A Shorter Guide to Osmosis & its Treatment

Written by Nigel Clegg

Revised Edition
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Includes Suggested Moisture Readings and Painting Specifications, and an introduction to the HotVac system

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Notes:

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Introduction:

Mankind has been building boats for thousands of years, yet the 'perfect' boat-building material is still as elusive as ever. Indeed, just about every boatbuilding material ever used has suffered at least one major shortcoming; whether it be rot and nail-sickness in wood, corrosion and fatigue in metals, efflorescence fractures and corrosion in ferro-cement, or our subject here, 'Osmosis' in glass reinforced plastic (or GRP) composites.

'Osmosis' first caused panic amongst owners of GRP boats in the late 1970's; a factor which has been exploited by the marine industry and the yachting press ever since; yet despite this weakness, 'fibreglass' (or GRP composites as they are correctly known) must be the nearest thing to the perfect boat-building material to date. After all, GRP is comparatively cheap to fabricate; light in weight yet remarkably strong; and can easily be moulded into complex shapes. And despite what you may be thinking as you read this document, it is *almost* maintenance free!

Nevertheless, osmosis can be a very real problem, and it only takes a handful of high moisture readings at survey time to render an otherwise sound boat un-saleable, and possibly uninsurable. And herein lies the greatest challenge of all: Nearly fifty years after osmosis was first identified as a problem in marine composites the subject is still surrounded by misconceptions and old wives tales, even amongst those who should know better!

The purpose of this document is to look at the causes of osmosis and how it may be prevented. We also look at ways of maximising the success of remedial treatment schemes while considering some of the pitfalls that may be encountered during repairs. We shall also consider recent advances in treatment techniques such as the HotVac Hull Cure® system.

Those wishing to ask more searching questions on the subject are advised to obtain a copy of "The Osmosis Manual" also written by the author, which covers this fascinating subject in much greater detail. This document will be updated from time to time as new information becomes available and opinions change, although it is thought unlikely that any substantive new discoveries will be made.

So what *is* Osmosis?

According to my old schoolbooks, osmosis is defined as '*The equalisation of solution strengths by the passage of a solvent (usually water) through a semi permeable membrane*'.

In biology, osmosis is used by plants and trees to draw moisture and nutrients from the soil and plays an essential role in the function of cells in body tissues. The basic principle is shown in Fig 1 below, where a hypothetical container is divided into two separate chambers by a 'semi permeable' membrane to form a simple osmotic cell. For our purposes, the membrane could be a polyester gelcoat or an epoxy paint scheme, although many other natural or synthetic materials would work just as well.

If both chambers were filled with clean tap water our cell could be said to be 'in equilibrium', and there would be no flow of liquid in either direction**:** but if we increase the density of the fluid in one of the chambers by adding a solute such as sugar or common salt, the '*solvent*' (water) will be drawn through the membrane towards the chamber having the greatest density in an attempt to restore equilibrium.

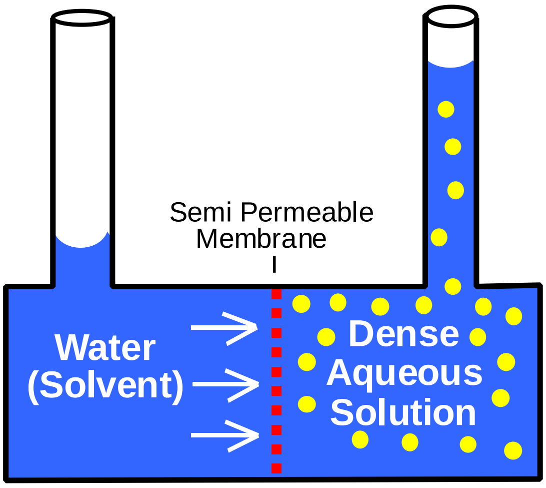

Fig 1. A Simple 'Osmotic Cell'

The fundamental principle here is that ‘stronger’ solutions will always try to draw solvent from their weaker neighbours - but as the more concentrated solution becomes diluted, so it must increase in both volume and pressure - which in the case of GRP boats leads to the all too familiar gelcoat blistering!

This osmotic process (but not osmotic breakdown) can be reversed; either by applying greater pressure than the ‘osmotic pressure’ (as in reverse osmosis water treatment systems), or simply by swapping the two solutions around.

But while this phenomenon provides us with a convenient, if rather simplistic explanation for the maladies suffered by GRP hulls, it also leaves some important questions unanswered:-

The first, and most obvious question must be ‘where do the solutions found in osmotic hulls come from, and how are they formed?’ After all, a fully cured GRP laminate should be chemically inert (or passive) when manufactured, and so in theory at least, should be incapable of creating ‘osmotic’ cells in the first place.

The second, and rather more fundamental question must be ‘how can water pass through a polyester gelcoat or epoxy coating anyway, especially when these materials are marketed as being impermeable to moisture?’

To answer the second question first, ***all*** organic materials used in boatbuilding are capable of transmitting small quantities of moisture at molecular level owing to the tiny gaps or ‘holes’ in their molecular framework. Densely cross linked coatings like epoxies and two pack polyurethanes exhibit the lowest moisture permeabilities, while ‘loosely cross linked’ polymers such as those used in conventional alkyd paints are more permeable, and provide only minimal protection for GRP hulls.

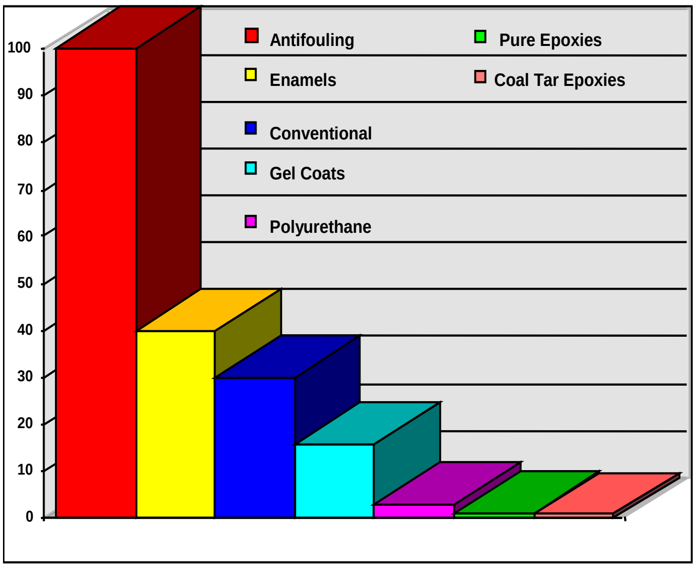

Fig 2. Chart Showing Comparative Moisture Permeability of Yacht Coatings

Similarly, the biocide release mechanisms in most modern antifouling paints depends on the free movement of seawater within the system, so these provide virtually no moisture barrier or anti corrosive properties to speak of.

In practice, the size of the ‘holes’ in organic polymers means that gelcoats and paint coatings could be described as ‘selectively’ permeable rather than semi permeable: or in other words, rather like a very fine ‘filter’.

Consequently, while gelcoats and paint films can transmit small amounts of simple compounds like water (H_2O) with comparative ease, their permeability to complex compounds like high molecular weight alcohols is significantly lower. This point is especially significant in the formation of blisters in boats hulls.

Some readers may regard these points as rather academic, but they do help to prepare the ground when explaining the causes of osmosis in GRP, and more importantly, when prescribing remedial treatment.

Why do GRP hulls blister?

If GRP boat hulls don't behave like trees or plants, how do they get ‘Osmosis’, and more importantly, why do they blister?

To answer these questions, it may be helpful to explain that there are three quite separate stages in osmotic process, starting with a brand new GRP hull, (which should, in theory, be chemically inert), and ending with the all too familiar gelcoat blistering.

Stage One:
A brand new GRP hull will start to absorb moisture through the gelcoat almost as soon as the yacht is launched and will suffer a gradual increase in laminate moisture content every day that she is afloat. Initially, this moisture will cause very little damage, and for the first two or three seasons at least, will pass slowly through the laminate and into the bilges, where it will disperse harmlessly and invisibly as water vapour.

When lifted out, any moisture absorbed by the hull should evaporate within a few days as there will be nothing to hinder or retain it. Moisture meter readings can therefore be expected to fall promptly after lifting.

Yachts built with newer Isophthalic and Vinyl Ester gelcoat resins, which have been used widely since the mid 1990's, will often show satisfactory moisture meter readings within an hour or so of lifting out. However, the older Orthophthalic resins tend to absorb and retain moisture; so, yachts built with these materials can be expected to show 'high' readings for at least a week or two after lifting out, even where the laminate is perfectly sound.

This is 'Stage One', where the laminate could still be regarded as chemically inert or 'passive'. Assuming that moisture meter readings fall quickly as described, this would be an excellent opportunity to protect the hull with an epoxy coating scheme, such as *Hempel's Gelprotect® SFE200* or *International Gelshield®* schemes whilst the hull is still in good condition: - and before its too late! However, don't forget that boats laid up with older Orthophthalic resins can take weeks rather than days to dry; so don't assume that high moisture readings necessarily indicate osmosis! In this respect, boat owners are often in a better position to use moisture meters and interpret their readings than surveyors.

A correctly applied and cured epoxy coating scheme will provide a better moisture barrier than virtually any gelcoat, and will reduce moisture absorption to levels which are *almost* insignificant. In most cases this tiny quantity of moisture should pass safely through the hull and into the bilges without causing damage, and on a new boat should prevent osmosis from ever occurring.

Epoxy coating schemes should have a lifespan of at least ten, and possibly up to twenty years, and so will not need to be replaced very often unless they are damaged.

Stage Two:
Without the protection provided by epoxy coatings, most GRP laminates will eventually suffer damage from long term immersion in water. The most common problem is that tiny quantities of *hygroscopic* (i.e. moisture absorbing) solutes within the resin are drawn together under the influence of incoming moisture to form what are called 'foci'. This usually occurs within poorly consolidated reinforcement and 'air inclusions' immediately behind the gelcoat.

In more severe cases, elements of the gelcoat and laminating resins themselves can be 'hydrolysed' (broken down by water into more basic constituents), to liberate a series of chemically active breakdown products. However, this is unlikely unless the resin is seriously under-cured or badly formulated.

The onset of this breakdown could well take six to seven years in a hull laid up with Orthophthalic resins, or perhaps twenty years where the newer Isophthalic resins have been used; - but it's at this point that osmosis starts! Blistering could well take another ten or twenty years to develop.

We have now reached 'Stage Two' in the osmotic process. Outwardly, the hull may still appear to be in perfect condition, but small amounts of moisture will be working overtime beneath the gelcoat, busily trying to destroy the laminate by breaking it down into its original constituents. Laboratory analysis would reveal a plethora of breakdown products in a laminate in this condition, including a variety of acids, alcohols and metallic compounds.

In older boats, the most obvious breakdown products will be acetic and hydrochloric acids, which are liberated by the emulsion binder used in the manufacture of glass reinforcing cloth. These acids give osmotic blister fluids their characteristic 'vinegary' odour, and can be readily detected with litmus papers. These acids can also contribute significantly to 'osmotic pressure'; so most boat builders now avoid using emulsion bound glass behind the gelcoat in an effort to reduce the risk of blistering.

However, some of the most harmful substances are liberated by the laminating resins themselves, and being *hygroscopic*, (i.e. water absorbing), they actively help to accelerate the rate of moisture absorption, and ultimately, the rate at which blistering develops.

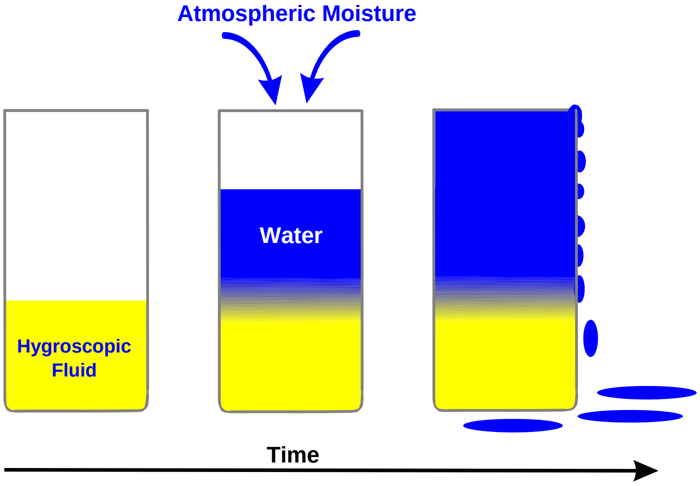

Fig 3. Diagram illustrating the moisture absorbent properties of hygroscopic fluids

One of the chief culprits here is Propylene Glycol (Propane 1,2 diol), a high molecular weight alcohol used as a 'water scavenger' to remove unwanted water from batches of polyester resin after esterification and 'cooking'. Glycols may also be used as an inert base (or vehicle) for the colouring pigments in tinting pastes; although these are generally avoided in marine resins.

