Fiberglass & Epoxy Basics

Fiberlay©

WELCOME

Let me welcome you to the Fiberlay Course.

We will discuss safety precautions and equipment, various resins and materials, and of course, your projects.
If downloaded, this manual is arranged with plenty of space,

...FOR NOTES...

Try to print instead of writing.
Printing forces you to slow down and helps your mind retain facts longer.

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SAFETY

	SAFETY **SAFETY** **SAFETY** **SAFETY**
Potential Hazards	Good!!! It's a safe bet we have your attention. Fiberglass and Epoxy materials present a potential health and safety hazard if used improperly.
	Let's look at a few safety considerations: fumes MEKP gloves eyes
Fumes	**Polyester** (fiberglassing) resins all have a distinct smell; That smell is the **Styrene Monomer** in them. Acetone, MEK, many solvents, and gasoline all have distinct smells too, and those odors should warn you that: 1. These liquids are probably *flammable* 2. you shouldn't *breathe* very much of them
	When working with materials that give off potentially hazardous or flammable fumes it's important to protect yourself, and work in a **well-ventilated** space.
Organic Vapor Respirator	Your first line of protection is a respirator; specifically an *Organic Vapor Respirator*. This is a rubberized face mask with replaceable cartridges that absorb organic vapors.
Proper Storage	Always store your respirator in a sealed plastic bag, two are even better. Remember, the cartridges will continue to absorb organic vapors (everything around you) if they aren't stored properly, and will not last very long.
Valves	Pay close attention to the valves inside the mask. If they are damaged, vapors will leak around them and into your nose.
Testing	You can use organic oils (lemon, orange, clover) from the grocery store to test the valves and the proper seal of your respirator.
	Don't smoke or have open flames around flammables

SAFETY

M.E.K.P.	MEKP stands for Methyl Ethyl Ketone Peroxide. MEKP is the catalyst for most polyester and vinyl ester resins. This is some nasty stuff. If you get it on your skin it will give you a chemical burn. If you get it in your eyes it can blind you! TREAT MEKP WITH RESPECT AND CAUTION Also, don't confuse MEKP with MEK. MEK is a solvent. The two look the same but smell differently.
Gloves	**Wear Gloves** Some people are very sensitive to chemicals; but most of us will become so if exposed enough. Epoxies are especially damaging to skin; and once you become sensitized to epoxies, you won't work with them again.
Latex Nitrile	Latex gloves are a cheap and simple solution. For those who are hypo-allergic to latex, nitrile gloves are the choice.
Vinyl	Avoid the clear vinyl gloves used in food handling. They go away rapidly when styrene or acetone touches them. You could wear the monster solvent gloves; but they are hard to manipulate objects with.
EYES	**Protect Your Eyes** That may sound like an obvious statement; but many people are blinded by chemicals (MEKP), or flying objects from a grinder.
Safety Glasses	Wear safety glasses; they are made of impact-resistant material and have side shields to protect your eyes. DO NOT wear regular glasses; they can shatter and become imbedded in your eye. Safety is an attitude as well as equipment!

SAFETY

A few final thoughts and we'll move on.

Safety is an attitude, a way of doing things.
Safety is a way of looking at any job or situation, then recognizing potential dangers, and avoiding or preventing them.

It doesn't matter how experienced or skilled you are, machinery and chemicals don't know or care.

We at Fiberlay care very much about you and your safety. Throughout this text, safety will be mentioned many more times.

If you have any questions about Fiberlay products, their safe handling, or usage, please email your questions to sales@fiberlay.com.

