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MILITARY HANDBOOK

GLASS REINFORCED PLASTICS PREVENTIVE MAINTENANCE AND REPAIR

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FOREWORD

1. This military handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, SEA 55Z3, Department of the Navy, Washington, DC 20362-5101 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. This document provides basic and fundamental information on the preventive maintenance and repair procedures for glass reinforced plastic equipment. This handbook is not intended to be referenced in purchase specifications, except for informational purposes, nor shall it supersede any specification requirements.

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TABLES

1. SCOPE

1.1 **Scope.** This handbook provides guidance for preventive maintenance of glass reinforced plastic (GRP) items, as well as instructions and illustrations on proper repair techniques for minor damage to reinforced plastic structures. Some specific equipments have their own dedicated repair instructions. For example, guidance on repair procedures for major repairs of boat hulls shall be in accordance with NAVSEA 0982-LP-019-0010; for submarine SONAR domes, see SE 300 BA-MMA-010/SONAR dome. Complete explanations of laminate properties and behavior, fabrication techniques, installation procedures, and other similar technical details do not fall within the scope of this handbook. This handbook does not cover repairs to very high performance applications such as aerospace structures, missile motor cases, pressure vessels, or filament-wound articles or repairs to articles primarily made with reinforcing fiber other than glass. This handbook does not apply to MIL-P-24608 products or to repair of GRP piping materials.

This handbook is limited to the practical considerations of preventive maintenance and to repair procedures based upon the use of the Navy's standard reinforced plastic repair kit or readily available repair materials. By following the procedures in this handbook carefully and applying common sense for unusual circumstances, all personnel, including those without previous experience working with GRP, can make effective and lasting repairs to GRP equipment.

1.2 **Purpose.** Over the past 30 years, the Navy has been researching, designing, and acquiring equipment made from GRP. Early applications of this material were generally restricted to small craft hulls. However, as fabrication techniques and materials technology have advanced, a wider variety of GRP equipment has come into use. With the increased use of GRP, it is important that all hands become familiar with the preventive maintenance and repair procedures for all types of GRP structures and equipment.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 **Specifications.** The following specifications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation (see 9.2).

SPECIFICATIONS

MILITARY

MIL-C-19663	Cloth, Woven Roving, for Plastic Laminate
MIL-R-19907	Repair Kit, Glass Reinforced Plastic Laminate

(Unless otherwise indicated copies of military specifications are available from the Naval Publications and Forms Center, (ATTN: NPODS), 5801 Tabor Avenue, Philadelphia, PA 19120-5099.)

2.2 **Order of precedence.** In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 **Definitions.** This section contains a list of terms and definitions used in this handbook. Other terms commonly used in working with GRP are also included for additional information.

3.1.1 **Accelerator.** An oxidizing material used in conjunction with a catalyst to produce curing at room temperature of liquid polyester resin. It is usually obtained from the resin supplier along with the resin.

3.1.2 **Acetone.** A cleaning fluid used to remove uncured plastic resin from brushes and clothing.

3.1.3 **Activator.** For the definition of activator, see 3.1.1.

3.1.4 **Adhesion.** The sticking together of two surfaces in contact with each other.

3.1.5 **Air-inhibited resin.** A type of polyester resin in which curing of the surface is inhibited or prevented by the presence of air. The surface remains slightly tacky or sticky.

3.1.6 **Alligatoring.** A laminate surface flaw resembling the texture of alligator skin.

3.1.7 **Bias.** The direction 45 degrees from direction of weave of a fabric.

3.1.8 **Bond strength.** The load per inch or per square inch required to cause failure of a bond.

3.1.9 **Benzoyl peroxide (BPO).** A catalyst, typically supplied in paste form.

3.1.10 **Bonding angle.** A connecting angle of several plies of reinforcement and resin used to connect two parts.

3.1.11 **Catalyst.** A substance which initiates or markedly speeds up the cure of a compound. Herein it refers to curing of polyester and vinylester resins. BPO and methyl ethyl ketone peroxide (MEKP) are catalysts.

3.1.12 **Chine.** The line formed by the junction of bottom and side of a boat hull; generally termed chine only when a definite angle is formed.

3.1.13 Cloth. Twisted strands of fiberglass (or other reinforcement) woven together to form a cloth material, usually somewhat coarse compared to ordinary clothing material. It is much finer in texture than woven roving (3.1.108).

