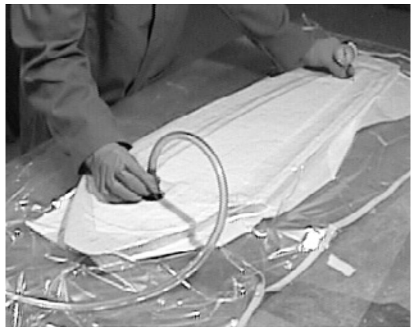
002-150

Vacuum Bagging Techniques


A guide to the principles and practical application of vacuum bagging for laminating composite materials with WEST SYSTEM® Epoxy.

Table of contents

1 Introduction

Understanding the theory of vacuum systems and the advantages of vacuum bag laminating

2 Vacuum Bagging Equipment

Evaluating the equipment and materials used in vacuum bagging

3 Vacuum Bagging Molds

Examining and building the various types of molds used for vacuum bag laminating

4 Vacuum Bagging Applications

Putting the principles of vacuum pressure to practical use in typical vacuum bagging applications

Appendix

8th Edition—January 2014

The techniques described in this manual are based on the handling characteristics and physical properties of WEST SYSTEM epoxy products. Because physical properties of resin systems and epoxy brands vary, using the techniques in this publication with coatings or adhesives other than WEST SYSTEM is not recommended. This manual is updated as products and techniques change.

The information presented herein is believed to be reliable as of publication date, but we cannot guarantee its accuracy in light of possible new discoveries. Because West System Inc. cannot control the use of its products in customer possession, we do not make any warranty of merchantability or fitness for a particular use or purpose. In no event, shall West System Inc. be liable for incidental or consequential damages.

Printed in the USA.

Table of contents

1 Introduction

1.1 What is vacuum bagging? 1

1.2 Theory 1

1.3 Advantages of vacuum bagging 2

1.4 Using vacuum bagging technology 2

2 Vacuum Bagging Equipment

2.1 Vacuum pumps 3

2.2 Vacuum bagging materials 6

2.3 Production equipment 9

3 Vacuum Bagging Molds

3.1 Flat molds 10

3.2 Curved molds 11

3.3 Building a master plug 11

3.4 Building a mold 13

3.5 Elevated temperature post-curing in molds 14

4 Vacuum Bagging Applications

4.1 Basic laminating in a female mold 16

4.2 Special considerations 26

4.3 Large scale vacuum bagging 27

4.4 Repairing laminates with vacuum bagging 28

4.5 Resin infusion and VARTM 29

Appendix

1 Introduction

1.1 What is vacuum bagging?

Vacuum bagging (or vacuum bag laminating) is a clamping method that uses atmospheric pressure to hold the adhesive or resin-coated components of a lamination in place until the adhesive cures. (When discussing composites, "resin" generally refers to the resin system—mixed or cured resin and hardener—rather than unmixed 105 epoxy resin.) Modern room-temperature-cure adhesives have helped to make vacuum bag laminating techniques available to the average builder by eliminating the need for much of the sophisticated and expensive equipment required for laminating in the past. The effectiveness of vacuum bagging permits the laminating of a wide range of materials from traditional wood veneers to synthetic fibers and core materials.

1.2 Theory

Vacuum bagging uses atmospheric pressure as a clamp to hold laminate plies together. The laminate is sealed within an airtight envelope. The envelope may be an airtight mold on one side and an airtight bag on the other. When the bag is sealed to the mold, pressure on the outside and inside of this envelope is equal to atmospheric pressure: approximately 29 inches of mercury (Hg), or 14.7 psi. As a vacuum pump evacuates air from the inside of the envelope, air pressure inside of the envelope is reduced while air pressure outside of the envelope remains at 14.7 psi. Atmospheric pressure forces the sides of the envelope and everything within the envelope together, putting equal and even pressure over the surface of the envelope.

The pressure differential between the inside and outside of the envelope determines the amount of clamping force on the laminate. Theoretically, the maximum possible pressure that can be exerted on the laminate, if it were possible to achieve a perfect vacuum and remove all of the air from the envelope, is one atmosphere, or 14.7 psi. A realistic pressure differential (clamping pressure) will be 12–25 inches of mercury (6–12.5 psi).

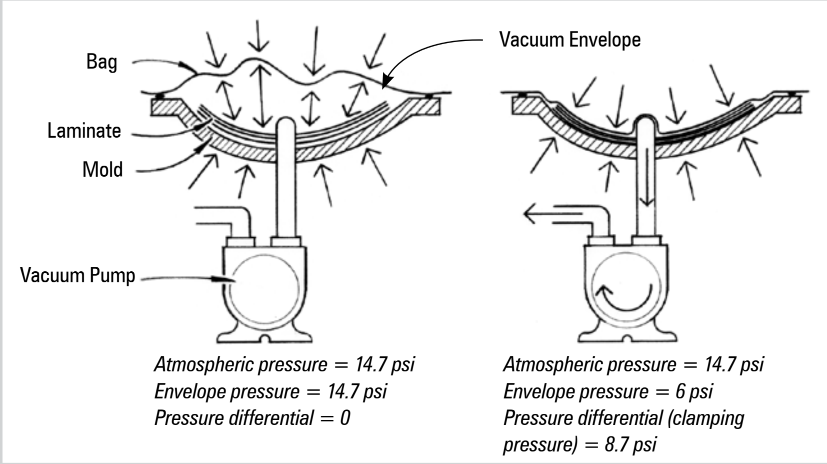


Figure 1-1 *A typical vacuum bagging lay-up before and after vacuum is applied.*

1

1.3 Advantages of vacuum bagging

Conventional clamps work well on thicker materials and narrow laminates like beams and frames. Large projects may require a large stockpile of clamps. Staples are commonly used to clamp thinner wooden plies when laminating wide panels for bulkheads or for applying veneers to cold-molded hulls. Vacuum bagging offers many advantages over conventional clamping or stapling techniques. As with other laminating methods, different materials can be incorporated into the laminate. Materials can be selected specifically to match the structural requirements of the component rather than the limitations of the clamping method.

Even clamping pressure

Mechanical clamping or stapling applies pressure only to concentrated areas and can damage fragile core materials in one area while not providing enough pressure for a good bond in another. When placed in a closely spaced pattern, staples exert less than 5 psi of clamping force and then only in the immediate area of the staple. They cannot be used at all if you are laminating to a foam or honeycomb core because of the core's lack of holding power. In addition, extra adhesive is often required to bridge gaps that result from the uneven pressure of clamps and staples.

Vacuum bagging, on the other hand, delivers firm, evenly distributed pressure over the entire surface regardless of the type or quantity of material being laminated. This allows a wider range and combination of materials as well as a superior bond between the materials. Vacuum bagging's uniform clamping pressure across the laminate results in thinner, more consistent glue lines and fewer voids. Because atmospheric pressure is continuous, it evenly presses on the joint as the adhesive spreads evenly within.

Control of resin content

Vacuum bagging also gives you the means to control excess adhesive in the laminate, resulting in higher fiber-to-resin ratios. This translates into higher strength-to-weight ratios and cost advantages for the builder. *See 4.2.2.*

Custom shapes

Another big advantage of vacuum bagging is in the simplicity and variety of the molds used. Keep in mind that the atmosphere is not only pushing down on the top of the envelope, but it is also pushing up equally on the bottom of the envelope or mold. Since atmospheric pressure provides equal and even clamping pressure to the back of the mold, the mold only has to be strong enough to hold the laminate in its desired shape until the epoxy has cured. Therefore, most molds can be relatively light weight and easy to build.

Efficient laminating

Because all of the materials in the laminate are wet out and laid up at the same time, vacuum bagging allows you to complete the laminating process in one efficient operation.

1.4 Using vacuum bagging technology

This manual is designed to give you the basics of vacuum bagging. Before producing a finished composite part, you should also have an understanding of composite materials and the engineering involved in designing composite structures. Experimenting is essential to that understanding and a valuable part of the design process. Composite construction is the ideal medium for experimentation, even on a small scale.

Composite construction and vacuum bag laminating are rapidly expanding technologies. The information in this manual is sure to be surpassed by the development of new composite materials and the refinement of vacuum bagging techniques. We hope this manual gives you the tools not only to expand your building capabilities, but also to explore the technology and improve on these techniques.

2 Vacuum Bagging Equipment

The vacuum bagging system consists of the airtight clamping envelope and a method for removing air from the envelope until the epoxy adhesive cures. This section discusses the components of this system (*Figure 2-1*), which include both specialized equipment and commonly available materials. Molds and mold building are discussed in Section 3.

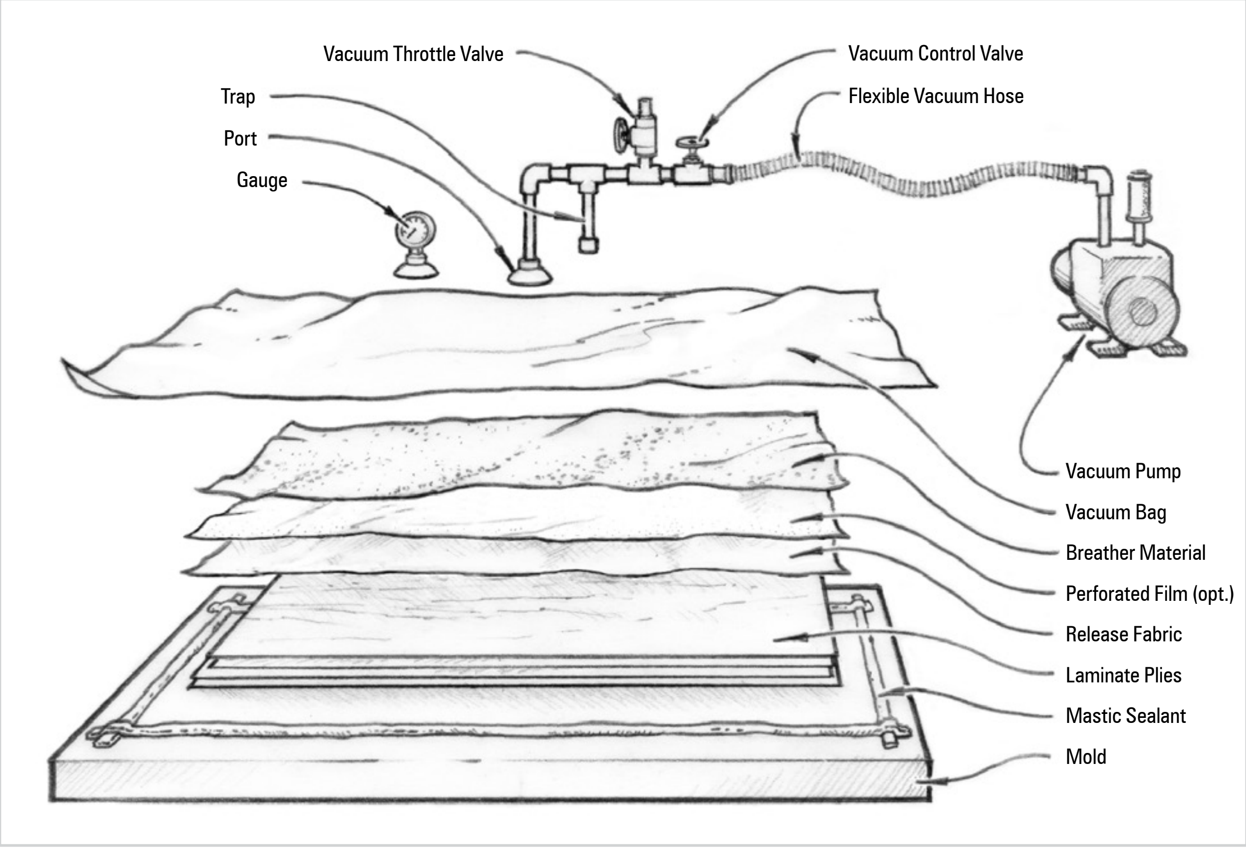


Figure 2-1 *Typical components of a vacuum bagging system.*

2.1 Vacuum pumps

The heart of a vacuum system is the vacuum pump. Powered vacuum pumps are mechanically similar to air compressors, but work in reverse so that air is drawn from the closed system and exhausted to the atmosphere. Vacuum pumps are designated by their vacuum pressure potential or "Hg maximum", their displacement in cubic feet per minute (CFM) and the horsepower required to drive the pump.

