Repair of Composite Boat Damage

One of the reasons people choose fiberglass boats overwhelmingly over other types of construction is the ease that damage can be repaired. Indeed, the proliferation of "do-it-yourself" repair books supports this assertion. Amateurs find that damaged fiberglass can be structurally repaired with relative ease but the restoration of that new gel coat finish achieved with polished female molds often proves to be more problematic. If we better understand how owners and boatyards are repairing their boats, perhaps we can produce a product with lower total ownership costs. We'll focus this article on E-glass laminates (FRP), as carbon and other high-tech laminates are less pervasive and require special attention to recover their original strength.

As noted in part one of this series, Damage Assessment, most failures in FRP constructed vessels fall into one of two categories. First, the failure can be the result of a collision or other extreme force. Secondly, the failure may have occurred because of design inadequacies. In the case of the latter, the repair should go beyond restoring the damaged area back to its original strength. The loads and stress distributions should be reexamined to determine proper design alterations. When the failure is caused by an unusual event, it should be kept in mind that all repair work relies on secondary bonding, which means that stronger or additional replacement material may be needed to achieve the original strength. In general, repair to FRP vessels can be easier than other materials. However, proper preparation and working environment are critical. The third type of damage noted in part one involves manufacturing defects, which we hope are only isolated to single cases.

Single-Skin Construction

This overview is applicable for repairs ranging from temporary field repairs to permanent structural repairs performed in a boatyard. General guidance related to material selection, repair techniques, quality control, and procedures is provided. The repair methods are based on well established procedures commonly used in commercial FRP boat fabrication and repair. The guidance and procedures set forth here provides the necessary basic information required to understand FRP boat repairs. Since the level of complexity of each repair situation is different, careful planning and tailoring of these procedures is expected.

<u>Selection of Materials</u>

An instinctual response to FRP repair is to use the same materials that the original laminate was built with. This is usually a safe option but often what was originally used is unknown or unavailable. Additionally, some materials are better suited for initial construction than repair.

Resin

The integrity of the repair will depend on the secondary bond strength of the resin to the existing laminate. When a laminate cures, the resin molecules crosslink to form strong, three-dimensional polymer networks. When laminating over a cured laminate, the crosslinking reaction does not occur to a significant degree across the bondline, so the polymer networks are discontinuous and the bond relies on the adhesive (mechanical) strength of the resin. In general, isophthalic polyester, vinyl ester, or epoxy resins are preferred for FRP repairs and alterations. General purpose (GP) resins are less desirable. When considering strength, cost and ease of processing, isophthalic polyester and vinyl ester resins are recommended, although epoxy laminates are generally stronger. Epoxy resins are highly adhesive and have longer shelf lives than polyesters and vinyl esters, which makes them ideal for emergency repair kits. However, they are intolerant of bad mix ratios and polyesters and vinyl esters do not bond well to epoxies. Therefore, any further rework to an epoxy repair will have to be made with epoxy.

Reinforcements
If practicable, the original primary glass reinforcement should be used in the repair, especially if the part is heavily loaded and operating near its design limits. If an alternative reinforcement is selected, it should be similar in type to that being repaired. Lighter weight reinforcements can be used in shallow repairs where it is desirable to have multiple layers of thinner reinforcement instead of one or two thick layers.

General Repair Procedures

Every fiberglass repair job is unique to some extent. Three key elements are paramount to achieving satisfactory repairs. First, the extent of the damage must be established, as outlined in Part One of this article. Second, a plan specific to the job at hand should be developed. Third, the repair itself must be completed by trained personnel (or a dedicated do-it-yourselfer) with care and diligence. To illustrate the versatility of fiberglass as a boat building material, specific repair procedures are presented herein.

Water Contaminated Laminates
If the contamination is from salt water, thoroughly rinse the area with fresh water. Let the area dry for a minimum of 48 hours. Heat lamps, hair dryers, hot air guns and industrial hot air blowers can be used to speed up the drying process. Use fans to circulate the air in confined or enclosed areas. Some repair yards have had success using a vacuum bag arrangement to extract water from wet laminates, especially with cored construction that have holes drilled in the skins. The laminate can be monitored with a moisture meter or better yet, samples can be drilled. The moisture content of a saturated composite laminate can reach 3% by weight. Repair work should not begin until the moisture content is 0.5% by weight or less.