3.1.14 Color pigments. Ground coloring materials supported in a thick liquid. Added to the resin to give it color.

3.1.15 Compressive strength. The maximum compressive stress which a material is capable of resisting, based on the original area of the cross-section.

3.1.16 Core. A lightweight material separating faces of a sandwich panel. Examples are structural foams, balsa wood and honeycomb.

3.1.17 Crazing. Hairline cracks either within or on the surface of a laminate, caused by stresses generated during cure, removal from mold, impact, or flexing.

3.1.18 Cross-linking. The setting up of chemical links between chains of molecules in a resin. This occurs in all thermosetting resins and is the basic mechanism for solidifying or curing of the resin.

3.1.19 Cure. The cross-linking of the molecules of a resin which alters the properties of the material and changes it from a liquid into a solid.

3.1.20 Cure time. The time required for the liquid resin to reach a cured or fully hardened state after the catalyst or hardener has been added.

3.1.21 Curing temperature. The temperature to which a resin or adhesive is subjected during cure - not the temperature of the material itself during cure which may differ from the temperature of the atmosphere in the vicinity.

3.1.22 Delamination. The separation of reinforcement layers in a laminate due to bond failure.

3.1.23 Dimensional stability. The ability to retain constant shape and size.

3.1.24 Doubler. Extra plies of reinforcement added to a laminate in areas of high stress.

3.1.25 Dry spot. An area of low resin content in a laminate.

3.1.26 Dry strength. The strength of a laminate after conditioning in the standard laboratory atmosphere.

3.1.27 Duplication mold. A mold made by casting over or duplicating another article.

3.1.28 Epoxy. A type of thermosetting resin made from compounds containing the epoxy structure characterized by high strength and good adhesion to many materials.

3.1.29 Exothermic heat. The heat released during a chemical reaction such as the curing of a resin. Peak exotherm is the point of highest temperature of a resin during cure.

3.1.30 Fatigue. A type of structural loading of a material involving the repeated application of stress.

3.1.31 Filament. A single, hairlike fiber of glass characterized by extreme length which permits its use in yarn with little or no twist.

3.1.32 Fill or sanding resin. A general purpose polyester resin used to impregnate and fill reinforcing material in the final lay-up of a surfacing application; usually contains wax.

3.1.33 Fill. The direction perpendicular to the length or long direction of a cloth.

3.1.34 Fillers. Any one of a number of inexpensive substances that are added to plastic resins to increase the volume, improve properties, or lower the cost of the article being produced.

3.1.35 Finish. The surface treatment applied to fibrous glass to promote adhesion between the glass and resin. Sometimes mistakenly called "size" or "sizing".

3.1.36 Fire retardancy. The property of a resin, by its nature or when combined with certain chemicals, to have a reduced tendency to burn.

3.1.37 Flash. The portion of glass or resin which protrudes beyond the edge of the finished molding (and must usually be trimmed off).

3.1.38 Foam. A plastic resin that has been expanded into a multi-cellular structure having low weight. As referenced herein, foams are of the rigid type usually made of urethane or polyvinyl chloride (PVC) resin, and are used as core material in sandwich panels. Some urethane and syntactic foams can be "foamed-in-place" and are used for filling floatation chambers in boats and for void filling in repair work.

3.1.39 Gel. A partial cure of plastic resins; a semi-solid, jellylike state.

3.1.40 Gel coat. A thin surface coat either colored or clear, of non-reinforced plastic resin. It is used for decorative purposes and as a protective coating for the underlying laminate.

3.1.41 Gel time. Time required to change a liquid resin into a non-flowing gel.

3.1.42 GRP. The abbreviation for glass reinforced plastic.

3.1.43 Hand lay-up. The oldest and simplest molding technique in which reinforcing materials and catalyzed resin are laid into or onto a mold by hand. These materials are then compacted with a roller to eliminate entrapped air.

3.1.44 Hardener. The additive that activates the resin to produce curing in epoxy resin systems. The hardener functions in a different way chemically than a catalyst (used with polyester resins, hence the difference in terminology), but the end result is the same.

3.1.45 Hat section. For the definition of hat section, see 3.1.102.

3.1.46 Honeycomb. A low density cellular material resembling a honeycomb, used as a core in sandwich construction.

3.1.47 Jig. A mechanical means for positioning a mold or part during construction.

3.1.48 Laminate. A material composed of successive layers of reinforcement bonded together with resin to form a structural composite.