2.1.1 Vacuum pressure

The Hg maximum level is the maximum vacuum level (measured in inches of mercury) recommended for the pump. This vacuum level translates to the maximum amount of work effect or clamping pressure that can be generated. Two inches of mercury (2" Hg) equals about one pound per square inch (1 psi) of air pressure. (Remember that 1 atmosphere = 29.92 inches Hg = 14.7 psi) If you are vacuum bagging a one square foot laminate, a 20" Hg vacuum will yield 10 psi clamping force or a total of 1440 pounds of clamping force over the entire laminate. If you are laminating a 4'×8' panel, the same 20" Hg (10 psi) will yield over 46,000 pounds of clamping force spread evenly over the entire panel.

2.1.2 Displacement

The volume of air a pump can move (rated in cubic feet per minute or CFM) is also an important consideration in the selection of a pump. If the vacuum system (the mold, bag, plumbing and all seams and joints) were absolutely airtight, any size pump should be able to eventually pull its rated Hg maximum vacuum regardless of the size of the system. However, creating a perfectly airtight vacuum bagging system is nearly impossible, especially as the system gets larger or more complex. The greater the CFM rating, the closer the pump can come to reaching its Hg maximum and maintaining an adequate clamping force against the cumulative leaks in the system. A vacuum pump with a high CFM rating will also achieve an effective clamping force more quickly. This is an important consideration if the working life of the adhesive is limited or if the laminate will not hold its position until the clamping force is applied.

2.1.3 Horsepower and performance

The horsepower requirement of the pump is an indication of how efficient the pump is and is not in itself an indication of how well a pump is suited to vacuum bagging. When selecting a pump, use the Hg maximum and CFM ratings as a guide rather than horsepower. Smaller pumps designed for specific applications may trade off either vacuum rating or air displacement to suit a particular job. Generally, to get both higher Hg maximum and CFM ratings, more horsepower is necessary. Pumps that are useful for moderate boat yard vacuum bagging may range from ¼ hp to 2 hp. Pumps for large production operations may be as big as 20 hp or 30 hp.

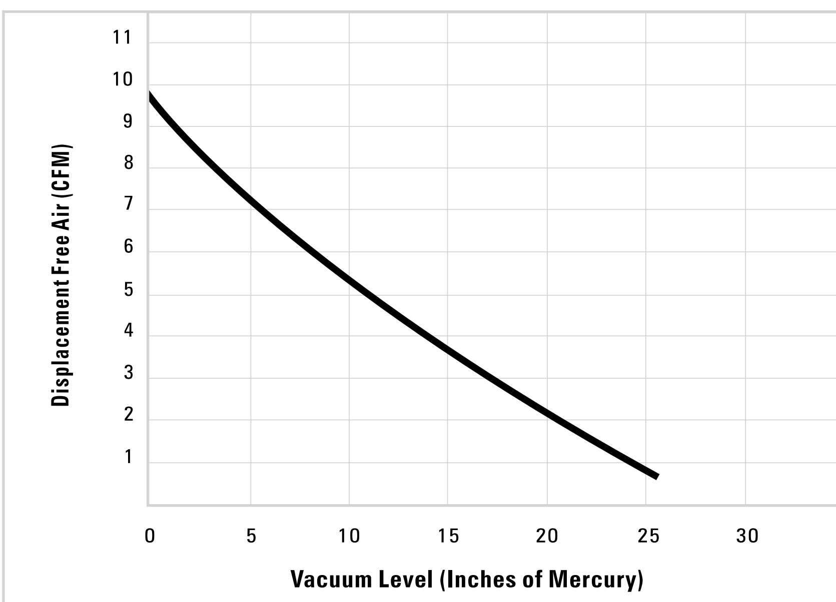


Figure 2-2 *A typical vacuum pump capacity vs vacuum rating diagram. Note that the free air flow decreases as the vacuum pressure level increases.*

2.1.4 Pump selection

The size and shape of the mold and type and quantity of the material being laminated will determine the minimum pump requirements. If you are laminating flat panels consisting of a few layers of glass, flat veneers or a core material, 5" or 6" Hg (2.5–3 psi) vacuum pressure will provide enough clamping pressure for a good bond between all of the layers. If the area of the panel is limited to a few square feet, a 1 or 2 CFM pump will be adequate to maintain that clamping pressure. As the panel area increases, the CFM requirement increases proportionately. A displacement of 3.5 CFM may be adequate for up to a 14' panel; for larger jobs, a pump with a displacement of 10 CFM or more may be required. Poor seals in the plumbing system or envelope, or material which allows air leakage, will require a larger capacity pump to maintain satisfactory vacuum pressure. *The more airtight the system, the smaller the pump you'll need.*

A higher Hg maximum rated pump will be required if you need more clamping pressure to force laminations to conform to a more complex mold shape. Curved or compounded mold shapes and/or laminations of many layers of stiff veneers or core materials may require at least a 20"–28" Hg vacuum to provide an adequate clamping force. Again, if the panel size is limited to a few square feet, a 1 or 2 CFM pump with a high "Hg rating" will work, if the envelope is airtight. However, a large panel or hull may take a minimum of 10 CFM pump to reach and maintain enough clamping force to press all of the laminate layers to the mold shape and produce consistent glue lines throughout the laminate. *Generally, the best pump for a specific vacuum bagging operation will have the largest air moving capacity for the vacuum/clamping pressure required while operating at a reasonable horsepower.*

2.1.5 Pump types

Vacuum pump types include piston, rotary vane, turbine, diaphragm and venturi. They may be of a positive or non-positive displacement type.

Positive displacement vacuum pumps may be oil-lubricated or oil-less. Oil-lubricated pumps can run at higher vacuum pressures, are more efficient and last longer than oil-less pumps. Oil-less pumps, however, are cleaner, require less monitoring and maintenance, and easily generate vacuums in a range useful for vacuum bagging. Of the several types of positive displacement vacuum pumps useful for vacuum bagging, the reciprocating piston type and the rotary vane type are most common. Piston pumps are able to generate higher vacuums than rotary vane pumps, accompanied by higher noise levels and vibration. Rotary vane pumps may generate lower vacuums than piston pumps, but they offer several advantages over piston pumps. While their vacuum ratings are more than adequate for most vacuum bagging, they are able to move more air for a given vacuum rating. In other words, they can remove air from the system more quickly and can tolerate more leaks in the system while maintaining a useful vacuum level. In addition, rotary vane pumps are generally more compact, run more smoothly, require less power and cost less.

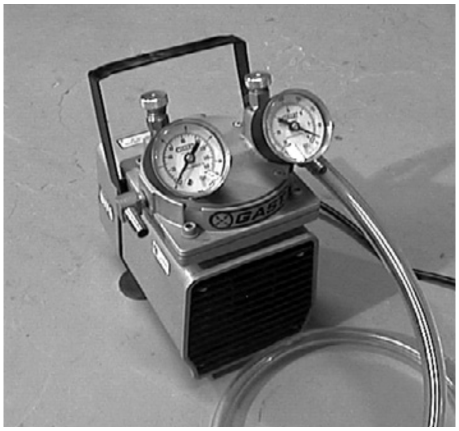


Figure 2-3 *A Gast Model 07061-40, ⅛ hp diaphragm pump. This pump displaces 1.2 CFM and will achieve a maximum vacuum pressure of 24.0" Hg. It is a practical pump for small projects.*

2

Non-positive displacement vacuum pumps have high CFM ratings, but generally at vacuum pressure levels too low for most vacuum bagging. A vacuum cleaner is an example of a non-positive displacement or turbine type pump.

Air operated vacuum generators are simple, low cost venturi devices that generate a vacuum using air pressure supplied by standard air compressors. Their portability, relatively low cost and the accessibility of compressors in many shops and homes make them ideal for many smaller vacuum bagging projects. Single stage generators have a high vacuum rating, but move a low volume of air, limiting the size of the vacuum bagging operation. The **WEST SYSTEM 885-1 Venturi Vacuum Generator** develops over 20" Hg (10 psi) at 1 CFM. It is designed to run off conventional shop air compressors that deliver at least 60 psi at 2 CFM. Larger two-stage pumps are comparable to mechanical pumps for most vacuum bagging operations, but require a proportionately large compressor to run them.

Vacuum pumps have been manufactured for a wide variety of industrial applications. Used pumps of various sizes and ratings may be found at a reasonable price. For small projects, some builders have successfully used old milking machine pumps and even vacuum cleaner pumps. If you find a used pump that you think will work for vacuum bagging, the vacuum and displacement ratings will give you an idea of the range of vacuum bagging you can do with it. If you are unsure about the pump, you can go through a dry run, following the procedures in this manual, to test the limitations of the pump. Keep in mind that the pump should be able to hold a vacuum continuously until the adhesive reaches an effective cure, which may take as long as 8 to 12 hours depending on the hardener used and ambient temperature.

2.2 Vacuum bagging materials

A variety of other materials are needed to complete the vacuum system and assist in the laminating process. The materials referred to in this manual are available from WEST SYSTEM or readily accessible through hardware or automotive supply stores. Alternate materials that function the same as those listed may be used.

2.2.1 Release fabric

Release fabric is a smooth woven fabric that will not bond to epoxy. It is used to separate the breather and the laminate. Excess epoxy can wick through the release fabric and be peeled off the laminate after the laminate cures. It will leave a smooth textured surface that, in most cases, can be bonded to without additional preparation. Surfaces that will subject to highly-loaded bonds should be sanded.

WEST SYSTEM 879 Release Fabric is a strong, finely woven polyester fabric, specially treated so that epoxy will not bond to it. It is not recommended for post cure temperatures over 120°F (49°C). A variety of release materials are produced specifically for vacuum bagging operations. They may be known as release fabric, peel ply or release film. Many are designed for use at higher temperatures or to control the amount of resin that can pass through them.

2.2.2 Perforated film

A perforated plastic film may be used in conjunction with the release fabric. This film helps hold the resin in the laminate when high vacuum pressure is used with slow curing resin systems or thin laminates. Perforated films are available in a variety of hole sizes and patterns depending on the clamping pressure, and the resin's open time and viscosity.

2.2.3 Breather material

A breather (or bleeder) cloth allows air from all parts of the envelope to be drawn to a port or manifold by providing a slight air space between the bag and the laminate.

West System 881 Breather Fabric is a 45" wide lightweight polyester blanket that provides air passage within the vacuum envelope and absorbs excess epoxy. A variety of other materials can be used such as mosquito screen, burlap, fiberglass cloth or a bubble type swimming pool cover.

