EPOXY® WORKS

BUILDING, RESTORATION, & REPAIR WITH EPOXY

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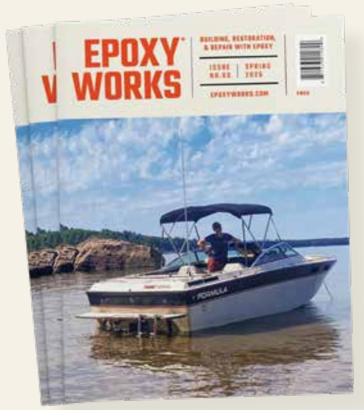
In This Issue



On the cover

Restoring strength and stiffness to a fatigued powerboat bottom. P.22

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DID YOU:

- Wrap up an interesting project?
- Discover a useful technique?
- Find a new or unusual use for epoxy?

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The Pleasure and the Pane

THE JOY OF MAINTAINING ANTIQUE HOMES

Our home was originally built in 1790 in Sutton, Massachusetts. It had never had running water nor electricity before it was demolished board by board and stored in a barn. Long story short, we bought it in 1978 and rebuilt it on a new foundation, with a new first floor framework and subfloor. We were able to reuse all of the chestnut and oak beams as the frame, as well as much of the floors, plank walls, and doors.

But this is not the main story.

46 years ago, I created thick plank frames for the windows to hold the 9 over 6 sash reproductions made by artisans. These sashes had to be glazed with individual 6" x 8" single pane glass. The seventeen window sets each require 15 pieces of glass, which meant that my wife, several family members, and I had to set, point, and glaze 255 panes. This truly was a pain.

Fast forward to 46 years later:

Sun, rain, and extremes of temperature had taken their toll on these sashes. I made a trompe-l'oeil set of replacement sash from plywood so that I could work on one set of windows at a time.

I took the time-ravaged parts out to the shop and hit them with 60-grit sandpaper on my random orbit sander. I then got out my trusty WEST SYSTEM® repair kit and 403 Microfibers.

First, I removed any rotted wood. Then I repaired any damage and sealed the wood with the WEST SYSTEM Epoxy. After it cured, I went back and filled any cracks and fissures with the epoxy, thickened to a heavy whip cream consistency, using a putty knife.

I sanded the cured epoxy flat once again, then primed the sash and painted both sides with two coats of latex paint.

These windows are good for another 46 years. Now I only have eight more sets to do!

1: The original house, before being demolished and stored in a barn.

2: The plywood faux window sash temporarily installed while the original was being repaired.

3: The WEST SYSTEM 101 packets were the perfect size for this project. Just pour, mix, and apply.

4: I used 403 Microfibers to thicken the epoxy to fill cracks and fissures.

5: The sash primed and painted with two coats of paint.

6: Our house and gazebo in the side yard.

RAY MCCARTHY

WEST SYSTEM® Epoxy works great bonding pieces of pine together for things such as this 6" x 18" finial. I turned it on a lathe 20 years ago for the top of my gazebo. The gazebo needed a repainting, so I took it off, resealed the cracks and checks with thickened epoxy, repainted it. It has been reinstalled as the crowning of our summer retreat.

Fabric Wet Out: When To Use What Tool

Wetting out fabric is very important when making or repairing any composite part. Making sure each fiber is encapsulated in resin assures the highest level of strength and durability possible. Most of us do it without thinking about what the best way might be—even I catch myself using the wrong instrument for the job sometimes. This article could help you speed up your process, make your laminates more consistent, or even save you a bit of money.

There are so many different wet-out tools and searching online brings up hundreds of results. This article will go over several different tools, when we recommend using them, as well as when it is okay to just start going at it with your gloved hands.

Rollers can be especially helpful at compacting multiple layers of reinforcing material, making for a stronger laminate.

What does wet out look like?

In order to select the best tool for the job, we need to understand what a properly wet out reinforcing fabric looks like. A wet-out reinforcing fabric is one in which every fiber is coated in the epoxy. When the epoxy fully encapsulates the fibers, loads can be evenly distributed among the fibers. The fibers are much stronger than the resin, so if that load is not distributed to the fibers, the resin can fracture, and the composite may fail. With fiberglass, it's easy to tell when the fabric is fully wet out. As fiberglass is wet it becomes translucent, and is very easy to notice. Conversely, carbon looks the same wet as it does dry—black. As you push the epoxy into the little, tiny gaps in the reinforcing fabric, air bubbles come up through the epoxy and pop. This popping sound is a good indicator that air is being forced out.

Our *Fiberglass Boat Repair & Maintenance* manual describes both the wet and dry application methods of wetting out reinforcing fabrics. One additional technique that is useful when working with heavy fabrics is utilizing a technique called back wetting, a combination of both our wet and dry methods. In this process, the fabric is placed on the surface dry, then folded back onto itself. Epoxy is applied to this backside of the fabric. When the fabric is laid flat again, the epoxy is forced up through the backside of the fabric (as opposed to top down in the typical wet method). This process makes it much easier to wet out.

Spreaders & Squeegees

Our 808 Reusable Flexible Spreaders are an inexpensive and effective method of moving epoxy, and they enable you to apply pressure to the weave to allow the infill of the yarns. Holding the spreader at a low angle makes it particularly effective at filling the yarns. Spreaders are ideal if you are applying a lightweight fabric to a hard and smooth surfaces. Spreaders are useful when making a surfboard or applying 4 oz fabric to a cedar strip canoe. An additional benefit is they also work well for fairing repairs after you have finished glassing. Using one of these plastic spreaders on thicker 17 oz fabric is possible, but it will take a long time, and your hand might start cramping before you finish. Any fabrics heavier than that are difficult to get fully wet out with just a plastic spreader, leaving dry fibers and stress concentrations in any repair or part you are making.

Serrated Rollers

Serrated rollers are typically metal, usually aluminum, with deep groves in them. This means they are substantially more expensive than plastic spreaders but still reasonable. These are particularly useful when wetting out heavy fabrics, especially if you have multiple layers of heavy fabrics. The serrations help focus your downward force into a more concentrated area and the grooves allow air to escape. This allows the epoxy to penetrate deeply into thick fabrics. These can move quickly over thick fabrics but begin to skid and slide when used with thinner fabrics. This means that while they can be used for thin fabrics you should save your time and effort and use something else. While most plastic spreaders can be considered disposable, I wouldn't want to buy new rollers every time I need to wet out some fabric, so it is important to keep these clean. You can do this by disassembling them and wiping them down with acetone, lacquer thinner, or denatured alcohol.

Corner Rollers

Corner rollers are not necessary for wetting out fabric, but I felt I should mention them. They are commonly sold with other rollers in a kit and are made of metal with several different-sized wheels on the roller. Nothing gets into a corner like these, especially in hard-to-reach places like under a bench or in a cabinet. These are primarily used to press pre-wet-out laminates into those tough corners so there is no air gap. These provide the same mechanical advantage that the serrated rollers do by focusing the downward force of your arm into a small area greatly increasing the pressure. Because these are so narrow, it would take way more time and effort to use one of these guys to wet out any large amount of fiberglass.

Bristle & Knob Rollers

Bristle and knob rollers take that mechanical advantage and dial it up to 10. What force was applied to several small strips of metal is now focused on either the points of knobs or the tips of bristles. These are usually used to wet out extremely heavy fabrics or even chop strand mats. While we don't recommend using epoxy with chop-stranded mats, this is what we would use if we did. Bristle rollers are beneficial when a thick fiber is used over a porous surface like foam. The bristles can penetrate the foam carrying the epoxy with it. This helps create a mechanical bond between the core and the laminate. However well they work for thick fabrics and mats, they work just as poorly on light fabrics. They just don't move the epoxy around nearly as well as a plastic spreader.

Hands

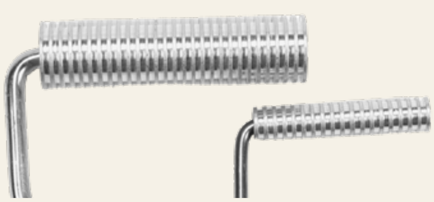
Hands are a great tool, and I'm pretty attached to my set. They are a fantastic tool for lifting and manipulating the fabric to ensure certain areas are wet out properly. They don't provide the even pressure like a roller or plastic spreader would, but they will certainly do in a pinch. They won't penetrate as deeply as any of the rollers, but hey--they're free! Finally, they won't put fabric into the corners as well as corner rollers, but they are certainly better than nothing. Like all tools that aren't disposable, you should do everything in your power to protect them. Whenever working with epoxy, be sure to wear gloves and cover any exposed skin that may get epoxy on it.

Consistently and fully wetting out your fibers is one of the most important aspects of composite repair and fabrication. There are plenty of tools that could be used to aid this process as opposed to simply using your hands. Plastic spreaders and squeegees are great for light fabrics on hard surfaces when moving epoxy around is the most important thing. Serrated rollers help force the epoxy into thicker fabrics by concentrating the force of your rolling. Corner rollers help move fabric where it needs to go but are too small for wetting fabric out. Finally, bristle rollers and knob rollers increase the applied pressure and force epoxy into very thick fabrics.

Roller Types

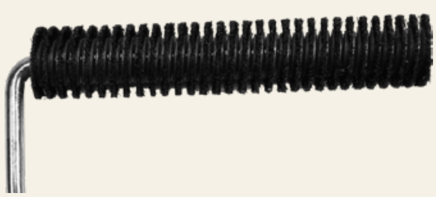
Rollers help to consolidate reinforcing layers and wet out heavier fabrics.

