Resin Properties for Composite Materials

Topics Covered

Comparison of Resin Properties

The choice of a resin system for use in any component depends on a number of its characteristics, with the following probably being the most important for most composite structures:

1. Adhesive Properties
2. Mechanical Properties
3. Micro-Cracking resistance
4. Fatigue Resistance
5. Degradation from Water Ingress

Adhesive Properties

It must be understood that the adhesive properties of a resin system is important in achieving the full mechanical properties of a composite. The adhesion of the resin matrix to the fibre reinforcement or to a core material in a sandwich construction is important. Of the three resin types discussed in the article (polyester, vinyl ester and epoxy resin) polyester resins generally have the lowest adhesive properties of the three systems. Vinyl ester resin shows improved adhesive properties over polyester but epoxy systems offer the best performance of all, and are therefore frequently found in many high-strength adhesives. This is due to their chemical composition and the presence of polar hydroxyl and ether groups. As epoxies cure with low shrinkage the various surface contacts set up between the liquid resin and the adherents are not disturbed during the cure. The adhesive properties of epoxy are especially useful in the construction of honeycomb-cored laminates where the small bonding surface area means that maximum adhesion is required. The strength of the bond between resin and fibre is not solely dependent on the adhesive properties of the resin system but is also affected by the surface coating on the reinforcement fibres.

Mechanical Properties

Two important mechanical properties of any resin system are its tensile strength and stiffness. Figures 1 show results for tests carried out on commercially available polyester, vinyl ester and epoxy resin systems cured at 20°C and 80°C.

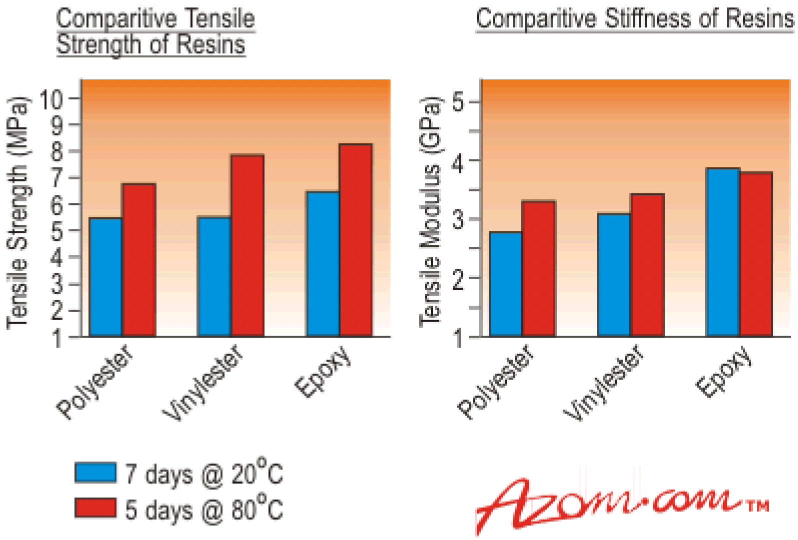

Figure 1. Comparative Tensile Strength and Stiffness of Resins

After a cure period of seven days at room temperature it can be seen that a typical epoxy will have higher properties than a typical polyester and vinyl ester for both strength and stiffness. The beneficial effect of a post cure at 80°C for five hours can also be seen.

Also of importance to the composite designer and builder is the amount of shrinkage that occurs in a resin during and following its cure period. Shrinkage is due to the resin molecules rearranging and re-orientating themselves in the liquid and semi-gelled phase. Polyester and vinyl esters require considerable molecular rearrangement to reach their cured state and can show shrinkage of up to 8%. The different nature of the epoxy reaction, however, leads to very little rearrangement and with no volatile by-products being evolved, typical shrinkage of an epoxy is reduced to around 2%. The absence of shrinkage is, in part, responsible for the improved mechanical properties of epoxies over polyester, as shrinkage is associated with built-in stresses that can weaken the material. Furthermore, shrinkage through the thickness of a laminate leads to 'print-through' of the pattern of the reinforcing fibres, a cosmetic defect that is difficult and expensive to eliminate.