Damaged laminate should be replaced to the extent determined by damage assessment methods. Wiping the surface with acetone will enhance the ability of the styrene in the laminating resin to penetrate the air-inhibited surface of the cured laminate. The acetone will produce a tacky surface on the existing laminate; however, it is recommended not to laminate on this surface. As long as the surface is tacky, acetone is still present. The acetone must be allowed to evaporate prior to lamination (at least 1 to 3 minutes). The tack is lost as the acetone evaporates.

If water contamination in a cored laminate is not extensive, it may be advantageous to retain the skin laminate and infuse resin into the dried out void space. This requires an injection hole and another hole where a vacuum can be pulled to ensure complete wet-out.

Removal of Damage

All repair jobs require some degree of surface preparation, including the removal of damaged laminate. When grinding away bad laminate, precautions should be taken to minimize the dispersion of fiberglass dust. Vacuum shrouded tools should be employed, and if necessary, the work site enclosed. Fiberglass dust is abrasive and can damage mechanical equipment. Once the damaged area has been determined and marked, the damaged composite can be removed to leave only sound structure behind.

For damage extending partially through the thickness, the damaged FRP can be removed using a grinder with a 16-40 grit disk. The damaged area can be smoothed and shaped using a 60-80 grit disk. For extensive FRP removal, grinding is inefficient and will generate a significant amount of fiberglass dust, thus an alternative method for FRP removal is suggested. Make close perpendicular cuts into the laminate using a circular saw with a diamond grit or masonry blade or using a die grinder with a 1-1/2" - 2" cutting wheel. The cuts should extend to the depth of damage. The damaged laminate can then be undercut and removed with a wood chisel or a wide blade air chisel can be employed to peel the damaged plies away. A laminate peeler can efficiently remove gel coat and FRP laminate while greatly reducing airborne dust and particulate matter. They can cut up to a ¼" (6 mm) of laminate per pass, leaving a faired surface. For damage extending through the thickness, the damaged FRP can be removed using a circular saw or Sawz-all.

Lay-Up Scheme

Two different schemes can be used to lay-up primary reinforcement on tapered scarf joints. One scheme, as shown in Figure 1a, is to lay-up the smallest ply first with each successive ply being slightly larger. The plies should butt up to the scarf. Each ply should be cut slightly oversized so that it can be trimmed as it is being laminated in place. Avoid using undersized plies, as this would create a resin rich pocket along the bond line resulting in a weaker joint. A second scheme is to lay the plies parallel to the scarf as shown in Figure 1b. This approach tends to require more finishing work to blend the repair into the existing laminate. However, repairs done with the largest ply first will produce a superior secondary bond for heavily loaded repairs.

Lay-Up Process

Repairs to marine composite structures can generally be accomplished using a wet lay-up approach, laminating the repair “in-situ”. The general approach is to apply a portion of the resin onto the prepared surface and then work the glass reinforcement into the resin. This approach will decrease the chance for entrapping air beneath the plies. Resin applied to dry glass will inevitably result in air bubble problems. The reinforcement may be applied dry or partially saturated with resin. Before beginning the repair, template reinforcement material as shown in Figure 2. Each ply should be completely wet-out and consolidated with small ridge rollers, eliminating any air bubbles and excess resin before the next ply is added. This approach is continued, always working the reinforcement into the resin and following the specific lay-up scheme until the laminate is built-up to the desired thickness.

When laminating on inclined and overhead surfaces, it maybe helpful to pre-saturate small pieces of glass reinforcement on a pasteboard, then apply the reinforcement to the resin wet surface. Another technique suited for large overhead areas is to roll up the dry reinforcement on a cardboard tube, wet-out the area being patched and start to roll out the reinforcement over the resin wet area. While one person holds the reinforcement, another rolls resin into it. If the reinforcement is wet-out as it is applied, the suction of the wet resin will hold it in place. The key is to not let the edges of the reinforcement fall.

The first reinforcement ply laid up should be chopped strand mat (CSM). For tapered scarf joints, the mat should cover the entire faying surface. This will improve the interlaminar bond with the existing laminate. The number of layers which can be laid at one time is dependent on the resin being used, the size of the repair and the surrounding temperature. Laminating too many layers over a large area near the resin's upper working temperature may cause excess exotherm and "cook" the resin, causing it to become weak and brittle. Rapid curing may also occur, which tends to cause excessive shrinkage. As a general rule, a cumulative thickness of approximately 1/4" (6 mm) is the maximum that should be laminated at one time.

