Antifouling paints applied within the “chemical window” of certain epoxy barrier coats adhere tenaciously to this surface, making for effective and long-lasting coatings.

Fiberglass blisters and barrier coats

Story and photos by Steve C. D’Antonio

Coating Technology

Editor’s note: In the first of this two-part series on the subject of fiberglass blisters, we’ll explore the basics of production boatbuilding, different types of resin, glass fabrics, and boatbuilding techniques, and the role they play in the formation of fiberglass blisters.

In the 16 years that I’ve worked in and managed boatyards, I’ve encountered few repair subjects that strike as much fear into the hearts of boatowners as that of hull blisters. To an extent, their fear is well placed; hull blisters, sometimes referred to as osmosis, are a serious problem that may, under some circumstances, weaken a vessel’s fiberglass laminate. However, one thing is certain: A case of hull blisters will compromise the marketability and value of most boats, just ask any broker. The validity of this devaluation is and will, no doubt, remain fertile ground for debate, primarily because experts continue to disagree about just how much osmosis weakens a laminate. Additionally, in my experience, the degree of compromise varies widely from boat to boat.

Researcher beware

The impetus for this article stemmed from a correspondence piece published in these pages several months ago (*Barrier-coat problems require extended fix* Issue 132, Sept./Oct. 2003). A voyaging couple, owners of an afflicted boat, lamented the dearth of information concerning the causes of and solutions to osmotic blistering. Before delving into this subject, let the reader be warned. In reality, no such scarcity of information exists on the subject of osmosis causes and repairs, much of which can be found on the Internet. Sadly, a great deal of this information is flawed, inaccurate or purely anecdotal.

Remember, anyone can create a Web page or post authoritative-sounding tomes on this and many other marine subjects. Consider the source — books and articles published by experienced, respected experts are usually vetted by equally experienced editors, while most websites are not. This is not to say that there isn’t a great deal of accurate information available on the subject of osmotic blisters, which may be found on the Web. In fact there is, and much of it originates from university researchers, chemical engineers and manufacturers of fiberglass resins and composites.

Simply put, if you are faced with a case of fiberglass blisters, research carefully and resist the temptation to accept solutions solely on the basis of expense, rather than expertise and techniques with a proven record of success.

The fiberglass-reinforced polyester (FRP) construction process uses several basic and a few complex components. Once again, in order to understand how fiberglass blisters form, it is necessary to understand these terms and materials.

The aforementioned gelcoat is simply pigmented resin. In the early days of FRP boatbuilding, many manufacturers thought that gelcoat would provide an impermeable barrier to water (more on why this is important later), although few had any idea of the importance of this feature at the time. Additionally, it was also billed as being so hard and slick that barnacles would be unable to keep their grip, thereby eliminating the need for antifouling paint. As history has proven, rather quickly in the latter case, neither of these claims was true.

The realities of gelcoat are: It provides a relatively stable, aesthetically attractive finish that, under even the best of circumstances, presents a modest barrier to water penetration. The ideal thickness for gelcoat is between 20 and 30 mils (20 to 30 thousandths of an inch). Less than this and it will not provide adequate coverage or quality of finish, while gelcoats any thicker than 30 mils are prone to cracking.

Resin, the glue that binds the FRP structure together, may take several forms. Typically, even today, most boats are manufactured using general-purpose polyester (PE) based resin. Subcategories of this resin are orthophthalic and isophthalic, which simply refers to the acid from which the resins are manufactured.

Without delving too deeply into the chemistry of these resins, the former is less expensive and less resistant to blis-

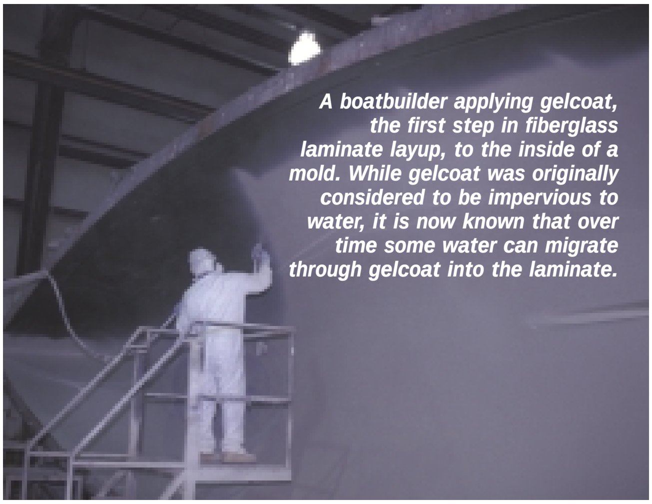
Can barrier coats stop osmosis?

It is an old but particularly appropriate expression where barrier coatings are concerned, "Pay a little now or a lot later." But what is a barrier coat, why is it sometimes a necessary weapon in the war against osmotic blistering, and when should it and should it not be applied?

