# APPENDIX C

# SUPERIOR ADHESIVES FOR THE MILLENNIUM

## Could Another Osmosis-Like Disaster Be Brewing?

Let's look at the following photographs with the eye of a surveyor/shipwright. Professionals in both of these fields will tell you that delaminations and the problems they cause form a substantial part of their workload. When I first started repairing boats, the failed glue joints always seemed to have a clear or light-brown glue line (pre-1970). John Guzzwell of *Trekka and Treasure* fame, and Cecil Lange, builder of the Cape George Cutters, two life-long boat builders, agree with me—they have never seen a failure that had the distinctive burgundy glue lines of resorcinol adhesives (page 510, note 23).

Unfortunately, the number of delaminations I see on all types of boats, from wood to fiberglass to metal, seem to have exploded since epoxy was introduced to the professional and home boat-building industry in the late 1970s. I see no signs of this problem decreasing in the near future. Furthermore, my observations of wood to wood epoxy failures raises yet another question: what about the durability of all epoxy composite boat construction, glass to wood, carbon fiber masts, and how durable are epoxy repairs of fiberglass hulls?

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**Photo 1.** When you look at a delamination such as this and see a clean break, with no wood torn away at all, you have a 100 percent glue failure. This is one layer of a laminated winch-mounting pad. The owner of the boat confirmed the pad was glued by a well-known and respected U.S. yacht yard, using a well-known marine epoxy formulation. He was winching his boat away from the dock in a blow when the epoxy let go. The winch shot right past his ear.

We all know this pad and winch should have been bolted through the deck structures. In fact one of the problems with epoxy literature is the suggestion that fastenings can be eliminated in many instances. This has led cost and weight-conscious builders to have more faith in the holding power of epoxy than is warranted. But in any case, as this photo shows, there is no tearing of wood at all. The wood is mahogany. The darker patches are epoxy. These epoxy remnants are 1/32-inch-thick, which rules out glue-starvation as the cause of failure. This type of catastrophic (i.e. sudden and unexpected) failure is not only potentially dangerous, but expensive, especially if you lose the winch overboard.

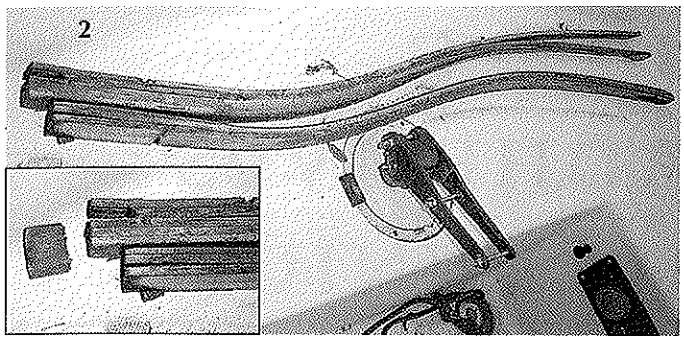



**Photo 2.** Take a critical look at various glue joints on both wooden and fiberglass production boats that are more than two or three years old. You'll learn a lot about modern adhesives vs. more conservative choices. This photo shows one of the most common delaminations we see when we walk through a marina, especially one in a sunny clime where boats are kept afloat year round. The timber used? Ash and mahogany. The adhesive? epoxy. I was pretty sure when I saw the light-yellow color. The shipyard owner not only confirmed it was a widely advertised epoxy, but offered to show us several more failures just like this one.

Note the close-up view in the inset. As the glue failed, the butt of the tiller wrenched right out of the rudderhead fitting. Hopefully, a steamer was not bearing down on this sailor as the tiller failed.

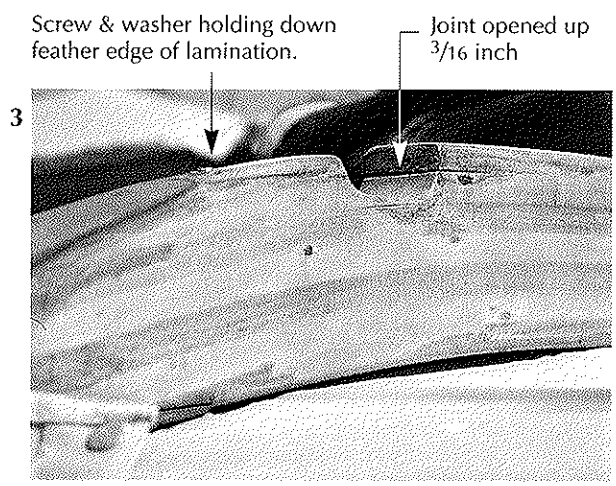



**Photo 3.** This is another common epoxy failure. Stressed or bent parts such as boom-gallows frames and toerail scarfs often separate as the epoxy warms up in the sun and softens or deflects. (Fig 1, also page 509, no. 13). The epoxy folks call this "creep". The main reasons given for epoxy failing as a wood adhesive are:

(a) It is sensitive to heat (Fig 1); (b) to UV (Fig 2); (c) to fatigue (Fig 3); and it cannot withstand the "severe stresses of water soaking and drying." (Fig 4).

It is quite likely the heat of the La Paz, Mexico, sun caused the boom gallows on this 40-foot cutter to delaminate. The owner is a master shipwright from New Zealand. He used mahogany and spruce with a well-known epoxy and protected the wood and joints with varnish. When the delaminations began to crack the varnish, it became a vicious cycle: more cracks in the varnish, more shrinking and swelling of wood around the joints, more delamination.

**Figure 1.**
**HEAT DEFORMATION TEMPERATURE (HDT)**

That temperature at which a plastic (epoxies are plastics) has lost 30 percent of its strength when tested using ASTM D 648 test methods.

Common Boatbuilding Epoxies have an HDT ranging from 101°F to 123°F (50°C)

*Some examples:*

At 118°F West System-brand epoxy 105, with 205 hardener has lost 30 percent of its strength *(www. concentric.net/-westsys/phisical.shtml)*

At 123°F (52°C) System Three Epoxy resin has lost 30 percent of its strength (*The Epoxy Book*, by System Three Resins, pub. 1998, page 37).

In each case, the following HDT figures were provided by the technical advisors of the formulators in telephone conversations, June 1999.

EPIGLAS epoxy resin–HDT 118°F (49°C) unless part-cured at elevated temperatures.

POXY-GRIP distributed by Glen-L–HDT 120°F (50°C)

T-88–HDT 101°F (38°C)

If there is no stress at all on the joint, the strength will probably be regained as the epoxy cools and hardens. But testing done at Gougeon Brothers Labs suggests "that wood/epoxy structures may have accelerated fatigue when stressed at higher temperatures." (see page 509 number 13)

**Figure 2.**

"This epoxy system is formulated to have maximum ultraviolet light resistance consistent with its other properties. However no epoxy resin system is ultimately resistant to degradation by sunlight."

—From *The Epoxy Catalog*, A System Three Resins Publication, January 1999, page 3.

**Figure 3.**

"Research to date suggests that epoxy-bonded joints will not last as long as the wood being bonded. The reason for this is that the fatigue-trend line for epoxy fails more quickly than that for wood. Wood retains most of its capabilities even after millions of cycles of tension and compression. Millions of cycles of stress are difficult to imagine but they can be translated into operating hours. Boats at sea have been carefully instrumented where cyclic load increases associated with waves were measured once every three seconds. At this rate, after about 833 hours, a hull would experience about a million cycles. The material used in a (wood/epoxy composite) boat would at this time still have about 60 percent of its ultimate strength." (Author's Note—In other words, in about five weeks, your epoxy bond loses 40 percent of its ultimate strength, and keeps on losing more due to fatigue.)

—From *Fatigue Aspects of Wood/Epoxy Composites*, page 32, Gougeon Brothers, Inc. 1987, and *Gougeon Brothers on Boat Construction*, New revised 4th Edition, 1985, page 27.

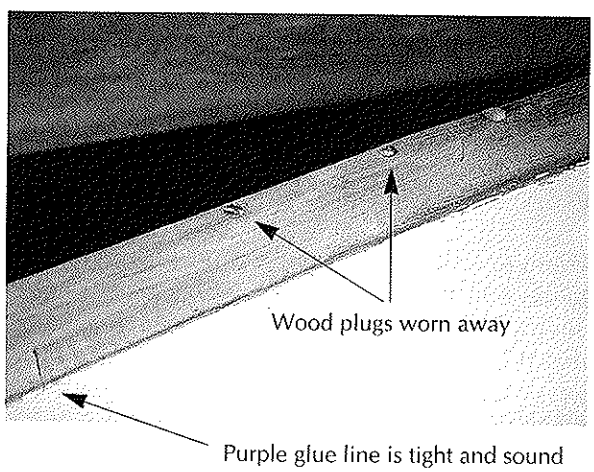
**Figure 4.**

"The Forest Products Laboratory (FPL) has received many enquiries over the years about the structural durability of epoxy bonds to wood, usually from builders of wood aircraft and boats, and manufacturers of speciality wood products such as architectural posts and railings. When reporting failures, users invariably have described bonds that delaminated on exposure to water in an exterior environment. Epoxy adhesives do not equal resorcinols in durability of bonds to wood. They develop dry sheer strengths that may exceed the strength of the wood itself, but the bonds fail in delaminations once exposed to the severe stresses of water soaking and drying."