SERRATED ROLLERS

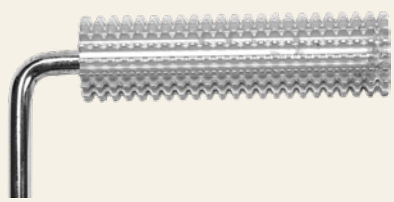


CORNER ROLLERS

BRISTLE ROLLERS



KNOB ROLLERS



 BY HUGH HORTON

Clam Girl's Capability

She's as tough as a sand barge, while light enough for octogenarians to haul her up a beach. Epoxy is key.

"But, Meade," I said in Cedar Key in 2016, "look at this model!" He'd been admiring the use of G/flex® on the house's shower pan. The 2' model was *Clam Girl*.

Clam Girl's a sailing dinghy—ten feet four inches long, four feet six inch wide—just for the Cedar Keys, on the Florida Gulf Coast eighty miles north of Tampa. Her interior is open without a dagger or centerboard trunk. No thwarts.

She's not like a windsurfer, meant to plane back and forth for the thrill of speed. *Clam Girl* is for the nuances of comfortable sailing in this unique area, most of which is within the Cedar Keys and Lower Suwannee National Wildlife Refuges.

Since I built her model from lofting back in 2013, I'd wanted to show it to Meade. Yes, convention says model first then loft. I, however, had the luxury of a big, new plywood floor, and racked on a wall were my 20' long (forty year old) fir battens. The lines drawing begged me to draw full size.

Leading up to the 2017 Everglades Challenge, Meade had been impressed by JF Bedard. The performance of RoG (JF's 15' micro expedition cruiser) that year confirmed Meade's opinion. After the Challenge, Meade told me, "JF could speed up *Clam Girl*, get you going… ." I followed Meade's advice.

JF and Simon Lewandowski brought their computers and professional software to Cedar Key. On February 2, 2018 my friend Karen and I drove back from St. Pete with JF's router cut panels lashed to my Ford® Focus. Most of the month was spent coating them with 105 Epoxy Resin® and 207 Special Clear Hardener®, and glassing selected panels.

We drilled 3⁄16" holes along the edges of the panels 3" to 4" apart. Zip day, Feb 23, we threaded zip ties through adjacent panels, snugged the ties and watched her shape resolve—the magic of stitch and glue.

Instead of a strongback, she was built on a level sheet of ¾" plywood. Before her chines hardened, I added a centerline string above her ends. I clamped on temporary gunnels and added five spacers across the sheer.

I checked and re-checked the shape, then "tacked" the seams with dabs of fillet mix. A final check because of my obsession for fairness, then the hull's shape was secured by filleting the inside seams. We faired and finished the seams with woven fiberglass tape and more 105 Epoxy Resin and 207 Special Clear Hardener. The seats and mast box were zip-tied and glassed in.

Late May was rich with fragrant teak from half inch strips, ripped from an 8⁄4" plank. Less patient builders than I could eliminate stages, but we fastened layer by layer, only with G/flex. (See "The Joy of Six10," *Epoxyworks* 48).

The last time I saw Jan Gougeon (in 2012) , he'd brought carbon cones he'd made for my Trinka 12 hull. Six years later, Simon Lewandowski molded two pairs for *Clam Girl* from Jan's cones.

September 13 2018, Simon and Bill Ling followed me and *Clam Girl* on her trailer four miles to the Shell Mound ramp in the Lower Suwannee Refuge.

Within ten minutes of pushing off, reality whacked me a vicious backhand—she didn't sound right. Instead of a light slapping-rippling from under her bow, it was a white noise of pushed, rushing water. I was glad it was just the three of us.

Jan, I know, would have frowned with empathy and commiserated, "Stuff happens." Meade might've said, "And you thought superstition was only for baseball?"

TOP LEFT:
Clam Girl cruising along comfortably.

BOTTOM LEFT:
The toe of a leeboard after the aluminum has been glued in with G-flex.

BOTTOM RIGHT:
The aluminum piece to be glued into the slot in the "toe" of the leeboard, which hits the sea bottom first. After twenty years of oyster-chewed leeboards, regardless of glass, Kevlar, and/or carbon powder experiments, the aluminum inserts are the fix.

TOP:
Kevlar in the outhaul system. The outhaul car is a Kevlar molding with a block for a double-purchase. The boom's end fitting is Kevlar, eliminating a sheave and almost all metal, while reducing length and mass.

BOTTOM:
Leeboard cone, molded off of ones originally built by Jan Gougeon.

When meeting with JF and Simon I'd forgotten to add an inch plus of rocker to my initial design. I'd thought about it months before.

Bill and Simon helped add the rocker by gluing cheap foam to her bottom with construction adhesive. Simon hot wire cut it following longitudinal guides. It was two inches thick amidships tapering to nothing at each end.

Ling, Simon and I carefully placed her bare foam into calf deep water. Displacement looked good.

We glued three millimeter plywood on the foam and again heavily glassed her with 105 Epoxy Resin and 207 Special Clear Hardener.

The relaxed "Ah, yes," launch was November 17th in Cedar Key. Friends carried her a few yards to the Faraway's beach on G Street.

Now, after four years and over a 120 daysails, with crew and solo, she and we, are happy. She's had long beats and reaches in open water. She's bashed and scraped, lurching across bars, and slipping into marshes. She wore out her first sail and has a beautiful new one, ten percent larger at 99 ft^2.

Quoting Jan, about sailing canoes compared to all his other sailboats, he often said, with a grinning, happy head shake, "Low grief!"

That's *Clam Girl*, too.

WOODEN BOAT BUILD

WOOD DINGHY BY ROBERT HALE

This design is Nick Schade's *"Coot"* plan. It was built by Robert Hale using clear old growth red cedar ¼" x ¾". He tried to orient as many strips fore and aft as possible, but the last eight strips went in straight, and he tapered the ends. These were edge glued and covered in 6 oz. fiberglass inside and out using WEST SYSTEM® Epoxy. The transom is cherry.

More on Cores

We have created videos, instructions, and *Epoxyworks* articles about repairing cored laminates, so why another article about repairing cored laminates? I thought it would be good to summarize some important aspects of cored laminate design and how to make the best repairs.

Balsa Core

First, let's discuss the most popular and dreaded topic about cored marine laminates in boats, wet balsa core. Many boat owners have had to perform major repairs to replace wet balsa and pre-purchase surveys have discovered wet core complicating a boat sale. Many boat owners ask why balsa is so popular after having a bad experience replacing wet balsa core, and there are good reasons that unfortunately can be outweighed by poor installation.

When we refer to balsa core, we are describing end-grain balsa core. This is an important distinction. Orienting the core with the grain perpendicular to the skins provides high shear strength when the laminate bends. The adjoining article ("Why Cored Composite Laminates?") explains the stress in a cored laminate and why high shear strength parallel to the skins improves the properties of the fiberglass skins. The compression strength perpendicular to the face of the laminate is also high because of the vertical grain, which improves resistance to point loads on the laminate such as walking on a deck. These high properties are achieved with a relatively low weight.

Foam Cores

Foam cores are available in many different materials and densities, but generally speaking, they do not have a weight advantage when compared to balsa IF the strength and modulus (stiffness) properties are equal. Foam is available in very low densities but the properties decrease compared to the higher-density, stronger cores. A significant advantage of foam core is the ability to tailor the properties to the application. Lower density can be used where properties can be reduced, maybe the topsides of a sailboat side towards the stern, and higher density such as near the keel sump. There are also several different types of honeycomb cores that can achieve high shear strength with low weight.

Water Intrusion

In all cored laminates water intrusion is a problem. In foam cores, water may not cause rot, but it does create a problem in freezing climates and it can cause delamination when the water is forced through the laminate from flexing when underway. Of course, balsa will rot when water is allowed into the laminate, but water intrusion into any core is a problem. Water intrusion is most likely from a manufacturing defect, poor installation of hardware, or lack of maintenance.

Unfortunately, many manufacturers do not follow the recommendations of the balsa core companies. It is always advised to fill in the scores or cuts in the entire sheet of balsa with epoxy. This process not only strengthens the laminate by filling in the gaps that create stress concentrations when bending but, if water does get into the core, it is isolated to the one compromised block. This same technique should be used with foam cores. Sealing all the cut lines in the core, when combined with vacuum bagging of the core during lamination, is an excellent way to seal every block and prevent widespread water intrusion.

Another technique a builder should use is "closing out" the core where there will be a hole. This involves eliminating the core in the area of a thru-hull fitting, beveling the core around the area (which can be done with triangular pieces of core called fillet strips), and then building up a thick solid laminate in the area with a plywood backer if needed. This adds significant labor to the building process and can often create a minor cosmetic issue in polyester resin-constructed boats due to uneven resin shrinkage but significantly reduces the risk of water intrusion. A boat that is laminated with these features is an indicator that good lamination techniques were used in the construction of the boat.

Some manufacturers make an effort to seal the kerfs and provide closeouts if modifications in the field do not follow similar practices. A new transducer, adding a new windlass, or even installing snaps for a new cover can allow water into the laminate. ALL penetrations into a cored laminate should be sealed with epoxy resin.

Maintaining and Repairing Cores

Maintenance on boats is not limited to mechanical machinery. As the boat reaches a certain age, depending on the environment, hardware should be re-bedded. This involves removing the hardware and existing sealant followed by the application of new sealant and reinstallation. My personal boat is trailered, used in freshwater, and stored indoors. As it approached its 25th birthday I removed the trim tabs and swim platform supports. The sealant had deteriorated noticeably and was causing a slight amount of movement in the swim platform. I was very glad I took the time to re-bed them, and I can even tell the swim platform brackets are stiffer now.