3.1.49 Lamination. The laying on of layers of glass materials and resin and the eventual bonding together of these layers.

3.1.50 Lap joint. A joint made by placing one piece partly over another and bonding the overlapped portions.

3.1.51 Lay-up. The reinforcing material placed in position on the mold. Also, the resin-impregnated reinforcement (as a verb, the process of making a lay-up).

3.1.52 Mat. Short, randomly-oriented strands of fiberglass formed into a thin sheet and held together lightly by a binder.

3.1.53 MEKP. The abbreviation for methyl ethyl ketone peroxide, a catalyst for polyester resins.

3.1.54 Milled fibers. Fiberglass strands hammer-milled into small modules of filamentized glass.

3.1.55 Modulus of elasticity. The ratio of stress to corresponding strain within the range in which these are proportional. It is a measure of the stiffness of a unit of material.

3.1.56 Mold release. A substance used to coat the mold to prevent the molded laminate from sticking to the mold, thus facilitating the removal of a part from the mold. Examples: PVA, wax, and ZELAC.

3.1.57 Molding. The forming of glass materials and resin by various means into a shape given by the mold and holding that shape by the mold until the resin cures.

3.1.58 Monomer. A simple molecule capable of linking (polymerizing) with other molecules of the same or different types.

3.1.59 Monocoque. A type of structure consisting of a continuous skin in which the skin carries a major portion of the stress. It is characterized by a greatly reduced amount of framing.

3.1.60 Non-air-inhibited resin. A resin in which the surface cure will not be inhibited or prevented by the presence of air. For most polyester resins, an additive, often a wax solution, is used to achieve this characteristic.

3.1.61 Parting agent. For the definition of parting agent, see 3.1.56.

3.1.62 Peel. A failure mode resulting in separation of a surface layer from the base laminate or separation of the structural skin from the core in a sandwich panel. It is caused by tensile forces perpendicular to the plane of the laminate and concentrated at a free edge. Secondary bonds often fail in this manner.

3.1.63 Plug. A form identical in shape to the finished object from which a mold is fabricated.

3.1.64 Polyester resin. A thermosetting resin produced by the reaction of dibasic organic acid and glycol alcohol.

3.1.65 Polymerization. A chemical reaction in which the molecules of a resin are linked together to form bigger, more complex molecules. Curing of polyester resins is a polymerization process.

3.1.66 Porosity. The condition of a material containing pits, fissures, or voids such that it can or may be able to absorb or pass liquids or gases. It is often caused by formation of undesirable clusters of air bubbles in the surface or body of the laminate.

3.1.67 Pot life. The length of time that a catalyzed resin remains workable.

3.1.68 Primary bond. The connection by chemical cross-linking of an uncured laminate or resin (new lay-up) to an uncured or partly-cured resin or laminate (an existing laminate, not fully cured).

3.1.69 Promotor. Definition of promotor, see 3.1.1.

3.1.70 PVA. The abbreviation for polyvinyl alcohol, a parting agent used in sheet or spray form.

3.1.71 Release agent. For the definition of release agent, see 3.1.56.

3.1.72 Resin. A liquid plastic substance used as a matrix for glass fibers. It is cured by cross-linking.

3.1.73 Resin pocket. An accumulation of excess resin in an area between plies or on the surface of a laminate.

3.1.74 Resin richness. The property of having more than the desired amount of resin.

3.1.75 Resin-thermoplastic. A classification of resin that can be readily softened and reformed by heating and be re-hardened by cooling. Typical of the thermoplastic family are the vinyls, acrylics, and polyethylenes.

3.1.76 Resin-thermoset. A resin material that can undergo a chemical reaction leading to the formation of a cross-linked solid. Once it becomes a solid, it cannot be reformed. Polyester and epoxy resins are typical thermosetting resins.

3.1.77 Riser. A support for items, such as seats, molded into the hull by primary or secondary bond.

3.1.78 Rovings. Straight bundles of continuous fiberglass strands resembling a loose untwisted rope.

3.1.79 Sandwich construction. A method of construction consisting of relatively thin high-strength facings bonded to each side of a less dense material or "core". The structure provides a high ratio of strength and stiffness to weight. Also referred to as cored construction.

3.1.80 Scarf. A bevel edge made in the laminate to add more bond surface area for a patch.

3.1.81 Scarf joint. A joint made by cutting the ends of two pieces at the same angle and fitting the two cut areas together.