Laminate Quality Requirements
The repair should be inspected prior to finishing and the following should not be observed:

- No open voids, pits, cracks, crazing, delaminations or embedded contaminates in the laminate;
- No evidence of resin discoloration or other evidence of extreme exotherm;
- No evidence of dry reinforcement as shown by a white laminate; and
- No wrinkles in the reinforcement and no voids greater than ½" (12 mm). (Voids greater than ½" (12 mm) should be repaired by resin injection. Two 3/16" (5 mm) diameter holes can be drilled into the void; one for injecting resin and the other to let air escape and verify that hole is filled).

The surface of the repair should be smooth and conform to the surrounding surface contour. The degree of cure of the repaired laminate should be within 10% of the resin manufacturer's specified value, as measured by a Barcol Hardness test.

<u>Major Damage in Sandwich Construction</u>
Determining the extent of damage with sandwich construction is a bit more difficult because debonding may extend far beyond the area of obvious visual damage. The cut back area should be increasingly larger proceeding from the outer to the inner skin as shown in Figure 3. Repair to the skins is generally similar to that for single-skin construction. The new core will necessarily be thinner than the existing one to

accommodate the additional repair laminate thickness. Extreme care must be exercised to ensure that the core is properly bonded to both skins and the gap between new and old core is filled.

Core Debonding

Repairing large sections of laminate where the core has separated from the skin can be costly and will generally result in a structure that is inferior to the original design, both from a strength and weight standpoint. Pilot holes must be drilled throughout the structure in the areas suspected to be debonded. These holes will also serve as ports for evacuation of any moisture and injection of resin, which can restore the mechanical aspects of the core bond to a certain degree. In many instances, the core never was fully bonded to the skins as a result of manufacturing deficiencies.

Small, Non-Penetrating Holes

If the structural integrity of a laminate has not been compromised, a repair can be accomplished using a “structural” putty. This mixture consists of resin mixed with milled fibers or other filler that contributes to the mixture's strength properties. There are many “off-the-shelf” pastes, putties and fillers formulated for marine use that are suitable for surface repairs. Note that auto body filler should not be used since it is more susceptible to moisture absorption. Gel coat putty can also be formulated on site by thickening the gel coat with Cab-O-Sil. Milled fibers should not be used with gel coat since the fibers are more susceptible to moisture absorption. Do not use epoxy putty where gel coat will be applied. The gel coat will not bond well to epoxy.

Thin scratches and gouges can be removed using a drill with a burr or sanding sleeve or a die grinder, forming a V-groove along the length of the flaw. Feather the edges of the “V” to the existing laminate using a 100 grit disk to provide a bonding surface for gel coat putty or a suitable filler, see Figure 4b. Remove the paint from the edges of the ground out area using a 60 grit disk, being careful not to grind away the gel coat.
For minor surface damage, filler is only required to thicken the mixture for workability. The following general procedure can be followed:

- Clean surface with acetone to remove all wax, dirt and grease;
- Remove the damaged material by sanding or with a putty knife or razor blade. Wipe clean with acetone, being careful not to saturate the area;
- Formulate the putty mixture using about 1% MEKP catalyst;
- Apply the putty mixture to the damaged area to a thickness of about 1/16";
- If a gel coat mixture is used, a piece of cellophane should be placed over the gel coat and spread out with a razor's edge. After about 30 minutes, the cellophane can be removed; then
- Wet-sand and buff gel coated surface or sand and paint when matching a painted finish.

Blisters

The technique used to repair a blistered hull depends on the extent of the problem. Where blisters are few and spaced far apart, they can be repaired on an individual basis.

If areas of the hull have a cluster of blisters, gel coat should be removed from the vicinity surrounding the problem. In the case where the entire bottom is severely blistered, gel coat removal along with possibly some laminate over the entire surface is recommended. The following overview and procedures should be followed:

> **Gel Coat Removal**: Sand blasting is not recommended because it shatters the underlying laminate, thus weakening the structure. Also, the gel coat is harder than the laminate, which has the effect of quickly eroding the laminate once the gel coat is removed. Grinding or sanding until the laminate has a "clear" quality is the preferred approach.
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> **Laminate Preparation**: It is essential that the laminate is clean. If the blister cannot be completely removed, the area should be thoroughly washed with water and treated with a water soluble silane wash. A final wash to remove excess silane is recommended. The laminate is then required to be thoroughly dried. Vacuum bagging is an excellent way to accomplish this. In lieu of this, moderate heat application and fans can work.
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> **Resin Coating**: The final critical element of the repair procedure is the selection of a resin to seal the exposed laminate and create a barrier layer. Research has shown that vinyl ester resins are superior for this application and are chemically compatible with polyester laminates, which to date are the only materials to exhibit blistering problems. Epoxy resin in itself can provide the best barrier performance, but the adhesion of subsequent repairs with other materials will not be as good. Epoxy repair might be most appropriate for isolated blisters, where the increased cost can be justified.