In my 25 plus years in the marine industry, I have witnessed many "Core Wars" between balsa vs foam vs honeycomb vs, etc. but the one thing that is an agreed-upon fact about core materials is that all cores can be poorly installed. With proper installation and maintenance, we always suggest using the core the builder selected. Using WEST SYSTEM® products and our recommended techniques, your installation may be better than new.

TECHNIQUES & TIPS

Over the years we provided many examples of core repair that may help you with your project.

HOG TIDE DECK REPAIR

CHRIS-CRAFT TRANSOM REPAIR

SWIM PLATFORM REBUILD

REPLACING DAMAGED BALSA CORE

VACUUM BAGGING TECHNIQUES

WHY CORED COMPOSITE LAMINATES?

BY RACHAEL GEERTS — **GBI COMPOSITE MATERIALS ENGINEER**

Core is a valuable part of composite construction. Core materials add stiffness while adding very little weight and usually low additional material costs. The construction of an I-beam is a perfect example of how increasing web height (or distance between two load-bearing flanges) increases the stiffness of a beam. **FIG. 1. FIG. 2** shows a solid laminate made of chopped strand mat and woven roving. The drawing on the right shows a fiberglass laminate with a balsa core. **FIG. 3** shows how a cored composite reacts to a bending load. The top fiberglass skins are loaded in compression while the bottom fiberglass skins are loaded in tension. Another visual representation of this is if you have a sponge and you draw vertical lines on the side of it. If you bend the sponge to mimic **FIG. 3**, you will see the lines toward the top of the sponge get closer together. Conversely, toward the bottom of the sponge, the lines will get farther apart. We call the pushing force that causes the lines to get closer to each other a compressive force. Meanwhile, we call the pulling force that causes the lines to move farther apart tensile force. It is the core in the middle that has to control the change between the movement on the top laminate. We refer to this opposing force as shear force. One of the good things about end-grain balsa core is that it has high shear strength for a core material.

Using these principles, we ran some calculations to find the comparative data shown in **FIG. 4**. This comparative data shows how adding balsa core to a composite panel affects different properties of the composite panel. In this table, 1t represents the thickness of a solid fiberglass laminate. For this comparative data, we kept the thickness of the fiberglass laminate the same and increased the thickness of the overall composite with the addition of balsa at varying thicknesses. As we would expect when considering the I-beam model, as the thickness of the composite increases the stiffness significantly increases. Since we are using balsa as the core material to increase the thickness of the composite, we can see that the weight increase is very minimal. When we moved on to calculating the strength of the composite, we realized we had to consider that the core may fail in shear before either of the fiberglass skins would fail. It is clear to see that the fiberglass laminates for the 4t sample would take about 9 times the load of the 1t laminate before it would fail. However, the overall cored composite of the 4t sample would only be able to handle about 2.5 times the load of the 1t laminate before the core would fail in shear. It is important to keep this in consideration because the core could have failed and there would be no visual indication of this failure when looking at the top and/or bottom skins. This is just one of the things engineers have to keep in mind when designing a composite structure, and now you can too.

Another possible failure mode that can happen in cored composite construction is crushing the core. This is most common in areas where fasteners are installed and the load is not distributed appropriately. This is why backing plates are critical when installing bolts through cored laminates. Fastener installation in cored composites is described in more detail in section 7 of our *Fiberglass Boat Maintenance and Repair Manual*.

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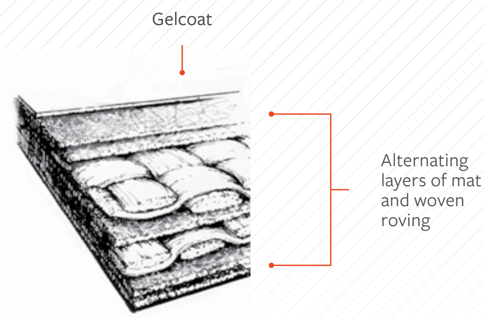

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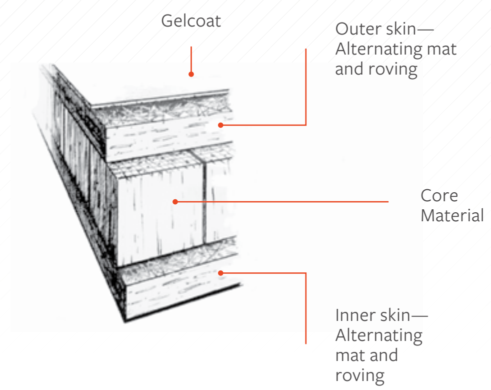

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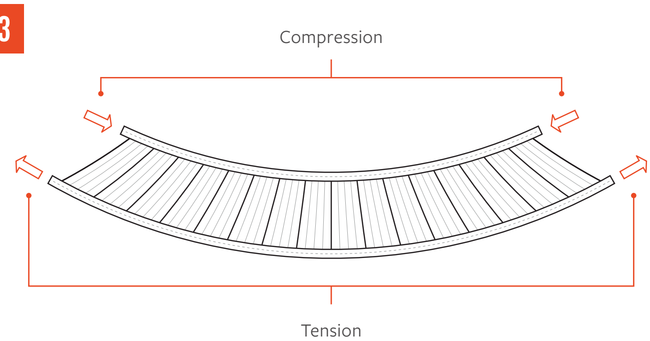


4 PHYSICAL AND MECHANICAL PROPERTIES FOR VARYING CORE THICKNESS

Total Composite Thickness*	Stiffness Increase	Weight Increase	Strength Increase to Fail the Skins	Strength Increase to Fail the Core
1t	1	1	1	N/A
2t	7	1.09	3.5	1.2
3t	19	1.19	6.3	1.8
4t	37	1.28	9.3	2.5

*Composite with a total thickness of t has no core. The thickness of the composite is increased by adding different thicknesses of balsa core.

BY ERIC SPONBERG

MY JOURNEY AROUND THE WORLD
WITH WEST SYSTEM® EPOXY

In 1978, at 28, my wife Arliss and I sailed our 27' Bianca, Duprass, from England to California **FIG. 1**. It was on that trip that I first learned of WEST SYSTEM® Epoxy in the form of an ULDB (ultra light displacement boat) named Circus Maximus. My first hands-on experience mixing WEST SYSTEM Epoxy came shortly after arriving in Ventura, CA, and opening my yacht design business there. A fellow boat designer, Richard Black, and his boat builder, Craig Ashby, together taught me the basics of mixing and using WEST SYSTEM Epoxy and fillers for rebuilding the cockpit seats on Duprass. Little did I know then how important a role WEST SYSTEM would play in the rest of my career and retirement.

Early Career

A short stint as the technical editor for a major sailing magazine took us east to Newport, RI, in 1979. Though that didn't last, I soon became a staff engineer at Tillotson-Pearson Inc. (TPI), Warren, RI. They are the builders of Freedom Yachts and J-Boats as well as truck body parts, chemical tanks, fan blades, windmill blades, lightpoles, flagpoles, and composite masts. This job became my crash course in composite engineering. Within a few months, I became chief engineer at TPI for the next year and a half. During that time, I built my first dinghy design, Chula, in my basement out of Luan Mahogany plywood, Teak, Spruce, and WEST SYSTEM **FIG. 2**.

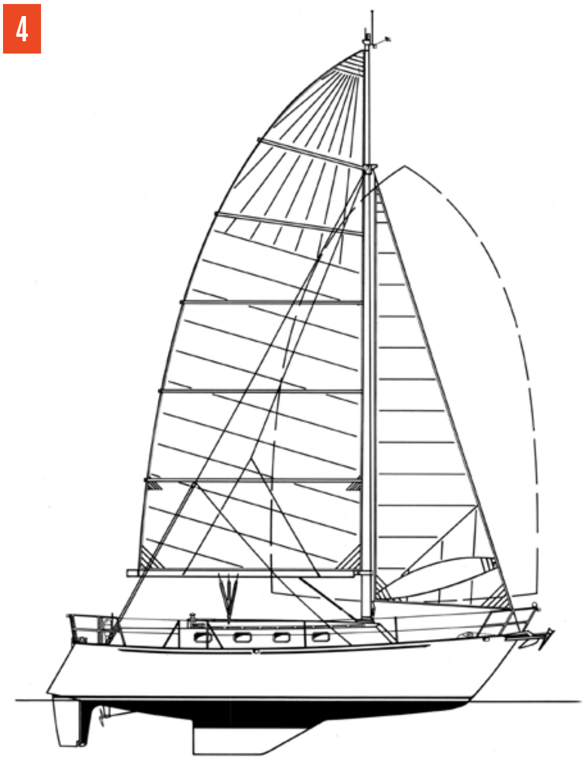
I went on my own designing again in November, 1981. In 1983 wrote the first technical treatise on free-standing mast design and engineering, as well as a lay-person's version for SAIL magazine. I also developed a DIY method of building wood-epoxy and carbon fiber wingmasts using WEST SYSTEM Epoxy **FIG. 3**. By the time I retired, I had designed 59 different free-standing masts.

