



SP Systems  
Composite  
Engineering  
Materials

# SP Guide to using Epoxies in the Restoration of Wooden Craft

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## Introduction

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The wood epoxy composite technique, which has revolutionised the way wooden boats are built, has also been successfully applied to the restoration of old wooden craft. In many restoration cases, the application of traditional boatbuilders skills to restore the boat to seaworthy conditions has been either not possible, due to the boats advanced state of deterioration, or it was prohibitively expensive. Today we can see many old wooden craft of all types and sizes being used actively and even engaged in competitive yacht racing, which would not have been in fit condition had not epoxy resins come to the rescue.

Whereas not all old wooden craft are of traditional shape and design, the oldest craft are the category with potentially the most to gain from the correct use of epoxies, and therefore the ones which represent the highest challenge. Many owners have spent sometimes months, and even years of work lovingly restoring traditional craft, yet all agree that the effort was well spent. The end result can be a craft of traditional appearance outwardly, but one which incorporates all the benefits of modern epoxy adhesive and coating technology - enhanced strength, hull stiffness and low maintenance.

This guide has been prepared for the benefit of those owners of wooden craft who want to achieve these benefits. All restoration on whatever type of boat requires careful planning and a detailed understanding of both the effort that must be made and the products at one's disposal to achieve lasting benefits.

This guide contains much information on how to use the various different formulations of epoxy which are available. To use these products in the best possible way, we must first examine how traditional wooden craft were built before the age of adhesive technology to see the extent which epoxies may be used.

#### **Traditionally-built Hulls as Candidates for Treatment with Epoxies**

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Most traditionally-built wooden hulls were constructed at a time when durable marine adhesives simply did not exist. Joints between wood elements were kept to a minimum by careful wood stock selection from a bountiful supply. Where joints did occur, they were often not sealed at all (if close fitting joints) or else sealed with a variety of products of sufficient flexibility to accommodate the natural cyclic movement of the wood due to uptake and loss of water associated with the alternating seasonal life of the craft afloat and ashore. Likewise, the coatings used had to be flexible so that

cracking and peeling were kept to a minimum. The coatings available at the time fitted their purpose well - all contained a high proportion of naturally occurring oil based products which provided the flexibility. The coatings were not required to act as an efficient moisture barrier, but had to permit a limited moisture exchange between the wood and its environment, whether it was water or air.

Today, there are relatively few of these hulls still afloat. Many have been scrapped, lost or simply become worn out. To avoid their sometimes inevitable loss at sea, many are now kept permanently ashore until their owners have the time and enthusiasm to address their problems. Many are now termed 'classic craft' and their rarity value has given them a term of suspended 'execution' whilst others may simply be kept because of the enduring attraction of their particular design or the sentimental value to their owners.

### Limitation on the Use of Epoxies

There are generally two types of approach using epoxies which can provide a new lease of life for traditionally built craft:

1. **Renovation:** to reduce the time consuming and costly annual maintenance that is a common feature of craft that are currently still giving good service and are in sound condition:
2. **Restoration:** to solve the structural problems that have gradually developed and which have rendered a once sound hull now unseaworthy.

Whilst epoxies can easily satisfy the low maintenance requirements of modern craft, their application to traditionally-built boats in the first category should be treated with more caution. To merely substitute traditional products for more advanced ones and expect all the documented benefits is often asking for too much from any product. Common sense and experience has shown that traditionally-built hulls will not readily accept epoxy products, if used in isolation in the course of simple annual maintenance. The only situation where epoxies can be used to provide significant benefits in terms of reduced maintenance and longer life on traditionally-built hulls, is as part of a well planned re-building programme or restoration project.

### Gaining the Full Benefits from Using Epoxies in Restoration

The precise techniques involved in reconstruction and the degree of preparation required can vary depending on the original construction method and the condition of the hull. However, to gain the full benefits from using epoxy to give increased hull stiffness, strength and reduced maintenance, it is essential that the following two operations are carried out irrespective of the exact hull construction method:

1. An epoxy adhesive must be used to bond together the individual hull elements (planking etc.) to create a rigid wooden unit.

2. All the exposed wood surfaces must be coated with a suitable coating epoxy to create a highly water resistant 'plastic membrane'. This serves to give the wood the maximum resistance to the influence of changes in outside moisture levels which would otherwise cause it to shrink and swell.

Both the adhesive part and the wood stabilisation are essential to the ultimate success of the operation for the following reasons:

1. Establishing an epoxy membrane but omitting the adhesive section would soon lead to fracturing of the coating along the planking edges due to a lack of hull rigidity. The inevitable water penetrations would continue unabated as the epoxy coated timber would be unable to expand sufficiently to close the gaps.
2. If adhesive was used to bond the hull, but the planking was still free to expand and contract through the influence of moisture, then the planking would swell and become distorted because of its restraints of the glue lines.

### Review of Principal Hull Building Methods and Associated Faults

#### **Clinker (Lapstrake) Construction**

This is composed of overlapping longitudinal thin planks which are close fitting along the top and bottom edges to adjacent planks and through-fastened to framing and to each other with rivets or nails. With uptake of moisture through permeable coatings, the planks are caused to swell and the joints close, thereby making a water-tight hull. The ribs, installed later into the hull during construction, help to determine the hull shape and give strength to the structure to avoid crushing.

Over a period of time, because of both ageing and use, the wood inevitably will show signs of decay and the fastenings will loosen, ribs crack and the hull will begin to leak. As the fastenings wear the hull will also become more flexible. Maintenance on old clinker hulls is very labour intensive.

