# PART IV

## MANUFACTURING DEFECTS AND REPAIRS

# 11 - MANUFACTURING DEFECTS

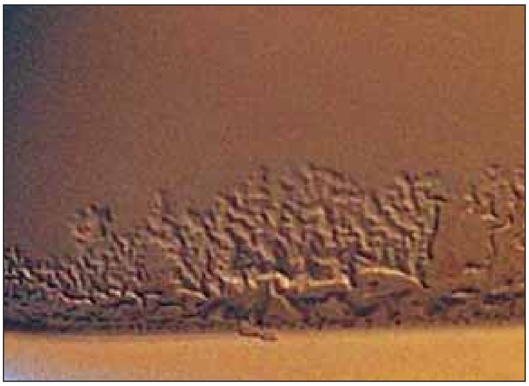


**Figure 133**

Wrinkling or "alligatoring" is a gelcoat fault caused by:

- insufficient catalyst in gelcoat.
- gelcoat too thin.
- backup layer applied too soon.

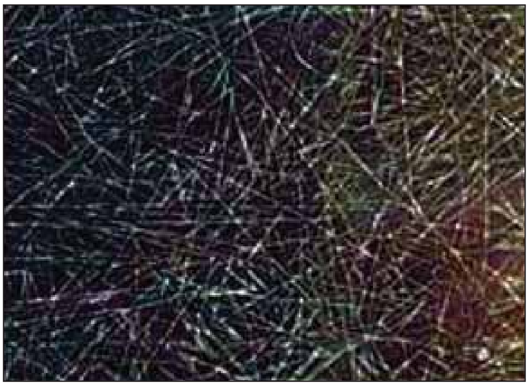


**Figure 134**

Fibre pattern is a result of:

- gelcoat too thin.
- high exotherm because of bulk curing.

**Figure 135**

Star crazing is caused by:

- gelcoat too thick.
- reverse impact.
- crack pattern transferred from mould.

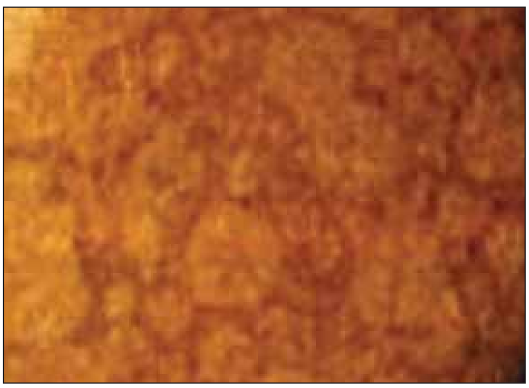


**Figure 136**

Blisters are caused by:

- moisture contamination.
- rapid cure of gelcoat.

# 12 - REPAIRS

Damages to the hull depend on the type of accident or the severity of conditions. They may be minor hairline fractures of the gelcoat, severe grazes caused by abrasion or scratches by a sharp object or through-hull puncture resulting from impact fracture.

## 12.1 HAIRLINE FRACTURE AND GRAZES

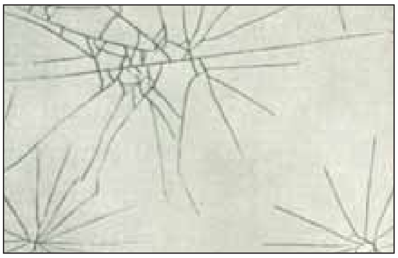


**Figure 137**

Hairline fracture and grazes.

**Figure 138**

Severe grazing caused by scratching.

Enlarge the hairline fracture into a definite V-shaped groove, using the corner of a chisel or a file. The groove must be deep enough to penetrate the gelcoat completely and expose the main laminate below.

Prepare and activate a small quantity of resin. A filled resin is best for this type of repair. Failing this, a general-purpose resin can have filler powder added. Work this into the groove, using a broad knife, until it is slightly proud of the external surface. Leave the repair to cure completely.

After the repair has cured, fair in the surface with grade 320 wet-and-dry abrasive, used wet on a rubber block. Rub lightly in one direction only to prevent the area surrounding the repair from becoming depressed. If the rubbing down is too vigorous, the original gelcoat surrounding the repair may be depressed or even removed, exposing the reinforced laminate underneath the gelcoat.

## 12.2 PUNCTURES

Punctures may or may not be accessible from both sides. Different methods are needed for each case. Note that the scarf should be at least 1:20.

