Understanding flexible properties

By Jeff Wright

The Technical Staff at Gougeon Brothers, Inc. regularly discuss material properties in a variety of applications. For example, it is not uncommon for us to discuss with a customer how to use carbon fiber to stiffen a structure, such as the shaft of a kayak paddle, and then within minutes discuss with another how to bond a dimensionally unstable wood, such as oak, and ensure precautions are taken so that the relative movement of the wood will not cause a failure.

For the kayak paddle, the customer's concern is that the epoxy will allow the stiff carbon fiber fabric to be as rigid as possible. For bonding the unstable wood, the customer would like an epoxy that will be able to elongate more than the wood to ensure that the movement of the substrates will not fracture the epoxy. These examples highlight people's interest in the flexibility of the epoxy. However, this interest also often leads them into the world of material properties, a field they know little about. Material properties form a complicated web whose threads include not only flexibility but also elongation, stress, creep, ultimate properties, yield properties and toughness.

We have previously discussed how the flexibility of WEST SYSTEM® 105 Resin mixed with 205, 206, 207, or 209 Hardener makes it very well suited for use with common boatbuilding materials (*see Epoxyworks 16*). The many boats that have been successfully built using these 105 Resin-based epoxies with wood, carbon fiber, and fiberglass illustrate this epoxy's excellent properties. However, since we have introduced a new WEST SYSTEM product—G/flex® Epoxy—that has increased flexibility, this is a good time to review the relationship of flexibility to other material properties.

Flexibility

The stiffness of a material is often confused with its strength and toughness. Stiffness, or modulus, is simply a measurement of the ability to resist elongating when a load is applied. Stiffness and strength are separate properties. Strength is the amount of stress a material can withstand before it fails. Strength and stiffness cross paths when a material exceeds its yield strength, leaves the elastic region, and enters a plastic region.

When a material is in its elastic region, it will always "return" to its original state after stress is removed. For example, when a wooden or fiberglass boat is taken out for a ride during the day, its hull deflects each time it hits a wave, but when the boat comes back to the dock, it has the same shape as when it left. The hull spent its entire day in the elastic region, and it always snaps back to where it started. In contrast, if you see an old steel freighter with its steel shell dented in around the frames, the steel has been put into its plastic region (beyond its yield strength) and experienced enough stress that the hull shell could not return to its original shape.

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Since wood and most composite materials, such as fiberglass and carbon fiber, are not appropriate for use in the plastic region beyond their yield strength, we did not formulate our WEST SYSTEM epoxies to work outside the elastic region. Instead, WEST SYSTEM epoxies were formulated to enhance the performance of wood and composite materials under real-world operating conditions. We have spent over 30 years optimizing WEST SYSTEM epoxies. Even when competitors criticized our product for not having the ability to operate in the plastic region, we knew that the elongation of WEST SYSTEM epoxy was ideally suited for common boatbuilding materials. Simply making the epoxy more flexible would have reduced the overall performance of the structures that were laminated and bonded with it.

The concern about a resin's flexibility may come from an inaccurate perception that low elongation numbers imply brittleness. Most production boats are built using polyester resins. Due to the brittle nature of polyester resins, these boats often have problems with the laminate cracking. WEST SYSTEM 105 Resin-based epoxy is much tougher than polyester resins, which makes it more resistant to cracking. As an engineer, I am jealous that the makers of pickup trucks can boast about the stiffness of their truck frames without raising any concern about brittleness.

G/flex vs. polyurethane adhesive/sealants

When something is bent, it must elongate a certain amount. Since joints can fail when they are flexed, a high-elongation material would appear to be a good choice for a strong joint. Many of the polyurethane adhesive/sealant materials advertise elongations of +100%, and they have often been used, inappropriately, as bonding adhesives. Sealants are designed to withstand the movement in a gasketed joint, for example between a bronze through-hull fitting and a hull bottom. The sealant has to deal with the relative movement as the hull flexes around the rigid thru-hull fitting or when a careless mechanic steps on the through-hull, also causing it to deflect. Since the film of sealant may be less than 1⁄32" thick, a 1⁄8" movement would require 200% elongation. The sealant only needs to adhere well enough to stay in contact with the through-hull fitting and the hull bottom; the backing nut is keeping the through-hull in place, not the sealant. Although polyurethane adhesive/sealants are great materials when used as intended, these products do not have nearly the strength of epoxy.