Many different woods have been used for hull planking (mahogany, pine, larch, etc.) and the resistance to decay is largely dependent on the wood's natural durability characteristics. This building method has been traditionally used for smaller boats of lightweight construction.

#### **Carvel Construction**

This is the most typical traditional construction and consists of longitudinal planks which are fitted edge to edge using a sealant (caulking) which is sufficiently flexible to take up the expansion of the timber caused by moisture uptake. These hulls are also built on a framework of ribs to which the planks are screwed or nailed. Like clinker constructed hulls, the owner can expect very high levels of maintenance. As the hull planks move, paint cracks along the seams and caulking needs renewing at regular intervals to avoid excessive leakage. Deterioration occurs usually following leakage, especially when pools of water are allowed to accumulate in

poorly ventilated areas such as around the keel and hog. More durable woods, such as different species of mahogany or sometimes teak, are common and the hulls tend to be heavier than clinker types. Because carvel construction was the most popular building method for 'classic' craft, there are potentially more boats of this type requiring restoration.

### **Multiple Skin Planking**

This type of construction has a total planking thickness equivalent to a carvel built hull of the same size but the individual planking is thinner. The planks are usually laid at 45°, but some are built with entirely fore and aft planking or a combination of diagonal, fore and aft. Between the planking, it is usual to find a woven cotton type membrane, sometimes of calico, originally soaked in linseed oil, a marine glue or even paint.

The two layers of planking are fastened through the membrane by clenched nails, screws or rivets or a combination of each and also fastened to the frames. Only limited caulking is used, but it is commonly found around the stern and at the junction of the transom with side planking.

It is very common to find some degree of rot and voids between the planking on boats of this type of construction. Usually this is associated with a disintegration of the woven membrane which was originally incorporated as a water barrier. Once this has deteriorated, water accumulates on the interior leading to further erosion. In the 1950's, adhesives were introduced to bond planking (which subsequently became thinner) but the fastenings were sometimes left in place. With these craft, delamination of the planking is quite common due to stress cracking of the adhesive.

### **Plywood Hulls**

These are usually of single or multiple chine design with flat sheets of plywood bent over and glued to a wooden framework. Plywood construction was particularly popular during the 1950's and 1960's, but declined with the advent of glassfibre construction.

Although plywood is an extremely useful and versatile building medium, it does deteriorate badly when wet. The usual entering point for moisture is on the panel edges which have exposed end-grain. Here, any free water can travel unimpeded through the core of the timber and this can be very difficult to dry out to an acceptable level.

Delamination of the plies is quite common following breakdown of the veneer adhesive. This often occurs before breakdown of the building adhesive used to bond the panels to the framework. Sometimes when non-marine or cheaper grades of plywood have been used to build the boat, deterioration is accelerated. These grades can be identified by poorly constructed, sometimes uneven but thick cores, usually of a different, less durable timber often with large voids where decay can start.

Vulnerable areas include deck edges, edges of chines and around the transom where it meets the bottom and side panels. On centre board boats the lower edges of the centre board case are often in poor condition. Here, exposed plywood end grain and abrasion

from the centreplate serve to accelerate wear and uptake of moisture.

### **General Preparation**

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Wood moisture content is of paramount importance, both because it affects timber longevity and the functioning of epoxy adhesives and coatings.

It was mentioned earlier that complete hull encapsulation is a desirable aim. It is most important before contemplating this treatment that the moisture status of the wood is assessed so that the treatment can start with the wood in its optimum physical condition.

Older types of coatings are much more permeable to moisture, but this was not considered too serious a drawback as the building timber was chosen to be of a high moisture content (m.c.) - in the order of 18-25%. Left continuously at this level it is not surprising that the wood decayed since 18-20% is generally considered to be the threshold level for fungal spores to multiply. The fungus attacks the cellulose and lignin which make up the cell walls of wood.

It was good practice therefore to build hulls from wood with a natural resistance to decay, choosing either a dense heavy timber with relatively low natural permeability or wood with high levels of natural resin. Periodic drying of the hulls, which usually occurred when the boats were hauled out during the winter months served only to temporarily reduce hull moisture and this was accompanied by a certain amount of shrinkage of the planks. This process continued until an equilibrium was established with the Relative Humidity of the surrounding air. Placing the boat back in the water was accompanied by an initial high level of water absorption into the interior of the hull, and into the hull planking, until the planks expanded and gaps closed.

Epoxy encapsulation is designed to overcome the drawbacks associated with this process. To work most effectively, hull moisture level should be reduced to a figure below which decay cannot start. 15% is considered to be the practical limit and this level can be maintained, irrespective of exterior values, with an appropriate epoxy coating scheme. The benefits in terms of reduced maintenance are obvious.

Another important aspect of moisture content is how it affects the chemistry of epoxy resins in terms of their relationship with wood. All adhesives and coatings work most effectively on 'dry' timber but some types can work adequately well if the moisture level is around 20%. Some types of adhesives, particularly the resorcinol - formaldehyde types such as Aerodux, fall into this category and with coatings, the oil-based types certainly do. Epoxy products, particularly the solvent-free types where resin and hardener are not carried in a solvent, are particularly sensitive to moisture before they become fully cured. The reason for this lies both in the effect of moisture on their ability to wet-out wood fibre and on their curing mechanism. With wood of an optimum m.c. for epoxy of 7-12%, epoxy can penetrate across grain perhaps 1-2mm under ideal temperature conditions (20-25°C). Dampness will serve to limit

penetration severely and hence limits the adhesion of the glue or coating.