As described in the main text, the osmotic blister's modus operandi involves the absorption of water through a vessel's skin coat and into the laminate. For production fiberglass-reinforced polyester (FRP) hulls, the skin coat is usually gelcoat; once thought to be impervious to water penetration, naval architects, chemists and many owners of vessels suffering from osmotic blistering now know otherwise. Although gelcoat formulation has improved markedly over the past decade, its usefulness as a barrier coating is marginal.

A true barrier coat will stem water penetration completely. Unfortunately, nearly every plastic, regardless of chemical makeup and density, will eventually absorb water molecules. Thus, other than steel, aluminum and other metals, the best an FRP-boat owner can hope for is a barrier coating that will significantly slow down the migration of water mole-

An epoxy barrier coat sprayed on a newly relaminated surface can stop further water permeation.



A boatbuilder applying gelcoat, the first step in fiberglass laminate layup, to the inside of a mold. While gelcoat was originally considered to be impervious to water, it is now known that over time some water can migrate through gelcoat into the laminate.

tering or osmosis, while the latter is more expensive and more resistant to osmotic attack. Because gelcoats are resin-based, they may also be orthophthalic- or isophthalic-based (*ortho* and *iso* in industry-speak), the latter sharing the same attributes of blister resistance with iso-polyester general-purpose resin and thus the current preference. Nearly all older boats were made using ortho resin and gelcoat. The demarcation varies, the switch occurring sometime in the ’80s.

A relative newcomer to the resin scene is vinylester (VE), which has proven to be superior to its cousin, poly-

cules. This is either accomplished through the chemical makeup of the product, such as vinylester’s long, heavily interlocked molecular structure, or by the addition of solids.

The use of vinylester laminates or skin coats, as well as all-epoxy construction, has proven to be highly effective in preventing water absorption and the resultant osmosis. Unfortunately, this doesn’t help all the boats that are already in service — and those that will be built — using a more permeable resin such as polyester. In these cases, an aftermarket barrier coat, which usually consists of a high-solids-loaded epoxy, can be applied as a prophylactic against osmosis or blisters.

New polyester hulls are the ideal candidates for barrier-coat application. Preventing water absorption before it occurs is the preferred and considerably less expensive approach to osmotic prevention. Although the incidence of osmotic blistering in vinylester hulls is extremely rare, many owners of these vessels often opt for the comparatively inexpensive new boat-barrier application as an added measure of security against the occurrence of blistering. In either case, it is generally acknowledged that a barrier coat, particularly when applied to a vessel when new, is a value enhancer.

Barrier coats can be applied as part of a comprehensive osmosis repair process; however, it is imperative that a barrier not be applied over a bottom that is “wet” or continues to suffer from osmosis. This is simply a case of closing the proverbial barn door after the horse has escaped. Barrier coating a wet laminate will neither arrest the osmotic process nor prevent the occurrence of new blisters. Laminates must be acceptably dry or new in order to benefit from an osmotic barrier coat.

Steve C. D’Antonio

ester, in nearly every way — including expense (it costs about 15 percent more than PE). Vinylester resins are extremely tough and elastic while embodying excellent permeability characteristics. Another valuable trait of VE resin is its compatibility with polyester resin. The two may be used virtually interchangeably and in direct contact with each other, with the same application equipment and catalysts. As a result of these attributes, VE resin is now preferred by high-quality hull manufactures either for their entire laminate schedule or for the outer layers of the hull.

Finally, epoxy resin has gained favor in the boatbuilding

Barrier coat manufacturers

Gougeon Brothers Inc.
100 Patterson Ave.
P.O. Box 908
Bay City, MI 48707-0908
989-684-7286
www.gougeon.com

105 epoxy resin: 105 resin is the base material of the West System family of products, on which all of the West System compounds are built. The resin is a clear, pale yellow, low-viscosity liquid epoxy resin. Formulated for use with West System hardeners, it can be cured in a wide temperature range to form a high-strength solid with excellent moisture resistance.

Hawkeye Industries Inc.
3050 Brookview Dr.
Marietta, GA 30068 USA
800-977-0060
www.duratec1.com

Duratec: vinylester primer for one-off and production composite yacht priming and osmosis and blister repairs. Formulated for below-waterline, topside and deck applications.

International Paint Inc.
2270 Morris Ave.
Union, N.J. 07083
908-686-1300
www.yachtpaint.com

Interprotect barrier coat 3000/3001: A high-solids, two-part epoxy coating, developed to protect old and new fiberglass hulls from water absorption, which can lead to hull blistering

Interprotect barrier coat 2000E/2001E: Interprotect 2000E is the newest development of Interprotect 2000. It has many of the same outstanding properties but does not contain methylene chloride. For this reason it is designated "E" as an environmentally preferred product.