2.2.4 Vacuum bag

The vacuum bag, in most cases, forms half of the airtight envelope around the laminate. If you plan to use vacuum pressure of less than 5 psi (10 hg) at room temperatures, 6-mil polyethylene plastic can be used for the bag. Clear plastic is preferable to an opaque material to allow easy inspection of the laminate as it cures. For higher pressure and temperature applications, specially manufactured vacuum bag material should be used. A wrinkled type film is available from Film Technology, Inc. Its special texture is designed to channel air and eliminate the need for breather fabric. **West System 882 Vacuum Bag Film** is a 60" wide, heat stabilized nylon film that can be used at temperatures up to 250°F (121°C) and high vacuum pressures. The vacuum bag should always be larger than the mold and allow for the depth of the mold. When a bag wider than the standard width is needed, a larger bag can be created by splicing two or more pieces together with mastic sealant.

2.2.5 Mastic sealant

Mastic is used to provide a continuous airtight seal between the bag and the mold around the perimeter of the mold. The mastic may also be used to seal the point where the manifold enters the bag and to repair leaks in the bag or plumbing.

West System 883 Vacuum Bag Sealant is a ½" by 3⁄32" flexible adhesive strip that peels easily from the mold after use.

Generally, the better the airtight seal between the mold and bag material, the smaller the pump you'll need. Poor seals, or material which allows air leaks, will require a larger capacity pump to maintain satisfactory vacuum pressure.

2.2.6 The plumbing system

The plumbing system provides an airtight passage from the vacuum envelope to the vacuum pump, allowing the pump to remove air from and reduce air pressure in the envelope. A basic system consists of flexible hose or rigid pipe, a trap, and a port that connects the pipe to the envelope. A more versatile system includes a control valve and a vacuum throttle valve that allow you to control the envelope vacuum pressure at the envelope. A system is often split to provide several ports on large laminations, or may include some type of manifold within the envelope to help channel air to a single port. A variety of pipe or tubing can be used for plumbing as long as it is airtight and resists collapsing under vacuum.

Vacuum hose is designed specifically for vacuum bagging and autoclave laminating. It is available along with fittings, pumps, and other vacuum bagging materials from manufacturers specializing in vacuum bagging equipment. Because of its higher cost, this type of plumbing system is most appropriate for large scale or production laminating operations. Other types of wire reinforced hose may work, but they should be rated for crush resistance or tested under vacuum for the appropriate length of (cure) time. Semi-rigid plastic tubing, with adequate wall thickness, can be used for a plumbing system, but it is often awkward to handle. If the laminate is to be post-cured during vacuum bagging, the tubing must also be heat resistant. Plastic tubing that may be able to withstand vacuum at room temperature may soften and collapse if heated.

Rigid ¾" PVC or CPVC pipe, elbows, T's, and valves work well. They are low cost and available at most local hardware or plumbing supply stores. The pieces do not need to be cemented together and can be rearranged to suit any configuration. This type of plumbing system, because of its low cost and versatility, is ideal for small scale or occasional laminating operations.

A **vacuum port** connects the exhaust tubing to the vacuum bag. It can be designed specifically for the purpose or built from commonly available materials. One of the simplest ports is a hollow suction cup that sits over a small slit in the vacuum bag. Cups designed for use with car top carriers can be easily adapted by drilling through the center of the cup.

A **control valve** should be incorporated into the vacuum line to allow you to control the volume of airflow at the envelope. The control valve affects the rate of air removal, but not the vacuum pressure. A second valve, the **vacuum throttle valve**, can be placed between the control valve and the envelope. This valve, incorporated with a "T" fitting, acts as an adjustable leak in the system to control the envelope pressure. For convenience, valves should be placed close to the envelope.

A **trap** should be incorporated into the line as close as possible to the envelope. The trap collects any excess adhesive that gets sucked into the line before it reaches the valves or pump and prevents a build up of adhesive in the line. A trap can easily be built with a small section of pipe, a "T", and an end cap.

A **vacuum gauge** is necessary to monitor the vacuum level/clamping force during the cure time of the laminate. Most gauges read in inches of mercury from zero (one atmosphere) to 30 (inches Hg below one atmosphere). The reading of negative pressure inside the bag equals the net pressure of the atmosphere pressing on the outside of the bag. To approximate this reading in pounds per square inch (psi), simply divide the reading by two. A vacuum gauge, available at most automotive stores, is modified by threading a hollow suction cup (similar to the port) to the base. A 1½" PVC pipe cap, with a hole drilled and tapped to match the gauge, will also work. The end of the cap is sealed to the vacuum bag with mastic.

A **manifold** is used in some situations to assist in air removal from the envelope. It can be a thicker section of breather material or other material that provides a channel for air movement under the vacuum bag to a port. A ¾" PVC pipe with holes drilled along its length was used in the applications shown later in this manual. Any hard object (such as the manifold) placed under the vacuum bag can leave an undesirable impression in the laminate.

The **WEST SYSTEM 885 Vacuum Bagging Kit** is a starter kit for room temperature repairs and small laminating projects up to 13 sq ft The kit includes a venturi vacuum generator (requires an air compressor delivering at least 65 psi), three vacuum cups (ports), 10 ft of ¼" tubing, a vacuum gauge, two T fittings, 15 sq ft of release fabric, 15 sq ft of breather fabric, 15 sq ft of vacuum bag film, 25' of mastic sealant, and kit instructions.

2.2.7 Mold Release

Mold release is essential for preventing the epoxy from sticking to the mold when laminating a part. There are generally three types of mold release used depending on the mold material and desired characteristics of the finished part. The most common type is a carnauba based paste wax. This is usually put on in up to 5 layers for new molds and at least one layer before each new part is molded. It is also a good idea to use something like PVA (polyvinyl alcohol) over the 5 coats of wax on a new mold to help prevent sticking. Fine detail and gloss level are obtained with the use of paste wax, but it can be difficult to buff anything with a textured surface.

The second type of release is the semi-permanent formulation. Many different manufacturers provide liquid release systems that apply much easier than paste wax and last for multiple parts on one application of the product. Generally a sealer and a release are used to provide the best results for new molds. Fine detail and gloss level are obtained as well as texture since buffing to remove excess is not usually necessary.

The final type of mold release is of the general contaminant variety. This can range from things like grease and Vaseline to toilet bowl wax, hair spray, hair gel or even clear packaging tape. These are generally used on rough or porous surfaces where detail, gloss, and texture are not issues for the final part. While not the prettiest, these release agents quick, cheap and widely available.

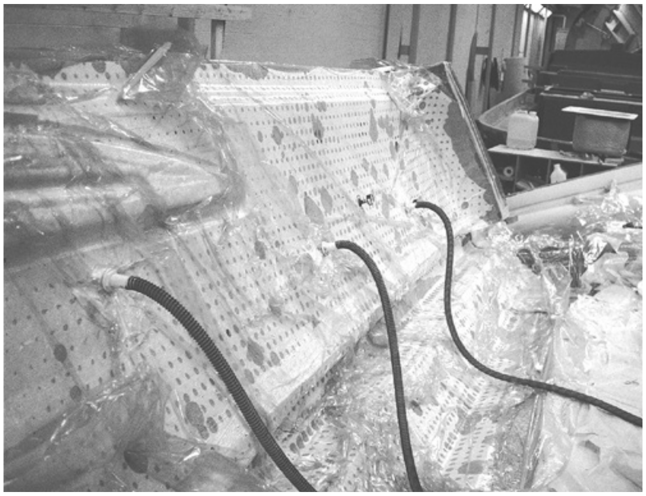


Figure 2-4 *A typical large vacuum bagging operation. This 50' half hull lay-up requires multiple vacuum lines and ports. Note the dot pattern of resin bleeding through the perforated film.*

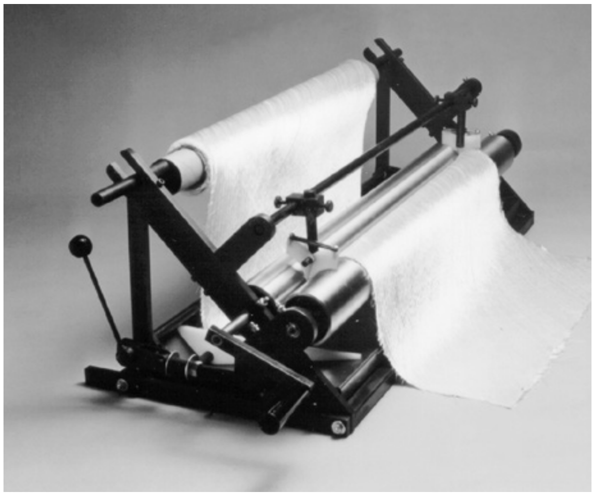


Figure 2-5 *A hand operated impregnator. Fabric passes through an epoxy bath and a pair of rollers. The adjustable gap between the rollers controls amount of epoxy in the fabric.*

2.3 Production equipment

Additional equipment is available to help large custom or production builders laminate more efficiently. Production equipment of the types listed here can help the builder take better advantage of the resin system's open time, reduce the labor required to produce a part, and laminate a part in less time.

2.3.1 Impregnators

An impregnator is used to wet out reinforcing fabric. Fabric is pulled through a resin puddle, and squeezed between rollers set at a specific gap. The roller gap controls the amount of epoxy in the fabric (*Figure 2-5*). Hand operated impregnators are available from WEST SYSTEM. Air and electric powered machines are available from some vacuum bagging equipment and material suppliers.

2.3.2 Permanent vacuum bags

Permanent vacuum bags, custom made to the shape of the part, can be used for a number of vacuum cycles. They are made of cured silicone rubber sheet, polyurethane sheet, and fiber reinforced versions of both. The bags are fastened to a rigid frame with an integral gasket that seals to the mold. The bag can be installed and sealed in a matter of minutes even on a very large part. These bags are rather expensive, but in the right production situation can readily pay for themselves.

2.3.3 Metering and mixing equipment

Many types of metering pumps and mixing equipment are available to help a shop increase production. Calibrated gear pumps and positive displacement pumps are used to dispense the epoxy resin and hardener in the correct ratio. Static mixers on the output hoses blend the resin and hardener together.

If you are undertaking a large project and would like more information or assistance selecting or finding production equipment for your operation, call the WEST SYSTEM technical staff.

3 Vacuum Bagging Molds

Vacuum bagging molds vary widely in shape, size, and method of construction. Generally they are designed to perform two functions. They must hold the wet-out laminate in a specific shape until the resin system has cured and form half of an airtight envelope that contains the laminate. Some small molds are designed to fit completely inside an envelope and only need to be rigid enough to hold the laminate's shape.

The mold surface must be airtight and smooth enough to prevent bonding to the laminate. Porous surfaces such as wood should be coated with epoxy or covered with a material such as plastic laminate to provide the necessary airtight surface. Each part produced in the mold will have a rough (bag) side and a smooth (mold) side. In most cases, the smooth, mold side of the laminated part will be its outer finished surface. Greater care in finishing a mold's surface will result in a part with a smoother finish. A colored gelcoat can be applied before the laminate is laid in, leaving the outer surface of the laminate completely finished when it comes off the mold. The appropriate mold release, most commonly paste wax, will allow the laminate to release cleanly from the surface.

The mold structure must be rigid enough to support the mold surface in its proper shape during the laminating process. Vacuum bagging molds take advantage of the fact that atmospheric pressure is equal everywhere on the outside of the envelope. Atmospheric pressure on the back of the mold will counteract all of the clamping pressure on the face of the mold. A mold only needs to be strong enough to hold its shape against the springback of the material being laminated. The quantity and stiffness of the laminate, the degree of compounding of the mold shape, the size of the mold and the precision of the finished laminate are factors that increase the amount of reinforcing required to stiffen the mold.

