REPORT
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News about

EPOXY CHEMISTRY

COMPOSITE PROCESSES

FABRICATORS

PRO-SET® Adhesion to Silicon Bronze

Brian Knight, Technical Services

At the request of Eric Goetz of Goetz Custom Boats, we conducted adhesion tests on silicon bronze. Goetz had to glue a bronze bushing into a carbon fiber sailboat hull and needed to know if there was enough surface area to keep the bushing in place. The bushing is a guide for a retractable keel and will experience some shear loads as the keel is raised and lowered. Bronze alloys are typically very difficult to bond to, so we were pleased with the results of the shear tests. The PRO-SET M1002/229 Toughened Laminating Epoxy required 3,800 pounds per square inch (psi) of compression load to cause a shear failure of the test specimens.

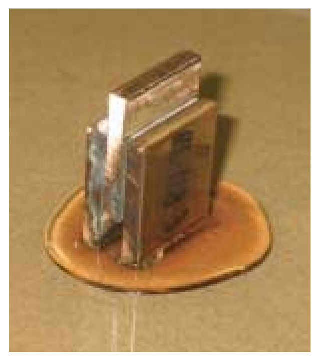
The first part of the test program was to identify the best surface preparation of the silicon bronze. For this portion of the test we chose to use PATTI (Pneumatic Adhesion Tensile Test Instrument) tests because they are fast and easy to perform. We tested four different epoxy formulations and three different surface preparations with five test specimens per combination. This meant preparing 60 test specimens.

The results of the surface preparation tests are shown in the top portion of the Tensile Adhesion Table shown on the next page. We were a little disappointed at the relatively poor showing for the M1002/229 combination. This is a toughened laminating epoxy and we thought it should perform better. We suspected that it was not completely cured in the short time we gave it. Therefore we ran another test on just the M1002/229 combination—this time post curing it at 140°F for 8 hours. The results were much better with the post cure.

Once we had chosen the surface preparation, namely to sand the metal with 80-grit sandpaper, we were ready to make the shear test specimens. We used a room temperature, low viscosity epoxy system as a control—something to compare results to.

We also tested two PRO-SET Toughened Resin/Hardener combinations—176/276 Highly Toughened Adhesive and the M1002/229 Toughened Laminating Epoxy. Once again, we made 5 samples per combination.

For the shear test specimens, we fabricated double shear tests (we have nicknamed them "Space Invaders" because of their resemblance to the electronic game from the 1970's).



"Space Invaders" Test Sample

We used 0.020" diameter wire to control the bond line thickness. The wires are visible in the photo below, which is a shot of a broken test sample. The surface area of each specimen was approximately 1 in^2 per side or 2 in^2 total.

Bond Line Thickness

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PRO-SET REPORT is published by
Pro-Set Inc.
PO Box 656
Bay City, MI, 48707 USA

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prosetepoxy.com

000-220

To test the samples, we set them between the platens of our MTS Servo-Hydraulic Test Machine and tested them in compression.

MTS Machine

The results are found in the charts at right. The M1002/229 combination with a post cure was the clear winner at 3,868 psi. The other two test adhesives also performed very well.

Since the bushing used for this project also has 24 bolts, a peel load cannot get started. With 400 in^2 of surface area, 3,868 psi will be more than strong enough to handle the shear load.

Tensile Adhesion (psi)

Surface Preparation	Control	M1002/229	175/275	176/276
Sand 80 Grit	1038	1232	1753	3806
Sand 80 Grit/Chemical Etch	599.9	760.8	1297	1559
No Sanding— Chemical Etch Only	827	745.5	1348	3774
Sand 80 Grit Post Cure 140°F x 8 hrs.		1564		

Sanding was done with a Fein Sander using 80 grit dry paper. Epoxy was applied within approximately 2 hours of completion of sanding. All values are the average of 5 test samples. Values derived from PATTI tests. Chemical Etch is a mild phosphoric acid. It was diluted 1:2 with water, applied with a brush, allowed to remain on the surface for 2 minutes. Rinsed with water and allowed to dry. Control = room temperature cure epoxy system.