Moisture also affects the chemistry of the reaction. The full properties of an epoxy resin can only be gained after the resin and hardener components have fully cross-linked to form a rigid plastic structure. Excessive moisture will interfere with the development of the cure degrading the amine hardener component before complete cross-linking has taken place. This degradation will impede the cure to the extent that the anticipated moisture proofing and other properties will never fully develop. Epoxy works best on the driest timber in warm conditions.

### **Surface Cleaning**

All existing coatings, both inside and outside of the hull should be removed using a paint stripper, an electric heat gun or other methods. If a paint stripper is used, it is important **not** to use the version which is based upon white spirit, as residues will affect the adhesion and quality of the epoxy coating. Use one which is cleaned off with water.

An electric heat gun of the type used for stripping paint is probably the most useful tool for amateurs and is especially effective on the traditionally used oil-based coatings which are easily removed.

Grit blasting is undoubtedly the most effective way to remove all traces of existing coatings but since this technique also erodes the surface of the timber, care must be taken not to cause too much damage. A skilled operator familiar with this type of application must be appointed. The surface left after grit blasting is ideal for absorbing high build epoxy coatings and adhesives and the wood, if correctly dried, is able to accept the resin to a greater depth, perhaps 3 or 4mm.

Prior to the application of epoxy adhesives or coatings, most surfaces should be rough-sanded with 60 grit paper, the dust removed by vacuum cleaner and surfaces wiped with SP Solvent A (Fast Epoxy Solvent), or other fast evaporating solvents, which must be allowed to fully evaporate before bonding or coating can commence.

## **Repair Techniques Using Epoxy Resins**

### **1. ADHESIVE BONDING**

For straightforward bonding operations on most woods the following epoxy systems are equally effective:

#### **SP 106, Spabond 120, SP 320**

A distinction, however, can be made when bonding teak or oak. Here Spabond 120 is especially recommended in preference to the others as it will show superior adhesion and a higher bond strength.

Epoxy adhesive systems always comprise a resin and hardener component of the 'solvent-free' type; that is they are not diluted with organic solvents such as is commonly used in paints or varnishes. Their viscosity is best described as being like 'thin syrup'. All epoxy adhesives characteristically have extremely low shrinkage (less than 2% by volume), low odour and virtually unlimited gap-filling

capability especially when cured together with one or more filler powders that can be added to the mix.

Choosing either fast or slow hardener can have a significant effect on pot-life and working times and a glance at the technical specification of each system will reveal comparative figures. Of particular interest is the 'gel time' figure which will indicate, in relative terms, how fast the resultant mix will harden at room temperature. A fast gel time of 11-12 minutes is appropriate to an adhesive for fast bonding (2-5 hours clamping time) but a gel time of 35-40 minutes reveals a system more suitable for bonding large areas, e.g. decks, where extended working time is needed. Usually any one resin system will cover the range mentioned with only two hardeners, and these hardeners can be pre-blended if required to give working properties intermediate between the two.

Inclusion of fillers modifies the properties of any resin/hardener mix both in terms of handling and performance. For 90% of all bonding operations, SP Microfibres are the most suitable filler powder as they produce the strongest glue line, and, being relatively absorbent, they will always be capable of holding resin in the joint and limit leakage both into the wood and out of the joint. Between 10% and 30% by volume is the usual percentage addition, less being required on the more absorbent timbers such as coniferous types, and more on the least absorbent types such as typical hardwoods (mahogany etc.).

Another filler, Colloidal Silica, can modify the properties further by increasing thixotropy where necessary. However, it also impedes penetration of the resin into any absorbent surface. Therefore, when using Colloidal Silica, it is always advisable to first pre-coat the surface with an unfilled resin mix. If this procedure is not followed then there is a risk that the joint may fail prematurely because there will have been insufficient resin penetration into the timber. Note that this procedure only applies to absorbent surfaces, not to plastics or metals.

The bubble-type fillers (SP Glass Bubbles and phenolic Microballoons) are sometimes used instead of Microfibres if the bond strength does not need to be as great, (e.g. bonding soft woods along the grain) or where the bonding area is sufficiently great (e.g. when using veneers for cold moulding). They also have the advantage of saving adhesive weight. For cosmetic use the brown colour of Microballoons may be useful. A typical adhesive mix for mahogany may have up to 30% by volume Microfibres for strength and 5%-10% Microballoons for colouring purposes to produce a mahogany coloured glue line. Adding Microballoons to any mix will also reduce the gel time and lead to a reduction in cure time, since the phenolic content serves to accelerate the resin and hardener reaction.

### **Fillet Bonding**

This is a bonding technique which can be used with all types of resin but is clearly most satisfactory with epoxy resins. A resin mix with added filler can be successfully used to bond two pieces of wood which meet one another at an angle. Not only is it a mechanically satisfactory method of bonding but it saves considerable time and materials over all other methods.

Two important things to establish when designing this type of joint are:

1. The size of fillet which is necessary to avoid failure
2. The density (filler type) of fillet required.

There is a relationship between fillet size and thickness of the two wooden panels being joined which will ensure that, when stressed, the wood breaks before the joint. Only prior experimenting can determine this.

Secondly, there is the type of filler to be used. The strongest fillet joint is composed of the heaviest materials, predominantly Microfibres with a small proportion of Colloidal Silica (high density fillet). For equivalent strength the fillet can be made smaller than the alternative type using Microballoons (or Glass Bubbles) with Colloidal Silica (low density fillet). The Silica addition, common to both types as the minor constituent, not only overcomes the sagging which would otherwise occur during curing, but also 'lubricates' the mix making it much smoother and easier to obtain an accurate radiused shape which will require the minimum amount of sanding.