Molds should be at least 6" larger than the laminate on all sides to allow excess laminate for trimming and to provide a clean area around the perimeter to seal the bag to the mold.

3.1 Flat molds

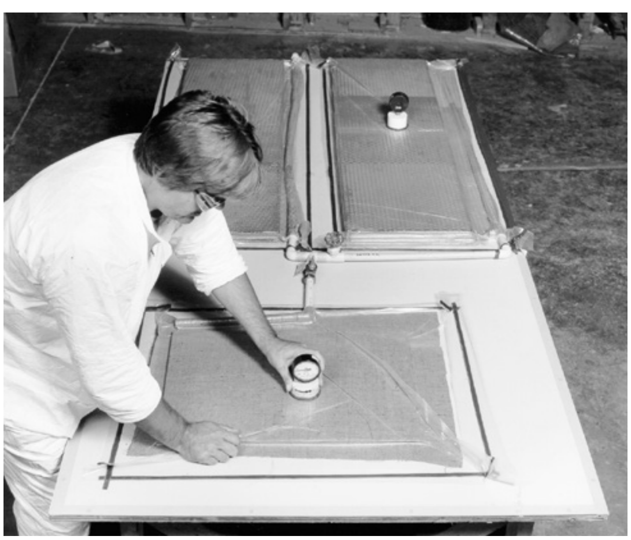


Figure 3-1 *A flat, smooth surfaced table is a versatile mold for a wide variety of projects. Several lay-ups can be completed at the same time.*

One of the simplest and most useful molds is a flat, rigid table faced with a smooth plastic laminate (*Figure 3-1*). This mold is useful for producing flat laminates or panels for bulkheads, doors, beams, and a wide range of custom structural components. Any portion of the table may be used, and multiple lay-ups of different sizes can be vacuum bagged at one time.

3.2 Curved molds

Curved parts can be laminated over male or female molds. A female mold's surface is generally concave, producing a laminated part with the smooth finish on the convex or outside–a boat hull for example. A male mold generally has a convex mold surface, producing a part with a smooth surface on the concave side–a bathtub or cockpit well. A male mold may also be used to produce a boat hull. An existing hull, for example, can be used as a mold to reproduce a slightly larger version of itself. However, when a part is laminated over a male mold, the rougher bag side of laminate will be the outside of the laminated part (the hull in this case) and will require additional fairing and finishing.

A curved mold can be lofted and built in wood or other low density material, with a layer of fiberglass cloth and several coats of epoxy to provide a smooth airtight molding surface.

Some parts, because of their shape or size, must be laminated in two separate molds. An open or bowl shaped part, such as a small open boat hull, can be easily pulled from a one piece mold if the opening of the mold is wider than any point on the inside. A closed object, such as an enclosed boat, requires at least two molds. The part is divided at its widest point so that both molds will be wider at the opening than any point inside the mold. A typical small boat is widest at the shear. (The catamaran plug in *Figure 3-2* is widest about a foot above the waterline, which is where the deck mold and hull mold are separated). The part will then be laminated in two halves and bonded together after the halves are pulled from the mold and trimmed.

Curved molds are often built in a two stage process. In the first stage, a plug or form is built to the exact dimensions and finish of the final object. In some cases an existing object, a hull for example, can be used as the plug. In the second stage, a mold is cast from the plug. In the case of a boat hull, a male plug (essentially a male mold) produces a female mold. To simplify construction, the female mold may be built upside down over the top of the plug, then flipped over after it is completed. For all but the simplest of forms, it's much easier to build, fair and finish a male plug than it is to build, fair and finish a female mold from scratch.

3.3 Building a master plug

The plug is an exact, full sized model or pattern of the finished part. A hull plug, for example, may be lofted and built in much the same way as a one-off hull, with frames, stringers and a skin. It may also be carved free form, using templates or calipers if necessary to transfer profiles, establish critical dimensions or keep the plug symmetrical.

The strength and durability of the plug should be determined by the number of molds that will be made from it and how long it will have to last. A plug may be used to build many molds for production manufacturing or from time to time replace a damaged or worn out mold. The plug may be altered after molds are made from it to create variations or revisions of a design.

Although any number of molds may be cast from a plug, a plug is often used only once. Any material or method of construction is acceptable, as long as the plug is fair, smooth and strong enough to accurately cast the required number of molds from it. Plywood frames and easy to shape materials like cedar or foam will help to reduce the costs and time to build the plug (*Figure 3-2*). The plug (and mold) should be extended at least 1" past the finished laminate edge to allow for trimming of the laminate. A 6" wide plywood shelf, attached to

Figure 3-2 *A plug can be built of any combination of easy to shape materials. This catamaran plug's cabin area was shaped in Styrofoam™ and then faired with epoxy/407.*

Figure 3-3 *The catamaran plug was faired and finished to the same degree as the finished product. The shelf was applied to the plug where the mold halves divide the form at its widest point.*

the plug at the edge of the plug extension, will provide a ledge around the top of the mold when the mold is right side up. The ledge will reinforce the mold and provide a clean area outside of the laminate to seal the bag to the mold.

Whether a plug is built for heavy use or to be used only once, no effort should be spared when fairing and finishing the plug. Every flaw in the surface of the plug will be transferred to the mold and to the finished product. The plug should be built as close as possible to the finished plug dimension, using any combination of materials. An outer layer of fairing compound can then be shaped to the exact dimension of the finished product. The final faired surface should be sanded to an 80-grit finish.

Two or three coats of epoxy applied to the faired plug will seal the surface. Wet sanding the cured epoxy to a 400 to 600-grit finish will make the surface smooth enough to prevent adhesion when the mold is cast. The plug's surface should appear as smooth and as fair as you wish the final product's surface to appear (*Figure 3-3*).

After final sanding, several coats of mold release should be applied to the surface of the plug and the shelf, with the last coat buffed to a high gloss. The mold release will fill pores in the surface and prevent bonding to the mold (*Figure 3-4*).

If the plug is a closed shape that requires a two piece mold, the break line or widest point around the plug should be determined. The plug should taper in from all points on this line. An epoxy coated, plywood shelf is attached to the plug at the break line (*Figure 3-5*). The shelf should be 6" wide and parallel with the floor. Small cleats fastened temporarily with drywall screws will hold the shelf to the plug until the mold is made. Beeswax (toilet bowl wax) can be used to seal the gap between the plug and shelf, and, if desired, make a small fillet in the mold/shelf corner. The completed mold will include a level 6" wide lip around the opening of the mold at the break (laminate trim) line, and the fillet will leave the edge of the mold rounded. During the lay up, the laminates are extended past the lip, 2" onto the shelf.

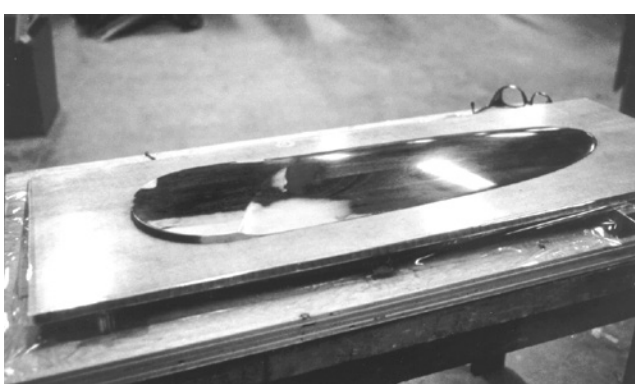


Figure 3-4 *A plug for a rudder, with the shelf positioned at the rudder centerline, is waxed and ready for the application of the mold half.*

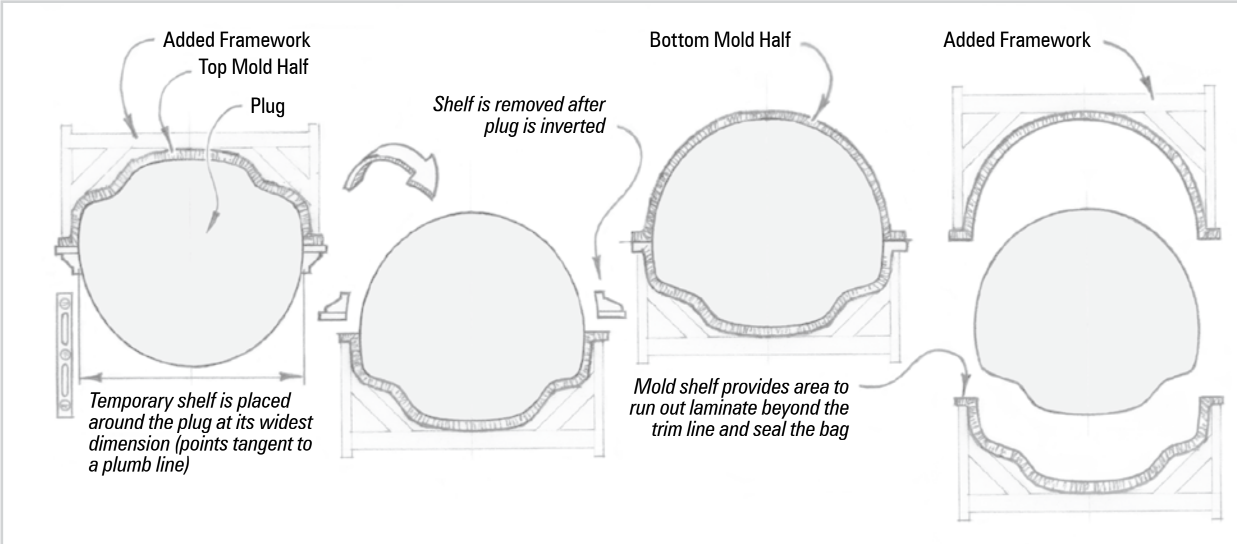


Figure 3-5 *A closed shape like a sphere or a hull with a molded deck requires two molds separated at the widest point. A 6" wide shelf at the edge of the mold allows the laminate to run beyond its trim line and provides a clean area to seal the bag to the mold.*

When trimmed, the laminate extension provides a flange around the edge of each laminate half that may be used to bond the two halves together. After the top half mold is completed, the plug and mold are turned upside down. The shelf is removed, and the holes from the drywall screws are filled and faired. The casting process is repeated for the bottom half mold, before the plug and top mold are separated. The top mold's 6" lip takes the place of the temporary shelf for casting the bottom mold's lip.

3.4 Building a mold

Building a mold over a plug is very similar to laminating a part in a mold. After the plug has been completed, the mold shell is built up in layers, or laminated, over the plug. Hull molds are generally built upside down. A framework is bonded to the completed mold shell to help keep it rigid (*Figure 3-6*) and to provide legs for level support when it is turned right side up (*Figure 3-7*).

The schedule of materials for a mold shell varies depending on the size of the mold. A typical schedule begins with an epoxy gelcoat to provide a high density surface. One layer of light fiberglass cloth followed by multiple layers of heavier cloth will make an adequate skin for small molds. Larger molds may require additional layers of glass, or a core material and additional layers of glass.

The following describes one procedure for building a mold over a plug. This procedure may be modified or other procedures may be used as long as the mold provides an airtight surface that holds the object's shape until the laminate has cured.

