Introduction To Carbon Fiber

Textbook

I-CAR®

Version 15.1

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Contents

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Introduction

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Obligations To The Customer And Liability

The Collision Repair Industry has an obligation to correctly repair the customer's vehicle. Collision repairs must be performed using:

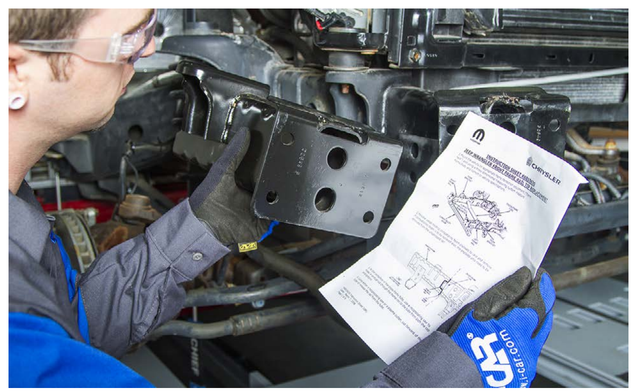
- recommended or tested procedures from vehicle makers, I-CAR, and other research and testing organizations.
- quality replacement parts and materials.
- repair processes and parts as written and agreed upon in the repair order.
- If items on the repair agreement are not consistent with the repair order, it can be considered fraud.

Performing proper collision repairs requires using parts and procedures that keep remaining warranties intact. Collision repairs must restore:

- safety.
- structural integrity.
- durability.
- performance.
- fit.
- finish.

Throughout the damage analysis and repair process the repairer and insurer must: communicate with each other.

- maintain constant communication with the customer.
- be in agreement with each other and the customer on how repairs will be performed.
- inform the customer of any changes in the repair plan from the original repair agreement, and explain the changes and why they have to be made.



To reduce liability:

- make sure that all repairs are performed thoroughly, correctly and as listed in damage report.
- follow proper procedures.
- use quality replacement parts and materials.
- have documentation of required repairs with detailed record keeping available for customers.

Technicians are considered the experts and are expected to be knowledgeable on how to perform a quality repair.

Keeping thorough records includes more than recording the date, mileage, and pre-existing damage. Record keeping also includes: making sure all notes are legible.

- verifying the repairs that were made or not made.
- having the customer sign a waiver for repairs that they do not want performed. Repairers must determine their liability on not repairing safety systems such as restraint and anti-lock brake systems.
- keeping computer printouts or worksheets on file showing wheel alignment readings or vehicle dimensions before and after repairs.
- keeping scan tool printouts and records of computer codes for airbag, anti-lock brake, emission, and powertrain control module (PCM) systems. attaching the OEM or other tested procedure printout to the vehicle repair order.
- keeping receipts for all sublet work performed.

Liability insurance that covers the repair facility may not always cover all damages. For example:

- the policy may not cover faulty repairs, leaving liability responsibility completely on the facility.
- a shop owner may find that repair facility liability coverage may not cover the full amount awarded in a lawsuit. The shop owner would have to pay the difference.

Module 1 - Carbon Fiber Now And In The Future

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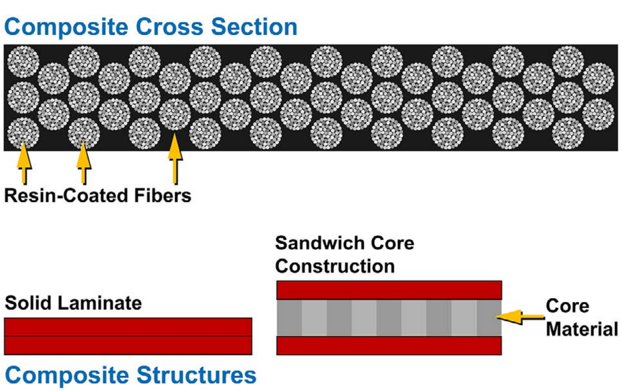
What Is Carbon Fiber?

Learning objectives for this module include:

- defining carbon fiber.
- identifying some of the different types of composites.
- describing the manufacturing process of carbon fiber parts.
- discussing some of the current vehicles that have carbon fiber parts.



Composites are made by combining fibers with a resin material.

Composites are made up of two or more dissimilar materials that become one part, usually these materials include fibers and resin. The fibers give the part its strength. Typical fibers used in composites are fiberglass, carbon fiber, and aramids. An aramid is a general term used when talking about very strong and tough fibers, which include materials like Kevlar. The resin gives the part its shape, keeps the fibers from collapsing, and protects the fibers from the environment. The resin also transfers the load between the fibers and layers and helps tie everything together.

There are two types of composites structures, solid laminate and sandwich core construction. Solid laminate construction is made by stacking layers of fabric and combining the fabric with a resin. A sandwich core construction is made by stacking multiple layers of fabric on both sides of a core material. This forms a top and bottom skin around the core material to make the part very stiff and lightweight.

These three generations of Chevrolet Corvettes all use different types of composites.

Composite materials have been used in automotive applications for years. Some examples of the composites that have been used are fiberglass, sheet molded compound (SMC), and carbon fiber.

Fiberglass was the first composite to be used for large body panels. In most cases, it was chopped fiberglass with high resin content. SMC replaced fiberglass panels in the '80s and '90s. The SMC panels were lighter, thinner, and more durable than fiberglass. Carbon fiber is replacing traditional SMC in many applications today. Carbon fiber is lighter and stronger than steel, aluminum, SMC, and fiberglass. Making carbon fiber parts is expensive and time consuming. However, new processes and techniques are driving the price down, making it more affordable.

2014 Chevrolet Corvette

Vehicle makers are using a wide variety of carbon fiber panels.

Carbon fiber, what is it really? Carbon fiber is a man made filament or fiber that has a high carbon content. The carbon content is typically between 92 - 99% carbon. Which is one of the reasons that carbon fiber has a grayish-black look. It is made into a variety of different cloths, weaves, or chopped fibers. There are also different weights and qualities of carbon fiber that can vary greatly and need to be chosen based upon the requirements of the part. The fibers are then combined with a resin material to make parts. This resin can be vinyl, vinyl-ester, epoxy, and many more types of resin.

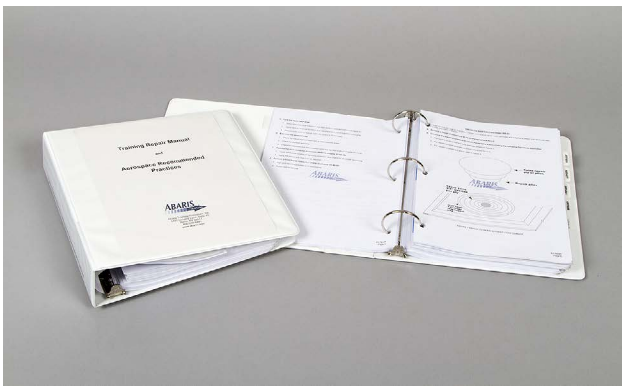
Vinyl decals can give the appearance of carbon fiber.

There are many ways to imitate the look of carbon fiber panels, which include vinyl decals, water transfer printing, and a carbon fiber cloth overlay. Decals can be identified by a seam in the decal or the appearance of a wrinkle or bubble in decal. Also, look for areas where the decal overlaps an edge. The part will be about the same weight and thickness of a normal part and, when damaged, will most likely not have any visible fibers.

Water transfer printing is somewhat more difficult to identify. It does not have the telltale signs that a vinyl decal has. In some cases, the only way to tell if it is a water transfer printing is by the weight of the part, or when damaged, the part will most likely not have any visible fibers.

When a carbon fiber cloth overlay is used, it can be difficult to see. Usually the edge of the cloth is visible or there is no carbon fiber on the underside the part. When damaged, the part will most likely not have any visible fibers except for the outermost layer.

Any of these identification methods can be used on virtually any material, including SMC, steel, aluminum, and plastic. However, the part, no matter the material that is underneath, will be about the same weight and thickness of a normal part made of that material. Also note that carbon fiber cracks and punctures when damaged, it does not bend.



Vehicle makers describe carbon fiber panels with many different names and abbreviations in the repair information.

Whenever working with composites, there are a lot of abbreviations that are used, which may be confusing at times. To help reduce that confusion, here are some of the more common abbreviations:

Fiber reinforced plastic (FRP) - This term is a general term that can be used to describe many different kinds of composites. When FRP is used, you know the part is a composite with some kind of fiber reinforcement.

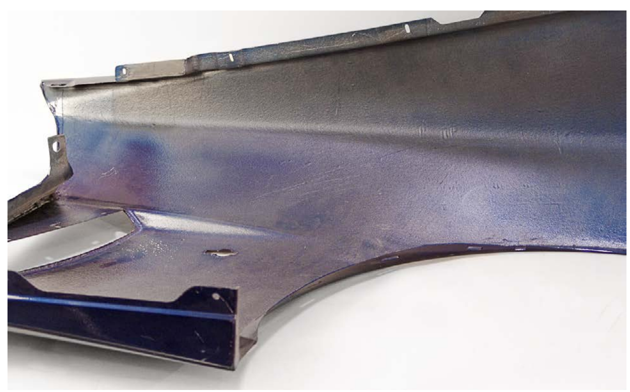
Carbon fiber reinforced plastic (CFRP) - This term calls out the type of fiber that is used, so in this case, CFRP is a more descriptive term than FRP, but they both mean basically the same thing.

