The Core of the Matter

A look at cored laminates in Yacht hulls and superstructures

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Most people will be aware that 'thick' materials are noticeably stiffer than 'thin' materials of similar type. Engineers refer to this as the 'I Beam' effect, where the stiffness of a member is related more to the distance between its inner and outer skins than to the material in between.

If we think about a steel joist or beam, the two outer plates provide most of the strength and stiffness. When a load is applied, the upper plate is in compression, and the lower plate is in tension, whilst the central web only serves to prevent the two outer plates from moving in relation to one another, and may well have large holes cut in it to save weight.

This 'I Beam' effect is put to good use in 'Cored' or 'Sandwich' laminates, where two thin skins are separated by a lightweight core; such as end-grain Balsa, polyurethane foam or aluminium honeycomb. The inner and outer skins are firmly bonded to the core during the laying up process, thereby preventing movement of either skin in relation to the other.

Many domestic doors are manufactured in a similar fashion, with a cardboard honeycomb sandwiched between two very thin skins of plywood. The resulting composite structure is remarkably stiff, lightweight and cheap to manufacture, but is severely weakened if the bond between either skin and the core fails.

Plywood itself is also a type of sandwich, which demonstrates the principle of cored laminates rather well: Plywood is comprised of several layers (or 'plies') of wood veneer bonded together with glue, and is usually faced with an attractive hardwood veneer for appearance and durability. Plywood provides a good strength to weight ratio, and is typically cheaper and more stable than an equivalent solid timber. Crucially though, if the bond between the veneers fails, virtually all mechanical strength is lost, and structural failure becomes a real possibility.

Apart from benefits of light weight and improved stiffness, sandwich construction composites provide inbuilt buoyancy in the event of hull damage, and provide a near optimum strength to weight ratio in superstructures, thereby keeping the centre of gravity as low as possible.

So what can go wrong?

Having read the introduction above, one could easily be forgiven for thinking that sandwich construction laminates provide some kind of unsinkable yachting panacea; which to some extent is true. However, owners of small craft should also be aware that cored laminates are extremely vulnerable to damage from water ingress, and are often difficult and uneconomic to repair. Added to which, some older cored hulls, such as those in Sadler yachts are now more than twenty years old, whilst cored superstructure mouldings may be older still, and will be suffering from the effects of age.

Water Ingress

By far the most common problem is water ingress. All it takes is one badly fitted skin fitting or a carelessly drilled hole and the core will slowly fill with water. At first this moisture will only be detected with a sensitive moisture meter, but with time the core will become unstuck (or de-bonded) from the skin, and our once stiff composite will become soft, flexible and very weak. Given even more time, the core itself will start to disintegrate, and in the case of wooden cores may well rot down to a fibrous black compost!

Poor sealing around skin fittings is a common source of water ingress, but we need to be aware that *all* laminates absorb small quantities of moisture whilst afloat, and with time, some of this moisture will accumulate in the absorbent core material. Applying protective epoxy coatings such as International Gelshield 200 or Blakes SFE200 to the *outside* of the hull will help to reduce this moisture ingress, but applying similar coatings inside lockers and bilges could actually make matters worse; as any moisture that finds its way into the composite will be prevented from dispersing. It will therefore be seen that it is far better to use a permeable paint such as conventional bilge paint, yacht enamel, or perhaps one or two coats of two-component polyurethane inside bilges rather than a full epoxy scheme. (The same advice applies to single skin hulls).

On this point, I have often felt that it would be helpful if small holes could be drilled through the inner skin above bilge water level, angled downwards, to allow any water or water vapour to escape from the core. Likewise, judiciously placed holes of 5 millimetres or so drilled through the inner skin of a superstructure, away from stress points, would help to disperse moisture before it caused damage, and could also provide early warning of leakage.

Superstructures:
Cored superstructures are just as likely to be damaged by water as cored hulls, and have the added challenge of shock loads from being jumped on, and extreme heat in summertime. Coach roofs also tend to be lightly laid up to reduce cost and to minimise weight above the waterline, which in turn makes them even more vulnerable to mechanical damage.

A common problem on cored superstructures is that many boat owners are fond of bolting accessories through coach roofs, so that that the core becomes crushed and weakened, and may also absorb water as the outer skin deforms. Crushing can often be spotted as a small depression around a fastening, which will probably fill with water in wet conditions. In extreme cases, the gelcoat layer may also show symptoms of stress cracking in this region.

To avoid crushing, it is best to drill a larger hole through the inner skin, so that a metal sleeve of the correct length can be fitted beneath a large washer or load plate. And of course any external fitting must be properly bedded in with a suitable sealant to prevent water ingress.