Significantly, in the early 1980's a major French yacht manufacturer used propylene glycol as an 'extender' for their organic peroxide catalysts - in a well intended, but ill-fated attempt to improve laminate quality and consistency by simplifying the resin to catalyst mixing ratio. Sadly, the results of this practice were quite disastrous, but they probably did more to confirm the connection between glycols and osmosis than any research project could ever have done.

Three interesting properties of propylene glycol are that it is strongly hygroscopic,[1] and has a boiling point of around 188 °C - or nearly twice that of water. And like all alcohols, propylene glycol is 'polar'; which means that it is readily soluble in water; and once in solution will conduct electricity; so we should be able to find it with a good moisture meter.

Once liberated, these hygroscopic solutes promote a steady increase in hull moisture content, which will fall only very reluctantly after lifting out. Long periods ashore or a spell of warm, dry weather may well show some temporary reductions in moisture content, but re-launching or a few days of heavy rain will soon send readings upwards again. Indeed, having reached this stage, there is very little that can be done to prevent further breakdown.

Ironically, the most widely accepted answer to this problem is to 'dry' the hull with infra-red heaters and dehumidifiers, after which the hull is quickly painted with an epoxy coating scheme 'before the water gets back in again'!

Fig 4. Infra-Red heaters and Dehumidifiers do little to help cure osmosis.

Unfortunately, this rather simplistic approach to correcting high moisture meter readings usually causes more problems than it solves; for whilst a correctly applied epoxy may ***slow down*** the rate of moisture ingress, its densely cross-linked polymers will also prevent the escape of hygroscopic solutes - which means that blistering is even more likely to occur than if the gelcoat was left unprotected!

(To illustrate this effect; if we were to take a tightly stoppered polythene bottle filled with propylene glycol, and place this in a bucket filled with water, the bottle would eventually burst owing to the osmotic pressure generated inside it. This happens because water molecules are able to pass through polythene comparatively easily, (albeit very slowly), but the glycol solution formed inside the bottle is far too dense to escape, so pressure increases.)

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[1] In typical UK boatyard conditions, Propylene Glycol will absorb more than 65% of its own weight in atmospheric moisture if allowed to stand in an open glass beaker for a prolonged period.

So, whilst ‘drying’ will undoubtedly help to reduce moisture meter readings, it will do nothing to remove the solutes which are the real cause of our problems, and will not provide a permanent cure. The osmotic process is not reversible in GRP, so simply removing moisture will never cure it!

I am not suggesting that abnormally high moisture readings should be ignored; but there is usually no need for alarm. In practice, many yachts have been sailed for with ‘high’ moisture readings for decades without their owners being aware of any problems; so the perhaps best advice at this stage would be to leave well alone but monitor the condition, delaying any further damage by wintering ashore if at all possible.

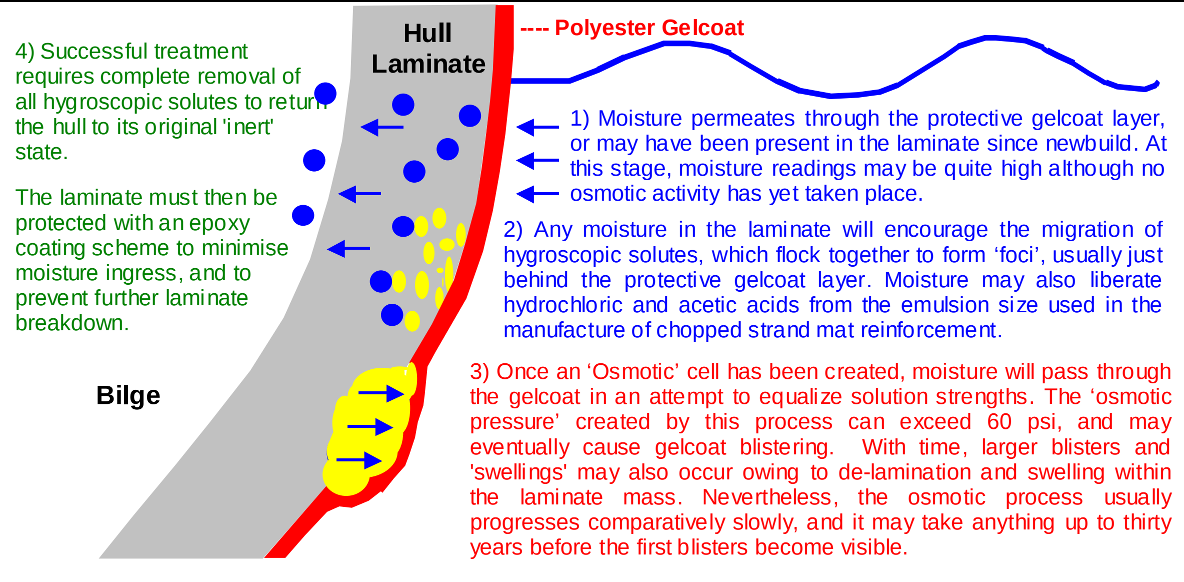
Furthermore, please note that, at Stage Two, the osmotic process is almost entirely ‘chemical’ in nature; therefore structural integrity, which is what we should be most concerned about, is unaffected.

Stage Three:

Eventually, this cycle of moisture absorption and laminate breakdown will accelerate to the point where moisture is absorbed more quickly than it can escape, with the result that hydraulic pressure develops within the laminate, and blisters appear in the gelcoat. This usually happens quite slowly, perhaps starting in a small area of the yachts bottom; but it will gradually become more widespread as the years go by. This is the third and final stage in the Osmotic process.

Localised treatment can sometimes be carried out, but this must only be regarded as a temporary measure. After all, if it has taken fifteen or twenty years for the port bow (for example) to start blistering, it is likely that the remainder of the yachts bottom will be in a similar condition.

The diagram below shows how this process evolves:-



4) Successful treatment requires complete removal of all hygroscopic solutes to return the hull to its original 'inert' state.

The laminate must then be protected with an epoxy coating scheme to minimise moisture ingress, and to prevent further laminate breakdown.

1) Moisture permeates through the protective gelcoat layer, or may have been present in the laminate since newbuild. At this stage, moisture readings may be quite high although no osmotic activity has yet taken place.

2) Any moisture in the laminate will encourage the migration of hygroscopic solutes, which flock together to form ‘foci’, usually just behind the protective gelcoat layer. Moisture may also liberate hydrochloric and acetic acids from the emulsion size used in the manufacture of chopped strand mat reinforcement.

3) Once an ‘Osmotic’ cell has been created, moisture will pass through the gelcoat in an attempt to equalize solution strengths. The ‘osmotic pressure’ created by this process can exceed 60 psi, and may eventually cause gelcoat blistering. With time, larger blisters and 'swellings' may also occur owing to de-lamination and swelling within the laminate mass. Nevertheless, the osmotic process usually progresses comparatively slowly, and it may take anything up to thirty years before the first blisters become visible.

Fig 5: Diagram Illustrating the Osmotic Process in GRP Laminates

So to sum up then; in practical terms, osmosis is best defined as ‘migration of hygroscopic solutes within a laminate owing to moisture ingress, which ultimately results in blistering of the gelcoat’.

However, it is important to stress that the osmotic process progresses very slowly in most boats, and the timescale between stage two, (when high moisture readings are first noted), and stage three, (when the first blisters occur), may be as long as thirty years. If we are to treat this osmotic condition successfully, we must remove all hygroscopic solutes from the laminate to restore it to its original neutral (or ‘passive’) state before any new coating scheme can be applied. This treatment will always be much easier at the end of a season (when the solutes are dilute), and when blisters are well developed.

Will it Sink?

GRP boats with blistered gelcoats are often difficult to sell, but are buyers concerns really justified? More importantly, does osmosis really cause a significant loss of strength or buoyancy in GRP boats?

Many people will have heard horror stories about boats that have sunk without trace because of osmosis, and how others have absorbed so much water that they can hardly float! Whilst I cannot say for sure that these stories are completely unfounded, the many years of practical experience that I have gained in the field would suggest that such eventualities are extremely unlikely. Nevertheless, safety must always be uppermost in our minds, so these questions deserve our serious consideration.

Blistering:

Osmotic blistering is usually a comparatively superficial problem which only affects the protective gelcoat layer on the outside of the hull. The gelcoat itself is rather like a thick coat of paint, typically about 500 µm (½ mm or 20 thou) thick; although there can be significant variations in thickness from one part of a hull to another, and between different hulls.

Crucially though, the gelcoat layer itself has very little mechanical strength, and is used only to provide a glossy, hardwearing exterior finish and to help protect the structural laminate beneath it from the effects of water ingress and ultraviolet degradation. Polyester gelcoats are also notoriously brittle, and will readily crack or shatter if stressed, resulting in the characteristic ‘spiders web’ effect.

Most yachts could be sailed perfectly safely without these protective gelcoat layers; although they would attract marine fouling very rapidly and would look quite ugly to most eyes. (Indeed, Naval Minesweepers and GRP Superyachts are purposely designed and built without gelcoats, but are protected with epoxy and polyurethane paint coatings at newbuild).

In most instances of osmosis, where only moderate blistering is visible, the structural laminate will be barely moist, and any reduction in mechanical strength will be negligible. Furthermore, the very nature of osmosis in GRP usually means that this moisture and any solutes are concentrated in the layer(s) of structural laminate directly behind the gelcoat, (sometimes known as the ‘skin coat’), so any negative effects will be confined to this region.

However, in some ‘very bad’ or ‘advanced’ cases, several layers (or plies) of laminate can become quite ‘wet’, with the result that bundles of glass reinforcement become swollen, and adhesion between the glass filaments and lay-up resin is reduced, resulting in a measurable loss of mechanical strength.

Delamination:

Osmosis does not cause delamination, but if the laminate is poorly invested with resin, the internal hydraulic pressure generated by the osmotic process may separate (or delaminate) any poorly adherent layers (or plies) from one another, severely weakening the hull. This effect will usually be identified by visible undulation or large ‘swellings’ in the hull surface, although classic ‘Osmotic’ blisters need not be present in the gelcoat. The hull may also appear slightly ‘soft’ if pressed firmly with a thumb nail or a tool, and may sound ‘dead’ or ‘dull’ if tapped gently with a plastic faced hammer.

In this context, the shape and size of any blister formations will often provide a useful indication of the laminate condition beneath:

- Small or well-formed blisters usually indicate that the gelcoat is adhering well to the laminate, and that the laminate itself has good interlaminar adhesion.
- Shallow and irregularly shaped blisters are usually formed where adhesion between the gelcoat and structural laminate is poor. In some instances, two or more blisters will merge together to form larger blisters, again indicating poor adhesion between the gelcoat and laminate.
- Very large and shallow blisters or unevenness (lumpiness) in the hull surface usually indicates some form of de-lamination.

Whilst most yachts can be sailed perfectly safely with their gelcoats in a blistered condition, symptoms of de-lamination must be investigated by a Surveyor as a priority.

Buoyancy:
Contrary to popular belief, the quantities of moisture involved in these processes are comparatively small, and are most unlikely to have any adverse effect on buoyancy.

To put this into perspective, a typical ten metre (33 foot) yacht will have an underwater area of approximately twenty square metres. If we assume a (generous) average laminate thickness of 10 mm, and an average hull moisture content of 20% by volume (which would be exceptionally high), that gives us a total of forty litres of water; which is significant, but certainly not enough to cause sinking.

In practice, the true moisture content of even the worst laminate is most unlikely to reach 20%. Unfortunately, electronic moisture meters are somewhat misleading in this regard, as they are calibrated for softwood rather than GRP, and their high sensitivity means that just 2.5% of moisture in GRP would give readings of 20% H_2O or more on either the Tramex or Sovereign instruments.

Moreover, moisture meters tend to indicate the moisture content of the ‘wettest’ layer(s) in the laminate; and as we have already discussed, moisture in osmotic hulls is usually confined to just one or two plies of laminate directly behind the gelcoat, and so represents a small proportion of the overall hull weight. The net effect is that any weight increase is likely to be less than that of a bottle of wine, or two cans of beer, and I know of very few yachtsmen who would sacrifice those to save weight!

De-Humidifiers:
Leaving aside moisture meters for a moment, one often hears claims of huge quantities of water being extracted from boat hulls by de-humidifiers. Apart from the dubious benefit of using these machines to help ‘dry’ osmotic hulls, much of the water allegedly collected tends to come from the workshop floor, and the workshop atmosphere generally; rather than from the hull itself. In practice, the total quantity of moisture in any GRP hull is unlikely to amount to more than a litre or so.

Nevertheless, even small quantities of moisture will have a ‘plasticizing’ effect on polyester resins, reducing their hardness and T_g (Glass Transition Temperature). Apart from increasing the mobility of solutes within the hull, (thereby accelerating the formation of blisters), excessive moisture content may reduce the responsiveness of some racing craft, perhaps making them feel heavier than they really are.