Polyester Resins

	Polyesters are commonly used in boatbuilding, storage tank construction, hobby projects, and many other products. They are inexpensive to buy, easy to use, and have predictable characteristics.
Styrene	Most polyester resins have a distinct smell caused by the styrene monomer added to dilute the very thick base resin. The smell is quite strong and can overcome a person in a short time, so…
Respirator	**Use an Organic Vapor Respirator, and ventilate your work space when using Polyester Resins**
	Polyesters are called "thermosetting" plastic resins because heat causes them to set up and cure. Actually, they will set up and cure all by themselves if left in the can for 3 to 18 months, depending on the type of resin;
	BUT
MEKP	Most projects have to proceed at a faster pace, so we add a catalyst to the resin to obtain a much shorter set and cure time. The most common catalyst is Methyl Ethyl Ketone Peroxide or M.E.K.P. for short.
Promoters	MEKP reacts with other chemicals (promoters) that have been added previously to the resin. This oxidation reaction generates internal heat and causes the resin to begin setting up. The process is called polymerization.
	Once the resin has been set up it will remain hard and cannot be softened by heating. It's tough stuff.
Working Time	We can control the time it takes for the resin to go from a pourable liquid, to a gel, and then to a solid by varying the amount of MEKP added, and also by using external heat or cold. The reaction is very controllable and predictable.
The 1% Rule	As a general rule, and remember this can vary somewhat depending upon the individual resin you are using and the amount of "promoters" added:
	Polyester Resins are catalyzed 1% by volume. – Or - 6-8 drops of MEKP per ounce of resin= @20-25 minutes working time at 72° Fahrenheit (this is for 100grams, or @3 ounces)

	Remember, I said polyesters are very controllable. The reaction on page 1 was at 72° F. What if the temperature is colder or hotter?
Colder	Suppose it's colder than 72°F. Suppose it's 18° colder or 54°F. The resin is now much colder than before and has less heat in it to begin with. It has less ambient heat. If we double the catalyst amount to 2%, or 12-16 drops MEKP per ounce of resin, we find that the working time is about the same- 20-25 minutes. AMAZING! The extra catalyst caused a hotter reaction that compensated for the colder resin temperature.
Warmer	Suppose it's warmer than 72°F, say it is 90°F. The resin is now warmer and has more ambient heat. You probably have guessed that if we halve the MEKP to ½% or 3-4 drops per ounce of resin, the working time remains the same. Since the resin was hotter to begin with, we didn't need as much catalyst to get the same reaction and working time.
Working Times	Let me say this again; these are approximate ratios and times. If you are uncertain, do a test batch. One other caution, these times are based on using @ 3 ounces of resin. If we catalyze a gallon of resin and leave it setting in a pot, the working time will be shortened because of excessive heat buildup. If we spread that same resin out in a thin layer, increasing the surface area, it will dissipate heat faster and the working time will be lengthened. This is not an exact science but with a little practice you can predict your working times and catalyst ratios very close. In very hot temperatures you may have to use ½% and work fast. A fan can also help dissipate excessive heat. In colder temperatures the temptation is to keep increasing the MEKP; DON'T. You can increase the ratio to 3 or even 4%; but you're better off adding a little external heat.

Polyester Resins

Test Batch

Too much catalyst can cause excessive exotherm and resin cracking; the resin will literally cook. Too little catalyst and it may not set up at all.

When in doubt, try a test batch!

Varying the Times

One more point that seems obvious but may not be. If we catalyze resin at 1% on a colder day, say 54°F, the working time will just about double to 40-50 minutes.

If we catalyze the resin at 2% on a hotter day, say at 90°F, the working time will be about half, 10-15 minutes.

The reaction works on heat, either internal from the catalyst, or external from the ambient temperature.

Deleted: Now is probably a good tie to stop reading and go through that just one more time!"¶

A safety note here before we discuss the different kinds of resins: BE CAREFUL WITH THE MEKP!!!!!!!

CAUTION!

We cannot emphasize this enough. You will get no second chances if MEKP gets in your eyes.

Resin Types

Polyester Resins are basically composed of styrene, the "fiberglass" smell that most people remember, an organic acid, and a glycol.

Ortho

The most common type of polyester resin by far is Orthopthalic resin named because of the Orthopthalic acid used to make it. Unless a resin is identified as something else, it's probably ortho resin. These are all-around resins that have been the mainstay of fiberglass manufacturing and repair since day one.

Polyester Resins

Iso

The next type of resin is Isopthalic, named for the Isopthalic acid used to make it. Iso resins have better secondary bonding (they stick better). They also resist moisture and chemicals better than Orthos.