Another common problem in cored decks is that the outer skin can simply become detached from the core, with the result that sections of the deck feel soft and springy underfoot. If the core is dry, the deck may make a slight ‘rustling’ sound like dry leaves when loaded; although this will only be audible in quiet conditions. If the core is wet it is unlikely to make any noise at all, although telltale brown stains may be visible around deckhead fastenings below.

Whilst this kind of failure is encouraged by moisture ingress, the effects of heat and wear and tear from being walked and jumped on should not be underestimated.

Checking for Moisture and Damage:
Owners of glassfibre boats always worry about osmosis below the waterline, which is quite understandable; however, a wet core is a far more serious and expensive problem, and must always be investigated at the very first opportunity.

The first line of defence against wet cores is a good marine moisture meter, which will read *though* the outer skin, and if used annually should detect wetness in the core well before it causes permanent damage. At first, any moisture will probably be localised around the point of entry, but with time will spread more widely. In this regard, there is a widely held belief that cellular foam cores are waterproof, and will therefore resist the spread of moisture, but this is incorrect.

Sometimes it is difficult to know whether high moisture readings are caused by a wet core, osmosis, or epoxy coatings; or simply because the hull has not had enough time to dry out after lifting. However, by a process of elimination, there are several ways in which the source of moisture can be identified:

Firstly, wet cores and osmosis can both be expected to give persistently high moisture readings, which will rarely fall significantly within a week or three of lifting. Secondly, wet cores will usually give ***very*** high moisture reading, so that the meter is always near to the very top of its scale in affected areas, whereas osmosis tends to give low*er* readings unless it is well advanced, in which case blisters will be clearly visible. Finally, a wet core will give high moisture readings both inside and outside of the hull in affected areas; whereas osmosis and moisture in surface coatings will only give high readings on the outside of the hull.

Similar logic can be applied to decks and superstructures, although osmosis is less likely to be an issue above the waterline. The effects of decking materials on moisture meter readings should also be taken into consideration.

If caught early enough you will probably be able to re-bed the offending fittings, and possibly drill some small temporary holes through the inner skin so that any moisture can escape. However, if leakage has been going on for some time, it is likely that the core will have detached from one or both skins, and may itself have begun to disintegrate.

Where will I find cored laminates?

Nearly all glassfibre deck mouldings built over the past thirty years or so will have at least some cored sections incorporated into them. Large, flat, horizontal sections such as decks and coach roofs are the most likely to be cored, as these gain maximum benefit from the added stiffness and reduced weight. Complex shaped mouldings and short vertical sections are less likely to be cored, as it is often difficult to incorporate core materials into such shapes, and in any case, complex mouldings tend to have natural ‘shape stiffness’, and so benefit less from being cored.

Moving down to the hull itself, with one or two notable exceptions, cored hulls were unusual until the late 1980’s, when designers moved away from heavily laid up hulls, and looked to new methods of producing stiff, lightweight structures, whilst also reducing material and labour costs. Since this time, cored hulls, and more often, cored sections became increasingly commonplace for all of the reasons already sated.

Cored Ribs and Stringers:

In addition to the above, boat builders have long used a variety of cores to create stiffening sections, often in the shape of small ‘ribs’ and ‘stringers’, or stiffening frameworks in flat deck sections. In some cases rolled up newspaper and centres from toilet rolls have been used, whilst odd pieces of timber, both softwood and hardwood have found service. Hollow sections have also been used.

The crucial point here is that the core material in these small sections was only ever intended to form a stiffening shape, and once the lay-up resin had cured, the core material effectively became redundant. This is very different to a sandwich construction.

The distinction between sandwich construction and small cored (or hollow) stiffening sections is important, because the latter often show high moisture meter readings, but these are rarely as significant as high moisture readings in sandwich construction composites.

Moisture Meter Settings:

The Tramex Skipper Plus and the new Sovereign Quantum Marine meters are best suited for use on cored composites, as they are capable of detecting moisture several millimetres beneath the outer surface. The older Sovereign meters (the Mk I and Mk II) are less suitable, as they have very limited sensitivity to moisture more than a millimetre or so beneath the gelcoat layer.

Whichever moisture meter is used, it should be set to its normal scale for GRP, as shown in the table below.

The figures in the right hand column indicate the maximum moisture readings expected from an 'in service' vessel in good condition at pre-purchase survey, although allowances may need to be made if the vessel has only been lifted form the water for a short time.