1


2


3


4



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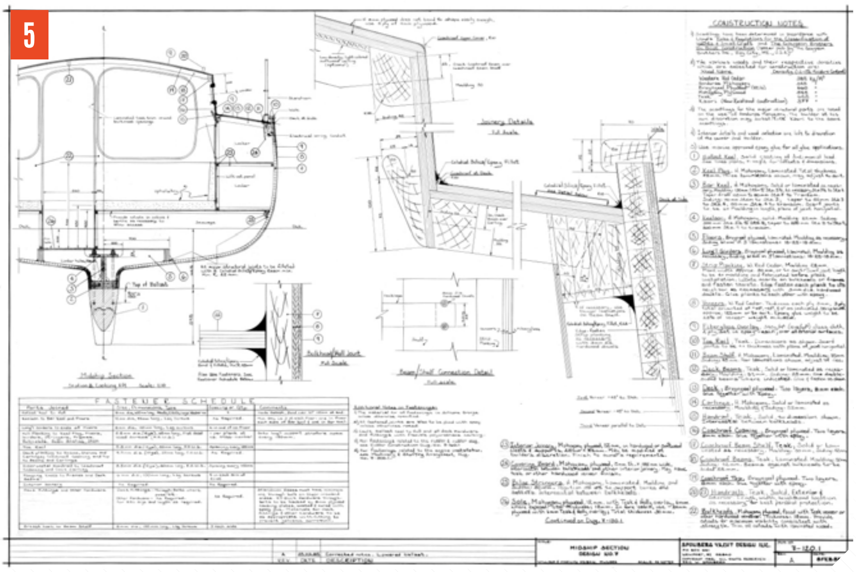

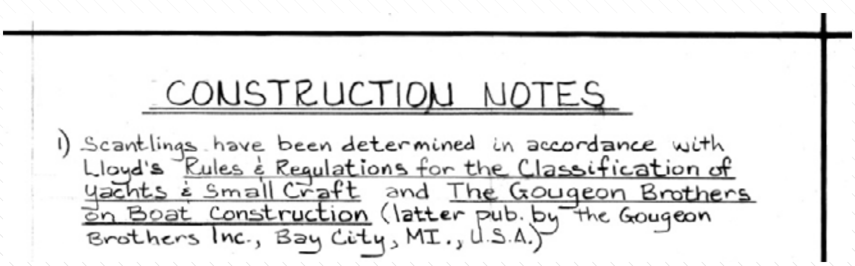
CONSTRUCTION NOTES

1) Scantlings have been determined in accordance with Lloyd's Rules & Regulations for the Classification of Yachts & Small Craft and The Gougeon Brothers on Boat Construction (latter pub. by the Gougeon Brothers Inc., Bay City, MI., U.S.A.)

I have Meade Gougeon to thank for my first professional yacht design commission. Bill and Marilyn McBain were avid sailors on the Great Lakes who were looking to commission a boat with a freestanding rig that would be easier to handle in heavy air than a traditional rig. They did not necessarily want another fiberglass boat. Bill called Meade Gougeon for advice, and Meade said, “Call Eric Sponberg, he can help you.”

At this point, I knew who Meade Gougeon was but had never met him, nor had I ever been to their Bay City, MI, boatbuilding shop. I did meet Jan Gougeon briefly at a wooden boat show in Newport in the early 1980s and had become an avid student of WEST SYSTEM Epoxy using their book, *The Gougeon Brothers on Boat Construction*. I relied on its design and engineering advice in my consulting work. Long story short, Bill and Marilyn visited me in Newport in September 1984, and we signed a design contract for what became *Corroboree*, a 35' wood-epoxy sloop with a free-standing carbon fiber mast **FIG. 4**.

My First Commission

On the drawings I specified that the scantlings were engineered to Lloyds Rules and Regulations for the Classification of Yachts and Small Craft, as well as *The Gougeon Brothers on Boat Construction*. I left the brand of epoxy to the discretion of the builder, not knowing which they preferred or were able to obtain **FIG. 5**.

At the time, Bill was working as a consultant for a new Ford® car program in Australia. A colleague of Bill's, recommended that he build his new boat in New Zealand because, in his opinion, they were the best boat builders in the world.

Corroboree was built by Lloyd Stevenson Yachts in Auckland, NZ, with 25 mm thick Western Red Cedar strip planking and a pair of 4 mm thick double-diagonal layers of Kauri, an indigenous conifer native to NZ which is now a protected species **FIG. 6**. *Corroboree* was delivered to the US by container ship in 1987. The carbon fiber mast was built in New Hampshire by another client of mine, and shipped to Michigan. The boat's name, *Corroboree*, is an Australian Aboriginal word that means "celebration." The McBains sailed her on the Great Lakes for the next 27 years **FIG. 7**.

Over my career I designed sail and power boats in wood-epoxy as well as composites, steel, and aluminum. Notable designs were Bagatelle built by Rick Waters, and Saint Barbara built by Van Dam Custom Boats. My last design in 2015 was Emerson, a 28' double-ended ocean-going rowboat, built by Schooner Creek Boat Works.

Sponberg Yacht Design Inc. became well known internationally for designing carbon fiber free-standing masts and rotating wingmasts. I nearly always specified Gougeon epoxy products for their construction. Over the years, I also engineered and directed complicated boat repairs. Builders and repair yards would hire me to engineer repair procedures and write process and material specifications to rebuild badly damaged boats. I frequently specified Gougeon epoxy products.

Around the World

Fast forward to July 2014, and Arliss and I were contemplating my retirement and an around-the-world voyage. What boat should we buy? Why not *Corroboree*? We approached McBains about selling her. Their sailing days were winding down, and they were thrilled that *Corroboree* just might complete an epic circumnavigation.

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By October we had the marine survey done and closed a deal. By early December, *Corroboree* was at a boatyard in St. Augustine under our care and ownership **FIG. 8**.

The survey revealed that water had seeped into the Kauri diagonal layers in three places: at the sheer near the stem, under the toe rail starboard aft, and most critically, in about 14 ft^2 of the hull bottom on centerline between the keel and the rudder **FIG. 9**. This last was due to a collision *Corroboree* had had some years before with a submerged container in Lake Erie and subsequent poor repair. We hired shipwright John Lubbehusen to craft repairs for all three spots by replacing the soaked Kauri layers with new African Mahogany layers set in WEST SYSTEM 105 Epoxy Resin® and hardener **FIG. 10**.

Shortly before launch we discovered that two of the nine bronze keel bolts were broken **FIG. 10**. It was another consequence of the collision and poor repair. A marine surveyor located the lower ends of the keel bolts in the lead keel casting by thermographic imaging and verified their positions with the construction plans. We replaced the broken bolts with new ones.

We left St. Augustine in January 2017 and worked our way down to Grenada. Turning west, we made it through the Panama Canal in March 2018, exactly 40 years after we had gone through with Duprass. Our next leg was the longest of the voyage, 4,000 miles to the Marquesas. By October 2018, we had sailed 12,000 miles and were in New Zealand, *Corroboree*'s birthplace. It was time for a refit and more repairs, so we hauled out for six months at Norsand Boatyard in Whangarei.

A mysterious weep of sea water into *Corroboree*'s stern had confounded us since the beginning of the voyage. I suspected it came from the rudder skeg, the one area of the boat I had not fully inspected back in Florida because dropping the rudder is a major undertaking. Well, now we had to do it. Off came the rudder, and there was the culprit: the backside of the rudder skeg was delaminated with open voids. After the repairs, no more weeping sea water ever came back into the boat **FIG. 11**. Repairs and refits along a voyage are usually pretty expensive, and this is why B.O.A.T. stands for "Bring Out Another Thousand."

Hitting a Reef

We continued westward to Australia in May 2019. While we intended to stay there just one year, COVID ultimately stretched that to three years. In May 2021, we continued up the Great Barrier Reef along the northeast coast of Australia. At Lizard Island, in a bone-headed maneuver during broad daylight, we banged the rudder on a coral reef. On inspection from above, it looked like we damaged the rudder skeg and punched a divot into the bottom of the rudder blade. I could not dive under the rudder for closer inspection because sharks were swimming all around the boat. We were 50 miles from Cooktown, the nearest port of refuge and repair. We wondered aloud if this was the end of our adventure. A boat with a broken rudder would be useful to noone, so we had to repair it. We managed to contact a fisherman from Cooktown who motored up to Lizard Island and towed us 50 miles back. What should we find in the local marine chandlery in this sleepy settlement of under 3,000 people in northeast Queensland? WEST SYSTEM Epoxy—resin, hardener, fillers, and fiberglass fabrics in sufficient supply to carry out our repairs!

Once on the town's only slipway, we dropped the rudder and discovered the front lower end of the rudder skeg was badly cracked. Fortunately, through the friendliness of locals eager to help two stranded Americans, we were able to locate a huge stack of 2" thick Teak flitches that had been harvested and air-dried naturally at a local farm four years previously. We bought a 10' x 18" flitch to fashion a new skeg. We cut off the cracked bits and then rough-cut a new Teak plug which we glued into place and anchored with four 8 mm dia. stainless steel threaded rods, pocketing them with WEST SYSTEM Six10® Thickened Epoxy Adhesive **FIG. 12**.

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Happy with our successful repair, we came to realize that Y.A.C.H.T. stands for "Yet Another Catastrophe Handled Today." For me, engineering and executing repairs during our circumnavigation sometimes seemed a lot like normal work, not retirement.

Tying the Knot

The rudder repair set us behind the tropical weather, so we spent the cyclone season in Darwin, Australia. In May 2022, we continued our trip to and through Indonesia. At one point, we spent an eerie night anchored inside the crater of Krakatoa—the ancient but still active volcano between Java and Sumatra. From Krakatoa, the Indian Ocean crossing was the most frustrating and worst weatherwise of our entire circumnavigation. On the way across we stopped at Maldives, Seychelles, and Mayotte before reaching Richard's Bay, South Africa in November. Then we harbor-hopped in favorable weather windows down around the southern tip of Africa to Cape Town where we arrived on New Year's Day 2023.

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The last legs across the South Atlantic Ocean were relatively easy and quick, thanks to consistent southeast trade winds and northwest-setting currents. We crossed our outbound track to "tie the knot" on our circumnavigation at Grenada in May 2023. We arrived back in Florida at Boca Raton in June, having travelled 31,709 miles in 6.5 years **FIG. 13**. We are now moored at a marina in Brunswick, GA, and *Corroboree* is up for sale.