High density fillets are used in all main structural applications, particularly when bonding hardwoods. For roughly equivalent strength, low density fillets need to be twice the radius of high density ones. Low density fillets are not usually used in high strength applications and are usually reserved for bonding thin plywood or bonding panels into hulls where the main structure has relatively weak across-grain strength (e.g. softwoods such as cedar). The colour of fillets may be an important consideration on clear finished interiors and here fillet mixes with at least a proportion of Microballoons, are often used. After curing, all fillets should be sanded smooth and over-coated with two coats of resin to prevent any moisture absorption by the exposed filler particles.

### **The Reinforced Fillet**

Both types of fillet can be reinforced with a woven fibre reinforcement such as E-glass, usually in the form of a tape (50-150mm wide) laid over the fillet and extending some way beyond it. A 50mm wide E-glass tape (RET160/50) is sufficient for 4mm and 6mm plywood panels but a tape 150mm wide (RET160/150) is appropriate for 12mm ply-to-hull fillet joints. If possible the fibre axis should be at 45° to the joint axis to follow the direction of the shearing forces on the joint, and therefore a  $\pm 45^\circ$  E-glass tape (such as XET300, 300g/m<sup>2</sup>) would be ideal and structurally the most satisfactory reinforcement. If tape is not available then a woven or stitched biaxial E-glass cut into suitable sized strips is adequate.

## **2. COATING**

For coating applications the following epoxy systems are suitable candidates: SP 106, SP 320 which are solvent-free and SP Eposeal 300 and SP Hibuild 302 which contain organic solvent. Normally the former type is favoured, at least on hulls, since fewer coats are needed to give the required level of moisture protection.

SP 320 is the superior system for clear coating where coating

quality (clarity, etc.) and build up of thickness are the most important criteria.

Protection is a function of both film thickness and degree of cure that has taken place, and solvent-free epoxies are superior on both counts. A thickness of 300-400 microns is the generally accepted level for hull exteriors. This equates to 3-5 coats with a clear solvent-free type such as SP 320 or SP 106 but at least double that number with a clear solvent-based product such as Eposeal 300. In addition, full cure is assured (with correctly mixed solvent-free epoxies) even with rapid (1-2hr) overcoating, since there are no solvents present which could become trapped in the coating due to poor evaporation. Trapped solvent causes poor curing and leads to blisters. Adhesion is also normally better as the solvent-free products serve as excellent adhesives.

Hull interiors are similarly coated but usually the coating thickness is reduced to 200-300 microns (except the floor) since they operate in a mostly dry environment.

If the hull has not been thoroughly prepared and old oil-based finishes remain in the wood, or if the wood has been wiped with an oil-based solvent such as white spirit, then solvent-free epoxies cannot be used on the wood surface. A quick test will determine if there is any incompatibility. One method which has proved successful in this case is to clean the surface with SP Fast Epoxy Solvent and pre-coat with Eposeal 300, a product more tolerant to contaminants. Following thorough sanding, it may prove possible to apply SP 106 or SP 320 over the top for subsequent coatings.

With any coating scheme, especially one which is to be applied to a previously coated wood surface, it is worthwhile making several test patches first before embarking on the whole hull.

Hibuild 302 is used not as a protective moisture barrier like the other products but primarily to improve the standard of surface finish after filling and fairing. This product also creates an ideal base for subsequent coats of paint or antifouling coatings.

## **3. SHEATHING WITH GLASS**

Hulls which require strengthening can be best repaired by encapsulating with a high strength fibre, E-glass. This is available in a variety of forms differentiated by type of construction, fibre orientation and weight.

Hulls which have become seriously weakened are candidates for high strength encapsulation. It is quite common to use the original hull as a mould and, in effect, build a glass hull on to its exterior surface.

Another approach, which is more effective in its use of materials, is to use the original wooden structure as the core to form a sandwich structure with glass skins on both surfaces. In this case the original wood needs only sufficient strength to transmit shear loads from one skin to the other and becomes largely redundant for strength, which is taken by the new skins. Typically on hulls up to 35ft, skins can be created, each up to 2mm thick. The fibre orientation is

chosen to complement the type of wooden construction but generally it is arranged to be at  $\pm 45^\circ$ ,  $0^\circ$  and  $90^\circ$  to the axis of the hull represented in as few layers as practicable.  $\pm 45^\circ$  biaxial fabrics (where the axis of the fibres are at  $\pm 45^\circ$ ) and quadraxial fabrics (fibres at  $0^\circ$ ,  $\pm 45^\circ$  and  $90^\circ$ ) of the SP range are ideal for this application as they give the required strength in the fewest plies. Weight per ply is typically  $450\text{g/m}^2$ ,  $600\text{g/m}^2$  and  $900\text{g/m}^2$ . Unidirectional E-glass has more specific uses since fibres run in only one direction and weights of  $250\text{g/m}^2$  and  $500\text{g/m}^2$  are typical.

If a true sandwich structure is to be created, then an inner skin is essential but in practice this is often impossible and the interior often receives only a coating. If the original frames remain intact and are in good condition, eliminating the inner sheathing can be structurally acceptable.

The simplest form of reinforcement with which users will be most familiar is woven fabric where the warp and weft are woven at  $90^\circ$  to each other and where the strength is usually approximately equal in both directions. Many boats are sheathed with this type of reinforcement simply to improve the wood's crushing strength and therefore its impact resistance.

Chopped strand mat (CSM) is rarely used with epoxy resins on wood since, for its weight, it absorbs over twice as much resin, and the orientation of the fibres is not sufficiently specific to be of maximum value. Woven or stitched fabrics are far superior, being over twice the strength for any given weight and much easier to finish because of their flatter construction. Additionally CSM is not required between adjacent layers of woven reinforcement, which is normal practice with polyesters resins, because epoxy shows superior adhesion over other resin types.

