PRO-SET

REPORT
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NEWS ABOUT

EPOXY CHEMISTRY,

COMPOSITE PROCESSES &

FABRICATORS

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Testing Capabilities

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Hydromat and MTS

FTIR Workstation

The interest in materials testing at Gougeon Brothers has fueled a long term commitment of resources to better understand the composites materials we use. This interest catalyzed the first testing program back in the early 80s, with more involvement and equipment added each and every year since then. This desire to understand the properties of composites and the materials with which they are fabricated initiates many questions that can only be answered with well thought-out test programs. A specific program begins by determining which test is appropriate for the specific application, fabricating the specimens, testing the composite, studying the results of that testing, and then determining how the results affect our customers. This issue of the PRO-SET® REPORT provides an overview of our testing capabilities. Future issues will focus on specific test methods and procedures, what we learn from them, and the value of this information for your projects.

Gougeon Brothers, Inc. has a considerable range of equipment. This includes environmental chambers, hot soak test tanks, and freezers and ovens. These items are used to expose materials to conditions from cold and damp to hot and dry or hot and wet. We have creep fixtures for testing the effects of long term exposure to load and elevated temperatures. In the mechanical testing lab, we have a 100,000 pound capacity MTS® Systems Corporation servo-hydraulic test machine, a 20,000 pound capacity MTS servo-hydraulic test machine, and fixtures for these machines to test everything from compression to tension to flexural, peel and cleavage, as well as some specialized methods developed here like the annular shear test and Hydromat panel test method (ASTM D6416). The Hydromat is a fixture that we invented to test flat panels for flexure. What makes it unique is the ability to deflect the specimen in two dimensions at the same time. Most of the equipment used with the MTS machines will allow multi-cycle fatigue testing as well as one-time static testing of both composite laminates and neat resin samples.

In the instrument lab, there is a Differential Scanning Calorimeter (DSC) for thermal analysis of polymers and a Fourier Transform Infrared Spectrometer (FTIR) for evaluating polymer compounds and blends. There is a battery of microscopes as well as analytical balances. We also have an accelerated UV and weathering test machine, adhesion testing systems, gloss and moisture measuring devices, Shore D and Barcol hardness testers.

Gougeon Brothers Inc. also enjoys very productive relationships with several universities. We use their labs to validate the testing we do in house. Any testing that cannot be done in our labs due to time constraints or equipment limitations will be sent either to the independent test lab at Saginaw Valley State University (SVSU) or to Michigan State University (MSU). These labs contain much of the same equipment we have, allowing us to increase the number of test programs underway at any time. MSU has additional thermal analytical tools like Thermal Mechanical Analysis (TMA) and Dynamic Mechanical Analysis (DMA). SVSU does all of our heat distortion under load testing (DTUL) of neat resin samples as well as laminate coupons. SVSU also does IZOD and Charpy impact testing of neat resin and laminate samples. The university labs can also perform any of the tensile, flexural, compression or impact type mechanical properties testing at temperatures within a range of about –250°F to 350°F. Michigan Technological University (MTU) works on cooperative and special projects, and provides engineering assistance when necessary. We also call on Michigan Molecular Institute (MMI) for their expertise in fracture mechanics and Scanning Electron Microscopy (SEM) work.

The results of all of this testing give us the knowledge to provide appropriate materials for our customers' projects. This is just part of the value that we provide to our customers every day. ■

Building Post Cure Ovens

Tom Pawlak, Technical Services
Gougeon Brothers, Inc.

The last issue of PRO-SET® REPORT discussed the benefit of post curing epoxy laminates. We demonstrated how 100°F to 125°F temperature post cures dramatically improve the physical properties of many room temperature cured epoxies. Here we discuss how to build cost-effective post cure "ovens".

Post cure ovens do not need to be fancy or expensive to be effective. At Gougeon Brothers, Inc, we have always built our post cure ovens for production boat building "in house." Early ovens were assembled from foil-faced 1" thick foam insulation and were held together with duct tape. Small space heaters and fans were placed inside the enclosure to heat and circulate the air. Light bulbs and heat lamps served as heat sources for some of the ovens. These heat sources worked best when they were directed at a flame resistant "heat sink" such as a piece of drywall or a large metal plate. These heavy objects came up to temperature slowly, but stored the heat, which dissipated into the air for a period of time before a thermostat turned on the light or heat lamp again. Heating a thermal mass like this is a good way to extend the life of your equipment because the heating element cycles on and off less often.

