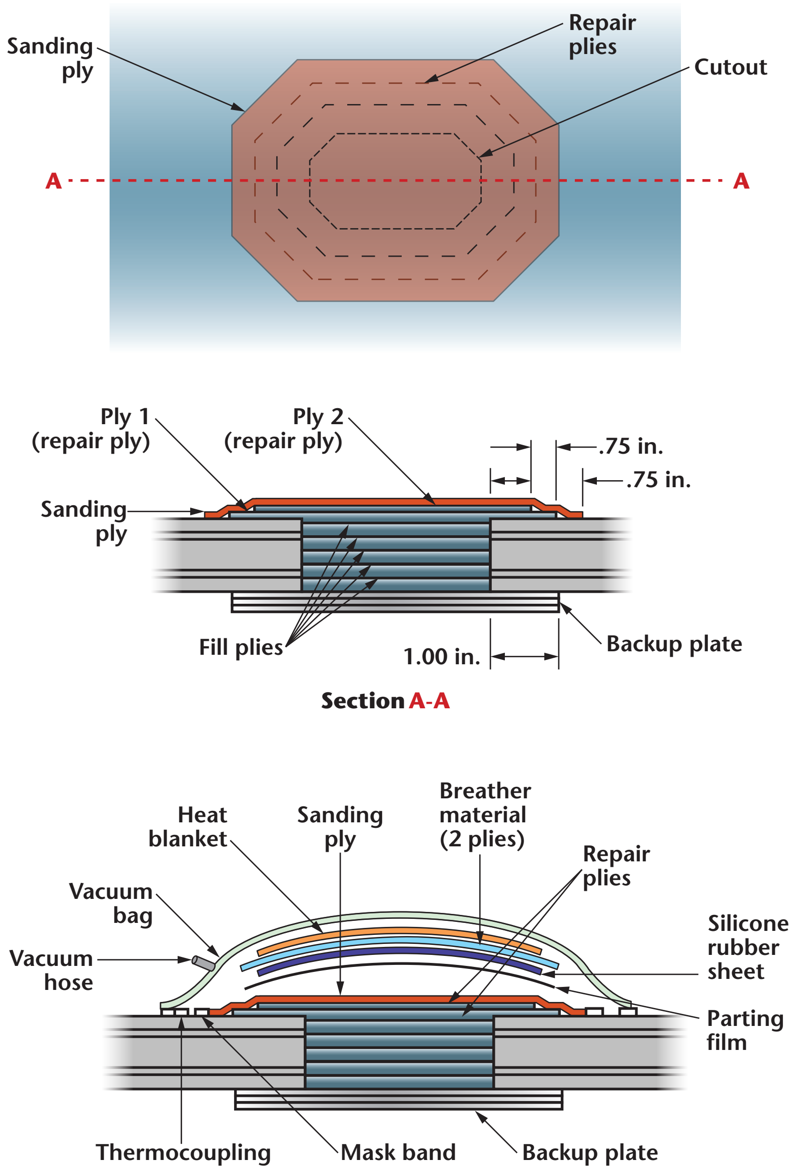


Figure 12-4-6. With damage extending through the laminate, this is what the layup and vacuum bag look like.

Edge Delamination

Minor edge delamination sometimes can be repaired by injecting resin into the delamination, clamping the edge, and allowing the resin to cure (Figure 12-4-7).

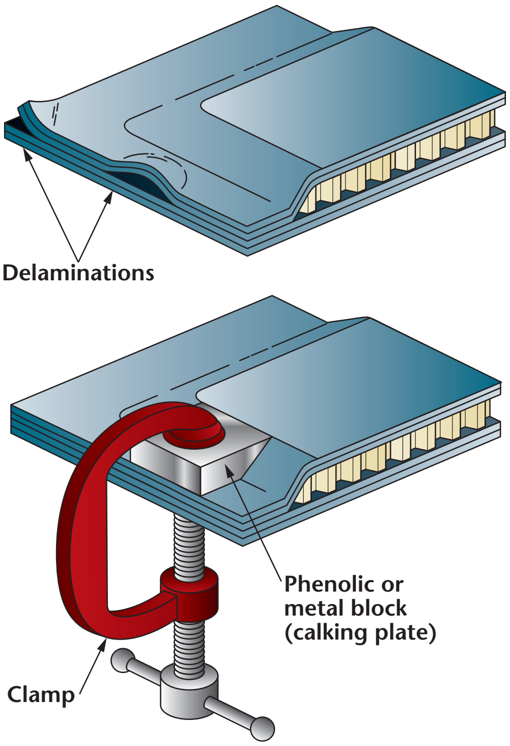


Figure 12-4-7. A typical edge delamination repair.

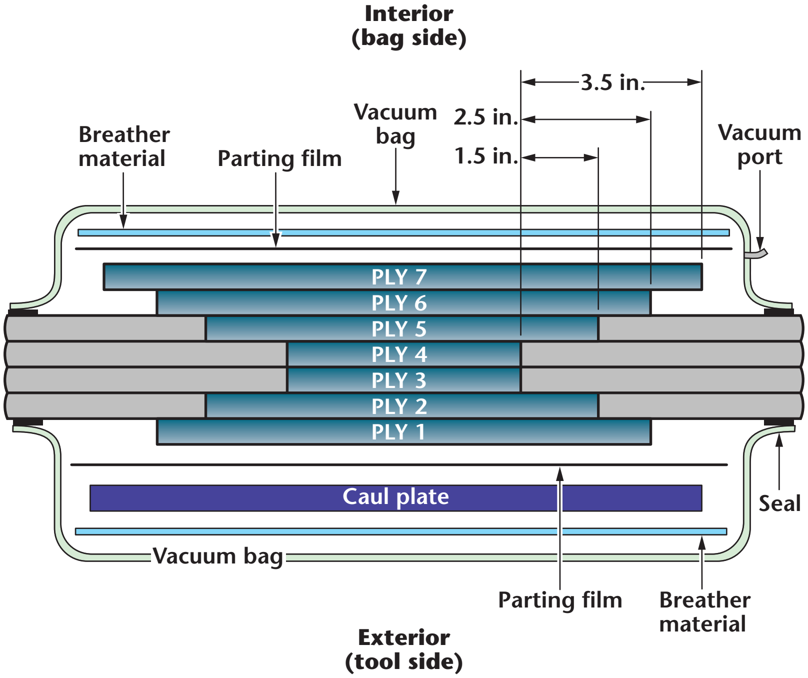


Figure 12-4-8. A typical repair and vacuum sequence for laminates with limited surface area.

Holes in Laminates with Limited Surface Area

If the damage is in a place where steps cannot be made 1/2 inch per ply and still stay on the composite, this type of repair is done. Instead of all the sanding being done from the top, some of the steps are done on the bottom or opposite side. This makes the area of the repair much smaller with the same amount of bonding area. This repair is illustrated in Figure 12-4-8.

1. Step cut the damaged area as illustrated.
2. A temporary stepped aluminum plate can be made to fit the cavity where plies 3, 4, 5, and 6 are shown.
3. Cover the aluminum plate with parting film.
4. Clean the area with solvent.
5. Make another temporary aluminum plate that is 2 inches larger than ply number 1, which is also covered with parting film.
6. Clamp the aluminum plate in place to provide a solid backup surface for plies 1 and 2.
7. Impregnate the fabric with a resin system approved by the manufacturer or use prepreg material.
8. Cut out plies to match the cutout areas, making sure the ply orientation is correct.
9. Apply repair plies numbers 1 and 2 and hold them in place with the other aluminum pressure plate.
10. Carefully remove the temporary stepped aluminum pressure plate and insert the other repair plies, matching the ply orientation of the adjoining levels.
11. Cover the repair with parting film or peel ply and apply pressure.
12. Cure and finish the repair, following the manufacturer's instructions.

Section 5

Repairs to Sandwich Structures

Sandwich structure panels are vulnerable to impact damage primarily because these structures involve relatively thin face sheets.

1. Delaminations can occur at the point where the core is laminated to the skin.

2. Punctures to one side that damages the face sheet and core can be repaired in several ways, depending on the damage size, extent, and location.

Delamination at the Core: Skin-to-Core Voids

A minor delamination between the skin and core can be repaired by resin injection similar to a laminate ply delamination repair. Holes are drilled into the skin, then resin is injected into the delamination cavity. The repair is then clamped and cured (Figure 12-5-1).

A more extensive way to repair a skin-to-core-delamination is to cut out the delaminated skin, scarf back the laminate skin, fill the core area with a potting compound, and install repair plies. Then cure the repair with heat and pressure. This same repair can be done without filling the core, but rather by adding a layer of adhesive to the top of the core material and then laying the patches in place and curing. Keep in mind that the repair procedure depends on the manufacturer and its recommendations.

Small Punctures through Skin and into Sandwich Structure

This type of repair is usually done if the damage is smaller than 1 inch in diameter and in a less structural area.

1. Determine the extent of the damaged area.
2. Clean out the hole by vacuuming any loose fragments, water, oil, or grease.
3. Prepare a hole-filler paste of resin and milled glass fibers.
4. Work the paste into the hole.

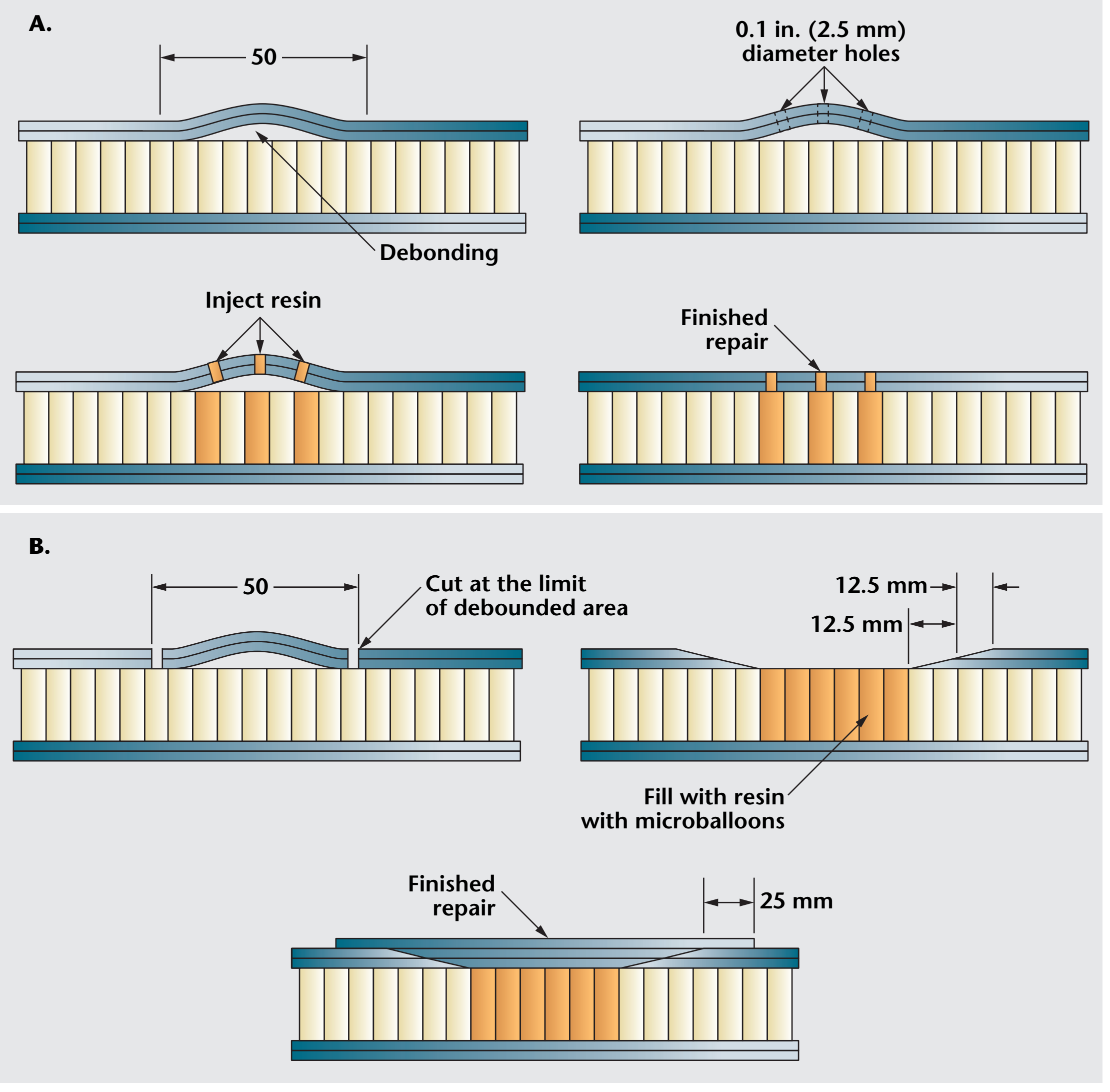


Figure 12-5-1. A. Delamination injection repair for a skin-to-core void. B. Scarfed repair for a skin-to-core void.