Apply two coats of thickened epoxy "gelcoat" to the waxed surface of the plug. Thicken the epoxy to a catsup consistency with 420 Aluminum Powder and 404 High-Density Filler to increase toughness and reduce fisheyeing when coating the waxed plug. This gelcoat layer will be the inside surface of the mold. After the gelcoat layer reaches its initial cure, apply the first cloth layers—4 oz. cloth followed by several progressively heavier layers of cloth. Take care to eliminate any air voids in the fiberglass/epoxy layers. When the cloth layers have reached an initial cure, apply a ⅛"–¼" thick layer of epoxy/407 (thickened to a peanut butter consistency) over the cloth and allow it to cure. This thick fairing compound layer

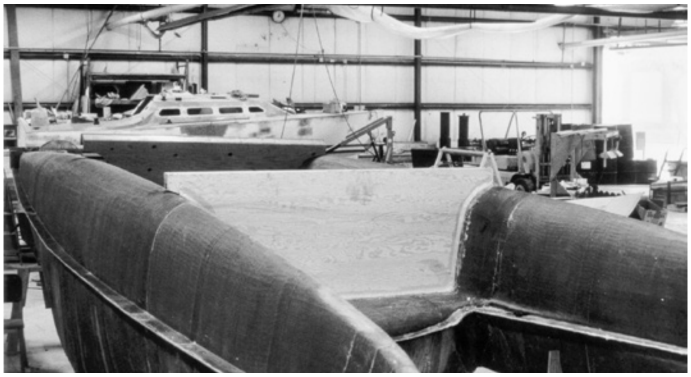


Figure 3-6 *Framing is being added to the bottom mold after lay-up is complete.*

Figure 3-7 *Legs and wheels are added to both mold halves.*

acts as an interface between the skin and the core material and helps to prevent the core from printing through to the inner surface of the mold.

The next step is to apply 1" core material over the inside skin of the mold. Sand the fairing mixture to knock down any ridges or high spots and provide texture for good adhesion of the next layer. After cutting the honeycomb core material to fit the entire mold area, remove a few pieces at a time and bond them back in position. Then apply a second ⅛" layer of epoxy/407 mixture over the cured epoxy/407 layer. Wet out the bottom contact side of the core material with unthickened epoxy and lay it into the fresh epoxy/407 mixture. Use weights to hold the core in position, firmly bedded in the thick epoxy/407 mixture until cured.

After the core application has cured thoroughly and sharp or raised edges are faired, apply the outer fiberglass skin directly over the core. The outer skin should consist of several layers of cloth, about equal to the thickness of the inner skin.

When the outer skin has cured thoroughly, bond the support framework to the skin. The framework should support the mold shell at a convenient height and keep the mold from flexing when it is removed and placed right side up on the floor. The mold framework may be fixed to the floor or mounted on wheels, in which case a strongback may be needed to keep the mold rigid. The framework should be built over the mold shell before removing the mold from the plug.

After the mold has cured thoroughly, remove it from the plug by carefully forcing wooden or plastic wedges between the edge of the mold and the plug. Then prepare the mold for vacuum bagging. Inspect the mold surface for pinholes or flaws which may be repaired with epoxy.

3.5 Elevated temperature post-curing in molds

The plug/mold construction and laminating procedures described in this manual are based on the use of room temperature cure epoxies and materials. Plugs, molds and laminates that will be post-cured or subjected to temperatures greater than 110°F (43°C) will require an alternate epoxy system and building method.

High performance, low-viscosity epoxies are often used in vacuum bag laminating. These epoxies may require curing or post-curing at elevated temperatures. If the finished laminate is to be post-cured in the mold, special precautions must be taken when building and selecting materials for the mold as well as the laminate. Molds must be built of materials and with techniques that enable the mold to withstand the elevated temperatures without distorting. And, if the mold must be post-cured on the plug, the same precautions must be taken when building the plug.

When building molds that will be used with high temperature curing applications, first establish the target post-cure temperature of the part. Consider the highest and lowest temperatures at which the resin system will cure. Then consider the size of the structure to be cured and the type of mold construction you would like to use. All of these factors affect the post-cure schedule (the rate of temperature increase and length of cure time).

The cure temperature of the mold and plug are based on the established target temperature of the part. The mold should be post-cured at a higher temperature than the part. The plug should be post-cured at a higher temperature than the mold. If, for example, the part will be cured at 140°F (60°C), the mold should be cured at 150°F (66°C), and the plug should be post-cured at 160°F (71°C). The objective is to keep the mold below the temperature at which it was post-cured. This way, the mold or plug can be used without exceeding the HDT (heat deflection temperature) of their structure's resin system.

When choosing materials for the mold, consider the fact that a cored mold will not transfer heat as well as a solid laminate. The core in a composite sandwich mold will act as an insulator. If a core is also used in the part being laminated, the skin between the mold surface and the part core will not warm up as well as the skin on the other side of the core. If there is a large temperature difference between the inner skin and the outer skin, the part could prerelease or distort during the post-cure. Verify the dimensional stability of the core material you intend to use for the intended post-cure temperature.

Call or write the West System technical staff if you have questions about mold building, post-curing at elevated temperatures or epoxy systems with higher thermal properties.

4 Vacuum Bagging Applications

Boatbuilding is just one of the applications in which vacuum bag laminating can replace conventional clamping or fastening. Vacuum bagging is a practical clamping method for large scale and very small scale applications, from product manufacturing to backyard building and hobby projects. Wind turbine blades, furniture, musical instruments, race car components, and model boats are just a few of the applications of vacuum bagging.

Natural and synthetic fibers are the most common materials used in composite construction. Wood and wood veneer represent the oldest and most widely used form of fiber in composites. Layers of wood can be laminated to make structural panels or beams. They can be used as structural or decorative skins over other core materials or as core materials themselves. They can be augmented with natural or synthetic fibers for cross-grain reinforcement.

Synthetic fibers such as fiberglass, carbon (graphite) and Kevlar™ (aramid) in the form of fabrics are designed for composite construction. When used alone, in combination with other fibers or with core materials, synthetic fibers allow the builder to accurately tune the weight, strength and shape of the finished part to its intended function.

4.1 Basic laminating in a female mold

This section describes two specific vacuum bagging procedures. These examples of small lay-ups are intended to demonstrate the basic principles of vacuum bagging. Keep in mind that vacuum bagging materials, molds, equipment, and laminate schedules will vary from these procedures. In all cases, however, the same principles of vacuum bagging apply.
If you are new to epoxy or vacuum bagging, we suggest laminating a small project to familiarize yourself with the equipment, and the sequence and timing of the procedures which are often based on the handling characteristics and open time of the epoxy.

Thorough preparation for the vacuum bagging process is essential. Be sure all equipment is working properly and that the vacuum pump is well lubricated (if it is the oil-lubricated type). Prepare a plastic covered work surface near the mold to wet out laminate materials. Rehearse all of the steps with your helpers, especially if they are unfamiliar with vacuum bagging. Everyone coming in contact with the epoxy should wear the proper protective clothing. Gloves should be worn until all of the laminates are in the mold.

Establish the maximum working time available, based on the resin/hardener you will be using and the ambient temperature. Be sure all of the steps (excluding gelcoat application) can be completed within the working time. *Refer to WEST SYSTEM product literature for cure time information.*

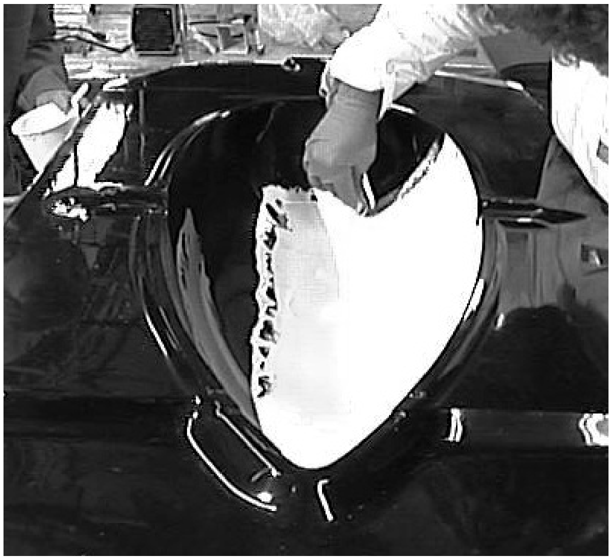
4.1.1 Laminating a masthead float half

The laminate in this example is half of a pivoting masthead float designed for a small catamaran. The teardrop-shaped float has a circular cross section. Both left and right halves of the float were made from the same symmetrical mold. The laminate schedule consists of an epoxy gelcoat, two layers of 15 oz. biaxial fiberglass fabric with two layers of unidirectional carbon fiber reinforcing the mid-section axis. The adhesive is WEST SYSTEM 105 Resin and 206 Slow Hardener.

1. Prepare the materials to be laminated. Cut fabrics, veneers and core materials to shape and place them in a convenient area for wet-out or placement in the mold.

Cut the release fabric, perforated film (if required), breather material and vacuum bag to size, then roll or fold them and placed them in a convenient location. Cut the vacuum bag 20% larger than the mold dimensions.

2. Apply the appropriate mold release to the mold and shelf surfaces. Follow the manufacturers directions for application. If you are using paste wax buff the last coat so excess wax will not be picked up by the laminate.



3. Apply a coat of gelcoat to the mold and allow it to cure. In this example, the gelcoat is a mixture of resin/hardener and white pigment, thickened slightly with 406 Colloidal Silica. It will provide a good base for paint and help prevent "print-through" of the fabric.

Wash the surface of the cured gelcoat with water and an abrasive pad to remove any amine blush that may have formed on the cured surface. Dry the surface thoroughly with clean paper towels. Sand bumps or rough areas to assure the laminate will lie flat in the mold.

4. Apply mastic sealant to the mold perimeter. Use firm pressure and overlap the ends so there are no gaps. Leave space around the laminate area and keep the paper backing in place on the mastic so it will not become contaminated with wet epoxy. It is nearly impossible to seal the bag to wet mastic.

5. Place the first layer of two layers of 15 oz. biaxial fiberglass fabric in position in the mold. In this example, it is easier to wet out fabric in the mold after it is positioned and trimmed.

Once the epoxy is mixed, the time limit for the entire process is established, based on the hardener used, ambient temperature, and the volume of laminate in the mold. When multiple batches of epoxy are used on larger layups, apply full vacuum pressure before the first mixed batch reaches its initial cure. *Refer to product literature for cure time information.*

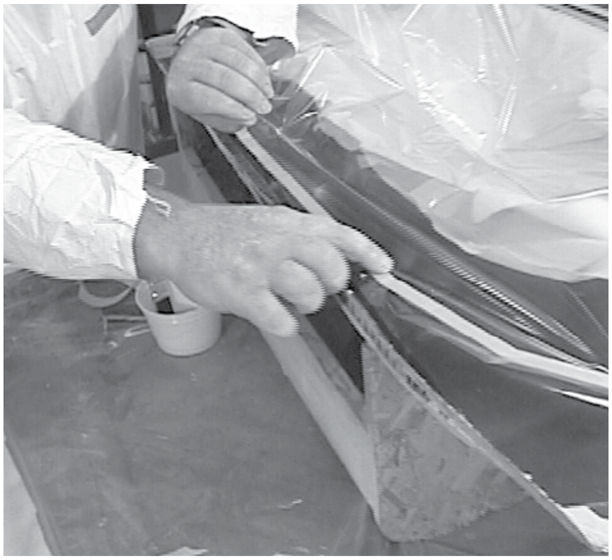
6. Squeegee excess epoxy from each layer of fabric after it is wet out. There should be no puddles of epoxy or air pockets under the fabric.

Because fabrics are compressed when vacuum bagging, less epoxy is required. Properly wet out fabric may appear drier than for a normal wet lay-up. When properly wet out, a puddle of epoxy will appear around the edges of a thumb print after a few pounds of pressure are applied with a (gloved) thumb.