**Figure 139**

Damage accessible from both sides

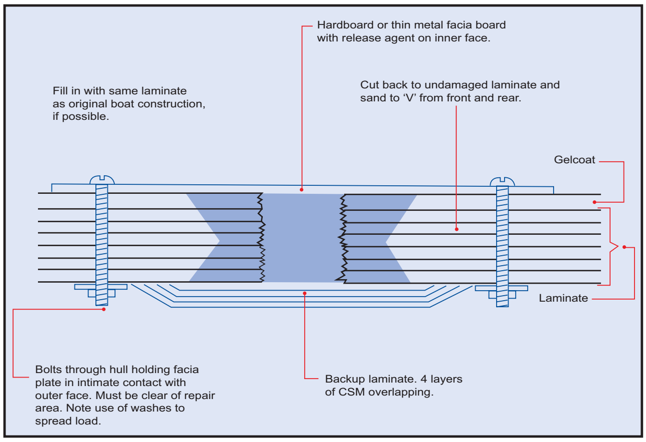
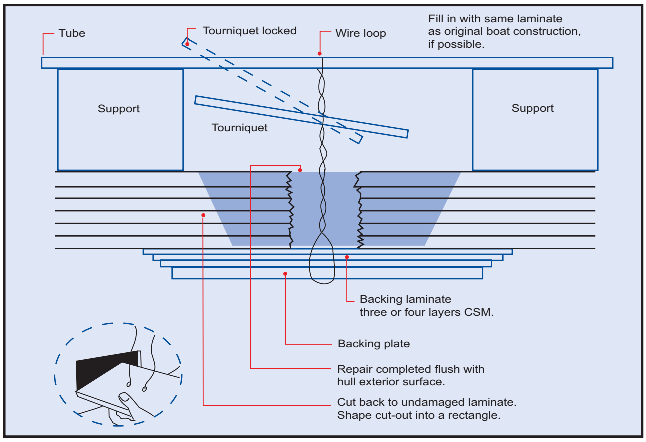



**Figure 140**

Repairing a puncture with only outside access



The following section explains the common types of damages found in beach boats and details the various steps in a proper repair procedure.

### 12.3 TYPICAL DAMAGES TO BEACH LANDING CRAFT

For everyday use, FRP generally does not need much maintenance, although this does not mean that a boat will last forever. Wear and tear and the absorption of water affect the lifespan of an FRP boat. The challenge is to determine whether what can be observed on the surface is merely cosmetic or constitutes more serious structural damage.

Remember the following important points:

1. A good secondary bond is essential.
2. The area of the repair should be made slightly stronger than what it was originally.
3. Access to both sides is often needed, so you must not hesitate to tell the customer that you need to cut a new hatch in the deck to repair the hull.

When a boat is left constantly in water, the water is absorbed by the polyester laminate. Gelcoat or topcoat does not stop water absorption. This absorption is not visible, but the laminate can absorb 1.5 to 2 percent water and become less stiff. After a certain number of years (5 to 15), the laminate may also react chemically with the water to produce hydrolysation, which is comparable to rust in steel. The speed and extent of hydrolysation depend, on the combination of water conditions, temperature, use of the boat and how good the quality control was when the boat was built.

**Figure 141**

In this figure, old laminate showing typical results of hydrolysation can be seen. The polyester becomes depolymerized and is washed out of the laminate.

The results are visible as dark spots on the surface and white pockets deeper in the laminate.

If the gelcoat is intact, osmosis blisters might occur.

Old laminate is weaker and less stiff than new laminate, even if damage is not visible.

Water absorption will be slowed and the working life of the boat improved if the hull laminate below the waterline is treated with several layers of epoxy barrier coat when the boat is new. Anti-fouling material applied to the hull to reduce marine growth improves fuel economy, but has no effect on water absorption.

**Figure 142**

Many boats have laminates that are just too thin.

On this boat, the laminate was 4 mm but the layers separated easily because of the excessive use of pigment and too much polyester with respect to glass.

The boat would have survived had the gunwale been made tougher.

The polyester to fibreglass volume percentage should be approximately 67 percent polyester to 33 percent fibreglass.

The coaming had layers of putty in between the laminate layers.

**The fibres do all the work.**

**Figure 143**

In addition to the iron posts working their way out, the area where the posts are connected to the hull is in itself a "stress riser" and many boats have failures here.