Long fiber reinforced thermoplastic (LFRT) - This term refers to a kind of fiber reinforcement that is combined with a type of thermoplastic. So again, this is a type of FRP that has more information about the makeup of the part.

Continuous fiber reinforcement (CFR) - This term refers to the fibers which are in some type of weave pattern that is uninterrupted. However, it does not tell us what type of fiber or resin is used, but it is still an FRP.

Even though the different abbreviations may say something specific about the part, these terms do not tell a person enough about that part to make an informed repair decision. More information is needed.

Types Of Carbon Fiber



On the backside of chopped carbon fiber parts, the fibers can sometimes be seen.

Chopped carbon fiber comes in a wide variety of appearances, which include parts that look similar to SMC. While these parts are smooth on both sides, they are typically stronger, lighter, and thinner than traditional SMC. The main difference between the two is that a carbon fiber part uses carbon fibers for the reinforcement in the composite.

Chopped carbon fiber may look similar to a fine-fibered fiberglass. This type of carbon fiber panel will have the appearance of very fine fibers that lie in random directions. While these types of parts look similar to fiberglass, they are extremely thin, light, and strong by comparison.

These chopped fiber parts are used for structural and non-structural parts. While a chopped carbon fiber part is heavier than a woven part, the weight difference is counteracted by the fact that the chopped carbon fiber parts are less expensive to manufacture than the handmade woven parts.

These parts are often painted body panels. When painted, material identification is more difficult, without information from the vehicle maker, it may be easy to miss that a part is carbon fiber. When these types of parts are being refinished, the same steps can be used as those for traditional composites.

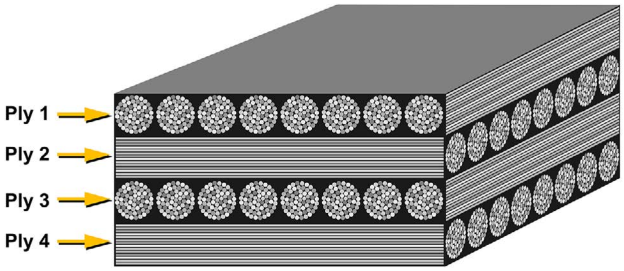
Exposed weave carbon fiber parts will have a special clearcoat or be manufactured with a clear resin. Both provide UV protection.

Woven carbon fiber parts are lighter and stronger than chopped carbon fiber parts. The way that the different weave patterns are oriented can give the part extreme strength while keeping the part very thin.

Woven carbon fiber is used for structural and non-structural parts. Woven carbon fiber is not limited to body panels. It can be used for driveshafts, suspension parts, the passenger cell, structural parts, and even engine and transmission parts.

The parts can also be made with an exposed weave. These parts are what everyone thinks of when they hear the words "carbon fiber." If the part is on the exterior of the vehicle, the part will have a special clear gelcoat or clearcoat from the vehicle maker to give it ultraviolet (UV) protection.

Manufacturing Process Overview



Each layer adds additional strength to the part.

With composites, each individual layer of cloth is referred to as a ply.

The plies are placed into position with each piece in a specific orientation to give the part the necessary strength. Carbon fibers are extremely strong in the direction that the fibers run, and weak in the perpendicular direction. By placing the plies in different orientations, the part can have different strengths in multiple directions. Ply orientations usually are 0º, 90º, 45º, and -45º. For example, depending on how the part is layered, it can have increased strength in one direction by having more fibers that run along the length of the part.

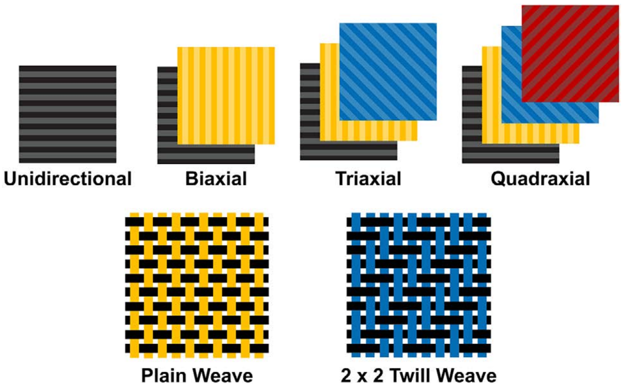
The plies can be wet or dry. Wet plies are called preimpregnated cloth, or prepreg, in which the resin is already imbedded into the ply, but not yet fully cured. While a dry ply has no resin in it, the resin is added later in the process.

Resins are manufactured for different applications, some are for an autoclave, some are for vacuum bagging, and some can be used for both.

Some common resins used when manufacturing carbon fiber parts are polyester, vinyl ester, and epoxy. Polyester resin is widely used to make both fiberglass parts and carbon fiber parts.

Vinyl ester is stronger and more environmentally resistant than polyester.

Epoxy is stronger than both polyester and vinyl ester. Epoxy resin is usually recommended for repairs because of its strength and the ability to bond to the substrate. There are many other resins available but these are three of the most common.



Each cloth has different strength characteristics and different abilities to conform to sharp curves.

There are several different kinds of cloth weave styles. With a unidirectional cloth, the fibers all run in one direction. This cloth is very strong in the direction that the fibers run, but would be weak in the direction that is perpendicular to the fibers.

Biaxial cloth has fibers that run in two directions that are often perpendicular to each other. This type of cloth is strong in two directions because the fibers run in two directions.

Triaxial cloth usually has its fibers running in the 0º, 45º, and -45º fiber orientations in their relation to each other. This type of cloth is a good choice when twisting of the part may be a concern.

Quadaxial cloth is less common, but is used when you need strength running in all directions equally across the part. The fiber orientation is usually 0º, 45º, -45º, and 90º. Cutting and layering a unidirectional cloth in four different orientations can also create this type of cloth. With all of these cloths, the fibers are simply layered on top of each other and sewn together with a stitching thread. This holds the cloth together until it is used.

With a plain weave cloth, the fibers run perpendicular to each other and are woven together. This type of cloth has a checkerboard appearance.

Twill cloth is often labeled as 2 x 2, 3 x 2, etc. In a 2 x 2 twill, the fibers usually run perpendicular to each other and go over and under each other to form a diagonal appearance on the cloth.

Dry cloth is used for both the wet-layup process and the resin infusion process.

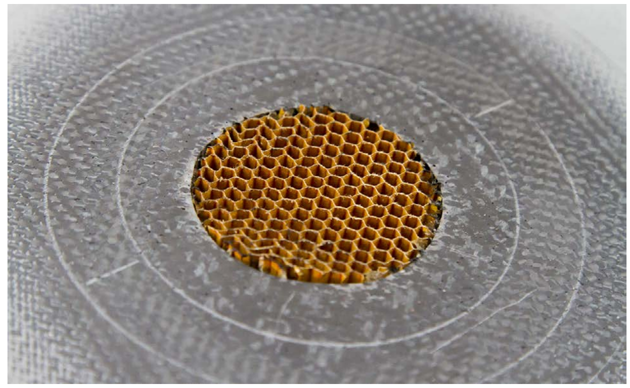
The cloth used for repairs and part construction are either dry or preimpregnated (prepreg). With the dry cloth, there is no resin on the cloth. The resin must be applied to the cloth through one of two processes, either resin infusion or wet layup.

The resin infusion process uses vacuum pressure to draw a premixed resin across the cloth from a container.

The wet layup is a process where a dry cloth has resin added to it manually with brushes or rollers. The cloth and resin are then placed under vacuum to compress the plies and draw out the excess resin. With this process, it is sometimes very difficult to achieve the correct resin-to-fiber ratio as the parts tend to be resin rich. If the part is resin rich, it would be weaker and more brittle due to the excess resin.

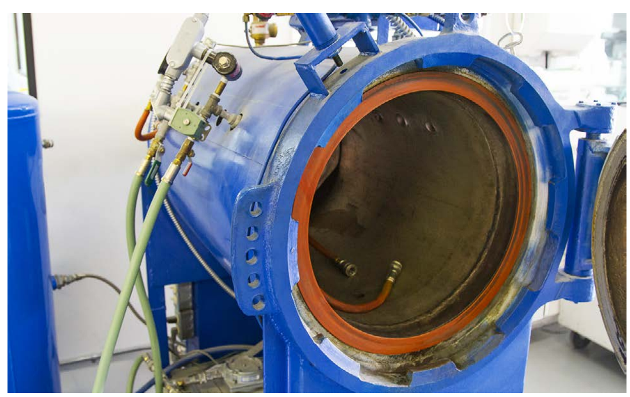
Another cloth is preimpregnated cloth, also referred to as prepreg. This type of cloth has a predetermined amount of blended resin already applied from the manufacturer. This type of cloth provides the most precise resin-to-fiber ratio, which will help to create a quality part or repair. It also can be made with almost any weave pattern.