Finally, after so many years associated with WEST SYSTEM products, Arliss and I found ourselves visiting friends in Bay City, MI, this past May 2024. We decided to make a first-ever visit to the Gougeon Brothers headquarters, a bucket list item for me. We were greeted warmly and given a complete tour of the plant by Jenessa Hilger, the editor for *Epoxyworks* magazine. She was sure to show us the original boatshop where all the WEST SYSTEM history and development took place. As we departed, Jenessa invited me to write this article.

Like tying the knot on our voyage, it feels like I have now tied the knot on my long association with WEST SYSTEM Epoxy and its associated products. What a ride!

Author's Note: *Eric Sponberg received his naval architecture degree from the University of Michigan in 1971. He practiced yacht design and consulting naval architecture from 1978 until his retirement in 2015. He and his wife, fellow U of M grad and author Arliss Ryan, have done two extended offshore voyages totalling 43,000 miles. Although they are now finished with sailing, they'll continue to travel by air to see more of the world. As Eric is fond of saying, "Nothing goes to windward like a 747!"*

Greg Bull

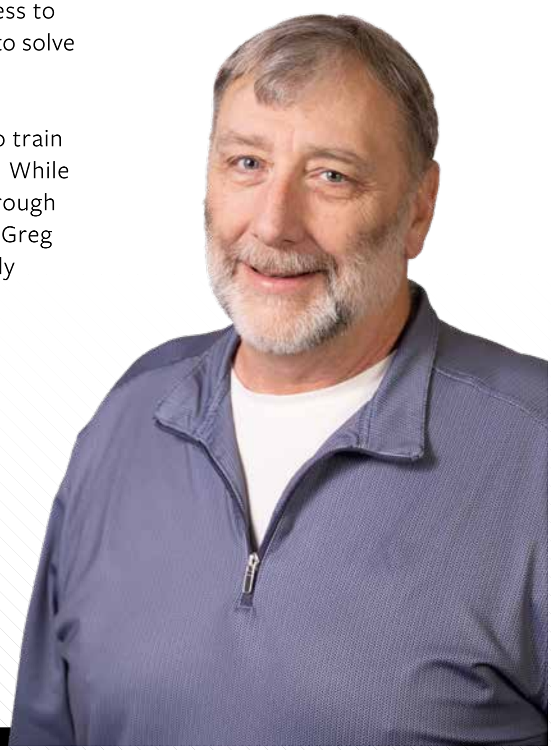
Gougeon Brothers, Inc. lost an integral part of our Technical Service Team and a cherished member of our boat-building history with the sudden passing of Technical Advisor Greg Bull. This loss is deeply felt by his coworkers, family, friends, and the local sailing community—all of whom have had a little wind taken out of their sails.

BY JEFF WRIGHT
GBI VP OF TECHNICAL SERVICE

With his passion for sailing, boatbuilding skills, and love of the Great Lakes, it was inevitable that Greg would end up working with Meade and Jan Gougeon. He competitively raced many sailboats and became the resident historian of the boats built by Gougeon Brothers, with particular expertise in sailing the high-performance G32. A "Greg Bull" tour of our boat shop was an essential introduction for new employees, helping them appreciate our history and innovative heritage. I am very grateful that his pride in our legacy has been passed on to our newer team members.

To say boats were a part of Greg's life is an understatement. Racing Lightnings in Brazil, sailing with Steve Fossett on *Stars and Stripes*, custom boatbuilding and repair, racing his G32, countless deliveries, and building *Strings* with Jan Gougeon, Greg's life revolved around sailing. This path led him to work 15 years as a Technical Advisor at Gougeon Brothers as he turned his passion into a career. He even spent many summers living on a 42' wooden cruiser with his wife, Rejean, and their well-traveled, much-loved dogs.

Greg was the "chainplate" that connected the instruction our customers needed with our products. While our chemists make molecules react, and our engineers measure their properties, Greg ensured that boatbuilders could successfully use our products. He instructed hundreds of customers, guiding novices away from trouble and helping expert builders gain an extra knot. His soft-spoken, calm demeanor was just as impressive as his boatbuilding knowledge. Even the most frustrated customers found comfort in Greg's patience and willingness to spend as much time as needed to solve their problems.



I traveled to Japan with Greg to train Japanese-speaking technicians. While I struggled to communicate through translators and hand gestures, Greg demonstrated techniques slowly and methodically, transferring his knowledge without needing words. It was a testament to his skill and patience that will be missed very much.

Fair winds and following seas, Greg. We deeply appreciate your passion and contributions to our legacy.

SKILL LEVEL

Replacing Core with Vacuum Bagging

When it rained, brown water leaked from the engine hatch and the mount for the cockpit table on my cousin's 31' powerboat. He keeps his engine hatch and cockpit covered when not in use, so there was no obvious point of entry for the leak. It was a mystery indeed. He asked if I could look at it and give him my two cents.

Initial Inspection

The engine hatch was roughly 5' x 7' with an integrated seat—the back of which faced the swim platform. The cockpit cover ended at the upper portion of the seatback, while in the lower seatback there was an opening locker. The locker door had a weather seal and inside the compartment were corner drains to remove excess water splashed up from the swim platform. In addition to providing seating, the engine hatch served as the cockpit floor. The floor area had two four-inch holes in which table leg bases were installed.

The hatch was built as you would typically see for a composite cockpit floor or deck. There was a finished, gelcoated layer of fiberglass (outer skin), a balsa/plywood core, and an inner layer of fiberglass (inner skin).

At the shop, I inspected the hatch for any areas of damage, or obvious sources of water intrusion. I removed the table leg bases to find them poorly sealed from the factory, but with no signs of water leaking in from the top. With the bases removed, it exposed the two layers of ¾" balsa that comprised the core. The balsa was soaked with water literally dripping out. When I pushed on the balsa with my finger, it crushed easily, and water ran out like a squeezed sponge. Though this showed the obvious results of the water issue, I was unable to determine the cause.

Determining the Damage

The water saturated hatch required a fork truck to position the hatch on its side to easily asses the damage. Then I could begin my investigation by determining the moisture content, weighing a sample of laminate, and utilizing a thermal camera.

Using a moisture meter every square foot, I took readings of the hatch. They ranged from 20-50% on the scale, including the areas that I could see were completely saturated with water. Moisture meters measure the conductivity of a laminate, therefore the more moisture in a laminate, the more conductive it will be.

For my own interest, I also chose to do a weight comparison. I removed a wet 2.5 ft^2 section of balsa and fiberglass. When first removed it weighed 124 oz. After the sample was allowed to dry completely, it only weighed 66 oz. That's nearly half of the original weight!

Finally, I used a thermal camera to get an idea of how large an area was likely to be affected by this moisture intrusion. Thermal cameras are one method surveyors use to determine wet areas in need of repair. It is a noninvasive test to show where the fiberglass skin needs to be removed to expose wet core, while keeping the repair as minimal as possible. I used one that plugged directly into my phone and that worked well enough.

Dry areas change temperature faster than wet areas, therefore a thermal camera will show you the temperature differential between two areas that recently went through a temperature change. On a chilly morning I rolled the hatch outside and let it sit for about an hour and a half. Looking at the thermal camera we did not see what we expected. We expected to see moisture concentrated near a single point of entry, but instead we were seeing saturation throughout the entirety of the hatch with the exception of a few isolated dry areas in the middle.

The thermal picture combined with the moisture readings made it clear that the entire core would need to be replaced. Though I still hadn't determined the source of the problem, I was still hopeful that once I peeled back the inner skin, and could see what was going on, I would have a better idea.

Getting Started

I cut the inner skin about 3" from the edge of the hatch. This would leave enough of a tab of the inner skin to grind a bevel to overlap fiberglass onto when

I was done. Next was removing the inner skin. I was hoping the core was rotted enough that I could remove it in one piece and reinstall it after replacing the core, but no luck. Cutting the skin into 1' strips, I could peel and chisel it off. Exposing the rotted core, I could see there was in a large grid pattern and the center of the grid was damp, but not completely rotted. This reflected what I saw with the thermal camera **FIG. 1**.

While removing the rotted core, I discovered roughly one-third of the hatch was two layers of balsa. The other two-thirds were comprised of one layer of balsa and one layer of ¾" plywood. The plywood had ½" relief cuts in a grid pattern to allow the plywood to flex into the shape of the mold.

The relief cuts functioned as channels allowing water to flow easily through the hatch and soak the balsa core.

One of these relief cuts ended at the hinge for the engine hatch. The hinge had a backing plate that went through into the locker. Any water that got into the locker soaked into that backer block and drained into the relief cuts, flowing throughout the engine hatch. The weather seal had failed on the locker allowing water to collect and soak into the backer before it could drain.

With the balsa removed, I was able to survey the plywood core. Other than dampness, and a few gouges from the balsa removal, it was in decent shape. I let it dry out for a few days, sanded the surface, and removed any remaining fiberglass from the surface. To clean the relief cuts and open up the end grain, I used a wire wheel on a drill and a router. I allowed the plywood to dry. Adding heat and/or a fan would shorten the overall drying time, but I had all winter. Every couple of weeks I would run the moisture meter across the plywood to make sure it was drying out.

Prep Work

While the plywood was drying, I began my prep work. First, I ground a 12-to-1 bevel on the fiberglass tab around the edge. By cutting into the bottom of the hatch, I would not have to do any gelcoat matching or color blending.

Utilizing 80-grit sandpaper, I sanded my bevel to smooth the grinder marks. Any exposed fiberglass from the upper skin was also sanded in preparation for bonding the new core. With everything sanded, I dry-fit the new balsa core making sure to make alignment marks so each piece so would fit back in the same way.