Why isn't everything made from Iso resins, $$$? The orthos perform will enough for most applications. Some manufacturers are using Iso resins, and many boatyards use them for repairs.

Gel Coat

Gel coat, the cosmetic outer coating on most fiberglass products, is usually made from Iso resins to improve the outer surface strength and durability of the product or boat.

There are many other types of specialty resins. You will find that these two cover most applications. A good text will cover the other resins in detail.

Characteristics

Most polyester resins share some common characteristics:

- They are normally catalyzed with MEKP.
- They are basically Ultra Violet stable
- They resist water and chemicals fairly well
- They are anaerobic in their curing properties.

Anaerobic

WHAT???

Let's take a little better look at that last one.

Anaerobic means without oxygen. Polyester resins will only completely cure outside of an oxygen atmosphere. Now unless you can build your project in the Space Shuttle bay or happen to have a vacuum chamber handy, the outside surface of your project will never completely cure.

It will harden, and air dry; but if a solvent touches the surface, that surface will become tacky.

This isn't as bad as it seems.

If you are laminating up a boat and have to stop every evening; having the resin surface ready to recoat the next morning with no sanding is great. The only problem is that very last coat; we need a way to keep the air away from it and allow a complete cure.

Polyester Resins

Mylar	One solution is to tape some Mylar or other plastic over the job. That's great for little things but what about a cosmetic gel-coat repair. We won't even talk about the mess.
PVA (Poly Vinyl Alcohol)	We could also use PVA, a liquid that forms a water-soluble film that blocks the air. That's OK but somewhat of a pain.
Surfacing Agent	Probably the best and easiest solution is to mix some paraffin (wax) into styrene and add it to the resin. As the reaction proceeds, the wax comes to the coldest part of the reaction, the surface, and forms a barrier to the air. This allows the resin to "Surface Cure".
Laminating Resin	Resins "without" a surface curing added are called Laminating Resins.
Finish Resin	Resins with a surface curing agent added are called Surfacing or Finish Resins. Surfacing agent can be bought and added as needed.
NOTES	That's about all the basic knowledge we need for polyester resins. The rest of this page is for notes. Now, lets move on to Epoxy Resins.

Epoxy Resins

Polyester Refresher

If you remember, polyester resins will set up and cure with nothing added; it just takes a year or two. We used a catalyst to give us a much shorter and more predictable gel, set, and cure time.

Also, remember that we could vary the amount of catalyst to adapt to different temperatures and working conditions. Not so with Epoxies.

Resin to Hardener Ratio

Epoxy resins are **hardened** resins; that means we mix a base resin with a hardener in a **very specific ratio,** and never vary that ratio.

You cannot, I repeat, CANNOT, change the ratio…

You must have the correct amount of resin molecules to hardener molecules. Obviously we cannot mix to the molecular level, and most systems allow for a certain percentage of error.

Remember, any molecules left over will have nothing to react with and will simply be encased in the matrix. If you mix as accurately as possible, the epoxy will perform to its specifications. If the ratio is too far off you may get a softer epoxy, or the whole mess may just not set up at all.

1. Always mix to the proper ratio for your system.
2. Always mix thoroughly.

Violating one of the above is 99.9% of all the reasons epoxies fail to perform.

This may be an obvious statement; but let me make it none the less.
You cannot add MEKP to an epoxy and get anything but a mess. Also, you cannot add epoxy hardener to a polyester resin without getting the aforementioned mess.

Some companies will label MEKP as hardener; others will label epoxy hardener as catalyst. Be aware of what you are buying and using.