A prepreg does have a short shelf life and is stored frozen so the resin does not start to cure before it can be used. When a prepreg is ready to be used, it must first be allowed to thaw. The prepreg should always be thawed in its sealed bag so that moisture cannot absorb into the resin. The amount of time that a prepreg has been thawed must be monitored because the shelf life will be greatly reduced.



This is replacement honeycomb core material.

Core materials can be made from a wide variety of materials. Balsa wood, honeycomb, foam, aluminum or aluminum honeycomb. During repairs if a honeycomb core is used, the direction of the cells should be noted because the replacement core material needs to have the same orientation as the original part. Core materials are used because it makes the part seven times as stiff and 3.5 times stronger when the core is twice the thickness of the composite while adding very little weight. When the core material is increased to 4 times the thickness of the composite it becomes 37 times stiffer and 9 times as strong while still adding very little weight.

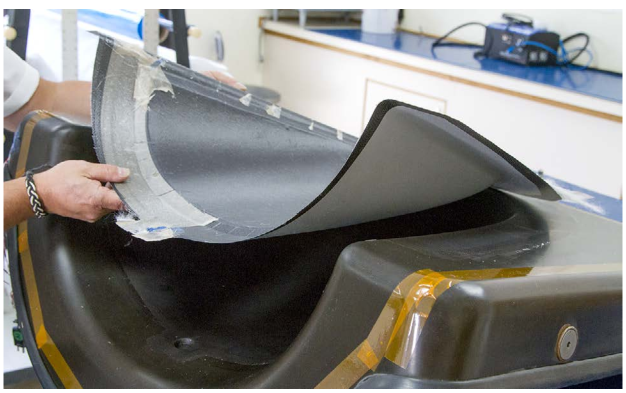


An autoclave is like a giant pressure cooker that applies both heat and pressure.

An autoclave is like a giant pressure cooker or a pressurized oven. The autoclave applies heat that is needed to cure the resin. It also applies pressure to compress the plies and draw out the excess resin and gases from the part.

Autoclaves have limitations for cycle time. The autoclave must be large enough to fit the part into it and is limited to a few parts an hour. This is a problem for high production demands.

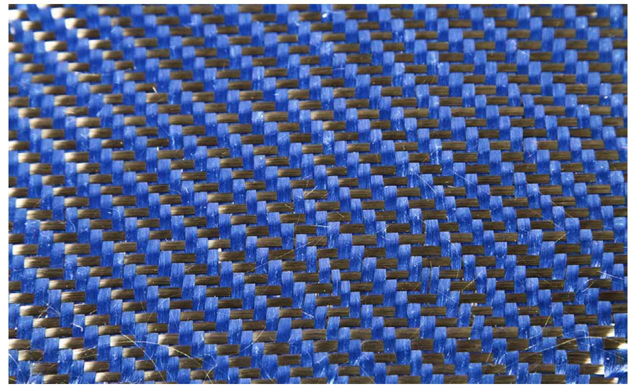
It is also labor intensive to set up. Using an autoclave requires each ply to be added one at a time by hand. This can lead to higher variations in the end product when compared to an automated process.



Molds can create a smooth exterior finish.

Molds are used to make chopped carbon fiber parts and woven carbon fiber parts. To make a chopped part, the fibers and resin are blown into the mold, then compressed and heated in an autoclave.

When making a woven part, the process is called layup. Layup's are done, either wet or dry, by placing each ply individually into a mold or a two piece die. Once complete, the part is put into an autoclave where the material is heated and pressurized.



This 2 x 2 twill cloth is half carbon fiber and half Kevlar.

Future manufacturing possibilities of carbon fiber include carbon fiber that is combined with an aramid, like Kevlar. This type of cloth already exists but is not being used currently in a production vehicle.

Other future developments include carbon fiber parts that can be put through the E-coat process. This ability for a composite to go through the E-coat process would allow the composite parts to be installed earlier in the assembly process. This will speed up assembly time and allow the composite parts to be painted at the same time as the rest of the metal parts.

Automation of the layup process would eliminate some variations and move the process into mass production.

There is a possibility of reducing the cycle times with new resins and molding techniques. Many of the resins and molding techniques used today have a relatively slow production rate. With the invention of new resins and molding techniques, manufacturers may be able to increase the rate of production.

Current Vehicles With Carbon Fiber Parts

This BMW i3 has exterior panels and a passenger cell made from carbon fiber.

BMW i3 and i8 have carbon fiber exterior panels wrapped in vinyl instead of painted. The passenger cell is made almost entirely of carbon fiber.

BMW has not released any repair procedures for the carbon fiber parts these vehicles.

The roof and underside of the hood are only repairable if the damage does not go through the clearcoat.

The 2014 Chevrolet Corvette has a carbon fiber hood, roof, floor, and fenders.

Repairable parts include the fenders and floor because they are not an exposed-weave part.

The Aventador uses carbon fiber throughout the entire vehicle.

The Lamborghini Aventador has a carbon fiber vehicle structure. The entire passenger compartment structure is made almost entirely of carbon fiber. Most of the exterior panels are also made of carbon fiber.

Repairable parts will include most of the carbon fiber parts. For repairs, Lamborghini has a team called the "flying doctors." The flying doctors will travel to where an Aventador is damaged, evaluate repair options, and if repairable, they will fix the vehicle.

The SRT viper has a painted carbon fiber roof panel.

The SRT Viper has a carbon fiber hood and liftgate that have a painted outer panel and an exposed weave inner (backside) panel. The roof is a painted carbon fiber outer panel only.

Repairable areas include the painted exterior panels. Exposed weave areas not repairable.

2015 Alfa Romeo 4C

The 2015 Alfa Romeo 4C has a carbon fiber monocoque.

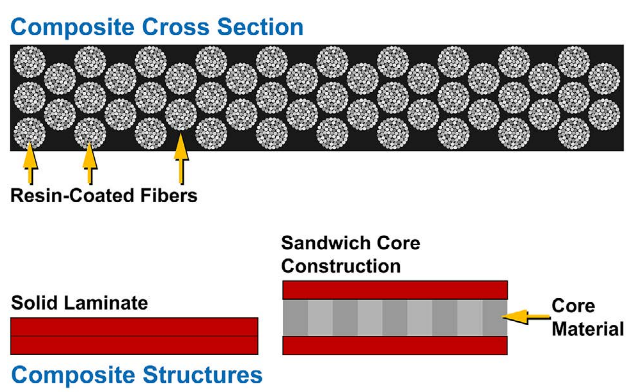
Vehicle makers may be looking to use more carbon fiber parts in different ways. The 2013 Lexus LFA has carbon fiber crush caps, but this is a limited edition vehicle that may provide a glimpse into the future.

The use of carbon fiber exterior body panels is only increasing with each year, and there are an ever-increasing amount of add-on aftermarket parts being installed.

Other areas being researched are suspension parts, structural reinforcements, and drivetrain parts. While some vehicles have these carbon fiber parts, look for their expanded use in the not-too-distant future.

Vehicle maker repair kits may soon be available that would contain all the necessary materials to complete the repair for a certain area. A kit may include items like a caul plate for a certain area or the correct carbon fiber cloth.

Module Wrap-up



Topics discussed in this module included:

- what carbon fiber is.
- some of the different types of composites.
- the manufacturing process of carbon fiber parts.
- some of the current vehicles that have carbon fiber parts.

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Module 2 - Repair

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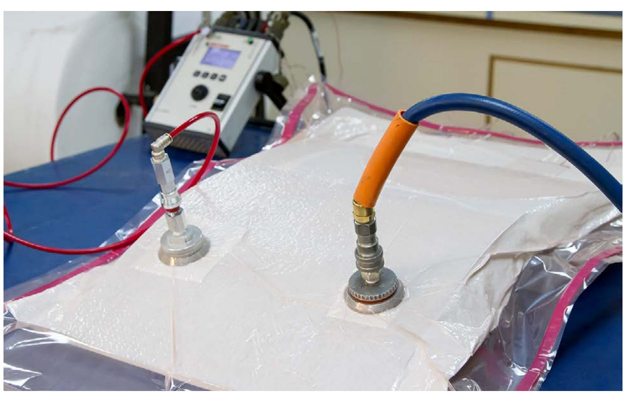
Inspection

Learning objectives for this module include:

- listing the visual inspection process.
- identifying the different inspection equipment.
- identifying the required tools and materials for the vacuum bagging process.
- listing the vacuum bagging repair process.



Vacuum bagging repairs are required to structurally repair a carbon fiber part.

There are several repair options for carbon fiber depending on damage and vehicle maker repair procedures. These include vacuum bagging, adhesive bonding, rivet bonding, and conventional composite repair.

Vacuum bagging is the main focus of this course. There are many different options and steps to this repair. With this type of repair, each of the damaged plies is removed and replaced in the area of damage. The repair is then compressed and heated to cure the repair.

Adhesive bonding is only done at a factory seam of the composite. It involves removing the damaged part, using partial replacement techniques, and adhesively bonding the seams. This type of repair is only done when there is a vehicle maker repair procedure.