Interprotect barrier coat 1000/1001: A high-build epoxy primer for use when gelcoat is removed and fiberglass laminate requires sealing. Interprotect 1000 is clear, and this enables the applicator to see that all the fibers are saturated and sealed.

VC Tar2: a two-component epoxy primer providing osmosis protection to GRP boats and anticorrosive protection to steel and alloy surfaces.

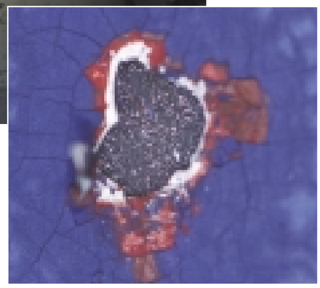
Interplastic Corp.
1225 Willow Lake Blvd.
St. Paul, MN 55110-5145
651-481-6860
www.interplastic.com

Low-VOC resins: CoRezyn CORVE8121LH series of low hazardous air pollution (HAP) vinylester resins. Regulatory-compliant marine vinylester resins. They meet or exceed all U.S. standards for blister and fatigue resistance while meeting the newest Environmental Protection Agency standards.

Gelcoats: Iso/NPG, isophthalic, low-VOC, vinylester, vinylester barrier and general-purpose gelcoat systems to protect finished marine fiberglass parts.

industry as a high-quality, extremely strong material that is also virtually impermeable. Additionally, it is more environmentally friendly than ordinary poly and vinylesters, thanks to the low emissions produced during its cure cycle. Epoxy is by far the most expensive of the available boatbuilding resins, and it is acknowledged by manufacturers as somewhat more difficult to work with. Saturating glass fabric with epoxy is more time consuming and difficult than ordinary poly and vinylester, and as a result, it is usually used where high strength and/or low emissions are required. It is worth repeating that epoxy laminates are among the strongest and most blister-resistant structures. Epoxy is not readily compatible with poly and vinylester resins, nor is it compatible with glass fabrics whose binders and coupling agents (materials that hold the fabric together or promote resin bonding, respectively) are formulated for poly and vinylester. This resin must only be used with epoxy-approved glass fabrics.

Spot-repairing blister domes by grinding and filling with epoxy or resin is strictly a cosmetic approach. The problem remains, and new blisters will continue to form.



A blister with dome removed, showing laminate structure.

Glass-fabric reinforcement is available in scores of configurations, sizes and weights. The individual filaments used to weave different types of glass for FRP construction are gossamer indeed, approximately 1/10 the thickness of a human hair or about 0.0002 inches. The principal types are chopped-strand mat, woven roving and cloth. There are other more exotic fabrics, such as knitted and biaxials, but most boats, particularly those that are suffering from blisters today, are built with these three primary materials. They are all used in different applications and for different desired results.

From the standpoint of osmotic blistering, the most relevant fabrics are the ones used just beneath the gelcoat, typically the chopped-strand mat and roving. Mat, which is made up of short (about 2-inch), random lengths of glass filaments, is not as strong as the heavy rug-like weave of woven roving. However, it is soft, sponge-like and absorbs resin readily, and as such, it works well for bonding to other types of glass. Chopped-strand mat (CSM) comes in roll form and is held together by a binding or sizing agent, which is designed to dissolve in resin, facilitating application of the mat into irregularly shaped locations.

In order to work effectively with polyester or vinylester resin, glass fabrics must be treated with additives that keep the fabric bound together until it is wet-out with resin; these are known as sizing or binding agents. Because of the short, random fiber makeup, binders are needed primarily for CSM fabrics. Additionally, glass is a relatively slick surface, so another agent, known as a coupler, is needed to allow the resin to get a grip on the filament.

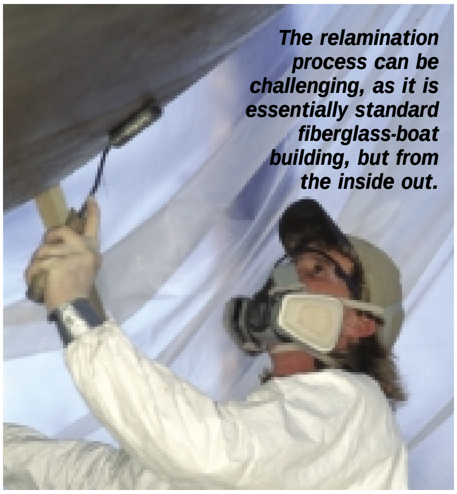
A hull peeler in action. This tool is capable of removing gelcoat and laminate with great precision.

Water, the universal solvent

The hot-tub and spa industry faced the osmotic blister problem in the '60s. As it turns out, hot chlorinated water is the ideal vehicle for promotion of osmotic blistering. Their response was to get rid of gelcoat altogether, opting for an acrylic-sheet skin instead. Further study revealed that acrylic is actually more permeable than good gelcoat that's applied in the proper thickness. The key to acrylic skin's success for the hot-tub folks was its lack of water-soluble materials (WSMs). WSMs, as we'll see, are the primary villain in the fiberglass blister saga.