7. Place a layer of release fabric over the laminate. The release fabric will peel off the cured laminate leaving a fine-textured surface. Excess epoxy which has bled through will be removed along with the release fabric.

8. Place breather material over the release fabric. WEST SYSTEM 881 Breather Fabric is a polyester blanket that allows air to pass through its fibers to the port and absorbs excess epoxy that passes through the release fabric.

Press all of the layers of material into contact with the mold to avoid "bridging" when vacuum pressure is applied. *See Section 4.2.1.*

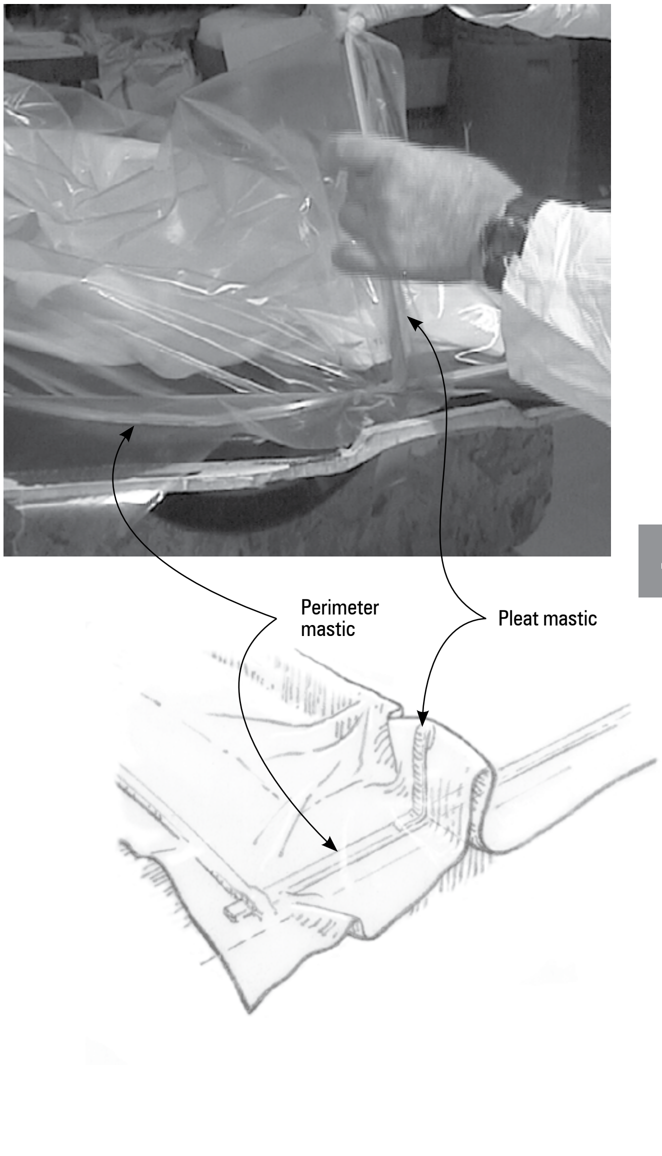


9. Place the vacuum bag over the mold and seal it to the mold's perimeter. Starting at a corner of the mold, peel the protective paper from the mastic. Press the edge of the bag firmly onto the mastic while pulling the bag taut enough to avoid wrinkles.

When cutting the bag to size, allow enough excess bag material within the sealant perimeter to avoid stretching the bag or bridging areas when the vacuum is applied. It should be at least 20% larger than the mastic perimeter, or larger if it is a deep mold such as this one.

10. Because the bag perimeter is greater than the sealant perimeter, you should create several folds or pleats of excess material as the bag is sealed around the mold.

11. Seal the pleats of excess bag with a strip of mastic from perimeter mastic to the inside top of the pleat. then press the bag to both sides of the strip forming a continuous airtight seal. Repeat this procedure wherever there is a pleat around the mold.

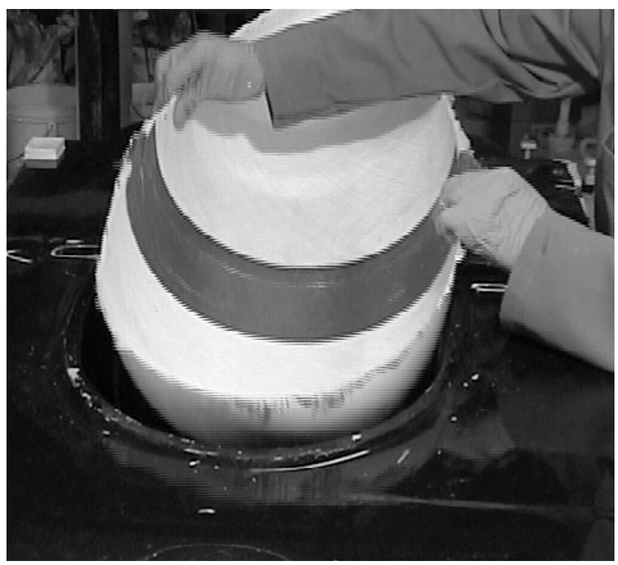


12. Connect the vacuum line to the bag with a vacuum port. The vacuum port used here is basically a suction cup with a hole through it, attached to the end of the line. Puncture a small hole in the bag and attach the port to the bag over the hole. Breather fabric provides a path to the port inside the bag over a wide area. Place an extra layer or two of breather under the port. On smaller molds, place the port outside of the trim line on the mold flange or shelf. Multiple ports may be necessary on larger parts. *See Figure 2-4.*

13. Turn the vacuum pump on, to begin evacuating air from the bag. If necessary, temporarily shut off the vacuum to reposition laminate or adjust the bag. As the air is removed from the bag, listen for leaks around the bag perimeter, especially at folds in the bag, laps in the mastic and at the vacuum line or port connection. Where leaks are found, push the bag into the sealant or, if necessary, plug the leaks with pieces of mastic or tape. Some shops use sensitive listening devices to detect leaks.

14. Attach the vacuum gauge to the vacuum bag over a puncture in the vacuum bag. A hissing sound will indicate that enough air is leaking through the puncture to draw a vacuum on the gauge. Place the gauge away from the exhaust tube or port connection.

Most gauges read in inches of mercury. To approximate the reading in psi, divide the gauge reading by two. Allow the laminate to cure thoroughly before turning off the vacuum pump.



15. After the laminate has cured thoroughly, remove the vacuum bag, breather and release fabric.

Separate the laminate from the mold by inserting small wooden or plastic wedges between the edge of the laminate and the mold. Insert wedges along one side of the part then insert additional wedges to extend the separation around the part until it pops loose.

After the other half is laminated, trim and bond both halves together.

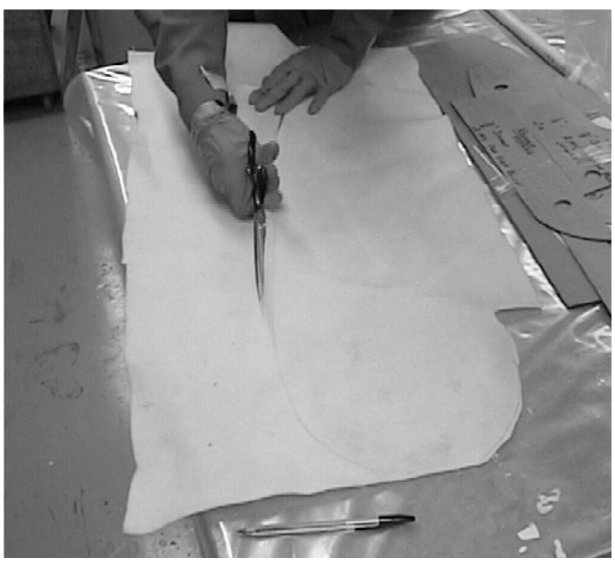
4.1.2 Laminating a rudder half

The laminate in this example is the right half of a rudder blade for a small catamaran. The method demonstrated here is a variation of the previous method. This laminate incorporates core material and the mold is enclosed in a vacuum bag envelope rather than relying on the mold as half the envelope.

The laminate schedule consists of an epoxy gelcoat, one layer of 15 oz. biaxial fiberglass fabric, a layer of core materials and a second layer of 15 oz. biaxial fiberglass. The adhesive is WEST SYSTEM 105 Resin and 206 Slow Hardener. The core material varies depending on its position in the rudder. Foam core is used in the lower blade area. Thinner material is used in the thinner trailing edge. Thicker material is used in the center and leading edge. Solid spruce and end grain balsa core are used in the more highly stressed upper area and where the pivot pin passes through the blade.

When using solid materials like wood veneers or cores, it is important to avoid air entrapment under the material. If the edges of the core contact the mold surface before the center, when vacuum pressure is applied, a pocket of air may become trapped under the core. In many applications, the core or veneer is perforated to allow air to escape. In the following application, the core is carefully bedded in a layer of thickened epoxy which holds the core in position and eliminates voids under the core. The thickened epoxy also conforms to the uneven space between the flat cores and the curved mold surface. *See Section 4.2.3.*

A strong mold is required when using a vacuum bag envelope. This method of vacuum bagging can deform or collapse a weak mold. A relatively flat mold, such as the used here, is more suited to the vacuum bag envelope.



1. Prepare the materials to be laminated. Cut fabrics, veneers and core materials to shape and place them in a convenient area for wet-out or placement in the mold.

Cut the release fabric, perforated film (if required), breather material and vacuum bag envelope to size, then roll or fold them and place them in a convenient location.

Apply the appropriate mold release to the mold surface and the shelf to act as a release agent. Follow the manufacturers directions for applying the mold release.

2. Apply a coat of gelcoat to the mold and allow it to cure. The gelcoat is a mixture of resin/hardener and white pigment, thickened slightly with 406 Colloidal Silica.

Wash the surface of the cured gelcoat with water and an abrasive pad to remove any amine blush that may have formed on the cured surface. Dry the surface thoroughly with clean paper towels. Sand bumps or rough areas to assure the laminate will lie flat in the mold.

3. Place the first layer of fiberglass fabric in position in the mold and then wet it out in the mold. This will be the outer skin of the rudder. Squeegee the fabric to remove excess epoxy and air pockets under the fabric.

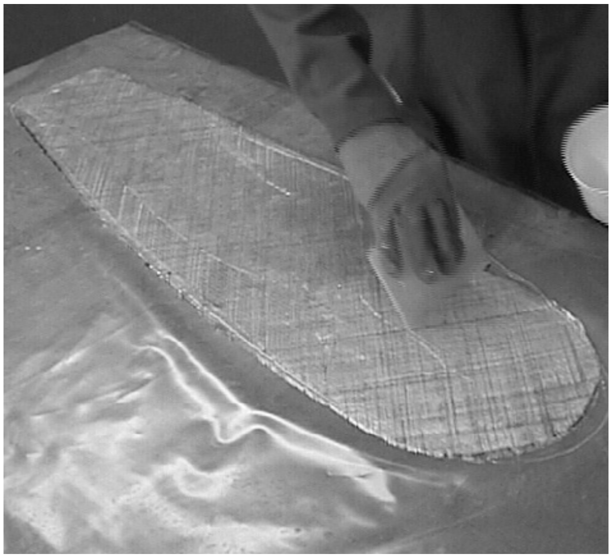
Once this first batch of epoxy is mixed, the time limit for the entire process is established, based on the hardener used, ambient temperature, and the volume of coated laminate in the mold. Apply vacuum clamping pressure before this first batch of epoxy reaches its initial cure.

4. Wet out and apply a layer of thickened epoxy to the bottom of each piece of core material to bridge any gaps between the core and the outer skin. Place each piece of core in position in the mold.