Ratios	Now, what is all this talk about ratios? The ratio is the amount of hardener we mix to a certain amount of resin. The most common ratios are 1:1, 2:1, 4:1, and 5:1. A 1:1 ratio means one part resin to one part hardener; 2:1 means two parts resin to one part hardener. There is always as much of or more resin, than hardener. Each system will have the proper ratio on the label. Always mix to that ratio for that system.
NEVER MIX SYSTEMS	NEVER MIX SYSTEMS, even if they have the same ratio. Even though two systems may have a 2:1 ratio, the resins and hardeners from each system may not give you the performance you expect if you mix them. Now, once your laminate is cured, you can laminate over it using another epoxy; just don't blend two systems together wet. Some surface preparation will be necessary.
Working Times	OK, enough about ratios. How do we control working times if we can't add more hardener? With polyesters, we added more or less catalyst and maybe a little external heat or cooling to vary our working times. With epoxy, we use different hardeners that give us different gel and set times. Most systems have a slow, medium, and fast hardener that works with their resin. As a general rule, slow means around 30-45 minutes to gel time, medium 20-30 minutes, and fast around 10-15 minutes. These figures are usually based on a 100 gram mass at room temperature, and sea level. Those chemists do love their figures.

Epoxy Resins

Exotherm	You need to remember, just like with polyesters, if you mix up a gallon and leave it in the container, it will gel up faster than expected because of trapped heat. Also, if you spread the mixture out into a thin layer, the working time will lengthen somewhat. Both systems build up heat; but epoxies can actually melt the plastic container they are mixed in. Once you've smelled overheated resin, polyester or epoxy, remember your nose will always remember.
Characteristics	Although epoxies look similar to polyesters when cured; they do have very different properties. 1. Epoxies, as a rule, are **not** UV stable. 2. They will soften when exposed to excessive heat. 3. Epoxies resist water intrusion and breakdown much better than polyesters. 4. They are stronger and more flexible than polyesters.
Cross-Linking	It's very important to remember that polyesters will cure (polymerize) completely given enough time. Epoxies have a **cross-linked** reaction and unless you mix molecule-for-molecule, will never completely cross-link. Mixing properly is critical in order to obtain the properties of the epoxy system you are using.

Comparisons

Polyesters are "wicking" resins. That means they will continue moving along the fibers in a material.

Wicking

Gap-filling

Epoxies are generally gap-filling resins. They will wick effectively, but will also tend to fill in minute gaps in materials. This difference will become important when we discuss laminates and the materials used.

Epoxy Resins

Cost	Epoxies are generally stronger, tougher resins. They make better wood glue if used properly, and are better for water proofing. Polyesters, for most people, are easier to work with and more predictable in their characteristics. Gel coats, made from ISO resin, are a tough, durable, and easy to repair cosmetic surface. Gel coats can be made in any color. At present, polyesters are considerably less expensive than epoxies. In most instances, that alone tips the scale.

Vinyl Ester Resins

	One final type of resin is a hybrid; Vinyl Esters.
Basic Makeup	They are essentially a modified epoxy backbone with vinyl acrilate groups and styrene monomer added.
	What all this means is that Vinyl Esters are strong, tough, water and chemical resistant resins that can be catalyzed with MEKP.
MEKP	Vinyl Esters generally use MEKP for a catalyst. This gives them a wide range of working conditions with a simple change in catalyst ratio.
UV Stable	Vinyl esters are UV stable and can be gel-coated.
Chemicals/H2O	They are resistant to water breakdown and intrusion, and aggressively resist most chemicals.
Temperature	Vinyl esters can be used at higher temperatures than most other resins without distortion or loss of properties.
	Why isn't everyone using Vinyl Esters???
	After promotion they have a short shelf life of about 90 days or so. They cost somewhere between polyester and epoxy resins. Not every project needs this quality in it's resin. Recommended with high performance reinforcements such as Kevlar and Graphite fabrics.
	You should be aware of this resin and read more about it. AS costs come down, more and more projects will be constructed using vinyl ester resins.