In simplified form, the chemical processes that must occur for blistering are as follows. WSMs (the aforementioned binders and couplers as well as thixotropes, such as fumed silica, which prevent resin from being too thin and runny) must be present beneath a semipermeable membrane — in this case, the gelcoat or skin coat. Water molecules, which are comparatively small and slippery, find their way through the molecular gaps in the gelcoat and FRP skin coat, where they encounter the WSMs. It's love at first sight, and marriage ensues, but the offspring are anything but cute.

As with any relationship, here's where it gets a bit tricky. Some composite experts believe that many of the WSMs aren't present in the laminate immediately after the vessel goes into service. Rather, it's only after long-term immersion that the process of hydrolysis, also known as the Le Châtelier principle, begins to work on the laminate, actually taking apart the resin matrix molecule by molecule. The result is that water-soluble components begin to appear in the laminate.


The relamination process can be challenging, as it is essentially standard fiberglass-boat building, but from the inside out.

The next process, the actual cause for the blisters themselves, then takes over. According to Thomas J. Rockett Ph.D., a research professor at the University of Rhode Island and co-author of the U.S. Coast Guard-funded study *The Cause of Boat Hull Blisters*, water molecules enter the laminate via a process known as permeation. That in and of itself is not a problem as long as the water doesn't react with anything on its journey through the laminate. Nearly all plastics, including FRP, are permeable to some degree. The difficulty occurs when the water encounters a reactionary agent, such as a WSM. Rockett describes the osmotic process as, "Water molecules can pass through this (semipermeable membrane, the gelcoat and laminating resin) layer, but the WSM molecules cannot (because they are larger than water molecules). Since the outside water and the solution are of different concentrations, water will permeate through the gelcoat, in an attempt to dilute the droplet of solution trapped in the laminate. During the process, more water enters the droplet, causing it to expand and create pressure on the surrounding hull material. It takes place whenever two solutions of different concentrations are surrounded by a semipermeable membrane. When the pressure exceeds the deformation point of the hull material, it begins to flow or crack. This decreases pressure and allows more space for water to be drawn into the solution. As the pressure grows, a blister forms on the surface."

From this description, it is clear that the blister is the final step in the hydrolysis/osmosis problem. The aforementioned WSMs, coupled with permeability and the resultant susceptibility to hydrolysis of the resin matrix, appear to be the real culprits. Thus, one could conclude that the primary cause for osmotic hull blistering is the WSMs, although this borders on oversimplification, because the WSMs are one of several necessary ingredients. These necessary evils are the previously mentioned couplers that allow resin to stick to glass filaments. Binders, particularly those applied as an emulsion, which were pop-

Interlux's Interprotect 1000 is a high-build epoxy primer used for sealing hull laminate after gelcoat is removed.

Courtesy Interlux

ular in the '70s and early '80s, that are used in some CSM and combination mat/woven/knitted-fiberglass cloth products, have also been identified as having strong WSM potential. Additionally, thickening agents or thixotropes such as fumed silica, which are added to resin to increase its viscosity (resin that's too thin will simply run out of a laminate), are also water-soluble.

Adding insult to injury in the blister-formation story is the recent release of research indicating that heavily stressed fiberglass laminates are more prone to osmosis than their less-stressed counterparts. This makes sense, because stressed laminates tend to microfracture. (Sometimes the fractures aren't so small. Ever see gelcoat cracks around on-deck hardware, cleats, chain plates, etc.?) These small fractures allow water to enter the laminate more quickly than if it had to take the normal route through even a semipermeable gelcoat. Thus, it appears that where FRP strength is needed most — at the garboard, keel stub or adjacent to rudder attachments — is where osmotic action may be most aggressive.

Studies also show that osmosis is accelerated considerably in warmer water. As a result, in Florida, for instance, osmotic blistering appears to occur with greater regularity than in Maine. However, beware of quick analyses from armchair chemists using anecdotal evidence. For example, the word on the street is that boat A blisters badly, while boat B hardly ever gets blisters. If, however, boat A was manufactured in Florida and most of the units were sold in the Southeast and, because of boat A's design, it's not used in colder climes, then boat A is certainly more prone to blistering because of design as well as environmental factors. Boat B, on the other hand, having been made using similar materials and manufacturing processes, but in New England, where it's heavily marketed and, because of it's design, is well suited for rougher, colder waters, may show far fewer examples of osmosis.

Courtesy Gougeon Brothers

West System 105 epoxy resin (shown with hardener) can be cured in a wide temperature range to form a barrier coat.