Will Osmosis Do Any Other Damage?
As we have seen, the effect of Osmosis in GRP boat hulls is usually quite superficial. However, I have often heard it said that osmotic acids will destroy the lay-up resin, making holes in the laminate, and severely weakening the hull.

While it is true that many osmotic hulls are found to have hundreds of ‘voids’ when their gelcoats are peeled off, (See Fig 18 on page 14), these voids will almost certainly have originated as simple ‘air inclusions’ at new-build, which remained hidden inside the laminate until they were exposed during osmosis treatment. Similarly, laminates which are found to be severely lacking in resin, and are de-laminating were almost certainly laid up this way. Lack of layup resin is not caused by osmosis.

In this context, polyester resins actually have very good resistance to strong acids, (they are less resistant to alkali), and are therefore most unlikely to be dissolved by the (comparatively weak) acids found in osmotic boat hulls. Furthermore, even if this were possible, there is no means by which the dissolved resin could be diffused through a thick gelcoat layer, and several layers of antifouling.

Nevertheless, laminates which are poorly laid up, and incorporate one or more layers of poorly consolidated reinforcement are prone to suffer de-lamination as a result of osmotic pressure within the laminate, which will tend to separate the poorly adherent layers causing large swellings. However, we need to be clear that any such damage is not caused by osmosis *per se*, but by the internal hydraulic pressure generated by the osmotic process.

Having read the above, it should be clear that osmosis is not necessarily the disaster that so many people fear. Indeed, some buyers actively seek a boat with high moisture readings or even a few blisters, and negotiate a reduction in price rather than paying top dollar for a ‘clean’ boat which might blister in a season or two. If the hull is otherwise sound, the new buyer may well be able to enjoy a few seasons sailing before having any treatment carried out.

Inspection and Diagnosis:

Having read the foregoing text, it will be seen that our first objective must be to determine whether a GRP hull is at Stage One, Two or Three in the osmotic process. Our second objective is to determine whether any preventative or remedial work is required or desirable.

Moisture Meter Readings:
The first stage in this process is to take a series of moisture meter readings from the hull using our chosen meter(s); the objective being to determine whether any moisture is being retained within the hull laminate.

Before any moisture readings can be taken, the boats bottom must be thoroughly pressure washed with plenty of fresh water to remove all weed, slime, silt and shell fouling before it is allowed to dry. This process is important, because marine fouling prevents a thorough inspection of the hull surface, whilst any residual salt will retain moisture, leading to excessively high moisture meter readings. The boat must also be dry and well ventilated internally, with no bilge water or condensation.

The first few minutes after pressure washing whilst the hull is still wet are valuable, as this is by far the best time to spot blisters and swellings and other irregularities in the boats bottom. These will be much more difficult to see when the hull has dried, especially if there is a heavy accumulation of antifouling. The first blisters are most likely to be seen in stressed areas, such as the bows and around keels, and around the waterline where water temperature tends to be slightly higher than elsewhere.

Once the hull has dried, a series of moisture readings should be taken, starting above the waterline at either bow, and then working down towards the centreline. This should be repeated every half metre or so along both sides of the hull until a complete grid pattern has been mapped. Note down readings using the % H_2O scale on your moisture meter. This is also a good time to look more closely for symptoms of blistering, swelling, stress cracking and mechanical damage.

High moisture readings can be expected near to metal fittings such as stern tubes, tanks, encapsulated keels and chain lockers. Bilge water and condensation will also cause high moisture readings. Persistently high readings that cannot be attributed to these causes are likely to be caused by hygroscopic solutes within the laminate, and may indicate an osmotic condition. A Table of Suggested Moisture Meter Readings can be found on page 17 of this guide.

Coupons:
A Surveyor will usually want to remove a series of antifouling ‘coupons’ from the boat’s bottom to expose the gelcoat or protective epoxy coatings beneath. The antifouling coupons should be scraped off using a blunt wood chisel held at 90 degrees to the hull surface. Do not use a sharp chisel or press too hard, as you are likely to shave off irregularities from the gelcoat surface, thereby destroying the evidence that you are looking for. Each coupon should be of at least three or four centimetres square.

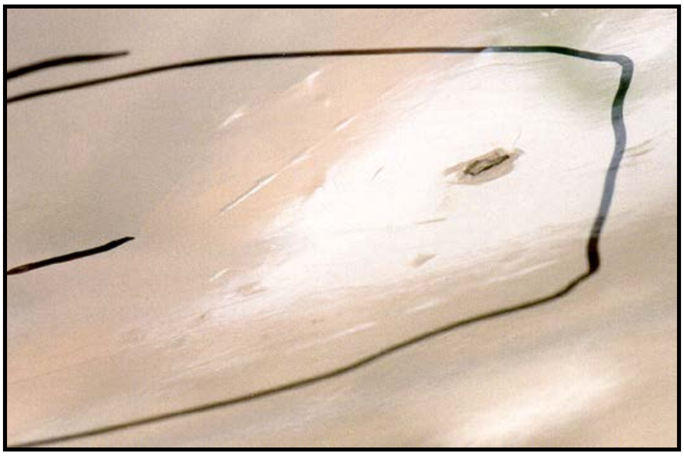


Fig 6: Fibre swelling in bare white gelcoat. Fibre swelling is not caused by osmosis, but by capillary action in fibre bundles behind the gelcoat.

If a comparatively new boat is being surveyed, the Surveyor may be happy to take four or five coupons from ‘stressed’ areas on each side of the hull, just to satisfy himself that there is nothing untoward going on.

Older boats usually warrant a greater number of coupons; say one or two per square metre; whilst a Surveyor examining a twenty-five year-old yacht may well keep on taking coupons until blisters are found!

Coupons also provide a good opportunity to take moisture meter readings without the influence of antifouling; although I should stress that antifouling does not usually need to be removed before taking readings.

Blisters:
If any blisters or swellings are found, we need to establish whether these are really caused by osmosis, or by other factors.

To deal with non-osmotic blisters first, the most common causes of concern are wicking, fibre swelling, voids and air inclusions:

Fibre swelling occurs when moisture is absorbed into bundles of reinforcing fibre immediately behind the gelcoat. This moisture is absorbed by capillary action, and separates the individual glass filaments from one another, making the fibre bundles swell. Capillary action is very powerful, and will sometimes result in quite large swellings which tend to reduce in size after lifting out. Fibre swelling is not usually caused by osmosis, but the absorption of moisture into the laminate over prolonged periods will inevitably encourage osmotic breakdown.

Fig 7: Antifouling coupon exposing gelcoat crazing.

Wicking occurs when the fibre bundles penetrate the gelcoat surface, or lay very close to the surface, providing an easy path for moisture into the laminate. Mild wicking can be difficult to see, but it often causes swellings similar to those associated with fibre swelling, above.

Air inclusions occur during the laying up process, and are created when air bubbles become trapped in the polyester lay-up or gelcoat resins shortly before they gel. Changes in temperature or atmospheric pressure make these bubbles change in size, at which point they may become visible. The smallest air inclusions may be only one or two millimetres in diameter, and will often be exposed when the gelcoat is sanded for painting. Air bubbles may also absorb moisture over time, and will gradually swell in size as a result. As would be expected, air inclusions in or near to the hull surface are easiest to see, whilst larger inclusions and voids within the structural laminate are less visible but are likely to cause more serious problems.

Voids usually occur when the glass reinforcement is not consolidated properly, with the result that air is trapped between layers of reinforcement, creating voids. Similar voids are often found in stems, skegs, spray rails and other tight corners where lack of space makes it difficult to lay up the reinforcement without creating air voids, and are easily broken open. Large air inclusions and voids often cause visible swelling, but in many cases they will remain hidden for twenty years or more until osmosis treatment is carried out. (See *Fig 18* on page 14).

Osmotic Blisters:
Osmotic blisters can vary in size from pinhead to 8 ~ 10 CM in diameter, and will nearly always be fluid filled. This fluid can be checked for acidity by using pH papers**;** an acidic reading anywhere between pH 0 to pH 6.5 would suggest an osmotic condition, although figures of pH 3 ~ 5 would be more usual.

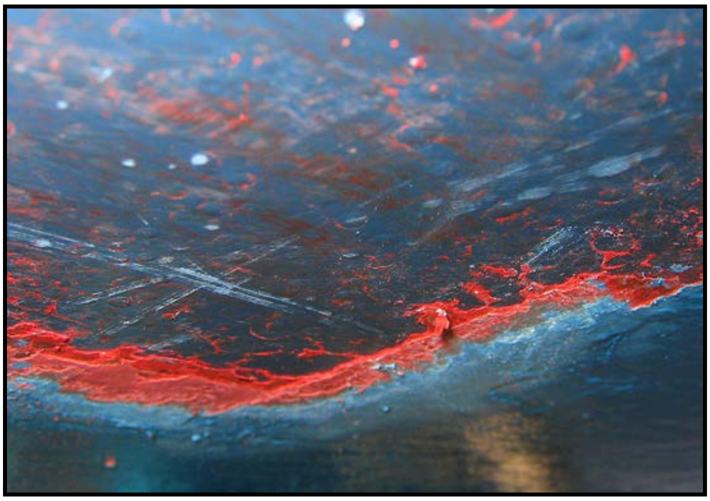


Fig 8: Shallow blisters in blue gelcoat, These blisters would not have been visible if the considerable antifouling build up had not been removed.

Alkaline readings may be encountered if amine accelerators were used in the lay-up and/or gelcoat resins. Alkaline readings may also indicate failure of an epoxy coating scheme.

Any blister fluid should be rubbed between thumb and forefinger to check whether it has a sticky or greasy feel, indicating the presence of glycol. If glycol is present, (which is nearly always the case), it must be completely removed if the laminate is to dry satisfactorily, and be successfully treated.

If possible, (and with the owners permission), one or more sections of gelcoat should be removed with a sharp wood chisel to allow examination of the laminate itself. Any laminate that has not been properly invested with resin must be removed before re coating, as it may be physically weakened, and is also likely to harbour hygroscopic solutes.

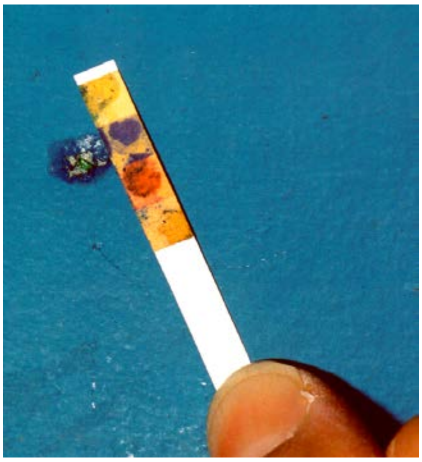


Fig 9: Checking the pH of blister fluid with a Universal Indicator. This blister fluid was strongly alkaline, and originated between coats of under-cured epoxy.

When examining the laminate, it is also useful to cut deeper into the hull to ascertain just how deeply seated the problem is. In many cases, osmotic activity will have been confined to the layer(s) immediately behind the gelcoat, and removal of these layers in isolation will prove more than sufficient to allow successful treatment.

However, I am now seeing an increasing number of older, heavily laid up yachts where osmotic activity has affected multiple layers of the hull, sometimes extending to a depth of 5 mm or more. Closer examination will usually show that several layers in the laminate are starved of resin, and are therefore comparatively permeable to moisture and any solutes. The shortage of lay-up resin means that any osmotic pressure generated within the laminate is quickly lost, (rather like a punctured tyre), so the osmotic condition must be well developed, and quite vigorous before sufficient osmotic pressure is developed to form visible blisters.

Fig 10. This poorly consolidated laminate had very little adhesion between layers of reinforcement, and was suffering from loss of mechanical strength.

Hulls in which the outer layers are laid up with pigmented resins are especially prone to problems, as any pigment or extender tends to inhibit the ‘wetting’ qualities of the resin, preventing thorough consolidation or ‘investment’. Moreover, some colouring pigments (most notably phthalocyanine blues and greens) are themselves soluble in water, and are known to encourage blistering.

Where these problems are identified, it will often prove necessary to remove all of the affected layers before the laminate will ‘dry’ satisfactorily. Also remember that well consolidated resin on the surface of a laminate may be ‘hiding’ and ‘protecting’ poorly invested material beneath, effectively preventing the removal of solutes.

Removing significant thicknesses of laminate usually means that expensive re-lamination is needed to restore mechanical strength; nevertheless, it is usually much more cost (and time) effective to prepare the hull adequately to begin with, rather than paying for a second peeling operation when the first has been found inadequate.

I would also add that, in my experience, yachts which have been re-laminated with a sheath of epoxy glass fibre after heavy peeling have proved very reliable in service, even where satisfactory moisture readings could not be achieved.

To Treat or Not To Treat?

Having carried out the basic tests outlined above and assessed the laminate condition, a decision will need to be taken whether to treat the boat or not.

My own experience is that early treatment of osmotic boats tends to be less successful than treatment of vessels with advanced blistering. While this statement may seem to contradict normal precautionary practice, experience has shown that the breakdown processes in GRP laminates take some time to reach their natural conclusion; therefore if treatment is carried out prematurely, it is much more difficult to remove solutes from the laminate, and a reoccurrence of osmosis is much more likely.