5. Cure the resin, following manufacturer's instructions.
6. Sand the surface with a fine sandpaper.
7. Wipe the surface clean using an approved solvent.
8. Refinish the surface.

Damage to One Face and the Honeycomb Core

If the damage is extensive and cannot be repaired by potting, and if it is only to one side of the face sheet, use the following repair procedure. The repair is illustrated in Figure 12-5-2, left.

1. Prepare the surface.
2. Remove the damaged honeycomb core by routing.
3. Remove the damaged laminate by scarfing or step cutting the plies.
4. Clean the area by vacuuming and wiping with solvent.
5. Cut a honeycomb plug to size, keeping the ribbon direction the same as the original.
6. Butter the interior ply with resin and install the honeycomb plug.

NOTE: Some manufacturers might call for a placing a layer of adhesive into the hole and using a foaming adhesive around the core edge.

7. Prepare patches and apply to the sanded area.
8. Apply pressure and cure.
9. Refinish the surface.

Damage to Both Faces and the Honeycomb Core—Two-Sides Access

When both sides are accessible, and damage is all the way through the part, repair it as follows (Figure 12-5-2, right).

1. Prepare the surface.
2. Remove the damaged honeycomb core by routing.
3. Scarf both sides of the face sheets.
4. Cut the core to size, keeping the ribbon direction the same as original.
5. Prepare patches for one side, making sure the ply orientation is maintained.
6. Vacuum bag each side of the repair while curing only one side.

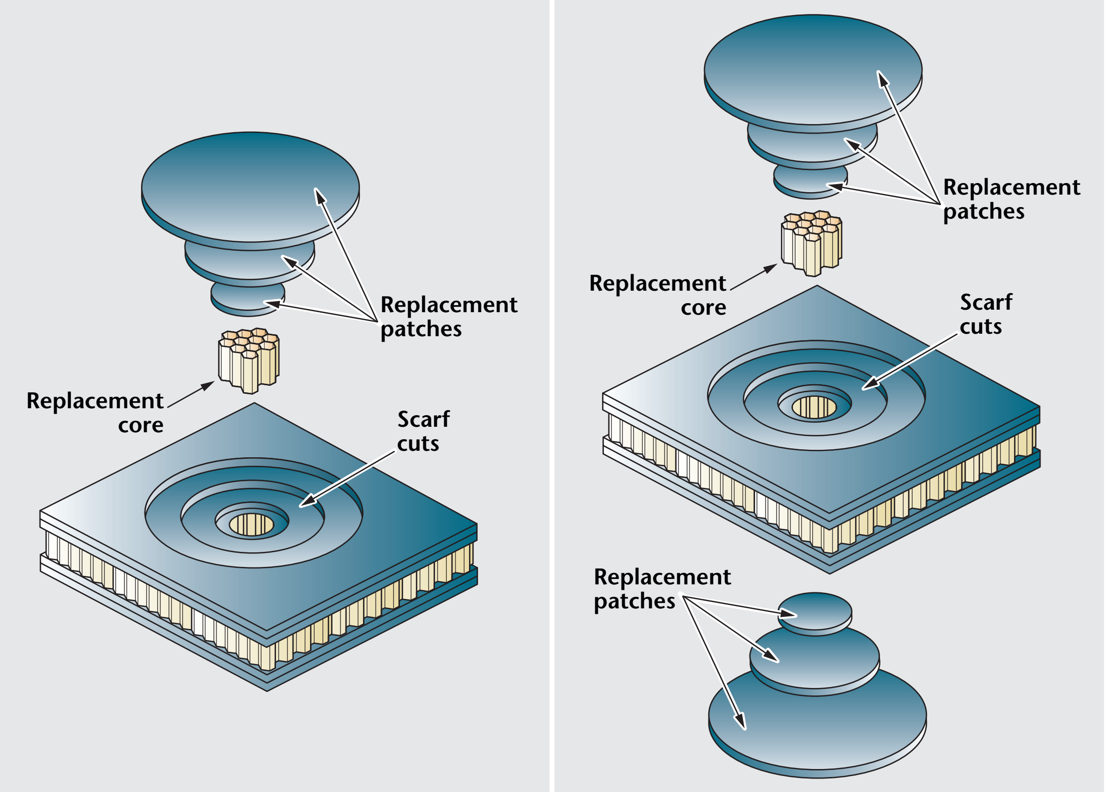


Figure 12-5-2. A honeycomb core replacement with laminate patches on one side (left), and with laminate patches on both sides (right).

7. Remove the vacuum bagging when it is completely cured and prepare the patches for the other side.
8. Apply the patches on the other side and vacuum bag this side, then cure.
9. Refinish both sides of the repair.

Repair to Both Faces and the Honeycomb Core—One-Side Access

If one side of the damaged area is inaccessible but the damage is to both sheets, make the repair using a pre-cured patch, which is bonded to the opposite side and cured. Then insert the core and lay the plies into the step cut or scarfed out area.

1. Prepare the surface.
2. Remove the damaged honeycomb core by routing.
3. Clean out the core area.
4. Apply adhesive to the backside of a pre-cured patch. To help apply pressure, drill a hole in the patch.
5. Insert the patch to the inside of the repair and apply pressure by using a temporary fastener (such as a Cleco) and some metal clamps.
6. Once it is cured, sand the top laminate by scarfing or step cutting.
7. Install the new core material.
8. Prepare the repair patches and apply to the sanded area.
9. Apply pressure and cure.
10. Refinish the surface.

Trailing Edge Repair

The trailing edges of airfoils are susceptible to damage because they are very thin at the ends, can be easily bumped, and can collect water in them. This repair is illustrated in Figure 12-5-3

1. Route out the core of the trailing edge and scarf or step cut the damaged plies.
2. Install a new core material.
3. Prepare patches and install them over the sanded area.

   NOTE: The patches should extend past the trailing edge of the part. After the curing operation, trim them off to the correct length.

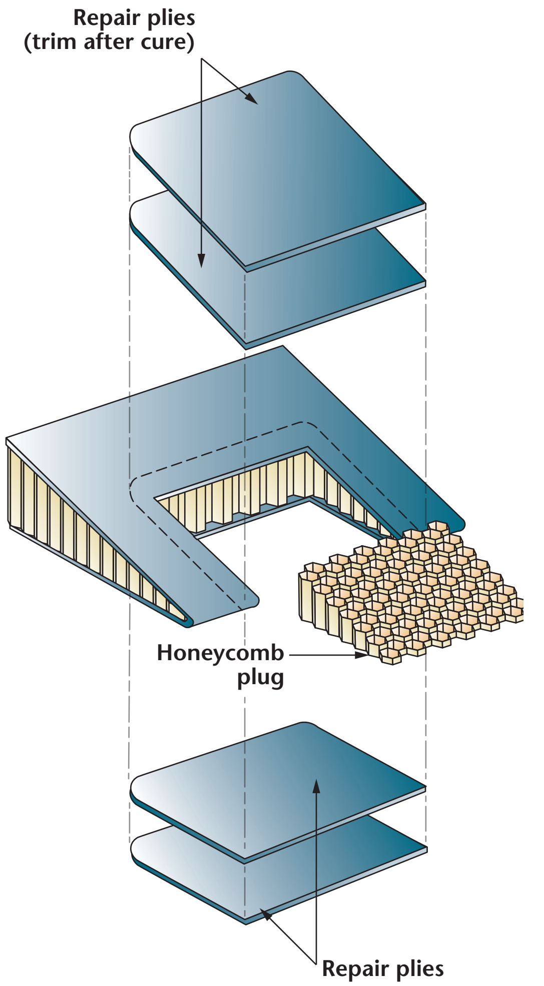


Figure 12-5-3. Trailing edge repair using a honeycomb filler plug.

4. Apply pressure. If vacuum bagging, use a self-enclosed bag all around the trailing edge. To prevent the soft edges from curling up during the cure, use a caul plate or pressure plate.
5. Cure the part. Sometimes the resins on either side of the part can cure at different temperatures. In such a case, use two heat blankets, each at a different temperature and controlled separately.
6. Refinish the part.

Section 6

Repairs to Mislocated, Oversized, or Delaminated Drilled Holes

One of the problems with drilling composites is that if too much pressure is applied while drilling, the fibers of each layer can delaminate, causing a void. The backside laminate layer can also break out during the drilling operation. Before a fastener can be installed, these voids must be repaired (Figure 12-6-1).

1. Lightly sand the outer area about 1/2 inch around hole.
2. Blend chopped fibers with mixed resin, and fill the hole.
3. Prepare patches.
4. Apply pressure and cure.
5. Redrill the holes to the correct size or location.

A problem that can be tricky to fix occurs when drilling a mislocated hole, filling it, and having to drill the hole one-half diameter from where the original hole is. The filled hole is softer to drill than the original structure, and the drill bit can wander over to the softer resin mixture. If you have access to a drill press, this problem does not occur; however, not all parts can be put into a drill press. The best solution is to practice to learn how to get the drill to go where you want it to drill and not wander into the soft resin. A drill block can also be used to keep the drill from wandering. These are shown in Figures 12-6-2 and 12-6-3.

Repairing Loose or Missing Fasteners

1. Standard aircraft procedures should be used for replacing loose or missing fasteners. Washers should be used under the expanded side of the fastener. This is to prevent delamination at the edges of the fastener holes.
2. If the hole or countersink is oversized, the next larger fastener/countersink size may be used.

Most fasteners are installed wet with some type of adhesive (Figure 12-6-4).