3.1.82 Secondary bond. A connection by adhesion of an uncured resin or laminate to a cured laminate.

3.1.83 Self-tapping. The characteristic of a fastener that forms its own threads as it is screwed into a material, in a fashion similar to sheetmetal practice.

3.1.84 Separating film. A thin plastic film that resin does not adhere to that is used as a covering over mold surfaces or any other surface from which resin must be easily removed; also called parting film. Polyethylene, nylon, or PVA film is often used.

3.1.85 Shear. An action or stress resulting from applied forces, causing contiguous parts of a body to be stressed in a direction parallel to their plane of contact.

3.1.86 Shear strength. The maximum shearing stress a material can resist, based on the original cross-sectional area.

3.1.87 Shelf life. The period of time during which a packaged material can be stored under specified temperature conditions and remain suitable for use.

3.1.88 Size. A processing protection or lubricant applied to glass fiber to allow weaving or other processing without damage to the fiber.

3.1.89 Sole. The interior deck forming the walking surface in a boat cabin.

3.1.90 Spray strake. The abrupt change in bottom shape of a boat hull, generally formed by a longitudinal step, whose primary purpose is to throw the bow wave clear of the hull. Also called "spray rail" or "spray knocker".

3.1.91 Spray-up. A number of techniques in which a spray gun is used to simultaneously deposit fiberglass and catalyzed resin on a mold.

3.1.92 Strain. A measure of the change in size or shape of a body, due to applied load, referred to its original size or shape.

3.1.93 Strand. The bundle of continuous glass filaments gathered together in the forming operation.

3.1.94 Stress. The intensity of the internal forces in a material resisting deformation by external forces expressed in force per unit area (for example, pounds per square inch).

3.1.95 Styrene monomer. A water-thin liquid used to thin polyester resins and act as the cross-linking agent.

3.1.96 Substrate. Any material which provides a supporting surface for other materials.

3.1.97 Tack. The stickiness of an adhesive.

3.1.98 Thermosetting resin. A type of resin that, once cured, cannot be remelted or reformed by the application of heat.

3.1.99 Thickeners. Material added to the resin to thicken it or raise the viscosity index of the resin so that it will not flow as readily.

3.1.100 Thinners. Material added to plastic resins to thin or lower the viscosity of the resins. They may also be cross-linking agents.

3.1.101 Thixotropic. The word to describe a resin that is more viscous at rest than while being stirred or agitated.

3.1.102 Top hat. A method of stiffening a flat GRP plate. A solid or hollow former or core, usually rectangular, is attached to the plate and a GRP laminate is laid-up over it, covering the core and fairing out onto the plate a specified distance. In cross-section the stiffener looks like a stylized top hat.

3.1.103 Vinylester resin. A type of resin similar to polyester in handling and use but producing a stronger laminate.

3.1.104 Viscosity. A measure of the resistance of a liquid to flow.

3.1.105 Warp. The dimensional distortion of a plastic object after molding; also, the direction of the weave in cloth or roving.

3.1.106 Weeping. Leakage made apparent by the slow flow of water through a surface.

3.1.107 Wet-out. The saturation of fiber reinforcement by liquid resin. For glass fiber it is characterized by the glass fiber appearing to become transparent.

3.1.108 Wet strength. The strength (tensile, compressive, and so forth) of a laminate that has been submerged in water for a predetermined period to simulate the effect of contact with water in service.

3.1.109 Woven roving. A type of reinforcement consisting of flattened bundles of rovings woven into a plain square weave fabric having a very coarse texture.

3.1.110 Yarn. A twisted strand or strands of glass fibers that can be woven, braided, served, and processed on conventional textile equipment.

4. GENERAL REQUIREMENTS

4.1 Preventive maintenance (PM). PM of reinforced plastic structures is important, since progressive damage can be prevented by early detection and repair of minor deficiencies. Scheduling of PM for reinforced plastic items is included in the ship's PMS, and the periodicity of a particular PM action is noted on the maintenance index page (MIP) for the item in question. Specific PM requirements are outlined on the maintenance requirement cards and will not be discussed here. The following paragraphs are, however, intended to give the rationale for PM of reinforced plastic items, as well as provide general guidance for PM actions.