Another useful point to remember is that laminates are much easier to treat shortly after a season afloat than after a long period on hard-standing, simply because any solutes in the laminate will be more dilute, and hence easier to remove.

Remedial treatment is sometimes recommended on the basis of high moisture meter readings alone; although in my view this is unwise, as moisture content has no direct correlation to laminate condition; and in any case, moisture meters do not give a sufficiently accurate indication of moisture content to allow a judgement of this importance.

However, the one overriding factor must always be the integrity (and safety) of the hull. Osmosis in its early stages is very much a chemical condition, which has very little effect on hull strength, but if allowed to deteriorate too far, the laminate may eventually start to ***de***-laminate (i.e. separate into individual layers), with a corresponding loss of hull strength.

Fortunately, de-lamination is quite easy to spot owing to the large “swellings” that invariably appear in the gelcoat, which are quite distinct from the smaller, and well defined blisters more usually associated with osmosis.

Clearly then, it is important that diagnosis is only made after careful evaluation of all symptoms, and to be certain that the symptoms really do warrant remedial treatment. The flow chart (***Fig 12***) overleaf may be found helpful when taking this decision.

Fig 11. Blistering like this takes many years to develop, and will not be cured by any amount of heating or de-humidification. The HotVac system has proved very successful for treating ‘problem’ boats, but peeling, blasting and thorough fresh water washing remain an essential part of the process.

1) Hull Inspection	Symptoms	Recommended Treatment
2) No indication of physical defects.	3) Moisture readings are satisfactory.	4) Protective scheme should be applied following suitable preparation.
2) No indication of physical defects.	3) Moisture readings are persistently high.	4) None: Application of a protective scheme is unlikely to have any long term benefits, and is therefore not advised.
2) Small "dry" blisters are found in gelcoat.	3) Moisture readings are satisfactory.	4) Protective scheme should be applied following suitable preparation.
2) Wicking and/or gelcoat crazing found.	3) Moisture readings are initialy high, but fall within 3 or 4 weeks of lifting from the water.	4) Protective scheme should be applied following suitable preparation.
2) Wicking and/or gelcoat Crazing found.	3) Moisture readings are persistently high.	4) Full remedial treatment should be carried out when convenient, idealy at the end of a sailing season. **Application of a protective scheme is not recommended.**
2) Localised blistering found.	3) Blisters are filled with fluid having an acidic and/or greasy nature. (Note that moisture readings are not relevant in this situation).	4) Full remedial treatment should be carried out when convenient, idealy at the end of a sailing season. **Application of a protective scheme is not recommended.**
2) Severe blistering found in many areas.	3) Blisters are filled with fluid having an acidic and/or greasy nature. (Note that moisture readings are not relevant in this situation).	4) Full remedial treatment should be carried out at the end of the sailing season. Localised treatment or the application of a protective scheme will have no benefit at this stage.

***** Persistently high moisture readings indicate that some laminate breakdown has already occurred, which ***will not*** be reversed by drying, (although gelcoat blistering may not develop for many years). Osmosis prevention schemes should not be applied to laminates in this condition, as these are likely to suffer from blistering within a season or two. Full remedial treatment can be carried out, but would not usually be appropriate at this stage given the costs involved.

Fig 12: Flow Chart of Symptoms and Recommended Treatment

Correct and Effective Preparation:

In my experience, abrasive grit blasting and slurry blasting are the two most effective methods of preparing GRP laminates for osmosis treatment.

The advantage of grit or slurry blasting over other methods is that the blasting process selectively removes soft, damaged or weak areas of laminate, while having little effect on sound areas nearby. Blasting also produces an excellent surface profile, which helps to promote good adhesion of paint coatings, while the enlarged surface area also encourages drying and removal of solutes.

Unfortunately, grit blasting is a slow, noisy, messy job, consuming large quantities of abrasive grit that must be disposed of safely after use. As a result, grit blasting and slurry blasting operations are now severely restricted in many modern marina complexes, and have been effectively banned altogether in some European countries such as the Netherlands.

A further practical disadvantage is that grit and slurry-blasting methods can produce a very uneven hull profile, which may require extensive filling and fairing if a satisfactory hull profile is to be restored.

These drawbacks have led to the increased popularity of gelcoat peelers in recent years, which are comparatively fast and clean, and produce a smooth hull profile requiring only minimal filling.

On the downside, gelcoat peeling has the major disadvantage that it only removes a pre-set thickness of material, and so does not remove or identify those areas where the laminate is soft, weak or under-bound. This is akin to peeling an apple with a knife, and not removing rotten areas; although unlike an apple, weak areas of GRP laminate are not always readily visible!

Fig 13. Gelcoat Peelers are ideal for bulk gelcoat removal, but note the very 'woolly' surface and unbound fibre left behind.

A further drawback of gelcoat peeling process is the comparatively smooth surface produced, which makes drying and removal of solutes an even more difficult task.

Where possible, the best compromise is to use a gelcoat peeler to remove the bulk of unwanted gelcoat and laminate, followed by moderately aggressive grit blasting to selectively prepare the laminate surface. A pressure washer fitted with a grit blasting attachment is often ideal for this purpose.

Alternative Methods:
Alternative methods of preparation include grinding and the use of heat guns.

Grinding is generally unsatisfactory for preparing large areas as it disperses significant quantities of dangerous dust into the atmosphere, and also produces a very smooth surface. Nevertheless, grinding can be useful for preparing limited areas of a yachts hull, and especially around the keel up-stand and fittings where a gelcoat peeler cannot be used.

Where grinding methods are used, ***all*** personnel in the vicinity must wear suitable respiratory protection to guard against the inhalation of irritant glass particles.

Heat guns should not be used on GRP as they can easily heat the laminate beyond the Glass Transition Temperature (or T_g) of the laminating resin, resulting in distortion and de-lamination of the lay-up; especially if the hull is very wet. Heating a GRP laminate strongly is also likely to generate toxic fumes, especially where old antifoulings are present.

The photographs below show various examples of good and bad laminate preparation, with comments on their suitability:-

Fig 14. A poorly prepared laminate.

Note that little or no gelcoat has been removed from this hull, making removal of hygroscopic solutes next to impossible.

Fig 15. Preparation by gelcoat peeling alone.

The limitations of gelcoat peeling are clearly evident in this photograph; note the unbound fibre that still remains, and the fossilised wasp near the centre of the picture!

Fig 16. Unbound fibre behind a yacht's gelcoat.

Unbound fibre like this tends to harbour solutes, and will make successful treatment difficult.

Fig 17. A well prepared laminate.

Note that nearly all gelcoat and unbound fibre has been removed from this hull.

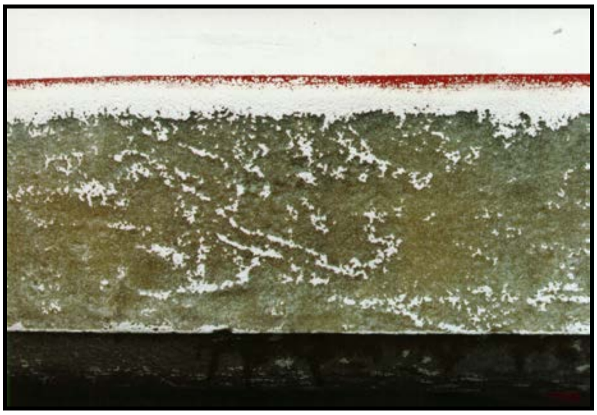


Fig 18 (left) and Fig 19 (right). These photographs show examples of good laminate preparation, with most or all of the gelcoat removed, and no loose or poorly consolidated reinforcement visible. Preparation to these standards will usually require extensive filling and fairing, but the treatment will be much more reliable as a result. Please note that the pock marks seen in Fig 18 above were caused by large air inclusions (introduced at newbuild), and not by osmosis.

Washing and the Removal of Glycols:

Propylene Glycol plays no useful role in the cure of polyester resins, but is used as a ‘moisture scavenger’ in the vital work removing unwanted ‘water of esterification’ from batches of ‘cooked’ resin. Additions of propylene glycol are always minimised and carefully controlled; but small quantities may remain in the finished product, and will cause blistering of GRP boat hulls. The problems caused by free glycol are often exacerbated by undercure of polyester resins and poor consolidation of glass reinforcement; as these conditions allow any glycol (and other solutes) to migrate comparatively easily, thereby accelerating the osmotic process and causing premature blistering.

Very few resin manufacturers have successful eliminated all propylene glycol from their finished polyester resin products; but the quantity of free glycol in marine resins is usually negligible. Nevertheless, even well-established boat builders have been sold non marine resins from time to time, (usually on the promise of improved performance), but after a few years in service, the marine performance of some of these resins has fallen a long way short of expectations.

Given that glycol is strongly hygroscopic (i.e. moisture attracting), it will be seen that all traces of free glycol must be completely removed from GRP laminates if osmosis treatment is to be successful. In this regard, even small quantities of glycol will prevent drying of the laminate, as glycol always retains some moisture. Heating or dehumidification may temporarily reduce moisture meter readings, but these will increase again as soon as the heat is removed, or when the boat is returned to the water.

Propylene glycol has a boiling point of 188 °C, or nearly twice that of water, and will not be removed by any amount of heating or dehumidification; although it can usually be flushed out by repeated pressure washing with fresh water, preferably used hot, but without any detergent or other additives. (Other glycols used in polyesters have very similar properties). Any free glycol will then migrate to the laminate surface during the washing phase, and will be removed, as it is readily soluble in fresh water.

Where possible, I would recommend that the prepared laminate is washed *at least* once a day for a week to ten days, after which the boat should be allowed to dry in *natural* drying conditions. As explained above, application of heat or dehumidification may give a false impression of drying.

When the washing phase is complete, the laminate should dry readily. If it does not, it is likely that some propylene glycol or other hygroscopic solutes are still remaining, and should be removed by repeating the washing process. It should also be noted that glycols are polar (conductive) substances, and so will be readily detected by a good moisture meter.

Drying:

There is no set period for laminate drying, as this will be dependent on ambient conditions, preparation methods, laminate thickness and condition.

Wherever possible, boats should be allowed to dry in natural conditions, either under cover in a well ventilated shed, or outside with a polythene skirt taped around the water line. There is no need to protect the laminate from the elements at this stage, indeed there is much evidence to suggest that exposure to the elements may well be beneficial.

In most cases, a laminate should be dry within two or three weeks of washing if all traces of free glycol have been removed. If the laminate will not dry, this indicates that further washing is required. Grit blasted laminates will normally be found to dry much more quickly than laminates that have been gelcoat peeled alone owing to their much larger surface area.

As already explained, the use of heat or dehumidification is not recommended during initial drying, although it is good practice to use this equipment during the final two or three days before painting, and of course, during the coating application itself.

The HotVac system will safely speed up the removal of solutes and subsequent drying, but I would recommend thorough fresh water washing is carried out beforehand, to remove the bulk of any solutes.

Moisture Meters:

A good moisture meter is an invaluable tool for gauging how much moisture has been absorbed by a GRP hull, but like any instrument, moisture meters have their limitations, and cannot be expected to provide foolproof readings under all circumstances. Moreover, it must be stressed that there is no direct correlation between moisture content and laminate condition, so moisture meter readings should never be used to make a diagnosis in the absence of other information.

A moisture meter can provide a very useful guide to the 'chemical' condition of GRP laminates, but older boats built with Orthophthalic reins may require a series of readings over a period of several weeks to see the full picture. Think of the meter as a barometer rather than an 'osmosis meter', and look for trends rather than absolute values. In this regard, a boat owner with a moisture meter often has the advantage over a Surveyor, as the owner has greater freedom over how and when readings are taken.

High readings may be expected shortly after lifting, but these will fall steadily to lower values if the laminate is in sound condition. However, if readings remain persistently high it is likely that the laminate has already started to break down and is unlikely to dry satisfactorily without unless full osmosis treatment is carried out.