Rivet bonding is usually done at a factory seam of the composite. It involves removing the damaged part and replacing the part with rivets and adhesive. This type of repair is only done when there is a vehicle maker repair procedure.

Conventional composite repair uses the same products and techniques that are used on SMC repairs. This type of repair can only be used for cosmetic applications because these products are weaker than carbon fiber and will not have the same performance standards.

Refer to "Video: Introduction of Abaris" in the presentation. This video explains what Abaris offers to the collision repair industry.

Vacuum attachments are available for grinders to help reduce the carbon fiber dust in the repair facility.

Personal Safety
Carbon fiber is extremely sharp. Wear protective gloves, especially when damaged fibers are exposed.

Carbon fiber dust is a lung and eye irritant. Wear an appropriate dust respirator and eye protection. Use a vacuum system to collect grinding dust to minimize your exposure.

Vehicle Protection
Any exposed carbon fiber can cause galvanic corrosion if it comes into contact with metal.

Carbon fiber and carbon fiber dust is conductive and can short out electrical connections on vehicles, electric tools, and wall outlets.

Disbonded

Punctured Or Cracked

Core Damaged

Vacuum bagging repairs are required to structurally repair a carbon fiber part.

When working with composites, there are several types of failures that can occur. These include delamination, disbonding, core damage, and cracking or punctures.

A delamination occurs when one ply separates from the another ply within the part. It can occur from a low-energy impact or a manufacture defect and are sometimes visible if the delamination is near the surface.

Disbonding occurs when a ply separates from a dissimilar material, like the core material.

Core damage is when the core material is damaged and can occur with any type of damage.

Cracking or punctures happen from higher energy impacts and is the easiest to visually see.

Damage on vehicles is often to a leading edge of the part. With damages that go to an edge, the repair will become more complicated. Most of the information in this course will deal with light damage in the middle of the part so that the basics of repair procedures can be taught in a clear manner.

In most cases, when damage is found, there will be two or more types of damage in one area.

Refer to "Video: Composite Damage Inspection" in the presentation. This video shows some techniques used to inspect damage on a carbon fiber part.

A visual inspection is only the first step in identifying damage.

When performing a visual inspection, a slight wave or ripple may indicate an area of damage. Scuff marks may also indicate an area of damage.

Even when the damage seams minor, the surrounding area should be inspected for hidden damage. The part may have visibly damaged fibers on the backside of the impact.

A visual inspection is limited when only one-sided access is available. Another limitation of visual inspection is when looking for delamination damage. Delamination may not have any visual indicators on the outside of the part.

Tap testing allows the technician to hear where the damage is located.

A tap hammer is effective at identifying ply delamination. The technician listens for a change in sound while tapping back and forth across the suspected damage and places a small mark just where the tone changes.

Tap hammers are limited to six plies or less in order to detect damages. This type of testing also requires information on the composition of the part to allow for an accurate inspection. Without this information, the change in tone may be indicating a change in composition and not a change from damages.

Tap hammers also cannot locate small defects. If the change in tone is too small, a defect could be missed.

Digital tap hammers are also available. In order to document the extent of damage, the technician can create a grid work, label the grid, and record the readings on a worksheet with a photo of the completed grid. With a standard tap hammer, there is not really a way to document what has changed in the part other than it sounds different.

Dye penetrant must not be used because dye penetrant can wick into exposed fibers and between individual plies. If all the affected areas were not removed, it would cause major adhesion issues and make the affected part unusable.

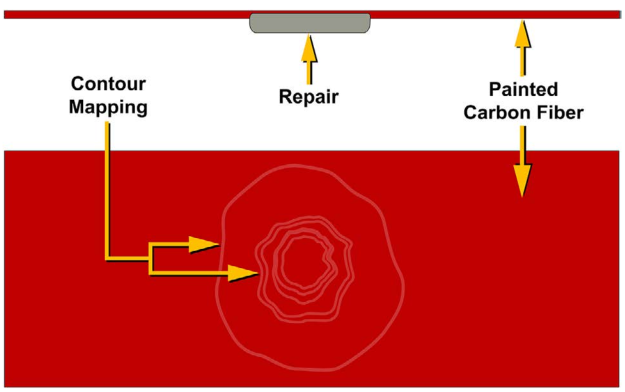
Some testers require training on how to use them and how to interpret the readings.

Thermal imaging testing equipment uses heat variations in the part to detect damage and can create an image or graphical representation of the damage. Extensive training in how to use and interpret the information produced by this equipment is required.

Resonance and ultra-sonic testers are options. These testers both use different frequency waves to detect damage and can create an image or graphical representation of the damage. Resonance testers use lower wave frequencies while ultra-sonic testers use higher wave frequencies. Extensive training in how to use and interpret the information produced by this equipment is also required.

Vacuum Bagging Repairs

Refer to "Video: Vacuum Bagging Overview" in the presentation. This video shows an overview of the vacuum bagging repair process.



Thermal expansion can cause a ghost affect that can cause the repair to be seen as it is heated and cooled.

Different types materials and material thickness expand and contract at different rates.

Carbon fiber panels by nature are very thin and carbon fiber will expand and contract at a certain rate.

Traditional repair techniques create a thick repair area that can lead to contour mapping. This is due to the difference in the expansion and contraction rate of the two materials.

Any exposed fibers can wick liquid between the plies.

Before any repairs can be started, the part must have all contaminants removed from the surface. When the part is cleaned, the damaged area is taped to cover any exposed fibers. This will prevent wicking of water and solvents into the fibers.

Next, the part is washed with soap and water. If water is trapped between the plies or in the core material, it can break apart the different layers due to freezing or heating. For example, if a part is heated by the sun, the resulting steam can force the layers apart.

Then the part is washed with a grease and wax remover. This is the only time a solvent is allowed to be used during the repair process.

Refer to "Video: Damage Removal" in the presentation. This video shows how to properly remove damage.

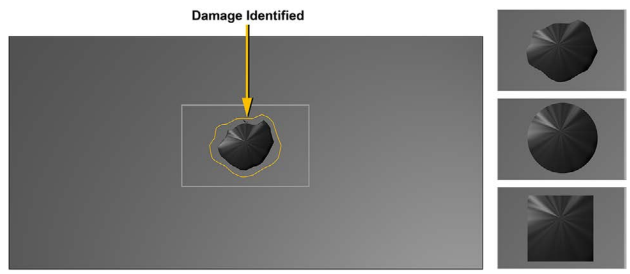
Care must be taken to ensure that all of the damage is removed.

Damage removal requires that the damaged area be cut out fully so only undamaged fibers remain. If any damaged fibers remain in the repair area, it will create a weak spot which may lead to a failure of the repair.

Make sure the part is put back into correct alignment after the damage has been removed. If the part has damage that extends to an edge or a large repair area, the part may have to be supported to hold it in correct alignment.

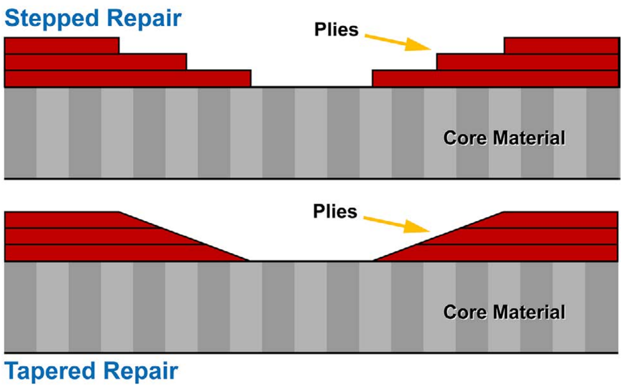
Once all damage has been removed, any corners must be rounded. If any sharp corners remain, the damage may spread out from the corner when put under load.

The damage should removed in symmetrical shape when possible. Making the area of removed damage symmetrical allows for templates to be used for a better quality repair.



Refer to Module 2, “Activity: Damage Removal” in the presentation for an activity on damage removal.

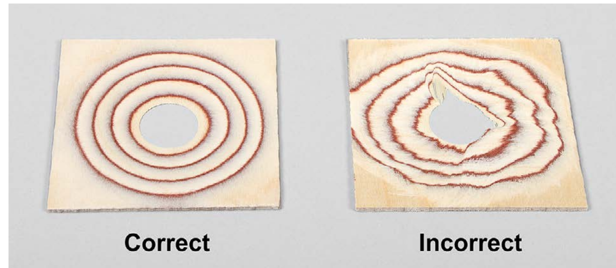
Refer to "Video: Making A Repair Taper" in the presentation. This video shows some techniques used to create a repair taper.



With a stepped repair, it may be difficult to not damage underlying plies.

A repair taper, along with the removed damage area, is used to create the final repair area. Repair taper, or scarf area, is the most common repair type and with practice, can be used to achieve a high quality repair. When making a repair taper, a grinder is used to gradually expose each ply. This allows the repair ply to link to the existing ply.

With a stepped repair taper, each ply must be cut out and separated individually, creating a stepped-like appearance. A stepped repair is best suited for a flat area, but it is extremely difficult to not damage underlying plies during the removal process, particularly on panels with a contour. Another challenge with this type of repair is that each repair ply must be cut exactly to the shape and size of the cut-out area.