Foam, end grain balsa and solid spruce core materials are used in this part. Core thickness varies depending on the position in the mold. Denser core material is used in the top of the rudder where loads on the part are concentrated.

5. Apply thickened epoxy to fill gaps between pieces of core and to fillet the edges of cores. The thickened epoxy will become part of the core.

6. Smooth the thickened epoxy to fill depressions around core pieces. The core material and thickened epoxy should fill the mold flush with the top surface of the mold which is the centerline of the rudder. When the two halves of the rudder are joined they should meet along the centerline with few voids. Remove any high spots so the halves will meet at the centerline.



7. Wet out the final layer of fabric on a plastic covered table before placing in the mold over the core material.

8. Place the wet out fabric in the mold. Squeegee the fabric to remove any air pockets and excess epoxy.

Place a layer of release fabric over the laminate. The release fabric will peel off the cured laminate, leaving a fine-textured surface. Excess epoxy which has bled through will be removed along with the release fabric.

9. Place perforated film and breather fabric over the release fabric. Perforated film restricts the amount of epoxy that can be drawn away from the lay-up into the breather fabric.

10. Place the mold and lay-up inside a vacuum bag envelope. Make the envelope by folding a large sheet of plastic in two and sealing the three open sides with mastic.

Seal two sides of the envelope before beginning the layup. Peel the protective paper from the mastic and seal the third side after the mold is placed inside.

11. Turn on the vacuum pump, and place the vacuum port and gauge over punctures in the vacuum bag. An extra layer of breather fabric under the port will help to insure that epoxy is not drawn into the vacuum line.

As the air is removed from the bag, listen for leaks around the bag perimeter, especially at folds in the bag, laps in the mastic and at the exhaust tube or port connection. Where leaks are found, push the bag into the sealant or, if necessary, plug the leaks with pieces of mastic or tape.

12. Place the gauge away from the exhaust tube or port connection. Monitor the vacuum pressure and check for leaks throughout the cure. Allow the epoxy to cure thoroughly before turning off the vacuum.

If you plan to reuse the vacuum bag, mark the port and gauge locations with a felt marker so the holes can be easily found and sealed.

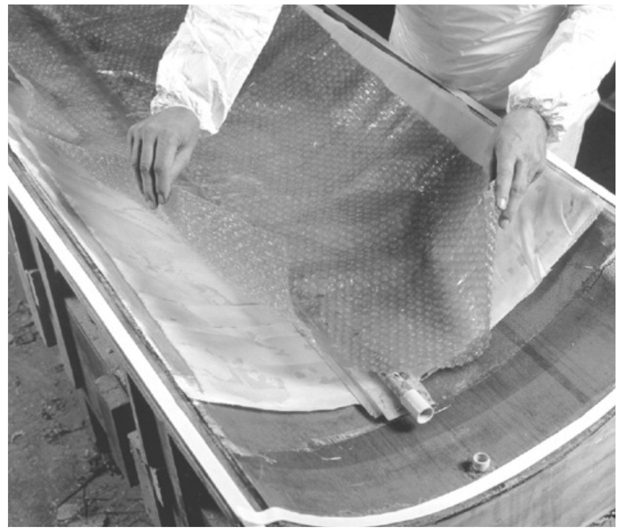
13. After the laminate has cured, remove the mold from the bag and peel the breather, release fabric and perforated film from the laminate. Separate the laminate from the mold by inserting small wooden or plastic wedges between the edge of the laminate and the mold. Insert additional wedges along one side of the part, extending the separation around the part until it pops loose.

14. Remove the finished right half of the rudder from the mold. Trim the laminate to the centerline of the rudder and grind down any high spots in the center of the rudder. Laminate the left half in the same way. Sand the bonding surface of the two halves and bond the halves together with thickened epoxy. Drill the hole for the pivot pin and seal the exposed core inside the hole with epoxy. Fair the bond line around the edges of the rudder and sand the outer surface to prepare it for paint.

4.1.3 An alternate vacuum bag system

The following example demonstrates an alternative plumbing system that uses a perforated manifold inside the vacuum bag as a method to draw air from a long lay-up using a single vacuum port. The laminate is a structural panel using two layers of $^1/_{10}$"-thick wood veneer and 12 oz. fiberglass cloth in a partial cylinder, female mold. With a flat base plate under it, the manifold can be used directly over harder material like Douglas fir veneer. It is not used on soft materials where it can leave a permanent depression in the laminate. The manifold and plumbing are ¾" PVC.

A manifold provides a rigid air path inside the vacuum bag to the port or place where the vacuum line penetrates the bag. It is placed on top of the release fabric. When the manifold is placed on top of the laminate, rather than alongside the laminate, a plate under the manifold will distribute the pressure of the narrow manifold.



A bubble-type breather material is placed over the release fabric and the manifold. Gaps between the bubbles provide air channels to the manifold. Bubble-type material may be reused several times, but it does not absorb excess epoxy.

After the vacuum bag is in place, the vacuum line is connected directly to the manifold. The bag is pushed about ½" into the manifold coupling that is under the bag. The bag is then punctured inside the manifold coupling.

The vacuum line is then shoved into the coupling, sealing the bag between the vacuum line and the inside of the coupling. The vacuum pump is turned on, evacuating air from the bag through the manifold. A glue trap, seen here, prevents excess epoxy from being drawn through the plumbing.

4.2 Special considerations

Previous examples show steps for several variations of vacuum bagging. Every combination of molds, laminate ply schedule and vacuum bagging method presents a different set of considerations. These are the most common.

4.2.1 Bridging

Narrow molds, deep molds or molds with sharp inside corners can create a problem called bridging. Bridging occurs when any of the composite material or vacuum bagging materials are too short for the mold or too stiff to drape completely into a narrow part of the mold or into a sharp inside corner. A fabric ply or the vacuum bag may be cut too short and "bridge" across a narrow part of the mold when the vacuum is applied; or, a wood veneer or foam core may not bend enough to contact the inside of a small radius in a mold. The result of bridging is a void in the laminate.

There are several ways bridging can be avoided. Cut all of the laminate and vacuum bagging material large enough to drape into all parts of the mold. When placing laminate into the mold, push each layer tight against the mold. Pound rigid wood veneer or core into tight inside corners with a padded block as the vacuum is applied. **Place overlapping joints of the laminate and vacuum bag material (not the vacuum bag itself) at the inside corner** (*Figure 4-1*). This allows the ends of the material to slide into the corner as the vacuum is applied.

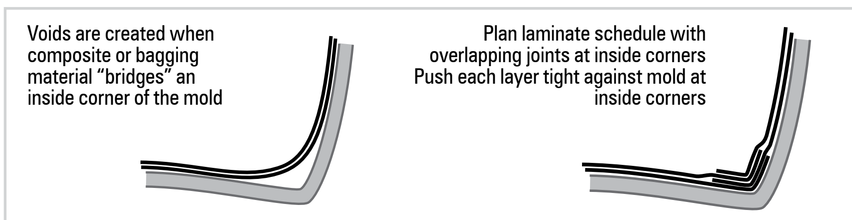


Figure 4-1 *Bridging creates a void in the laminate where laminate or vacuum bag material spans the inside corner of a mold and creates a void under the laminate.*

4.2.2 Controlling resin content

The fibers in a laminate contribute to its strength more than the resin. Achieving the greatest strength with the lowest weight can be accomplished by reducing the ratio of resin to structural fabric, up to a point. A typical wet lay-up (without vacuum bagging) is limited to about a 50% fiber/50% resin ratio. Vacuum bagging compacts the laminate so fibers can be thoroughly wet out with as high as a 65% fiber/35% resin ratio. The fiber-to-resin ratio is affected by 1. vacuum pressure, 2. resin viscosity, 3. resin cure time (time under vacuum, before gelation), and 4. perforated film pattern and hole size.

High vacuum pressure results in greater compaction of the laminate, but can also draw too much resin out of the laminate into the absorbent breather fabric, especially if you are using low viscosity resin with a long open time. Perforated film restricts the flow of resin out of the laminate and allows you to use higher vacuum, achieve greater laminate compaction and lower the weight of the composite. Perforated film is available in various hole sizes and patterns. You will need to experiment to determine the right combination of perforated film, vacuum pressure, resin viscosity and cure time for a particular laminate. For small project, you can try making your own perforated film by puncturing a thin layer of plastic drop cloth or polyethylene film with holes in a grid pattern between ⅜" and 2" apart.

4.2.3 Air entrapment under laminate sheets

Solid or non-porous sheet material, such as wood veneer, foam core or pre-laminated skins, may need to be perforated to allow air and excess resin to escape. In a flat or concave mold, they may seal around the edges when vacuum pressure is applied, trapping air and resin beneath them. Some solid foam cores are available with small holes every 4". Air entrapment is less of a problem in convex molds where the center of the ply will contact the mold first and allow air and resin to bleed out around the edges of the ply.

4.3 Large scale vacuum bagging

The limiting factors in the size of the lay-up include vacuum pump size, the shape and complexity of the mold, open time of the resin used, and the labor available to lay-up all of the composite and bagging material within the resin's open time.

This example shows the lay-up of a prototype 32' hull in the female mold shown in the photographs in Section 3. The vacuum bagging procedure used here is the same basic procedure described earlier.

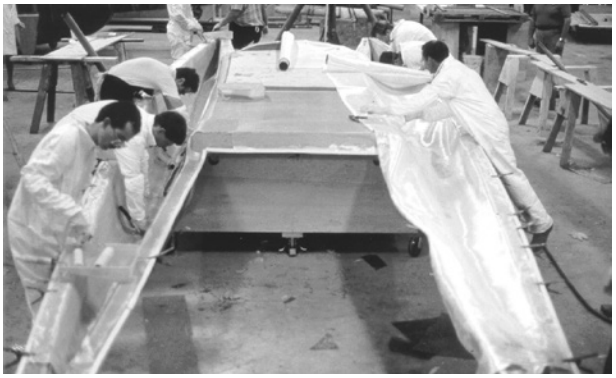


Figure 4-2 *Fiberglass cloth is wet out in the bottom (hull) mold of the 32' catamaran after the cured epoxy gelcoat is washed and sanded.*

Figure 4-3 *After laying in the outer layer of cloth, core materials are placed. Both foam and Douglas fir veneers are used where they are most appropriate.*

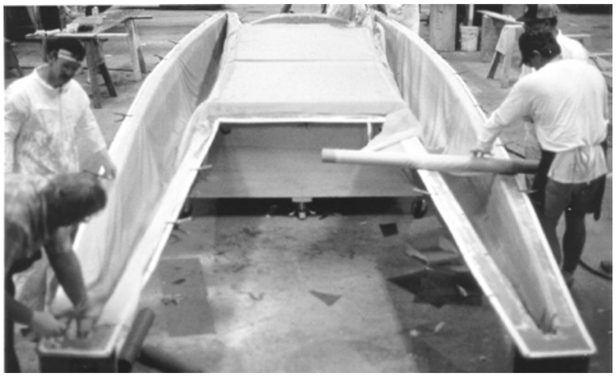


Figure 4-4 *After applying an inner layer of fiberglass cloth, release fabric is placed over the laminates.*

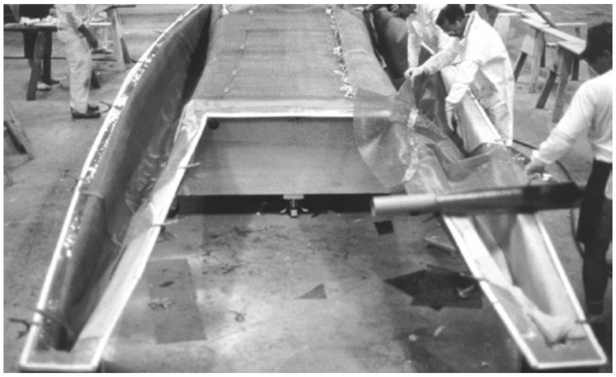


Figure 4-5 *Breather material (bubble-type) is positioned over the release fabric after a manifold is in place.*

Figure 4-6 *The laminate's position is checked as the vacuum is being applied. Note that there is plenty of extra bag to allow for the depth of the mold. Narrow bag material can be joined with mastic into larger sheets.*

Figure 4-7 *A finished laminated part (deck/cabin), suspended over the bottom (hull) mold. The mold also serves as a jig to hold the laminated hull in while interior components and the laminated deck are bonded in place.*

4.4 Repairing laminates with vacuum bagging

In many cases, the same procedures that are used to manufacture new panels can be used to repair damaged fiberglass hull or deck laminate. For most fiberglass boat repairs, vacuum bagging is not necessary to make a repair that equals or surpasses the strength of existing laminate. For highly stressed, lightly built composites, using vacuum bagging techniques to laminate new fabric into an excavated damaged area is an effective way to get a high fiber to-resin ratio repair that should be as strong as the existing panel. The following procedure describes the use of the vacuum bag laminating process for fiberglass laminate repairs (*Figure 4-8*).

