The Advantages of Epoxy Resin versus Polyester in Marine Composite Structures

Introduction

In any high-tech structural application, where strength, stiffness, durability and light weight are required, epoxy resins are seen as the minimum standard of performance for the matrix of the composite. This is why in aircraft and aerospace applications, as well as offshore racing boats, epoxies have been the norm for years.

However 95% of pleasure boats under 60 feet today are still made with polyester resin. The main consideration for materials selection for most composite builders is **cost**, with performance and more importantly **value** for money often being a secondary consideration. As a general rule epoxy resins are twice as expensive as vinyl ester resins and vinyl ester resins are twice as expensive as polyesters. Since the resin can constitute 40 to 50% of the weight of a composite component, this price difference is seen as having a significant impact on the cost of the laminate.

However, when considered against the cost of the whole structure (the boat) the **cost** is relatively insignificant, and the **value** of higher quality and long term gain of better durability (therefore better resale value) can be tremendous.

What contributes to this better value…..?

Epoxy resins have performance advantages over polyester and vinyl esters in five major areas:

- Better adhesive properties (the ability to bond to the reinforcement or core)
- Superior mechanical properties (particularly strength and stiffness)
- Improved resistance to fatigue and micro cracking
- Reduced degradation from water ingress (diminution of properties due to water penetration)
- Increased resistance to osmosis (surface degradation due to water permeability)

Adhesive Properties

Epoxy resins have far better adhesive properties than polyester and vinyl ester resins. However many times have you known a polyester car body filler fall off a ding repair? The superior adhesion of epoxy is due to two main reasons. The first is at the molecular level, where the presence of polar hydroxyl and ether groups improves adhesion. The second is at the physical level - as epoxies cure with low shrinkage, the various surface contacts set up between the liquid resin and the reinforcement are not disturbed during cure. The result is a more homogenous bond between fibers and resin and a better transfer of load between the different components of the matrix.

High adhesion is especially important in resistance to micro-cracking (see later) and when using sandwich construction. The bond between the core and the laminate is usually the weakest link of the laminate, and the superior adhesive properties of the epoxy resin greatly increase the strength of the interface between skins and core.

Mechanical Properties

Two important mechanical properties of any resin systems are its tensile strength and stiffness. The figure below shows results of tests carried out on commercially available polyester, vinyl ester and epoxy resin systems, either cured at room temperature or post cured at 175°F.

After a cure period of seven days it can be seen that the tensile strength of the epoxy resin is 20 to 30% higher than those of polyester and vinyl ester. More importantly, after post cure the difference becomes ever greater. It is to be noted that boats built with polyester resins are rarely post cured in the workshop while boats built with epoxy quite often are. However, in practice all boats can quite often see “natural” post cures – particularly dark coloured surfaces under a Caribbean sun!

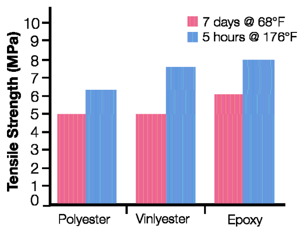
The consequences are two fold:

Structurally

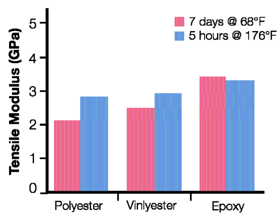
A post-cured epoxy laminate will exhibit tensile strength and modulus (stiffness) close to double that of a non-post cured polyester or vinyl ester laminate.

Cosmetically

Polyester and vinyl ester resins shrink up to 7% volumetrically and because the resin continues to cure over long periods of time this effect may not be immediately obvious. This cure accounts for the print through effect observed on a lot of older polyester boats. In comparison, epoxies shrink less than 2% and an epoxy laminate will be a lot more stable and have better cosmetics over a long period of time than a polyester one.



Comparative Tensile Strength of Resins



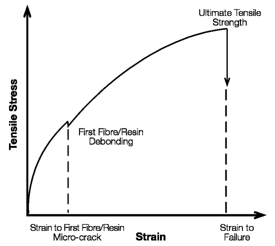
Comparative Stiffness of Resins

Fatigue Resistance and Micro-Cracking

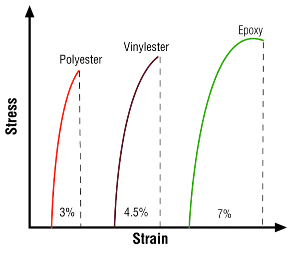
In most cases a properly designed hull laminate will never be subjected to its ultimate strength so physical properties of the resin matrix, although important, are not the only criteria on which a selection has to be made. Long before ultimate load is reached and failure occurs, the laminate will reach a stress level where the resin will begin to crack away from those fiber reinforcements not aligned with the applied load. This is known as 'transverse micro-cracking' and although the laminate has not completely failed at this point, the breakdown process has commenced.

The strain that a laminate can take before micro cracking depends strongly on the toughness and adhesive properties of the resin system. For relatively more brittle resin systems, such as many polyesters, this point occurs a long way before laminate failure, and so severely limits the strains to which such laminates can be subjected. In an environment such as water or moist air, the micro-cracked laminate will absorb considerably more water than an uncracked laminate. This will then lead to an increase in weight, moisture attack on the resin and fiber sizing agents, loss of stiffness and with time, an eventual drop in ultimate properties.

The superior ability to withstand cyclic loading is an essential advantage of epoxies vs. polyester resins. This is one of the main reason epoxies are chosen almost exclusively for aircraft structures.



Typical FRP Stress/Strain Graph

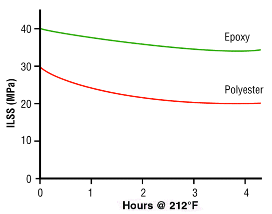


Typical Resin Stress/Strain Curves (Post-Cured for 5 hrs & 176°F)

Degradation from Water Penetration

An important property of any resin, particularly in a marine environment, is its ability to withstand degradation from water penetration. All resins will absorb some moisture, adding to a laminate's weight, but what is more significant is how the absorbed water affects the resin and resin/fiber bond in a laminate, leading to a gradual and long-term loss in mechanical properties.

Both polyester and vinyl ester resins are prone to water degradation due to the presence of hydrolysable ester groups in their molecular structures. As a result, a thin polyester laminate can be expected to retain only 65% of its inter-laminar shear strength after immersion over period of one year, whereas an epoxy laminate immersed for the same period will retain around 90%.



Effect of Periods of Water Soak at 212°F on Resin Inter-Laminar Shear Strength

Osmosis

All laminates in a marine environment will permit very low quantities of water to pass through them in vapor form. As this water passes through, it reacts with any hydrolysable components inside the laminate to form tiny cells of concentrated solution. Under the osmotic pressure generated, more water is then drawn through the semi-permeable membrane provided by the gelcoat in an attempt to dilute this solution. This water increases the fluid pressure in the cell. Eventually the pressure will distort or burst the gel coat, leading to a characteristic "chicken-pox" surface.

To delay the onset of osmosis, it is necessary to use a resin that has both a low water transmission rate and a high resistance to attack by water. A polymer chain having epoxy linkages in its backbone is substantially better than polyester or vinyl ester systems at resisting the effects of water.

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