Shear Adhesion (psi)

Surface Preparation	Control	M1002/229	176/276
Sand 80 Grit Post Cure100°F x 12 hrs.	1806.0		2282.2
Sand 80 Grit Post Cure 125°F x 18 hrs.		3868.3	

Sanding was done with a Fein Sander using 80 grit dry paper. Epoxy was applied within approximately 2 hours of completion of sanding. All values are the average of 5 test samples. Values derived from double-sided samples tested in compression. Bond line thickness was maintained by two stainless steel wires .020" diameter and placed parallel to the shear direction. Control = room temperature epoxy system.

The great properties of PRO-SET Products combined with application specific testing provide our customers. ■

New PRO-SET® Hardener

Jeff Wright, Technical Services

The PRO-SET line has expanded with the addition of 224 Hardener. This new hardener provides a faster cure than our 226 Hardener, which previously was the fastest standard hardener in the PRO-SET product line. 224 Hardener can be used with all of our standard resins as well as many of our custom resins.

We developed 224 Hardener to reduce thin film gel time so parts can be handled or de-molded sooner. Reducing the time needed for a laminate to cure can often improve efficiency by allowing the next task in the lamination process be started earlier. An example would be the ability to remove jigs and fixtures sooner when using 2 layers of 15 oz. double bias fabrics for tabbing. Some fabricators may find the faster cure helpful when applying a thin veil fabric for a skin coat, reducing the waiting time required before the next lamination step can be started. It can also be used with our 117LV Infusion Resin for smaller infused parts.

The difference in the pot life with 224 Hardener compared to 226 Hardener can be seen in the table below. The shorter pot life requires the user to work in small batches that can be spread quickly. Warmer temperatures shorten the pot life further. The working time is similar to many common polyester and vinylester laminating resins. Viscosity is higher than our other standard PRO-SET hardeners to minimize viscosity drop with the increased exotherm this hardener generates.

Customers can expect high physical properties similar to those of other standard PRO-SET hardeners. Physical properties can be improved with an elevated post-cure, but in many cases a room temperature cure will provide the required degree of cure and structural performance. PRO-SET 224 Hardener is available in all of our standard sizes and can also be tinted blue (as with our other PRO-SET hardeners) for quality assurance during mixing.

Additional information and physical properties are available from Pro-Set Inc. at 888-377-6738. ■

Pot Life Comparison in Minutes

Resins	Hardeners	
	224	226
117LV	21	*44*
125	*20*	*37*
135	18	*31*
145	18	*31*

100g @ 72°F

Building and Sailing Earth Voyager

J.R. Watson, Technical Services

The equation for fast sailboats is pretty simple: easily driven, sufficient power, and a means to apply that power. The 60' trimaran *Earth Voyager* epitomizes this combination and is recognized by many as the fastest sailing craft on the Great Lakes—perhaps all of North America.

"Easily driven with sufficient power and the means to apply it" may be a simple equation, but the structural issues are not so simple to accomplish. Light enough, stiff enough, yet strong enough to survive enormous forces are the forte of careful composite construction. The construction of *Earth Voyager* illustrates how to choose the right materials to address the anticipated forces. PRO-SET® epoxy was used throughout in combination with the chosen reinforcing fibers.

A trimaran has three parallel hulls. The central main hull is the largest. Two crossbeams, running athwartship, connect the main hull to two outer hulls, called amas. The sailing rig is stepped on the main hull and supported via stays. The centerboard (daggerboard) is a retractable keel that offers lateral resistance. A rudder controls steering. *Earth Voyager* is 60' length overall with a 44' beam. The main hull contains accommodations for a crew of six. Overall weight is 15,000 pounds.

A trimaran's main hull is a torque tube that must bear the racking forces exerted by the two connecting crossbeams and their rigid attachment to amas as they address waves. These are not only dynamic forces but also a classic fatigue environment, as impulses from waves can occur every second. The main hull must also accept headstay and sheet tension loads of the mainsail and jibs. The daggerboard and rudder penetrate the hull and introduce another torsional force, especially when the boat becomes airborne and then reenters the water at high velocity.

Earth Voyager's main hull is comprised of western red cedar strips edge-glued

Earth Voyager docked at Mackinac Island

to serve as a permanent mold and active core. The cedar is covered inside and out with two layers of bi-directional woven, 12K carbon fiber. Drain-out not an issue with this fabric, so it was wet out in place. PRO-SET 125/226 was used for its good wet-out performance. Vacuum bagging allowed the parts to achieve a 40% fiber content. Post-cure temperatures of 160°F were held for 20 hours, achieved by salamander heaters in a hybrid foam insulated greenhouse which served as a huge oven.