—Charles B. Vick, Research Scientist and E. Arnold Okkonen, Physical Science Technician, USDA Forest Service, Forest Product Lab. *Forest Products Journal* Vol. 47, No. 3, page 71, 1997. *(www.fpl.fs.fed.us/documnts/pdf1997/vicks97c.pdf)*

**Photo 4.** Here you see a joint that has suffered through years of the worst possible conditions. Constant exposure to the heat and UV of the sun with no coating to protect the adhesive or wood, plus the stress of being bent to conform to the curve of the hull and deck.

These unvarnished toe-rails are built of that oily wood which is known to challenge all adhesives – teak. Yet here they are, 25 or 30 years down the road, perfectly sound and tight, but worn. The wood plugs are, in fact, worn right off. Notice the dark, almost burgundy-colored glue line. It is especially visible at the nibs. This is that rarely-advertised, extreme-exposure adhesive, resorcinol.

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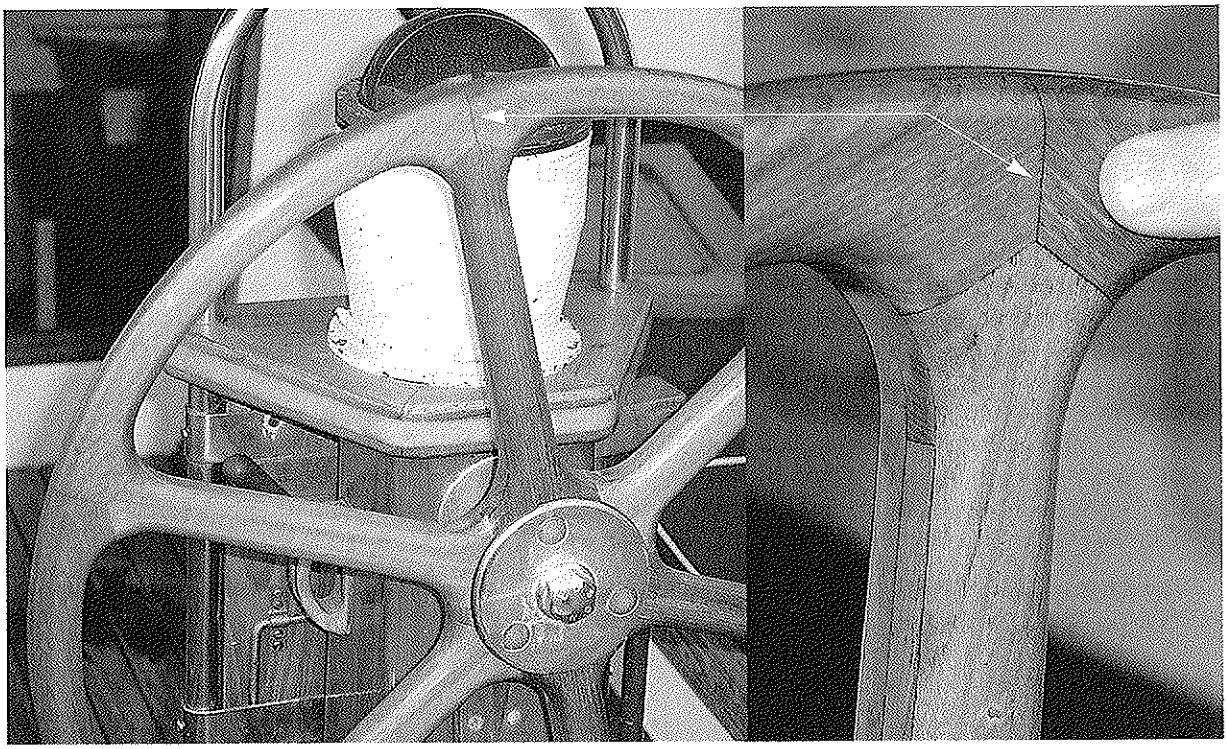

**Photo 5.** After John Guzzwell read the first draft of this appendix, he suggested we take a photo of the laminated teak wheel that has steered *Treasure* through 38 years of tropical and high latitude voyaging. This wheel is made up of 42 separate pieces of teak, glued with Cascophen (U.K.) resorcinol adhesive. It has survived constant exposure to tropical heat, UV rays of the sun, and stress, yet the joints are as solid today as all of the rest of the resorcinol glue joints on *Treasure*.

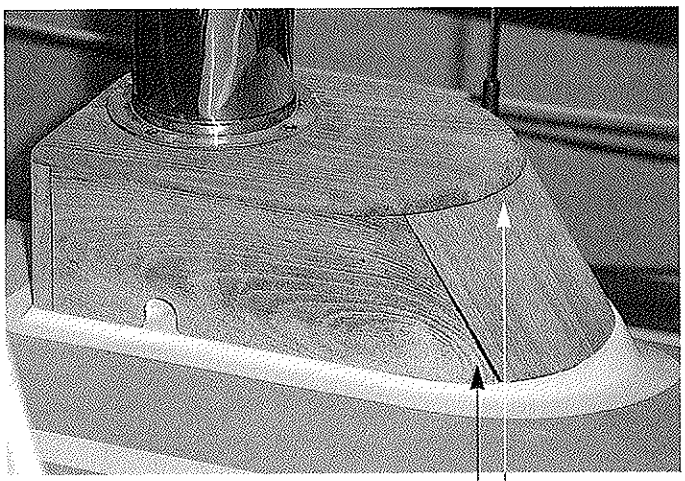


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**Photo 6.** This Dorade box has no stressed or bent parts. But, the epoxy (yellowish glue line) failed anyway. The craftsmanship of the woodwork shows that the builder cared. The boat was about eight years old and well maintained when I took this photo near Annapolis, Maryland. It has spent its life away from the constant heat and UV of the tropics.

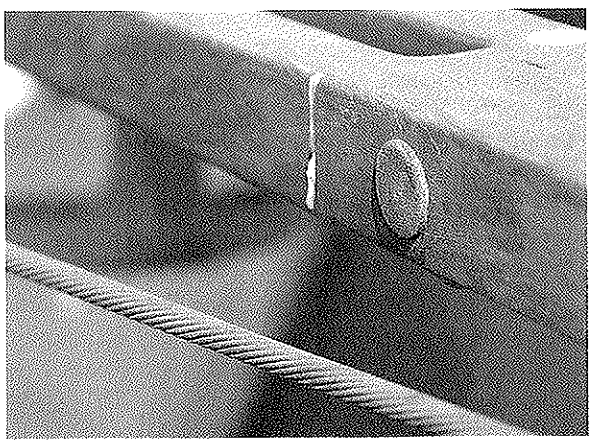

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**Photo 7.** Wood plugs are under minimal stress compared to toerail scarfs. But after I took the photo, I pulled this half-inch-deep, 1¼-inch-diameter wood plug out easily using my fingers. The adhesive? Well known epoxy.

**Photo 8.** We saw this skylight hatch on a professionally built 36-foot Herreshoff Neria ketch at the Risor Woodenboat Festival in Norway. She is sailed in Norwegian waters and laid up under cover half of the year, so heat and UV from the sun are not a major problem. A sign on the deck of this boat proudly stated its particulars: "Constructed in 1983 with oak and mahogany, teak deck, using -------- brand epoxy." After seeing the open corner joints of the skylight, we also discovered that ALL of the 42 laminated oak frame heels in the bilge had separated and opened up like a fan. This is typical of the delamination problems I have seen on all types of timber in many bilges. After several years, the wet and dry conditions of the bilge stresses glue, and only the best adhesives can survive.