Micro-Cracking

The strength of a laminate is usually thought of in terms of how much load it can withstand before it suffers complete failure. This ultimate or breaking strength is the point at which the resin exhibits catastrophic breakdown and the fibre reinforcements break. However, before this ultimate strength is achieved, the laminate will reach a stress level where the resin will begin to crack away from those fibre reinforcements not aligned with the applied load, and these cracks will spread through the resin matrix. This is known as 'transverse micro-cracking' and, although the laminate has not completely failed at this point, the breakdown process has commenced (Figure 2). Consequently, engineers who want a long-lasting structure must ensure that their laminates do not exceed this point under regular service loads.

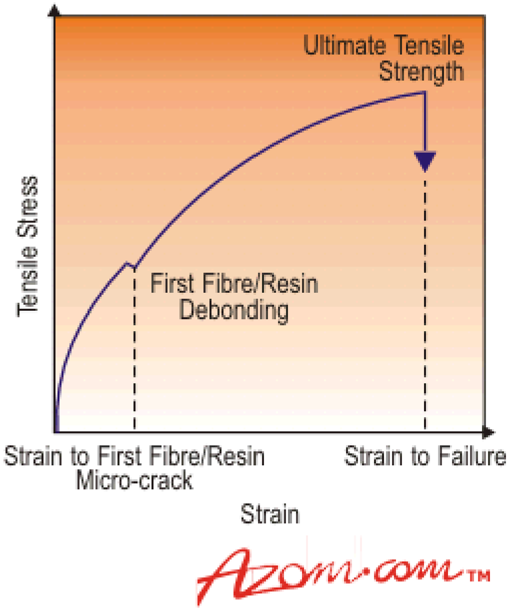

Figure 2. Typical Fibre Reinforced Plastic Stress/Strain Graph.

The strain that a laminate can reach before micro cracking depends strongly on the toughness and adhesive properties of the resin system. For brittle resin systems, such as most polyesters, this point occurs a long way before laminate failure, and so severely limits the strains to which such laminates can be subjected. As an example, recent tests have shown that for a polyester/glass woven roving laminate, micro-cracking typically occurs at about 0.2% strain with ultimate failure not occurring until 2.0% strain. This equates to a usable strength of only 10% of the ultimate strength. As the ultimate strength of a laminate in tension is governed by the strength of the fibres, these resin micro-cracks do not immediately reduce the ultimate properties of the laminate. However, 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 fibre sizing agents, loss of stiffness and, with time, an eventual drop in ultimate properties. Increased resin/fibre adhesion is generally derived from both the resin's chemistry and its compatibility with the chemical surface treatments applied to fibres. Here the well-known adhesive properties of epoxy help laminates achieve higher micro cracking strains. As has been mentioned previously, resin toughness can be hard to measure, but is broadly indicated by its ultimate strain to failure. A comparison between various resin systems is shown in Figure 3.

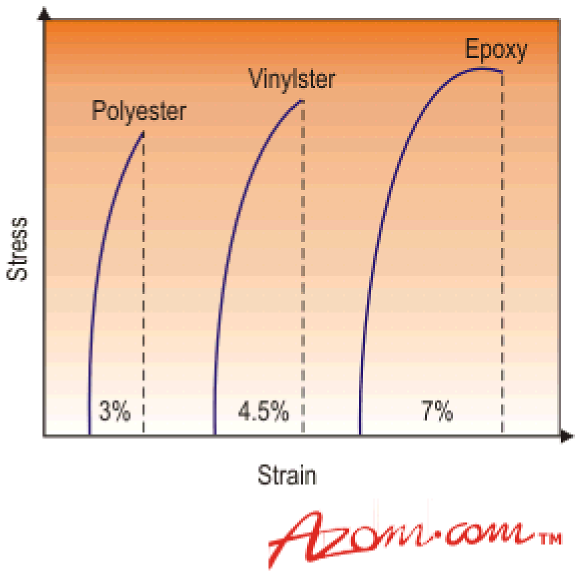

Figure 3. Typical Resin Stress/Strain Curves (Post Cure 5hrs @80°C)

Fatigue Resistance

Generally composites show excellent fatigue resistance when compared with most metals. However, since fatigue failure tends to result from the gradual accumulation of small amounts of damage, the fatigue behaviour of any composite will be influenced by the toughness of the resin, its resistance to micro cracking, and the quantity of voids and other defects, which occur during manufacture. As a result, epoxy based laminates tend to show very good fatigue resistance when compared with both polyester and vinyl ester, this being one of the main reasons for their use in aircraft structures.