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Gel Coat & Epoxy

No MEKP over Epoxy	One final discussion and you may experiment with these yourselves. As a general rule do not over coat any MEKP catalyzed resin with an epoxy. Now having said this I will add that a major epoxy supplier disagrees with this in no uncertain terms. When epoxies cure, a water soluble film, an amine carbamate, forms on the surface. This film usually forms in the presence of carbon dioxide and water vapor; so you would expect more of this on cool, damp days than on dry, sunny ones. If you are recoating with epoxy, this film doesn't normally affect the recoat and need not be removed. If you were going to paint, it would be necessary to remove this film and sand the surface. So far so good. The problem is when you are going to recoat your laminate with an MEKP catalyzed resin, specifically a gel coat. Apparently the unreacted amine (amine carbamate) inhibits the peroxide catalyst and can cause an incomplete cure on the gel coat surface. Now, what this all boils down to is the need to protect the epoxy surface since it is not UV stable. Paint is one option; but many people like to use gel coat for its durability and ease of repair. Gel coat is catalyzed with MEKP, If you apply the catalyzed gel coat over the epoxy, the cure of the gel coat is unpredictable and you may end up with a sticky mess. The unmentioned company says as long as you let the epoxy "fully cure", and properly abrade the surface, there is no problem. They say they do it all the time. You may want to experiment a bit before you try it on your marine pride and joy. This is the end of the resin section. We will now move on to materials.

Materials

The materials used in any laminate contribute most of the strength to that laminate. The resin binds the materials together and transfers the loads from fiber to fiber or to the core and outer skins.

Fiberglass, graphite, Kevlar, and even cotton cloth have all been used for laminating materials. Fiberglass is by far the most common and we'll discuss it first. Fiberglass materials are made from, amazingly enough, glass fibers.

Chopped Strand Mat

1. Chopped Strand Mat- short glass strands laid down in a random pattern and held together by a resin-soluble binder. Easily wet out and able to conform to almost any shape, CSM is used as the base layer for many laminates. It is also the most watertight and adhesive of the glass materials. CSM is sold in various widths and lengths. The most common weights are $\frac{3}{4}$ oz., 1.5 oz., and 2 ounces per square foot. Do not use with epoxy.

Woven Roving

2. Woven Roving- coarse plain weave material made of large flat bundles of glass fibers called rovings. WR is woven in 0-90 degrees; the highest strength is in these directions. Woven roving does not bond well to other layers well. It's best to use alternate layers of CSM as a binder. In fact, most all boats larger than about 20' are built with alternating layers of mat and roving.
   Woven roving is sold in various lengths and widths; the usual weights are 18 and 24 ounces per square yard.

Materials

Cloth	3. Cloth- cloths of various weaves have exceptionally high tensile strength but provide little rigidity. Cloths come in many widths, and also in tapes which are selvedged on both sides to prevent unraveling. Cloths come in various weights from ¼ oz. to 10 oz. per square yard.
DBM	4. Dual Bias Mat/Roving- this is a specialty material composed of a lightweight mat, usually ½ oz., and two layers of rovings at + and – 45 degrees, all stitched together. This material reduces lay-up time, conforms better than woven roving, and can be used with any resin system since the fibers are stitched together. It also provides a more efficient use of resin than woven roving as the fabric design avoids the "lace pattern" characteristic of the woven material.
Graphite	5. Carbon/Graphite- exceptional stiffness to weight ratio (flexural modulus). Does not point load well and may shatter when impacted. Use with Kevlar to add toughness. Graphite is measured in thousands of filaments (called tow). Common examples are 1K, 3K, 6K, 12K. Graphite tows come with a finish applied at the factory and are compatible with epoxy, polyester and vinyl ester resins.

