

“If you were just more flexible, you’d see thing my way!”

Are flexible epoxies better than stiff epoxies?

How stiff is too stiff?

How flexible is too flexible?

By Bruce Niederer

Read the title of this article again. Could a statement be more confrontational? I sure didn't think so when my ex-wife laid it on me! The issue of “flexible” vs. “stiff” epoxies seems to have become a battleground in a continuing debate among adhesive manufacturers, wooden boat builders, restorers and repair yards. Who's right and who's wrong? Is it even a “right or wrong” argument? To deal with this controversy, the tech staff at Gougeon Brothers, Inc. did what we're known for—extensive testing. Armed with the facts, we hope to persuade you to be more flexible and see things our way! The terms “flexible” and “brittle” are not often used by engineers to describe the physical properties of a particular material. “Work of fracture” is an engineering term and it has much to do with people's perceptions of materials as flexible or brittle. As defined below, work of fracture is the energy required to break a material sample into two pieces, expressed in Joules per square meter. It is one of the ways to characterize the toughness of a material. As J.E. Gordon, Professor of Materials Technology at the University of Reading, writes: “Thus the chief safeguard against brittle failure lies in a high work of fracture. This is basically why glass ($W = 6 \text{ J/m}^2$) is brittle and steel ($W = \text{about } 105 \text{ J/m}^2$) is tough, although both these materials have roughly the same tensile strengths.” The Izod pendulum impact test (ASTM D 256) gives an approximate measure of the work of fracture, and is, by the way, one of the many research tools Gougeon Brothers uses to qualify its products.

I know what you're thinking...SO WHAT!?

You want to know if your epoxy is flexible enough. Tensile elongation and modulus are the engineering terms most often used to describe the characteristic referred to as flexibility. (*See Terms of Engineering below.*) This may seem like splitting hairs, but the distinction is important from an engineering standpoint.

Your boat project in the garage is designed and engineered to meet specific criteria and the materials you use for building or repair should match the design criteria. Armed with an understanding of elongation and modulus, it is quite easy to determine if the WEST SYSTEM[®] Brand epoxy that you use religiously will be too stiff for your project. First, look at the elongation of the materials you are bonding together or coating, and be sure the elongation of your brand of epoxy is equal to or greater than your substrate materials. Here are a few examples of some materials used for boat building and repair (remember, the higher the number, the more it stretches before it breaks):

- Glass fiber, in its different forms, has a tensile elongation at rupture (strain to failure) of 3.5%–4.8%.
- Carbon fiber in its different forms has a tensile elongation of 0.5%–2.0%.
- Typical boatbuilding woods have a tensile elongation of 0.4%–0.6%.

- WEST SYSTEM Brand epoxy has a tensile elongation of 3.5%–4.5%. (By comparison, polyester resin has a tensile elongation of 1.4%–4.4%.)

This means that on almost any of these substrate materials coated or bonded with WEST SYSTEM epoxy, the substrate will reach its ultimate strength and strain limit and fail before the epoxy fails. To avoid catastrophe, structures are normally engineered to operate in an environment where the working strains are no more than 25 to 50% of the ultimate load capacity of the reinforcement or substrate.

I can see you're still not convinced

Here is a simple little test you can do in your shop to convince yourself that WEST SYSTEM Brand epoxy is plenty "flexible". Rip a 1/16" thick by 1" wide by 18" long strip of ash. Now apply 3 coats of your favorite epoxy. After it's cured, bend the strip by bringing the two ends together. If the strain to failure, or modulus of rupture, of the epoxy is less than that of the wood, the epoxy will crack. If it is greater, the epoxy will not crack. If the strain limit of the epoxy is equal to or greater than the strain limit of the substrate, the combination will work well together.

Now you're thinking...It's not that simple!!

Well, of course not. There is a penalty for too much flexibility. Strength and creep resistance must be considered. In the grand scheme of things, if the adhesive or coating is very stretchy, creep (the movement under a constant load) can become a big problem, and all materials will creep. Sagging rafters have crept into that position slowly over a long time. A bar of taffy lying on an uneven surface would soon creep into the uneven contours of the surface. What degree of creep or flexibility is acceptable?

You wouldn't use a flexible adhesive to bond together parts that will be under a constant heavy load. So too should you think twice about springing a hardwood rub rail around a hull and bonding it to the surface of a flexible epoxy coating. Aside from structural problems, creep is also a factor in the eventual "print through" of an underlying fabric's texture through the surface of epoxy.

There is a balance between allowing more elongation at the expense of creep resistance, or limiting creep and accepting lower elongation. It is well known in the adhesives and coatings industry that you give up strength and creep resistance to increase elongation in a plastic material. This tradeoff is important to understand.

Frequently, the term flexible is used to market products that aren't very strong. Some epoxies have a tensile elongation as high as 23%. Why would anyone say that flexibility is a good thing for structural applications? Because flexible sounds (and sells) better than weak. If you're going to bond a structure together with a product that is not as strong as the structure, that product had better be flexible! The flip side of the flexible coin is to describe stiff products as brittle, a marketing gimmick that tries to associate stiffness with weakness.

So what am I saying? The real battle in the epoxy wars should not be about flexible vs. stiff. It should be much more about testing, engineering, and experience vs. guesswork, posturing, and arm-waving. We believe WEST SYSTEM will always win in that arena. To produce a reliable, quality material, actual testing and engineering are essential. There is no other way to achieve the right balance of material properties for real-world applications.

Is WEST SYSTEM epoxy the only adhesive you will ever need, on every project you ever undertake, with nothing but unqualified success after unqualified success? Maybe. Probably not. OK, no. Although WEST SYSTEM is versatile enough to be used in many different applications, we all use a range of adhesives. Just as we would use the right nail for a particular job, we choose the right adhesive for the job at hand. WEST SYSTEM epoxy is strong, creep resistant and appropriately flexible for the materials used for boatbuilding.

Terms of engineering

Strain (e) is the change in length when a test sample is subjected to load, expressed as a percentage. The formula is: $e = (L_f - L_i) \div L_i \times 100$. That is, the final length (L_f), minus the initial length (L_i), divided by the initial length (L_i), times 100 (to get the percent).

Elongation (ef) is the strain measured at “the breaking point” when the sample has been stretched far enough to fail. A paper clip would have a low elongation value compared to a rubber band.

Stress (s) is the applied load or force, divided by the specimen cross section, usually expressed in pounds per square inch (psi).

Modulus (E) is the ratio of stress (s) to strain (e), usually expressed in pounds per square inch [$E = s/e$]. A rubber band is a high elongation/low modulus material; the paper clip is a low elongation/high modulus material.

Work of Fracture (W) is the energy required to break the chemical bonds of the test material and produce fracture. Most materials perceived as “brittle”, such as glass, have a very low work of fracture, less than 10 J/m^2 (Joules per square meter). As you might expect, the paper clip has a high work of fracture. Oddly, the rubber band has a very low work of fracture, and so, in this sense, is more brittle than the paper clip.

For a better understanding of this subject, some good reference books are J.E. Gordon's The New Science of Strong Materials published by the Princeton Science Library, and The Wood Handbook published by the US Dept. of Agriculture.

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