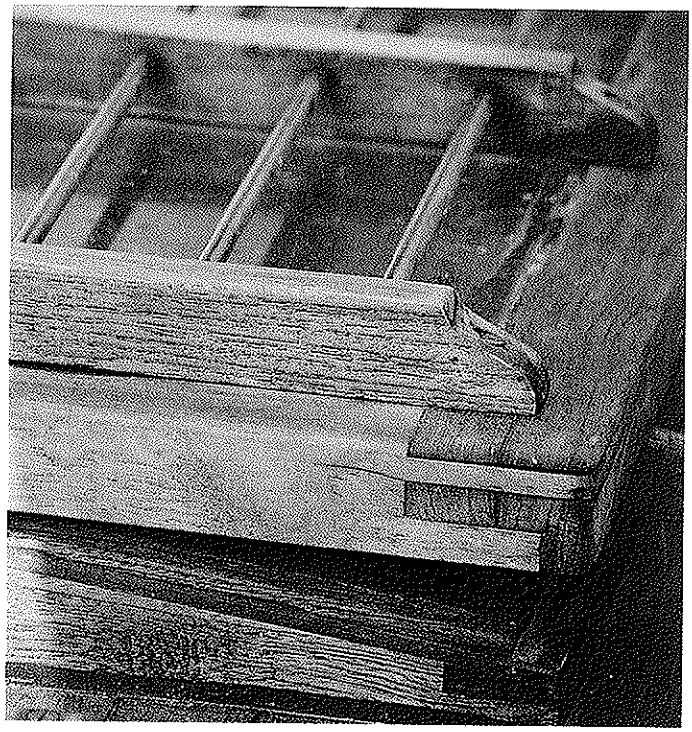

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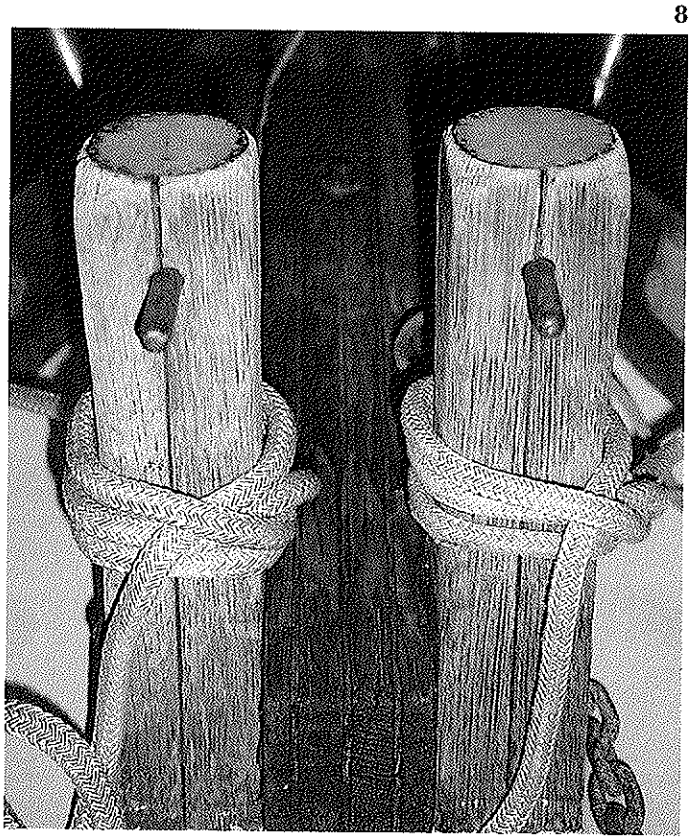
**Photo 9.** Oak, like teak, is a difficult wood to glue. The bitts, (Samson posts), shown here were glued with epoxy and have opened up 3/16 inch. The USDA Forest Service Technical Bulletin No. 1512, page 77, states oak ships, timbers and frames should be glued with resorcinol (*www.fpl.fs.fed.us/documnts/FPLGTR*). Back in 1965, we laminated Seraffyn's backbone from 1 inch by 8 inch planks of white oak. Her sawn frames were laminated from Philippine mahogany. I feel fortunate we chose U.S. plywood brand resorcinol for that job as I am pretty certain (knowing what we know today) epoxy would have failed four or five years later, leaving us in Portugal with a delaminated stem, forefoot, and frames and little possibility of finishing our voyage around the world. Now, 31 years and over 50,000 miles later, the resorcinol structures on *Seraffyn* have been found fully sound in a recent survey.



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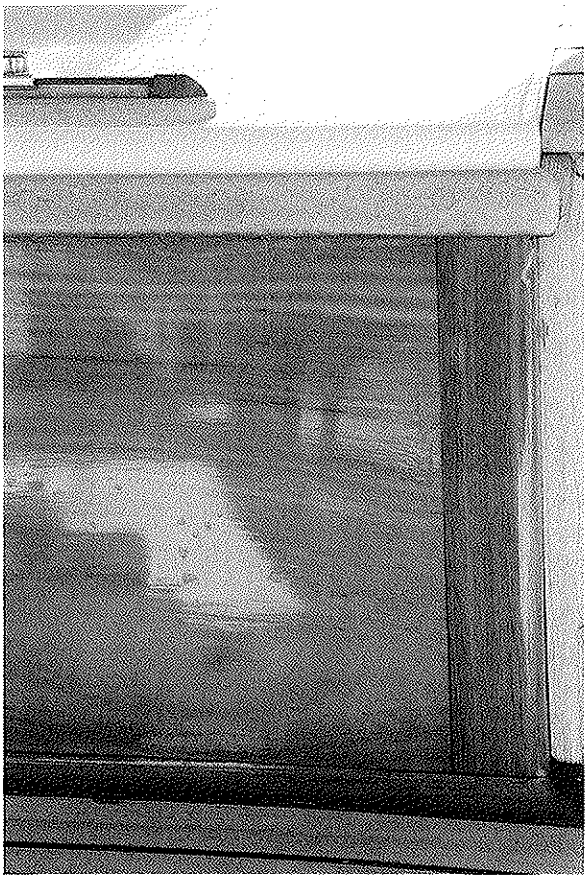

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**Photo 10.** The marine epoxy formulators will say, if you protect the epoxy joint from swelling by sealing it, (encapsulate it) you will solve the problem. You won't convince this boat owner. His whole dreamboat is coming apart. The cabin side on his custom-built 30-foot cutter is delaminating along the deck sill seam and at the lower part of the corner post. This is only one of several failures he pointed out to us during a visit in Southern California. He told us this work was done with a widely advertised epoxy, used by a trained professional two years before we took this photo. The wood was seal coated per the formulator's instructions, using epoxy first, then seven coats of varnish. It was kept well varnished after it was finished. The boat is up for sale.

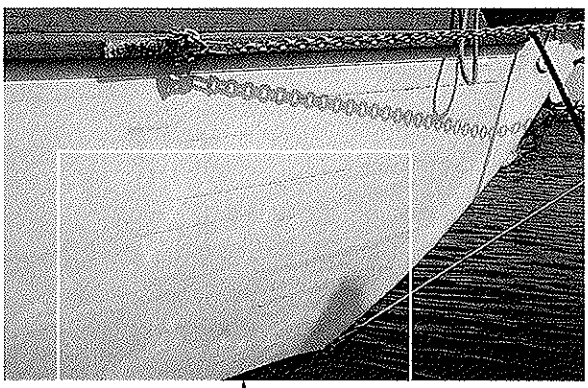

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**Photo 11.** This boat has delaminated almost completely outside and even inside where it has had minimal weathering. The frames and deckbeams have become structurally unsound. It is leaking so badly it is unseaworthy. Professionally built using a recognized brand of epoxy, this 18-year-old strip-planked mahogany 50-footer was lying in Mexico. The owner said he realized his dream was shattered when he could see light through 30 percent of the topside seams from inside the boat. Now he has been stalled for two years, his life savings tied up in a boat he cannot sell or sail. Are we being alarmist by showing this photo? We don't know, but this is the third major (i.e. whole-boat) disaster we've tripped over in the past four years of traveling. We haven't scoured the world for these delaminations but do wonder how many more are out there.