A repair taper must have even ply exposure around the entire repair area.

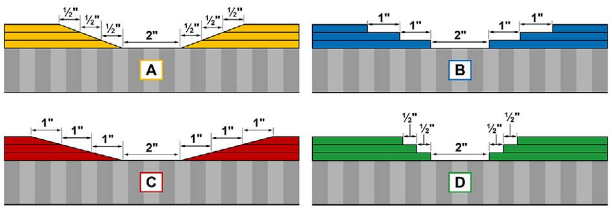
When creating a repair taper, it is important to expose each ply evenly around the entire repair area. Some damages may be an odd shape, but each ply still must be evenly exposed in order to restore the part to the proper strength.

As a best practice, about 1/2" of each ply should be exposed. This is a general rule and may be changed based on the repair specifications of the repair procedure.

When grinding, the grinder should be held relatively flat. This will help to prevent the underlying plies from being damaged by the grinder disc.

Also, avoid using a course grit grinding disc. If the grinder disc is too course, the disc could damage the underlying plies. As a general rule, the disc should be about 180 grit or finer.

It is always a good idea to practice grinding techniques before making the repair taper on the part. A good way to practice these grinding techniques is to use a piece of plywood. Place a hole in the plywood and taper each ply evenly, in the same way that the taper would be created on a carbon fiber part.



Refer to Module 2, "Activity: Repair Taper Selection" in the presentation for an activity on repair taper selection.

Extra planning is required when working with a prepreg cloth to ensure that the material is fully thawed before making repairs.

Whichever repair method is chosen, the answers to these questions must be found in order to have a quality repair.

What does the repair manual call out to be used?

If a wet layup process with dry cloth is required:

- How will the correct resin-to-fiber balance be achieved?
- What is the work time of the resin?
- At what temperature will the resin need to be cured?

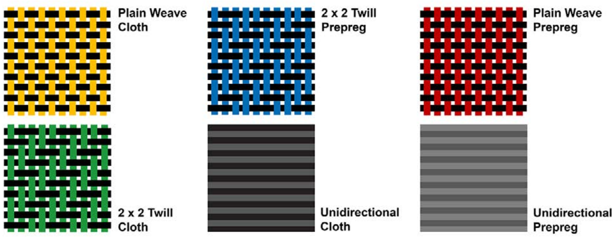
If prepreg cloth is required:
- How long will it take to get the prepreg?
- How much will be needed?
- How long can it be out of the freezer?
- At what temperature will the prepreg need to be cured?

Wet-layup resins typically have less work time than prepreg cloth.

When selecting resin, epoxy resins are usually recommended for repairs. This type of resin will provide the best adhesion and durability for the repair. If the repair manual calls out a specific resin, that is the type of resin that should be used.

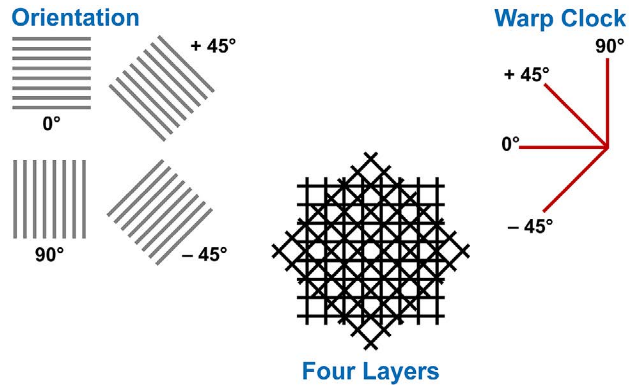
As a best practice, resins with a longer work time should be used for larger areas. Having a longer work time allows for the extra time that is needed to set up all the material for the vacuum bagging process.

Low viscosity resin is used for wet-layup repairs. These low viscosity resins allow the resin to flow into the cloth and coat all the fibers of the cloth. This also will aid in the process of removing the excess resin from the repair area.



Refer to Module 2, “Activity: Cloth Selection” in the presentation for an activity on cloth selection.

Refer to "Video: Ply Orientation" in the presentation. This video shows the importance of ply orientation.



The warp clock is used to callout the orientation of each ply.

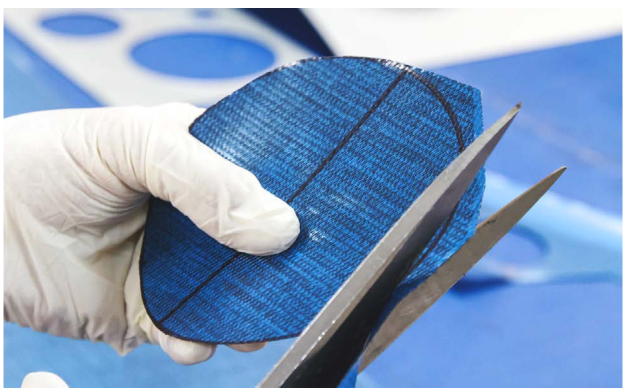
Understanding ply orientation is critical when making repairs. Warp fibers run the length of the role of cloth. A thread called selvage is stitched into the cloth and is used to prevent the cloth from unraveling. Selvage runs parallel to the warp direction and can be used to help identify the warp direction.

During repairs, the warp fibers are used to identify the ply orientations on a warp clock. The warp clock identifies if the warp direction of the repair ply should be 0°, 45°, 90°, or -45° orientation.

The fibers than run in the opposite direction are called fill fibers and run across the role of cloth.

It is critical that the repair plies match the orientation of the ply that is being repaired. If the repair does not have the correct fiber balance and symmetry, it can lead to the repair being preloaded with stress and can actually make the repair curl up. Whatever type of cloth was used in the damaged area is what should be replaced during repairs. This way the load path is able to transfer through each ply and does not have to take a different path through the repair.

To illustrate the importance of matching repair plies with the existing structure, imagine that the fibers were electrical wiring that is being repaired. Would you repair a damaged wire by twisting the two damaged wires together and then taping two replacement wires to the outside of the harness? Of course not. The wires would still be broken and there would not be a continuous path. It is the same thing in composites. If you simply bond a ply to the structure, you have not fix the problem because it will no longer function as designed.



Make sure to cut each repair ply carefully to allow for a good interface of the ply.

As a best practice, a piece of plastic film should be used to trace each repair ply because there is no backing material on a dry cloth.

Also, make sure to mark the warp direction on the backing. This will allow for proper ply orientation with the part. If this is not done, it will be difficult to align the repair ply correctly.

The repair ply must be cut to the correct size so that it can interface with each layer of the repair taper as closely as possible. If there are any layers that are too wide, it will interfere with how the load is transferred through the part and will lead to a poor repair.

Refer to "Video: Repair Ply Placement" in the presentation. This video shows some proper repair ply placement.

Film adhesive is recommended to be used for prepreg repairs.

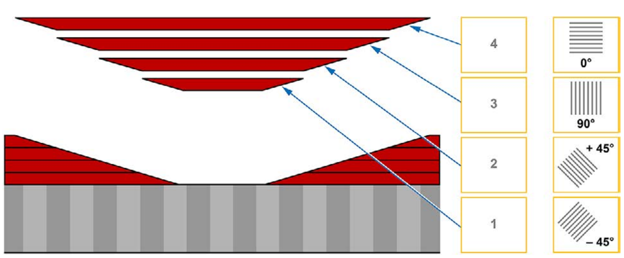
Film adhesive is used to co-bond when one surface is already cured and one surface is uncured. This is done to act as a bond interface between the two dissimilar surfaces. Usually film adhesive is used with prepreg cloth repairs and acts like an additional layer of resin. On wet-layup repairs, a brush coat of resin is used instead to act as a bond interface. The adhesive film is used to adhesively bond the repair plies allowing the prepreg resin to bond with the repair area and the adhesive film.

Mark each ply spacing for easy identification. This is done by placing a dot on the film adhesive where each ply begins and ends, creating a target area for accurate placement of each repair ply.

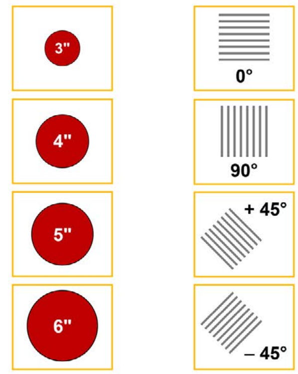
This thin layer that aids in the adhesion of the repair plies requires frozen storage. Keeping the film adhesive frozen is similar to what must be done for prepreg. Before it can be used, it must be thawed. The time it has been out of the freezer must be tracked.

Film adhesive can also be used for bonding core materials. The film adhesive that is used for this application was originally designed for bonding the honeycomb core material.

Most film adhesives will require an elevated cure temperature in order to work as intended.



Refer to Module 2, “Activity: Ply Orientation” in the presentation for an activity on ply orientation.



Refer to Module 2, “Activity: Ply Layering” in the presentation for an activity on ply layering.

Peel ply and release film are materials that will not fuse with the repair resin.