Structural Damage

After removing the damaged laminate, mark the perimeter of the scarf zone and select an appropriate scarf method with a minimum taper (grind distance over laminate thickness) of 12:1. Start from the damaged area and grind back to the scarf perimeter using a 16 - 40 grit disk or rough cut the scarf, then fair it out with a grinder. The scarf must be smooth and even. There should not be any sharp edges or ridges. Corners should be rounded, with a minimum radius of 1" (24 mm). A wooden template shaped to the desired slope can be used as a guide in forming the scarf. Figure 5 illustrates single- and double-sided scarves. The structural repair should then be completed as per "Lay-Up Process" above. Figure 6 shows a typical repair to through-thickness damage using a temporary backing plate.

Conclusion

Although not intended as a step-by-step repair guide, we've gone into considerable detail on how repairs are accomplished with fiberglass laminates. Admittedly, we've avoided a detailed discussion of finishing techniques to fair our repairs and apply a gel coat finish. For the most part, this requires the expertise of specialized applicators. Conversely, the techniques presented herein are used by a wide number of repair yards and do-ityourselfers. No matter how well we build boats for the consumer, commercial and military markets, they will always be driven into waves larger than expected or foreign objects. Understanding the nature of repairs that will be normal over the course of a boat's life will help us select materials and structural arrangements that can accommodate those repairs.

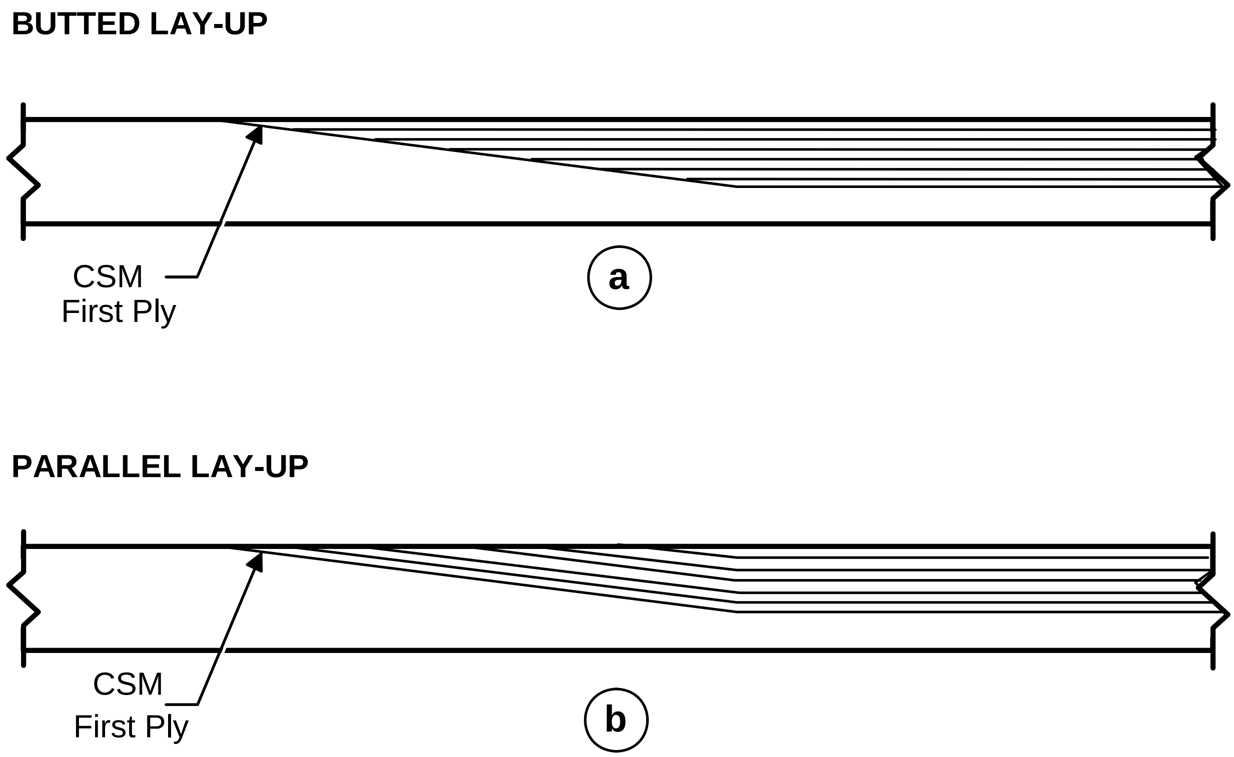

Figure 1. Lay-Up Schemes [Kadala & Gregory]