It might be easy to think that the boat breaks at this point because of the pull in the steel bars, but the truth is that it breaks because the rest of the boat is soft and this is a stiff and weak point.

**Figure 144**

Since the structure of the boat is somewhat "soft", the bending of the laminate will concentrate in "hard spots" where cracks and delaminations will develop.

All corners should be well rounded and areas with stress risers should have additional layers of FRP to absorb and distribute the stress and strain.

**Figure 145**

At the bottom of the boat, there are wear-and-tear failures caused by abrasion, as well as cracks and delaminations resulting from thin laminates and local stress risers, such as the leeboard holes and poor detailing in internal structural supports.

Additional strips of prefabricated FRP laminates could be glued on for additional stiffness and abrasion resistance.

In order to enable readers to understand the importance of dealing with a crack in an FRP laminate and not underestimate the strain and stress of a loaded area, the following sections address basic structural repairs. The figures in the following section show that a small crack can have major consequences and proper repair work takes a long time.

**No shortcuts should be taken if a repair is meant to last!**

## 12.4 PRACTICAL GUIDELINES FOR STRUCTURAL FRP REPAIRS

In general, repairing FRP boats is easier than repairing boats built of other materials. However, proper preparation of the site, a dry working environment and the correct air temperature are critical.

**Figure 146**

This figure shows a typical fatigue fracture inside the transom on a boat powered by an outboard engine.

In this case, an attempt has been made to repair the crack, but putty and gelcoat cannot mend structural damage.

Ideally, a boat should be repaired indoors to protect the work from rain and sun, and to ensure a stable temperature. If working indoors is not possible, a tent should be erected over the boat. All hardware and equipment that prevent access to the damaged area must be removed. A dust mask and eye and ear protection should be worn before any grinding starts. The grinding dust should be extracted at source. A commercial dust extractor or vacuum attached to the grinder can be used..

**Figure 147**

Prior to grinding, all surface contamination such as oil and silicone should be washed off and removed with an appropriate solvent. For grinding, 40-grit sandpaper is a good choice.

In the example shown here, grinding has uncovered deep delaminations. To ensure a lasting repair, the full extent of the delaminated fibreglass must first be removed, no matter how far or deep it extends

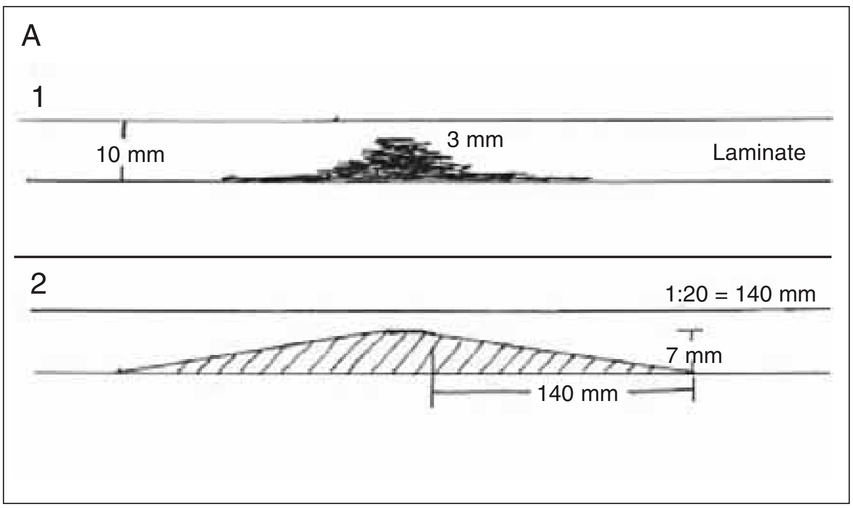
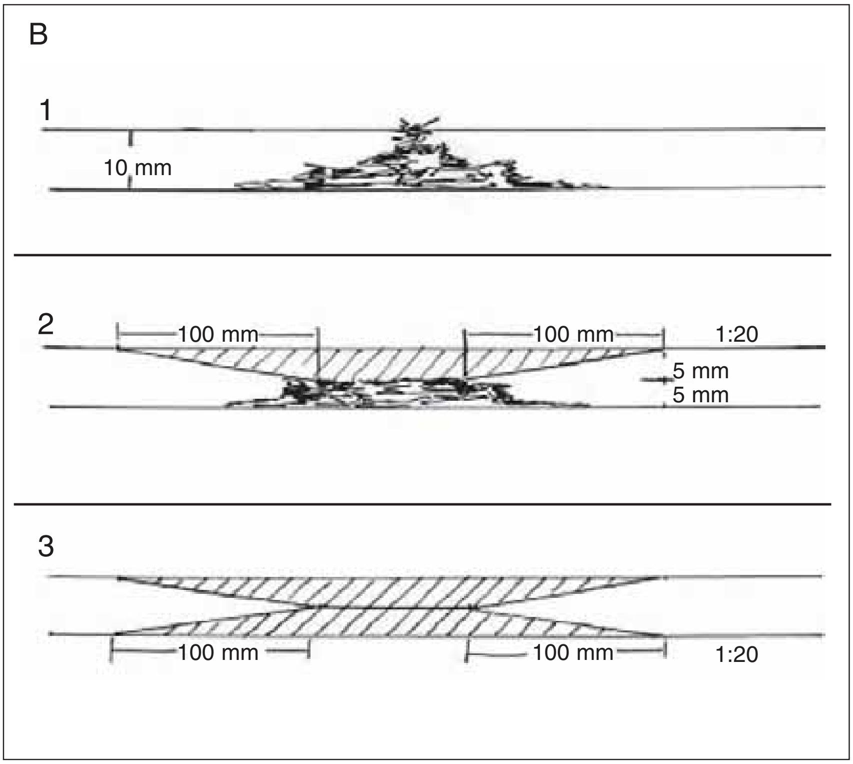