The first layer in the bagging schedule is the peel ply or release film. The materials used for a peel ply can be porous or nonporous.

The peel ply does not become part of final repair, it will not adhere to the resin. If the other layers of the bagging schedule were to come into contact with the repair, the other layers would fuse with the repair causing the repair to fail.

Some peel plies may have a release agent applied. In those cases, special care must be taken if the part will be painted. This ensures proper adhesion of any finish material. If the repaired surface will be bonded to another structure, a peel ply with release agent should not be used.

When the peel ply is porous, it can leave a texture on the repair that can aid in the adhesion of finish coatings.

Porosity of the peel ply can restrict or prevent resin flow. A porous peel ply will restrict the resin flow while a non-porous peel ply will prevent the resin flow. This will force the excess resin to flow toward the edge of the nonporous peel ply. The peel ply should also be slightly larger than the repair area.

Bleeder cloth can be made from a wide variety of materials.

A bleeder cloth creates a path for resin and gas to be removed from the repair area. This layer helps draw out air bubbles from the repair material to reduce porosity in the final repair. At the same time, it is absorbing the excess resin.

The texture of the bleeder cloth can transfer into repair. Therefore, if a smooth finish is required, a flat cloth should be used.

It must also be larger than the repair area and should be larger than the separator layer. This will allow a path for the excess resin to be absorbed into the bleeder layer without any hard edges on the repair.

Enough layers to absorb the excess resin are also required. If the repair is resin rich and saturates the bleeder cloth, it can create a condition called hydraulicing. In this case, instead of vacuum pressure being applied, now hydraulic pressure is being applied, which can damage the part, the repair, and the vacuum bagging equipment.

A separator is plastic film with or without holes.

A separator film is placed between the bleeder and breather layer.

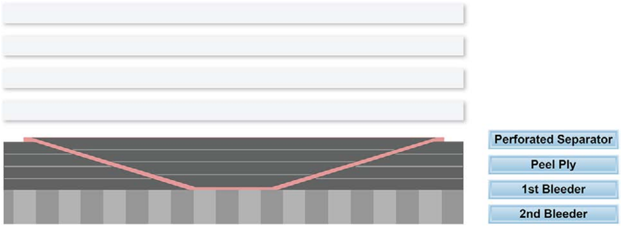
It is cut to be slightly smaller than bleeder and breather cloth. This allows a gas path to the vacuum pump.

The film can be solid or perforated. A solid separator is used to prevent resin flow into the next layer. In this case, instead of traveling through the separator, the resin and gas must travel to the edge in order to escape. A perforated separator acts as filter between multiple bleeder layers and restricts the resin flow, but allows the resin and gases to move through it.

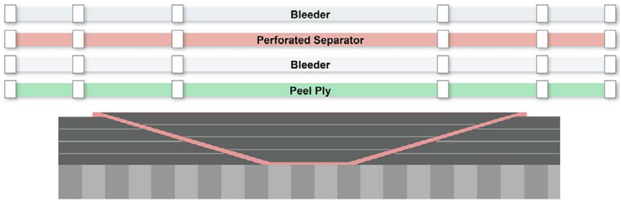
A breather cloth should cover nearly the entire vacuum bagging surface area.

The breather cloth allows continuous vacuum pressure to be applied and provides a path to remove excess gas. If the breather cloth is missing in an area, it may create an area that would not be brought to the correct vacuum pressure. This can lead to the repair not being compressed adequately, leaving high spots or trapped gasses in the repair.

This layer must be larger than the repair and cover the previous layers of the bagging schedule. This will prevent excess gasses from being trapped in a pocket of the bagging material. The breather layer should also make contact with the edges of the bleeder cloth at the edge of the separator layer.



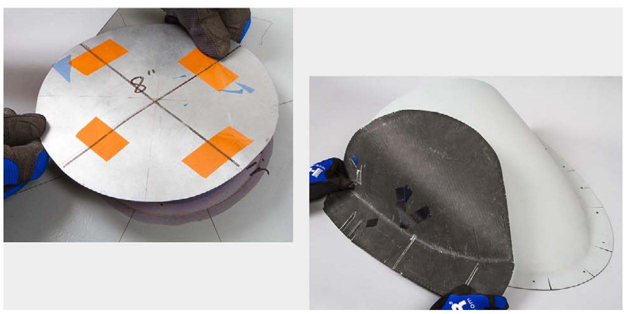
Refer to Module 2, “Activity: Bagging Schedule Order” in the presentation for an activity on bagging schedule order.



Refer to Module 2, “Activity: Bagging Schedule Size” in the presentation for an activity on bagging schedule size.

Refer to "Video: Curing Methods Part 1" in the presentation. This video shows a method of curing the repair.

Refer to "Video: Curing Methods Part 2" in the presentation. This video shows a method of curing the repair.



Caul plates help compress the repair so that when complete, the repair is almost perfectly flat.

A caul plate compresses the repair plies evenly. Repairs can be made without a caul plate, but the repair may have bumps and ridges because the repair material was not fully compressed.

The heat source may be prone to creating hot spots in the repair area. The caul plate can help distribute the heat across the repair instead of concentrating it in one area. This is especially true with aluminum caul plates.

An aluminum caul plate is usually used in areas that are flat or have a slight curve. Aluminum can be used to repair a more complex shape, but these are more difficult and expensive to create.

A composite caul plate, also called repair tooling, can be created to repair flat or complex areas. The existing part can be used to create a caul plate, but temporary repairs will have to be made first. Another option would be to use a part from the other side of the vehicle to create a composite caul plate.

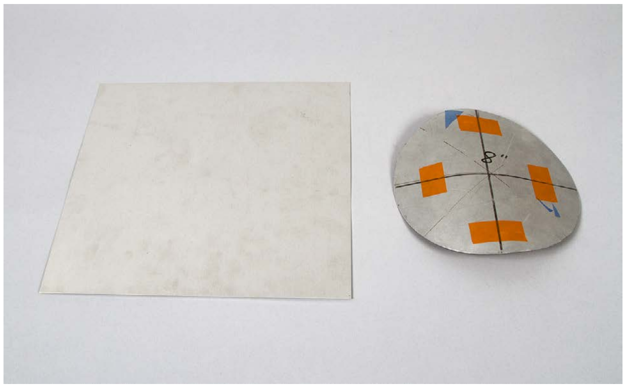
When sanding the temporary filler, care should be taken to not sand into the undamaged area of the part.

To make a caul plate for a damaged part, the part must first be realigned. A repair taper is not needed at this point, it will be created after the filler is removed.

Once the part is back into alignment, remove any high spots before filler application. The damaged area must be ground down below the surface, but take care not to grind too far into the material as this could cause additional damage.

The filler can be a glaze or regular body filler, no special filler is required because the filler will only be there until the caul plate is complete.

The filler is then sanded to contour. This will create a surface that is the correct shape and contour to create an accurate repair tool.



An aluminum caul plate works best if the repair area is flat or has a slight curve.

When making an aluminum caul plate, use 1000-series aluminum. This series aluminum is used because it is very soft and formable, which works well when making a plate for flat or slightly curved areas.

The caul plate should be larger than repair area. If the caul plate was made the same size as the repair, it may not adequately cover the entire repair. A best practice is to make the caul plate at least 25 mm (1") larger than the repair.

Bend the aluminum to conform to part contours. When bending to shape, do not exert too much pressure on the part or the temporary filler. This could damage both.

A composite caul plate must be strong enough to compress the repair plies.

Making a composite caul plate is like vacuum bagging to make a new part. A non-porous peel ply must be laid down first. This is to prevent the caul plate plies from sticking to the part.

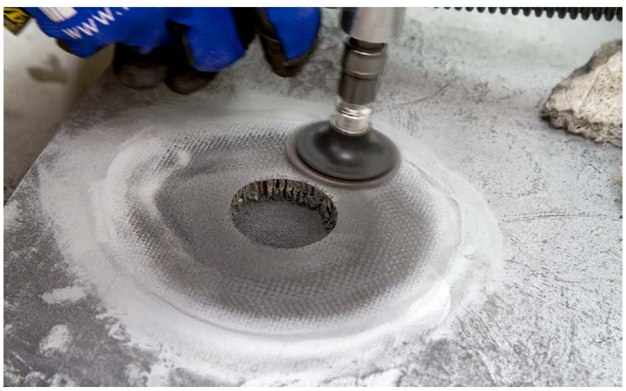
The number of plies vary. The caul plate needs to be made with enough layers to make it strong enough to withstand handling it and the pressure applied by vacuum bagging.

The cloth material used to create the composite caul plate can be the same or different from what will be used for the repair. This eliminates the need to have extra products and material on hand. However, carbon fiber can be more expensive than a fiberglass cloth for example. If a fiberglass cloth is used, the same resin that is used for carbon fiber cloth can be used with a fiberglass cloth. The strength of fiberglass is less than that of carbon fiber, but this caul plate may only be used on this specific repair.

A best practice is to make the caul plate at least one inch larger than the repair.

If the caul plate was made the same size as the repair, it may not adequately cover the entire repair. With the caul plate plies cut to size, a two-part resin is applied, unless a prepreg cloth is used for this application. Then the plies are laid onto the peel ply that is already on the damaged part.