Our largest oven, built for post curing G-32 catamaran hulls and decks, was 40'x12'x8' and built from 5/8" drywall or sheet rock over 2x4 frame walls and 2x6 ceiling supports. The walls were insulated with 3.5" thick fiberglass and the ceiling was insulated with 6" thick fiberglass insulation. The 5/8" drywall provided a fire barrier for the interior walls and ceiling and also served as a heat sink. Electric radiant heaters were directed at the upper walls where the drywall thickness had been doubled *(photo left)*. The heat stored in the drywall provided warmth between heat cycles that were regulated by a controller. The temperature controller, made by Honeywell, was programmable which allowed the temperature to be brought up slowly, held at a selected temperature, and brought down slowly before turning itself off. Air movement was provided by two heat resistant fans, one at either end of the 40' oven. This oven proved to be very reliable and provided 125°F post cures for our G-32 hull and deck laminates. If we needed to post cure at higher temperatures, we covered the concrete floor in the oven with 1" or 2" foam insulation. This isolated the cool floor from the heated space and allowed us to post cure at higher temperatures without adding more heaters.

Temporary Enclosures

If permanent ovens are not practical, builders sometimes use temporary enclosures built in place over large laminates for post curing. Heavy plastic or flame-resistant tarps can be draped over a temporary framework to contain the heat. Propane and/or kerosene-fired heaters are often used because they provide lots of BTU's and can be rented locally. These are unvented style heaters and you must be careful to minimize hazards due to fire, carbon dioxide poisoning, and oxygen depletion. Propane-fired salamander style heaters are available that can be controlled with temperature controllers.

For example, Jon Easley at Westease Yachts in Holland, Michigan uses a temporary enclosure which is actually a portable greenhouse made of a double-walled plastic tarp. Steel tubing arches over the hull to support the plastic and create an enclosure to contain the heat. An air space between the two plastic layers is inflated with a small fan to create a dead air space to improve the structure's insulation value. Jon uses a 350,000 BTU propane-fired salamander style heater to provide the heat. He prefers heating with propane instead of kerosene because propane burns clean and does not produce soot as a byproduct of the burn. The heater components and controllers used to build his portable oven were purchased through Grainger® Industrial Supply (www.grainger.com) and McMaster-Carr® (www.mcmastercarr.com). The temperature recording equipment was purchased through Omega® (www.omega.com).

Controlling Post Cure Temperatures

There are two approaches to controlling post cure temperature. Some builders post cure infrequently and opt to manually adjust, monitor and record temperature during the cure or post cure cycle. It helps to monitor the temperature of the laminate at multiple locations so you can position fans and heaters with the goal of achieving uniform temperature throughout (top to bottom, end to end, and inside and outside the mold). Other builders spend money up front and purchase programmable controllers and recorders for their ovens so they don't need to be in the shop while the post cure is in progress. Both methods work.

Programmable Temperature Controllers

A good programmable temperature controller is a nice addition to an oven. It allows you to gradually increase temperature (ramp up) over time, hold at a given temperature (soak), and gradually decrease (ramp down) the temperature after the cure is complete. A temperature recorder is valuable for verifying that the oven has achieved the intended post cure temperatures and duration.

Temperature Indicator Labels and Wax Pellets

If a temperature recorder is not in the budget, you can purchase inexpensive nonreversible temperature indicating labels from industrial supply companies like McMaster-Carr. These indicator labels will verify that your part has been exposed to specific temperatures. There are also wax pellets that melt at specific temperatures to verify temperature. Accuracy is ± 1% for labels and wax pellets. Reversible temperature indicating labels are also available which are reusable. These labels come in a variety of temperature ranges including one from 86° to 140°F.

If you decide to assemble your own post cure oven, be sure to check with local code enforcement officials to make sure that the equipment will satisfy their requirements. ■

176/276 Toughened Adhesive

The 176/276 Toughened Adhesive is a highly toughened version of our popular PRO-SET 175/275 Epoxy Adhesive. It is formulated to bond a diverse variety of materials, including pre-cured carbon fiber parts, SMC and many plastics. It is also used to bond a combination of composite and metal parts which have much different rates of thermal expansion.

Toughness is a determining factor in an adhesive's ability to stop crack growth and prevent bond line failure. Epoxy adhesives can be toughened a number of ways. PRO-SET® 176/276 uses a combination of technologies to create what could be termed a hybrid adhesive. This enhanced toughness provides increased peel and cleavage strength in the joint.

A common misconception is that a flexible, stretchy adhesive is tough. A high elongation material may allow significant movement in the bond line, which relieves stress. This mimics the way a toughened system works to some degree. Too much motion, however, may accelerate damage due to cyclic fatigue and creep under load (static fatigue). A high elongation/low strength material may not have enough strength to carry the applied load through the bond line, causing a failure.

The other end of the spectrum is an adhesive that is too rigid. When a joint is stressed, a less forgiving adhesive may develop a crack within the bond line. Once a crack begins, the stress is concentrated at the tip of the crack and it continues to grow. If the adhesive cannot absorb some motion and dissipate the stress through a greater area within the bond line, the localized stress increases, causing failure. A higher modulus (more rigid) adhesive is also less forgiving to flaws introduced during manufacturing and assembly of the bonded components.

