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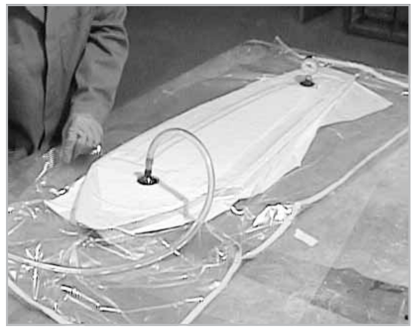
Vacuum Bagging Techniques

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



WEST SYSTEM®

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.

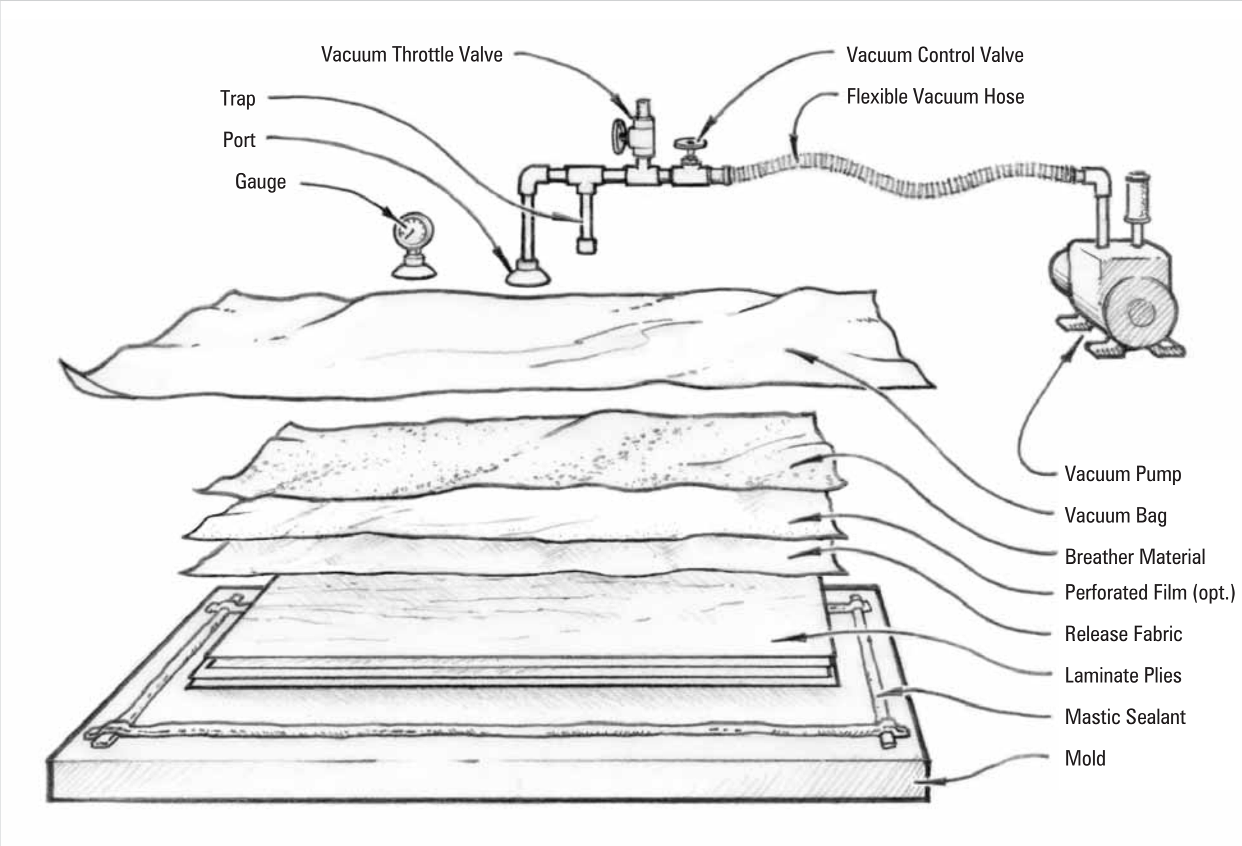


Figure 2-1 *Typical components of a vacuum bagging system.*

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" (Hg is the chemical symbol for mercury), 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 1/4 hp to 2 hp Pumps for large production operations may be as big as 20 hp or 30 hp.