Aramid (Kevlar 49)	6. Aramid (Kevlar 49) - low density (light weight) extremely tough fabric. Difficult to cut and almost impossible to sand. Use in light weight applications to improve toughness, abrasion resistance and augment other reinforcements such as graphite.
	There are many other materials that can and have been used for laminates and construction.
Unidirectional	Unidirectional strands are laid down in a flat panel that is usually sewn or scrimmed together. Unidirectionals are used to strengthen a laminate in one direction. Unidirectional materials come in fiberglass, graphite, and Kevlar.
Surface Veil	Veils are like mat but instead of small chopped strands they are one continuous strand laid down in a mat. Veils are used as a cosmetic outer coating or for very lightweight model parts.
S-2 Glass E Glass	S-2 Glass is similar to standard fiberglass (E Glass) but with substantially higher tensile strength (30%-40%). Originally, fiberglass was called 'E" glass because of its high electrical resistance. The"S" in S-2 glass simply means structural.
Ceramic	Ceramic glass is for use in very high temperature laminates.
	One final note about materials and we'll move on. Most materials will not allow a resin to attach to them. The resin will encapsulate the material but not actually touch it. Various chemicals, called sizings, are applied to the fibers to allow the resin to bond directly (Generally organo-silane chemistry compatible with polyester, vinyl ester and epoxy resin systems).
	Also, never allow the materials to become wet; resins will not bond to wet fibers. Also, water will dissolve and wash away chemicals used in finishes.
	The best way to learn about the various materials is to buy samples and try them yourself. The basic materials we have covered here will be adequate for almost every project.

Glueing, Fairing, Filleting

Polyesters, epoxies, and vinyl esters are versatile resins and can be mixed with a variety of filler powders to make fairing/filleting compounds and structural glues.

Fumed Silica

There are essentially three types of filler/additives for resins.

The first is fumed silica (trade names Aerosil or Cabosil) used to thicken the mix and add thixotropic properties. This gives the mixture "hang" on a vertical surface.

Glass Bubbles
Phenolics
Wood Flour

Secondly there are bulking agents which reduce the density of the putty and make it easy to sand. These include glass microspheres, phenolic microspheres, and wood flour.

The former is microscopically small hollow glass and phenolic (resin) spheres which add light weight bulk to the mix. Wood flour is also a thickener.

Lastly are milled fibers, which add a matrix of glass fibers to the mix. These are used to add structural strength.

Milled Fibers

A typical fairing/filleting compound would include equal parts by volume resin/hardener to microspheres (glass or phenolic) then add fumed silica up to 20% of volume. This may be varied depending on the thickness and desired density. The microspheres will thicken the epoxy but will sag on a vertical surface. Only the thickening agents allow for non-sag mixtures.

Compounds

To make a structural filler or filleting compound add the milled glass fibers first, mixing well to fully wet out the fibers. (Adding glass fibers to a thickened mixture may not allow the glass fibers to be properly "wet" with resin). Then mix the other compounds to complete the recipe.

Pre-Made	For those who prefer ready-made compounds, Fiberlay carries a full line of fairing and structural compounds already formulated for you.
Structural Glue	Structural glue is made by adding thickening agents (fumed silica or wood flour) to the epoxy to give it body. Before thickening; however, coat each contact surface with liquid epoxy, which has been measured and mixed.
Cure Time	Add thickened mixture and apply just enough pressure to hold the parts immobile while curing. Too much clamping pressure will result in a glue-starved joint with resultant weakness. Because epoxies continue to cure and therefore gain physical strength several days after initial setting, it is necessary to allow plenty of time to cure on joints which will come under stress as soon as clamping is removed.
Metals	Metals and certain plastics may be bonded with epoxy although surface preparation is critical. Testing on sample materials is recommended.

Basic Laminating

One of the most basic skills is laminating material over an inner core of wood, foam, or some other material. Let's discuss wood for a moment.

Pre-Coat

Wood is composed of cells. In order for a laminate to adhere properly, it's important that we penetrate those cells with resin as much as possible, no matter what resin system we use. This penetrating coat is called a **pre-coat.**

Polyester Pre-Coat

When we are using polyester or vinyl ester resins, the pre-coat is made by properly catalyzing a quantity of resin, allowing it to sit for a moment or two to get the reaction going, and then reducing, or thinning it with 10% acetone by volume. This pre-coat is painted or rolled on the wood and allowed to sit for an hour or so.

The pre-coating resin acts like billions of tiny "resin nails" by penetrating the wood cells an increasing the bond strength of the next layers of resin and material.

Epoxy Pre-Coat

When pre-coating with epoxies, a special penetrating epoxy should be used (such as the S-1 Epoxy Sealer). You can also thin an epoxy and hardener mixture with 10% by volume anhydrous (no water) isopropyl alcohol. It's important to use clean alcohol that has no water or thinners added. Epoxy does not like water or oil-based additives.