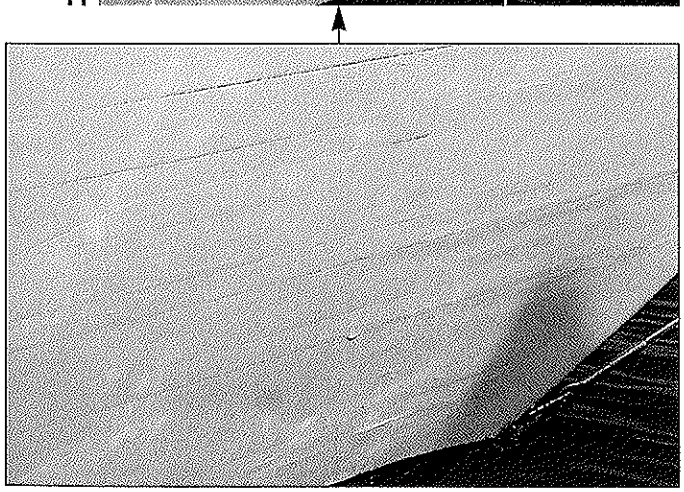


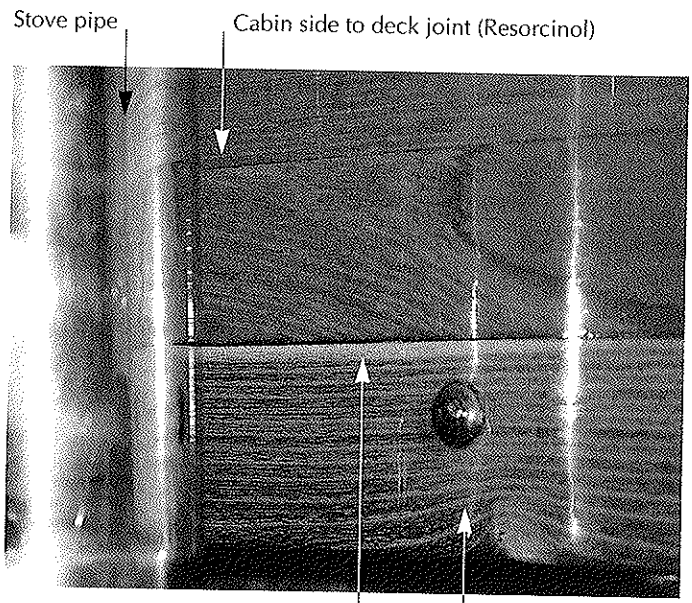
**Figure 5.**

"You will learn to use our products well with practice. . . It's okay to screw up now and then. That's how you learn. Besides, anything you do with our products can be fixed if you make a mistake."

—*The Epoxy Catalog*, System Three Publications, 1999.

**Photo 12.** The dilemma of the owner of the 50-footer in Photo 11 is a strong reminder to us of what might have happened had we chosen epoxy for *structural* glue joints on *Taleisin*. There was a lot of pressure to do so back in 1980, just as there is today: from formulators, advertisers, other builders, peer pressure. . . As it is, we did choose a well-known epoxy, urged on by the durability promises of its formulator and their technical advisory department. (They did not put these promises in writing.)

This photo shows not only the results, but a perfect comparison between epoxy and resorcinol. When we were making our decisions, we had heard that epoxy could suffer from UV degradation and might not be adequate for extreme exposure (waterproof) usage, so we chose resorcinol for the cabin side-to-deck sill joint as it would be exposed to the sun and salt water outside. But to make clean-up easier around the deckbeams and carlins inside the boat, we used the light-colored epoxy system. The formulators never mentioned *anything* about heat deformation problems. Heat from the stove pipe of our kerosene heater has caused the epoxy to fail. You can see that the 15-year-old spar varnish is still in great shape. It is more heat-resistant than the epoxy. The resorcinol joint, two-and-a-half inches above the delaminated epoxy joint is tight and in perfect condition. The epoxy joints on our forehatch and cockpit hatch have also delaminated as has our ash, galley sink drainboard.




The interesting thing is, our spruce ultra-light, barrel-staved spinnaker pole, plus the teak skylight, sliding hatch and cabin beams were also glued with epoxy and are still okay. But now we are worried; when will they come apart?

Now that we have hopefully caught your attention, we would like to help you be an aware buyer instead of one frightened by the caveat "Buyer beware." So, for simplicity and brevity—and hopefully to keep you interested enough to read onward—we have chosen the following question-and-answer format and highlighted some facts that should give you food for thought.

QUESTION – Are you implying that all epoxy-laminated boats are ready to fall apart?

ANSWER – I think any epoxy joint that is exposed to the elements or to hard use could fall apart even if it is sealed with epoxy. One formulator told the owner of the boat in Photo 11: "That batch of epoxy only had about a 20-year lifespan." As I mentioned, the failure rate is not consistent. Not all epoxy joints will come apart, just as not all fiberglass boats will develop osmosis.

When osmosis was finally recognized as a problem, existing fiberglass boats dropped in value dramatically and new boats became suspect. It has been estimated that osmosis concerns increased the cost of new fiberglass boats by 10 to 15 percent, the maintenance cost of older ones by 10 percent. I think the over-enthusiastic use of epoxy will eventually have similar fall-out.

"Some years ago my firm was persuaded to use epoxy in preference to the Casco Glues and resorcinols we had used for more than 50 years. The result was costly: seams split along the glue lines and scarfs delaminated.

I have also seen a bowsprit with a plate stating: 'This bowsprit was built by so-and-so yard in Florida using xx epoxy system. The brass plate looked good—and so did the view through the delaminated seams in the timber. Never again."

—H.R. Spencer, Spencer Thetis Wharf Ltd., Cowes, Isle of Wight, England.

Henry Spencer is a highly respected spar builder/boat builder, and rigger. This letter appeared in *Classic Boat* magazine, U.K., 1997.

Q – If this problem exists, why don't we hear more about it?

A – People are not eager to discuss their delaminations, just as they would be reluctant to discuss their bankruptcy. The people we interviewed in Mexico asked us not to mention their names or boat names. It is about resale value first, pride second.

Q – Do you think there is an actual cover-up?

A – It would seem so. Take a look at Figure 6 and consider the financial impact once people start asking questions about epoxy, especially if they turn to other products. And all companies worry about ongoing litigation. A chemist who was hired as a witness in a suit against one epoxy-formulating company told us the case was settled out of court on the stipulation that

**Figure 6.**

**A FEW OF THE REASONS YOU DO NOT HEAR ABOUT EPOXY FAILURES**

1. Would you want to devalue your boat by showing off delaminations?
2. If you call your epoxy formulator's help line and are asked what you did wrong, could you prove you followed all of their directions?
3. If you were an epoxy formulator, marine epoxy salesman, chandler, boatyard store manager,or boat builder who sells epoxy, would you want to discourage people from buying a hot-selling, high-profit item?
4. If you were a boatbuilder, would you risk losing a contract by saying you want to use a less popular adhesive when the competing boatyard would willingly use whatever the customer or designer requests?
5. If you were a builder who had previously used epoxy, would you want to cast doubt on the longevity of the boats you had already built?
6. If you were a publisher or editor, would you want to upset readers, advertisers, or boatbuilders, by discussing problems with such a popular class of products? Would you have the time to do the research and editorial work necessary to cover this subject in a fair and even-handed way?

no party (chemist included) disclose any details of the boat's delamination, glue type, nor the final cash settlement.

Q – Why don't you name brand names?

A – If we name one or two brands, other formulators will jump up and say, "But ours works better." Research with Charles B. Vicks, USDA Forestry Products Research Lab; Brian Boult, University of Auckland Construction Materials Research Dept; Richard Jagels, Professor of Construction Forest Biology, University of Maine, Orono, and others, as shown in the various figures here show that all of the "user-friendly, relatively affordable" marine epoxies have similar shortcomings as a structural wood adhesive.

**Figure 7.**

**CAUTION**

Before you decide to purchase any adhesive for structural wooden parts of your boat, ask for written confirmation that the adhesive meets all tests for exterior structural use, as required by the construction industry for use in your area.

In the U.S. the normal specification used to qualify adhesives for structural glued-lamination timbers intended for wet-use exposures under industry standard ANSI/AITCA 190.1 - 1999 (1) is ASTM Specification D 2559. In the UK the standard is BS 1204

"This specification covers adhesives suitable for the bonding of wood, including treated wood, into structural laminated wood products for general construction, for marine use, or for other uses where a high-strength, waterproof adhesive bond is required."

(from *FPL journal* Vol. 47, no. 3, March 1997)

You'll notice we use the term "formulator." None of the epoxy companies actually make anything. They buy epoxy resins, additives, and hardeners from big chemical companies, blend, decant, label and sell them to you (Ref 1, page 508).

Q – What about *Taleisin's* delamination?

A – Showing this in print presented a tough moral decision. We know it will reduce *Taleisin's* value; it might cast doubts on my boatbuilding knowledge. But we've decided to keep the boat indefinitely so price is academic. We are glad our early research encouraged us to confine our use of epoxy to parts that can be replaced relatively easily, not structural components of the boat.

**Figure 8.**

"The American Institute of Timber Construction (AITC) does not recommend that epoxies be used in design or repair of structural timbers if the bonds are expected to withstand either sheer or tension loading without steel reinforcement."

Q – What are you trying to accomplish with this Appendix?

A – To encourage epoxy formulators to list the limitations of their products on easy-to-understand instruction sheets—use parameters, limitations, problem areas, health restrictions, just as required for most industrial products (or like the info sheets that come with each medication).

2. – Encourage people to speak out about problems they have encountered and help others avoid costly delaminations, while at the same time encouraging a more serious, professional attitude toward the use of adhesives.