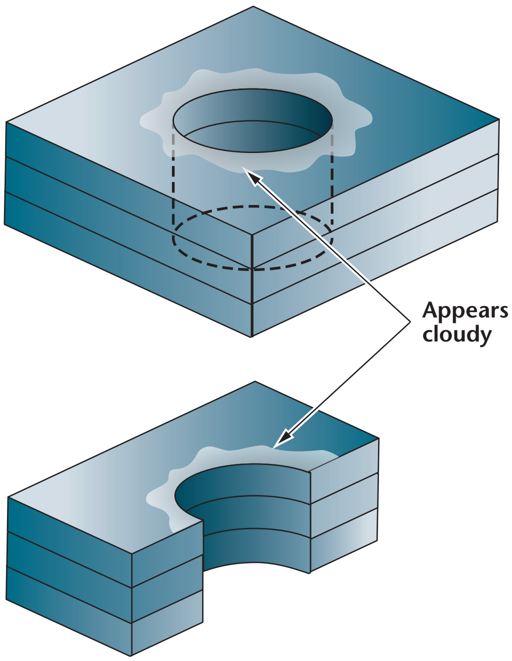


Figure 12-6-1. Typical drilled hole damage that must be repaired before a fastener can be installed.

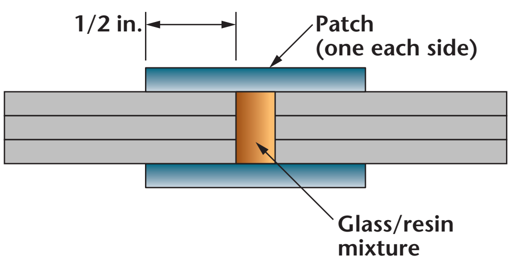


Figure 12-6-2. A mislocated drilled hole is filled and repaired in this manner.

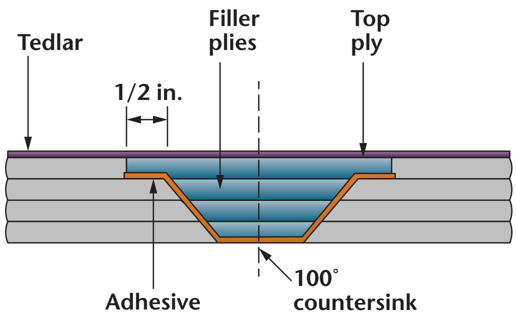


Figure 12-6-3. An example of a typical mislocated hole repair using reinforcing plies to fill the hole.

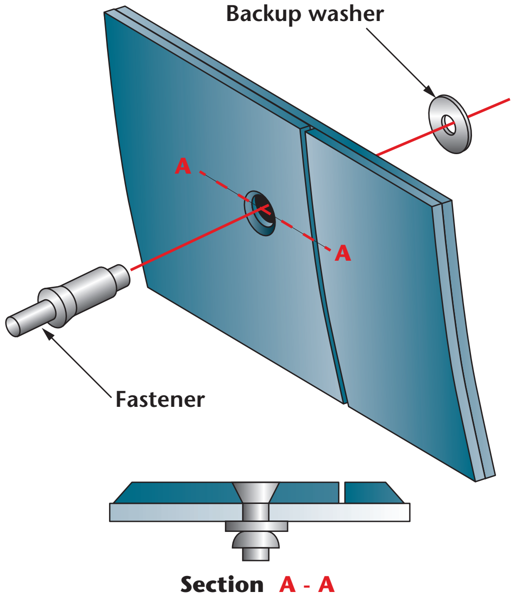


Figure 12-6-4. An oversize fastener installed with a backup washer to prevent delamination at the edges of the fastener hole.

Section 7

Specialty Repairs

Specialty repairs are those that may be done only with special permission from a designated engineering representative (DER) from the manufacturer, or that are not considered ordinary and for which technicians might need special training.

Repairs to Structural Ribs

Many manufacturers do not approve the repair of many parts, such as structural ribs, because of their critical nature. The most common problems associated with such repairs concern the failure of the fix caused by severe flexing and stress. The repairs made to a structural rib are sometimes considered temporary until the entire rib can be removed and replaced.

These examples of repairs assume that the rib is made of a sandwich structure using a cellulose acetate foam core and a carbon/graphite laminate skin. Some SRMs recommend using fiberglass as a repair material instead of carbon/graphite. The fiberglass is used in the repair because the rib takes so much stress that if it is reinforced with carbon/graphite, it could continue to crack on the outer edges of the repair. Fiberglass is not as stiff as the carbon/graphite, so if it is used instead of the carbon/graphite, there is less chance of these imposed stresses.

Crush Damage

If the edge of the rib is crushed, and the manufacturer does not want a technician cutting into the structural materials, the SRM could state that the foam and repair plies should be applied without removing the damage. This repair is illustrated in Figure 12-7-1.

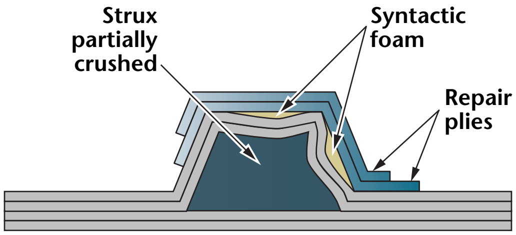


Figure 12-7-1. A typical crushed rib repair.

1. Remove the damaged material (if approved by the manufacturer) and replace the foam core with a syntactic foam. This foam can be in a liquid form and can be injected or brushed into the cavity.
2. After the foam has cured, sand the foam into the shape of the original part.
3. Prepare the repair patches and apply them over the foam.
4. Apply pressure and cure.

Rib End or Edge Damage

The end or edge of the rib is usually where it fastens to other components. It can be somewhat fragile and can become easily damaged in this area.

1. Remove the damaged core material and scarf or step sand the laminate plies.
2. Fill the damaged core area with syntactic foam.
3. Allow the foam to cure and sand down to the original contour of the part.
4. Prepare the new laminate patches.
5. Apply the patches to the sanded area.
6. Apply pressure and cure.

Mid-Rib Damage

Reinforcing ribs are often damaged in the process of loading or unloading an aircraft. In such cases, a temporary repair could be allowed.

1. Remove the damaged foam core by scarfing it out to an angle.
2. Scarf or step cut the laminate surrounding the core.
3. Apply syntactic foam to the area and allow it to cure.
4. Prepare new repair plies, and lay them into the scarfed out area.
5. Apply pressure and cure.

Repairing Damage to Composite Skin and Rib

This repair is illustrated in Figure 12-7-2.

1. Remove the surface coating and clean the surface with solvent.
2. Sand the skin plies to a 45° angle to remove the damaged area. On the rib area, remove any damaged area of core. Clean the area.
3. Impregnate fabric with properly mixed resins or use pre-preg fabric, according to the manufacturer's instructions.
4. Cut fabric replacements for filler plies to replace the removed damage.

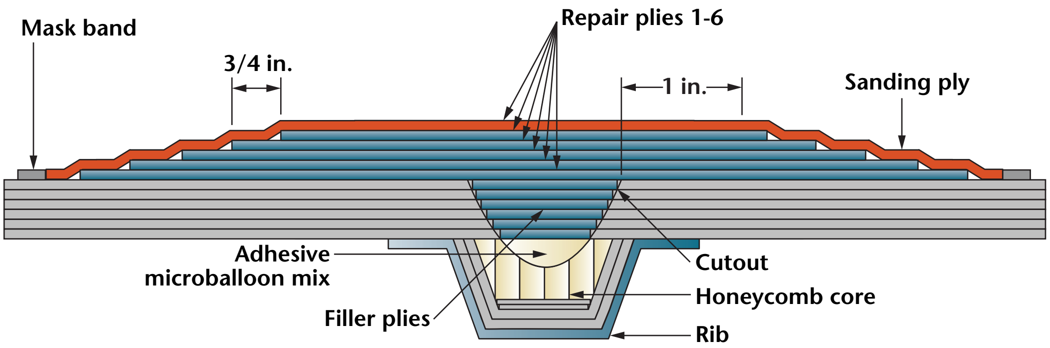


Figure 12-7-2. Repair to a composite skin and rib.

5. With an approved filler, fill the damaged area of the honeycomb.
6. Place the filler plies over the core.
7. Place a layer of parting film over the area, apply pressure, and heat the part to cure.
8. Sand the area lightly and clean with solvent.
9. Make the repair plies by tapering up from the damaged area. Make the first repair ply so it extends 4 3/4 inches beyond the damaged area all the way around the patch.
10. Make each ply thereafter 1 inch smaller all the way around.
11. Use an overall repair ply for the entire repair.
12. Once the repair plies are installed, apply heat and pressure to cure.

Working around Deicer Boots

When a repair takes place near a deicer boot, carefully remove the boot to produce a good working area around the repair. Be sure to allow enough room for the vacuum bagging materials to fit around the repair. If the boot needs to be partially taken off, be careful not to damage it or the underlying structure. When deice boots are installed over a composite structure, remove the boot by using a solvent-soaked rag (usually toluene, acetone, or MEK if permitted in your area) and slightly pulling up on the boot, then spraying or wiping underneath with the solvent. This can take some time, but in the long run, it is well worth it.

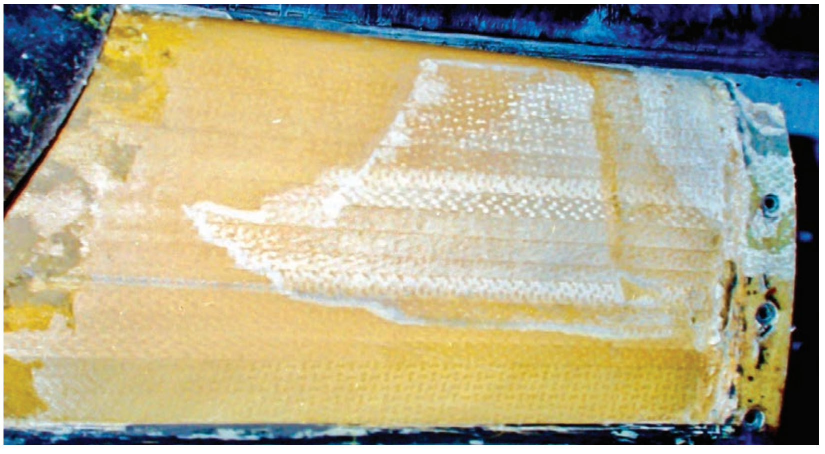


Figure 12-7-3. The boot is pulled back (to the left) and the glue must be removed from the area of damage.

Using a razor blade is common practice when removing a boot that is over a metal leading edge. Do not use a razor blade when removing a boot over a composite leading edge because it could damage the composite surface if the glue or cement is not softened up enough. This could cause some of the composite material to peel up with the boot. This area would then need to be repaired.

Do not use any kind of paint stripper with the composites or in removing the boot because the chemicals damage the composite structure.

Once the boot is pulled back but before a repair is done, all the glue from the deice boot must be removed in the area of the repair (Figure 12-7-3).

You can remove the glue by soaking rags in solvent and laying them over the glue area. The rags might have to be resoaked a few times before the glue wipes off cleanly. Once the glue is removed and the surface is clean, proceed to make the repair to the composite material (Figure 12-7-4). After the repair is cured, put the boot back in place, secured with the appropriate cement.

An exception to the above practice is when working around propeller deice boots. Because many propellers are made with foam cores, the solvent used to remove the adhesive on the boot could deteriorate the foam core. If the propeller has a foam core, the only way to remove the boot is to use mechanical means such as a flat blade of a razor knife. If you follow this process, be careful not to etch or cut into the surface of the composite material.

Figure 12-7-4. The repair is vacuum bagged and cured, then the boot is reinstalled.

Figure 12-7-5. Damage to the part goes through the top two layers of Kevlar, into the core, and one layer below the core.

Splash Molds

A splash mold is made to maintain the contour of the part during the repair, while vacuuming and curing. It can be made of inexpensive materials and is usually used for one repair then disposed of. Splash molds are used on parts that have a curved or contoured surface where the outside of the repair must conform to the shape or contour of the part. The mold holds the patches in place and makes a very nice surface on the outside of the part.