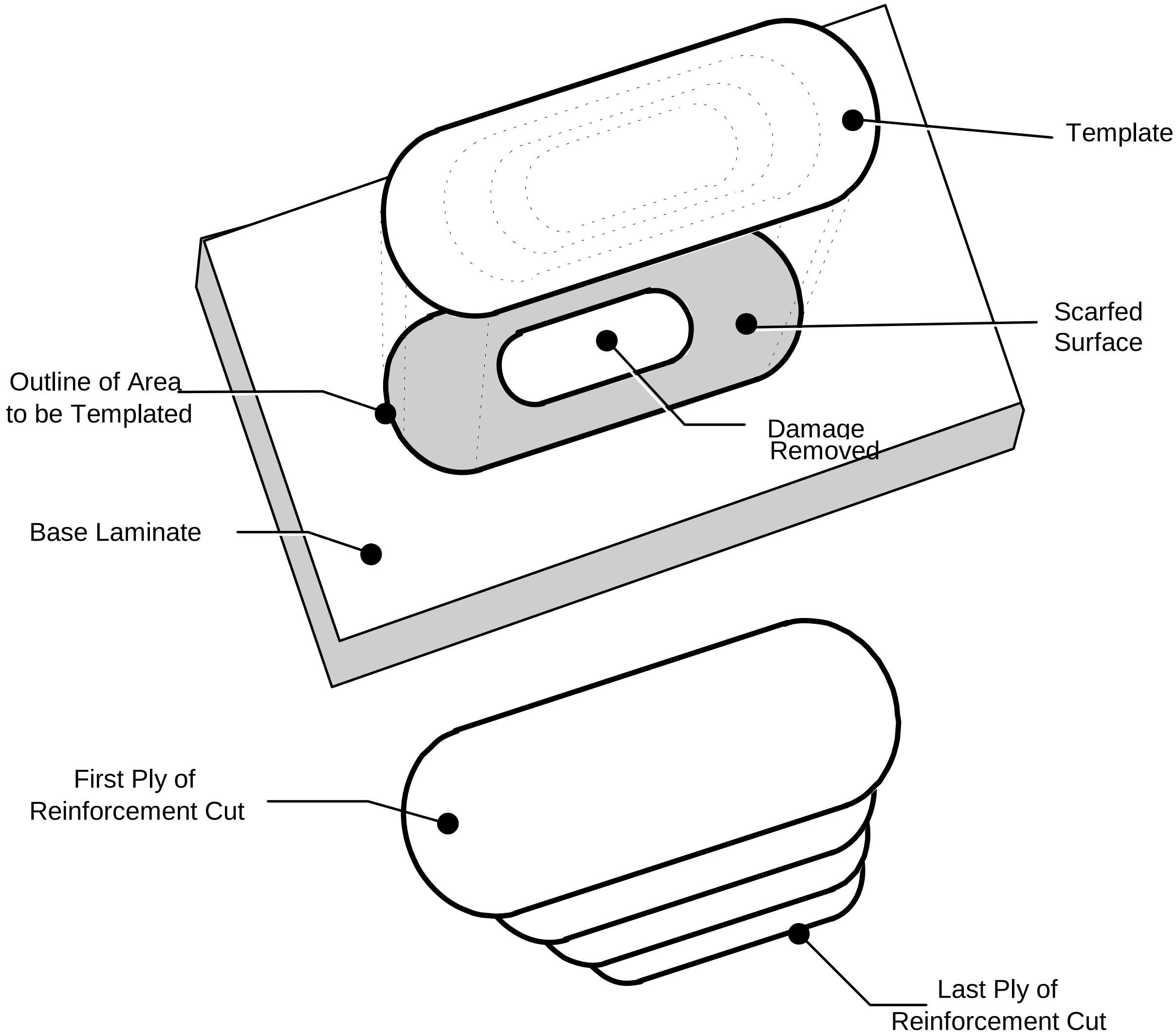

Figure 2. Templating Reinforcement [Kadala & Gregory]