3. – Expose the epoxy formulators' systematic and unfounded trashing of resorcinol, the standard against which all other adhesives are tested for exterior structural use. They have inferred in word and cartoons that resorcinol is so difficult to handle that only a few gifted geniuses can use it. They have exaggerated the health problems of resorcinols, and at the same time under-played those associated with epoxy—not only while you are applying it, but later when you are sanding the finished epoxy product. They have even lied about its strength. Witness this patently false statement. . ."Its use is limited to surface where peel and cleavage forces are negligible, and vibration and impact unlikely. . .we also note that resorcinol does not produce reliable joints with oak, especially if subjected to repeated wetting and drying." *A Low Temperature-cure Structural Adhesive*, Gerald Schindler, (president of Chem-tech T-88) *Woodenboat* magazine, issue 4, page 47.

Epoxy resins. . . Their use in wood-to-wood bonding is limited since their permanence has not been adequately established.

—Canadian Plywood Association, 1999. (*www.canply.org/hand5.htm*)

"The lack of structural durability of epoxy bonds to wood has been a continuing frustration to fabricators of adhesive-bonded wood assemblies intended for service in exterior environments."

—*Adhesives Age*, July 1997, Volume 40, Number 8.

"Epoxy resins—Good adhesive to metals, glass, certain plastics and wood products. Permanence in wood joints not adequately established."

—*Wood Handbook: Wood as an Engineering Material*, U.S. Department of Agriculture, pages 9-11.

4. – Get people to realize you can laminate the skins on a boat, (three-skin, strip-planked) without epoxy. The Luders 16s were "cold molded" using an early type of resorcinol and are still in fine shape today. Sparkman and Stephens specified resorcinols for many of their 1950 - 1960 designs, which are still going strong. Furthermore, newer resorcinols have gap-filling

abilities, required only close contact, and cure at low temperatures, so work very well for any laminated structures we boat builders can construct.

5. – Get people to open their glue arsenal to include all of the non-colored adhesives that give results as good as or better than epoxy for non-structural uses at far lower prices, with lower health risks. (See following pages.)

Q – So what do you think the consumer and boat builder should be doing?

A – Research, research, research. Distrust heavily advertised products. In 45 years around the boating industry I have found the modestly advertised products are frequently the most satisfying in the long run.

Call the adhesives suppliers, formulators, and chemical companies and ask questions based on the information we have provided.

Demand proof of compliance with industrial standards for marine or exterior use. (Figure 7.)

Q – Why do you call this Appendix Superior Adhesives For the Millennium?

A – With the access provided by the internet today, I feel it is easier to find real information about adhesives than it was in 1980 when we built *Taleisin*. Had the net existed, I would have been able to check information sources right around the world and I would have limited my use of epoxy to sealing, coating, or sheathing.

I feel superior adhesives are ones chosen because they have fine track records throughout all industries, not ones chosen just because they are easiest for the unskilled boat builder to use. I am sure most of you would agree that the job of a structural boat-building adhesive is to guarantee that our boats will have good resale value ten, twenty, or thirty years from now. Just as important is that they will continue to be seaworthy and sail safely well into the millennium.

**At the suggestion of our attorney we include the following:**

The observations here contain the opinion of the author. In part they are reflective of his experience, and, where expressly indicated in the text, made in reliance upon information which has been supplied from collected sources.

Before embracing a project involving boat construction, I encourage the reader to conduct extensive research on the comparative suitability of alternative adhesives. Further, I encourage the reader, if there is any uncertainty as to the suitability of an adhesive for his intended application, to request express written representations from the manufacturer that the product is suitable for the *precise* use intended.

# CHOOSING ADHESIVES

*Refer to pages 508-510 for further information where numbers appear.*

Saying that there is one perfect adhesive for every bonding job is as simplistic as saying that there is only one perfect wood, or one paint for every job on the inside and outside of your boat. To be a well-versed boatbuilder, you must know the characteristics of a variety of adhesives so you can choose the best one for each situation. You should know about the exposure resistance, heat and fire resistance, waterproofness, pot life, cost, health considerations, ease of use, and the adaptability of each adhesive to the skills you have available and your shop conditions. Your choice then should be based on (1) where the joint will be in the boat, (2) what type of exposure it will get to sunlight, heat, and amazingly corrosive salt water, and (3) how difficult it will be to repair the joint if it does fail. Unfortunately, with the advent of high-profit-margin epoxies[1] has come overenthusiastic advertising,[2] which, in effect, discourages builders from considering other, probably more suitable, adhesives.[3]

I have worked with a wide variety of adhesives and discussed their pros and cons with boatbuilders (including John Guzzwell and Raleigh Kalayjian, to name just two) who have used some of them for up to forty years. I have also corresponded with chemical engineers, including Scott Earnshaw of Dimet Industries, Kern Hendricks of System Three, and Brian Boult, materials engineer and research fellow at the University of Auckland, New Zealand, who organized research for us on how various adhesives react to wet environments.[4] I have spoken to chemists and formulators at Gougeon Brothers Inc., Chem-Tech Inc., and Ciba-Geigy Ltd. Based on this research, I have tried to present a realistic picture of the pros and cons of five types of adhesives used in the construction of *Taleisin*. The adhesives are divided into three groups, starting with water-resistant melamine-urea types; then water-resistant, gap-filling epoxy systems formulated for boatbuilding; and, finally, extreme-exposure, waterproof-rated, gap-filling,* low-temperature resorcinols.

Although you may feel I am being cautious in my assessment of adhesives—and, in fact, in the whole matter of laminations in boatbuilding—I have good reasons. Many of the repairs I have had to deal with during a thirty-year career have involved glue failures (delaminations).

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* Although gaps filled with glue are acceptable where they are out of sight (such as between multiskin layers or under paint), all joints—and especially varnished or natural (bare) joints—are more professional and more attractive when they are tight. A 1/16-inch or wider glue-filled joint in a cabinside, in a table, or in a varnished caprail is, in my eyes, unacceptable.[5]

## Melamine-Urea, Water-Resistant Adhesives

Weldwood and DAP plastic-resin glue, Casco UF 109, and Aerolite 306 and 308 adhesives are inexpensive and relatively easy to use. Cleanup can be done with water. This saves money and eliminates the use of special solvents (e.g., acetone, lacquer thinner), which have high health and fire risks. Each gives full-strength joints with light-colored glue lines that are not affected by elevated temperatures or ultraviolet light. None are suitable for extreme exposure use, nor for long-term deep-cycle situations.*

### *Weldwood Plastic-Resin Glue*

This adhesive is not reliable on woods that contain tannic acid, such as oak. It is only water-resistant and should not be used for structural parts of a boat, such as frames and the backbone. I (and many other builders) have used it successfully for spars, which are kept sealed from moisture by varnish or paint. It is excellent for interior joinery, such as tables, paneling, and wood plugs, as it produces the least-obvious glue line of any adhesive I have used. This is not only because of its color, but also because it can be used to make tight-fitting hairline joints with no loss of strength.

| Pro | Con |
|---|---|
| Almost invisible glue line. | Water-resistant only. |
| Easy mixing. | Not good for use on oak. |
| Water-soluable for easy cleanup and lower health risk. | Requires good joint and firm clamping pressure. |
| No joint-fatigue problems. | Little gap-filling ability—1/32 inch maximum. |
| Not sensitive to high air temperatures or UV light. | Assembly time short at temperatures over 80°F. |
| Crosshatch sanding not required. | |
| No gloves or respirator required. | |
| Can be used at 50°F for full-strength joint. | |
| Difficult to starve joints. | |
| Adequate instructions on container. | |
| Inexpensive. | |

* Deep-cycle situations exist with such structures as keels, stems, or the bilge end of frames, which will be subjected to constant shrinking and swelling caused by wetting and drying and heat changes.

## *Casco UF 109*

This adhesive has one outstanding feature: The open assembly time and pot life can be controlled by adding more or less of the catalyst powder. We used it with excellent success in 95°F conditions to glue up the spars for *Taleisin*. Although it gives a clear glue line, it is not quite as invisible as plastic-resin glue.

| Pro | Con |
|---|---|
| Controllable assembly time. | Water-resistant only. |
| Clear glue line. | Little gap-filling ability—1/32 inch maximum. |
| Water cleanup, so lower health risk. | Requires firm clamping pressure. |
| Not sensitive to high air temperatures or UV light. | Sold only in Canada by Borden Ltd., P.O. Box 58098, Vancouver V6P 6C5 Canada. |
| No joint-fatigue problems. | |
| Crosshatch sanding not required. | |
| Can be used down to 50°F for full-strength joint. | |
| No respirator or gloves required. | |
| Difficult to starve joints. | |
| Easy to measure. | |
| Inexpensive. | |

## *Aerolite 306 and 308*

Aerolite is the most convenient water-resistant glue I have used. The powder component is mixed with water to form a creamy resin. This resin and its attendant hardener can be left in covered glass jars, ready to use. Whenever there is a gluing job, you brush the resin onto one side of the joint, brush the acid-based hardener onto the other side, and then clamp together the two pieces to set up and produce a full-strength joint. For larger jobs, the acid hardener can be mixed directly into the resin. (Brushes with metallic parts should not be left in the hardener because a reaction can stain the wood near joints.) This glue is used in the United States for home-built aircraft. Some English and New Zealand builders use it for the structural parts of boat hulls. Brian Boult's tests[4] showed that Aerolite was more water-resistant than either Weldwood or UF 109, but since it is rated water-resistant only and not for extreme exposure, I feel it is a risky choice in the long run. However, it is excellent for dinghies, interiors, hatches, and any nonstructural woodwork that will be protected by coatings.