Beam attachment areas and deck were reinforced with radiated unidirectional carbon fiber buildups. These buildups are connected to wooden bulkheads. All were vacuum bagged in a separate operation.

A high-modulus skin and wooden core composite structure like this does very well with dynamic forces as well as exposure to fatigue. It is reasonably light and a good choice for a trimaran's main hull where there are many connections and complicated forces. Ultimate low weight is not as important near the hull's center as it is further out in the amas.

The amas must have sufficient stiffness to endure compression forces caused by sudden, frequent immersion in waves. Bulkheads were built into the hulls at beam attachment points to address torsional forces. Bulkhead material is marine plywood, tabbed with carbon fiber biaxial tape. Like the main hull, all is laminated with PRO-SET 125/226. To minimize weight, yet protect the amas from bumps and scrapes from locks, docks and other craft, the material choice for the amas was Airex™ foam core with bi-directional aramid woven fabric, vacuum bagged and post-cured.

Earth Voyager's crossbeams are 44' long. They are cantilevered beams whose bending moment must resist the heeling force of the craft (on the order of 300,000 ft./lb.) as well as sidestay tension forces. The beams are comprised of end-grain balsa covered with biaxial fiberglass. The corners contain 30 layers of unidirectional carbon fiber.

The daggerboard is 20' long, end-grain balsa, shaped for a NACA (National Advisory Committee for Aeronautics) foil section. The cantilevered foil must resist lateral movement, both static and dynamic, as the craft passes through the water. It is covered with 20 layers of unidirectional carbon fiber.

The 85' mast was built in two female half molds of alternating unidirectional and bi-directional carbon fiber, vacuum bagged, and post-cured using PRO-SET 125/229. The slower hardener provided the extra working time required as gantries were used to roll carbon fiber out continuously over the mast. The mast hound and tang fittings are stainless steel with fasteners bonded through the skin and into wooden reinforcement joined inside. The shrouds and halyards are Samson™ Amsteel UHMW (Ultra High Molecular Weight) 12 strand single braid line. This material replaced 1 x 19 stainless steel wire, saving 400 pounds of weight aloft.

Earth Voyager is painted with a flattened two-part polyurethane, producing a pleasing, easy-to-maintain surface. Non-skid additive was placed in the paint on deck surfaces.

So what is it like to sail on *Earth Voyager*? I've sailed on her for six seasons. The craft glides smoothly over the seas. On deck, it's always windy and the wind is always in your face. Spray from an errant wave can knock you down. You remain tethered so you're not swept away. The helmsman heats the boat up a little and then, with the increased wind energy now available, lays her away. You rock back with the acceleration. The sensation of speed is lost until you see a Boston Whaler skipping over the waves trying to stay with *Earth Voyager* to capture a photograph. Soon the Whaler drops behind and disappears.

Inside the boat at night, it is dark. The carbon fiber interior is not painted. To conserve electricity, glow sticks give off an eerie greenish glow. As the boat rushes through the water, the sounds are amplified through the high modulus carbon, like a tightly strung guitar. You hear the bang of a lazy block or the groaning tension of a steel ball bearing traveler grinding on steel track. Earplugs are required to get rest.

Earth Voyager was built in the backyard of a house in Rochester, NY, in 1992. The trimaran is fundamentally a Walter Greene design, strongly influenced by her creator Ray Howe. Howe has built a number of large trimarans. *Earth Voyager* has raced and won races on Lakes Ontario, Erie, Huron, Michigan and Superior, most recently breaking its own first-to-finish record in the 2005 Port Huron to Mackinaw Race. ■

Earth Voyager

Revisiting an Old PRO-SET® Repair

Tom Pawlak, Technical Services

In 1994, Tony Shepherd and his crew at Captain's Yachting Services in Point Edward, Ontario, repaired an extensively damaged pre-preg carbon fiber sailboat using wet lay-up and vacuum bag techniques with PRO-SET Epoxy.

In 2004, Tony said the boat, *Promotion*, was still happily sailing the Great Lakes. In all that time, the repair held strong with no sign that the repair ever took place, even though the boat was sailed aggressively and painted dark blue. The color is significant because dark paint will heat up laminates considerably in the sun and often cause composite repairs to print through or telegraph the repair.