I removed the plywood that was used for backers on the hinges and replaced it with Coosa® Board. Coosa Board is a high-density, polyurethane foam reinforced with fiberglass. This board eliminates any plywood end grain that is exposed to water inside the locker. Coated plywood would have done the job, but I was afraid the plywood coating might get damaged, allowing moisture to seep in.

I drilled oversize holes for the hinge screws and used Six10® Thickened Epoxy Adhesive to fill them. Six10 is great at gap-filling with its thick and creamy consistency. It also worked perfectly for bonding the Coosa board backing block where the water was originally entered the core **FIG. 2**.

Finally, it was time to start setting up to vacuum bag. Vacuum bagging sounds more arduous than it is. While it does require extra prep work, it is a great way to hold an even clamping pressure across a large surface. The even clamping force ensures excellent contact fo the core to the outer skin and minimizes any potential voids reducing the chance of water intrusion.

The top skin needed to be airtight for the vacuum to work properly. Using two layers of our 737 Biaxial Fabric, wet out with 105 Epoxy Resin® and 205 Fast Hardener®, I made fiberglass laminates to use as cover plates for the table support openings. G/5® Five-Minute Adhesive worked great to bond them inside the outer skin quickly **FIG. 3**.

Then I applied the Vacuum Bag Sealant around the outside perimeter of the hatch.

Installing the New Core

With the shop temperature in the low 70's (°F), and the prep work completed, it was installation time. To start, I rolled the hatch upside down to create an easier working surface. Since this was a bigger project, I chose to work with the WEST SYSTEM® 209 Extra Slow Hardener®. When combined with the WEST SYSTEM 105 Epoxy Resin, it would give me 3-4 hours of working time to get the core coated, put in place, and the vacuum bag on. Working alone, I would surely need all this working time. Luckily for me, just as I started, fellow Technical Advisors, Don and Greg, offered to join in the fun.

We coated the plywood and the back side of the outer fiberglass laminate with unthickened 105 Epoxy Resin and 209 Extra Slow Hardener. Don started mixing 406 Colloidal Silica into the epoxy to create a catsup consistency. He troweled this mixture over the fiberglass laying a bed of epoxy for the balsa core. Mixing a little thicker batch, he used it to fill in the corners and near the edges where the balsa core wouldn't be able to reach.

While Don was laying the bed of epoxy, I coated the balsa core with unthickened epoxy, and Greg used a mixture of epoxy and 410 Microlight to fill in the gouges in the plywood and the relief cuts that had initially allowed water to migrate throughout the hatch **FIG. 4**.

We installed the first layer of balsa. Any remaining gaps were filled with epoxy thickened with 406 Colloidal Silica. The first layer only needed to cover about one-third of the surface area of the hatch due to the plywood layer. Now we were ready for the second layer of balsa which would cover the entire area.

Greg and Don coated the plywood and the first layer of balsa with a catsup consistency of epoxy mixed with 406 Colloidal Silica. I simultaneously applied a neat coat of epoxy to the balsa core side that would be mating with the first layer of balsa and plywood. The top side of the balsa would be coated later when we applied the fiberglass. The alignment marks from dry fitting made quick work of installing the second layer of core.

Vacuum Bagging

We draped 879 Release Fabric over the balsa and out to the edge of the hatch. Release fabric does not stretch so you must make sure to tuck it into corners and valleys to prevent it from bridging. The bridging holds the vacuum bag off the surface, creating air voids that will collect extra epoxy and may leave hard spots. These pockets of epoxy can also generate too much heat from the exothermic reaction.

Over top of the release fabric, the next layer would typically be perforated film to control epoxy content. For this project it was not a concern, so I skipped it. We draped the 881 Breather Fabric over top of the release fabric. The breather fabric allows air to move freely under the film towards the vacuum pump.

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The final layer to seal the envelope was the 882 Vacuum Bag Film **FIG. 5**. Even though this was a flat panel with minimal contour, I still cut my bag approximately 1.5 times the size of the overall hatch. The bag had to be large enough to fit tightly into the contours. The core only steps up about ¾", but it is better to have too much film than not enough. I peeled the paper backing off my 883 Vacuum Bag Sealant that I had adhered around the perimeter of the hatch and applied extra to seal any pleats or folds in the bag film.

The end of the vacuum tube, wrapped in a bundle of breather fabric, was inserted through one of the pleats before being sealed closed. The other end of the tube connected to a "T" before continuing on to the vacuum pump. I added the "T" to attach a valve. Our vacuum pump in the shop can pull 29 plus inches of mercury (29" Hg). By adding the "T" into the vacuum line, I could control the vacuum, bleeding it down to about 5 inches of mercury (5" Hg or roughly 2.5 psi) (See vacuum bag techniques 1.2).

For our engine hatch, we have the convenience of working at table height, however that is not always an option. One of the great things about vacuum bagging is that since you are drawing a vacuum, you'll have the same pressure on all the surfaces underneath the bag, whether it's horizontal, vertical, or even inverted.

With my bleeder valve mostly open, it was time to turn on the vacuum pump. As the vacuum bag was slowly pulled down onto the hatch, we adjusted the bag so there was enough slack for it to follow the contours of all the corners, preventing bridging. Once satisfied, we added a vacuum gauge on top of the breather fabric opposite the vacuum line. Then we slowly closed the valve until the gauge read 5" Hg. We checked the vacuum bag for air leaks.

It is important to keep the vacuum pump on until the epoxy has become firm. This period can vary, depending on the choice of hardener and the temperature. In this case, with the 209 Extra Slow Hardener, I kept the vacuum on overnight.

The following day I removed the vacuum bag, breather fabric, and release fabric (all one-time-use products). The release fabric can be left on for days and even weeks at a time to keep the repair area clean until you're ready to move on to the next step. In this instance, it was time for the release fabric to be removed as well.

Applying Fiberglass Layer

I used a small grinding wheel to smooth out imperfections from the vacuum bagging process and to freshen up areas of my 12-to-1 bevel that had gotten some epoxy on them. The new layers of fiberglass would be adhered to this edge. I slightly beveled the top edge of the balsa core as well to help the fiberglass roll over the edge.

I had precut five layers of 738 Biaxial Fabric, giving me a thickness of just over one-eighth of an inch to match the laminate I had removed. The roll of fiberglass was

LEFT: The bottom of the finished engine hatch—sealed and gelcoated.

not wide enough to cover the entire surface in a single piece, so each layer was made from two pieces butted together. The seams were staggered for a stronger joint. Even though I wasn't planning on vacuum bagging the fiberglass I still used the 105 Epoxy Resin and 209 Extra Slow Hardener for the longer working time.

With help from Don and Greg, we started by coating the balsa core with unthickened 105 Epoxy Resin and 209 Extra Slow Hardener. We then thickened the mixture to a mayonnaise consistency with 406 Colloidal Silica and applied it around the edges to make fillets. This would help the fiberglass transition over the 90° corner where the core met the flange. Then we coated the entire repair area with 105/209 slightly thickened with 406 Colloidal Silica. This filled in any imperfections and made a nice base for laying our first (and largest) layer of fiberglass.

We used an 808 Flexible Plastic Spreader to work the fiberglass into the epoxy, adding more epoxy as needed to wet out the 738 Biaxial Fabric. After the first layer was saturated, we continued with the next four layers of fabric, working from the largest layer to the smallest.

Just like our vacuum bagging stage, we used 879 Release Fabric over the top. When using release fabric for a hand layup project, I use the 808 Flexible Plastic Spreader to work the fabric into the epoxy. The goal is to have no visible white spots remaining on the release fabric. If the epoxy has soaked in properly, the fabric should go translucent and all that should be visible is the thin red tracer lines. These red lines allow you to easily tell if you have removed the fabric entirely. After letting the epoxy cure for a few days, I removed the release fabric and used a small grinder and sander to remove imperfections.

Finishing

We had our choice between paint or gelcoat for the final finish on this project. I prefer a gelcoat finish in an engine compartment as it performs better in the event of a spill. When buying gelcoat there are two basic kinds - finish gelcoat with a wax additive that cures to a hard finish and laminating gelcoat that cures to a tacky finish allowing for additional layers. For this project I used the finish gelcoat and brushed it on heavily.

After the gelcoat dried, I flipped the hatch over onto sawhorses and used a jigsaw to cut out the openings for the table leg bases. I wanted to ensure that if these bases ever leaked, the water would not find its way into the core of the engine hatch. I removed about ¼" of balsa from in-between the skins, all the way around the openings. I filled that space with Six10 Thickened Epoxy Adhesive, sealing off the core.

After numerous hours of labor, and roughly $800 in materials, the hatch looked almost the same as the day it was delivered for repair. A noticeable difference, however, was the weight. We were now able to hand lift the hatch onto the trailer without the use of a fork truck.

This was a substantial project with hours of messy labor, but it is a far more approachable project than it seems at first glance. Replacing the core from the underside allows you to avoid the finish side gelcoat color matching and application. The addition of vacuum bagging makes for a terrific way to save time and hold materials in place and get consistent clamping pressure as the epoxy cures. When combined, these techniques make for a great cost-saving DIY project.

WATCH THE VIDEO

Check out Terry's video on restoring the rotted balsa core of an engine hatch utilizing vacuum bagging techniques.

 BY KAI STURNMANN

SKILL LEVEL

Rebirth of a Classic Rowing Shell

Not having any particular skills in wooden boat building or repair, I embarked on a project to resuscitate a near-derelict wooden rowing shell. *Determination* is a 23', Joseph Garofalo-built, single sliding-seat wherry. While fully expecting this to be an immersive project and learning experience, my confidence to take this on was built on the expertise of friends and my faith in epoxy.