The helicopter component shown in Figure 12-7-5 has surface damage that penetrates through the part. The damage is not totally removed at this point, and a filler material is used to smooth out the damage so that the desired contour is maintained on the outside surface. Once the filler material is hard, sand it down to maintain the contour.

A layer of nonporous teflon peel ply with an adhesive backing is applied over the damage and extends past the area of the repair (Figure 12-7-6). The material is nonporous to keep the mold-making material from attaching to the part. It is commonly used when fabricating a part in a mold. Where there is extra material at a contour, it should be cut out and matched up. The seams should not overlap.

Fiberglass is cut to the size needed. For this example we used five layers. Usually a finer weave is used for the first layer to produce a smooth surface, then heavier weaves or mats can be used for building up the mold. A high-viscosity resin is mixed to the correct proportions; a polyester, quick curing resin works fine. Brush a layer of the resin over the teflon peel ply, and lay down the first fine weave layer (Figure 12-7-7). Smooth it down using a squeegee or brush.

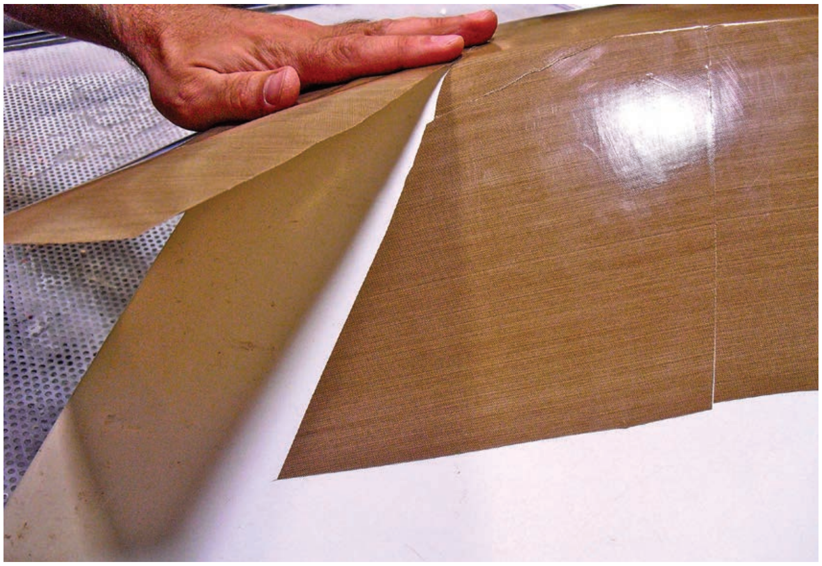


Figure 12-7-6. Apply a nonpourous Teflon peel ply with an adhesive back over the area to create a smooth surface on which to make the mold.

Figure 12-7-7. Build up the mold by layering fiberglass with resins. In this example, five layers of fiberglass were used to build up the mold.

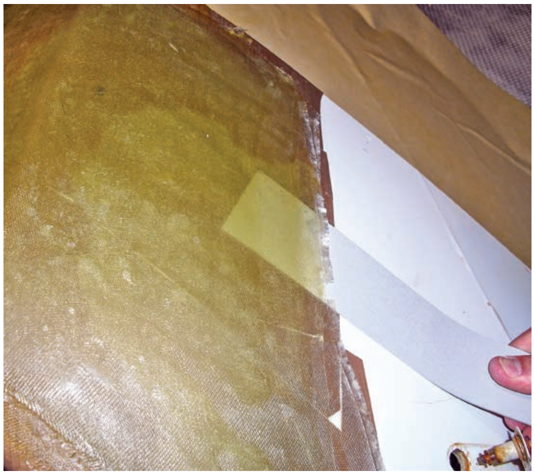


Figure 12-7-8. Once the mold has cured, remove it using wedges to lift the mold from the Teflon.

Figure 12-7-10. The patches are cut to size noting the weave direction, and a layer of peel ply is placed over the repair.

Figure 12-7-9. The damaged honeycomb has been removed, and the fiber layers have been sanded down.

Figure 12-7-11. The splash mold is laid over the repair area and taped down temporarily until the vacuum is applied to hold it in place during the cure.

Add more layers over the first using enough resin to coat all the fibers. It is okay if air pockets exist between layers, but the first layer should be absolutely smooth. If using a mat, a roller with serrated edges works well for smoothing it out. When all the layers are saturated with resin, cure the mold. A polyester resin cures at room temperature in usually an hour or two depending on how thick the mold is.

Once cured, remove the mold using wedges (Figure 12-7-8). If it is completely cured, it should "pop" off the part and not stick.

To repair the part, remove the Teflon and clean the part with solvent. The part is repaired on both sides by removing the paint around the repair area, then routing out the damaged honeycomb, and sanding down each layer as a step or scarf cut (Figure 12-7-9).

Cut the honeycomb to fill the hole, keeping the ribbon direction the same as the original. Make patches to fit the sanded out area, keeping the ply orientations the same as the original plies. Clean the area thoroughly. Be sure to use the correct solvent, with a clean cloth to wipe it with.

Place the patches over the core on the outside of the part, keeping the correct orientation of the plies (Figure 12-7-10).

Place a layer of peel ply over the patches, followed by a barrier like bagging film, and another layer of peel ply. Fit the splash mold over the repair, and tape it down temporarily (Figure 12-7-11).

To repair the inside of the part, turn the part over and fill the inside with the patches, placing peel ply and a barrier over the patches. Lay a heat blanket and thermocouple over the inside of the repair, and vacuum bag the part. A vacuum bag is used on both sides of the part, extending beyond the edge of the part to facilitate bleeder/breather material and a vacuum valve. Place sealant tape around both sides of the repair. The splash mold is on the inside of the vacuum bag (Figure 12-7-12). Apply vacuum and cure with heat according to manufacturer directions.

When cured, remove the vacuum bag, and the heat blanket, splash mold, and peel ply (Figure 12-7-13). The result should be a very smooth, contoured part on the outside.

The rough surface from the peel ply allows paint to adhere to it. Paint the part.

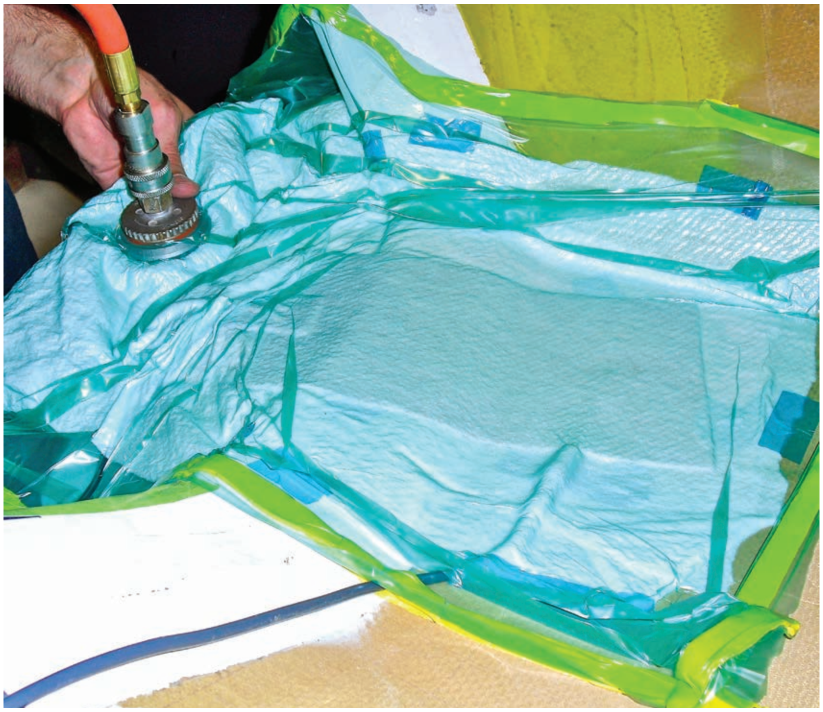


Figure 12-7-12. The vacuum is applied on both sides of the part. Here, the heat blanket is on the underside of the part, and the splash mold is on the other side.

Metal-To-Metal Bonding

Metal honeycomb cores with metal skins have been in use for years. The older type of repairs made to the skin might have been to rivet a new metal patch into place or to use fiberglass patches. The rivets would crush some of the honeycomb core and make a weak area. These metal honeycombs with metal skins are sometimes considered composite components and have newer types of repair procedures that use hot bonding equipment. The newer repairs bond metal patches in place using adhesive and can be made without using rivets or fiberglass.

Metal-to-metal bonding is done by taping off the area to be repaired and removing the paint. Use caution when using a paint stripper so it comes in contact only with those areas to be repaired and bonded. Remove the damaged skin area with a router or hole saw. If the honeycomb is not damaged, be very careful not to route into the honeycomb under the skin. The pilot bit in a hole saw should be a very small diameter to prevent too much damage to the core.

Figure 12-7-13. After removing the vacuum bagging materials and the splash mold, the peel ply is removed, and the repair is finished, except for painting.

After the skin is removed, check for internal corrosion, vacuum out any cutting debris, and use a solvent to clean the area with a clean cloth. If the core is damaged or shows internal corrosion, remove the affected core. If moisture is in the area, remove it by vacuum bagging the area, just as drying out the fiber composites is done. If the core is removed, make a new core using the same type, weight, and ribbon direction as the original honeycomb.

A skin plug that fits the removed area must be made from the same alloy and with the same metal thickness as the damaged skin. A doubler can also be made from the same alloy as the damaged skin. The doubler should cover and overlap the repair area. The most important factor in achieving a sound repair is to clean the surface and properly prepare the metal for bonding. If the metal surfaces are not prepared properly, the metal

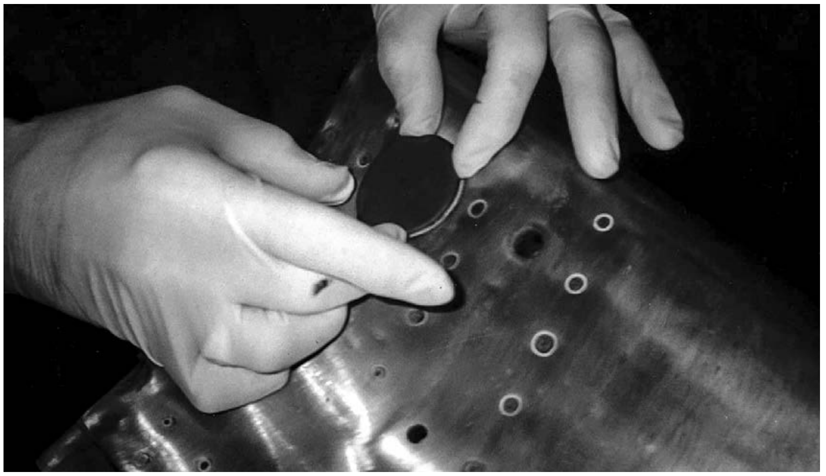


Figure 12-7-14. Use an adhesive film over the core to bond in the new skin plug.

might not adhere to the honeycomb or the metal. Surface preparation is critical. Use a phosphoric acid anodizing etch to prepare the surface. Alternative solutions can include chromic acid anodize or an alodine. The bond can also be affected if clad aluminum is used for the plug and doubler. A non-clad aluminum surface is best.

