SYSTEM THREE
EPOXY TALK

Notes on Post Curing Epoxy.

Postcuring - Part 1
Background

Years ago boat building epoxy resins were generally formulated for wooden boats. Prior to the advent of epoxy resins wooden boats were built using "traditional" methods such as carvel planking, caulked plank on frame, lapstrake, etc. In the mid 1970s Meade Gougeon and his brother, Jan, showed that wood veneers could be glued with epoxy resin and, more importantly, that wood could be protected from moisture egress by coating all exposed sides with epoxy resin. This use of epoxy resin made monocoque (single piece) hull construction possible. These hulls can be constructed using veneer, wood strips and the like and the effect of water on these materials could largely be ignored so long as they were epoxy coated (using fibreglass where appropriate) and maintained so as to keep the epoxy coating intact. Wood/epoxy hulls generally require no more maintenance than all fibreglass hulls. Since traditionally built hulls partially rely for their watertight integrity on wood getting wet and swelling; they can have significant maintenance problems.

One of the chief requirements for epoxy resins used in wooden boat building is that the resin cure sufficiently at room temperature and that the resin system retain enough flexibility and resiliency so that the epoxy coating does not crack from impact during normal use. Epoxies formulated with these properties paramount generally become quite flexible and rubber-like at temperatures in excess of 65ºC. It can be said that their modulus (a measure of stiffness) has dropped sufficiently so that their behaviour has changed from glass-like to rubber-like. While tensile, compressive, flexural, and shear strengths have dropped significantly at this temperature, they are still sufficient to bond wood together. The coating qualities of the epoxy are largely unaffected. Obviously, one should carefully choose a painting scheme when completing a wood/epoxy boat to minimise the effects of heat - any colour you like so long as it is light (save the dark for accents on hull and cabin sides).

The strength and stiffness of a wood/epoxy boat primarily comes from the wood. The role of the epoxy is to hold the wood together and to protect it from moisture. Except for strip planked and the "corners" of stitch and glue boats epoxy/fibreglass laminates add little to the overall strength of wooden boats. Strip planked boats generally have fibreglass sheathing on both the inner and outer hull sides. Here the epoxy/glass laminate holds the planks in a fixed position relative to each other so that the hull is strong. For a boat built this way to break it is necessary to shear the fibreglass laminate from the wood. Stiffness results from two layers of fibreglass cloth (parallel planes) held a fixed distance apart (I-Beam). Still, the wood strip core adds significantly to the overall stiffness and strength of the boat. A boat built this way could be thought of as a "wood-cored fibreglass boat". Standard room temperature cured boat building epoxies are perfectly adequate for this construction because the wood takes the load.

But, what happens when the core has little strength or stiffness - a balsa or foam cored boat for example? Here, unlike the "wood-cored fibreglass boat" described above, the skins (epoxy and fibreglass laminates) take the entire load. This significantly changes the requirements of the epoxy resin used in the laminates.

Postcuring - Part 2
Resin Properties

In foam or balsa cored epoxy/fibreglass laminate boat the skins must take the load - the core has little strength or stiffness. A load on the hull (falling off a wave, for example) will generally put the loaded side laminate in compression and the opposite side in tension. Like rope, reinforcing fabrics are great in tension but poor in compression. It is the epoxy resin that must take the compression load. So, the first requirement of the epoxy here is that it be very stiff so that it does not buckle in compression. Most wood boat building epoxies have sufficient compressive strength for this when at room temperature. However, they rapidly loose stiffness and compressive strength as the temperature rises and, finally, about 65ºC they are totally inadequate and a sufficient compressive load will result in a catastrophic failure - first on the compression and then on the tension side. The laminate literally blows apart. So, the second requirement for this type of construction is that the epoxy maintain adequate compressive strength throughout the expected operating temperature range - generally considered to be up to about 80ºC (higher if the boat will be painted a dark colour.)

As the temperature of a cured resin is increased the modulus (a measure of stiffness/resistance to bending) decreases. At first, the decrease is very gradual. As the temperature increases the rate of modulus decrease accelerates. Finally, at some point the rate of decrease hits a maximum and then begins to diminish with further increases in temperature. If one were to graph this with modulus on the vertical axis and temperature on the horizontal axis, both increasing as one moves away from the origin, a reverse "S" shape curve would result. At the point of maximum modulus rate change the curve would change from concave downward to concave upward. The lower temperature end of the curve is where the resin acts as a glass-like material while the resin acts as a rubber-like material. The point of maximum modulus change is called the Glass Transition Temperature (Tg pronounced as "tee-sub-gee"). (This is an important concept so take a break now, re-read this paragraph and draw things out.)