4.2 Failure reports. In keeping with the established procedures of the maintenance data collection subsystem (MDCS), each repair of any reinforced plastic item requiring outside assistance should be reported. The report should note whether the damage was necessitated by a defective part, design deficiency, wear, service conditions, or other cause. These reports serve as "feedback" of service experience so that improvements in design and materials used for specific applications can be made. Considering new applications for reinforced plastics, several questions arise:

a. Is this a suitable application for reinforced plastics?
b. Are materials of proper strength and quality being used?
c. Are there inadequacies in design that will become apparent in service?

The failure report is intended (1) to provide background information on previous applications that will help assure proper application of reinforced plastics in the future, and (2) to give the forces afloat an opportunity to express opinions as well as give factual reports on repair situations.

4.3 Rationale. Periodic inspections, upkeep, and corrective action are necessary PM functions having the following objectives:

a. To detect and correct defects or deficiencies introduced by improper installation of a structure

b. To anticipate and prevent damage due to service experience such as loosened or missing bolts, failure of structural supports, and so forth

c. To minimize or prevent propagation of minor failures such as small fractures, enlarged bolt holes, slight separation of panel stiffeners, and so forth

d. To preclude progressive and extensive failures.

4.4 Periodic inspection and general preventive maintenance guidance.

4.4.1 Reinforced plastic structures should be visually inspected at frequent intervals during the initial or breaking-in period. The time between inspections can be lengthened as service experience is gained. Structures should always be examined after the ship returns from sea. They also should be inspected at regular intervals during extended service periods at sea, and after exposure to unusually severe weather conditions.

4.4.2 The following outline briefly describes the type of defect or deficiency to look for during the visual inspection.

4.4.2.1 Fastener or connection areas. Defects may occur in these areas due to improper design, such as insufficient distance allowed between adjacent bolt holes, insufficient distance between the bolt hole and the edge of the laminate, or insufficient bearing area under the bolt heads and nuts. Defects may also be caused by the applied loads exceeding design loads, loose or missing fasteners, stressing the laminate at initial assembly, or allowing an excessive bolt hole clearance. Resultant defects often appear as elongated bolt holes, fasteners pulled through the laminate, fastener heads sheared off, cracks, fractures, or delaminations. All bolts should be checked periodically for tightness. Additionally, all connection areas between metal and plastic or plastic and plastic should be smooth and close fitting. Rough connecting surfaces should be sanded until smooth to the touch; otherwise, they will tend to abrade the connection. This abrasion will weaken the joint, leading to a premature failure of the equipment. Likewise, a close fitting connection will prevent working of the connected pieces, which could lead to an early failure due to fatigue induced cracking.

4.4.2.2 Stiffeners. Separation due to shear or peeling action (noted by milky colored laminate, a dull, soft or hollow sound when tapped, or a spongy feel when pressed) may occur in these areas due to inadequate surface preparation, insufficient flange area, poor adhesive, or poor application.

4.4.2.3 Metal supports or connections to GRP equipment. Reinforced plastic structures do not exhibit ductility or ability to take a permanent deformation without breaking as metals do. Therefore, if a metal supporting structure deflects or deforms, stresses are introduced into the plastic structure that will add to any stresses due to service loads. If any damage to the supporting structure occurs, immediate action should be taken to relieve the locked-in stresses and to permit the plastic to revert to its normal shape. It is also advisable that during assembly, the plastic structure never be sprung or pulled in to meet the mating surface or otherwise deformed.

4.4.2.4 Areas around openings in a laminate. Such areas should be inspected for cracks, fractures, and delaminations.

4.4.2.5 Other laminate areas. In addition to the critical areas previously described, all areas should be examined for possible laminate or core failures, especially at hard spots (that is, areas of sudden changes of thickness, abrupt ending of stiffeners, or square corners) where localized stress concentrations may occur. Failures in these areas will leave the laminate with a soft, more flexible feel than sound laminate. A whitish color may also be present, accompanied by a dull or hollow sound when tapped. The surface of unpainted laminates or areas where paint has flaked off should be inspected for erosion characterized by bare glass fibers or thinning surface resin.

4.4.3 Corrective action. Any damage that is detected during the periodic visual inspection of the laminate should be corrected as soon as practicable, in the following manner:

a. Fasteners should be replaced or retightened as necessary, and connecting pieces should be shimmed or replaced if excessively worn.

b. Damaged metal, connecting structure, or supports should be repaired or replaced.

c. Unpainted laminates should be coated with clear resin when surface erosion exposes the weave of the glass reinforcement.

d. Painted laminates should be repainted only when badly soiled or the paint peels, blisters, or becomes chipped. Paint in accordance with instructions as specified in 7.1 through 7.3.