This carbon fiber pre-preg sailboat was built with Nomex™ honeycomb core and high-density foam cores. She was built in England for use in the 1993 Admiral's Cup where she was t-boned on the port side just aft of amidships during one of the races. Tony got involved when he was asked by an interested buyer to go and look at the boat in Southampton, England.

View of the damage of the port-side of the hull.

Tony determined that the extent of the damage was repairable and that the boat was a good value for his client.

Tony visited the builder, Green Marine, near Southampton, who provided the laminate schedules and fiber direction for the 5 to 6 layers of uni-carbon. He then came back to Canada and purchased the dry carbon fiber fabrics, honeycomb core, and PRO-SET epoxy for the repair.

The repair involved both the hull and deck. Different honeycomb core densities were used in each. High-density foam core was used under hardware locations on the deck.

The original builder recommended 6" overlaps/bevels for transferring loads from the repair to the original hull. Tony's crew actually used wider scarf/overlaps to be even more conservative in their approach.

They applied the biggest patch first and then progressively smaller patches to create a gentle transition. This minimizes stress concentrations, which is key for long-term success when repairing high fiber-volume composites (HFVCs). Composite repair professionals argue for and against placing the big patch vs the small patch first. It is likely that either method would have worked nicely for this repair as long as good surface preparation was used and a nice gentle bevel angle was incorporated. In this case, the bevel angle was about 100:1.

Not interested in repairing with pre-pregs, Tony called to see what we recommend in laminating resins that would approach pre-preg properties. We recommended a medium viscosity laminating epoxy that has 2 ½ hours of open time before the vacuum bag should be in place. He used PRO-SET 145 Resin and 229 Hardener, allowed the skins to cure at room temperature overnight, and then post cured at 165°F for 8 hours. This produced cured epoxy properties with a glass transition temperature around 190°F.

The hull shape was recreated by building a strip-planked (bead & cove) mold on the inside of the hull.

The outside of the hull had more than 1" of fairing applied, which would have complicated making a mold from that side. The excess fairing was on the boat to meet the now obsolete International Offshore Rule (IOR) measurement bumps.

Cut-away of the hull showing excess fairing.

About 10" of additional carbon fiber (outer skin only) and core were removed all around the perimeter of the repair. This exposed the core side of the inner skin, which allowed the perimeter of the inner skin to be sanded to a gentle taper.

Prior to laminating the inner skin repair, a dry run with a vacuum bag verified no leaks existed. This is important when vacuum bagging. If leaks had been found, the edges of the exposed Nomex core would have been sealed with thickened epoxy and allowed to cure prior to re-testing for vacuum integrity and doing the actual repair.

***Promotion* during repair.**

Each layer of uni-carbon was oriented to match the original laminate. The inner carbon skin went on without any problems, was bagged, allowed to set up overnight, and then post cured.

The core was installed into an epoxy/microballoons combination that was applied about 1/16" (2 to 3 mm) thick to the cured laminate with a flat spreader. The core was placed in this and held in location with duct tape until the vacuum bag applied uniform pressure. This was allowed to set up overnight and then post cured.

Prior to applying carbon fiber to the Nomex core, a light fiber scrim was hand laid with epoxy, without vacuum bagging, and allowed to cure. This was done so the carbon layers would be supported between core channels on the honeycomb core during vacuum bagging. If the scrim had not been applied and cured prior to vacuum bagging, the carbon skin would dimple at each unsupported space between core webs and not carry load as effectively. If this were aluminum honeycomb, a layer of fiberglass would typically be applied to act as an insulator prior to covering with carbon fiber to prevent electrolysis.

Post cure was achieved by tenting off the repair with plastic tarps. Heat was provided via a salamander-type oil-fired heater at 165°F for 8 hours. Initial attempts to cure with radiant heat were unable to achieve adequate temperatures.

The IOR fairing bumps were recreated over the repaired hull using epoxy and microballoons applied in layers to achieve the 1" thickness. Barrier coats of room temperature cure epoxy were applied to seal the epoxy/microballoon surface prior to applying primer and the dark blue finish paint.

Tony was very pleased with how the repair went, saying the actual repair was very straightforward compared to the effort it takes to identify and procure the specific unidirectional carbon fiber and core materials required. Eleven years of hard sailing have proved the repair was successful. ■

Note

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