Once the caul plate plies are in position, a bagging schedule is put in place and cured at the appropriate temperature.



After the filler is removed, the repair taper can then be created.

The temporary filler is removed after the caul plate is completed. Caution should be used when removing the filler to avoid damaging the plies of the part. The goal is to only remove the temporary filler.

Next, a final repair taper is created to allow the correct interface for the repair plies.

Repair materials are then prepared and cured using the new caul plate and a bagging schedule is put in place to complete the repair.

Hot-bonders can be programmed with different cure cycles.

A hot-bonder controls heating equipment output. The hot-bonders can control many different types of heat sources.

It also reads sensors called thermocouples. These sensors send a signal to the hot-bonder, which translates the readings. It then turns the power source on and off to control the temperature of the repair.

Hot-bonders usually have programmable heat cycles. This allows the cure cycles to be programmed depending on the resin cure requirements. Then, the technician simply has to choose that specific program whenever that resin is used.

They may also provide a record of the cure cycle. This is important for documentation of the repair when the repair resin has a specific cure cycle that must be followed.

Depending on the model, the hot-bonder may be able to control multiple heat sources at the same time. These hot bonders are typically used on large areas that require multiple heat sources.

There also may be a built-in vacuum pump. These internal pumps are usually found on larger equipment that can control multiple areas.

Flash tape must have a higher temperature rating than the highest cure cycle temperature.

Flash tape is used to hold the various layers of the bagging schedule in place until vacuum pressure has been applied.

This type of tape has different temperature ratings. When choosing the proper flash tape, it needs to have a higher temperature rating than the highest cure cycle temperature.

This is a thermocouple.

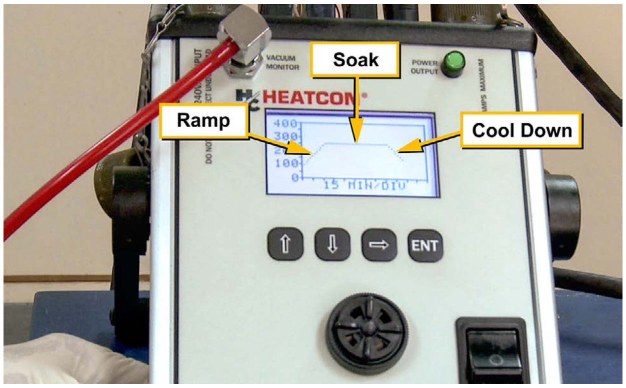
Thermocouples are sensors that monitor heat level during curing. This is critical for some resins to cure correctly.

These sensors are ONLY placed on top of the caul plate. If thermocouples are placed under the caul plate, they will leave dimples in the repair once vacuum is applied. If no caul plate will be used, then the thermocouple must be placed outside of the repair area to prevent dimples in the final repair.

Flash tape is put under the thermocouples to prevent them from making contact with conductive surface. This can lead to false readings. Flash tape is put over the thermocouple to hold it in place. This also keeps it free of resin that may make contact with it during the vacuum bagging process.

The more thermocouples that can be used in a repair area, the better. Thermocouple failures during a heat cycle are common and replacement during the vacuum bagging process is nearly impossible.

They also must be wired with the correct polarity. If they are wired in reverse polarity, the hot-bonder may read that the temperature of the repair is going down. The hot-bonder would then increase the heat output and may create a situation that could start the part on fire.



The different stages of the heating cycle may be displayed graphically depending on the hot-bonder.

Resins may be a room temperature cure, which means that once mixed, a chemical reaction takes place and cures the resin. This type of resin is typically used for the wet layup process. With this type of resin, there is a narrow window of work time to complete the repairs. It may also be difficult to achieve the correct resin-to-fiber ratio. With the wet layup process, the repair typically will be resin rich. Some resins that are room temperature cure will require post-cure heating to fully cure. A common cure temperature for these resins is 150 - 200°F.

There also resins that may require an elevated cure. The cure temperatures can vary and depends on the repair material instructions. The temperatures can be from 150 - 700°F.

An elevated cure resin may also require three different stages of heating. The ramp stage is the amount of time required for the repair to reach a certain temperature. For example, the resin may require that the part reach 350°F, but it should be done slowly over an hour. The soak stage is the amount of time that the repair should be kept at that maximum elevated temperature. The cool down stage is the amount of time the repair is required to cool down to a certain temperature. For example, a part that was in the soak stage of heating at 350°F would now need to cool down to 100°F over two hours.

The heat source should be selected based upon the repair situation.

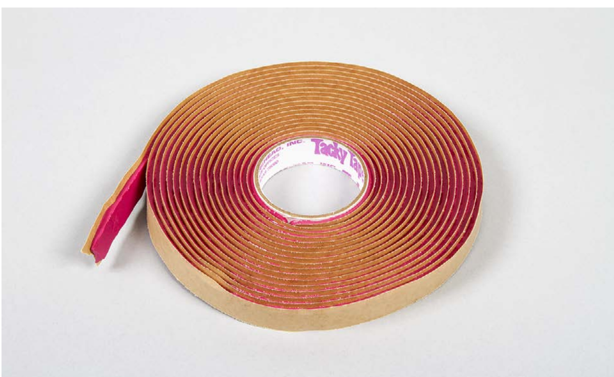
There are a wide variety of heat sources to cure resins. Heating blankets come in various sizes and shapes and offer the best heat control and distribution of curing temperature. The heating blankets can be wrapped around bends, but sharp corners or complex shapes can be difficult to apply even heat. Heating blankets should also be four inches bigger than the repair to allow for the two inch cool area at the edge of the heating blanket.

Infrared heat lamps can also be used. These are the same infrared lamps that are found in collision repair facilities today. The infrared heat lamps work well in slightly larger repair areas or areas with multiple contours.

Another heat source is a hot-air machine, which is basically a larger version of a heat gun. This type of heat source can require additional setup and materials. However, this is great way to heat a complex shape that heating blankets or infrared lamps would not be able to heat evenly.

All of the heat sources should be controlled by a hot-bonder. If a hot bonder is not used, it can be very difficult to heat the repair to the correct temperature for the correct amount of time.

Always layer the bleeder and breather cloth evenly across the heating area. If there is an additional thickness of cloth in one area over another, it may lead to uneven heating of the repair.

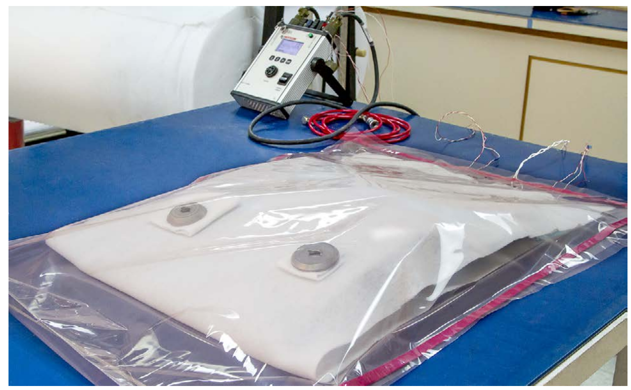


Sealing tape is able to create an airtight seal.

Sealing tape is used to seal the bagging material to the part being repaired or to seal the bagging material to itself in the case of an envelope bag. It is also sometimes referred to as mastic tape.

Each sealing tape will have a different temperature rating that will determine which one to choose. An important note is that this tape may look similar to butyl tape, but it is not the same thing. Butyl tape is not rated for the heat or pressure of the vacuum bagging process.

The sealing tape often comes in different colors, and depending on the supplier of the sealant tape, the color may indicate the temperature rating of the tape, but this varies between product makers.



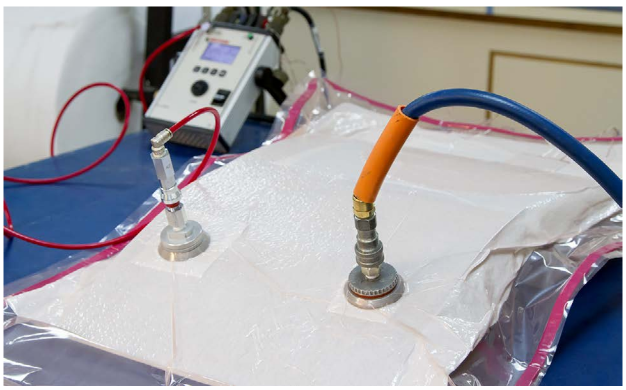
The bagging material should be selected based on the repair situation.

There are a variety of bagging materials, there are different thicknesses, elongation ratings, and temperature ratings. A thicker bagging material may be difficult to conform to sharp bends. While thinner bagging material may not have enough strength for a particular bagging schedule which could lead to leaks. So the thickness of the bagging material will vary based upon the application.

Elongation ratings refers to the amount the bagging material will stretch. Depending on the application a bagging material that stretches too much may not compress the repair material as well.

The temperature rating of the bagging material is extremely important. If a cure temperature is higher than the bagging material temperature rating, the bagging material will melt which would cause the repair to be ruined.