Add to this already complicated scenario a further wrinkle. Evidence appears to suggest that prolonged immersion accelerates hydrolysis and the osmotic process. Thus, boats that are used and stored in the northeast United States or Great Lakes, where climate dictates seasonal hauling, are less likely to suffer from blisters than their tropical and subtropical brethren, regardless of laminate makeup. Simply put, periodic hauling, which facilitates some drying of the gelcoat, tends to stave off or at least delay the onset of osmosis.

There remains some disagreement on the subject of frequency of osmosis occurrence in fresh water vs. seawater. Some believe that osmosis occurs more quickly in the fresh water rather than salt water, while others believe the inverse. Those in the latter group point out that salts (not just sea salt or sodium chloride, but a vast array of ionic compounds created during a combination of elements) promote osmotic reactions. Science and history, however, appear to be on the side of accelerated osmosis occurring in fresh water because it is less dense than seawater and thus permeates semipermeable membranes with greater ease. Again, anecdotal evidence can be misleading. While osmotic blistering does occur in the Great Lakes, it is far less common on a per-capita basis than osmosis in the southeast United States. The Great Lakes freeze over, requiring boats to be hauled every winter, facilitating drying.

Resin manufacturers and laboratories that carry out osmosis-resistance tests nearly universally use hot, sometimes boiling fresh water, in order to accelerate testing. A wet doormat, saturated with rainwater, left on a gelcoated surface will cause blistering, sometimes in a matter of weeks. Experience shows, however, that osmosis does occur in both fresh water and seawater environments.

In the second part of this two-part series, we'll explore the details of what happens to an osmotically challenged hull, the chemistry of how it may be weakened, moisture testing, osmosis repair and prevention. ■

Contributing Editor Steve C. D'Antonio is also the boatyard manager of Zimmerman Marine in Mathews, Va.

Web Extras *For more information on fiberglass laminates, go to* **www.OceanNavigator.com** *and click on the Web Extras button.*

Author's note: *In the interest of full disclosure, it is important to clarify that I am not a disinterested party where the subject of fiberglass blisters is concerned. For the past 16 years I have worked in the marine industry, the last seven as the manager of a boatbuilding and repair yard that, among many other specialties, repairs osmotically blistered boats. For the past 11 years, I have written and lectured about this and many other marine service and repair subjects.*

Lest any reader draw the conclusion that my goal in writing this article is self-serving, rest assured, the quantity of revenue derived from blister repair in the yard I manage constitutes a small fraction of the overall business conducted. Simply put, although I have supervised scores of these repairs and no doubt will supervise many more in coming years, osmosis repairs do not bear heavily on the profitability of my boatyard.

Although considered worthy of debate by some, all of the notions set forth in this text are well established within respected quarters of the professional boatbuilding, resin-manufacturing and blister-repair trades. I break no new ground in what follows. My goal in writing this article is wholly educational, an attempt to assist the boatowner in making the best, most economically sound decisions as well as preventing him or her from being misled by inaccurate information when contemplating a blister repair or the purchase of a new and hopefully blister-resistant boat.

A fiberglass peeler at work. Sometimes the only solution to blisters is removal of several layers of fiberglass from a hull.

Blister analysis and repair

Part two of our series on blistering in fiberglass hulls and how it can be fixed

Story and photos by Steve C. D'Antonio

In the first of this two-part series on fiberglass blisters (see *Fiberglass blisters and barrier coats* Issue 136, March/April 2004), we detailed how fiberglass boats are built, the materials that are used and some of the causes of fiberglass blisters. In this, the second installment of the series, we'll explore the chemistry of fiberglass that suffers from osmosis, as well as moisture analysis, repair strategies and prevention.

For the most part, the causes of osmotic blistering are well understood, by both the reader and the industry as a whole. So one might ask, other than cosmetics, why is it a problem? The answer to this question is multipronged. Primarily, during the osmotic process, chemically acidic compounds are created, such as acetic acid. Acetic acid attacks resin, leading to what the industry calls resin corrosion or fiber whiting. The purple, vinegar-smelling liquid (the Latin name for vinegar is *acetum*) that runs out of some burst osmotic blister is a result of water mixing with polyvinyl acetate (PVA), which is used as a coupling agent. When water encounters the acetate component of PVA, the byproduct is acetic acid.

When fiberglass laminates are removed for blister or other repairs, these resin-starved areas are often mistaken for poorly wet-out glass fabrics. Essentially, it's easy to conclude that the vessel was built poorly because the laminating crew didn't take the time to ensure that the glass filaments within the fabric were completely saturated with resin. Thus, when the blister problem first began to rear its ugly head, many in the industry put two and two together and concluded that the cause of osmotic blistering — poor wet-out — had been discovered. In fact, while this may be true in some cases, FRP (fiberglass-reinforced polyester or vinylester) laminates that are in an advanced state of osmosis often exhibit large areas of fiber whiting, and experts now know this is an effect of osmosis, not the cause. These areas of resin starvation or resin corrosion within an FRP laminate are not as strong as the day they left the mold or before they began to suffer the ravages of osmosis. To what extent they are weakened is subject to continued debate.

