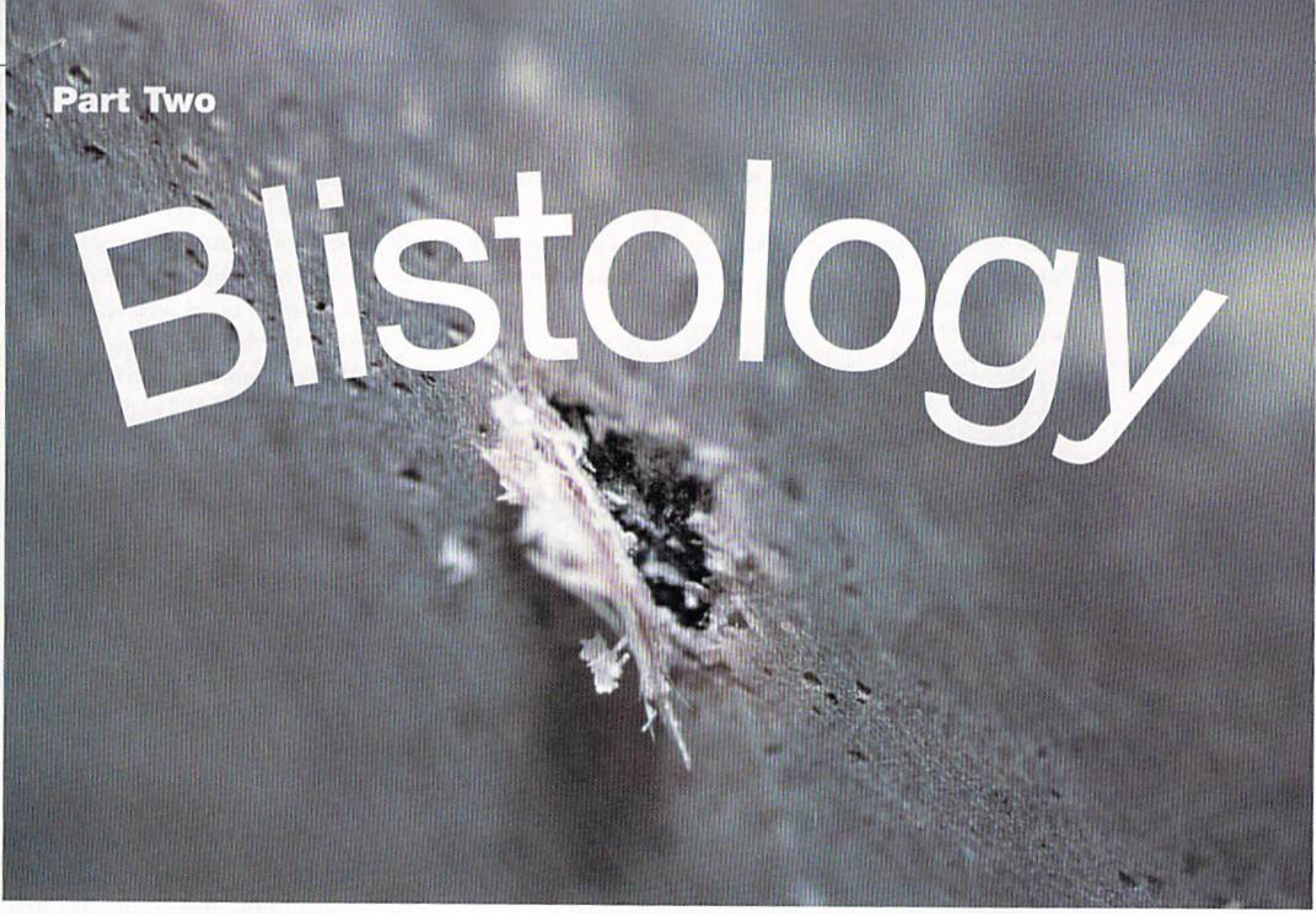


Treating And Preventing Hull Blisters

Story And Photography By STEVE C. D'ANTONIO

In the first part of this two-part series on fiberglass blisters (see *PMM*, July '06), we detailed how fiberglass boats are built, the materials that are used, and some of the causes of fiberglass blisters. In this final installment of the series, we'll explore why the chemistry of fiberglass makes it susceptible to osmosis, and we'll also look at moisture analysis, repair strategies, and what can be done to prevent hull blisters.