The hull is constructed of thin cedar plywood on oak keelson and frames built over temporary molds. In essence, a one layer cold molded construction. *Determination's* condition presented two primary challenges:

1. Several of the frames had rotted away at their lower ends, allowing the keelson to separate from the rest of the structure, thus deforming the hull and rendering it unstable **FIG. 1**.

2. The skin of the hull was perforated in several places, showing several unsightly and deteriorating fiberglass repairs. At the bow, the plywood skin had pulled back from the stem post.

A knowledgeable friend provided a solution to the first problem by suggesting that I fashion gussets and pull the keelson up in line utilizing throughbolts **FIG. 2**. Once the hull shape was restored, new frame ends were scarfed onto the existing upper frame remnants and secured using thickened WEST SYSTEM® Epoxy **FIG. 3**. Structural integrity was further enhanced by thickened epoxy fillets on either side of the keelson, running the full length of the boat (up to, and including, the stem and stern posts).

Having achieved integrity of the frame structure, it was time to address the problems of the hull itself. A proper wooden boat repair—restoring the shell to original, as-built condition—was out of the question. *Determination* was too far gone for that. Despite that assessment, the interior of the boat (apparently somewhat protected from the elements) cleaned up extremely well. The beautiful old-growth cedar showed remarkable potential. The exterior of the boat was a different story. It was worn and weathered, and in some places, completely done. The once beautiful hull had slowly transitioned through patina to unsightly. I wanted *Determination* to be seaworthy and beautiful. Which way to go here?

Would form follow function, or could function follow form? Epoxy allowed me to have it both ways.

Applying a layer of woven E-glass, set in epoxy, over the exterior hull was the obvious solution. This would provide structural integrity and, if painted, a satisfactory appearance. However, it occurred to me that carbon fiber was a better option aesthetically and might provide additional structural resilience.


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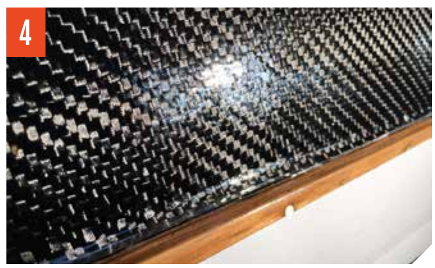
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One challenge was the upper edge of the carbon fiber sheathing which would abut the spruce sheer strake. Carbon cloth frays immediately upon cutting, so I had to find a way to create a clean edge. I had no experience with vacuum bagging but felt that it might be successful in forcing the saturated carbon fiber to conform to that concave edge. Once the epoxy set, the excess cloth could then be trimmed in a clean line **FIG. 4**.

I fashioned a vacuum pump apparatus utilizing a medical ventilator pump that had exceeded its certified lifespan (Gast model 0870) **FIG. 5**. Materials were sourced from Jamestown Distributors, Fibre Glast Developments, and Composite Envisions, utilizing WEST SYSTEM products exclusively, whenever available.

The interior and exterior of the hull were stripped and sanded to bare wood. Any existing fiberglass patches were removed, and work began on the interior surfaces.

Perforations and large cracks were filled with a thickened epoxy mixture. Once faired and sanded, these areas were covered with a thin layer of cedar veneer bonded with epoxy under vacuum pressure **FIG. 6**. This worked well, allowing me to get used to the vacuum pump and assorted materials. I placed two layers of 4 oz. woven E-glass into clear epoxy on the lowest section of the bilge as reinforcement for a pair of suction bailers **FIG. 7 & 8**.

The outside surface was prepped, and the defects were filled with thickened epoxy. I added additional longitudinal stability with a single layer of 6" unidirectional carbon tape running the length of the boat along the centerline below the keelson **FIG. 9**. At this point, timing and scheduling became critical. The intent was to ensure chemical bonding between the various layers applied.

Lay-up began by wetting out the hull with a black-pigmented epoxy saturation coat. This was done to prevent the wooden surface from showing through the carbon fiber. Once this became tacky, 4 oz. carbon fiber twill weave cloth was rolled out over the hull, draped into place, and trimmed. This was quickly wet out with clear epoxy (WEST SYSTEM 105 Epoxy Resin®/207 Special Clear Hardener®). The epoxy was followed by the application of release fabric, breather fabric, and the vacuum bag film. Sealant tape along the edges made the vacuum bag film air tight and appropriate hose connections were made, before applying the vacuum pressure at (-)15mm Hg. **FIG. 10**.

Once the epoxy had cured, the vacuum apparatus was peeled away, and the carbon cloth was trimmed. A hot coat of clear epoxy was then applied and allowed to cure. The finished surface was surprisingly fair and required minimal sanding. The final stage was application of Epifanes® Poly-urethane Clear Satin for UV protection.

Shrink-wrapping tape was used to prevent epoxy from contacting the wooden surfaces not intended for the carbon sheathe. This worked well; there was no bleed through the tape and excess was easily removed leaving a smooth surface and clean lines **FIG. 11**. The interior and sheerstrakes were finished with five coats of Epifanes Clear Varnish.

I'm pleased with the results. To my knowledge, this approach has not been reported before and lends itself well to repair and restoration of light rowing or sailing craft. Working with the epoxy in a temperature controlled environment was predictable and straightforward. I'm grateful for the assistance provided by my brother and friends.

One day after the initial launching, *Determination* completed the 20-mile open-water Great Peconic Race. She successfully competed in the Head of the Charles Regatta (2022) **FIG. 12**.


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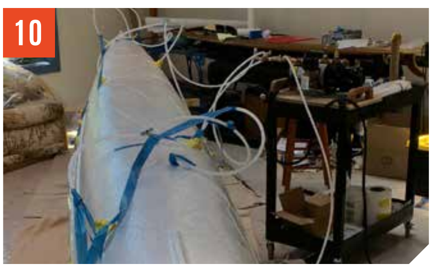
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11


12

 BY JEFF WRIGHT - GBI VP OF TECHNICAL SERVICES

Repairing a Fatigued Laminate

The bottom of a typical trailered powerboat is not something that gets a lot of daily attention but has a very important job. Since I have been involved in boat building and repair my entire career, I may think more than most boaters about what is going on below my feet when running through waves. This leads me to get out my creeper and rolling under my boat once a year to see the condition of the bottom. Last spring I realized that the bottom of my boat was not doing so well. There's a specific area where gelcoat cracks had continued to grow. My old friend was telling me she needed some attention if we wanted to continue our adventurous relationship.

ABOVE: 1986 Formula 242, *Funktional*.

RIGHT: The gelcoat cracks were isolated to the forward end of the bunk (highlighted).

The Bad News

My 1986 Formula 242, *Funktional*, has been taking me around the Great Lakes and beyond for 20 years. With over 2,500 total hours running time on the hull, and having been trailered at least 100,000 miles since I have owned her, the bottom has had its share of choppy waves and Michigan potholes. What I noticed this year was significant growth of longitudinal gelcoat cracking near the keel on the forward portion of the bottom. The cracks were at the forward end of the long primary trailer bunks. After looking at the cracks I made some notes to determine the cause and solution:

- The cracks were only in the forward area of the bunk and concentrated around the end of the bunk.
- The bottom would have maximum deflection from wave pounding between the keel and the inboard stringer, not at the keel.
- The cracks were in an area of high deadrise which reduces slamming loads.
- The forward edge of the bunk is located midway between the axles and the trailer tongue where the trailer has the greatest deflection.
- This area of the bunk has significant wear from road vibration, loading, and unloading.
- They have been forming over the course of several years.
- The cracks do not continue forward of the frame that creates the aft end of the vee-berth.
- When tapping this area, it did not have the sharp ring as with other areas, instead it produced a dull thud indicating less stiffness than the surrounding area.

Taking some measurements of the gelcoat cracking location, and comparing it in relation to the hull framing, it appeared all the cracking was underneath the cabin sole. Since I had replaced the original sole several years ago due to rot (see *Epoxyworks* 37 “Replacing a Small Boat Cabin Sole”), I decided to attack the problem from the inside. I view the gelcoat cracks as both an indicator of a laminate problem and a cosmetic flaw. I personally don’t mind if the cracks are repaired or not, as long as the hull is sound. The gelcoat is a final finish and not meant to protect the hull from moisture. For people to notice the cracks, the boat would be capsized—which would be a bigger issue!

The Plan

It’s not an easy decision to take your boat apart and delay the start of the short Michigan boating season, but it had to be done. I decided to remove some of the cabin’s interior components and carpet, then cut out the cabin sole.

I closely inspected the inside of the hull bottom and could see very fine cracks in the vinylester resin of the laminate. This explains why the tapping test produced the dull noise. Even though Formula used vinylester resin, as opposed to polyester, this area of the hull has lost stiffness due to fatigue when compared to the rest of the hull. Additional tapping, measuring and examination of the gelcoat cracks enabled me to conclude all the cracks were in this “panel”.

The panel is defined by the area between the stringers and the frames. In hull bottom laminate design, the size of these panels, along with the estimated pressure from wave pounding, is used to determine the required laminate strength and stiffness. I decided to only stiffen this panel since all other portions of the hull shell did not show signs of fatigue, and all the framing was dry with undamaged laminates.

A critical part of this repair is the focus on stiffening the entire panel. My repair laminate will extend from the forward fuel tank frame, to the frame at the aft end of the vee-berth, and all the way across to each stringer. This approach avoids any hard spots in the hull shell because the additional laminate is completely attached to the framing.

TOP LEFT: Close up of the gelcoat cracks on the bottom of the hull.

TOP RIGHT: Fatigue cracks in the epoxy as seen from inside hull.

BOTTOM LEFT: Materials used: 105 Epoxy Resin®, 206 Slow Hardener®, 2415 fiberglass fabric

BOTTOM RIGHT: Roll paper was fitted to the inside the repair area to make a pattern for cutting the layers of fiberglass.