When using multiple layers of fabric it is strongly recommended that nylon peel ply is used to provide a clean, dry, grease-free, stippled surface, ready for further bonding or coating without preparation (which is very labour intensive and hence best avoided). Like most thermoplastics, the nylon fibre in the peel ply does not adhere to the epoxy very well. The peel ply is applied to the laminate as the final layer and therefore protects it during the cure process. After leaving the resin to harden, it can be easily ripped off exposing the fresh surface ready for the next stage (bonding, more laminating, etc.) The 'peel ply technique' is also useful for single fabric layer skins to minimise the volume of resin used and obtain improved consolidation.

Hulls that require sheathing usually have wood which has become more absorbent with ageing and, if they are suitably dry, they have a potentially high resin uptake. In order to encourage resin absorption to a greater depth it is worthwhile heating the hull internally. The greater resin penetration will serve to significantly strengthen the surface fibres. In this case a slight departure from the normal sheathing procedure is called for. Two or three coats of resin should be applied to the dry, prepared timber and allowed to fully cure before the hull is sheathed. During the course of this 'preliminary' coating the wood will turn quite dark as the resin is absorbed. To avoid 'gassing' (trapped air bubbles in the coating), the heat should be removed during the coating operation and only

resumed after the coating has gelled sufficiently to become immune to air release.

Local use of a local warm air source helps penetration considerably on all types of wood. As the coating is applied, a brush must be used to remove the air bubbles as they are formed but care must be taken to avoid excessive heat concentration which will lead to resin exotherm.

Full details of sheathing can be found in SP Systems Guide to Sheathing.

#### **4. FILLING & FAIRING**

This forms an important part of any restoration programme for both structural and cosmetic applications.

##### **Structural Filling**

Epoxy filler mixes can create very effective structural fillers. Any of the solvent-free epoxies can be used as the liquid component. For the strongest filler, only Microfibres and Colloidal Silica are added, in proportions similar to the high density fillet joint. For maximum adhesion it is beneficial to first 'prime' the area with a thin layer of unfilled resin mixture.

##### **Surface Fairing**

Fairing mixes are appropriate after sheathing or coating, to provide a smooth fair surface for paints. Such mixes are always composed of the resin and hardener mix, to which hollow 'sphere' type fillers are added. This makes the resultant epoxy filler much easier to cut back with abrasive paper. Typically up to  $2\frac{1}{2}$  times (250%) by volume of Glass Bubbles or Microballoons added to the resin/hardener mix makes a good mix for horizontal surfaces but an additional  $\frac{1}{2}$  volume (50%) of Colloidal Silica is required for vertical or sloping surfaces to prevent sagging. These volumes are based on the volume of the original resin and hardener (=100%). The volume of individual fillers need not be precise and may be adjusted to suit the application.

#### **5. REPAIRING DECAYED WOOD**

Wherever possible decayed wood should be replaced. When this is not possible epoxy can serve to consolidate much of it and it can thereby regain much of its original strength. Like sound wood, it is most important that the decayed wood is dry.

The first step is to drill holes up to 5mm diam. at intervals of approx 100mm over the surface and heat the timber with a heat gun to drive off any residual moisture. When this has been accomplished Ampreg 20 epoxy resin system with a 'slow' hardener, Ampreg 20 slow, is used to penetrate the wood fibres. The use of 'slow' hardener will give the mix more time to penetrate before it gels and safely permits additional heat to lower the viscosity of the mix without causing an exotherm. The mix is introduced into holes via a syringe and the area heated with a heat gun, applied until the resin disappears. Additional epoxy is added until the wood has become fully 'saturated'.

Finally liberal coatings of epoxy are applied to the surface with a brush, again using the heat gun to assist penetration. Heating should be discontinued if the mix starts to emit fumes. When the

surface has become tacky a proportion of Glass Bubbles or Microballoons is added to the mix (and Colloidal Silica if necessary) and trowelled over the wood surface to level it off. This operation will make sanding easier. If the component is a structural member the surface should be reinforced with unidirectional E-glass orientated with the wood grain to replace the strength originally provided by the wood fibre. Some light woven E-glass is usually also applied as the final layer.

## **Preparing the Hull for Treatment**

### **The Hull Environment**

This type of work cannot be carried out without good working conditions. Needless to say one must have access to a covered building with heaters and moisture extracting equipment.

After removing all coatings, hulls must be dried. This is most effectively carried out within a sealed polythene 'envelope' with a dehumidifier of adequate capacity installed. Other methods are only effective during hot summers when hulls can be installed under glass and baked. Whilst this sounds a crude method good results have been recorded.

The moisture content of the timber can be measured by two types of meter. The first is the 'probe' type which records electrical resistance between two metal pins which are inserted to a given depth into the wood. The second is known as a 'capacitance' type which has the double advantage of both recording moisture level over a depth of timber (8-10mm) rather than laterally between two points, and leaving the surface unmarked. The two types are often used together to obtain a moisture profile of the hull planking. If the hull has many, closely spaced (less than 50mm), metal fastenings, the capacitance meter will read incorrectly and in these situations the probe type is more useful.

If access cannot be gained to these types of moisture meter then one must rely on judgement by observing the output from a dehumidifier. When no further water is being extracted, the wood is likely to be sufficiently dry. Drying is always accompanied by much shrinking of the timber and sometimes splits will be seen running parallel to the grain. These are not serious and can be repaired with a filled epoxy adhesive later.