Now that, for the most part, the causes of osmotic blistering are well understood by both the reader and the industry as a whole, one might ask why blistering remains a problem. The answer to this question is multi-pronged. Before a boat owner can proceed to secure a successful repair for osmotic blistering, or take steps to prevent hull blisters in the first place, it is crucial to understand not just how osmosis causes fiberglass blisters, but also how osmosis affects the fiberglass laminate and how to determine what level of repair is needed.

CAUSE AND EFFECT

During osmosis, the primary chemical reaction is one in which glycols and acidic compounds, such as acetic acid, are created. For example, when water encounters the acetate component of polyvinyl acetate (PVA), which is used as a coupling agent in the laminate process, the byproduct is acetic acid. The purple, vinegary-smelling liquid (the Latin name for vinegar is *acetum)* that runs out of some burst osmotic blisters is a result of water mixing with PVA. The acetic acid attacks the resin in the laminate, leading to what the industry calls resin corrosion or fiber whiting. The effect is to starve the laminate of resin, thus weakening the structural integrity of the laminate.

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 would be easy to conclude that a vessel in this condition was poorly built 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 (incorrectly, as it turned out) that the cause of osmotic blistering had been discovered: poor wet-out.

In fact, while poor wet-out may be a problem in some cases, FRP (fiberglass-reinforced polyester) laminates in an advanced state of osmosis often exhibit large areas of fiber whiting, and experts now know that this is an effect, not the cause, of osmosis. 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 these areas are weakened is a subject that continues to be debated.

An additional problem created by osmosis is the effect that water absorption has on polyester (PE) 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 water-saturated laminates may work-harden or crystallize at rigid points, such as bulkheads, stringers, and keels. The question is, just how much will a wet, "plasticized" laminate flex compared to a dry laminate? The answer: No one really knows for sure. There are a host of variables, and any tests done with resins now available would be meaningless for older resins that have a different chemical makeup and have been in service for many years. The bottom line is that whatever theory you subscribe to, water absorption by FRP laminates is less than beneficial.

Some in the blister-analysis and repair industries—surveyors, repair yards, and so on—have postulated that the incidence of osmotic blisters in FRP laminates coincided with the oil crises of the 1970s. True, the price of resin, which is a petrochemical, did increase dramatically during this time and has remained expensive. Five gallons of polyester resin costs between $80 and $120 today, while in the pre-oil-crisis '60s and '70s, it sold for a mere fraction of this price. Thus, the more valuable this commodity became, the stingier the manufacturers were with its use, which led to poor wet-out, or so the theory went.

In reality, we know today that the majority of osmosis problems originate from resin and glass fabric additives, such as binding agents. As explained in Part One, the process of hydrolysis turns these additives into water soluble materials (WSMs) that then react with the water molecules present in the water-saturated laminate. Although poor wet-out can accelerate osmosis (for example, 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, 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.

Opposite page: Anatomy of a blister. The dome of this blister has been dislodged by the first pass of a peeler, revealing the delaminated section beneath. Above: This blister's dome has been broken, revealing the short glass strands that are probably part of either chopper gun-applied reinforcement or chopped-strand mat. Many fiberglass experts believe that these short strands provide a path for water ingress into the laminate.

To cite once again the University of Rhode Island study mentioned in Part One, this theory is borne out by the fact that chopper gun-applied chop, which is similar to CSM but applied with a gun rather than in rolls, is less likely to blister. While 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, an additive that could introduce WSMs, to maintain its structure until laminated with resin.