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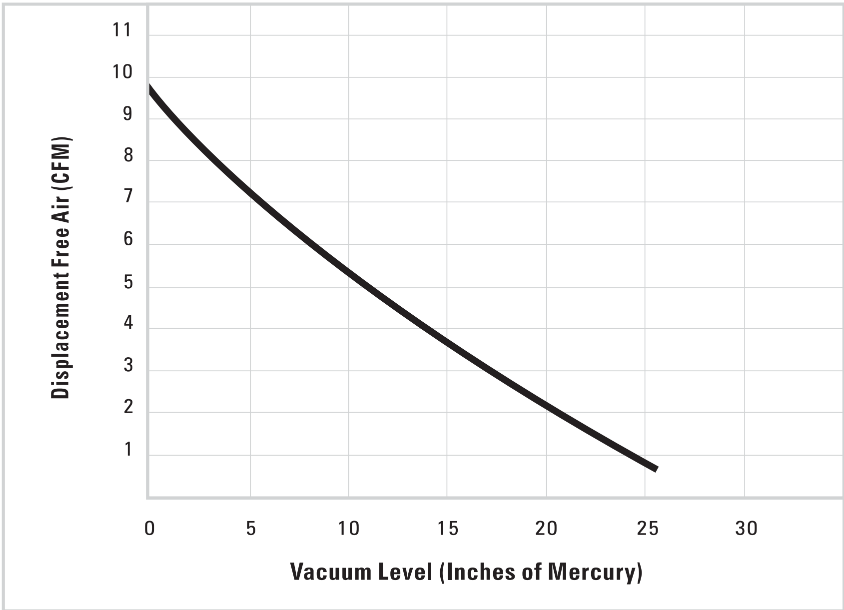

Figure 2-2 *A typical vacuum pump capacity vs vacuum rating diagram. Note that the free air flow decreases as the vacuum pressure level increases.*

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.

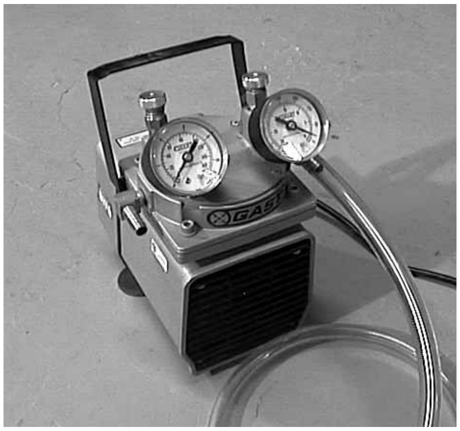

Figure 2-3 *A Gast Model 07061-40, 1/8 hp diaphragm pump. This pump displaces 1.2 CFM and will achieve a maximum vacuum pressure of 24.0" Hg. It is a practical pump for small projects.*

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. See Section 5.3 for cure time information. *See Appendix C for a list of vacuum bagging equipment and material suppliers.*

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 350°F (176°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. *See Appendix C for a list of vacuum bagging equipment and material suppliers.*

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.

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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.

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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.

Refer to the WEST SYSTEM User Manual & Product Guide for more information.

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.

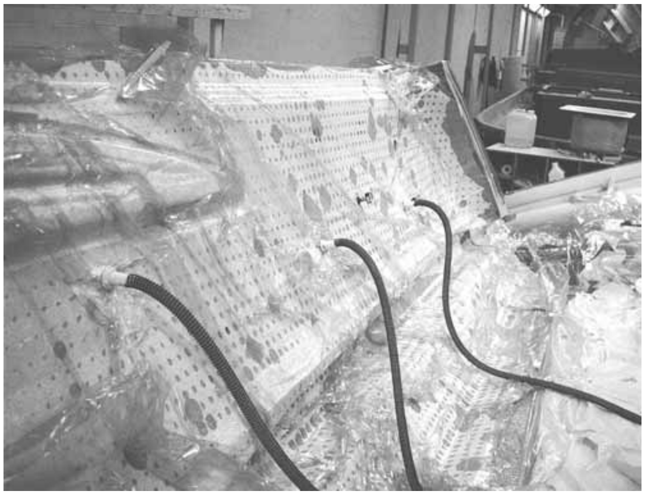

Figure 2-4 *A typical large vacuum bagging operation. This 50' half hull lay-up requires multiple vacuum lines and ports. Note the dot pattern of resin bleeding through the perforated film.*

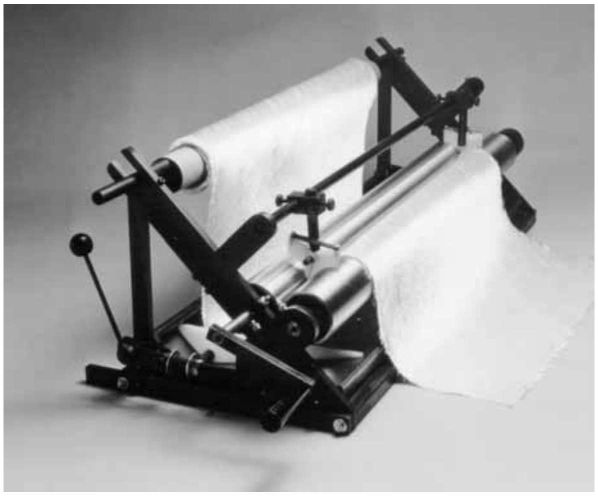

Figure 2-5 *A hand operated impregnator. Fabric passes through an epoxy bath and a pair of rollers. The adjustable gap between the rollers controls amount of epoxy in the fabric.*

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.