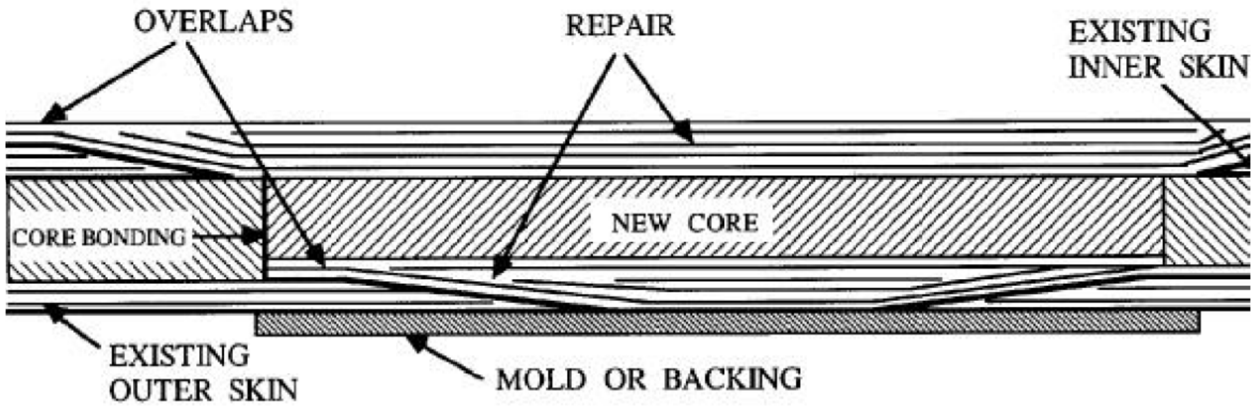

Figure 3. Technique for Repairing Damage to Sandwich Construction [USCG NVIC No. 8-87]