One thing should now be obvious: One does not want to "operate" a laminated panel at a temperature above the Tg of the matrix resin. To be safe one wants to have the maximum operating temperature a few degrees below this. The operating temperature is the temperature of the skin laminate, which may be considerably higher than the temperature of the day if sunlight is beating down upon it. (See why light colours are preferred?) Something else ought to be obvious: One wants to use a high Tg resin for these laminates.

What may not be obvious is this: Not only must the resin have "a high Tg capacity" it must be cured at a temperature approaching its ultimate Tg or it will not fully cure. It may get hard enough at room temperature to hand-sand but it will not be fully cured. At some point you must raise the temperature of the laminate to within not less than 15ºC of the ultimate Tg for several hours in order for it to fully cure. You can speed things up a bit by going a little over this but doing so will not raise the Tg further. So, the resin system must have the capacity to have an adequate Tg and it must be cured about this temperature. A laminate laid up at room temperature and later heated for ultimate curing is said to be "post-cured". Note that if a resin system does not have the capacity for a high Tg post curing will accomplish nothing. Wood/epoxy resins generally do not have the capacity to have high Tg's because the requirements stated in Part 1 are more important. In the 3rd and final part (next week) we'll explore the proper way to post cure a laminate.

Postcuring - Part 3
Techniques

A high Tg resin may be cured in two ways: It can be cured initially at elevated temperatures or it can be partially cured (becomes solid) at room temperature and then heated (post-cured). The two routes get one to the same place if sufficient time is allowed for both. The first route can be tricky because the epoxy reaction is exothermic and may excessively spike the temperature. Most boats are laid up at room temperature - hand lay up, vacuum bagged or infused - and post cured later simply because this route is considerably easier. This is the one we'll concentrate on.

Recall the reverse "S" shaped curve of Part 2 - the one you drew out, right? If a high Tg resin is room temperature hardened at 20ºC it will have a curve slightly to the left of the curve for the same resin hardened at 30ºC. In the case of a high Tg resin system both of these curves are to the left of the ultimate curve. The object of post curing, therefore, is to PUSH the curve to the right as opposed to PULLING it to the right. When it is pushed one stays in the glass-like region of the curve. When it is pulled then one is in the rubber-like region. Since you want to keep the laminates stiff while post-curing stay in the glass-like region. You do this by starting the post curing process at room temperature and ramping up slowly - maybe 5-8 degrees per hour depending upon the size, shape and mass of the part. You can never go too slowly but you can go too quickly. If you go too quickly you will still post cure the part but it may warp in the rubber-like area and take on a permanent set once it has fully cured. Post curing in a mold may help avoid warping. Waiting for several days at room temperate before post curing helps, also.

There are many ways to create a post cure "oven" and none need to be complex since all you have to do is get to 60 - 70ºC and hold things there for several hours. On a hot July day the back of your mini-van will do it for small parts. Ramp up by slowly closing the windows as the morning wears on. Put a thermometer somewhere near the curing part and you'll control things about as well as the engineers operating the autoclave at the Boeing plant. For larger parts you can rig some black polyethylene sheeting on some ropes over than hull set out in the sun. Put the pointy end of a cheap digital meet thermometer into some kid's play clay stuck on the laminate. Use a fan to circulate the air in the tent. If you're inside the barn, tent with clear polyethylene and use a couple of space heaters. Electric is best. Defeat the temperature control and use fans to circulate the air. If you must use direct fired heaters chose propane. Kerosene will fill the tent with un-burned hydrocarbons, which may affect secondary bonding. Remember that these heaters use oxygen so you must provide a source. They will create carbon monoxide if there is not enough oxygen so stay out of the tent and provide adequate room ventilation. In larger communities it may be possible to rent these heaters with indirect fire capabilities. These keep burnt gases out of the tent.

We once post cured a repair on a thirty-foot spinnaker pole by running the pole through a big cardboard box so that the repair area was inside the box (the pole was on sawhorses). We cut a small hole in the box bottom and inserted a hot air gun nozzle. A lab thermometer stuck in the top provided temperature control. We sat around monitoring things while quaffing a beer or two and talking about the importance of removing the sub forestay before jibing.

The points to remember are this. Heat is heat and the epoxy doesn't give a twit about the source. Monitor the process in some way and stick around to make sure you don't catch anything on fire. Oh, have an extinguisher handy just in case.