### **Accessing the Component Parts**

To be completely effective, as much of the original structure of the hull as possible should be unfastened, both to dry inaccessible areas and to allow adhesive to be used as the primary fastening medium. On boats with fixed keels it is worth removing the ballast and taking the opportunity to renew the keel bolts at the same time. The 'dead wood' on long keeled boats can also be taken away to be renewed and later fastened permanently with adhesive. Keel floors are important parts which are difficult to dry out in-situ and if possible should be replaced with new ones created from thin strips of glued laminated wood. If possible the hull should be inverted during the course of the work in order that heating and drying can be carried out more efficiently.

## **Notes on the Repair and Restoration of Different hull Type**

Assuming that the hull is correctly prepared and within a dry warm environment, the repairs can commence. For the full repair programme, it is preferable to start with the hull inverted. This will only be possible on boats which are more easily handled, say less than 25ft in length - the remainder will be repaired in the upright position.

### **CLINKER CONSTRUCTED HULLS**

#### **Fastening the Planks**

The first task is to enlarge the gaps which have developed in the overlap area of the planks (lands). To a certain extent this can be done by inserting a hacksaw blade between the fastenings.

When the lands have been cleaned out as much as possible, inject a resin and hardener mix (SP 106 or SP 320) into the gap using a 50cc syringe. A small proportion of microfibres, perhaps 10-20% by volume, will be beneficial to help keep the mix from flowing immediately out from the other side. If the gaps are wider than 1-2mm, then use masking tape on the lowest part of the gap to help prevent excessive resin drainage.

A heat gun is helpful to obtain better resin penetration into the timber and it is essential that the wood to be bonded is suitably dry for the epoxy to be effective. Local heating of the lands with a heat gun will considerably boost the drying out process and at least create a surface dryness which will ensure an effective bond.

Whilst the resin is still wet or tacky, make another, stiffer adhesive filler mix again using Microfibres but add a small proportion of Colloidal Silica to give non-sag qualities. The mix should be thin enough so that it can be injected into the joints in the same way as sealant from a sealant gun. While still wet, smooth off as much of the epoxy filler as possible from both inside and outside and leave to cure for at least 12 hours.

If any unsightly runs have developed, remove them simply by heating with a heat gun and scraping the softened resin away from the timber. Try to avoid using an abrasive method since this may damage the wood.

At the hood ends, the planks are usually rebated over a length of perhaps 12 inches. Remove the screws holding the planks to the framework, thoroughly clean the planks, remove all traces of old sealant and then refasten into position with a thickened epoxy adhesive mix.

#### **Coating**

Use SP 106 or SP 320 for all coating whether under paint or varnish. If a varnish finish is required, then SP 320 will be superior, but it does demand warmer cure conditions. Full details of coating with these products can be obtained from the respective product data sheets and practical tips on using the products in less than ideal conditions are included in the "SP User Guide to Handling Solvent-free Epoxies in Cold Conditions".

### **Sheathing and Coating the Exterior**

Clinker hulls are very tedious to sheath and it is important that the hull is in the inverted position for the best results. Sheathing is best accomplished using long strips of cut fabric or glass tape of a width sufficient to cover one plank and the lower edge of the adjacent plank. In order to help the glass drape up the edge, it is a good idea to first create a small radiused fillet between the two planks using a mix containing Microfibre and Colloidal Silica which should be allowed to cure hard and sanded smooth before applying the glass. This technique will maintain sharply defined plank edges. If the plank edges are well worn, then they should be suitably rounded and glass tape applied over the edge to give protection. If sharp edges are required these can be later built up with a high density filler mix and sanded to shape.

Using peel ply will help to smooth out any glass overlaps and give a surface which is ready for filler and final finishing. When sufficiently hard, rip off the peel ply and apply a thin low density filler mix using Microballoons, together with a small proportion of Colloidal Silica. After sanding smooth, we recommend two consecutive coats of either SP 106 or SP 320 over the hull surface before either varnish or paint top coat systems.

The most suitable application method for applying solvent-free coatings to clinker boats is by using a foam roller with cut down tubes to suit the plank width. This application method is much faster than using a brush and there will be less risk of the epoxy in the tray warming up too quickly and becoming unworkable. It is wise however, to mix up only sufficient epoxy which one can use within a 10 minute working period. Leave the surface coating to cure for at least 3-4 days, sand to a flat finish and overcoat with Hibuild 302.

The hull can now be turned over and the inside coated.

### **Internal Coating**

The first operation is to clean off all epoxy which has drained through from the outside and hardened. This is best accomplished using the heat gun technique previously described, or a metal scraper.

Coat the inside in the same way as the outside, including the ribs and any gaps under the ribs. Use a heat gun again to obtain maximum penetration, both into the wood and into more inaccessible areas. If possible try to apply all three coats in one continuous operation and apply successive coats as soon as the previous one has become tacky. This will eliminate having to sand between coats to obtain a suitable key. After the final coat, leave the coatings for at least 7 days in a warm environment to fully cure hard. After this time has elapsed, the epoxy will prove easier to sand. If SP 106 has been used, first wipe the epoxy surface with SP Solvent C (Cleaning Fluid) to remove any traces of greasy surface by-product. Sand all surfaces using 80-120 grit paper. Although this is a very tedious task, it must be done thoroughly, so that subsequent coatings will adhere adequately. A labour saving technique which has proved effective is to overcoat the last coat of clear epoxy with Hibuild 302 before it has become hard enough to sand (usually about 2-4 hours). Hibuild 302 will bond well to the original solvent-free epoxy and give a surface which is more easily sanded

to accept a final finish. However, as the interior does not need to be "cosmetically" finished, many leave the Hibuild 302 as a final finish on the interior.