Increased flexibility and elongation

Our newest product, G/flex®, has utilized a new chemistry that provides a very tough epoxy with greater flexibility and elongation than WEST SYSTEM® 105 Resin-based epoxies. The need for a higher elongation material was not driven by any shortcomings with 105 Resin combinations. Instead, G/flex was developed for applications for which no products are currently available. These applications include substrates that are prone to excessive flexing, hard-to-bond tropical woods, flexible laminates, and bonding to wet substrates. G/flex is an extremely tough epoxy that is more flexible than 105 Resin-based epoxies without sacrificing adhesion strength.

We do not recommend G/flex for building a stitch-and-glue kayak. In this case, 105 Resin-based epoxy is a perfect choice since the plywood will never exceed the elongation of the epoxy. However, G/flex will better match the modulus of flexible substrates, such as thin sheets of aluminum or even canvas that need to be joined. G/flex also has the ability to stretch after its ultimate strength has been exceeded, which allows G/flex to elongate beyond its elastic range. This can provide a safety factor for some bonding situations.

G/flex: resistance to creep stress

While we are proud that we developed an epoxy with more elongation, high strength, and excellent adhesion, G/flex's resistance to creep rupture is possibly the most notable achievement. Engineers typically use dimensions, strength properties, and predicted loads to calculate the stress that an assembled joint will be subjected to in service. However, the duration of the load also needs to be considered. Structural engineers who are Star Trek fans refer to this as the "Stress/Time Continuum." It is more often referred to as creep stress.

Creep stress is a material property that describes how a material resists the stress of a constant long-term load. Creep stress problems can be evident when something simply does not hold its shape, such as the roof on my 100-year-old home that has sagged from its original shape. Creep stress can also result in a complete failure, such as when a highly stressed glue joint at the stem of a boat fails months after the glue has fully cured when the boat is moored at the dock. In these cases, it can be said that the material has flowed or "crept" due to constant stress. Creep rupture often occurs at a stress below the material's ultimate strength. This is why creep loads are built into design safety factors. Creep stress is common in stitch-and-glue boats after the plywood has been bent into the desired shape and also in scarf joints in boards that are constantly bent.

Testing the creep characteristics of 105 Resin-based epoxies

Fortunately for users, our WEST SYSTEM 105 Resin-based epoxies are formulated to be resistant to creep stress. Our understanding of creep stress spans over 20 years, including studies of WEST SYSTEM 105 epoxy-bonded fasteners in 70' wind turbine blades exposed to constant high loads created by the centrifugal force of the spinning blades. Over the years, we have used several methods to test the creep characteristics of our epoxy. All the testing was done in a 95°F environment to accurately reflect the environment that many epoxy joints will experience in a boat's cabin or bilge.

Our first generation testing method was the Notched Beam Test, which is illustrated in Figure 1. The Notched Beam Test applies bending stress to a notch cut across a wooden beam that has been filled with the adhesive that is being tested. When the correct load is applied to the beam, the resulting bending moment will cause a creep rupture. Too small a load results in an infinitely long test. Too much weight results in a sudden ultimate strength failure. (For details on conducting your own notched-beam testing ask for 000-815 *Notched-Beam Test for Creep-Rupture*. This paper is available free from Gougeon Brothers. Call 866-937-8797.)

The Notched Beam Test provided very valuable data but had shortcomings. The main one was that it took a great deal of time to generate a substantial set of data points. In the 1990s, we developed the next generation creep test, affectionately referred to as the Drip and Grip. The test sample was constructed with two ¾" × ¾" × 3" wood laminate coupons that were bonded with a butt joint using an 1⁄8" glue line. This test utilized a tensile load that was increased very slowly over the span of 12 to 24 hours. Results from the Drip and Grip and the Notched