There are also different types of bagging material that include Nylon, Kapton, urethane, and PVA (poly-vinyl alcohol).

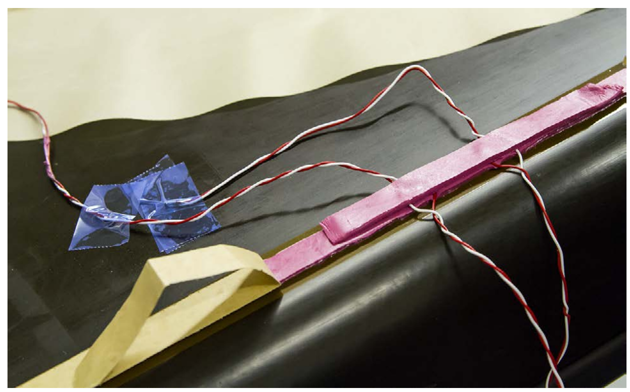


The vacuum port base plate must be placed under the bagging material before it is sealed.

Vacuum ports allow for airtight attachment of vacuum lines. The vacuum port is made of two halves, a base plate and a top plate. The base plate is placed under the bagging material and the top plate is installed through the outside of the bagging material. The top plate will also have a quick disconnect so that the vacuum lines and gauges can be quickly disconnected without loss of vacuum. The fittings that are used for this can be the same as the ones used for standard air tools.

As a best practice, two vacuum ports minimum should be installed. One vacuum port is used for the vacuum line and the other is for a vacuum gauge or a vacuum monitor for the hot-bonder. For larger areas, more ports may be necessary to allow additional vacuum lines to be attached.

The base plates should always be placed on the breather cloth away from the repair area. The two ports should be installed at the opposite side from each other and as far away from each other as possible. Vacuum ports should never be directly over the repair area because the vacuum port may imprint the repair and resin could be drawn into the pump.



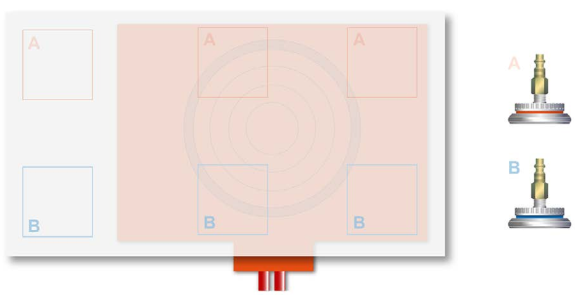
The sealing tape must completely seal around the thermocouple wires to maintain vacuum pressure.

When applying vacuum bagging materials, pleats are required, especially when a part has sharp contours or curves. The pleats are extra bagging material that is used to allow the bagging material to compress evenly on the entire surface of the part. If there is not enough bagging material available, it can lead to bridging of the resin on the part contours.

Sealing tape is positioned around the perimeter of where the bagging material will be placed. This area is larger than just the repair area and it must allow enough space for the vacuum lines.

The bagging material is then applied. Extra care should be taken to seal the vacuum bagging material to the sealing tape. A little extra time at this step will save time and prevent leaks when the repair is vacuumed. Make sure that the thermocouple wires are fully sealed in sealing tape. Also, be sure that the vacuum port base plates are underneath the bagging material before the bagging material is sealed.

The vacuum port top plate is installed to complete the installation of the vacuum port. To install the vacuum port, cut two small slits into the bagging material over the base plate opening. Insert the top plate and lock into place. There is now an airtight seal.



Refer to Module 2, "Activity:Vacuum Port Placement" in the presentation for an activity on vacuum port placement.

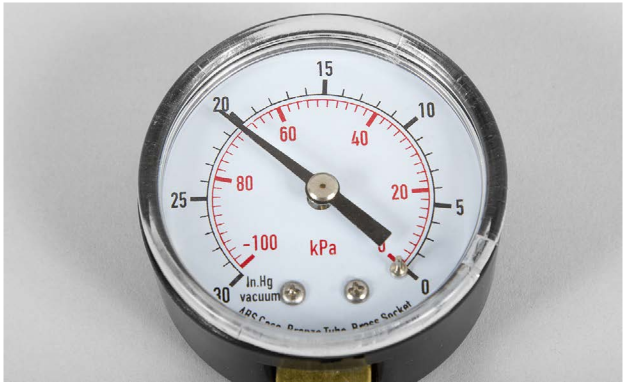
The size and type of pumps that are required is dependent on the size of the repair.

The vacuum pump should be able to pull 20 inches of mercury (in Hg).

There are a few different types of pumps. The venturi-style pump needs a compressed air source to operate. The pump converts air pressure to vacuum pressure.

There are also external electric pumps. These work like A/C vacuum pumps used in automotive refrigerant equipment.

The vacuum pump can also be built into the hot-bonder. Many of the hot-bonders will have a built-in venturi style pump, but they could be equipped with an internal electric pump instead.



If vacuum pressure can be maintained for 2 - 5 minutes, then the seal of the vacuum bag is good.

To start the vacuum bagging process pull down vacuum on the part. Once full vacuum has been achieved disconnect the vacuum hoses, and watch gauge for 2 - 5 minutes. Checking for leaks is critical for a quality repair.

If vacuum holds the seal on the bag is good. When the seal has been held for 2 - 5 minutes it is unlikely that the bagging material will develop a leak after this amount of time.

If the vacuum gauge goes down there is a leak. If there is a leak that is not found it can have several negative affects. First the vacuum pump may have to work much harder than is necessary which can lead to the pump burning out. The repair may also not be able to reach the correct pressure to compress the repair. Depending on where the leak is located it could also cause porosity in the repair.

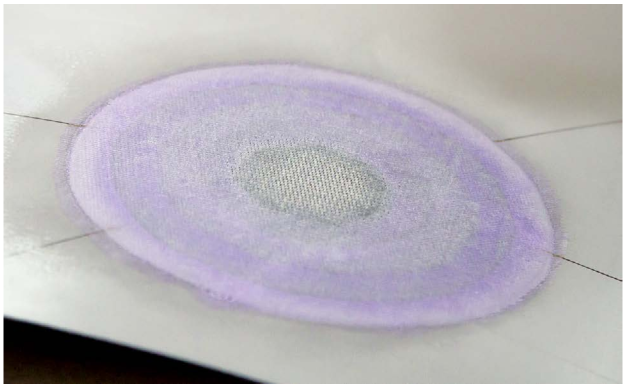
To find a leak there are a couple of methods, the first is to listen for the leak. This method while low tech can be a valuable way to detect the leak. When the leak is found just because the sound has stopped does not mean that there is not another leak. So after stopping the sound of the leak reattach the vacuum lines and retest for another 2 - 5 minutes to verify that all leaks have been found.

Ultrasonic leak detectors are another option, it is a device that amplifies ultrasonic frequencies while filtering out background noises. These devices are the same as the ones used for finding a wind noise on vehicles.

When removing bagging material after curing, avoid cutting the thermocouple wires.

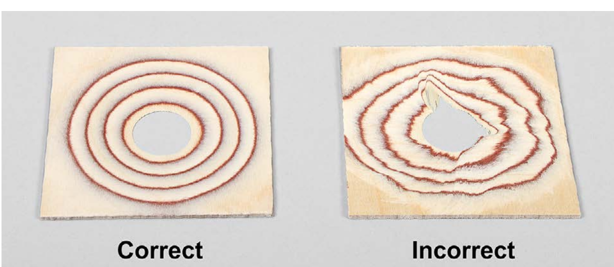
After the part has fully cured, remove all bagging materials. Make sure to carefully cut around the thermocouples so they are not damaged.

The repair should be almost flush with the surrounding area, especially if a caul pate was used.



Sanding is not recommended because it can damage the fibers and weaken the repair.

If refinishing is required, scuff the repair area lightly with a scuff pad. No grinding or sanding should be done at this time because it could damage the fibers and ruin the repair. If the correct peel ply was used, it can leave a texture that will aid adhesion of a primer filler. The primer filler, when cured, can be sanded. Careful sanding of the primer filler is required. If there is any cut through of the primer, sanding should be stopped and primer reapplied.



Practice on a piece of plywood until even ply exposure is achieved.

Try some of the techniques discussed in this course. Make a repair taper on a piece of ply wood, get some carbon fiber or fiberglass cloth with some room temperature cure resin, and make a part.

To start, make a flat sheet part with four layers of cloth. Add the resin onto each layer and place it into a vacuum bag. Place peel plies on the top and bottom layers and place the remaining bagging schedule over the top ply. Make sure to keep track of the order and orientation of each ply when making the part.

Once the part has cured, put a gouge or puncture into the middle of the part. Remove the damaged fibers and make a repair taper. After the repair taper is complete, inspect the part and see if you can identify the ply orientation of each ply and compare to the notes that were taken earlier. Repair the damage on the part. Once repairs are completed on the flat part, repeat the process on a more complex part.

Module Wrap-Up

Topics discussed in this module included:

- the visual inspection process.
- different inspection equipment.
- the vacuum bagging repair process.
- the required tools and materials for the vacuum bagging process.

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