Lower moisture meter readings are required for successful treatment of osmosis, and ***must*** be achieved before any epoxy coatings or new laminate is applied. Persistently high moisture readings suggest either a wet core, and/or residual glycol in the laminate, which is absorbing and retaining moisture. This subject is dealt with more fully in the **Short Guide to Osmosis and its Treatment.**

Moisture Meter Type	Setting	Guideline Maximum Moisture Readings	
		For Osmosis Treatment	**At Pre-Purchase Survey**
Tramex Skipper or Skipper Plus	Range 2	14% H_2O	18 % H_2O
Sovereign Mk I or Mk II	Scale A	5% H_2O	10 ~ 12 % H_2O
Sovereign Quantum	Shallow Mode	5% H_2O	10 ~ 12 % H_2O
Sovereign Quantum	Deep Mode	TBA	TBA

Table 1 Table of Maximum Suggested Moisture Meter Readings

Assessing the Damage:

If a wet core or skin detachment is suspected, the first course of action should be to gently 'sound' the suspect areas with a small hammer to determine whether the skin is firmly bonded to the core, and that the core itself is intact.

When sounded, a good composite should make a slight ringing sound, rather like a bell, which will continue for a fraction of a second after tapping. However, if the skin has detached from the core, or dry delamination is present, tapping will make a shallow, high-pitched sound over a shorter period. If the core is wet, or if delaminations are filled with water, tapping will make a dull sound.

Of course the above assumes that delamination or detachment failure is not visible. In practice, such failures are often visible as swellings in the composite surface, and just occasionally, cored structures can blow up like a balloon owing to internal pressure!

If any of the above problems are found, the next step will usually be to take core samples with a core drill, so that the type and condition of the core, and inter-layer adhesion can all be assessed. If the core is damp, but the composite is otherwise well bonded together, it may be sufficient to dry the core by the most appropriate means. However, if the core has become rotten or disintegrated, or if the skin has parted from the core over a wide area, major surgery will be required.

Repairing Deck Mouldings:
Sandwich construction is almost universal in deck mouldings and superstructures, and is far more commonplace than anywhere else on board, with a corresponding number of core failures, so this would be a good place to start.

As discussed above, many problems on cored decks are caused by crushing damage, where fittings are fasted through the moulding without any form of spacer.

When repairing this type of damage, it will often prove best to remove the offending fitting during the winter period, allowing the skin to relax back to something like its original shape, after which the void space can be filled with liquid epoxy or polyester resin before reinstalling the fitting with a suitable spacer and load plates.

The easiest way to fill any voids is to plug the holes from beneath using masking tape or Plasticine, and to fill from above. New holes can then be drilled through the moulding when the resin has completely cured.

In the case of widespread detachment of laminate skin from a core, the treatment will depend on the condition of the core itself:

In many cases, core detachment is caused by a combination of heat and shock loads, even though the core itself may be dry. The most practical option here is to drill a series of small holes through the outer skin into the core, so that a slow curing liquid epoxy resin can be injected into the sandwich using disposable syringes. However, take care when handling epoxy resins as they are known irritants and skin sensitisers, and can cause dermatitis by repeated skin contact.

However, if the core itself has rotted or disintegrated, the available choices are limited. Some people have successfully injected polyurethane spray foam into the void space, having first flushed out the any muck and allowed the laminate to dry. This may be adequate in lightly stressed members where failure would not be dangerous, but hull and deck mouldings usually require a more positive approach to recover the original design strength. In many cases this involves cutting out either the inner or outer skin as appropriate, so that the damaged core can be completely removed, and replaced with a new core before re-lamination. Clearly this is a very expensive operation, which may not be cost effective for many older craft, but may be the only practical option nonetheless.

Advanced Drying Methods:
Where wet cores are identified, but no core damage has yet developed, there are a variety of ways in which drying can be accelerated.

In good ‘natural’ drying conditions, moisture from wet cores will diffuse *very* slowly through both inner and outer glassfibre skins, and may eventually show a reduction in moisture meter readings. However, I must stress that the rate at which water vapour can diffuse through an intact glassfibre laminate is very slow indeed, and will almost certainly take many months or even years to show any real benefit – by which time the core material may well have deteriorated beyond the point of no return!

The moisture permeability of glassfibre laminates increases slightly as temperature increases, so exposure to radiant heat from the sun, or from infrared heaters will accelerate drying to some extent. All the same, it is necessary to raise temperature to around 85 °C (i.e. above the tG (or Glass Transition Temperature) of the laminating resin) before any real benefit is seen. However, heating laminates to such high temperatures can itself cause problems, as mouldings can distort if heated strongly whilst loaded, whilst adhesive and core materials can fail if heated excessively in wet conditions. Similarly, wet balsa cores are even more likely to rot in hot conditions. It will therefore be seen that some mechanical assistance is required:

Where damp (rather than ‘wet’) cores are being treated, the HotVac system has proved very successful, by using a combination of heat and high vacuum to draw water vapour through the outer laminate skin.