Aerolite 308 is a slightly more expensive version of this same adhesive. It is rated as highly water-resistant, to British Government Standards 1204. It is not—as unfortunately designated in some suppliers' catalogs and also in Robert Steward's *Boatbuilding Manual* (see Bibliography)—a waterproof-rated adhesive, nor is it rated for extreme-exposure, deep-cycle situations.

| Pro | Con |
|---|---|
| Convenient to use. | Water-resistant only. |
| Water cleanup, so lower health risk. | Little gap-filling ability—1/32 inch maximum. |
| Almost clear glue line. | Requires firm clamping pressure. |
| Can be used at 50°F with no loss of strength. | Available only through mail order in United States (Wicks Aircraft Supply, 410 Pine St., Highland, IL 62249). |
| No crosshatch sanding required. | |
| Accurate measuring not essential. | |
| Not sensitive to high air temperatures or to UV light. | |
| Difficult to starve joints. | |
| No joint fatigue problems. | |
| Adequate instructions on container. | |
| Inexpensive. | |

## Epoxy Boatbuilding Adhesives

Epoxies present more of a health risk than the other adhesives I have used. This is due partially to the solvents required for cleanup, partially to the chemical content of the hardeners. They require accurate measurement, are laborious to apply if done according to the manufacturers' recommendations,[6] and, with their required gloves, cleanup solvents, respirators, and safety glasses,[7] more expensive and time-consuming to use than any other boatbuilding adhesive. Information about the correct uses and the limitations is difficult to find, as it rarely is listed on the container labels. Instead, the user must buy a separate technical manual from either the retailer or the formulator. Over the past nine years, Lin and I have studied much of this technical information and found that it often was ambiguous,[8] exaggerated,[9,2,3] couched in legalese, and full of fine print that seems designed to protect the formulators from lawsuits.[10]

If I sound unhappy with epoxy as an adhesive, it is because over the past fifteen years I have tried several different systems and found them unreliable, especially for use in the tropics. I have experienced and seen failures on deck structures, with stressed scarf joints such as on toerails and laminated tillers. Although I once thought these failures happened because epoxies are rated as water-resistant only,[11] I have since learned that epoxy loses strength when it is applied below 65°F[12,8] and when it is subjected to heat[13] and, apparently, to salt spray.[14]

As shown,[13] common boatbuilding epoxies lose strength (deflect, creep) as temperatures rise above 100°F. The most flexible systems, such as T-88, start to lose strength at temp-eratures as low as 101°F; West System epoxy has an HDT (heat deflection temperature) of 118°F; System Three's HDT is 124°F. On an 80°F day, sunlight can cause the temperature of painted white surfaces to raise to 128°F, light blue or aluminium surfaces to 143°F; red surfaces can reach 178°F and black 198°F, according to the West System "Cold Strategy" phamplet. Bare teak decks can reach temperatures above 140°F in the Tropics, as can engine rooms after several hours of powering.

I am uncomfortable with the apparently incomplete testing results available from boatbuilding epoxy formulators.* Brian Boult in 1988 did a worldwide computer search for tests performed to determine how epoxies would perform in deep-cycle marine situations. He found nothing that could apply to boatbuilding.[4] The marine formulators to date have only made available test information related to the fatigue resistance of epoxy structures under dry conditions. The results showed epoxy to be more prone to fatigue than the wood it bonds.[15]

The 3M Company and Dexter Corporation performed tests on room-temperature-cure structural epoxies they formulate for the aerospace industries, which *do relate* to boatbuilding. They subjected adhered aluminum joints to both saltwater spray and tap water at 100 percent humidity. After thirty days, the saltwater-sprayed joints, which initially had a shear strength of over 3100 psi, sheared apart at 500 psi, while those subjected to thirty days of tap water still had a shear strength of 2942 psi.[14] (It is interesting to note that the epoxy-laminated composite boats cited by marine epoxy formulators as long-term successes, such as the trimaran *Adagio,* are kept and sailed on the Great Lakes—fresh water.)

With all of these reservations, where would I choose to use epoxy? It is an effective sealant for endgrain situations and as a base for interior varnish, or for under two-part (reaction lacquer) paints.[16] If you do choose it as an adhesive, its gap-filling ability will be useful and its clear color will facilitate preparation for clear finishes. But since it is labor-intensive, costly, and presents more of a health risk than water-soluble adhesives, I would reserve it for coating jobs or for applying sheathings to the outside of a hull.

* More complete testing of polyester resins in the 1960s and 1970s might have eliminated many of the osmosis and blistering problems plaguing fiberglass boat owners today.

| Pro | Con |
| --- | --- |
| Effective outside seal coat. | Water resistant only.[11] |
| Clear glue line; easier to clean up inside varnished hull. | High health risk due to solvents, chemicals in hardeners, and fumed silica used as filler.[7] |
| Effective for bonding sheathing material to hull. | Poor instructions both on label of container and in technical manual—i.e., limitations are not stated clearly. |
| Widely available. | Loss of joint strength if used below 65°F.[12] |
| Good gap-filling characteristics when used with fillers. | Joint not as resistant to fatigue as the wood it is bonding.[15] |
| Helps wood resist rot. | Three steps required to ensure full-strength joint, including crosshatch sanding, before applying two separate coats of epoxy.[17] |
| | Gloves and safety glasses required for use with all components.[7] |
| | Respirator required with West System 205 hardeners (and presumably those of others' systems).[7] |
| | Not reliable on oak, teak, or maple.[18] |
| | Can lose strength at temperatures above 101°F.[13] |
| | Regular epoxy is not fire-resistant.[19] |
| | When properly used, including three recommended seal coats, costs more than twice resorcinol, triple other water-resistant glues.[20] |
| | Measuring and mixing must be very accurate.[17] Chemists recommend weighing components to ensure accuracy. |
| | Applying warm epoxy to cold surfaces can cause condensation to settle on the adhesive before parts are mated and will give a low-strength bond.[21] |
| | Not UV-resistant. If not coated with UV inhibitors, will begin to decay within six months of exposure to sun.[22] |
| | Firm clamping can starve joint. |
| | Short pot life—12 minutes at 85°F. |

## Resorcinol Glues

There are two types of resorcinols. The first, sold by Weldwood, Borden, and DAP in the United States, can be used only at temperatures above 70°F, with close-fitting joints and firm clamping pressure required. (I call this summer-grade resorcinol.) The second, which has been used in Britain, New Zealand, and continental Europe for about twenty years under the name of Aerodux (diagram A), or Cascophen resorcinol, is often called winter-grade resorcinol. It is gap-filling up to 1/16 inch (1.3mm) and can be used to obtain full-strength joints at temperatures as low as 50°F. It requires only close contact while setting and light pressure. On the other hand, it can be used with high clamping pressure to get tight-looking joints with no loss of strength. I feel that this is the best marine adhesive currently available. It passes all government and military specifications, tests for extreme exposure and deep-cycle situations, and is rated waterproof. It has been used successfully since World War II for minesweepers and amphibious aircraft. It comes from the same family of adhesives used to make marine- and exterior-grade plywoods. In thirty years of boat repair work, I have never seen a single glue failure in any structure that had the distinctive purple glue joints of resorcinol. John Guzzwell says the same, and resorcinol is the glue he used to lay up his three-skinned cruising boat *Treasure,* now twenty-seven years old.[23]

Resorcinol is rarely advertised in boating magazines, since this market is minuscule compared with its primary market, industrial construction-materials companies. In that industry it is the standard adhesive for severe-exposure conditions and where fire resistance is important, such as fire doors, and for the structural beams in buildings and bridges.[24] Lloyd's Register of Shipping accepts resorcinol as a standard adhesive for hull construction, and builders need not submit independent test data if they use it on vessels being built under supervision. All of the various epoxy formulations must be reviewed separately and evaluated before Lloyd's will approve their use on a hull. It is interesting to note that Lloyd's Register will not give a 100A1 rating to any laminated hull, no matter what adhesive is used, unless the boat is built in an enclosed shop with temperature and humidity controls. (See appendix B, Lloyd's Rules.)