1. Prepare the damaged area. Using a buffer/polisher with an 8" foam pad and 40-grit paper, grind out all of the damaged area. Remove any delaminated laminate, exposing solid undamaged laminate. Grind the repair area to a circular or oval shape. Bevel the edges of the cavity to a 12 to 1 angle (up to 50 to 1 for heavily stressed areas or thin skinned laminates).

2. Seal the back of the opening to provide an airtight envelope. If it is necessary to grind completely through the laminate to remove all damage, bond a piece of plastic laminate over the back of the opening to back up the lay-up. If a temporary backer is desired, such as in an exposed interior area, 833 Vacuum Bag Sealant may be used to hold the plastic backer in position and seal the opening. Wax the portion of the plastic backer that covers the opening so that it can be easily removed after the lay-up has cured. If the laminate is cored, it may be necessary to seal the core with epoxy. A scored or porous core may make it difficult to draw a good vacuum and should be coated with epoxy to make the surface airtight.

3. Cut an appropriate number of pieces of fabric the same shape as the excavated repair area. The first piece should be slightly smaller than the outside of the beveled edge. Each of the remaining pieces should be cut slightly smaller than the preceding piece with the last piece

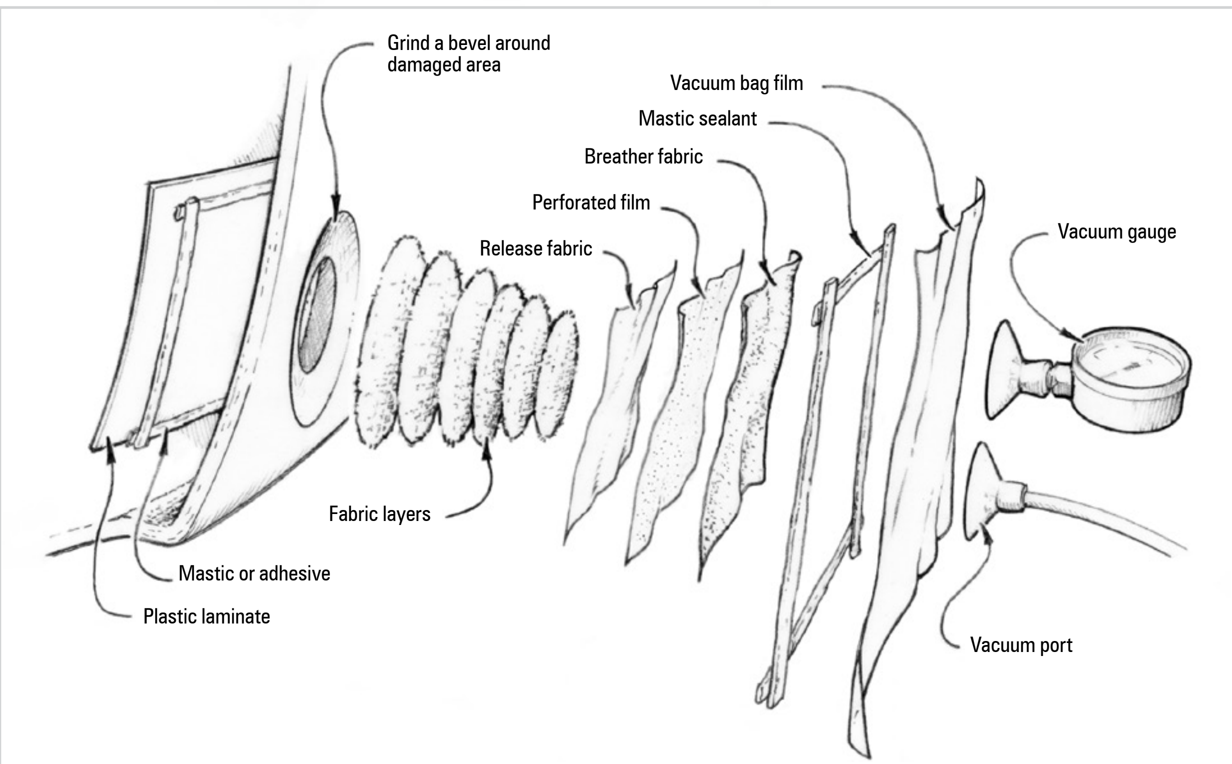


Figure 4-8 *Rebuild a damaged laminate to its original thickness using multiple layers of fiberglass cloth bonded with epoxy. Back up the opening with an airtight panel that conforms to the shape of the damaged laminate.*

the same size as the bottom of the cavity at the inside of the bevel. The combined thickness of the layers when compressed should be slightly thinner than the laminate that was excavated.

4. Prepare the vacuum bagging materials. Cut release fabric, perforated film and breather material slightly larger than the repair area. Cut the vacuum bag several inches larger on all sides than the repair area. Apply mastic sealant several inches outside the perimeter of the repair area.

5. Wet out the repair area with a resin/hardener mixture. Apply a thin layer of thickened epoxy/404 mixture to the repair area to fill any voids or unevenness.

6. Apply the wet-out layers of cloth beginning with the largest layer and then with the progressively smaller layers centered in the repair area. Wet out each layer of cloth on a plastic covered table, then smooth each layer in place on the repair area, removing air bubbles and excess epoxy with an 808 Plastic Squeegee.

7. Squeegee the layer of release fabric over the layers of cloth to remove any trapped air and excess epoxy. Place the perforated film and breather material over the lay-up and seal the vacuum bag to the mastic. If necessary on vertical surfaces, hold the breather material in position temporarily with tape.

8. Attach the vacuum port off to the side of the repair if possible to avoid dimpling the repair with the vacuum port.

9. Turn on the vacuum pump and attach the vacuum gauge. After the vacuum has stabilized, moderate heat from a heat lamp or portable heater may be applied to the lay-up to speed the cure. Allow the lay-up to cure thoroughly and remove the bag, breather, perforated film and release fabric.

10. Grind any high spot or bumps and fill any low areas with a thick mixture of epoxy and 407 filler. Sand the repair area fair after the mixture cures thoroughly and apply two coats of epoxy to seal the repair. Apply paint or gelcoat for UV protection.
    For more information about fiberglass repair, refer to ***002-550 Fiberglass Boat Repair & Maintenance*** *available from WEST SYSTEM.*

4.5 Resin infusion and VARTM

There are several methods of laminating parts that use a vacuum bag to consolidate the laminate and seal the mold, and use the vacuum pressure to draw resin in to the dry laminate stack. In these processes, rather than wet laminate being placed in the mold, the various fibers, and perhaps even a core, are placed in the mold dry. The vacuum bag is sealed to the mold and vacuum drawn. Once the full vacuum pressure is applied and no leaks exist, resin and hardener are mixed, then drawn into the laminate, much like a soft drink is sucked through a straw, and allowed to gel.

This is a simple description of a somewhat complicated process. The details can take some time to work out. Very good vacuum bagging skills are required for these techniques because leaks cannot be tolerated in these processes. For more information concerning these processes, refer to *Professional Boatbuilder* magazine, or American Composites Manufacturers Association's (ACMA) *Composites Fabrication* magazine for reprints of articles on these techniques.

Appendix

Building and repair information available from WEST SYSTEM®

Publications

002-950 WEST SYSTEM User Manual & Product Guide
The primary guide to safety, handling and the basic techniques of epoxy use. It includes a complete description of WEST SYSTEM Epoxy resin, hardeners, fillers, additives, reinforcing materials, tools, supplies and publications.

002 The Gougeon Brothers on Boat Construction
This book is a must for anyone building a boat or working with wood and WEST SYSTEM Epoxy. Includes extensive chapters on composite construction techniques, materials, lofting, safety and tools, with many illustrations, diagrams and photographs.

002-970 Wooden Boat Restoration & Repair
An illustrated guide to restore the structure, improve the appearance, reduce the maintenance and prolong the life of wooden boats with WEST SYSTEM epoxy. Includes information on dry rot repair, structural framework repair, hull and deck planking repair, hardware installation with epoxy and protective coating.

002-550 Fiberglass Boat Repair & Maintenance
A complete guide to repair fiberglass boats with WEST SYSTEM Epoxy. Includes illustrated procedures for structural reinforcement, deck and hull repair, hardware installation, keel repair and teak deck installation.

002-650 Gelcoat Blisters-Diagnosis, Repair & Prevention
A guide for repairing and preventing gelcoat blisters in fiberglass boats with WEST SYSTEM Epoxy. Includes an analysis of the factors that contribute to blister formation and illustrated steps for preparation, drying, repairing and coating for moisture protection.

002-740 Final Fairing & Finishing
Techniques for fairing wood, fiberglass and metal surfaces. Includes fairing tools, materials and a general guide to finish coatings

DVD

002-898 WEST SYSTEM Epoxy How-to DVD
An interactive compilation of three instructional videos. **Basic Application Techniques**, a video primer on WEST SYSTEM Epoxy Products and their use, includes safety procedures and application tips for coating, bonding and fairing. **Fiberglass Repair with WEST SYSTEM Epoxy** is a guide to structural repair on fiberglass boats. It covers repairs to cored and non-cored panels and how to apply gelcoat over epoxy repairs. **Gelcoat Blister Repair with WEST SYSTEM Epoxy** is a guide for repairing and preventing gelcoat blisters on fiberglass boats. It includes an analysis of the factors contributing to blister formation and steps for preparation, drying, repairing and coating for moisture protection.

Additional Reading

Composite Basis
by Andrew C. Marshall, published by Marshall Consulting, Walnut Creek, CA.
Technically oriented background on composite materials and design, mold making and fabrication techniques.

Fiberglass & Other Composite Materials
by Forbes Aird, published by The Berkley Publishing Group, NY, NY.
Automotive and marine oriented topics about fiber reinforced plastics (FRP), techniques, molds, materials and structures.

Handbook on Vacuum and Pressure Systems
Gast Mfg. Inc., A Unit of IDEX Corp., gastmfg.com

002-150 **Vacuum Bagging Techniques**

Published by
Gougeon Brothers Inc.
P.O. Box 908
Bay City, MI 48707
866-937-8797
westsystem.com

8 11343 01282 3