An additional problem created by osmosis is the effect that water absorption has on polyester resin. Water is a plasticizer: When plastics (such as FRP) absorb water, they become pliable. This softening has some effect on the fatigue resistance of an FRP laminate. Under the right circumstances, severely saturated laminates may work-harden or crystallize at hard points, such as bulkheads, stringers and keel stubs. The question is, just how much will a wet, plasticized laminate flex compared with a dry laminate? Unfortunately, no one really knows for sure. There is a host of variables, and if the tests were done with current resins, it would be meaningless for those older resins that are of a different chemical makeup and have been in service for many years. All other theories aside, water absorption by FRP laminates is less than beneficial.

We know today that the majority of osmosis problems originate from resin and glass fabric additives — the water-soluble materials (WSMs) — rather than insufficient wet-out of the fibers when the hull is laid up. Although poor wet-out can accelerate osmosis — each glass filament that is not saturated with resin becomes a wick for water ingress into the FRP laminate — it is of secondary concern. Short glass filaments, such as those used in chopped strand mat (CSM), tend to promote osmosis; however, as mentioned, it is really the emulsion binders found in this material that cause the problem. The short, wispy strands, which tend to poke through cured resin, are simply a vehicle for water molecules to reach the WSMs that lie within the laminate.

This theory is borne out by the fact that chopper gun–applied chop — similar to CSM, but applied with a gun rather than in rolls — is less likely to blister, once again citing the University of Rhode Island study. In spite of the fact that it, too, is made up of short, wick-like fibers, it lacks the binding agent found in roll mat. Because it is applied with a gun from a spool of material that passes through cutting or chopping blades, it requires no sizing to maintain its structure until laminated with resin.

It is ironic that chopper gun laminates — frequently used in production boatbuilding and often looked down upon as machine- rather than hand-built laminates — while perhaps not as sturdy as hand lay-ups, are less likely to fall prey to osmosis.

Finally, it's worth noting that several factors, in addition to the poor wet-out of the skin coat, can act as accessories to osmosis. Less-than-careful or -ideal FRP boatbuilding practices go a long way toward assisting the osmosis demon. These include inattentiveness to the timing window when applying the skin coat over the gel coat in the mold, as well as allowing fiberglass fabrics to become contaminated with moisture, sawdust and other contaminants before they are used in FRP construction.

Moisture testing

Confirming the presence of water in a blistered hull may seem unnecessary; if the blisters are there, then it's obvious the laminate is wet, right? Not necessarily. There are a few, albeit less common, causes of blistering. Blisters found in a vessel's topside, well above the waterline, are usually not the result of osmotic action. Defective or improperly catalyzed resin may develop blisters. Additionally, FRP manufacturing tools that are malfunctioning may promote osmotic blistering through localized over-catalyzation.

Additionally, knowing how deeply affected the laminate is by the presence of water is important for the repair process. If, for instance, osmosis has affected only the gel coat, then attacking the problem any deeper than that is a waste of effort and money. Conversely, applying a surface repair to a laminate that is suffering from deep water saturation is applying the proverbial Band-Aid to a gaping wound.

Moisture testing comes in two forms, nondestructive and destruc-

A moisture meter, used by a seasoned professional, is a valuable tool in determining the extent of water saturation in fiberglass. Note, readings taken through antifouling paint are not definitive.

tive. The former can be performed by a boatowner with a minimal investment in tools or time. Begin by sanding the antifouling paint from a 1-square-foot area of the hull, exposing bare gel coat or whatever is beneath the paint (sometimes it's a barrier coat from a previous, oft-times failed, osmosis repair). Do this in at least one, but preferably several areas below the waterline. It is important to note that most antifouling paints either retain water or contain metal, both of which will affect moisture tests, and thus, antifoulants must be removed from the equation during any moisture analysis.

Over this area, secure a layer of restaurant-grade clear plastic food wrap, using all-weather masking tape, or an equivalent waterproof tape. Do not use ordinary masking tape or duct tape; it is not water resistant. Leave the test area for several days. If, upon your return, moisture is detected on the inside of the plastic, chances are good that the laminate contains water. How much water and how deeply it has penetrated is anyone's guess. This is what the cheap test buys you, a yes or no answer rather than one of degrees.

The remaining two tests are semi-destructive and destructive. The first involves a moisture meter, which — through capacitance and impedance measurement, essentially using radio waves — assesses the amount of moisture in a laminate. Technically, it is nondestructive in that it reads through a laminate to a depth of approximately a quarter inch. However, in order to assess where the water-saturation wave ends, some laminate disassembly — and thus destruction — is necessary.