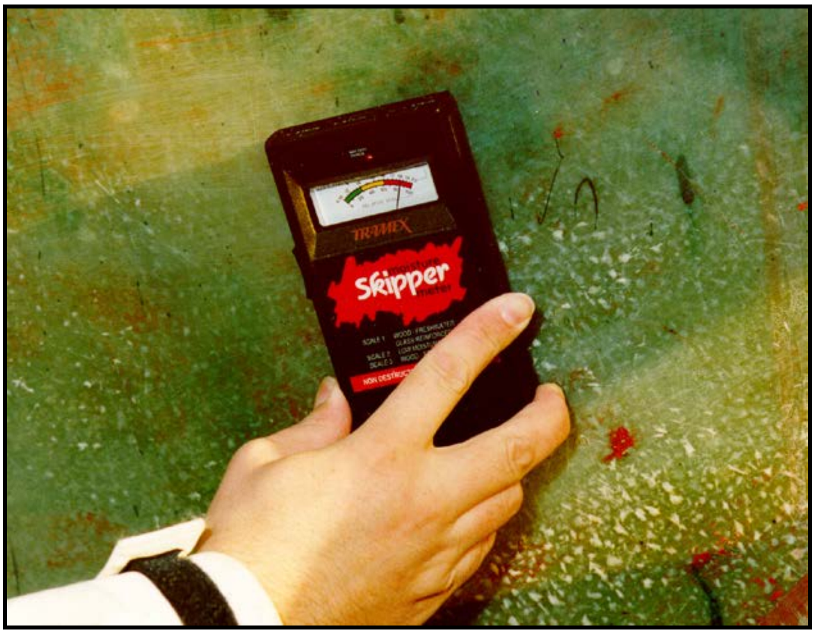


Fig 20. A Tramex Skipper meter being used on an exposed clear gelcoat. The white spots are caused by an effect known as 'fibre swelling', where bundles of glass reinforcement have absorbed moisture, which forces the filaments apart by capillary action. A pigmented gelcoat would only show small swellings at its surface.

Modern moisture meters determine moisture content by applying a radio frequency signal between two electrodes, which are held against the laminate surface. As moisture content increases, electrical capacitance between the electrodes rises, and is interpreted by the meter to give an approximate moisture value. However, the shape and spacing of these electrodes has a significant effect on the response patterns of different types of moisture meters, sometimes resulting in contradictory and confusing readings.

Instruments with their electrodes spaced widely apart will provide meaningful readings even when moisture is hidden deep within laminates. By contrast instruments with closely spaced electrodes tend to be unduly sensitive to moisture on or near to the surface, and may give misleading readings where epoxy coatings have been applied.

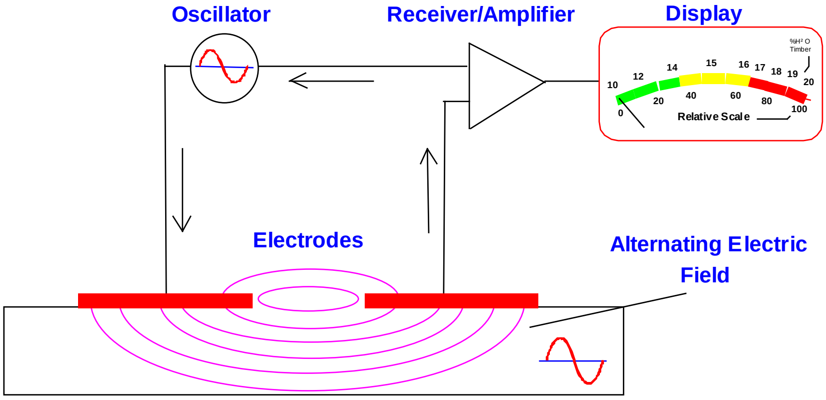


Fig 21. Schematic of a Typical Electronic Moisture Meter

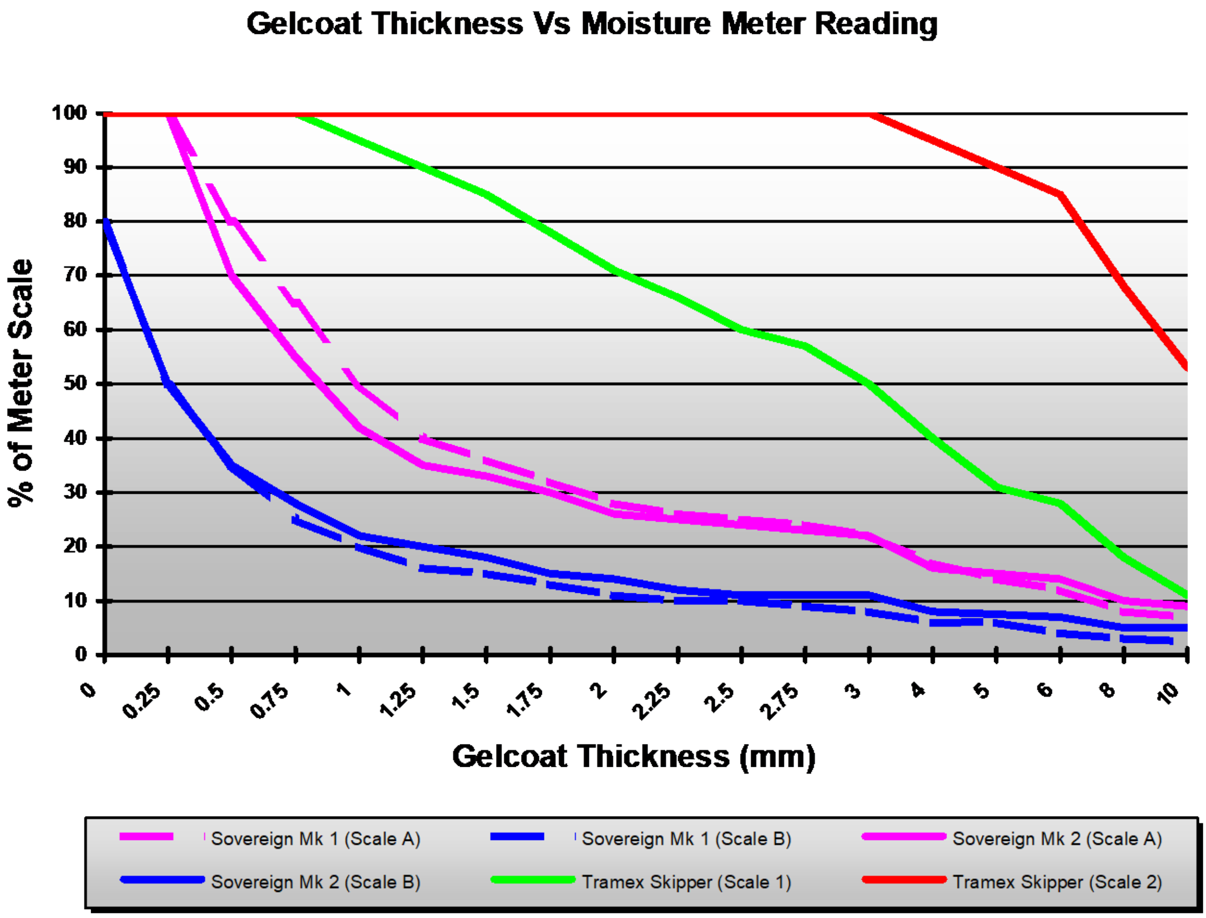


Fig 22. Graph Showing Moisture Meter Response relative to Gelcoat Thickness

Some boatbuilding resins, (especially epoxies), retain a certain amount of moisture for long periods after lifting out. The high apparent moisture content may lead the unwary into believing that the coating scheme has failed. Removal of coatings will usually show that this is not the case.

‘Acceptable’ Moisture Readings?

The following moisture meter readings are usually regarded as ‘acceptable’ within the small craft industry, although I must stress that these values should only be used as a guide, and in conjunction with other ‘visual’ and ‘physical’ indications:-

Moisture Meter	**In-Service Yacht** [2]	**Osmosis Treatment** [2]
1. Tramex Skipper or Skipper *Plus* Set to ‘Scale 2’ (GRP):	17 % H_2O or Lower [2]	14% H_2O or lower [2]
2. Sovereign Marine Moisture Master (Mk I or MK II) Set to ‘Scale A’:	10 ~ 12 % H_2O or Lower [2]	5% H_2O or lower [2]
3. Sovereign Quantum (set to Shallow)		

Fig 23: Table of Suggested Moisture Meter Readings

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[2] The figures suggested here refer to readings taken from ‘in-service’ yachts, (i.e. during a normal pre-purchase survey) following an appropriate drying interval. Lower readings are required before epoxy coatings can be applied, and/or when the gelcoat has been removed (as indicated under the Osmosis Treatment column).

Important Notes:

1. Surfaces must be visibly dry, and bilges should be dry and well ventilated before moisture readings are taken.
2. Moisture readings should not usually be taken within seven days of lifting out unless the vessel is known to have been laid up with Isophthalic or vinyl ester gelcoat and lay-up resins. (Isophthalic resins were not widely used in production boat building until the 1990s. Vinyl ester resins are a more recent development, and are less widely used than Isophthalic resins).

   If readings are unacceptably high, further readings should be taken a week or two later to see if the moisture level has fallen significantly.
3. The moisture readings quoted in the table refer to the relevant moisture scale, and are expressed as % H_2O.
4. Moisture meter readings are relative to timber, and do not indicate absolute moisture content in GRP. Furthermore, readings given by different instruments of the same type may vary.
5. Moisture readings taken from laminates prepared for full osmosis treatment should fall quickly as soon as the washing phase has been completed**;** persistently high readings indicate that hygroscopic solutes are still present, and must be removed by further washing.
6. Moisture readings required for osmosis treatment or prevention, or for GRP repair are lower than those expected at pre-purchase survey. If in doubt moisture readings taken from prepared GRP should be lower than from a piece of clean, dry timber kept in the same conditions.

Deciding When to Apply Coatings:

The question of when to start applying coating is often thought to be a difficult decision. Questions like **‘**when will it be dry enough?**’** and **‘**have I left it long enough?**’** are frequent queries, but it really is not that difficult if we know what to look for.

If a boat dries satisfactorily in ***natural*** drying conditions, (i.e. without heating or dehumidification), one can be sure that it is ready for coating, as laminate moisture levels will only fall if when all free glycol has been removed from the laminate. The risk of force drying is that it often gives the impression that all is well, but if glycol is still present, moisture levels will start to rise again as soon as the heat or dehumidification is switched off.

It really is as simple as that: there is no set period of so many weeks or months drying. If the laminate has been correctly prepared, has been washed as outlined above, and has dried readily in natural conditions, then it is ready to coat.

Likewise, there is absolutely no reason why any yacht should take six or nine months to be treated for osmosis. With correct preparation, it should be possible to complete this work in just four to six weeks, and with a much reduced risk of re-blistering than would otherwise be the case

Choosing the Correct Paint Coatings:

Solvent free epoxies are almost always specified as the initial coating for bare GRP laminates, both to avoid the risk of solvent retention within the laminate, and to maximise impregnation and adhesion of the first coat.

Solvent free epoxies may also be used for subsequent coats, however, solvent containing types such as *International Gelshield 200* are sometimes chosen here for their more flexible over-coating times, and their tolerance to lower temperatures. It is also worth noting that solvent containing epoxy formulations can be better optimised to achieve the lowest possible moisture permeabilities, and will usually perform better than any other coating in this application.

However, if several coats of solvent free epoxy need to be applied, it is usually best to keep over-coating intervals to an absolute minimum to ensure good intercoat adhesion, and to reduce the risk of amine sweating. Note that solvent free coatings can generally be overcoated with similar coatings as soon as they are ‘tacky’ without any risk of solvent retention.

Where protective epoxy schemes are used, it is normal practice to specify an "antifouling tie coat", as antifoulings have poor adhesion to many epoxy coatings; adhesion of antifoulings to solvent free epoxies is particularly poor. Products such as *Hempel’s Antifouling Primer* and *International’s Gelshield 200* are often specified for this purpose, as they offer good adhesion for all antifouling coatings, although it is still necessary to apply antifoulings within the recommended intervals to optimise antifouling adhesion.

However, conventional coatings like yacht enamels are totally unsuitable for underwater use, as they will break down and detach if immersed for prolonged periods. They also offer very limited moisture barrier properties.

Fillers:

When it comes to underwater filling, there is really no option but to use solvent-free epoxy fillers.

Ready mixed types are probably the easiest to use, and will have been developed for optimum performance, but they do not always provide the best consistency for every application.

Where a more flexible approach to filling is required, it is often better mix you own filler using materials supplied by one of the specialists in this field, such as SP Systems or Wessex resins. Nevertheless, it must be pointed out that many of the raw materials used in fillers are difficult to handle, and some may be injurious to health if not used with care, especially the silicaceous materials used to provide thixotropy, and liquid epoxy resins.

Fig 24. Epoxy fillers must be mixed thoroughly to ensure complete incorporation of the two components. Protective gloves should always be worn whenever mixing or applying epoxy materials!

Fillers must always be applied ***between*** coats of protective epoxy paint to ensure that the filler adheres well to the substrate, while also providing good protection against moisture ingress. Nevertheless, do remember that all paint coatings are slightly permeable, so all fillers used below the waterline must be properly constituted, and specified for underwater use.

Note that polyester fillers (such as those used for car body repairs) are ***not*** suitable for use below the waterline, as their resin systems and pigmentation tend to encourage moisture absorption, and will cause early failure of the treatment scheme.

Also remember that epoxy fillers are prone to ‘amine sweating’ in just the same way as epoxy paints, and must be thoroughly fresh water washed and dried before over-coating if sweating is suspected. Similar temperature constraints also apply, and heating may be required to ensure satisfactory curing conditions.

Coating Schemes:

A number of excellent coating schemes have been developed by the paint manufacturers, and are designed to protect laminates by minimising the amount of moisture which finds its way into the hull, and by avoiding the use of organic solvents where this could be detrimental.