**Figure 148**

These schematic drawings illustrate the principle of laminate repair.

The first two images [A1 and 2] show damage that has not penetrated the whole laminate. The next three show a two-sided repair [B1-3].




Many manuals state that a scarf of 1:12 is sufficient for fibreglass repairs. This may be true for unloaded areas with thick laminates; however, for thinner laminates and loaded areas, the scarf should be at least 1:20.

In many cases, a scarf of 1:40 or more must be used to ensure adequate adhesion and absorption of stresses in loaded areas.

**Figure 149**

When grinding has been completed, the area to be laminated will probably be much larger than suggested by the initial visual inspection.

For example, in this boat, tiny cracks in the gelcoat were visible on only one side of the engine well, but grinding revealed that the delamination was just as deep on both sides.

A decision must be taken on what kind of materials to use for laminating once the repair area has been identified and prepared. The following text is a guide to making this choice.

### 12.5 PRIMARY BONDING

Primary bonding occurs when two surfaces are connected directly to each other, forming a chemically homogenous laminate containing no weak bond line.

A fresh or “green” polyester laminate has active molecules on the surface that will bind chemically to a new laminate. Laminating on to a green laminate gives a primary bond.

Except for sanding off bumps and fibres that could cause defects and air pockets in the laminate, a fresh green polyester laminate requires no other preparation before adding another layer.

How long the laminate surface remains active depends on a combination of the technical properties of the resin and the temperature during curing. Generally, the open time for polyester resin is 24-48 hours.

When building a medium-sized boat, primary bonding can usually be achieved. When building larger FRP boats, more time is needed to complete a layer of laminate, which makes operating within open time windows more difficult. Even so, achieving primary bonding between laminates in the main hull is crucial. In most cases, only secondary bonding will be achieved when laminating frames, stringers and bulkheads into larger boats.

An older polyester laminate is rarely completely cured. It will still have some reactive molecules that might, if properly sanded first, bond with the repair laminate. Wiping a sanded laminate lightly with styrene, immediately before applying a fresh polyester laminate, may also improve the bonding properties.

### 12.6 SECONDARY BONDING

All repair work relies on secondary bonding. Consequently, stronger or additional replacement material will be needed to bring the damaged area back to its original strength.

When laminating over a cured laminate, the cross-linking reaction does not occur to a significant degree across the bond line. Since the polymer networks are discontinuous, the bond relies mainly on the adhesive strength of resin.

### 12.7 CHOOSING A RESIN FOR STRUCTURAL REPAIRS

In general, iso-polyester, vinylester or epoxy resins are preferable to general-purpose polyester resins for FRP repairs and alterations. After considering strength, cost and ease of processing for each, iso-polyester and vinylester resins are usually recommended for most repair work.

For more critical structural repairs, laminates made with epoxy resin are generally stronger (but not stiffer). Epoxy resins are highly adhesive and have a longer shelf-life than polyester and vinylesters. These characteristics make epoxy ideal for emergency repair kits. As it requires no solvents, epoxy resin does not contaminate the surface of the original laminate and shows no shrinkage when curing (less tension).