### **CARVEL HULLS**

#### **Preparing the Seams**

First remove all existing fillers and sealant between the planks. The best preparation is to router out all the gaps to expose new clean wood and ensure that the gaps are all of a consistent width. To achieve this task, nail some thin wood battens to the hull planks so that they butt to the edges of, and are exactly parallel to, the seams. These guides will ensure that the router can be moved smoothly along the length of each seam. Set the router guide to the correct distance and use a router bit 30-50% larger in diameter than the width of the seam. Set the depth so that the router bit cuts approximately to 75% of the plank thickness.

#### **Fastening the Planks**

There are two options, both of which have proved successful. The first is to use an adhesive epoxy filler mix between the planks whilst the second involves fitting and glueing wooden splines.

For the first method use an adhesive filler mix containing Microfibres and Colloidal Silica. For a clear finished hull, a proportion of microballoons will be required to give the mix a wood colouration. First brush in an unfilled mix of resin and hardener in order to obtain maximum resin penetration into the timber. Using a pallet knife force the filler mix into the seam so that it appears on the inside. When hard remove the excess filler using a Surform tool, or similar, then sand smooth with 80 grit paper.

The second option is more suitable for hulls requiring a clear external finish, but is also used for painted hulls. This method uses less epoxy materials and will be lighter. The splines can be of any type of wood though it is usual to match the hull wood type. Cut the splines to be approximately 3-4mm deeper than the depth of the prepared seams in the hull and up to 1mm greater thickness. Bevel one edge 1-2mm so that the splines will form a tapered wedge; they will initially be a fairly loose fit. Apply a thin epoxy/Microfibre adhesive mix to the seams and onto the surface of the splines, then tap the splines into place working from midships towards the ends of the hull. If sufficient adhesive has been applied some will be forced out of the seams on the inside of the hull as the splines are tapped into position.

It may be necessary to devise some method to retain the splines in position while the adhesive hardens. In this case cut several small bridges of polythene-covered plywood and nail across the splines at suitable intervals. When the adhesive has hardened sufficiently (approx 12 hours) remove the bridges and plane the splines to be a flush fit with hull surface.

#### **Sheathing Carvel Hulls**

After fastening the seams with adhesive, the next stage is to either sheath the hull with woven glass or coat the wood with an epoxy coating system. Sheathing is the preferred choice since it will ensure long term strength and durability for only a relatively small increase in weight and cost.

In carvel hulls all wood fibres run longitudinally. When sheathing, arrange for the reinforcement fibres to cross the seam glue lines at either 90° or ±45° to the wood fibre axis. SP Systems UT-E250 or UT-E500 unidirectional E-glass is ideal for this type of application and can be applied in tapes 500mm wide across the hull initially at 90° and then at ±45° for subsequent layers. One layer of RE210 woven E-glass applied over the final layer will protect the unidirectional fibres from damage which might be incurred during later sanding stages.

An alternative biaxial (±45°) E-glass reinforcement in fabric form would be XE450 (450g/m<sup>2</sup>).

If the hull is considered to be sufficiently strong, then sheathing with a lightweight fabric such as RE210 will help to establish a reinforced coating of uniform thickness. However, if possible, orientate the woven fabric at ±45° to the direction of the wood fibres for maximum benefit. Commence laminating at the midship section and work out towards the bow and stern.

Many restored traditional racing classes such as the X One Design prohibit hull sheathing and these boats rely on the adhesive bonds between the planks.

#### **Modifications to Carvel Racing Yacht Hulls**

All racing yacht classes need to withstand high rig loads and these loads are often higher than the boat was originally designed to take, particularly if it is an old design. Many builders therefore take the opportunity during the reconstruction to re-engineer the structure in order to relieve the hull from excessive loading. This is done by feeding the shroud loads, via adjustable steel wires from the chainplates, down to the mast heel where they are fastened. The original wooden mast tenon, which is generally fitted into a slot in the keel framing, is clearly unsatisfactory for this new function and can be improved by making a thick stainless steel base plate to which the chainplate wires can also be attached. Shroud loads acting in an upward direction are therefore counteracted by the mast loading acting vertically downwards. To prevent the hull from being compressed from both sides a wooden frame should be installed between the mast gate and shrouds and bonded in place with epoxy. The kingplank beneath the foredeck (between stem and mast gate), should also be reinforced to cope with the anticipated loadings and demands of a tight forestay.

#### **Framing**

Once the planking has been fastened with adhesive, much of the framing becomes redundant. However, it is a good idea to replace broken ribs by removing the old ones and replacing with new ribs or adding sister ribs alongside. Ribs can be constructed in situ by bending thin veneers into place and fastening with staples. By creating one lamination at a time the staples can be removed after the glue has cured and before the next lamination is fastened into place.

Unlike clinker hulls the ribs of carvel hulls should be a close fit throughout girth of the boat. To ensure a thorough seal it is worth making small (10mm) radius fillet joints on either side of each rib using a low density filler mix.

#### **MULTIPLE-SKIN HULLS**

As for other forms of construction, the prime objective in restoration is to create a monocoque structure from the different hull elements. This type of construction is perhaps the most difficult to restore especially when the deterioration can be attributed to failure of adhesive bonds within a hull laminated skin. Sometimes, however, an adhesive has been used.

#### **Dealing with Delamination**

A survey of the hull is essential to find areas where serious delamination has taken place. After it has been located and marked, drill a series of holes to a pre-determined depth and inject warm epoxy adhesive using a suitably slow hardener (eg. Ampreg 20 resin with Ampreg 20 slow hardener) using a syringe until the voids are filled. During this procedure heat the area with a hot air gun until the wood feels warm before injecting. The more epoxy which can be introduced between the veneers, the stronger and stiffer the hull will become.