Three examples are given here. The first two are suitable for full osmosis treatment, while similar schemes without profiling fillers are commonly used for osmosis prevention.

Stage	Product	Sequential Over-coating Intervals	Film Thicknesses and Theoretical Coverage rates
Preparation	Prepare laminate as detailed in the text, ensuring that all unbound fibre and solutes have been removed. Any damage must be repaired before coating.		
1. Saturation Stage ***(Optional)***	***SP Systems Ampreg 20*** with standard or fast hardeners Contact Hempel for further details on this application	3 ~ 5 Hours 15 °C 2~ 4 Hours 20 °C	Variable - Apply until laminate is completely saturated.
2. First Priming Stage	***GelProtect SFE200*** Cream (35651,24700) Clean tools with Hempel ***No 5 Thinners*** **Do Not Thin**	7 Hours ~ 4 Days (10 °C) 4 Hours ~ 3 Days (20 °C)	200µ Minimum Thickness Typical Coverage**:** 5m²/Lt
3. Filling and Fairing	***Pro Filler*** or ***Finefill*** Epoxy Filler (35251,19810) Clean tools with Hempel ***No 5 Thinners*** **Do Not Thin**	12 ~ 24 Hours (10 °C) 8 ~ 24 Hours (20 °C)	Apply as Required Always sand fillers before over-coating
4. Second Priming Stage	***GelProtect SFE200*** Grey (35651,13700) Clean tools with Hempel ***No 5 Thinners*** **Do Not Thin**	7 Hours ~ 4 Days (10 °C) 4 Hours ~ 3 Days (20 °C)	200µ Minimum Thickness Typical Coverage**:** 5m²/Lt
5. Third Priming Stage	***GelProtect SFE200*** Cream (35651,24700) Clean tools with Hempel ***No 5 Thinners*** **Do Not Thin**	7 Hours ~ 4 Days (10 °C) 4 Hours ~ 3 Days (20 °C)	200µ Minimum Thickness Typical Coverage**:** 5m²/Lt
6. Fourth Priming Stage	***GelProtect SFE200*** Grey (35651,13700) Clean tools with Hempel ***No 5 Thinners*** **Do Not Thin**	7 Hours ~ 4 Days (10 °C) 4 Hours ~ 3 Days (20 °C)	200µ Minimum Thickness Typical Coverage**:** 5m²/Lt
Over-coating *GelProtect SFE200* with *Antifouling Primer*		**6 ~ 9 Hours**	See Hempel Data Sheets for more information
7. Antifouling Tie Coat	Hempel's ***Antifouling Primer*** (26200,20800) Use ***No 3 Thinners*** for thinning and equipment cleaning	14 Days Minimum to 6 Months Maximum	100µ Wet, 40µ Dry Typical Coverage**:** 10 m²/Lt
8. Antifouling	Choose from the range of Hempel's antifoulings	8 Hours + (10 °C) 6 Hours + (20 °C)	Two Coats at 100µ Wet Film Thickness Each Typical Coverage 10 m²/Lt

Fig 25: Hempel's Coating Scheme for Full Osmosis Treatment
Seek further advice from the manufacturer before proceeding

Stage	**Product**	**Sequential Over-coating Intervals**	**Film Thicknesses and Theoretical Coverage rates**
Preparation	Prepare laminate as detailed in the text, ensuring that all unbound fibre and solutes have been removed. Any damage must be repaired before coating.		
1. Saturation Stage ***(Optional)***	***Epiglass HT9000*** (YAA900) Contact International Paint for further details on this application	Contact International Paint for Further Details	Variable - Apply until laminate is completely saturated.
2. First Priming Stage	***Gelshield Plus*** Green (YAA222/YAA220) Clean tools with ***Thinners No 7*** **Do Not Thin**	16 Hours ~ 4 Days (10 °C) 7 Hours ~ 4 Days (15 °C)	150µ Minimum Thickness Typical Coverage**:** 5 M²/Lt
3. Filling and Fairing	***Interfill 830 Fast Cure*** Profiling Filler (YAA867/YAA869) Clean tools with ***Thinners No 7*** **Do Not Thin**	24 Hours Min (10 ~ 15 °C) 6 Hours Min (23 ~ 35 °C)	Apply as Required Always sand fillers before over-coating
4. Second Priming Stage	***Gelshield Plus*** Blue (YAA222/YAA221) Clean tools with ***Thinners No 7*** **Do Not Thin**	16 Hours ~ 4 Days (10 °C) 7 Hours ~ 4 Days (15 °C)	150µ Minimum Thickness Typical Coverage**:** 5 ~ 6 M²/Lt
5. Third Priming Stage	***Gelshield Plus*** Green (YAA222/YAA220) Clean tools with ***Thinners No 7*** **Do Not Thin**	16 Hours ~ 4 Days (10 °C) 7 Hours ~ 4 Days (15 °C)	150µ Minimum Thickness Typical Coverage**:** 5 ~ 6 M²/Lt
6. Fourth Priming Stage	***Gelshield Plus*** Blue (YAA222/YAA221) Clean tools with ***Thinners No 7*** **Do Not Thin**	24 Hours ~ 4 Days (10 °C) 12 Hours ~ 4 Days (15 ~ 23 °C)	150µ Minimum Thickness Typical Coverage**:** 5 ~ 6 M²/Lt
7. Antifouling Tie Coat	***Gelshield 200*** (YPA213/YPA214)	5 ~ 9 Hours (15°C) 3 ~ 7 Hours (23°C)	110µ Wet, 50µ Dry Coverage: 8 m²/Lt
8. Antifouling	Most antifoulings can be applied satisfactorily; refer to manufacturer for further advice.	Typically 12 Hours to 6 Months at 15° C	Antifoulings typically cover at 8 ~ 9 m²/Lt

Fig 26: The Gelshield Plus Coating Scheme for Full Osmosis Treatment
Seek further advice from the manufacturer before proceeding

† Minimising over-coating intervals helps to improve intercoat adhesion of solvent free coatings. International Paint recommends over-coating Gelshield Plus solvent free as soon as it is tacky enough to support a further coat. Readiness for over-coating can be checked by pressing against the surface with your thumb, but will generally be within 3 ~ 4 hours at 15 °C, or 2 ~ 2½ hours at 23 °C.

Either of the above schemes can be used for osmosis treatment, or for osmosis prevention if the filling and fairing stages are omitted. Nevertheless, both schemes require warm, dry conditions if they are to perform well, and are likely to suffer from problems of amine sweating and undercure if applied under unfavourable conditions.

If adequate temperatures cannot be maintained, or if application must be carried out in outdoor conditions, the following specification may prove useful. A further benefit of this scheme is that most of the over-coating periods are very flexible, making it ideal where work may have to be interrupted. It is also worth noting that initial coat(s) in the scheme may be substituted with solvent free coatings if the scheme is to be applied to exposed laminates.

Stage	**Product**	**Sequential Over-coating Intervals**	**Film Thicknesses and Theoretical Coverage rates**
1. Preparation	Prepare gelcoat by degreasing and sanding to achieve a good mechanical key. Ensure moisture readings are satisfactory before coating, as the scheme will blister if applied to an 'osmotic' hull. The optional solvent free epoxy priming stage (Stage 2) should be used if this scheme is applied to laminate where the gelcoat has been removed.		
2 Solvent Free Priming Stage **(Optional)**	***Gelshield Plus*** Green (YAA222/YAA220) Clean tools with ***Thinners No 7*** **Do Not Thin**	24 Hours ~ 4 Days (10 °C) 12 Hours ~ 4 Days (15 ~ 23 °C)	150µ Minimum Thickness Typical Coverage: 5 M²/Lt
3. Priming **5 Coats**	***Gelshield 200*** Epoxy (YPA213/YPA214) The use of alternate colours is recommended. Do not use at temperatures below 5° C	10 Hours ~ 6 Months (5°C) 5 Hours ~ 6 Months (15°C) 3 Hours ~ 6 Months (23° C)	110µ Wet, 50µ Dry ***Per Coat*** Coverage: 8 m²/Lt
4. Antifouling Tie Coat	***Gelshield 200*** Epoxy (YPA213/YPA214) Do not use at temperatures below 5° C	10 ~ 24 Hours (5° C) 5 ~ 9 Hours (15° C) 3 ~ 7 Hours (23° C)	110µ Wet, 50µ Dry Coverage: 8 m²/Lt
5. Antifouling	Most manufacturers antifoulings can be applied satisfactorily; refer to manufacturer for further advice	Typically 12 Hours to 6 Months at 15° C	Antifoulings typically cover at 8 ~ 9 m²/Lt

Fig 27: International Gelshield Osmosis Prevention Scheme for Outdoor Use
Seek further advice from the manufacturer before proceeding

However, it must be stressed that the protection given by any coating scheme is very much dependent on an adequate thickness of paint being applied. The easiest way to check that paint is being applied at the correct thickness is to use a Wet Film Thickness gauge as shown in the diagram.

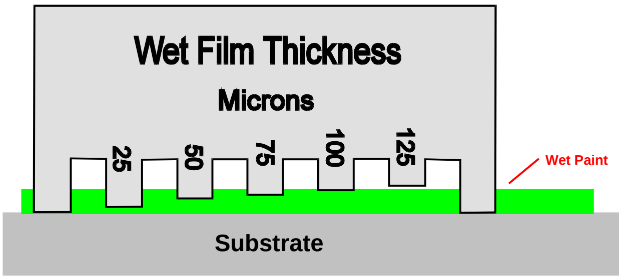

Fig 28. Using a Wet Film Thickness Gauge

To use a Wet Film Thickness Gauge, press it vertically into the wet paint as soon as it has been applied. On withdrawing the gauge, note the highest reading tooth with paint on it, and the next higher tooth that is not coated with paint. The true wet film thickness will lie between these two readings, although for accuracy this exercise should be repeated several times, and the readings averaged. To maintain accuracy, always clean the gauge with a cloth and suitable solvent between readings, and again after use.

Accurate measurements may be found difficult during application of the first coat owing to the absorbency of the laminate and it's irregular surface profile, although it is always worthwhile taking some measurements from smooth areas to make certain that an adequate thickness is being applied.

Paint and Coating Application Conditions:

All coatings must be applied in warm, dry conditions if they are to achieve optimum cure, and perform as intended.

Most yacht coatings are specifically formulated to be used in less than ideal conditions, but curing problems may still occur, resulting in reduced performance and failure of coating schemes.

High performance paint coatings cure for 24 hours a day, not just during working hours, therefore it is essential that good curing conditions are maintained during the entire application process.

If good curing conditions are not maintained, there are three likely results: **-**

1. **Undercure**
   It is not commonly known that the curing mechanism of epoxy coatings and fillers can fail if the curing temperature is allowed to fall below a critical minimum. This means that the material will ***never*** cure, even if temperatures are subsequently elevated. An epoxy affected in this way will usually have to be removed and then re-applied.

2. **Amine Sweating.**
   Low temperatures are also likely to result in amine sweating, where the epoxy curing agent migrates to the coating surface, forming a thin, sticky or greasy layer. This must be removed by fresh water washing before any further coatings are applied. If the amine sweat is not removed, any subsequent coatings will almost certainly detach, usually after a season or more afloat.

   Amine sweating is most likely to occur at temperatures below 10 ~ 12 ºC
   (14 ~ 15 ºC for solvent free coatings), and at relative humidities of 70% and above.

3. **Solvent Retention.**
   Low temperatures, high humidity and poor ventilation can all result in solvent retention, especially in combination with excessive film thicknesses.

   This is a particular problem when painting bilges, or inside tanks, as solvent vapour is heavier than air, and can not escape from these locations unless forced ventilation is provided. This also poses a risk to the applicator, as he or she will be working in a solvent laden atmosphere, which can pose both a health risk and a fire hazard.

   These problems do not arise when using solvent free coatings, which are widely specified for enclosed environments, although adequate ventilation must still be provided to remove irritating epoxy fumes from the working area**.**

Overcoating:

Correct over-coating intervals are especially important when using epoxy coatings.

Solvent free epoxies tend to have a surface like polished glass when fully cured, and therefore ***must*** be thoroughly sanded to ensure good mechanical adhesion if the specified over-coating period is exceeded. If this is not done, detachment will occur.

For best results, products such as International Gelshield should be overcoated after two or three hours, while they are slightly soft or ‘Tacky’, and before they have fully cured. This will maximise adhesion between coats, and greatly reduces the time needed to complete treatment.

Remember that products like Hempel’s Gelprotect SFE 200, International’s Gelshield and West Systems epoxy are solvent free**,** so there is absolutely no risk of solvent retention when using this technique. This method also significantly reduces the risk of amine sweating, as the uncured material is exposed to the atmosphere for a much shorter period. If there is any suspicion that amine sweating may have occurred, the coating must be allowed to cure, and then be washed with fresh water before proceeding with the coating scheme. It's always better to be safe than sorry!