Epoxy resins do not hydrolyse and this, together with good adhesion, low shrinkage and high ratio of elongation to break, make them more liable to perform well as a primary bonded laminate. However, they are intolerant of bad mix ratios and the setting time cannot be shortened or lengthened by altering the amount of hardener. In addition, an epoxy surface is definitely not active with styrene; therefore, any further work on an epoxy boat or an epoxy repair will have to be done with epoxy. Avoid using 5 minute or very fast epoxy for structural repairs.

A thorough cleaning and preparation of the bonding surface is very important to achieve good epoxy adhesion.

### 12.8 CHOOSING REINFORCEMENT FOR STRUCTURAL REPAIRS

If practical, the same reinforcement used when building the original boat should be used in the repair, especially if the part being repaired is heavily loaded and operating near its design limits. Use of lighter weight reinforcement will allow for better contact with the surface, but the importance of this feature should be weighed against the importance of using the original reinforcement for maximum support.

Meanwhile, it should be remembered that there will be no continuous fibres attaching the old to the new laminate, and the strength of the join will depend solely on adhesion of the new laminate to the old. Almost 100 percent of stiffness can be recovered if the laminate is built up to its original thickness; however, the strength and fatigue properties of the repaired laminate will be weaker than the original. The dimension of the fibre bundles is critical for the repair to perform well, because large bundles and heavy mats/fabrics obscure air and resin-rich pockets that are more likely to form at the borderline between the old and new laminates.

It is important to take all these matters into consideration when designing the repair laminate (see Figure 150). If additional reinforcement is required to maintain the boat's overall strength, care should be taken to avoid excessive laminate buildup, since this can increase the risk of developing stress concentrations.

**Figure 150**

In this example, the resin chosen for use was epoxy, but vinylester might also have performed well.

It should be borne in mind that this was a single-sided repair and the original polyester laminate was already showing weakness from fatigue.

The reinforcement was a mix of 290-g woven twill and 450-g double-bias fibreglass, chosen because of drape ability and good performance with epoxy.

## 12.9 SURFACE PREPARATION

It is important not to clean a freshly sanded, porous, fibre laminate with acetone or solvent prior to lamination, unless it has been contaminated with oil or grease. If cleaning is necessary, a light grinding with clean sandpaper after washing is required, followed by sufficient time for the solvent to "air out" (evaporate). When the solvent is absorbed by the porous surface, it "contaminates" the surface laminate and can dilute the new resin, preventing optimum adhesion.

When using polyester, a light styrene wipe prior to laminating is the only acceptable procedure. A small amount of styrene will activate the surface slightly and improve adhesion. Too much styrene will weaken the bond line.

For repairs under the waterline, fresh styrene in the new polyester laminate is also liable to trigger hydrolysis (absorption of water) at an earlier stage than in the original laminate and cause premature failure in the borderline area between the old and the new laminate.

An important issue when making repairs is to check the water content of the laminate with a moisture meter. If the laminate contains too much water, the bonding will fail sooner than it should and the new laminate will separate from the old one prematurely.

When it comes to the actual laminating, the same procedures as for making a new boat should be followed, including the maintenance of high quality control standards.

**Figure 151**

At this stage, the laminate buildup has been completed and the surface has been ground flat to a nice "finish". Use of any form of putty on structural repairs is to be carefully avoided.

Putty has a low ratio of elongation to break, and will break up and crack much more quickly than a laminate.

**Figure 152**

This figure shows the finished product. Gelcoat has been applied, water-sanded, buffed and polished to a decent gloss.

Polyester gelcoat can be used on top of epoxy as long as the epoxy is cured properly and the epoxy surface has been fully sanded before the gelcoat is applied.

In this case, a 5-mm aluminium plate has also been attached to distribute pressure from the bolts over a larger area.