Once the wood is properly pre-coated, unthinned resin can be brushed on the surface and material applied.

Foams and other core materials will need a pre-coat before applying material or attempting to bond a second core to the first.

Basic Laminating

Joining Cores	If you were gluing two pieces of wood together, they would be pre-coated first, then a layer of resin applied, then a paste or glue made from the resin thickened with fumed silica. The pieces would then be pressed together and left alone until everything sets up.
Laminating Roller	When applying any material, or whenever you are laminating, a laminating roller should be used. This special roller works the resin in and the trapped air out. It makes the difference between an amateur and a professional job.
Laminate	A laminate is basically any piece of material that has been impregnated with resin. Most laminates are more than one layer of either material, or material and cores. The material or cores in a laminate contribute most of the strength and characteristics, while the resin bonds the layers together and transfers loads from layer to layer. As a general rule, the material should be impregnated with just enough resin to completely wet it out.
Excess Resin	Excess resin adds nothing but weight to the laminate and actually weakens it. The material weave should be clearly visible when the laminate is cured. Slick or obviously over-resined. Areas are weak spots.
50/50 Rule	Most hand-laminates (not vacuum-bagged) are at optimum strength when the resin content and the material weight are about 50/50. That means a one square yard piece of10ounce material will be properly wetted out with @ 10 ounces of resin. 10 ounces of material + 10 ounces of resin.

This 50/50 rule is a good starting point for material to resin calculations. Basically if you calculate the material at 100 ounces or so, you should be using 100 ounces or so of resin to wet it out. This does not include the pre-coat nor does it include a sanding coat over fiberglass cloth (to fill the weave).

If you end up using 150 ounces the laminate is probably resin-rich and brittle.

If you end up using 50 ounces of resin, the laminate is probably very dry and weak.

Again, the 50/50 rule is a starting point; but gives you an idea of how much resin to purchase, and about how much you should be using.

The Basic Gelcoat Repair

	Gel coat is the outer cosmetic layer on laminates. The basic sequence for repairing gelcoats is:
Excavate	Excavate the site with sand paper or a countersink. Insure that the edges are rounded to eliminate stress.
Clean	Clean the site with acetone.
Tape	Tape the repair site to allow for a raised plug when filled with gelcoat. Polyesters contract as they cure. By taping and overfilling the repair site, you eliminate having to refill the repair due to contraction.
Fill	Fill in the hole with catalyzed gelcoat or patch paste.
Cure	Go Away!! Don't check it every few minutes. Leave it alone, overnight if possible.
Wet Sand	Remove the tape and begin wet sanding. Start with 220/320 grit wet/dry paper, switch to 400, then 600, 1000, and finally 2000. You can also use 1000/2000 grit buffing and polishing compounds.
Wax	Complete the repair by polishing with a carnauba based was. The wax protects the new gelcoat.

The Basic Repair

It is important to note that most marine fiberglass single skin laminates consisting of woven roving and chopped strand mat are over designed to a factor of probably 10 times. That is to say, the composite part is capable of withstanding up to ten times the maximum load contemplated in normal service. The "penalty" for this safety margin is a great deal of extra weight which is considered an acceptable trade off considering that most mariners want the added safety in the event of a possible catastrophe at sea. (Foul weather, accident, etc.) However where added weight will inhibit performance such as in the aircraft industry or with high performance racing craft, the safety factors are reduced considerably (to as low as 1.2 to 1.5 times). This makes it necessary for designers to understand the maximum loads that the laminates will experience during use. The repair of advanced composite single skin laminates is similar to heavy fiberglass laminates other than much greater care must be taken in preparing the surface and rebuilding the damaged part.

Evaluate Damage

Repair Where Both Sides Are Accessible – A visual inspection will tell only part of the story. Single skin composite damage will usually spread in a "cone" shaped direction outward from the point of impact. This will take the form of cracked matrix (resin), fiber breakage and delamination. After removing the gel coat or paint, examine the surrounding area by gently tap testing with a light hammer. Listen for changes in the tone and mark with a felt tip pen. For larger areas other methods such as thermal imaging might be necessary.