On the other hand, solvent containing epoxies like *Gelshield 200* are much more flexible in respect of over-coating periods and curing conditions, and may be overcoated with similar coatings up to 6 months after application, or up to 24 hours later with antifouling (dependent on temperature). Some will also cure at temperatures down to around 5 °C, but don't forget that most epoxies are prone to amine sweating in cold or damp conditions, and all will perform far better if applied and cured in a warm and dry environment.

However, most of these coatings contain a large proportion of solvent, (***Gelshield*** 200, for instance, contains around 55%), and this must be allowed to evaporate completely before any further coats are applied. If solvent release is impaired by premature over-coating, or by poor ventilation, etc., the coating scheme is very likely to remain permanently soft owing to solvent retention, and will be easily damaged. More importantly, moisture permeability will also be increased, so the coating will not provide its intended level of protection for our yacht.

Coatings in this condition can be easily identified by their dull appearance and softness, and may well have a characteristic odour of solvent when they are removed or rubbed vigorously. In most cases, it will be necessary to remove the coatings involved, although it is sometimes possible to release the trapped solvent by heavily abrading the coating surface.

Coating Scheme Failures:

In this final section we shall look at some of the practical difficulties that can result in failure of the coating schemes used in osmosis treatments**;** we shall also take a closer look at some of the products themselves, and their characteristics. While some of these subjects may have been covered in previous sections, the importance of these items is such that they are well worth repeating: -

Amine Sweat:

Amine sweating is a common problem, which affects all types of epoxy paints, resins and fillers. The amine curing agents used in epoxies are *hygroscopic* (i.e. moisture absorbing), and they tend to migrate or "sweat" to the surface when applied or cured in cold and/or damp conditions.

Amine sweat will usually be apparent as a greasy or sticky film on the surface of the paint coating or filler. In some extreme cases, it can dull a glossy finish, and can cause brown or yellow staining.

If necessary, the presence of amine sweat can be positively verified by using a simple litmus test, in which a small area of the suspect surface is swabbed using a small piece of cotton wool (or a "Cotton Bud") wetted with distilled water. The dampened surface or the cotton bud can then be sampled with the litmus paper to detect any alkalinity.

If free amine is present, a positively alkaline reading will be given, (pH 9 or above) which indicates that the surface must be thoroughly washed with fresh water before any further coatings are applied. If not removed, amine sweating will result in poor intercoat adhesion, and will almost certainly cause failure of the scheme due to blistering and detachment. In extreme cases, removal of the affected material may be required to avoid failure in service.

Undercure:

Paint coatings cure for 24 hours a day, not just during working hours. While epoxy coatings may continue to cure slowly at temperatures down to 7 ~ 8 °C, if the temperature falls any lower, the curing mechanism will fail, and cannot be re-started. Some epoxies are more flexible in this respect, but the same principles still remain**: adequate temperature is vital!**

An under-cured coating will remain soft or "Cheesy" long after the specified drying time, and will probably not respond to heating; it is also likely to show symptoms of amine sweating as already discussed. Incorrect mixing ratio or inadequate stirring can also result in undercure, although in the latter case the symptoms tend to be more patchy and localised.

Whatever the cause of undercure, the only sure remedy is to remove the affected coatings; over-coating will not make the problem go away, and is almost certain to result in failure in service. Similarly, over-coating with a paint rich in curing agent, or with some other witches brew added to it is simply asking for disaster. Remember that epoxy curing agents are hygroscopic, and will cause blistering and detachment if used in excessive quantities.

Osmosis Treatment Failures:

We have looked briefly at failures due to the coating scheme, and will now consider failure owing to laminate defects which may not have been not rectified during the initial treatment. While these failures are rare, problems can, nevertheless occur, although the causes are usually very simple, and do not require extensive technical knowledge or complex instrumental analysis to identify.

Most failures appear as blistering or detachment problems, and will be caused either by a laminate problem, or by one of the causes already discussed. A simple litmus test of the blister fluid will quickly establish where the problem lies :-

Alkaline blister fluid indicates that free amine is present, and would suggest that either amine sweating had occurred and was not removed, or that a mixing error is responsible. Amines will typically give pH values 9 to 11 (i.e. mildly alkaline) when present in blister fluids.

A neutral or acidic blister fluid indicates that a laminate defect has probably caused the problem. Osmotic laminates usually give a mildly acidic indication (typically pH 6 ~ 3), however, if a neutral (pH 7) reading is obtained, check to see if the fluid feels sticky or greasy indicating that glycol is present. Glycol is nearly always detected in boats that have already been treated for osmosis, and would usually be associated with a hull that was difficult to dry.

However, boats which are suffering from osmosis for a second time usually have rather less acidic blister fluids than when first treated, although glycol will almost certainly be present in both.

Boats That Refuse to Dry:

If the preparation and washing procedures outlined here are followed, the majority of boats will dry satisfactorily, and will be ready for coating within four or five weeks of gelcoat removal, or even sooner.

Nevertheless, there will still be occasions when boats simply refuse to dry, or will only do so very slowly; which in both cases should warn us that applying a high performance epoxy coating scheme is likely to end in failure.

The most common reason for reluctant drying, (and indeed for failure of osmosis treatments generally), is that insufficient gelcoat and laminate was removed during the gelcoat peeling and slurry blasting stages; with the result that solutes are trapped within the hull, where they retain moisture.

But even those hulls that appear well prepared can hide unbound material beneath the surface. This is a particular problem where boats have been prepared by gelcoat peeling alone, as the planing tool is incapable of distinguishing between sound and unsound laminate, with the result that weak and unbound material can remain undetected.

To verify that this is the case, cut out an area of the prepared surface with a sharp wood chisel, so that the condition of the laminate can be properly established. If the underlying material is poorly bound, has a greasy feel, and/or has a vinegary odour, this indicates that further preparation and washing is required. (This examination should of course be carried out during initial preparation, to avoid the cost and inconvenience of additional preparation later on).

However, if the laminate is found to be sound, and has no noticeable odour when opened, then we need to look for other causes.

Look for the obvious first, such as water in bilges, and surface moisture. Also, remember that metal fittings, integral water tanks and chain lockers can give high moisture readings.

Many boats will also benefit from additional washing with fresh water, especially if washing was not carried out thoroughly the first time, or only with cold water.

However, there are a small number of boats which always give high moisture readings; either because of raw materials used in their lay-up, or because they are so badly consolidated that solutes have permeated right through the hull, and are therefore almost impossible to remove.

There are two possible remedies in this situation: The first is to prepare the hull using "best known practice" as detailed in this paper, and with the agreement of the owners, to apply the epoxy scheme knowing that moisture readings are unacceptably high, and that failure may occur.

Clearly this should be regarded very much as a last resort, and it must be emphasised that no insurance cover will be available for vessels treated in this way.

The alternative is to re-laminate the hull with two or three layers of epoxy/GRP before applying a standard osmosis treatment scheme. Experience has shown that this treatment is usually very reliable, although the cost of treatment is significantly increased, and again, no insurance cover is available.

Nevertheless, this option provides an excellent long-term solution for 'problem boats', and is an ideal treatment where significant thicknesses of poorly bound laminate need to be removed.

The **HotVac** System:

Throughout this paper I have emphasised the importance of removing hygroscopic solutes (and specifically glycols) before coating to avoid failure of the new treatment. I have also emphasised the difficulty of removing these materials from the laminate with currently available methods.

This is a subject which I have been writing about almost continually since 1987 in the yachting press and elsewhere, and has now been generally, (if somewhat reluctantly) accepted throughout the marine industry around the world.

Fig 29. The Terry Davey "HotVac" system in use on a large GRP patrol boat at Fox's of Ipswich.

This message has undoubtedly resulted in significant improvements to osmosis treatments over the past fifteen years or so. It also inspired east coast surveyor Terry Davey to invent and develop a new system called HotVac, which overcomes many of these practical difficulties by using a combination of heat and high vacuum; so that glycol and other breakdown products can be vaporised and removed at temperatures that are not harmful to the laminate.

I am frequently asked to comment on this system, so I will give my views now:

The HotVac system is comprised of a powerful vacuum pump, which is capable of creating a vacuum as low as 4 millibars absolute, and special silicone rubber blankets of approximately 0.75 M^2 each. These blankets are fitted with seals around their outside to retain vacuum, and can be heated to temperatures of 100 °C or more as required.

Being inherently flexible, the heated silicone blankets conform intimately to the shape of the yachts hull, and are simply applied after normal mechanical preparation as outlined in this paper. Specially shaped blankets and small blankets are available for confined spaces, bows and unusual hull configurations.

Each HotVac system can run up to four blankets at a time, and these are applied in sequence around the yachts underwater area until it is completely dried. Alternatively, the blankets can be applied to selected areas as required, or used for localised repairs.

The blankets are usually applied for periods of between four and eight hours at a time for complete drying, but can be used for longer periods on heavier lay-ups, or where drying is slow.

HotVac has proved very successful for drying ‘problem’ boats, and also provides some guarantee of turnaround times; which is especially important where working boats or charter yachts are being treated.

There has been some speculation as to whether the HotVac process can actually improve the state of cure of polyester resins, or whether it can improve consolidation.

Fig 30. The heated silicone rubber blankets conform well to irregular surfaces such as chines and spray rails.

Certainly, laminates which have been treated with the HotVac system tend to be measurably harder when tested with a Barcol Hardness tester, and those laminates which are laid up with clear resins also appear much more transparent after drying. I have also heard reports that racing yachts handle more responsively after the HotVac treatment.

Learned opinion is that polyester resins are unlikely to start curing again after a period of several years, as the reactive groups are not sufficiently mobile to cross link, even at elevated temperatures. Furthermore, it is likely that any residual styrene monomer (which is essential to the original cross linking reaction) will either have dispersed, or will have broken down into substances such as Benzaldehyde and ultimately Benzoic Acid (under the influence of water) by the time any osmosis treatment is carried out.

However, the observations of increased hardness, rigidity and clarity in polyester resins can easily be explained, as water acts as a ‘plasticizer’ when absorbed into these resin systems, significantly reducing the T_g (or Glass Transition Temperature). This will have the effect of noticeably softening the resin and the laminate mass as a whole, so any means of removing excess moisture must be beneficial.

Furthermore, water has a different refractive index to polyester resin, so the removal of moisture (and other unwanted substances) would be expected to improve the transparency of clear resins.

Does Hot-Vac work on every GRP boat?

The HotVac system has been proven to work well on the vast majority of boats, including those which had been found impossible to dry with other methods. But inevitably, there are a small number of vessels which fail to respond to this treatment.

However, even where the HotVac treatment does not work as expected, the negative results are usually known within twenty four hours, whereas other drying methods often need to be continued for weeks or even months before we can be sure whether they are successful or not. Furthermore, the HotVac system is significantly more energy efficient than the typical infra-red heater and dehumidifier combinations used in boatyards, so overall treatment costs should be much lower as a result.

The HotVac system should not, in my view, be used as an alternative to thorough mechanical preparation and repeated hot water washing (as outlined in this paper), but it can be used as an extremely useful adjunct; both to improve the quality and consistency of treatments where boats appear to ‘dry’ normally, and as a practical solution where boats simply won’t dry by any other means.

Visit HotVac at www.HotVac.com or phone on +44 (0)1656 773408 for further information.

Summary:

Having read through this introduction to osmosis and the use of moisture meters, it may be useful to remind ourselves of some of the more important points discussed:

- Osmosis in GRP is best defined as *'the migration of hygroscopic solutes within a laminate owing to moisture ingress, which ultimately results in blistering of the protective gelcoat layer'*.
- There are three distinct stages in the osmotic process. Blistering is the final stage, and may take many years to develop.
- While osmotic breakdown is caused by moisture ingress, simply removing the moisture will ***not*** reverse the situation. **Osmosis in GRP is not a reversible process.**
  - Application of an osmosis prevention scheme will not stop osmosis once it has started.

    (Please note that ***all*** organic coatings (including epoxies) are slightly permeable to moisture, and will therefore allow some moisture to permeate into the laminate. As the resultant solutions cannot escape, and they will ultimately cause blistering of the protective coating scheme).
- Diagnosis of laminate condition must be based on a thorough inspection and evaluation of **all** symptoms, and not on moisture meter readings alone.
- When a yacht is to be treated for osmosis, it is essential that all hygroscopic solutes and other soluble materials are removed from the laminate before any epoxy coatings are applied.
  - Removal of solutes is best accomplished by repeatedly washing the prepared laminate with fresh water (preferably hot) to remove glycol and acidic breakdown products.
  - No amount of heat or dehumidification will remove solutes. It is impossible to 'dry' a laminate satisfactorily while propylene glycol is still present.
  - Preparation methods are also important: Gelcoat peeling alone does not usually provide an adequate standard of preparation. Grit or slurry significantly improves the treatment process.
  - Grit or slurry blasting methods may be used in isolation, or following gelcoat peeling. This increases surface area and helps encourage the removal of glycols. Adhesion of epoxy coatings is also improved.
  - However, new systems such as the HotVac treatment can effectively remove propylene glycol and other breakdown products even where conventionally accepted treatments fail.
- A moisture meter is rather like a Barometer**:** if possible, look for changes in readings over time rather than absolute figures on a single day.
- Yachts laid up with orthophthalic resins (before about 1990) may need several days on hard standing before moisture readings are taken. Measurements taken too quickly after lifting will invariably be high, and may prompt an incorrect diagnosis. Boats built with Isophthalic gelcoats and lay-up resins will often show low readings within an hour or two, but this cannot be guaranteed.
- Epoxy coatings such as International Gelshield, West and SP will retain moisture for some time after lifting. Measurement with a moisture meter may give misleading readings, even though the underlying laminate is sound.
- Bilge water, condensation and metal fittings will result in misleading moisture meter readings. Boats must be dry inside and well ventilated before moisture readings are taken.
- If moisture meter readings are unexpectedly high, fresh moisture readings should be taken in dry conditions after two or three weeks on hard standing, and the diagnosis reconsidered.