My repair needed to be stiff enough to reinforce the weakened laminate. If the repair laminate was not stiff enough, it may just peel off as the hull flexes. I decided to double the thickness of this bottom panel knowing it would provide enough stiffness and strength no matter the condition of the original laminate. In our *Fiberglass Boat Repair & Maintenance* manual (section 3.6), we discuss stiffening laminates using a cored stiffener. I did not pursue this method because it would raise the cabin sole and reduce the already limited headroom in the cuddy cabin.

From my experience in the marine industry, and the appearance of the inner hull, I assumed the original laminate was a layer of 3 oz/ft^2 of chopped strand mat (csm) followed by two alternating layers of 1.5 oz/ft^2 csm and 24 oz/yd^2 woven roving. Two more alternating layers of 1.5 oz/ft^2 csm and 24 oz/yd^2 woven roving went over the stringers and then onto the hull bottom.

Using the equations in *Epoxyworks* 56 “Calculating Laminate Thickness”, I calculated the bottom to be about $\frac{3}{8}$" thick. Using WEST SYSTEM® 738 fabric this would take about eight layers to achieve the same thickness. Although this would have worked, I was able to find a roll of knitted 2415 fiberglass fabric in our shop (2415 indicates the fabric will have 24 oz/yd^2 of a triaxial knitted fabric and 0.75 oz/ft^2 of a chopped strand mat.) Using that would reduce the number of layers to six layers.

It is important to note that more layers of a modern knitted fabric like WEST SYSTEM 738 is required to match the thickness of a woven roving type fabric of the same weight. Woven fabrics generally have a higher epoxy content because of the crimps in the fabric where the knitted fabrics achieve less thickness per oz. but have a higher fiber content. Since I was most worried about stiffness, matching the original thickness, and higher strength, the knitted fabric was a nice bonus.

The Repair

Preparing the surface is labor intensive and critical for a successful repair. If the new lamination does not adhere well, it will not stiffen the bottom or transfer the load into the stringers and frames. The first step in this process was removing the carpet glue. Time and patience are the key to letting the adhesive remover work. It took longer to remove the carpet adhesive than it did to laminate all the fiberglass.

The next step was cleaning. Since bilge water can flow into this area there was engine oil on the surface. Using lacquer thinner and paper towel, it took many iterations of wiping on and off until the paper towel had no discoloration. Removing all contaminants should be done before any grinding or sanding is started. After cleaning, I made a paper pattern of the largest piece of fiberglass and set that aside.

With the surface extremely clean, the part most people dread begins—grinding and sanding the original laminate. With some preparation, the grief of grinding can be minimized. I used plastic sheeting to keep dust out of the rest of the cabin, suited myself up, and had many high-quality sanding discs available. After using various power tools to smooth the surfaces, and removing the remaining tabbing from where the cabin sole was attached, I finished by hand sanding with 80-grit sandpaper. I cleaned the surfaces with a shop vacuum. No need to solvent wipe at this point, which may introduce new contaminants.

Pulling out the paper pattern, I was fortunate to find that the pattern was just a little bit narrower than the fiberglass roll I had decided to use. Butt joints were acceptable in this repair, which eliminate several overlaps that would raise the cabin sole more than I desired. The first two layers of fiberglass would extend about 2" up on each stringer and frame, laying across the bottom as one piece.

I knew it would be challenging to laminate one piece of fabric into several corners. It is difficult to force the fabric into one corner without pulling it out of another. In the end it worked out satisfactorily, but it was challenging and tedious. Others may have preferred to have overlaps down the keel, but I thought the resulting build up could end up higher than the limber holes in the frames, reducing the flow of bilge water.

LEFT: The forward six layers of fiberglass were all applied in one session. Each layer stepped back so the butt joints would be staggard.

MIDDLE: Once cured, and the surface prepared, the aft layers could be applied.

RIGHT: The was carpet reinstalled, looking as good as new.

The first layer was critical to ensure good adhesion. I used WEST SYSTEM 105 Epoxy Resin® and 206 Slow Hardener®, mixed with 406 Colloidal Sillica to fillet any sharp inside corners and smooth other imperfections on the inner hull surface. I placed the first (largest) piece into the wet epoxy, then folded half of it back onto itself. I brushed a generous layer of 105/206 on the back side of the fabric then folded it back onto the hull and repeated the process with the other half. This back-wetting process makes wetting out heavier fabrics much easier and more thorough. Instead of forcing the epoxy down into the fabric, you are forcing the fabric down into the epoxy. Any extra on the surface will wet out the next layer.

Having a bright light in the cabin was important to determine that good contact was being made to the hull surface and there were no trapped air bubbles. I estimate it took twice as long to laminate the first layer as it did the last layer due to the time spent ensuring excellent contact to the hull.

Laminating this heavier fabric also required an aluminum grooved roller. Squeegees work well on fabrics 17 oz/yd^2 and lighter, but the increased pressure of the grooved roller makes wet-out easier with heavier fabrics.

Using WEST SYSTEM Epoxy also ensures good adhesion. The entire laminate relies on secondary (mechanical) adhesion, a property where epoxy exceeds both vinylester and polyester. The extremely low VOC, due to the lack of styrene, eliminates the need for a respirator. Also, there will be no chemical smell lingering in the cabin for weeks after the repair is completed. Mixing and measuring small batches in the small cabin was made simple by using the 300 Mini Pumps. They eliminate the need to pour and measure liquids in a very confined work area.

105/206 provided the pot life I needed, and there was no risk of the laminate having excessive exotherm. I was able to laminate as many layers as my back could handle. Since I needed to have somewhere to stand during the lamination process, I cut each layer into a forward and aft piece. I could get all six layers for the forward section down in one session. After it cured, I could stand on it to laminate the aft section with staggered butt joints connecting the layers. The layers that were applied wet-on-wet formed a chemical bond, but anywhere that overlapped the aft layers had to be prepared to ensure a good mechanical bond. The overlap areas were washed with water and sanded with 80-grit sandpaper before laminating the remaining six layers.

After the entire panel was laminated, I was inside the cabin removing my tools. I accidently dropped a screwdriver, and when it hit the bottom, I could hear a very sharp bang. It was very satisfying to hear my boat bottom was back to the desired stiffness!

Time to prepare to tab the cabin sole back in place. The cabin sole had to be trimmed to accommodate the thicker bottom. This left some exposed wood that was sealed with epoxy. Two layers of 4" 737 Biaxial Fiberglass Fabric was used to tab it back into place. New carpet was glued into place which was the most challenging part of the whole job. Trimming the carpet, not making a mess with the glue, and keeping the edges from unraveling was more difficult than the lamination process.

This repair does not exactly follow our fiberglass boat repair process, where we suggest removing the damaged laminate and replacing it with a new laminate matching the original thickness. In this case, that would require essentially cutting away the bottom of the hull in this area and building a new section which would be a much bigger project. Since the hull still had sufficient strength, I believed its life could be extended by reinforcing the area with attention paid to how the increased stiffness would transfer stress to the hull structure.

The Good News

After a full season, this repair appears to have stopped the gelcoat cracks from growing, and the bottom still sounds stiff. Although it did add 40 pounds of weight to the hull, it is low and forward which is good for the hull trim in rough water. Most importantly, it is reassuring to have a nice solid bottom when an adventure takes you out of sight of the shoreline!

EPOXYWORKS®
Building. Restoration. Repair.

Readers' Projects

WOODWORK

BOAT PLANTERS BY ED MAURER

Yard Yachts are small, boat-like planters and displays for use in homes, gardens and businesses. Working from his shop in Dunedin, FL, Ed Maurer builds these 3'-8' yachts. He choses to use interior grade plywood (for its flexibility and affordability) in addition to various types of lumber. To ensure the yachts can stand up to the exterior elements, he uses WEST SYSTEM 105 Epoxy Resin® and 206 Slow Hardener® for bonding and sealing the wood. The exteriors, and sometimes the interiors, are painted with high-grade exterior household paints to the customer's order. Any unpainted epoxy receives several coats of marine-grade spar varnish.

BOAT RESTORATION

MOONPIE BY ROBERT PETERSEN

Over the last off-season, Robert Petersen converted the bare aluminum hull of his RIB dinghy into a hybrid plywood/aluminum hull using ¼" ply and WEST SYSTEM® products. Robert looks forward to using her as a dinghy for his 1971 Jim Brown 37' Searunner as he sails the United States Virgin Islands in St. Thomas.

KNIFE BUILD

KNIFE BY MATTHEW GREGORY

This neo-Japanese style fighting knife, with composite construction handle, was made by Matthew Gregory. The 6" long blade is made of a Crucible Steel laminate of CPM-154 stainless cladding over a core of high wear resistance tool steel Crucible CPM-10v. The handle consists of a G10 and carbon fiber frame, with an aerospace foam material called Rohacell (to add dimension with almost no weight). It's sleeved in carbon fiber, and bonded with WEST SYSTEM® 105/207 under vacuum. The seppa and menuki are both titanium, and the guard is carbon fiber. WEST SYSTEM 105/205 was used for the final assembly. Instagram @mgregoryknives.

WOODWORK

CONDO BENCH BY PAUL HAYES

Reader Paul Hayes recently donated this bench to his condo association so residents would have a nice location near the mailboxes to sit and read their mail. This teak bench had spent some time outside and therefore had become discolored. He sanded the bench on his dry, enclosed porch and removed any sanding dust. Having some limited exposure to WEST SYSTEM® Epoxy from the sailing world, he decided to use that to seal the wood. He applied four applications, being careful not to create "gas bubbles" by letting the porch get too hot or humid. He sanded between each coat. Over top he applied 4-5 coats of a marine grade varnish, wet sanding as high as 2,500-grit.