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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 companies such as Venus Gusmer. *See Appendix C for a list of 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.

See Appendix C for a list of vacuum bagging material and equipment suppliers. 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 400-600 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.

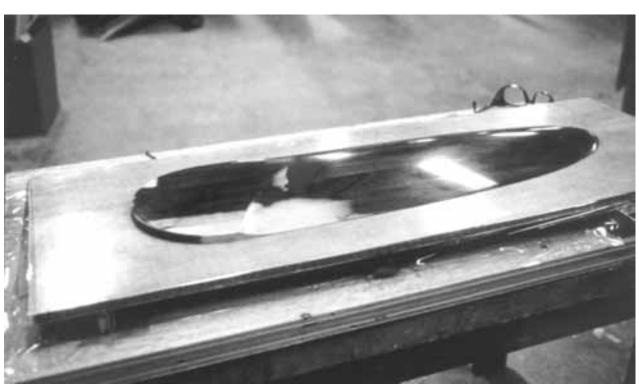

Figure 3-4 *A plug for a rudder, with the shelf positioned at the rudder centerline, is waxed and ready for the application of the mold half.*

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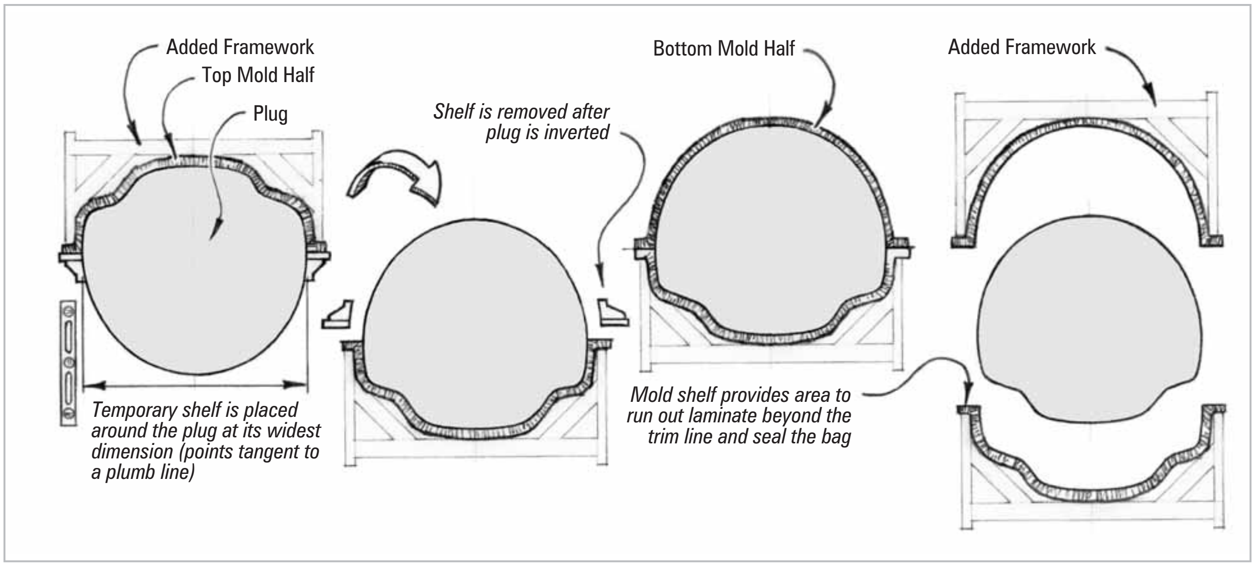

Figure 3-5 *A closed shape like a sphere or a hull with a molded deck requires two molds separated at the widest point. A 6" wide shelf at the edge of the mold allows the laminate to run beyond its trim line and provides a clean area to seal the bag to the mold.*

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

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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

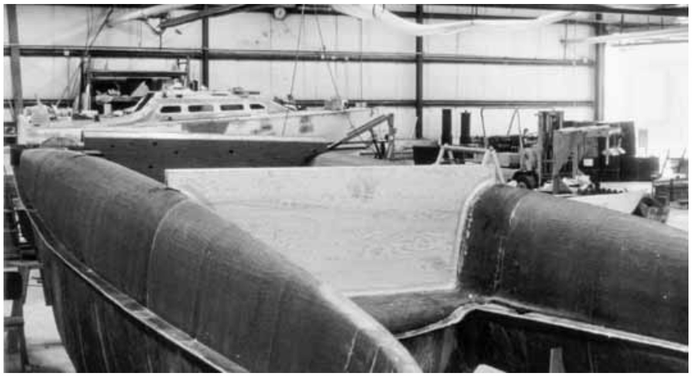

Figure 3-6 *Framing is being added to the bottom mold after lay-up is complete.*

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.

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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.