Thoroughly clean the area with the appropriate solvent and do not touch the metal surfaces with bare hands; otherwise, the oils in the skin contaminate the surface. Scrub the surface with a very fine, clean scour pad (such as Scotch-Brite). Conduct a water break test to ensure that the surface is oil free. Once the area has been cleaned, bond it within 24 hours to prevent contamination of the surfaces. To help bond the components, an adhesive primer can be used on all the metal areas.

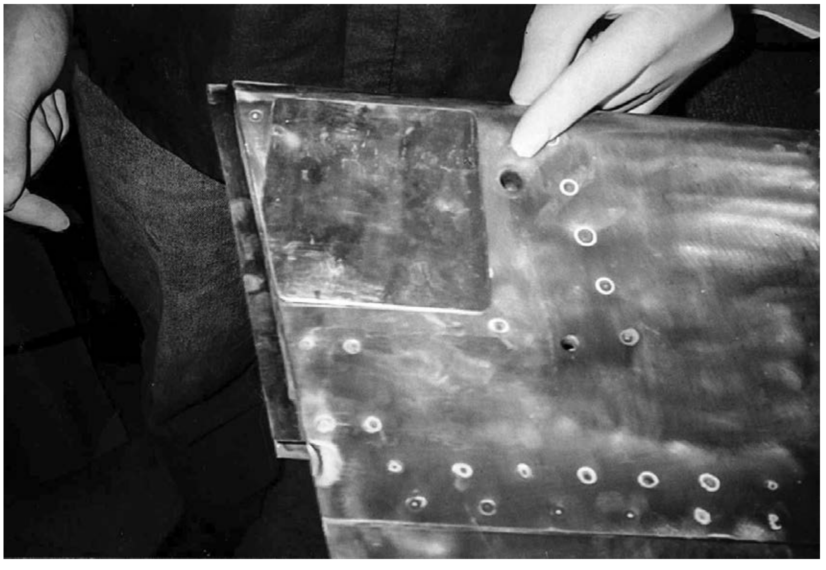


Figure 12-7-15. Once the doubler plate has cured and the edges have been sealed, the repair area can be painted to match the surrounding area. This repair is not flush with the skin.

If a new core is to be inserted into the repair, use a foaming adhesive. Remove the foaming adhesive from the freezer and cut it so it fits around the core. Place the core plug into the routed out area. This should be cured first to prevent the foaming adhesive from expanding up into the sheet metal skin plug area and creating a gap. Cure the foaming adhesive at the proper cure temperature. Once it has cured, sand out any excess foaming adhesive and clean the area thoroughly again.

Use a film adhesive over the core to bond the new skin plug into place, then use another layer of film adhesive to bond the doubler in place (Figure 12-7-14).

When all materials are placed properly into the repair area, use a high temperature or flash tape to hold the materials in place while the part is prepared for vacuum bagging. A parting film, bleeders, heat blankets, and breathers are all vacuum bagged over the repair. Apply vacuum, and cure the part using a heat blanket at the proper cure temperature. During the cure, the metal acts a little differently from when curing an all-composite structure. The metal dissipates heat much more quickly; for best results, use an insulated blanket of fiberglass over the entire repair area and surrounding metal.

After the repair has cooled completely, remove all bagging material. Place masking tape around the metal that surrounds the doubler and expose about 1/8 inch at the metal bond line. Apply sealant around the doubler edge. For a smooth bead, use a mixing stick on its edge around the area. Cure the sealant according to the instructions. Take off the masking tape and inspect the repair (Figure 12-7-15).

Composite Fabric Patching to Aluminum Skins

Cracks and fatigue stresses occur in aluminum aircraft structures, known as the *aging aircraft syndrome*, and repairs are being tested with composite patching. The composite used can be fiberglass, aramid, carbon, and boron. Carbon can be used, but a layer of fiberglass is usually placed directly on the aluminum, followed by layers of carbon. Fiberglass acts as a barrier between the carbon and aluminum that, if left in contact with each other, creates a galvantic potential between the two materials, causing corrosion. Using fabric patches is effective in reducing the fatigue of the aluminum panels. The procedure can vary depending on the type of metal or aluminum and the area of damage.

Similar to the metal-to-metal bonding repair, the fabric patches eliminate the need for fasteners, which can cause additional stress concentrations and cracks. Many times, the component does not need to be disassembled from the aircraft, which reduces the time and labor involved in making these repairs.

The metal surface preparation is extremely important to establish a good bond to the patch. All paint, grease, and dirt must be removed from the surface. Next, prepare the metal by acid etching the surface. Use pre-preg unidirectional patches for the bonding, with the direction of the fibers at a 0° to a 45° orientation. Vacuum bag the patches to the surface, usually with peel ply over the patches, and cure at an elevated temperature. The patching is relatively simple because the orientation does not necessarily have to match up with any existing orientation of the fibers—the orientation is more for direct strength between the two plies themselves.

The composite patches will take the bending and flexing of the aluminum part and prevent the micro cracks in the aluminum from becoming larger

Radome Repairs

Repairing radomes can be quite an involved task. Radomes are made to protect the aircraft's radar antenna from the flying environment. It needs to be almost transparent for the radar signal emanating from the aircraft, and the signal returning back to it. If there is a defect or improper repair in its field of vision, it can distort the readings and give inappropriate information to the pilot. The biggest problem with the radar is that it is in the front of the aircraft, and rocks, birds, rain, snow, and hail can damage the structure. Static discharge can also present a problem if it burns small holes and chips in the paint (Figure 12-7-16). These are very small but large enough for moisture to penetrate the fibers causing delamination of the skins. If the moisture fills some of the honeycomb cells, it could freeze at altitude and expand causing the skin to delaminate.

It is important to inspect the damage to a radome before and after a repair is made. Before the repair, the extent of damage must be determined. The test can be a simple coin tap test to check for delamination or a transmissivity check on specialized equipment. A moisture meter can also be helpful in detecting moisture in the radome's fiber structure. The extent of the damage is important to check. Many times, too many repairs, or repairs that are too close together, can cause the maintenance technician to opt for sending the structure out to a repair station specializing in radome repair. Such shops have the molds to completely replace skins and cores to build up a damaged radome back to optimum condition. Be sure to check the SRM to see if the damage is within the limits.

When repairing a radome, it is very important to follow the instructions exactly as the manufacturer states to do the repair. If the electrical properties are altered, it can cause a loss of signal, and can produce numerous problems that might appear to be deficiencies of other components in the radar system. Be sure to use the exact type and thickness of fabric, honeycomb, and resin specified by the manufacturer. The thickness of the repair can effect the quality of the repair.

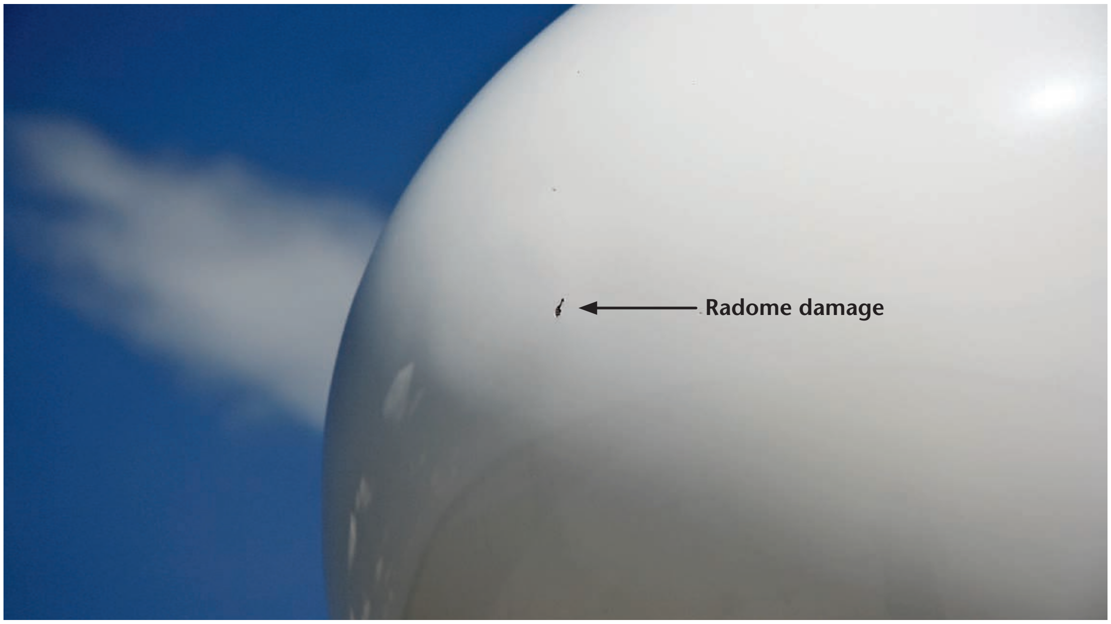


Figure 12-7-16. Even small chips can allow moisture in, which can begin delaminations.

Although the FAA does not require transmissivity tests before returning a repaired radome to service, other types of electrical test procedures can be found in most SRMs. These checks can ensure that the repair does not affect the signal's transmissivity, reflection, or diffraction. These checks might need to be made after repairing and after painting the surface, because the paint type or thickness of the paint can also interfere with signal transmission. Repair stations set up to do many radome repairs have extensive testing equipment to check the soundness of the repair and the signal transmissivity.

Polybutadiene resin. One of the most common applications of polybutadiene resin is in preparing pre-preg materials for use in radomes. The operation of radar systems in both aircraft and marine environments presents a list of contradictory requirements. The radome structure must be very thin to ensure the maximum efficiency of the radar. At the same time, the radome must be very strong to endure the severe impacts that occur such as in a hail storm. The radome must be stable over a wide range of temperatures so that it does not expand or contract significantly, causing mechanical problems or cause a distortion of the radar signals. The radome must also be resistant to exposure to ultraviolet light and the corrosive action of water.

As the electrical performance of radar systems has improved, the performance capabilities of radome materials have also improved. For example, using advanced radar systems that operate in the K-band or 10.9–36.0 gigahertz has proven that the standard epoxy-E-glass radome composite system is too opaque. Polybutadiene resins are the preferred choice of matrix materials in such an application because of their very low dielectric constant and low power dissipation factor. In addition, when subjected to high-voltage arcing, polybutadiene resins resist forming carbon compounds that obscure radar signals. The mechanical characteristics of polybutadiene resins make them strong enough to enable making thin radome walls that still withstand the stringent structural demands of a high-speed aircraft.

Propeller Repairs

With the introduction of composite structural fibers, many propellers are made from composite material. Always follow the manufacturer's repair manual to see if the damage is repairable. The following is a guide to repair propeller blades. Identify the materials used in the blade. The composite materials can vary from blade to blade. Inspect the area, typically by coin tapping, to see the extent of the damage. Identify where the damage is. Damage to the tip of the blade might have larger areas that can be repaired, rather than the root where it is very structural. If the damage is to the root area, you might only be allowed to repair a small area of damage.

> **CAUTION:** When a deice boot must be removed, do not use strong solvents that can penetrate into a foam core. The solvents could dissolve the foam and cause greater damage.

Trailing edge damage is common, and a basic repair procedure could be to remove the damage by step sanding or scarfing. Clean the part with a solvent, and place replacement fiber reinforcements in their correct orientation with the proper resin system. Next, vacuum bag and cure, following the manufacturer's requirements.

Erosion shields sometimes become disbonded, and a simple way to apply adhesive to the disbonded area is to drill a small hole into the erosion shield at the end of the disbond. Vacuum bag over the drilled hole, and pull a vacuum while applying the mixed adhesive to the edge where the disbond starts. Remove the vacuum when resin is pulled into the hole that was drilled. The entire area is then vacuum bagged to provide pressure while the adhesive is curing.