It is ironic that chopper gun laminates frequently used in production boatbuilding, while perhaps not as sturdy as hand layups and often looked down on by some as laminates that are "machine" rather than"hand" built, are less likely to fall prey to osmosis.

Finally, it's worth noting that in addition to poor wet-out of the skincoat, several factors can act as accessories to osmosis. Less than careful or less than ideal FRP boatbuilding practices go a long way toward assisting the osmosis demon. These include inattentiveness to the "timing window" when applying the skincoat over the gelcoat 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, it's obvious the laminate is wet, right? Not necessarily. There are several other, albeit less common, causes of blistering. For instance, 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 boatbuilding tools that are malfunctioning may, through localized overcatalyzation, promote osmotic blistering.

Additionally, it is important to know how deeply water has penetrated into the laminate before beginning a repair. If, for instance, osmosis has affected only the gelcoat, 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 destructive. The former can be performed by a boat owner with a minimal investment in tools and time. Begin by sanding the antifouling paint from a 1-square-foot area of the hull, exposing bare gelcoat or whatever is beneath the paint in at least one, but preferably several, areas below the waterline. (Sometimes it's a barrier coat from a previous, often failed, osmosis repair.) It is important to note that most antifouling paints either retain water or contain metal, both of which will affect moisture test readings; 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, as they are not water resistant. Leave the test area for several days. If, when you return, you detect moisture on the inside of the plastic, chances

One step in the process of ensuring that blisters will not reoccur involves removing the "wet" or affected laminate. The most efficient and least invasive way of doing this involves using a planer-like tool, known as a peeler.

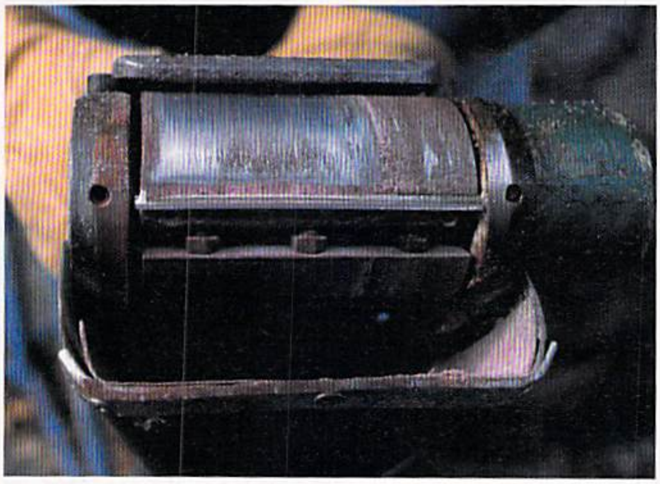
are good that the laminate contains water. How much water has sunk in and how deeply it has penetrated is anyone's guess. This is what the cheap test buys you—a yes or no answer, rather than one of degrees.

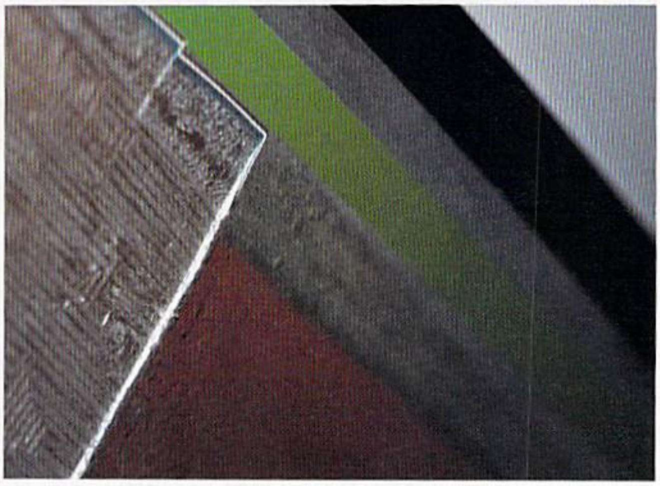
The remaining two tests are semidestructive and destructive. The semidestructive test involves a moisture meter that measures capacitance and impedance, which are essentially radio waves, to assess the amount of moisture in a laminate. This test is technically nondestructive in that it reads through a laminate to a depth of approximately 1/4 of an inch. However, to assess where the water saturation wave ends, some laminate disassembly, and thus destruction, is necessary.