Remove Damaged Material

Remove the damaged laminate with a high-speed cutting tool. Avoid reciprocating blades as the rapid up and down motion causes delamination at the cutting edges. A cutoff wheel or circular saw works best. High speed and slow feed is preferable. Carbide tipped blades will outlast conventional high-speed steel blades. When cutting out the damaged area round the corners of the repair hole in a circle or oval shape.

	Avoid square corners. Examine the existing laminate for type and weight of glass reinforcement. It is usually preferable to rebuild the part with material the same or similar to the original design. In advanced composite repair it is important to also match fiber orientation with the original part.
Match the Strength of the Repair	In order to closely match the strength of the repaired part to the undamaged part it is necessary to spread the load of the new matrix and fibers to the original. We do this by creating the largest bonding area around the repair that is possible or practical. Taper the edge of the repair to accept the patch. In conventional marine type laminates the taper scarf will usually range from 10:1 to 12:1. Advanced composite structures may be 20:1 or more. The flatter the angle the more surface area will be bonded with the new material.
Prepare	This is important in order for the repair to achieve the highest possible tensile, compressive and shear strength as the original part. In order to achieve comparable bending stiffness, it may be necessary to add additional material to the "back side" of the part. All else being equal, stiffness increases with an increase in thickness approx. by a power of three. In other words, if the repair is 25 percent thicker than the original part, by adding the extra material, the part will be almost twice as stiff. (1.25 x 1.25 x 1.25 = 1.96). By making the part 50 percent thicker it will be almost 3.4 times stiffer and so on. After taper sanding the repair edge keep it meticulously clean. Use only clean solvents and rags.
Repair – Back Side is Accessible	Plan the repair by cutting out replacement plies as close as possible to the original repair. Each new ply will be slightly larger than the one before. Place a backing plate to cover the hole at the rear of the repair (where back side is accessible). Where the back side is inaccessible see next section. Wet out each ply of material working from small diameter to larger diameter pieces taking care to match fiber orientation as much as possible. When reaching the surface plies you may want to

	add a sacrificial ply for fairing purposes. Once cured, the area can be sanded fair for gel coat or paint application (do not apply gel coat to an epoxy surface without first testing compatibility). To allow the top coat to blend into the surrounding surface care must be taken to allow for the thickness of the top coat (up to 20 mils for gel coat or 2-3 mils for linear polyurethane paints).
Inaccessible – Reverse Side	Where the reverse side of the repair is inaccessible, a backing plate may be positioned as follows: • A backing plate may be fashioned from stiff cardboard to which is applied chopped strand mat well saturated with resin. • Avoid chopped strand mat when using epoxy unless it is suitable for epoxy saturation (i.e. Multi purpose mat or stitched mat). • When using epoxy the stitch bond fabrics are ideal in this application. The backing plate will be cut in the shape of the repair hole but larger (approx. 2" larger all around). This works best if the repair hole is "oval" shaped so that the backing plate can be inserted through the repair hole. • Reach through the hole with sandpaper and abrade the edges of the backside of the repair. Wipe with clean solvent and rag. • Run wire through holes in the backing plate with the ends protruding from the wet side. • Position the backing plate through the hole turning to align with the shape of the repair hole. • Pull wires taut and secure tourniquet style around wooden blocks until resin cures. Remove wooden blocking and cut off protruding wires. • Proceed with repair as described above.

Final Page

We have included extra pages for your notes on laminates, composites, and general vacuum bagging principles. There are many good books available on these subjects.

What you should take from this discussion are general principles of safety, and a basic knowledge of resins, materials, and techniques.

No matter how well-designed a widget is; someone still has to fabricate the pieces and attach them to each other.

We are reminded of a child's recipe for making baked chicken:

1. Get a chicken.
2. Bake it.
3. Eat it.

Wish that it were that simple.

Thanks so much for your time and participation

Have a Great Day!