Bonding very highly loaded assemblies requires an optimized combination of toughness, elongation, strength and stiffness: the 176/276 combination is just that. As a general rule, when the bonded components are subjected to high peel, cleavage, or impact loads, taking advantage of the increased toughness of the 176/276 Toughened Adhesive is critical.

A comparison of properties	176/276	175/275
Pot Life (100g, 72°F)	30 minutes	30 minutes
Working Time (1/2" bead, 72°F)	90 minutes	75 minutes
Tensile Strength	5084 psi	7255 psi
Tensile Modulus	2.90×10^5	4.20×10^5
Flexural Strength	9,069 psi	11,914 psi
Flexural Modulus	2.70×10^5	4.10×10^5
Izod Impact	1.46 ft-lb/in	1.13 ft-lb/in
Lap Shear A-366 Steel	2,880 psi	2,330 psi
Lap Shear 2024T Aluminum	2,864 psi	1,987 psi
Tensile Adhesion A-366	4,296 psi	2,829 psi
Tensile Adhesion 2024T	3,415 psi	1,756 psi

Fabricator Profile:
Forespar® Products Corp.

Dennis Gallegos, Composites Manager
Light Composites

Forespar Products Corp. was founded in 1966 by Robert Foresman. With its plant located in Rancho Santa Margarita, CA, Forespar has become a large and diversified supplier of sailing and boating products to the world market. Composites manufacturing began at Forespar in 1979. The Light Composites division, established in 1993, is a top producer of carbon fiber structures from spinnaker poles to AeroRig® mast systems. The composites mast division specializes in wing spars and cruising spars, including the AeroRig. They are highly experienced with free standing spars.

Light Composites has been using PRO-SET products since early 1993 for their composite product construction. Primarily, they use carbon fiber and PRO-SET 125/229 and 237 Laminating Epoxies. Most bonding is done using PRO-SET 175/275 Adhesive.

Dennis Gallegos, Composites Manager at Light Composites, writes:

"One of our recent projects was the *Monashee II* sailing catamaran. *Monashee II* was fitted with an AeroRig. The carbon freestanding foil-shaped mast measured 23 meters and the boom measured 13.7 meters. One of the engineering challenges we faced with this boat was that there was only about 1.3 meters of bury to set the mast in the boat. Constructed in Cape Town, South Africa, *Monashee II* has sailed over 10,000 nautical miles and is currently circumnavigating the globe.

We have developed a molding technique which allows us to build virtually any shape possible. This has greatly benefitted in developing our mast building business since we can build lighter masts based on the strength required rather than on a tooled shape. It also allows us to work more directly with sail makers to create more aerodynamic shapes for masts.

Another recent project was a high aspect ratio wing mast for a Wormwood 55 catamaran. The design staff at Wormwood Performance Yachts contacted

Monashee II

Wormwood 55

us to see if we could construct a mast that had sectional dimensions of 570mm by 220mm. Due to the required dimensions, the overall mast height would be 24 meters. Since this mast was being installed on a performance-based catamaran, weight was a concern. We made the mast using carbon fiber and PRO-SET® 125/237. We've found that this combination works well when running up to 500 feet of material at a time in our wet-preg machine. The core was bonded in with PRO-SET 125/229 and the mast was joined using PRO-SET 175/277 Adhesive. All ancillary composite fittings were bonded in using PRO-SET 176/276 Toughened Adhesive. The bare tube weight was 475 pounds. The Wormwood 55 catamaran has sailed in excess of 29 knots-so construction was obviously a success."

Dennis Gallegos looks forward to further developments using PRO-SET infusion resins in upcoming projects. He emphasizes that Light Composites demands the consistent quality which PRO-SET provides. He thanks Joe Parker for the samples and technical support, and values the on-time service. ■

Photos of Wormwood 55 and *Monashee II* courtesy of Forespar® Products Corp.

PRO-SET Adhesives Available in Larger Quantities

Due to requests by a number of customers, the PRO-SET Adhesive Resins and Hardeners are now available in a 5 gallon pail size, which is coded as a dash 2 size, and in an open head 55 gallon drum size, coded as a dash 3 size. The dash 2 size will supersede the dash 1 size.

The products are not packaged as kits in the dash 2 and dash 3 sizes. The containers of resin and hardeners are purchased separately. Because the mix ratio is 2 parts resin to 1 part hardener, you will need two units of resin for each unit of hardener.

All of the Adhesive Resins and Hardeners are available in these new sizes. Contact your distributor for price and availability. ■

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PRO-SET

- laminating epoxies
- adhesives
- process equipment

www.prosetepoxy.com