Degradation from Water Ingress

An important property of any resin, particularly in a marine environment, is its ability to withstand degradation from water ingress. 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/fibre 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 in water for a period of one year, whereas an epoxy laminate immersed for the same period will retain around 90%.

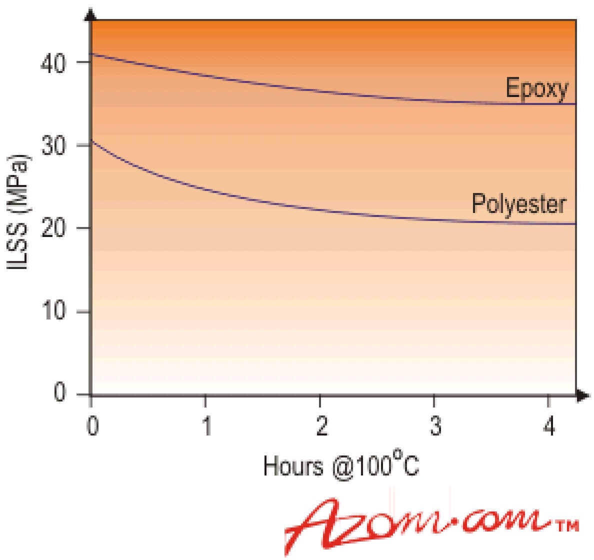

Figure 4. Effect of Periods of Water Soak at 100°C on Resin Inter-Laminar Shear Strength

Figure 4 demonstrates the effects of water on an epoxy and polyester woven glass laminate, which have been subjected to a water soak at 100°C. This elevated temperature soaking gives accelerated degradation properties for the immersed laminate.

Osmosis

All laminates in a marine environment will permit very low quantities of water to pass through them in vapour 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 cycle, more water is then drawn through the semi-permeable membrane of the laminate to attempt to dilute this solution. This water increases the fluid pressure in the cell to as much as 700psi. Eventually the pressure distorts or bursts the laminate or gel coat, and can lead to a characteristic 'chicken-pox' surface. Hydrolysable components in a laminate can include dirt and debris that have become trapped during fabrication, but can also include the ester linkages in a cured polyester, and to a lesser extent, vinyl ester. Use of resin rich layers next to the gel coat are essential with polyester resins to minimise this type of degradation, but often the only cure once the process has started is the replacement of the affected material. To prevent the onset of osmosis from the start, it is necessary to use a resin, which has both a low water transmission rate and a high resistance to attack by water. When used with reinforcements with similarly resistant surface treatment and laminated to a very high standard, blistering can then be virtually eliminated. A polymer chain having an epoxy backbone is substantially better than many other resin systems at resisting the effects of water. Such systems have been shown to confer excellent chemical and water resistance, low water transmission rate and very good mechanical properties to the polymer.

Source: SP Systems

For more information on this source please visit SP Systems

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Primary Activity

Material Manufacturer

Service Provider

Company Background

With years of experience and expertise in composite materials and technologies, we offer a comprehensive range of solutions for customers around the globe. High performance and cost-effectiveness are our drivers for satisfying demanding requirements in markets such as wind energy, marine and automotive.

With headquarters in the UK, and further operations in North America, Spain and Australia, our product range includes heavyweight structural prepregs, liquid epoxies for resin infusion and laminating, structural adhesives, dry reinforcements, core materials and structural design and process engineering services.

Number of Employees

700

Territories Serviced

Global

Services

- Supply of composite materials
- Engineering and design consultancy

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