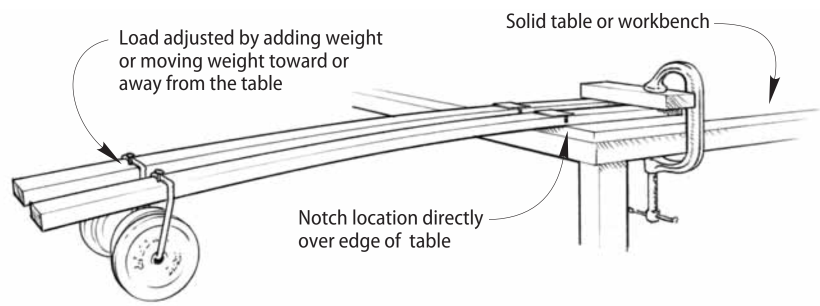

Figure 1—Original Notched Beam Creep Test—developed as a low-cost test for the home user.

Figure 2—The new Creep Stress Test Machine

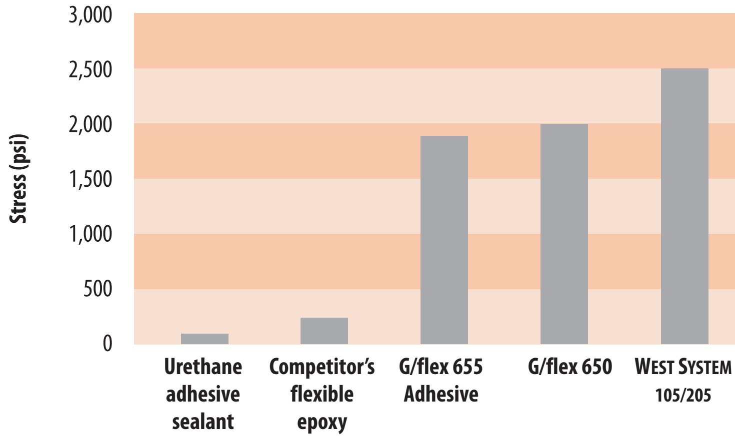

Figure 3—Comparison of creep rupture performance

Beam Test showed good correlation. This new test provided a data point every 24 hours.

Our current generation of creep test machine has been in use for 5 years. It uses the same concept as the Drip and Grip, but the load is applied pneumatically and data acquisition is computerized. We can now test multiple specimens at the same time with different load rates and capture data throughout the test. Recording the data every minute of a 24-hour test allows the engineer to have a full record of stress, load, and temperature. This ensures that any problems during the test are easily recognized. Figure 3 is a photograph of our current creep stress test machine.

Gougeon Brothers, Inc. has developed a large database of creep stress performance of our epoxy, competitive epoxies, and popular urethanes. Constantly testing for creep stress performance allows us to provide our customers with products that perform well under long duration loading. Testing has also demonstrated the risk of adding chemicals to the epoxy that make it more flexible. Testing also shows the poor creep performance of common urethane.

Developing G/flex®

Since many flexible adhesives have poor creep performance, the challenge has been to develop a formulation which has more flexibility than our 105 Resin-based epoxies without a significant loss in creep stress performance. Our chemists met that challenge with the development of our new G/flex Epoxy. G/flex offers a higher degree of flexibility without a significant loss in creep stress performance. This is a significant breakthrough in adhesive performance. G/flex provides long-term performance that common one-part elastic urethane adhesive/sealants can not offer. Figure 4 compares the creep performance of G/flex and other products.

As always, our Technical Staff are available to help you determine the best WEST SYSTEM product for your application. Remember that the performance of an adhesive joint can be greatly improved by avoiding peel loads, having the proper adhesive thickness, and ensuring there is enough surface area. Addressing these and other issues with our Technical Staff can help ensure a successful application. Call the Tech Staff toll free at 866-937-8797. ■

Stiffness of neat epoxies vs. laminate

G/flex can be used to bond many different materials, but it can also be used to create a more flexible fiberglass laminate. This is useful in unique applications that must bend more than a typical fiberglass laminate, such as a scupper flap or repairing a sheet-molded ATV fender. Although G/flex is not intended as a laminating system, it is useful for small projects that need to be a bit more flexible. This chart shows the **Relative Stiffness** of neat, or unmodified, West SYSTEM 105/205 and G/flex, and their respective fiberglass laminates. The stiffness of High Density Polyethylene (HDPE) is shown as a comparison.