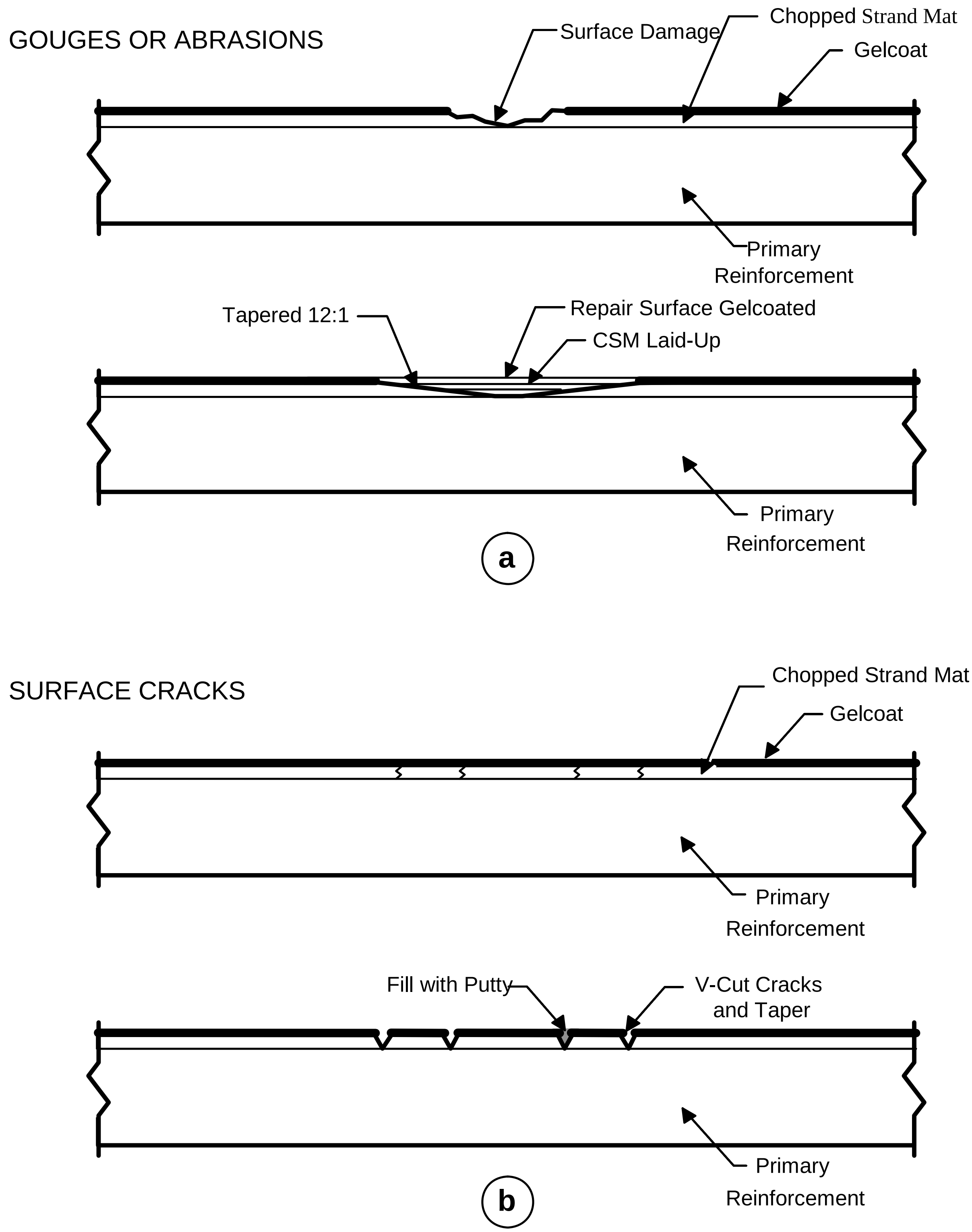

Figure 4. Surface Damage Repair [Kadala & Gregory]

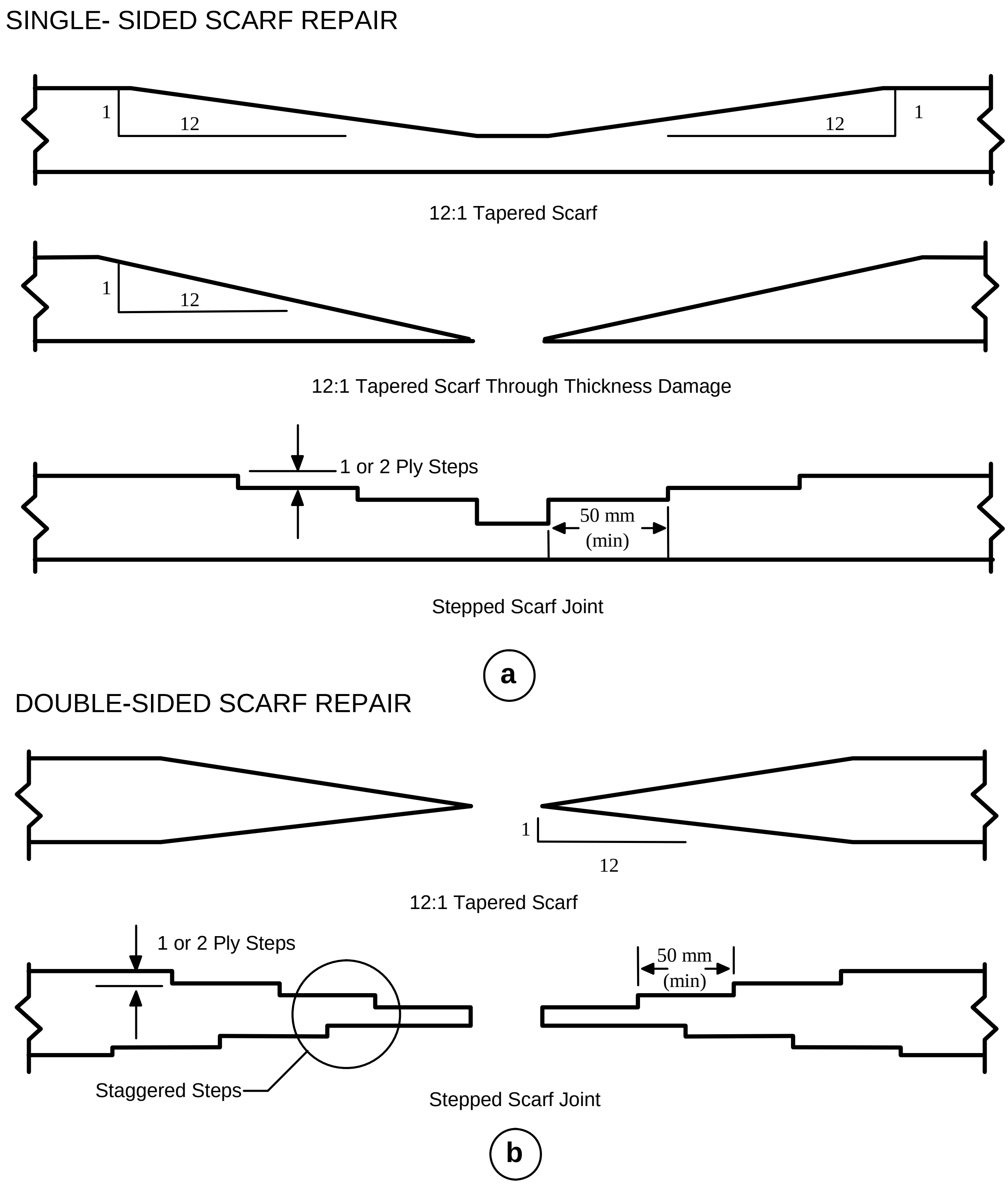

Figure 5. Scarf Joint Preparation [Kadala & Gregory]