A valuable tool

In the hands of an experienced professional, a moisture meter is an extremely useful and valuable tool in the osmosis analysis process. In the hands of an inexperienced user, however, the results this tool yields are valueless at best and costly at worst. Most capacitance-type moisture meters will, for example, show a block of ice to be a dry substrate. Therefore, these tools should only be used on a hull that has not experienced freezing temperatures in the past 48 hours. Metal objects, such as an imbedded strut, fastener or even a tank on the inside of a hull, will falsely peg a moisture meter as if it had been placed on an aquarium.

The moisture meter test, sometimes known as a patch test, begins the same way as the plastic-wrap test, with removal of antifouling paint in an area or areas roughly 10 or 12 inches square. The gel coat or other substrate is then tested. If the meter reads “dry,” then no further testing is necessary. However, if the hull has blisters, this is unlikely. Then, in the hands of a skilled operator, a grinder is used to remove the first layer of substrate, gel coat or barrier, exposing the first FRP laminate. This is tested with the meter and the results recorded. The process is repeated, removing successively deeper laminates, one laminate at a time, until an acceptably dry laminate is reached.

The final destructive test involves drilling a 1-inch hole in the hull in one or more locations. (Because repair of a hole like this can be expensive, whether osmosis repairs are undertaken or not, a seacock can be installed to fill the gap.) This provides a 1-inch sample of the bottom that can be sent to a laboratory that specializes in this type of analysis. The presence of moisture can be confirmed, laminate ply by laminate ply.

On the occasions where I’ve decided to confirm the results of the moisture meter with a lab test, the results have always been parallel. Thus, I have faith in the moisture meter, provided it is in the hands of a skilled professional.

What is considered dry as far as a moisture test is concerned? It’s amusing to hear even seasoned professionals refer to osmotically saturated hulls as reading 50, 70 or 100 percent wet. In reality, the numbers are a measure of a relative scale. For the meter I use, a Tramex, one of the scales is 0 to 100, and anything over about 5 is considered compromised and thus too wet to barrier coat or laminate over with new FRP. That 5, however, translates to 0.5 percent moisture by weight. Anything below that is, of course, cause for celebration. Hulls in the sub-5 category are dry and will, in all likelihood, fail to develop blisters, although numbers above 5 do not guarantee protection

The results of a patch test are written on a hull. The percent symbols seen here are not correct, as all moisture meters read out on a relative scale.

from future blistering. A thoroughly water-soaked hull may contain 2 to 3 percent moisture by weight, and a 100 on the same Tramex scale indicates only about 1.75 percent moisture by weight. As a standard field check, moisture meters should be calibrated on a vessel's topside, well above the waterline. Under all but the most unusual circumstances, these should read dry.

The repair process

Since the advent of the osmosis-induced fiberglass hull blister, several repair strategies have emerged. Initially, there was a period of trial and error, particularly in the early 1980s. Repair yards struggled, with good intentions, to cure this ill that was plaguing what was now known to be far from maintenance-free FRP.

Once the causes of osmotic blistering were defined clearly — essentially the permeation of water into what was hitherto thought impermeable — the natural repair progression leads toward drying out these water-logged laminates. In the early days, this involved removal of the gel coat, in order to let the hull breathe, then allowing Mother Nature to suck the moisture out by simple evaporation, the same way a puddle evaporates when the sun comes out.

Unfortunately, the drying method rarely yielded a long-term repair, then and now. Hulls that indicated dry according to the moisture meter were placed back in service only to redevelop blisters. Despite refinements to the drying technique, the application of infrared heat, dehumidifiers and vacuum pumps, the results were less than positive. Most boats that were dried out and coated with a proper barrier, usually a form of epoxy, suffered from blisters at some point in the near future, sometimes as long as three or four years or as quickly as a few months, after being placed back into service.

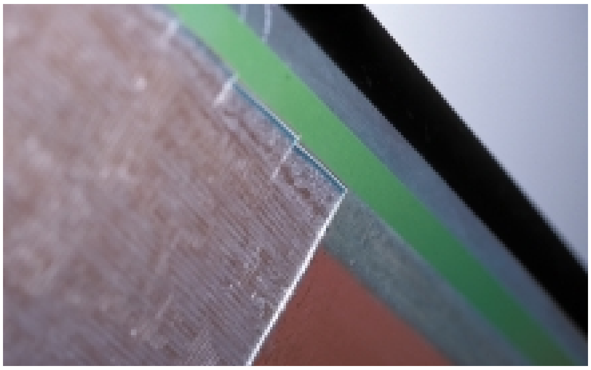
Why is the drying process so ineffective? Because the root causes of the osmosis, WSMs, are not removed through evaporation. They remain, waiting for even the smallest amount of moisture with which to react, beginning the osmosis process once again. Additionally, drying, even if successful, does not address the resin corrosion and delamination that usually accompanies osmotic blisters. Finally, some of the osmotic byproducts — acetic acid and glycols — evaporate very slowly, if at all, under even ordinary atmospheric conditions. The likelihood of these chemicals evaporating out of a dense substrate such as FRP is slim, indeed. Left behind, they continue to take their toll on the resin, particularly the acetic acid.

