SP Systems

Composite Engineering Materials

Bonding with Epoxy in Wood Construction

Introduction

One of the main changes that has occurred in wood construction in the last 50 years has been the adoption of resin technology both to glue structures together and to make wood available in a more stabilized, laminated sheet form as plywood. Modern epoxy glues are very strong and highly waterproof, as well as being resistant to chemicals and changes in temperature. Although traditional styles of construction were not designed with these types of glue in mind, it is now possible to combine the modern and the traditional to produce a strong, durable, good looking structure that will please both the traditionalists and those who want modern quality.

Why is Glue Better Than Fastenings?

Gluing wood with a suitable adhesive brings many benefits. One of the most important is that loads can be more evenly distributed throughout the structure when compared to the conventional use of metal fastenings. In this respect, using glue is nearly twice as good as using nails. As a consequence, in modern boatbuilding where SP products are extensively used, structures can be both thinner 'skinned' and more rigid instead of thick skinned and relatively flexible, which is how boats have traditionally been designed. Modern wooden boats, like modern motor cars, can now be lighter and stiffer. The use of glues makes it possible to include only the minimum of internal framing, and even to go as far as producing true monocoque structures. They also use less wood in their construction and this has tended to reduce material costs which partially compensates for the increased cost due to the adhesives.

Different forms of construction have evolved which make these benefits possible. It is important to point out when discussing modern versus traditional construction that simply gluing structures designed for traditional construction can cause problems - problems which in fact serve to highlight some of wood's basic drawbacks.

Why Use Epoxy Adhesives Compared to Conventional Glues?

Bonding wood is unlike bonding materials such as grp or metals. With wood the objective is to create joints which are stronger than the wood itself. This is not the same with other, stronger materials. The joint line in a glued metal bond, even with epoxies, is rarely stronger than the metal itself. Many types of glue create perfectly adequate waterproof joints with wood. Phenol-formaldehyde types are commonly used in the manufacture of plywood. Resorcinol and urea-formaldehyde types have been used since the 1940's to bond wooden aircraft structures with largely satisfactory results. So why is epoxy needed? There are many reasons.

Whilst glues other than epoxies can form joints of adequate strength, they usually require much stricter conditions to achieve a good bond. Requirements such as good operator skill, well prepared substrate (the surface to be bonded), good workshop conditions and a service environment which does not cause them to deteriorate with age are usually necessary for a successful glued joint. Some of the most important factors are considered here:

Wood Moisture Level

For many traditional wood glues, moisture content (m.c.) plays an important part in the gluing process and water is an essential requirement for the glue. The wood must therefore have the required level of moisture for the chemical reaction to take place. For phenol-formaldehyde it is 8% - 12%, for urea-formaldehyde it is 6% - 14% and for resorcinol 12% - 18%. Some of the moisture required can be gained from the glues themselves - urea-formaldehydes can generate up to 50%-60% water and phenol-formaldehydes approximately 35% water by weight.

Epoxy adhesives cure by a different chemical process. They neither contain water, nor is water necessary for them to form bonds with wood. Epoxies can therefore perform very satisfactorily below 6% m.c. as well as giving excellent bonds up to 20% - 25% m.c., well outside the limits of the other glues. Kiln dried timber often has a moisture content well below 8% and is therefore best glued using epoxy adhesives.

Pressure Requirements During Cure

Glues other than epoxies require the mating wood surfaces to be in close contact and under pressure. In the manufacture of plywood, both of these requirements are met since the wood veneer is compacted in giant presses using heat. Both the resorcinol and urea-formaldehyde types, which are the most common alternative glues to epoxy, require high clamping pressure in the order of 7-14 kg/m^2 for an effective bond. In part this is to overcome natural surface roughness of the wood but the main reason that pressure is necessary is to counteract the shrinkage in the glue itself which occurs when the glue loses moisture as part of its curing process.

The most important reasons why epoxy adhesives are so universally popular are that:-

- they do not require pressure to effect a cure
- they do not need the parts to be in intimate contact since only minimal shrinkage occurs during cure.

These features make epoxy particularly effective for bonding less well prepared surfaces.

The criteria for judging how good a structural adhesive is for wood must be based both on strength performance in ideal conditions and on other factors such as:

- how easy is it to work with
- workshop conditions (minimum cure temperature required)
- resistance to degradation in extremes of environment
- moisture resistance and toughness to resist cyclical stressing.

Table 1 below compares the two most common conventional wood adhesives with epoxy and illustrates how epoxy is the most tolerant to different levels of operator skill and environmental influences.