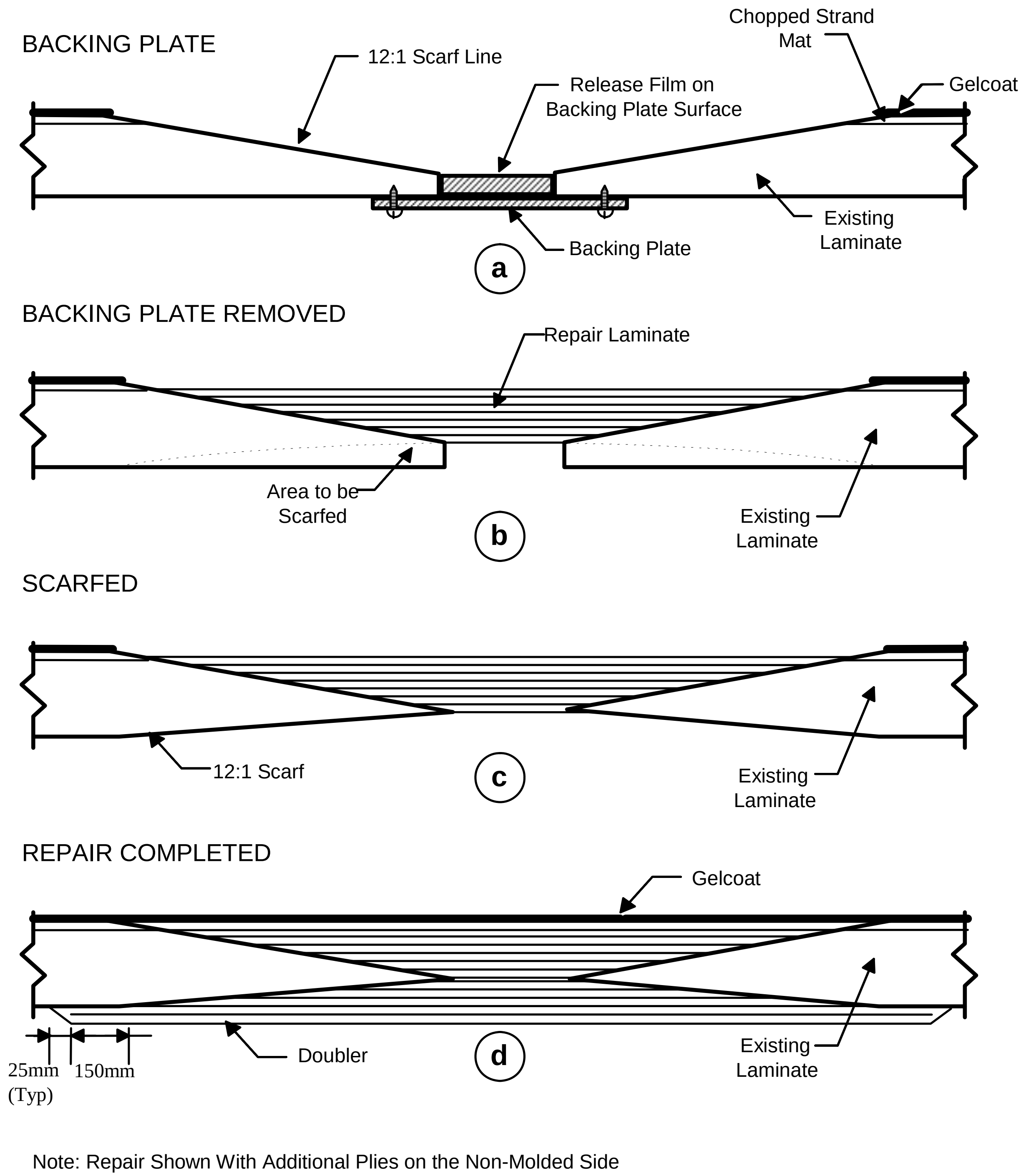

Figure 6. Backing Plate Installation – One-Sided Scarf Repair [Kadala & Gregory]