I particularly like resorcinol because it penetrates the sap cells of the wood. I have seen it go as much as 5/16 inch into the endgrain of an ash scarf joint. This absorption is caused by the capillary action activated by the alcohol in the resin, plus the firm clamping pressure that hydraulically pushes the glue into the cells. This rootlike penetration helps spread the strains that occur in deep-cycle situations. This adhesive works well on any timber, including teak or oak, and it needs no crosshatch sanding or special preparations to give good bonds.[25]

I would recommend the use of resorcinol for any part of a boat, but since it leaves a dark glue line, it would be my second choice for any light-colored woods that will be finished clear and highly visible. It would be my only choice for teak deck structures that are to be left bare (especially in the sunlight) and for any structural hull parts; for outer laminations on a three-skinned hull; for laminated floors and frames; and especially for stems, rudders, and deadwoods.

| Pro | Con |
| --- | --- |
| Rated waterproof, for extreme-exposure and deep-cycle situations. | Dark glue line. |
| Water cleanup, so lower health risk. | Excess glue hard to clean up on light-colored woods. |
| No gloves, glasses, or respirator required, just clean working habits. | Winter grade must be bought by mail order in the United States (Jamestown Distributors, 28 Narragansett Ave., Jamestown, Rhode Island); Or Ciba-Geigy Ltd., Duxford, England; Or Dimet Ltd., P.O. Box 11123, Ellerslie, New Zealand |
| Test data readily available. | U.S.-type summer-grade resorcinol requires 70°F gluing temperatures and firm clamping pressure and is not gap-filling. |
| Helps wood resist rot. | |
| Time-tested in salt water and on heavy marine structures for more than forty-five years. | |
| Good on all hardwoods, including oak, teak, and maple. | |
| Fire-retardant. | |
| No concern about heat distortion. | |
| Can be used as low as 50°F (10°C). | |
| Not sensitive to UV light. | |
| Not affected by boiling water, solvents, acids, molds, or fungi.[25] | |
| Does not require coatings to encapsulate.[23] | |
| Can be used on timber with moisture content as high as 25 percent and as low as 6.[25] | |
| Exact mix ratio can vary by as much as 10 percent. | |
| Gap-filling to 1.3mm (1/16 inch).[25] | |
| Long pot life—60 minutes at 86°F. | |
| Crosshatch sanding not required.[25] | |
| Difficult to starve joints. | |
| Moderate cost. | |

## Aerodux 500

There is now a more user-friendly resorcinol available. Formulated by Dynochem UK for structural use outdoors in the building industry, the resin comes in three grades, fast, medium, and slow. The same hardener is used with each grade. Aerodux 500 has several advantages over the older resorcinols. It can be used as low as 45°F (10°C) and still give full-strength joints that meet all tests set by the British and German governments for extreme-exposure, waterproof, heat-proof, load-bearing structures. It is lighter in color than most resorcinols, giving a reddish-brown glue joint, rather than the purple-black one. With up to 20 percent fillers added, it can be gap-filling up to 1/16 inch and only requires close contact, not high pressure, while setting to give full-strength joints. The fillers are cheap and easy to handle—wood flour (finely ground sawdust), china clay, or fine chalk. Potlife and clamping time can be varied from as fast as 15 minutes to as long as two hours on a 90°F day. This adhesive will even work on pressure-treated timbers. This is a liquid-to-liquid mix, one-to-one, either by volume or weight. There is latitude for up to 7 percent error in proportions. For a complete review of Aerodux 500 see *Woodenboat* magazine March/April 1999, page 119. For larger quantities contact Dynochem, Ireland Ltd. For quantities of less than 250 kilograms contact B & K Resins, Ashgrove Estate, Ashgrove Road, Bromley, Kent, BR1 4TH, UK. Tel: 44 181-3151207; fax 44 181-3130280.

## PVA-Type Adhesives (Gorilla Glue, Wonderbond)

John Guzzwell chose a PVA one-part glue for the skins of a light race boat and commented on the ease of use, relatively low cost and good cosmetic appearance. It is, however, not rated as waterproof to any current standard testing parameters. The chemical manufacturers warn "because of the thermoplastic nature of PVA glues, they are subject to creep under high stress. They should not be used in structural bonding applications." (Bordon Co. specifications.) The Gorilla Glue Comparative Analysis sheet *(www.gorillaglue.com.html)* does state that "resorcinol is a good gap-filling glue, and is a superior adhesive in this regard."

## Conclusion

Whichever adhesive you choose, remember first that *all* glue companies are protected by disclaimers. To put it bluntly, no company will accept responsibility for loss of materials or loss of labor in case of glue failure. All you will get from them is some more glue. It will be your own *personal* tragedy if your boat has delaminations caused by poor glue choice or poor technique. I know; it has happened to me. The professional boatbuilder may be less directly affected by adhesive failures, since the boat probably will be out of his shop when they do occur. But in the long run, delaminations could jeopardize his reputation as a knowledgeable builder.

Second, the health risks involved with the use of solvents, hardeners, and any boat-

building chemicals will be relative to the number of hours you use them, the precautions you take, and the ventilation in your shop. A builder who uses epoxies and their solvents for 20 or 30 hours a week, working indoors in the winter or inside a hull without a respirator, will be exposed to a far-higher risk than a person building in his spare time, especially if he is working in an open shed. But in each case, it pays to check all of the health warnings available both from the formulator and from the Poison Control Center in your state. (Give the center the brand name of the product you are planning to use.) Be cautious, and remember that it took more than forty years for workmen to recognize the dangers of inhaling asbestos and coal dust.

# REFERENCES


[1] "There has been a significant increase in the availability and use of epoxy resin adhesives over the past few years and many 'manufacturers' are now putting products on the market. These firms are not strictly manufacturers as their function is to purchase the basic epoxy resin in bulk from the few large chemical groups like Monsanto, Shell, etc., and then modify it for viscosity and add certain fillers to make the difficult basic epoxy more workable. They then retail the modified resins in small lots, being handsomely rewarded for their efforts.

"Their use is still not so simple and each adhesive has a slightly different handling characteristic and the builder cannot readily change materials without undergoing a further re-learning and familiarization period." A. McInnes, Deputy General Manager, Lloyd's Register—Yacht and Small Craft Services, 71 Fenchurch, London, England—Letter, March 9, 1988.

[2] "Designed to perform without qualification under hostile building conditions. Proven in daily use by boatbuilders working from above the Arctic Circle to right smack on the equator and everywhere in between." Advertisement, System Three Resins, *Small Boat Journal,* April/May 1987.

[3] "The epoxies are excellent bonding agents to a wide variety of surfaces and vastly outperform the earlier resorcinol and urea glues." "The use of West System resins dramatically lowers the cost of bonding and makes laminated construction possible for the home builder." Gougeon Brothers, Inc., Bay City, Michigan, *West System Products Technical Manual,* 1981, page 5.

[4] In 1987 and 1988, Brian F. Boult, M.E. MIPENZ, registered civil engineer, completed comparative tests of different adhesives bonding different timbers subjected to cyclic wetting and drying. Testing paid for by *WoodenBoat* magazine, *Sail* magazine, Lin and Larry Pardey, Ciba-Geigy NZ Ltd., and High Modulus NZ Ltd. Copies of report available from Brian Boult, 7 Edenvale Road, Mt. Eden, Auckland, for $25.

[5] "While West System epoxy can be relied on to fill gaps and span voids, your boat will be lighter, it will look better and it will be cheaper if you work your wood until you have good fits." *The Gougeon Brothers on Boat Construction,* 4th ed., Bay City, Michigan, 1985, page 123.

[6] "Once surface preparation is complete, we recommend applying West System resin-hardener in a two-step process. The first step is to apply a straight resin-hardener (without fillers) to the surfaces to be joined. If the surface has been pre-coated with epoxy and has cured, you should sand the surface lightly before proceeding with the second step. Woods such as balsa and Western red cedar are quite porous and are likely to soak up more of the mixture than other wood species. Therefore they need to be re-coated to maintain enough epoxy at the surface of the wood for maximum adhesion. The end grain of most woods absorbs more than the flat grain, so re-coating may be required in these areas as well. Re-coating is required if the surface starts to take on a dry flat look as the wood absorbs the epoxy mixture. The second step is to modify the resin with the desired fillers to bridge any remaining gaps and provide a dependable bond. The thickened resin can be applied immediately over the surface that has been wet out without waiting for the coating to dry." *West System Products Technical Manual,* Bay City, Michigan, 1987, page 5-4.