It is worthy of note that 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. For example, most capacitance/impedance-type moisture meters will 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—that is, very wet.

The moisture meter test, sometimes known as a patch test, begins the same way as the plastic wrap test, with the removal of antifouling paint in an area or areas roughly 10 or 12 inches square. The gelcoat or other substrate is then tested. If the meter reads "dry" (more on what this means in a moment), no further testing is necessary. However, if the hull has blisters, a dry reading is unlikely, and a skilled operator then uses a grinder to remove the first layer of substrate, known as gelcoat or barrier coat, to expose the first FRP laminate. This is tested with the meter, and the results are recorded. The process is repeated, removing successively deeper laminates, one laminate at a time, until an acceptably dry laminate is reached.

The final, and clearly destructive, test involves using a hole-saw to drill out a 1-inch core sample from the hull in one or more locations. (Because repair of a resulting hole can be expensive, a seacock can be installed to fill the hole, whether or not osmosis repairs are undertaken.) This drilled-out core provides a 1-inch sample, or "coupon," of the bottom that can then be sent to a laboratory that specializes in this type of analysis. The presence of moisture can be confirmed, laminate ply by laminate ply.





Left: The business end of a peeler. The carbide blades are capable of removing several laminates in a single pass, quickly and accurately. The material is sucked into a storage drum by a vacuum as it is cut away by the peeler. Right: The depth of laminate removal can be precisely controlled using the peeler, as seen here. This removal depth can be checked as the work progresses.

I am often asked about the accuracy of a moisture meter. My answer is always prefaced by the same words: "In the hands of an experienced professional...." In my experience, the moisture meter that I (and the FRP professionals who work in my yard) use nearly always yields accurate and reliable results. 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 acceptably dry as far as a moisture test is concerned? It's always amusing to me to hear even seasoned professionals refer to osmotically saturated hulls as reading "50, 70, or 100 percent" wet. In reality, the numbers quoted are a measure of a relative scale. For the meter I use, a Tramex, one of the scales is

While the peeler removes the bulk of the affected laminate, the surface must still be dressed using a grinder. In the hands of an experienced professional, a grinder is a useful tool. The uninitiated, however, can quickly cause more harm than good if this tool is used incorrectly.

0–100, and anything above a reading between 5 and 10 is considered compromised and thus too wet to barrier coat or laminate over with new FRP. That 5–10 reading, however, translates to roughly .5 percent moisture *by weight.* That's right, half a percent. Anything below that is cause for celebration. A hull in the sub-5 category is "dry" and will, in all likelihood, not develop blisters, although numbers above 10 are far from a guarantee of future blistering. A thoroughly water-soaked hull may contain 2–3 percent moisture by weight, while 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 areas should read dry.

THE REPAIR PROCESS

Since the advent of osmosis-induced fiberglass hull blisters, several repair strategies have emerged. Initially, there was a period of trial and error, particularly in the early '80s. Repair yards struggled, with good intentions, to cure this ill that was plaguing what was by then known to be far-from-maintenance-free FRP.

Once the causes of osmotic blistering were clearly defined—essentially, the permeation of water into what had, until then, been thought of as impermeable—the natural repair progression led toward drying out these waterlogged laminates. In the early days, this involved removing the gelcoat 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 or now. Hulls that indicated "dry" according to the moisture meter were placed back in service, only to redevelop blisters. In spite of refinements to the drying technique, which was 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) invariably suffered from blisters at some point, 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 WSMs, which are the root cause of the osmosis, 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 accompany osmotic blisters. When exposed for repair, many osmotically affected hulls reveal either osmosis-induced damage or building defects and delamination, both of which are typically repairable. Finally, some of

Top: After the first pass, one can clearly see that the blisters on this boat extend deep into the laminate. In this case, two passes with the peeler will be required in order to remove all the affected fiberglass. Above: Precut rolls of new fiberglass reinforcement ready to be applied to a recently peeled hull. Because the application is essentially carried out upside down, it is important that the applicator do as much premeasuring and cutting of the fabric as possible.