Getting a peel

When it became evident to the boatyards that were carrying out the drying of osmotically sick vessels that this was not a long-term solution, the search for a cure began anew. The method that was eventually developed and the one that is used extensively today, involved peeling off the affected laminate and relaminating with the improved vinylester resin.

After a moisture analysis has been carried out, it is possible to determine the depth to which an afflicted laminate needs to be peeled. The “wet” laminate is peeled off using a planer-like device, whose depth of peel can be controlled precisely to increments as small as 1/32 of an inch. Most electric peelers utilize vacuum containment, and as a result, they are neat, clean and efficient. Other hydraulically powered peelers use water for cooling and carrying away the removed FRP slurry. This detritus is often captured beneath the vessel by mesh plastic sheeting. Because osmotically affected FRP is far from inert, it should not be allowed to run directly onto the ground or into nearby estuaries.

Vinylester (VE), the repair resin of choice, has proven to be virtually blister proof over the past 15 years, in both field use and in laboratory testing. The reason for this is vinylesters



The depth of a peeler's cut on a single pass can include gel coat and one or two laminates. Deeper cuts require multiple passes.

are nearly immune to hydrolysis, the disassembly of the resin matrix as a result of long-term exposure to water. In keeping with the theory that all plastics permeate, recent studies show that VE resin will absorb water and plasticize, to some extent. But VE will not suffer from hydrolysis. If the resin fails to hydrolyze, WSMs, a necessary ingredient for osmosis, never become available, and blisters never form.

The relaminating process using VE resin, after the hull has been peeled and properly prepared, must incorporate a minimum of two laminate layers or 1/10 of an inch of laminate. This depth of applied material ensures that an appropriate exothermic reaction or heating takes place. This reaction is necessary for the resin molecular chains to interlink properly. Ideally, the laminate that is removed should be duplicated exactly, once again to the previously stated minimums. Any FRP material that is removed must always be replaced. Although it is tempting to add a little more, chances are good that the naval architect who designed your boat knew what he was doing, and thus, his laminate schedule is appropriate and is worthy of duplication. For the same reason, failing to replace some or all of the removed material is forbidden.

VE resin has a higher tensile strength and tensile elongation factor than the original PE resin as well as possessing excellent secondary bonding attributes. Provided the moisture analysis, peel, preparation and lay-up are carried out properly, the relamination should be quite strong and immune to future blisters.

Epoxy barrier coat

The final step and what may be termed the suspenders of a belt-and-suspenders approach is the application of an epoxy barrier coat over the relaminated hull. My preference is for a high-solids, epoxy-based, warranted coating that is backed by a reputable manufacturer of marine products. Resist the temptation to use products that make incredible or fantastic claims. Instead, go with a proven performer who has a long-term track record of standing behind their product.

Because osmotic blister correction is not a do-it-yourself process, choose the yard that undertakes your blister repair carefully. Using the method described here or a reasonable facsimile, a repair yard should be prepared to offer a warranty against blister reappearance for a minimum of five years, preferably 10. Ask for references, and talk to the owners of boats who have had the treatment, both recently and in years past. Inspect at least one finished product and insist on a written, fixed price *quote* rather than a verbal or written *estimate*.

As the old expression goes, an ounce of prevention is worth a pound of cure. The owner of any vessel that is manufactured from PE resin and is not currently suffering from blisters or a saturated laminate, should strongly consider the application of the barrier coat described here. A few barrier coat manufacturers offer excellent osmosis warranties of their own, provided the product is applied over a certified dry laminate. Applying a barrier coat to a new vessel that has not yet been coated with antifouling paint is relatively inexpensive, while applying a barrier to a dry laminate that has already been coated with antifouling paint is a bit more time consuming, requiring the removal of the antifouling paint. This is still very much worthwhile and recommended for blister prevention.

The business end of a fiberglass peeler. The interchangeable blades must be kept sharp for precise cutting.

Today, high-quality boat manufacturers are building entire vessels using VE or epoxy resin, which yields not only a blister-resistant structure but one of superior strength as well, or they are skin coating with VE resin.

If you are shopping for a new boat, the value of a VE resin laminate, skin coat or all epoxy must be weighed carefully. Additionally, a no-blister hull warranty of no less than five years should be considered a prerequisite. ■

Contributing Editor Steve C. D'Antonio is a freelance writer and the boatyard manager of Zimmerman Marine in Mathews, Va.