[7] Materials safety data sheets, May 1987, System Three Resins, P.O. Box 70436, Seattle, Washington 98107. Materials safety data sheet, 205 and 206 hardeners, 105 resins, March 1, 1986. Gougeon Brothers, Inc., Bay City, Michigan.

See also *The Epoxy Book,* System Three, Seattle, Washington, 1987, page 11; *The Gougeon Brothers on Boat Construction,* chapter 8, pages 51-58.

[8] "Tensile and comprehensive strengths are *more than adequate* [Pardey emphasis] for wooden boat construction. The heat distortion temperature is fully adequate for boats painted light colors, but suggests that dark colored hulls subject to intense sunlight might experience some softening of the epoxy coating." *The Epoxy Book,* page 8.

"We know that our epoxy will work at low temperatures as well as or better than the other brands. The problem is, we also know our product doesn't perform at its best at low temperatures. Neither will anyone else's. Experienced craftsmen know that, even under ideal conditions, they must exercise diligence and great care in their building practices. In cold temperatures, maintaining good quality control of

epoxy bonds becomes even more difficult because the chance of joint failure seems to increase as the ambient bonding temperature decreases. . . . Just because an epoxy has set up and become hard, doesn't necessarily mean it has reached a good cure. In fact, it may have only developed a fraction of its required strength. The tough part is that it's really difficult to tell a well-cured joint from a bad one; that is, until it prematurely fails under load, days, weeks or even months later." Advertisement, *WoodenBoat* magazine, January/February 1987, Gougeon Brothers, Inc., entitled "Should Epoxies Be Used in Cold Conditions?"

[9] "Permanent bonding power—cures as low as 35°F, non-critical 1:1 mix." Advertisement for T-88, *Small Boat Journal,* July 1987, page 108, by Chem-Tech Inc.

"Can be effectively used at 100% humidity. Can be effectively used to 35°F." Advertisement from same issue, page 7, by System Three Resins.

[10] "Has an excellent balance of properties for use with wood . . . where the substrate carries the major portion of the load and the surface temperature is not extreme." *The Epoxy Book,* page 8.

[11] "Works where an application calls for an extremely strong, water resistant adhesive or coating." *West System Products Technical Manual,* page 1-1.

[12] "Epoxies can be made to be forgiving; however we know that they must be used within certain latitudes of application, temperature, humidity, joint fit, surface preparation and cure times. Epoxies rely on an extremely complex chemical reaction to achieve their strength and longevity; and all of these variables can drastically affect, and in many cases compromise, the short and long term performance of epoxy resins. . . . There exists a comprehensive body of fatigue test data that supports wood/epoxy bonding at temperatures of 60°F and above. To our knowledge, no significant body of such test data exists that would suggest 100% bonding effectiveness can be achieved at temperatures as low as 35°F with any epoxy adhesive system." *Strategies for Successful Cold Temperature Bonding and Sealing with Epoxy,* Gougeon Brothers, Inc., Bay City, Michigan, January 1987.

[13] "At about 120°F, common epoxy loses 30% of its strength. At 140°F, it loses another 20%. By the time the temperature reaches 160°F, the temperature at which epoxy begins to soften, it has retained only 40% of its original strength. The loss of strength is not permanent, lasting only as long as the temperature is elevated. However, testing done at Gougeon Brothers suggests that wood/epoxy structures may have accelerated fatigue when stressed at higher temperatures. This sounds frightening, because a teak deck can certainly hit 120°F in the hot summer sun." Aimé Ontario Fraser, *WoodenBoat* magazine, September/October 1988, page 55.

[14] Initial overlap shear strength after a minimum of five tests, 2500 psi. After environmental aging:

| | | |
|---|---|---|
| Tap water at 75°F | 14 days | 3120 psi. |
| | 30 days | 2942 psi. |
| | 90 days | 2075 psi. |
| Salt spray at 95°F | 14 days | 2300 psi. |
| | 30 days | 500 psi. |
| | 60 days | 300 psi. |

From product specification sheet, 2216 B/A Structural Adhesive, revised to January 1980. 3M Company, St. Paul, Minnesota.

"Resists salt spray." From specification sheet, aerospace adhesive EA 93r by Hysol, Division of Dexter Corp., 15051 E. Don Julian Road, Industry, California. (Both of these adhesives are thixotropic epoxy resins with amine curing agents rated as excellent for bonding rubber, metal, wood, most plastics and masonry products. They are commonly used for space-shuttle applications.)

[15] "Research to date suggests that epoxy-bonded joints will not last as long as the wood being bonded. The reason for this is that the fatigue trend line for epoxy falls more quickly than that for wood. At just a few load cycles, epoxy is much stronger in shear than wood, but ultimately at some point the two trend lines will converge and the failure mode will transfer from the wood into the epoxy region of the laminate. This is not necessarily cause for alarm; for most applications, a well-conceived epoxy will last long enough for structural success." *Fatigue Aspects of Wood/Epoxy Composites,* page 32, Gougeon Brothers, Inc., 1987.

"For maximum life, sound wood/epoxy design calls for loading the structure at about 10% of its ultimate strength—as opposed to conventional wood construction, which calls for 20 to 30%." (Pardey note: In other words, to get the same strength over the long haul, you have to increase the scantlings to allow for the possible fatiguing of the epoxy.) Aimé Ontario Fraser, *WoodenBoat*

magazine, September/October 1988, page 53.

[16] "If it weren't for the superior sealing aspect of epoxy resins, I doubt that they'd really be used much as boatbuilding glues." Letter from Kern Hendricks, president, System Three Resins, Seattle, Washington, November 14, 1987.

[17] "Disadvantages of Epoxies are—they require far superior cleanliness and preparation prior to gluing and very precise mixing compared with resorcinol or UF-type adhesives. Most joint failures with epoxies relate to poor mixing and/or poor accuracy of measuring resin-hardener; starving of glue line due to excessive clamping pressures; oily timber not being thoroughly degreased, which means the epoxy will not wet surface and therefore does not bond; timber not being crosshatch-sanded to enable epoxy glue to wet out surface." Letter to editor, *Boating New Zealand,* August 1987, from Russell J. Pauling, marine marketing manager, Healing Industries Ltd., Auckland, formulators of marine epoxies.

[18] "Although we have never had any trouble with it, some varieties of teak are notoriously hard to bond. Try some sample joints with teak if you intend to use it before applying it to the deck." *The Gougeon Brothers on Boat Construction,* page 257.

"Epoxy seems to have trouble with oak, but no one knows exactly why." Aimé Ontario Fraser, *WoodenBoat* magazine, September/October 1988, page 52.

[19] "We recommend using 421 (fire-retardant powder) in engine and galley areas where fire hazards may exist. A 421 resin coating is more fire resistant than epoxy alone and it will self-extinguish when the source of flame is removed. It should, however, be considered combustible in a major fire." *The Gougeon Brothers on Boat Construction,* page 45.

[20] "Is it not better to heed the one [sic] limitation of epoxy resin adhesives (prevent from deep-moisture cycling) and use resorcinol where this is a problem?" Letter from Kern Hendricks, president, System Three Resins, November 14, 1987.

"Wood surfaces should be coated with a minimum of two coats of West System epoxy to provide an effective moisture barrier; three coats should be applied if sanding is to be done." *West System Products Technical Manual,* page 5-1.

[21] "A hull, for example, which is colder than the surrounding air, may experience condensation and result in water contamination to epoxy applied on it." *Strategies for Successful Cold Temperature Bonding and Sealing with Epoxy,* Gougeon Brothers, Inc., page 5.

[22] "Unprotected epoxy resins are not ultimately sunlight resistant. After about six months of exposure to intense sunlight they begin to decay. Additional exposure will induce chalking and eventually the epoxy will disintegrate, losing its mechanical properties." *The Epoxy Book,* page 6.

[23] ". . . but with resorcinol I've never had any glue failures. I've used all the epoxies, but for gluing wood together there's nothing better than resorcinol, in my opinion, especially if the wood is going to be subjected to repeated or continuous water saturation." John Guzzwell, interviewed by Jim Brown, *WoodenBoat* magazine, September/October 1988, page 71.

[24] "Resorcinol and melamine-urea adhesives appear to perform well at high temperatures and the glue laminated timber industries in New Zealand boast about the structural integrity of their material during a fire." Report by Brian Boult (see note 4), page 12.

"Aerodux RL 188 NZ is also suited to the production of heat-resistant composite structures including fire-check doors." Materials safety data sheets, Aerodux RL 188 NZ, March 1986. Available from Dimet Adhesives, P.O. Box 11123, Ellerslie, New Zealand.

[25] Materials safety data sheets, Aerodux RL 186 NZ and RL 188 NZ, March 1986. Available from Dimet Adhesives.