Homebuilt Aircraft Repairs

With the decline of manufactured general aviation aircraft in recent years, the homebuilt industry has grown at a phenomenal rate. These aircraft are built by individuals at home or at airports using many composite designs. Figure 12-7-17 shows an example of a homebuilt aircraft. The builders themselves are technically the manufacturers of the aircraft. If a person has built a homebuilt aircraft, the repair to that structure should not be a problem. However, many of these aircraft are being sold and bought by people who did not originally manufacture the aircraft, and consequently, repair technicians are called in to do the repair. These aircraft typically do not have an SRM to follow, and finding the correct procedures might be next to impossible.

The following is a basic procedure for repairing homebuilt aircraft components. The composites used are typically fiberglass, foam, and Nomex honeycomb. Some later models use some carbon graphite. Before beginning a repair, identify the type of material that the structure is made of. Use the same weight and weave of fabric as the original structure, if possible.

1. Remove the paint and test the area for delamination by coin tapping the area and listening for a difference in tone. Remember that a difference in tone is not always a sign of delaminations, but could be a change in core structure or materials. Mark out the area that is damaged. Check for core damage. If the core is damaged, it might have to be removed and a new core inserted. If the damage is small, the core can be filled with a potting compound and sanded to shape.
2. Remove the damaged skin, and step or scarf sand the surrounding area. To make the proper step cuts in the laminate, each successive layer of fiber and matrix must be removed without damaging the underlying layer. When sanding, take great care to avoid damaging the fibers surrounding the area being removed. Sand down about 1/4 inch all the way around the damaged area for each ply.
3. Clean out the sanded out area with a solvent to remove any excess sanding dust or grease that might be on the surface.
4. Mark out the plies on a clear piece of plastic, noting the weave direction of each ply. The patches made from the reinforcing material for the repair must carry the stress loads that were originally carried by the fibers that were manufactured into the part. Make one fabric bonding patch ply of the same thickness and ply orientation for each damaged ply removed. Whenever repairing a composite component, the fiber orientation of the new patches must be in the same direction as the original structure.
5. Lay a clear piece of plastic material on top of the repair area. Trace the shape of the repair cutout onto the plastic. Note the warp orientation on the plastic for the layer being traced.
6. The resin system should be compatible with the structure. Most homebuilt parts do not use a polyester resin system on the structural components. Weigh out a two-part epoxy system to the proper ratio and mix together. Impregnate the fabric with the mixed resin system. Place another clear plastic piece over the wet fabric, and cut the repair patches to the correct shape outlined on the plastic.

Figure 12-7-17. The Rutan VariEze is a high-performance, homebuilt aircraft made with composites.

7. After the patches are cut out, lay them onto the sanded area. Remove the plastic backing and place down using the correct fiber orientation.
8. If using a room temperature cure *homebuilt epoxy* system, the resin usually cures very quickly. If this is the case, the repair cannot be vacuum bagged because it cures so quickly. The vacuum bagging cannot be applied in time, and the part will not benefit from the vacuum. Instead, a layer of peel ply helps to hold down the repair plies during the cure cycle and gives the repair a finished look that requires little sanding except to feather out the edges.
9. If the type of resin used is a slower cure type (over 2 hours), there is plenty of time to vacuum bag the repair. It also helps squeeze out much of the excess resin to give a stronger repair. Vacuum bag the repair using peel ply, bleeder, bagging film, and sealant tape.
10. Cure the repair. Most homebuilt part surfaces are finished with a resin mixture that has microballoons to make a slurry. This is used all over the surface to smooth out any defects. To help match the repair with the existing part, make a slurry and spread it over the repair area. This can have a layer of peel ply added to create a smoother, finely etched area that requires less sanding. Next, paint the part with the same type of paint that was used on the original aircraft.

Afterword

Author's Note

This book is intended to familiarize the technician with basic repair techniques, terminology, tools, and materials frequently used in composite repair. After being properly trained and the knowledge gained from this book, a technician should be able to easily translate the information in the SRM using the correct materials, following the correct procedures to the repair.

Composites represent new materials and techniques that must be mastered by those who want to stay in tune with the aviation industry. One characteristic of the aviation industry is that it is always changing, always improving. As a result, it requires that the best people in the industry are also improving. Aviation produces some of the most beautiful, intriguing, and inspiring, machines made by humans. These are the best machines. The best maintenance professionals are needed to inspect, maintain, and repair these machines.

So, why do manufacturers even use composites?

- High strength-to-weight ratio (which means more payload)
- Ability to withstand stresses (flexibility and stiffness)
- They can be formed into one complex piece, in aerodynamically contoured shapes
- They do not corrode like aluminum
- They have reduced wear

Sounds like an ideal aircraft manufacturing material!

Or is it?

Problems with composites:

- Some might wick in moisture (aramids)
- Some exhibit dissimilar metal corrosion when bonded to aluminum (carbon/graphite)
- They are hard to inspect
- They can be difficult to repair properly without the proper training
- Finding the proper composite materials in small quantities can be very difficult
- Drilling into a composite can cause the structure to become weaker – Yet some repairs are being made today are not considered temporary, and use the bolted repair.

A technician faces many problems when working in the composite repair field. Because the materials are new, many support resources are not in place. Here is an outline of what I see as lacking for the maintenance professional when facing a composite repair:

Small Quantities of Materials. It is difficult to find small quantities of some of the materials required. The weavers do not want to sell a few yards, so other distributors buy full yards and sell smaller quantities for repair use. It is very hard to track a specific material.

Certification of Materials. Because many distributors are selling the materials, a certification of materials is required to trace the materials back to the weaver. There is no marking on the fabric. WHY? As AMTs, we know that the fabric used in covering a dope and fabric aircraft is required to have a marking on edge every 3 feet. This was put into effect in the 1940s. Yet today, the weavers are refusing to stamp the edges. It would be great to see a TSO number, weave number, or anything to identify it on the fabric.

Standardization of Materials. Speaking of TSO numbers, it would be nice if the weavers would standardize their weaves and assign a standardization number to each weave. That way, when a repair called for a 584 carbon, we know we could also use 584 graphite, or a G105, or a MI-1029 depending on the weaver, all of which are the same materials. When we ask for the compliance papers, we get the Boeing Material Specification (BMS) number. If we are working on something other than a Boeing, we have no idea what that BMS stands for and, therefore, require more paperwork from someone to write a clarification that indeed this material does in fact meet the specifications of a 584 carbon.

Standardization of Terms. It's so cute when I get a request for a quote, and the items listed are baby blanket, gorilla snot, sticky tape, etc. When I question the person about it, they are very defensive about it: "We used these terms when I worked at McDonnell Douglas." So, if you use these terms, others around you will be impressed with your professionalism. No, it's not very professional. Consistency begins with terminology. Standardization of terms is important for communication among maintenance people, parts people, buyers, etc. If the communication is poor, the resulting material might not be what you want. If you are an instructor, please do not use cute terms when teaching your students. Thanks.

Updated Structural Repair Manuals. When working in the field, I am extremely disappointed with some of the SRMs for composite repair. On one aircraft delivered to a commuter airline, one page said that an update would be out soon. There was nothing showing the components that were made of composites (as I remember, about 40 percent of the airframe), there were no lists of materials to repair with, no damage limitations. This update came two years later. Many times it is the maintenance professional that suggests types of repairs to be done, submits it to a tech rep, which then becomes the approved repair in the update. Many students who have graduated from my course are doing this in the field, using the illustrations from this *Advanced Composites* book.

The Number of Thermocouples Used. Here's a pet peeve of mine. How can the recording of the temperature prove the repair was done correctly? Many FAA professionals and shops are requiring numerous thermocouples in the repair. The repair done on Flight #587 could have used 10 thermocouples to record the temperature, but it failed. If the repair is not the correct repair, the wrong type of repair materials were used, all the oil or water was not cleaned from the repair area, if it was improperly bagged, if it was improperly sanded, or any other number of reasons, the repair could fail. It is not the number of thermocouples that determines a correct repair.

Training. One of the most common problems associated with using aircraft composites is that too few technicians are trained in the techniques and materials of composite repair. As more manufacturers equip their aircraft with composite parts, the need for trained aviation technicians to fabricate, inspect, and maintain these aircraft also increases. The availability of trained technicians to provide airworthy repairs has not yet caught up with the industry demand. Although anyone with an airframe license is authorized to perform a repair to a composite component, some specialized training is usually needed to ensure a complete and airworthy job. This training is of increasing significance because many advanced composite materials are being used to fabricate structural components and primary control surfaces.

My hope is that we can work together as manufacturers, FAA personnel, airlines, industry trainers, and maintenance professionals to continue to make aviation one of the truly great industries.

Glossary

A–stage: The initial stage of mixing the two parts of a thermosetting resin system. The material is soluble in some liquids and fusible.

aircraft maintenance manual (AMM): Also called a manufacturer's maintenance manual (MMM). A manual published by the aircraft manufacturer that includes information for a technician who performs work on units, components, and systems while they are installed on the airplane. It is normally supplied by the manufacturer and approved by the FAA as part of the original process of certification. It contains the required instructions for continued airworthiness that accompany each aircraft when it leaves the factory. An AMM can also be developed by a Part 125 operator as part of its operating manual. As such, the FAA does not approve the manual.

accelerator: A chemical additive that quickens cure or a chemical reaction.

additives: Materials that are mixed into a two-part resin system to improve its properties.

adhesive: A substance that is applied to two mating surfaces to bond them together by surface attachment.

adhesive film: Premixed adhesives cast onto a thin plastic film. Requires refrigerated storage.

advanced composites: A fibrous material embedded in a resin matrix. The term *advanced* applies to materials that have superior strength and stiffness and the process in which they are manufactured. Advanced composites are used structurally on an aircraft.

alloy: A blend of polymers or copolymers with other polymers or elastomers. Also called polymer blend.

anisotropic: Constructed such that fibers are placed in different directions to respond to the stresses applied in different directions.

aramid: A type of fiber that is an aromatic polyamide. Several companies weave aramid fabrics for aircraft use. DuPont's brand name of aramid is Kevlar®.

area weight: The weight of fiber reinforcement per unit area (width × length) of tape or fabric.

aspect ratio: The ratio of length to diameter of a reinforcing fiber.

autoclave: A large vessel used to cure laminates and bonded parts, using pressure, vacuum, and heat in an inert atmosphere.

autoclave molding: A manufacturing method that uses an autoclave. The composite assembly is placed into an autoclave at 50 psi to 100 psi to consolidate the laminate by removing entrapped air and excess resin.

axial winding: A manufacturing method using filament-winding equipment. In axial winding the filaments are parallel to the axis.