To bring this guide to a conclusion we have seen that effective osmosis treatment is perhaps not as difficult as is sometimes thought, and it is certainly not the ‘Black Art’ that many people seem to believe.

While some of the chemical processes involved in osmotic laminates are undoubtedly complex, the principles of effective treatment are very simple, and are really no more mysterious than washing salty oilskins with fresh water to get them dry!

But perhaps the most important lesson is that machines such as dehumidifiers and infra-red heaters, and specialist tools such as moisture meters do not always provide the answers and solutions that we need; indeed, their ill-informed use can often lead us in entirely the wrong direction.

However, with a logical approach, the causes of osmosis can easily be understood, and effective treatment can be completed in a much shorter timescale than is currently accepted. Furthermore, new treatments such as the HotVac process should significantly improve the consistency, reliability and speed of osmosis treatments, so that even elderly boats can be treated quickly and efficiently.

Nigel J. Clegg

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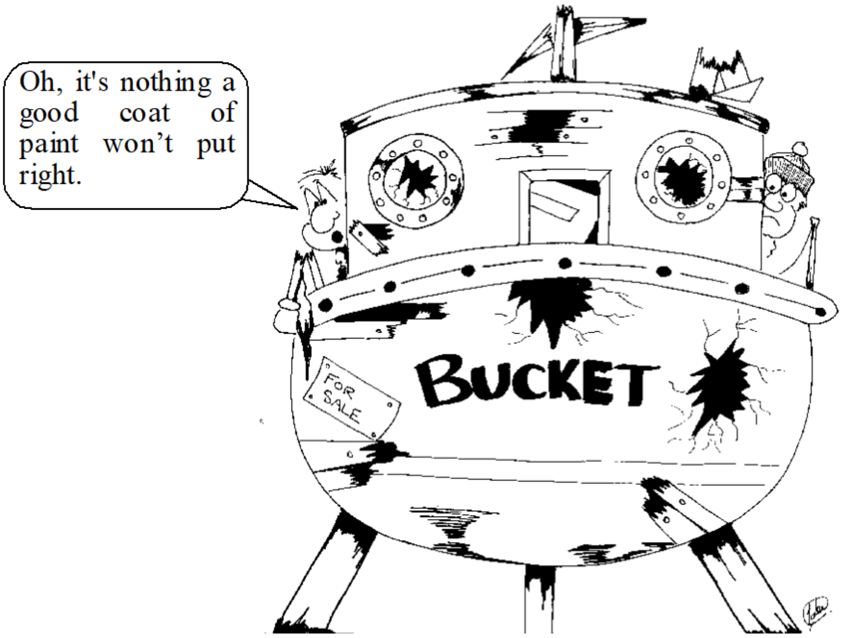
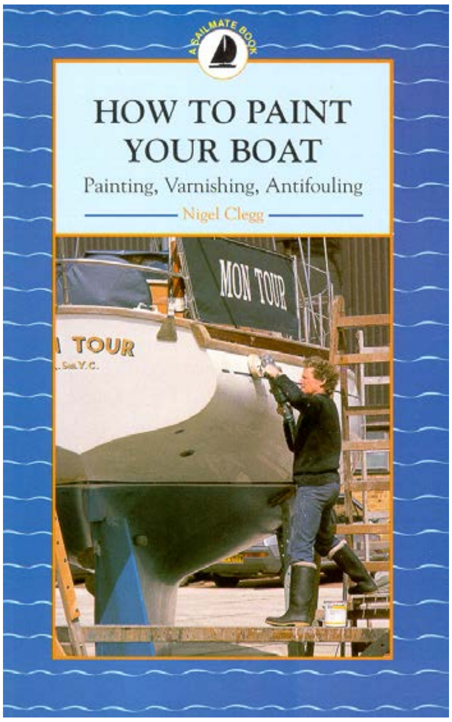


Important Notice: Please note that whilst every effort has been taken to ensure the accuracy of information contained in this booklet, no responsibility can be accepted for any errors or omissions that it may contain. Please also note that the coating schemes are included only for the convenience of the reader, and are in no way binding. Readers are therefore urged to seek advice from the manufacturer(s) concerned before proceeding with any treatment. The prices shown in this document are valid as of 16 March 2023. E&OE.

About Nigel Clegg Associates

I left the International Paint Company rather unexpectedly in April 1993, having spent a total of sixteen years working in that company's aviation, industrial, marine and yacht coatings divisions. Whilst working for International Paint (now Akzo Nobel) I was closely involved in the development and testing of many of the companies yacht coatings systems including the *Gelshield* system (launched in 1986), and the various cosmetic finishing schemes such as *Perfection 709* and *Interspray 800* finishes and their associated base coats.

My last five years with the company were spent as European Technical Manager (Yacht Coatings division), which involved the detailed investigation of a wide range of coatings failures and defects on vessels from GRP dinghies to aluminium super-yachts, and steel narrow boats to wooden fishing vessels.



With the benefit of this experience, I set up the business to provide a Europe-wide independent yacht coatings and osmosis consultancy to support boatyards, yacht surveyors, insurance companies and private owners, as well as the paint manufacturers themselves.

My services include detailed investigation of yacht coatings faults and failures, application issues, coatings specifications, supervision and inspection, as well as providing recommendations for remedial work where required. Where required, these services extend to negotiation, arbitration, and Expert Witness duties at Court; although I firmly hold the view that litigation should only be used where all other options have been exhausted.

The investigation of osmosis treatment failures has become a particular speciality, with much of my time being spent examining yachts on behalf of various coatings insurance companies.

However, modern paint coating systems are becoming increasingly demanding in use, therefore it is essential that end users fully understand the technical requirements of the materials they're using.

To this end, I have written a book called simply *How to Paint Your Boat* which encompasses the entire subject of boat painting and varnishing, and includes a definitive guide to the many different types of coatings now available. I also write extensively for the yachting press, as well as writing and producing technical literature for major paint manufacturers including Hempel's Paints, Camrex Chugoku, Jotun, and Indestructible Paint.

To help service the yachting industry, we stock a wide range of test equipment and literature, including leading moisture meters, Barcol hardness testers, Ultrasound Testers, pH (Litmus) indicators, hygrometers, sample bottles, vials, and many other useful items. All of these products are supplied at competitive prices, and come with first class technical support before and after purchase.

Our most popular items are shown opposite, but please do not hesitate to call if you need further information or impartial advice.

Our web site has also undergone a major refit and provides a wealth of useful information on a variety of topics relating to boats, osmosis and painting and allows secure online ordering of our most popular products. Please visit **https://www.passionforpaint.co.uk** to see what we do.

Passionforpaint.co.uk

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† All items above include batteries and first-class postage within the UK only except where indicated †

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Please note that our eBay prices are always higher owing to eBay's substantial charges!

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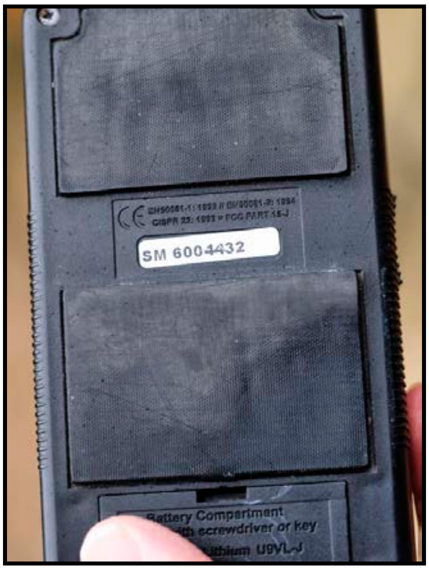
Moisture Meter Repair and Calibration

Whether you use your instruments to earn a living, or to care for your own pride and joy, you’ll want to keep them in full working order and properly calibrated.

Modern instruments like the Tramex Skipper *Plus* are extremely reliable in service, and should require little maintenance beyond occasional battery replacement. Careful circuit design with the use of CMOS technology, stabilised voltage rails and crystal-controlled oscillators means that re-calibration is rarely, if ever required. Nevertheless, we recommend that instruments be returned periodically for a calibration check. It’s also a good idea to check your meter occasionally against a hardwood or GRP reference sample kept in a dry place.

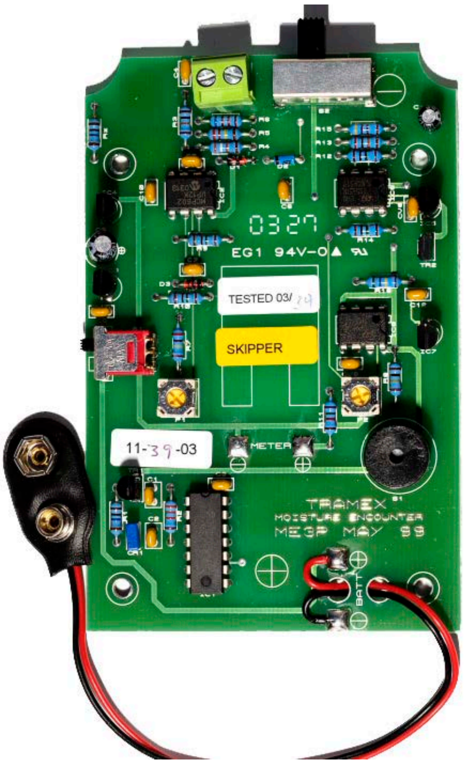
However, with constant use, the soft rubber electrodes on Tramex meters eventually lose their fine surface pattern, becoming worn and shiny like those in the picture below. This will noticeably reduce the instruments sensitivity to moisture. And of course meters can easily be damaged whilst in use, or even dropped into the water!



Worn electrodes like these will reduce sensitivity.

Thankfully, the majority of components can be quickly and economically replaced, restoring your meter to full working order – even if it is ten years old or more! And if you’re pushed for time, we can even provide a ‘Courtesy Meter’ for a small charge whilst yours is being fixed.

Whilst there are no formal ‘Standards’ as such for moisture meter calibration, we can undertake periodic re-calibration checks of Tramex meters your behalf, and will issue a manufacturers' calibration certificate, valid for one year. We also stock replacement parts for Barcol Impressers, and can repair and re-calibrate these to original specification. Most other instruments can be returned to their respective manufacturers for more specialist attention.



Selected prices are provided below, but please do not hesitate to call for more specific information, or advice on repair or calibration.

Skipper V Calibration Check Box. **£60.00 if ordered with a Skipper V Meter**.	£75.00 †
Skipper Plus Calibration Check Box. **£65.00 if ordered with a Skipper Meter**.	£98.00 †
Skipper/Skipper *Plus*/ Skipper V Calibration Check with Calibration Certificate	£55.00 †
Replace Electrodes and Check Calibration.	£POA †
Replace Moving Coil Meter (Skipper & Skipper +).	£POA †
Replace Complete Circuit Board	POA †
GYZJ-6-5 Indenter Point for 934/935 Barcol Impresser	£98.50 †
Standard calibration disks for Barcol Impressers	£14.96

† *Prices above include VAT but exclude postage* † **EOA**

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From dinghies to superyachts, we offer a comprehensive technical consultancy service to Boatyards, Shipyards, Surveyors, Owners and Insurers. From the smallest painting defect to osmosis treatment failures or major filling and fairing works, we can provide an objective assessment of paint condition, together with a detailed report and professional photography. Dispute resolution and Expert Witness work also undertaken.

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We stock an extensive array of test and surveying equipment including the full range of Tramex and Sovereign marine moisture meters, Cygnus & Tritex ultrasound metal thickness gauges, Barcol Hardness Testers, etc. and can provide expert advie on how to use them. We also stock ultrasound couplants, pH Indictors, thermo-hygrometers, sample vials, books and many other useful items.

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Technical Training

Nigel Clegg lectures regularly at the University of Plymouth's Small Craft Surveying courses, and at many other venues. With the benefit of this experience, specialist training can be provided on many subjects involving marine paint coatings, osmosis, and related disciplines. This service also extends to authoring of high quality technical manuals and short print runs. Please call for more information.

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