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Visit us at **www.fischerpanda.com**, or e-mail us at sales@fischerpanda.com the osmotic byproducts, acetic acid and glycols, evaporate very slowly, if at all, under even ordinary atmospheric conditions. Therefore, the likelihood of these chemicals evaporating out of a dense substrate such as FRP is slim indeed. Left behind, these chemicals, particularly the acetic acid, continue to take their toll on the resin.

When it became evident to the boatyards that trying to dry out osmotically sick vessels was not a long-term solution, the search for a cure began anew. The method that was eventually developed, and is still used extensively today, involves cutting or peeling off the affected laminate and relaminating with vinylester (VE) resin, which has been shown to be superior to other resins.

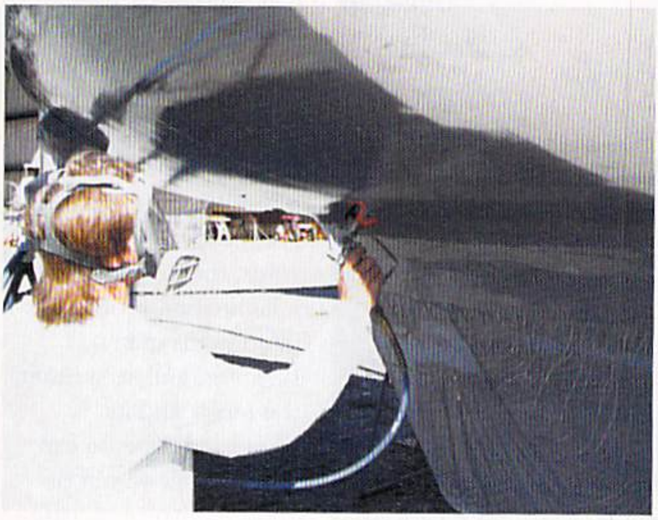
After a moisture analysis has been carried out, it is possible to determine the depth to which an afflicted laminate needs to be peeled. The wet laminate is peeled off using a planer-like device whose depth of peel can be precisely controlled to increments as small as 1/32 of an inch. Most electric peelers use vacuum containment, and, as a result, they are neat, clean, and efficient. Other hydraulically powered peelers use water for cooling and to carry 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.

Particle blasting with sand or other media is an alternative to peeling and is more readily available; this method is being used extensively in the coating business and in other industries. Beware, however, as it is much less precise than peeling, and it requires tenting the bottom of the boat that is being treated, making visibility for the blast operator quite difficult. Contained blasting has its place in the boatyard, but, in my opinion, it is not appropriate for precise gelcoat and fiberglass removal.

As a measure of control, I can rout (using a standard router) several lines into the bottom of a hull that is to be peeled, to the precise depth of cut required. After the peeler has passed over these route lines, I can determine immediately whether the operator is peeling too deeply, not deeply enough, or to the correct depth. Standing behind the sand blaster to confirm depth of material removal is simply not a practical option, as the results become evident only during breaks or after completion.

Vinylester, the repair resin of choice, has proven over the past 15 years, in both field use and in laboratory

While a skilled pro can make it look easy, the relamination process is often difficult at best, requiring fiberglass technicians to essentially apply resin-soaked fiberglass reinforcement while working upside down.



Top: Applying an epoxy barrier coat and then bottom paint using an airless sprayer ensures good coverage of both of these coatings, as well as an exceptionally smooth finish. Middle: The key to the proper performance of an epoxy barrier coat is its thickness. Here, a coating technician measures the millage of a coating as it's applied. Above: An epoxy barrier coat offers a formidable deterrent to water penetration. This can and should be used on all new vessels, as well as those that have undergone a proper blister repair.