Glass sheathing is usually the best remedy if delamination is very extensive.

#### **Strengthening Multiple Skin Hulls**

Double diagonal (±45°) veneers or doubled diagonal combined with an outer longitudinal veneer is the usual orientation of wood fibres. Sheathing with a biaxial XE450, (450g/m<sup>2</sup>) or a quadraxial fabric QE600, (600g/m<sup>2</sup>), ideally on both sides of the hull skin, will restore the original strength and make a very rigid hull.

An alternative approach is to laminate and glue into place over the exterior skin two layers of 3mm or 4mm mahogany veneers at ±45° and cover with one or more layers of light weight woven glass fabric (e.g. RE 210) to protect the wood fibres from crushing loads.

In terms of material costs, this is a less expensive method of restoring a weakened hull, but the labour content is much higher.

#### **Plywood Hulls**

Plywood has been used for all sizes and types of craft, power and sail. There are probably more examples of smaller craft, such as sailing dinghies, with this construction than any other and nearly all are of a chined type. Many of the problems encountered with plywood craft stem from either adhesive failure of the panel-to-frame joint or adhesive failure within the laminated ply structure itself which results in delamination. Both are usually aggravated by moisture.

#### **Replacing Panels**

Rather than repair delamination in existing panels, it is often cheaper to replace panels, since plywood is a relatively cheap material. The panel will have been screwed into place using brass screws (which are always left in place) and it is doubtful that they can be removed by using a screwdriver. The best method is usually to cut the main unsupported area of plywood away using a jigsaw and chisel off the remaining ply from the framework leaving the screws isolated. The screws can be unscrewed most effectively by using a 'Vise-grip' or 'Mole' wrench-type tool with the grip fastened onto the screw head.

Before bonding a replacement panel into position, remove all traces of the original glue using an angle grinder fitted with an abrasive disc and hard rubber backing pad. Follow on with a plane or spokeshave to obtain a fair surface. Bond into place using a microfibre/epoxy bonding mix and hold temporarily with steel screws which have been coated with WD-40 - these can be later removed and re-used.

Steel screws are more durable than brass screws for this purpose and are considerably more economical to buy. The screws can be withdrawn fairly easily with a good fitting screw driver, but if in difficulty use a heat gun to heat the screw head. This will soften the surrounding epoxy holding the screw in place and allow easy withdrawal. After fairing up the edges, coat the panel with epoxy in the usual manner before applying paint.

### **Glass Sheathing and Taping Plywood Hulls**

On most hulls it is good practice to sheath the exterior surface with one or two layers of E-glass fabric. RE210 woven E-Glass (210g/m<sup>2</sup>) is the most suitable one to use in this application. Some boats were originally sheathed using polyester resin and chopped strand mat, but this will undoubtedly be showing signs of delamination from the wood and should be peeled away completely and the surface prepared for re-sheathing with epoxy. Other craft may have had Cascover sheathing (nylon fabric in resorcinol adhesive) which may be showing signs of delamination and can be more effectively and more easily replaced by using epoxy and E-glass fabric.

Ply hulls are usually either single or multiple chine types. Chines are particularly prone to wear and tear and should be protected with at least two layers of glass fabric or tape. The wood edges should be well rounded and all screw holes filled before taping.

Apply a coat of unfilled resin mix to the hull along the chines to allow for the resin to penetrate - again a heat gun is helpful to obtain better penetration. Start laminating the glass tape from one end, usually the stern, and stretch gently as it is being applied. For the best cosmetic effect, the tape can be recessed in a shallow groove formed by removal of some of the top ply lamination using a small block plane. If two layers of tape are being used, estimate the total depth on the basis that each layer will be approximately 0.3mm thick. If possible use tape of a different width for the second layer and preferably use peel ply over the two layers for additional consolidation and improved surface finish.

### **Repairing Damage within Panels**

On small areas, measuring only a few square feet, panels can be effectively repaired by one of two methods.

The first involves cutting out the damaged area and inserting a replacement panel so that it is a flush fit with the original. The plywood should be cut to a rectangular outline to cover the damaged area including any cracks that are apparent. Cutting the patch slightly oversize, and chamfering the edges of both the hole and the patch will increase the adhesive bond area, enable the patch to be more easily held in position and give the neatest repair.

The second method can be regarded as the 'quick repair' method. Plywood left in a damaged condition will quickly take up water and become locally waterlogged. Water penetrating the core will become trapped and eventually permeate through to the opposite interior skin, causing any varnish to discolour and paint to blister and peel away. Although such areas should ideally be replaced by a new section of plywood, this is often not possible for one reason or another.

In such cases, simply apply heat to the area to be repaired using a heat gun until the surface is dry. During this procedure water will be exuded from the wood and heat should be applied until no more water is seen. The wood will in the course of this treatment turn lighter in colour.

The damage should then be repaired with solvent-free epoxy resin (SP 106 or SP 320) woven glass fabric or glass tape and finished with low density epoxy filler mix.

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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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### **Structural Polymer Systems Limited**

St Cross Business Park . Newport . Isle of Wight . PO30 5WU . United Kingdom  
Tel: +44 (0)1983 828000 . Fax: +44 (0)1983 828100  
E mail: info@spsystems.com . Web site: <http://www.spsystems.com>

### **SP Systems (Australia) Ltd**

4b Wilmette Place . Mona Vale . Sydney . NSW 2103 . Australia  
Tel: +61 2 9979 7248 . Fax: +61 2 9979 6378  
E mail: [simongrosser@compuserve.com](mailto:simongrosser@compuserve.com)

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