Summary of Properties of Adhesives Found in Wood Construction

Table 1

	Adhesive Type		
Property or Criterion	**Epoxy**	**Resorcinol-Formaldehyde**	**Urea-Formaldehyde**
Bond strength	Excellent	Excellent	Good
Resistance to moisture and weathering	Excellent	Very good	Poor
Gap filling	Excellent	Poor	Poor
Toughness (resistance to cracking with ageing)	Good. Ideal for high stressed joints.	Poor (brittle)	Poor (brittle)
Curing temperature	5-30°C. Can be variable but ideally 15°C+	Min 15°C	Min 10°C
Bonding dissimilar materials eg: wood to grp or metal	Excellent	Special primer required for good bond	Poor
Gluing difficult timbers, eg: oak	Forms excellent bonds	Curing temperature of 40°C required	Not recommended
*Relative prices/kg (retail ex VAT)	£15.00	£22.00	£8.50

*Based on pack sizes between 0.6-1.0kg in 1991. Price/kg will be lower if larger packs are purchased. Prices based on SP 106, the least expensive system from SP Systems.

SP Epoxies for Wood Construction

SP 106

An all-purpose epoxy primarily designed for gluing, but also suitable for coating, laminating and filling, particularly in the manufacture of wood/epoxy composites in boatbuilding. Designed to be used with the SP Systems' range of filler powders.

SP 320

An extremely versatile, high performance, all-purpose epoxy primarily designed for coating, but also suitable for gluing, laminating and filling. Especially recommended for the manufacture of wood/epoxy composites in boatbuilding, as a solvent-free clear coating epoxy and low viscosity epoxy laminating system.

SP Spabond 120

Exceptional high strength and toughness properties make Spabond 120 the best adhesive for bonding a wide range of high strength materials, particularly metals, grp and composite components. Also recommended for all wood boatbuilding bonding operations, including teak decking, particularly where long working time and easy mix characteristics are required. Although partially pre-thickened, Spabond 120 should be used with the SP range of filler powders to make adhesives and fillers.

SP Handipack

An all-purpose epoxy ideally suited for repair and small application work. Useful for gluing, coating, laminating and filling on wood, metals and concrete. The relatively high curing speed makes the product ideal for use in cold conditions but prohibits its use as a general wood epoxy system for construction of wooden boats and other wooden items.

SP 110

SP110 epoxy system can also be used as a glue after fillers have been added. Many professional organisations using SP110 for their fibre lamination work, use the system to make glues. This is economical for them as they do not have to buy another system. However, since it holds no adhesive advantages over the above products, and is more expensive, it is not generally recommended and therefore not included in any comparison.

Technical and Working Data on SP Epoxy Adhesives

	SP 106	SP 320	SP 120	SP Handipack
Mix ratio Resin: Hardener by vol	5:1	5:2	2:1	2:1
Gel times with different hardeners (150g, 25°C) mins:				
Fast hardener	15	17	18	7
Slow hardener	24	40	46	-
Approx thin film working time @ 20°C (mins):				
Fast hardener	65	100	120	70
Slow hardener	190	160	240	-
Clamping times @ 20°C (hrs):				
Fast hardener	$3^1/_2$	3	4	2
Slow hardener	5	$4^1/_2$	8	-
Lap shear strength on steel (MPa)				
Fast hardener	14.67	16.0	16.0	14.5
Slow hardener	15.67	15.0	19.0	-
Density g/cm^3	1.13-1.14	1.11-1.12	1.11	1.11

The Bond Strength of Epoxy Adhesives

The criteria for a good bond are:

(i) That on testing, the wood itself should fail and not the adhesive at the bondline.

(ii) This performance should be maintained as a permanent feature during service.

This latter criterion is especially important as it relates to the adhesive's resistance to environmental effects and its behaviour when stressed. These are areas of performance where epoxies show a marked superiority over other glues.

How Wood Strength Relates to Glue Performance

Wood strength in lap shear joints is measured by assessing the shear strength parallel to the grain. The following gives the shear strength parallel to grain for five different wood species:

Wood Species	Strength (psi)	kg/cm^2
Western Red Cedar	770	54.30
Sitka Spruce	760	53.60
Honduras Mahogany	1310	92.40
Teak	1480	104.37
African Mahogany	159	112.48

Glue strength is assessed by measuring the lap shear strength in appropriately designed joints. For cured epoxy adhesive mixes it is generally between 1500 - 2200 psi (120 - 150 kg/cm^2) depending on the epoxy system employed.

As the shear strength of the epoxy adhesive exceeds the shear strength even of the strongest wood species, it can be expected that, if the joint is correctly prepared, the wood will be the first to fail.

Types of Wood Bonding

(i) Most wood bonding operations are with the grain on the two parts parallel to one another (flat grain jointing). Here there will be relatively little penetration of the glue across the grain and the strength of the joint is dependent on the grain strength of the particular timber species used. The heavier, more dense timbers will have the highest strength.