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testing, to be virtually blister proof. The reason for this is that vinylesters 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. VE will not, however, suffer from hydrolysis. If the resin fails to hydrolyze, WSMs, a necessary ingredient for osmosis, never become available, and blisters never form.

After the hull has been peeled and properly prepared, a relaminating process using VE resin must use a minimum of two laminate layers—a minimum of 1/10 of an inch of laminate. This depth of applied material ensures that an appropriate exothermic reaction or heating, which is necessary for the resin's molecular chains to properly interlink, takes place. Ideally, the laminate that is removed should be exactly duplicated, 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 or she was doing. The laminate schedule for the original construction was appropriate, and, therefore, is worthy of duplication. For the same reason, it is mandatory that any repair replace the same quantity (and type) of laminate that was removed—not less.

Unlike polyester resin, which was, and still is, commonly used in FRP boatbuilding, VE resin has a higher tensile strength and tensile elongation factor and possesses excellent secondary bonding attributes. Provided that the moisture analysis, peel, preparation, and layup are carried out properly, the relamination should be exceptionally strong and immune to blisters in the future.

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 coating that comes with a warranty backed by a reputable manufacturer of marine products. Resist the temptation to use products for which manufacturers 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 DIY process, carefully choose the yard that will undertake your blister repair. Using the peel and relamination method described above, or a reasonable facsimile, a repair yard should be prepared to offer a warranty against blister reappearance for a minimum of five years and preferably 10. Ask for references, and talk to the owners of boats that have had the treatment, both recently and in years past. For inexperienced repair yards, the peel and relamination process often holds many surprises, and, as a result, the repair and its associated expense can quickly balloon out of control. Inspect at least one completed repair job and request a written, fixed-price quote rather than a verbal or written estimate. (The definitions and legal implications of the words "quote" and "estimate" vary from state to state; make sure you

This trawler has had her bottom peeled and relaminated. The blue material seen on the port side is a vinylester fairing compound that improves sandability of the vinylester resin, which makes for an exceptionally smooth bottom. Also, notice the "bottom-free" stands, which support the vessel while the work is being done without interfering with the lamination.

understand them for your region.) Finally, get it all in writing: a description of the work to be performed, exclusions, if any (if additional damage is found during peeling, for instance, this is usually not covered under the terms of the quote), and the terms of the warranty.

TODAY AND TOMORROW

As the old axiom goes, an ounce of prevention is worth a pound of cure. The owner of any FRP vessel that was manufactured using PE resin and is not currently suffering from blisters or a saturated laminate should strongly consider the application of the epoxy barrier coat mentioned above. 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 is recommended for blister prevention.

Today, high-quality boat manufacturers are either building entire vessels using VE or epoxy resin—which yields not only a blister-resistant structure, but one of superior strength as well—or skincoating the hull with VE resin. Either approach is preferable to ordinary iso-polyester laminates, although even these are more blister resistant than their ortho-polyester cousins.

If you are shopping for a new boat, the presence of VE resin laminate, a VE skincoat, or all-epoxy laminate must be considered valuable, indeed. Additionally, a hull warranty that includes coverage of blisters (many specifically exclude blisters) for at least five years should be considered a prerequisite.

The blister story has a happy ending. For the most part, the boatbuilding and repair industries now fully understand the causes behind, and cures for, osmotic blistering. Reputable, conscientious boatbuilders are aware of the problem and have addressed it by switching to blister-resistant materials and techniques. If your boat already has blisters, the news, while maybe not good, is better than it would have been a decade or more ago. More and more yards are becoming familiar with proper, long-lasting solutions for osmotic blisters. However, it's up to the consumer to choose the repair facility carefully and ensure that the process is carried out in accordance with the protocols mentioned above.

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