B-stage: The intermediate stage in the reaction of the two parts of the resin system after being mixed. The resin system reacts to heat by softening. The resin in a pre-preg material is usually in the B-stage before the curing process.

bagging: Applying an impermeable layer of film over an uncured part and sealing the edges so that a vacuum can be drawn.

bag side: The side of a part that is cured against the vacuum bag.

balanced design: In filament winding, a winding pattern so designed that the stresses in all filaments are equal.

balanced laminate: Each layer except the 0°/90° are placed in plus and minus pairs around the centerline. These plies do not have to be adjacent to each other.

basket weave: A woven reinforcement in which two or more warp threads go over and under two or more filling threads in a repeat pattern. The basket weave is less stable than the plain weave but produces a flatter and stronger fabric. It is also a more pliable fabric than the plain weave and maintains a certain degree of porosity.

batch (or lot): Material that was made with the same process at the same time and has identical characteristics throughout.

bearing area: The cross-section area of the bearing load member on the sample.

bearing strain: The ratio of the deformation of the bearing hole, in the direction of the applied force, to the pin diameter.

bearing stress: The applied load in pounds divided by the bearing area.

bias: A 45° angle to the warp threads. Fabric can be formed into contoured shapes by using the bias.

bidirectional cloth: A cloth in which the fibers run in various directions. Usually woven together in two directions.

bidirectional laminate: A laminate with the fibers oriented in more than one direction.

bismaleimide (BMI): A type of polyimide resin that cures at a very high temperature and has a very high operating temperature range (such as 550°F–600°F, and some around 700°F). These are more difficult to cure because moisture emissions during the cure can cause voids or delaminations.

bleed: An escape passage at the parting line of a mold (like a vent, but deeper) that allows material to escape, or bleed out.

bleeder: A layer of material used in manufacturing or repairing a part to allow entrapped air and resin to escape. It is removed after curing. It also serves as a vacuum valve contact with the part.

bleedout: Excess resin that flows out in the curing process, usually into a bleeder cloth. Sometimes it appears in the filament winding process if the fiber has been through a resin bath.

blister: An unwanted, rounded elevation of a plastic surface that resembles a blister on human skin.

bond ply: The ply or fabric patch that comes in contact with the honeycomb core.

bond strength: The amount of strength of the adhesion. Equal to the stress required to pull apart two plies or to pull a ply from the core.

boron filament: A strong, lightweight fiber used as a reinforcement; it is a tungsten-filament core with boron gas deposited on it. It has a high strength-to-weight ratio.

braiding: Weaving fibers into a tubular shape instead of a flat fabric.

breakout: An occurrence of the fibers separating or breaking when drilling or cutting the edges of a composite part.

breather: A loosely woven fabric that does not come in contact with the resin and is used to provide uniform venting and pressure under a vacuum cure. Breather material is used under the vacuum valve to allow the air to be evacuated inside the vacuum bagged part. It is removed after curing.

bridging: 1. The plies of fabric over a curved edge that do not come in full contact with the core material. 2. The excess resin that has formed on edges during the curing process.

buckle line: On a honeycomb core, it is a line of collapsed cells with undistorted cells on either side. It is usually found on the inside of the radius on a formed core.

buckling: A failure of the fabric in which it deflects up or down rather than breaking.

component maintenance manual (CMM): A manual published by a component manufacturer and commonly adopted by an airframe manufacturer. A CMM is usually not approved by the FAA. Blanket approval comes through the aircraft maintenance manual or structural repair manual.

C-stage: The final stage in curing the mixed thermoset resin system. In this stage, the resin cannot be softened by heat and is insoluble.

carbon fiber: A lightweight, high-strength, and stiff fiber. It it produced by placing carbon in an inert atmosphere at temperatures above 1,800°F. Used as a reinforcing material. The material can be graphitized by heat-treating it to a very high temperature.

carbon/graphite fiber or fabric: A fiber used in advanced composites composed of carbon filaments that are woven together. The terms *carbon* and *graphite* have been used interchangeably for years. In the United States, graphite was the preferred term, and might still be used in older maintenance manuals; in Europe, carbon is preferred. Carbon/graphite is used throughout this book to include both terms.

catalyst: A substance that initiates a chemical reaction.

catalyzed resin: A resin mixture after it has been mixed with the catalyst or hardener. It might still be in the workable state.

caul plates: Smooth plates used during the cure process to apply pressure uniformly.

coefficient of expansion: A measure of the change in length, area, or volume of an object.

coefficient of thermal expansion: The change in length, area, or volume accompanying a change of temperature.

cocured: Laminates are cured and bonded to another prepared surface.

cohesion: The tendency of a substance to adhere to itself. The force holding a substance together.

coin tap: Using a coin to tap a laminate construct in different spots to detect a change in sound, indicating the presence of a defect.

composite: Two or more substances that are combined to produce material properties not present when either substance is used alone.

compression molding: A manufacturing method that uses a two-part mold that is in the shape of the finished part. To produce the part, the resin and fibers are placed into the mold cavity, the mold is closed, and then cured with heat.

compressive strength: The resistance to a crushing force.

contaminant: An impurity or foreign substance in a material or environment that affects one or more properties of the material, especially adhesion.

continuous filament: An individual reinforcement that is flexible and indefinite in length. The fibers used to weave fabric are considered continuous filaments.

core: The central member of a sandwich part (usually foam or honeycomb). It produces a lightweight, strong component when laminated with face sheets.

core crush: Compression damage of the core.

core depression: A gouge or indentation in the core material.

core orientation: Placing the honeycomb core to line up the ribbon direction, thickness of the cell depth, cell size, and transverse direction.

core separation: Broken honeycomb core cells.

core splicing: Joining two core segments by bonding them together, usually with a foaming adhesive.

crazing: A region of ultrafine cracks that can extend in a network on or under the surface of a resin or plastic material.

critical strain: The strain at the yield point.

cross linking: With thermosetting and certain thermoplastic polymers, setting up chemical links between the molecular chains.

cross-ply laminate: A laminate with plies usually oriented at 0° and 90° only.

cure: To change the physical properties of a material by chemical reaction, by applying catalysts, heat and pressure, alone or in combination.

cure temperature: The temperature at which the resin system attains its final cure. It does not include the ramp up or down.

curing agent: A catalytic or reactive agent that causes polymerization when added to the resin. Also referred to as a hardener.

delaminate: The separation of layers caused by adhesive failure. This also includes the separation of the layers of fabric from a core structure. A delamination can be associated with bridging, drilling, and trimming.

denier: A numbering system for filaments in the yarn used for weaving. The number is equal to weight in grams of 9,000 meters of yarn.

disbond: The separation of a bond of one structure from another. Many times, this term is used to refer to the laminate skin separating from the core structure. It is also used for a fitting separating from the skin.

doubler plies: A patch that extends over the sanded out area to the existing structure that strengthens the repair. A doubler can also be used where fasteners are applied or where abrupt load transfers occur.

drape: The ability of a fabric or pre-preg to conform to a contoured surface.

dry fiber: A condition in which fibers are not fully encapsulated by resin.

dry laminate: A laminate containing insufficient resin for complete bonding of the reinforcement.

E-glass: A type of fiberglass. The E stands for electrical. It is used primarily where interference to radio signals, such as with a radome, can occur.

eight-harness satin: A type of fabric weave. The fabric has a seven-by-one weave pattern in which a filling thread floats over seven warp threads and then under one. Like the crowfoot weave, it looks different on one side of the fabric than the other. This weave is more pliable than any of the others and is especially adaptable to forming around compound curves, such as on radomes.

environmental stress cracking (ESC): The susceptibility of a resin to cracking or crazing when in the presence of surface-active chemicals.

epoxy resin: A common thermoset material used in aircraft construction as the bonding matrix to distribute the stresses to the fibers and hold the fibers together. When mixed with a catalyst, epoxy resin is adhesive, chemical resistant, water resistant, and unaffected by heat or cold. It is one part of a two-part system that combines the resin and the catalyst to form the bonding matrix. In composites, *resin* is often used to describe the two parts mixed together.

fabric: Individual fibers woven together to produce cloth. Unidirectional or matted fibers can be included in this classification.

fabric warp face: The side of a woven fabric in which the greatest number of yarns is parallel to the selvage.

faying surface: The surfaces of materials in contact with each other and joined or about to be joined.

fiber: A single strand of material used as reinforcement because of its high strength and stiffness.

fiber bridging: Reinforcing fiber material that bunches up on an inside radius. This condition is caused by shrinkage stresses around such a radius during cure.

fiber content: The amount of fiber in a composite expressed as a ratio to the matrix. The most desirable fiber content is a 60:40 ratio. This means there is 60 percent fiber and 40 percent matrix material.

fiber direction or orientation: The orientation of the fibers in a laminate to the 0° reference designated by the manufacturer.

fiber reinforced plastics (FRP): A term used interchangeably with advanced composites

fiberglass: A glass fiber produced by spinning molten glass into long, continuous fibers; it is used as a fiber reinforcement.

fiberglass reinforcement: Fiberglass used as reinforcement in a plastic matrix.

filament: The smallest unit of a fibrous material.

filament winding: A manufacturing method in which a long, continuous fiber is wound around a mandrel to produce a structure.

fill threads: Also known as the *weft* or *woof*. These are the crosswise fibers woven at 90° to the warp fibers.

filler: Material added to the mixed resin to increase viscosity, improve appearance, and lower the density and cost.

filler ply: An additional patch to fill in a depression in the repair, or to build up an edge.

film adhesive: A resin adhesive in the form of a thin film of resin cast onto a plastic sheet. It must be kept in cold storage.

four-harness satin: A fabric weave. Also called crowfoot satin because the weaving pattern resembles the imprint of a crow's foot. In this type of weave, there is a three-by-one interlacing.

finish: A material that is applied to the fabric after it is woven to improve the bond of the fiber to the resin system.

gel coat: A coating of resin, generally pigmented, applied to the mold or part to produce a smooth finish. Considered as a nonstructural finish.

gel time: The time from initially mixing the reactants of a liquid material composition until when gelation occurs, as defined by a specific test method.

glass cloth: See *fiberglass*.

graphite: A carbonized fiber used as a reinforcement. Graphitization occurs when heating the carbon fiber to temperatures up to 5,400°F. See *carbon fiber* and *carbon/graphite fiber*.

hand lay-up: Assembling layers of reinforcement by hand. This includes both methods of a technician working in the resin and that of using a pre-preg fabric.

hardener: Used to promote or control the curing action.

harness satin: A weaving pattern producing a satin appearance. See also *eight-harness satin* and *four-harness satin*.

honeycomb: A core material resembling natural honeycomb to produce a lightweight, high-strength component.

hot bond repair: A repair made using a hot patch bonding machine to cure and monitor the curing operation. Hot bonding equipment typically includes both the heat source and the vacuum source.

hybrid: The combination of two or more types of reinforcing materials into the composite structure.

illustrated parts catalog (IPC): A required document produced by the manufacturer. It has the parts and their part numbers exploded for identification. It does not contain FAA-approved data.

impregnate: In reinforcing plastics, to saturate the reinforcement with a resin.

inclusion: A physical and mechanical discontinuity occurring in a material or part.

interlaminar shear: Shearing force that breaks the bond between two laminates where they interface.

Kevlar®: A strong, lightweight aramid fiber used as a reinforcement fiber. A DuPont trademark.

laminate: A structure made by bonding together two or more layers of material with resin. It contains no core material.

laminate ply: One fabric-resin or fiber-resin layer that is bonded to an adjacent layer.

lap joint: A joint made by placing one layer partly over another and bonding the overlapped portions.

lay-up: Reinforcing material that is placed in position in the mold.

manufacturer's maintenance manual (MMM): See *aircraft maintenance manual*.

mandrel: The forming shape used in the filament-winding process.

mat: Chopped fibers held together with a binder. When the resin matrix is applied, the binder melts. Typically used in the mold-making process with polyester resin systems.

matrix: The material that bonds fibers together and distributes the stress evenly to the fibers. Typically in advanced composites, the matrix is a resin.

metal-matrix composites (MMC): Fibers bonded together with a metal as the bonding material.

microballoons: Very small glass or phenolic spheres used as a filler.

modulus: The ratio of a stress load applied to the deformation of a material.

moisture absorption: Water vapor picked up from the air by a material. This is distinguished from water absorption, which is the gain in weight from water absorbed by immersion.

mold: The hollow form used to give shape to a laminate part while curing.

mold release agent: A lubricant used to prevent the part from sticking to the mold.