(ii) End grain jointing is the joining of two pieces of adjacent wood with an end grain interface. Obviously this is a much more absorbent part of the wood but offers a much smaller area to bond and is hence much weaker. Simple butt joints can be successful with epoxy if the gluing technique ensures good penetration into the absorbent wood fibres before the thickened mix is applied.

(iii) A much stronger joint results from increasing the bonding area as in the 'scarf-joint' where the wood is cut at a predetermined angle to expose some long fibres. Bond strength is determined partly by grain strength and partly by the degree of glue penetration achieved.

(iv) Fillet bonding - whilst most joints will be designed in the conventional way to form a 'lap-joint' or 'scarf-joint' there are many instances where the special adhesive and working properties of epoxies can be used to provide cost saving solutions to various bonding problems using a special form of joint - the fillet joint. The fillet joint can be used to conveniently bond components which meet at an angle to one another, such as bulkhead to hull skin where the angle along its edge will vary. Conventional solutions using tailored wood battens are very labour intensive and in some instances, such as bonding a wood bulkhead to a grp hull, are hardly applicable.

The epoxy fillet joint provides a neat solution to this problem as it requires no permanent fasteners, increases the bonding area of the joint and, if correctly carried out, eliminates the joint as the weakest part of the structure. In addition, it is relatively quick to carry out. The fillet itself is composed of a continuous bead of epoxy resin thickened with fillers and applied to the angle between the two components. Fillet bonding is best used to bond relatively thin panels, typically up to 6mm or 10mm, but it can be used for panels of 12mm.

Fillet mixes may be high or low density types depending on application and weight requirements. Both types can be further reinforced with woven glass strips or glass tape where additional strength is required but the glass must extend over the edges of the fillet by a distance approximately equal to the fillet radius.

Surface Preparation Techniques for Wood

General surface preparation combines an abrasive stage with a chemical cleaning stage. All timber to be glued should be clean and dry. The moisture content should be under 15% and it must be free from contamination from oil based paints, preservatives or stains, natural waxes, resins or gums.

Abrasion

The best bond can be obtained from wood where the bonding surfaces have been roughened. If surfaces have been planed beforehand there is a danger of the 'case-hardening' effect giving an insecure bond. This can happen whatever glue is used for bonding. To ensure that this does not happen roughen all planed timber by sanding 30° to the grain direction using 40 - 60 grit aluminium oxide paper.

Chemical Cleaning

(i) If timber is oily, eg: teak, wipe with a volatile solvent such as SP Solvent A (SP Fast Epoxy Solvent) or acetone and allow to flash off before applying adhesive.
(ii) If timber is resinous, eg: Douglas Fir or Oregon Pine, use a 2% caustic soda solution on the face to be glued, wash off with fresh water and allow to dry.
(iii) Wiping with solvent also removes sanding dust.

Using Filler Additives in Epoxy Adhesive Mixes

For an epoxy to be an adhesive, the use of fillers is essential to:

(i) Bulk out the adhesive and make it 'thicker' for joining uneven surfaces.
(ii) Give non-sag properties (thixotropy) for vertical glue joints.
(iii) Form radiused fillets to increase bonding area.
(iv) Hold glue in between absorbent surfaces, to prevent dry joints.

Fillers are in the form of powders which are added to the resin/hardener mixture. A brief guide to the types of filler available, the suitability of each, is given below. A separate Filler Guide, available from SP Systems, gives full details of quantities to use, mixing methods, etc.

Type of wood	Filler Adhesive	Typical Applications	Notes
Flat Grain Jointing	Microfibres	Wood laminating Strip planking with dense timber Cold moulding veneers Lap joints in general bonding	Pre-coating unnecessary.
	Colloidal Silica	Lap joints in general bonding	Pre-coating of bond surfaces with an unthickened mix is required where the highest strength joint is required.
	Glass Bubbles/ & Phenolic Microballoons	Cold moulding adhesive only Cedar strip planking adhesive.	For wood joints having a large surface area.
End Grain Jointing	Microfibres and/or Colloidal Silica	Scarf joints Butt joints	Pre-coating with an unthickened mix first is essential to obtain good end grain penetration.
Fillet Joints	Microfibres + Colloidal Silica	High density fillet bonding where maximum strength for minimum size fillet is required.	Structural applications.
	Microballoons (or Glass Bubbles) + Colloidal Silica	Low density fillet bonding where lower strength is acceptable but fillet is lighter in weight.	Microballoons give a colour which can match many hardwoods. This type is generally used in non-structural applications.

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SP Systems therefore strongly recommend that representative test panels and component sections are built and tested by the user in order to define the best process and materials to use for the desired component. This should be done under conditions as close as possible to those that will be used on the final component.

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