However, the HotVac system will not work effectively where very wet cores are encountered, simply because the rate of moisture extraction [through the outer laminate skin] is far too slow to be of any practical use. Furthermore, it is likely that unwanted solutes (such as salt and core decomposition products) will be left behind by this process.

Care also needs to be taken if the outer skin has any holes in it, (even very small ones), as the high vacuum generated by the HotVac system may result in the collapse of the cored section being treaded. Additionally, there is a risk that any liquid water sucked up by the HotVac system will cause serious damage to the vacuum pump.

There is probably no such thing as an ‘ideal’ treatment for very wet cores, as all have their disadvantages. However, some yards have achieved success by drilling a series of holes though both inner and outer skins, so that small vacuum pumps can be connected via a network of hoses to draw dry air through the core, often over a period of several weeks. Similarly, some boatyards have used low pressure compressed air in an attempt to drive out moisture, although this procedure must be used with great caution if it is not to blow the composite apart.

Where these procedures fail, there is little option but to cut open the affected laminate to allow direct repairs, but this option is expensive, and where external repairs are carried out, it may prove difficult to achieve a satisfactory cosmetic result.

Choice of Resins for Repairing Detached Cores:
Epoxy and polyester resins can be equally effective for the repair of damaged and detached cores, but it is worth taking a moment or two to consider the relative merits of these materials. Moisture cured polyurethane adhesives provide yet another alternative, and may prove ideal in some circumstances.

With the exception of a few exotic racing craft, nearly all production glassfibre boats are laid up with polyester resins, therefore it follows that polyesters tend to be an automatic choice when it comes to repairs. Moreover, polyester resins are readily available at around a quarter of the price of equivalent epoxies, making them an obvious choice for general use around the boatyard. However, polyesters resins have three specific limitations, which need to be considered before using them to repair failed cores:

Firstly, polyesters are usually very much faster curing than epoxies. This may be advantageous for general repair work, but their short working life (or ‘pot life’) of ten minutes or so can be a major problem when trying to coax the resin through small holes into cavities inside a failed sandwich composite. In this respect, epoxies tend to be more appropriate, as they can be worked for up to half an hour before they start to thicken. Furthermore, the epoxy curing process is much less vigorous than that of polyesters, so they tend not to get as hot when used to fill larger voids.

Secondly, polyester resins do not cure well in the presence of air or moisture, owing to an effect known as ‘oxygen inhibition’. This is not a problem when polyester resins are used inside a female mold, as the mold effectively excludes all oxygen. However, this is not usually the case when effecting repairs, with the result that the exposed surface of the polyester resin fails to cure properly, and so remains soft and sticky; often with a distinctive odour of styrene monomer.

Finally, the styrene monomer evolved from freshly cured polyesters effectively inhibits the cure of epoxy resins; therefore I would advise against applying ***any*** epoxy (whether solvented or solvent free) over recently cured polyester resin.

Epoxies, on the other hand, are much more flexible in use, but are expensive, and need to be cured in warm and dry conditions if the curing mechanism is to be reliable. More importantly, an adequate curing temperature (usually 10 °C or more) must be maintained until complete cure has been achieved, as the epoxy curing mechanism can fail at low temperatures, and cannot be restarted by subsequent heating.

However, a much more serious concern is that the amine curing agents used to ‘cross link’ (or ‘cure’) epoxy resins are known skin sensitisers. Repeated skin contact poses the greatest risk, but some individuals are especially sensitive to epoxies, and may develop a skin rash and irritation at first or second exposure, or following exposure to vapours from the curing agent in a confined space.

Moisture cured polyurethane adhesives:
Moisture cured polyurethane adhesives are similar to isocyanate curing agents of the type used in polyurethane paints, and some moisture cured wood primers such as International UCP. These materials readily react with moisture from the atmosphere or a substrate (such as timber) to form a urea, which is both tough and waterproof.

In many ways, moisture cured adhesives are ideal for our purposes, as they readily cross-link *in situ* with moisture in core materials, are not reliant on external mixing or temperature for curing, and have a long working life.

Unfortunately, the lower viscosity isocyanate solutions contain organic solvents (to reduce their viscosity), making them unsuitable for repairing most cores, as the solvents would be unable to evaporate. However, the Sikka company supplies a range of moisture cured polyurethane adhesives in cartridge tubes, making them ideal for injecting into small voids in cored laminates.

Health and Safety:
It will be seen from the above that many of the materials used in boat building and repair have associated health and safety risks.

Whichever material is used, it is essential that gloves, safety glasses and other personal protection is worn, that all materials are applied and handled in well-ventilated conditions, and used in full accordance with the manufacturers safety data sheets.

Footnote:
This is a draft document, issued free of charge in response to popular demand from yacht owners and surveyors. To save time this first daft does not include any photographs or diagrams, but these will be added as time permits.

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