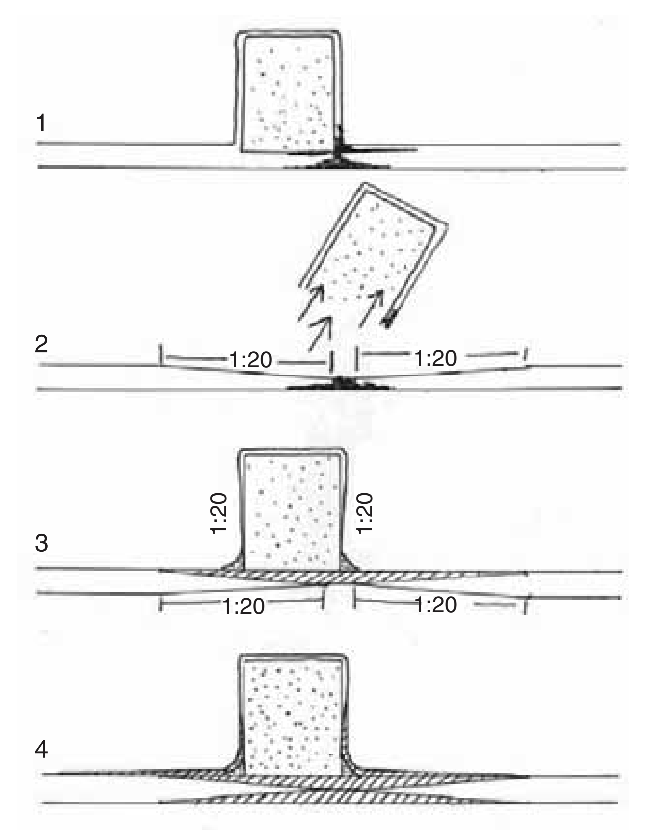



**Figure 153**

Cross-section showing structural damage to the frame of an FRP boat and the proper method of repair.

1. A fracture in the outer skin has penetrated the whole laminate and caused delamination in the framework.

2. For the repair to be effective, the wooden frame must be cut and removed. Next, the hull laminate must be repaired as described earlier.

3. The frame has to be ground to a scarf wherever it will be joined with other laminates and then bonded down with putty/glue and finished with a radius fillet.

4. All lamination work on the frame is best done with easily drapable fabrics or 450 g/m² and lighter CSM.

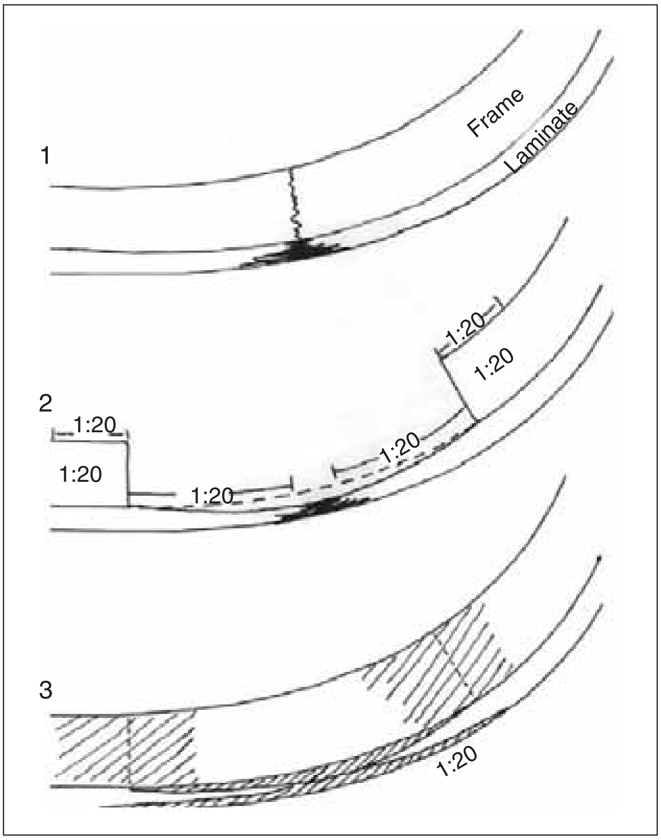



**Figure 154**

**Side view**

1. This represents almost the same structural damage as shown in the previous figure, but viewed from the side.

2. The frame is shown cut and taken away, making the damaged laminate accessible. In this case, no scarf in the core of the frame is required as it would be on a wooden boat, because this frame is filled with foam or air, which is not a structural member.

3. The place to cut and how to cut the frame will vary depending on the damage and will have to be estimated carefully in each case. Sometimes, when structural foam is involved, it is necessary to make a scarf in the same way as with a wooden frame. In some cases, "stepping" the scarf may also be an alternative. Using additional extra length reinforcement, such as unidirectional fibres along the top of the frame, must also sometimes be considered to add strength to the repair.