Nomex®: A nylon paper treated material that is made into a honeycomb core material. A DuPont trademark.

nondestructive testing (NDT) or nondestructive inspection (NDI): Inspecting a component for damage without permanently damaging the part.

orientation: The alignment of the fibers (0°, 45°, 90°) to the baseline set by the manufacturer for a component.

out time: The time a pre-preg is exposed to ambient temperature, namely, the total amount of time the pre-preg is out of the freezer. This can include shipping time and the time it takes to cut off a piece from the roll.

parting agent: See *mold release agent*.

parting film: A layer of thin plastic to prevent bagging materials from sticking to a part. It can be perforated to vent excess resin. It can be used instead of peel ply. It is removed after cure.

peel ply: A layer of synthetic fabric used in manufacturing to vent excess resin up into the bleeder material. It prevents bagging materials from sticking to the part, and it leaves a very finely etched surface for painting. It is removed after cure.

peel strength: The amount of strength it takes a part to resist the stress applied when peeling apart two plies.

perforated parting film or release film: A thin layer of plastic film used to prevent bagging materials from sticking to the part. The perforations allow some resin to flow through small holes in the plastic. It is used in the same way as peel ply.

phenolic resin: A thermosetting resin produced by the condensation of an aromatic alcohol with an aldehyde, namely of phenol with formaldehyde.

pin holes: Small holes caused by the mold used.

plain weave: A weaving pattern in which the warp and fill fibers alternate; that is, the repeat pattern is warp/fill/warp/fill.

ply: One layer of reinforcement in a laminate.

polyacrylonitrile (PAN): The base material used in manufacturing some types of carbon fibers.

polyester resins: A resin system that is usually used for nonstructural components or used in fabricating a mold.

polyvinyl chloride (PVC): A thermoplastic material composed of polymers of vinyl chloride. Some aircraft structures use PVC foam for the core material. The foams come in many different weights and densities.

postcure: During the curing cycle of a manufactured component, the postcure is an additional elevated temperature soak to improve the mechanical properties.

pot-life: The length of time that the resin, mixed with catalyst, is in a workable state.

preform: A preshaped fibrous reinforcement of mat or cloth formed to the desired shape on a mandrel or mock-up before being placed in a mold press.

pre-preg: Reinforcing material that is pre-impregnated with resin/catalyst mixture. The resin system is in the B-stage and requires refrigerated storage. When heated, the resins begin to flow and complete the cure when the temperature is elevated to its cure temperature for the proper amount of time.

process control record: A record of the materials and processes used in making the repair.

puckers: Local areas on pre-preg material where the material has blistered and pulled away from the separator film or release paper.

pultrusion: A manufacturing process that pulls the resin-impregnated fibers through a shaping die to form a shape. The curing process also is done while it is in the die.

puncture: A break in the skin that might or might not go through to the core material or completely through the part.

ramp and soak: A curing process in which the temperature is slowly raised at a given rate to the final cure temperature and held for a specified time. After that, the temperature is slowly lowered to room temperature. This process is typically done by using a temperature controller, which is part of hot patch bonding equipment.

reinforcement: Material used to strengthen the matrix. Fiber-reinforced plastic is an example. Fibers are used to reinforce the plastic material.

release film: A layer of plastic material that is used in the vacuum bagging process that does not allow resin to bleed through it. It does not bond to the part when the resins cure. Perforated release film allows some resin to bleed through.

resin: A type of matrix system used when mixed with a hardener or catalyst. The term *resin* is sometimes used to describe the matrix.

resin rich: An area that has an excess amount of matrix. A resin-rich laminate usually is more brittle and weighs more than laminates with the proper amount of resin.

resin ridge: A ridge of excess resin that contains only resin.

resin starved: An area that is deficient in resin. A resin-starved part does not exhibit the structural strength that a part made with the proper amount of resin has.

resin system: A mixture of resin and ingredients required for the intended processing method and final product.

resin transfer molding (RTM): A manufacturing process in which the resin/catalyst mixture is pumped into a two-sided mold where a fabric reinforcement has been placed. The part is then heated and cured.

ribbon direction: On a honeycomb core, the way the honeycomb can be separated. The direction of one continuous ribbon.

roving: A bundle of filaments that are twisted together for weaving into fabric.

S-glass: The S stands for structural fiberglass. This type of fiberglass is used for much of the structural strength in advanced composite structures. A magnesium aluminosilicate composition that is designed to provide very high-tensile strength glass filaments.

structural repair manual (SRM): A manual published by the manufacturer to cover all items not listed as minor maintenance, including instructions for structural repair, major component removal, installation, adjustment, setup, and such. It contains manufacturer-approved data for major repairs and replacement.

sandwich structure: A thick, low-density core (usually foam or honeycomb) between thin faces of high-strength material.

scarf joint: An angled joint made by cutting away material and mating the new surface with the existing angular cut.

sealant: A material applied to a joint in paste or liquid form that hardens or cures in place, forming a seal.

sealant tape: A clay-like tape that is used to form an airtight seal for vacuum bagging.

secondary structure: In aircraft and aerospace applications, a structure that is not critical to flight safety.

selvage edge: A manufactured woven edge on fabric that runs the length of the fabric or in the warp direction. It is removed for all fabrication and repair work.

separator: A permeable layer that also acts as a release film. This could be in the form of a peel ply or a porous Teflon®-coated fiberglass. Often placed between the lay-up and bleeder to facilitate the excess resin wicking into the bleeder. It is removed from the laminate after cure.

shear: An action or stress resulting from applied forces that causes or tends to cause two contiguous parts of a body to slide relative to each other.

shelf life: The time span that a product remains useful. This should be listed on the label. Temperature during storage affects the shelf life.

sizing: A treatment of a fabric or other surface with gelatinous or glutinous substances. Fabric weavers use it to lubricate threads and act as a protective shield in the weaving process.

solvent: A liquid used for dissolving and cleaning materials.

starved area: An area in a plastic part that has an insufficient amount of resin to wet out the reinforcement completely.

starved joint: An adhesive joint that has been deprived of the proper film thickness of adhesive because of insufficient adhesive spreading or from applying excessive pressure in the lamination process.

stiffness: The relationship of load and deformation. The ratio between the applied stress and resulting strain.

storage life: The time that a liquid resin, packaged adhesive, or pre-preg can be stored under specified temperature conditions and remain suitable for use. Also called shelf life. The storage life should be printed on the label.

strand: Normally, an untwisted bundle or assembly of continuous filaments used as a unit. Sometimes a single fiber or filament is called a strand.

stress: The internal resistance or change in shape and size expressed in force per unit area. A stress concentration is an area where the level of an applied stress causes a notch, void, hole, or inclusion.

stress corrosion: Preferential attack of areas under stress in a corrosive environment, where such an environment alone would not have caused corrosion.

stress crack: External or internal cracks in a plastic caused by tensile stresses less than that of its short-time mechanical strength. The stresses that cause cracking can be present internally or externally or can be combinations of these stresses.

structural adhesive: Adhesive used for transferring required loads between two cured parts. An adhesive can also be used to bond metal to a composite structure.

structural bond: A bond that joins basic load-bearing parts of an assembly. The load can be either static or dynamic.

strux: A foam-like material used to form structural sections for stiffening.

surface treatment: A material (size or finish) applied to fibrous material in the forming operation or in subsequent processes. The process used to enhance bonding capability of fiber to resin.

symmetrical laminate: A laminate in which the stacking sequence of plies below its midline is a mirror image of the stacking sequence above the midline.

tack: Stickiness of the adhesive of a pre-preg material.

tape: A term used for thin unidirectional material, which is usually no wider than 12 inches. The material might or might not be a pre-preg.

tape laying: A manufacturing process where pre-preg tapes are laid across or overlapped to build up a shape. The parts are sometimes vacuum bagged and cured. This process can be automated by using tape-laying equipment.

Tedlar®: A material used on the surface as a waterproof barrier.

telegraphing: Dimpling of the fabric into the honeycomb core.

tensile strength: The pulling stress sustained by a specimen before it fails.

thermal stress cracking: The crazing and cracking of some thermoplastic resins from overexposure to elevated temperatures.

thermocouple: A wire assembly used with a control device to sense temperature readings.

thermoplastic: A plastic material used in advanced composites as a matrix material. Heat is used in the forming operation at very high temperatures. If heated at a high temperature again, it softens and flows to form another shape.

thermoset: A plastic material used in advanced composites as a matrix material. Heat is used to form and set the part permanently. Once cured, it cannot be reformed by applying heat. Most composite structural components are made of thermoset plastics.

thixotropic: An agent used to thicken a resin system without adding weight. It makes the resin system less dense. Thixotropic agents include chopped fibers, microballoons, and fiber flox. Some agents give more strength than others do.

tool: The mold used in manufacturing a composite component.

tooling resins: Resins that are used to make molds.

toughness: A measure of the ability of a material to absorb energy.

tow: An untwisted bundle of filaments

tracer: A fiber, tow, or yarn added to woven fabric for verifying fiber alignment for distinguishing warp fibers from fill fibers.

unidirectional: A fabric, tape, or laminate with all the major fibers running in one direction, giving strength in that direction.

vacuum bagging: A means of applying atmospheric pressure to a part while curing by sealing the part in a plastic bag and removing all air.

viscosity: The resistance to fluid flow. Resins have a viscosity rating that corresponds to how thick they are.

void: An empty area in the composite laminate. The term *void* is sometimes substituted for delamination.

volatile content: The percent of volatiles that are evaporated off as a vapor from a plastic or an impregnated reinforcement.

volatiles: Materials, such as water and alcohol, in a resin formulation, that are capable of being vaporized at room temperature.

warpage: Dimensional distortion in a plastic object.

warp direction: The threads running the length of the fabric as it comes off the bolt. Parallel to the selvage edge.

warp face: The side of the fabric where the greatest number of yarns are parallel to the selvage edge.

water absorption: The ratio of the weight of water absorbed by a material to the weight of the dry material.

water break test: Spraying water on a part to be bonded to ensure that no oil or grease contamination is on the surface.

waterjet: Used primarily in the manufacturing process as a cutting tool. A very high-pressure stream of water is used to cut through the component.

weave: The manner in which a fabric is formed by interlacing yarns. It is usually assigned a style number, which is used in ordering materials for a component repair.

weft direction: Fibers that are perpendicular to the warp fibers. It is sometimes referred to as the woof or fill.

wet lay-up: A method of making a reinforced product by applying the resin system as a liquid when the reinforcement is put in place.

wet-out: The saturation of an impregnated fabric in which all areas of the fibers are filled with resin.

wire mesh: A fine wire screen used to dissipate an electrical charge from lightning or static buildup. It is used for lightning protection usually directly under the top layer of fabric.

working life: How long a liquid resin or adhesive remains usable.

woven fabric: A material constructed by interlacing yarns, fibers, or filaments to form fabric patterns.

wrinkle: A surface imperfection in laminated plastics that has a crease or fold in one or more outer sheets of the paper, fabric, or other base. Also occurs in vacuum bag molding when the bag is improperly placed, causing a crease.

X-axis: The axis or the direction of the laminate used as the 0° reference on a part.

yarn: Twisted filaments, fibers, or strands that form a continuous length suitable for use in weaving into materials.

zero bleed: A laminate fabrication procedure that does not allow loss of resin during cure.

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