4.4.4 Removal of marine growth. The removal of marine growth is an important factor in the PM of reinforced plastic craft. Accumulation of marine growth, slime, grass barnacles, and so forth, reduces the performance of craft and may also lead to permanent damage to the hull finish. Antifouling paint will deter the attachment of marine life, but such paint cannot be depended upon to keep the bottom of a boat clean indefinitely. Periodic scrubbing with a coarse bristle brush will be most effective in cutting down on marine growth as well as helping to get the most out of the antifouling paint. Such scrubbing can be performed either in or out of the water. For hulls that have developed an accumulation of growth, a haul out will be required to facilitate a thorough cleaning. The boat should be placed in a sturdy cradle to permit access to all areas of the hull. The tools necessary for the removal of the accumulated growth include the following: brush, bucket, detergent, paint scraper or putty knife, sander, and sandpaper. Safety items that are necessary include goggles, respirator, gloves, and coveralls. After hauling out, it is important to get to the growth before it dries out, since most marine organisms come off more easily while wet.

The first step in cleaning the craft is to thoroughly scrub down the hull with a coarse brush and detergent. Wear eye protection and a mask to prevent stray particles from getting into the eyes and lungs. (A mask is especially important if antifouling paint is present on the hull.) This initial scrubbing will remove most of the slime and grass as well as some of the barnacles. For more stubborn growth, use a putty knife or paint scraper. If the barnacles resist the putty knife, a hammer and chisel may be the only alternative. When using the chisel, keep the blade as parallel to the surface as possible to avoid puncturing the hull. When all the growth that can be removed using these tools has been removed, wash down the hull with water and allow it to dry. Barnacles and other types of marine growth will leave a residual mark on the hull that should be sanded off before beginning painting or repair work. A respirator, eye protection, coveralls, and gloves must be worn while sanding as protection to the skin from particles and dust from the residue and antifouling paint. One hundred-fifty grade paper should be sufficient to remove the last traces of growth and to prepare the surface for repainting.

4.5 Summary. The preceeding steps are basic procedures for the care and maintenance of GRP equipment. Attention to these procedures will help insure against early failure of equipment as well as helping to retain a new appearance. If minor damage does occur, it should be repaired as soon as possible in accordance with the repair techniques described in the following sections of this handbook. Prompt attention to such damage will help prevent failure as well as minimize downtime of the equipment.

5. DETAILED REQUIREMENTS

5.1 Materials. The raw materials used to repair reinforced plastics are similar to those used in the manufacture of the original product. Typically, these materials consist of a reinforcement, a core material, a liquid resin, and an activating chemical known as a catalyst or hardener. These materials, when combined and applied properly, can form a repair that approaches the strength of the original laminate. To a great extent, the quality of the repair is directly dependent upon the quality of workmanship used in making the repair. It is important that the repairer be familiar with not only the proper techniques, but also the proper materials to be used for any particular repair.

5.1.1 Reinforcing materials. The reinforcing materials used in any reinforced plastic provide the real strength of the laminate. In general, they are the part of the laminate designed to take the majority of the loading applied to the laminate. To prevent contamination, all reinforcing materials should be stored in clean, dry areas and protected from high humidity. A secure bond depends on the quality of the prepared surface and uncontaminated bonding surfaces. Dirt, especially grease and oil, will inhibit bonding action and cause bond failure. Moisture can also degrade the fiber as well as detract from proper resin wet-out of the glass fiber. Therefore, if these materials must be stored in an open or non-humidity-controlled area, it is advisable to wrap them in a protective covering, such as moisture proof paper or suitable plastic film.

5.1.1.1 **Woven glass cloth.** The glass cloth usually used in marine laminate is a simple woven fabric made from many twisted thin, glass filaments as shown on figure 1. Of the widely used glass reinforcements, glass cloth is the strongest and easiest material to work with, especially when used for complex shapes. Glass cloth comes in a variety of weights ranging from 2 to 14 ounces per square yard. The most common cloth specified is a square weave type weighing 10 ounces per square yard. It is known as style 7500 (formerly style 1000) and is often referred to as boat cloth. This cloth will be suitable for the large majority of repair situations with lighter weight cloths more suited for nonstructual or special applications. The finish used on the cloth should be specified to be a type compatible with the resin to be used.

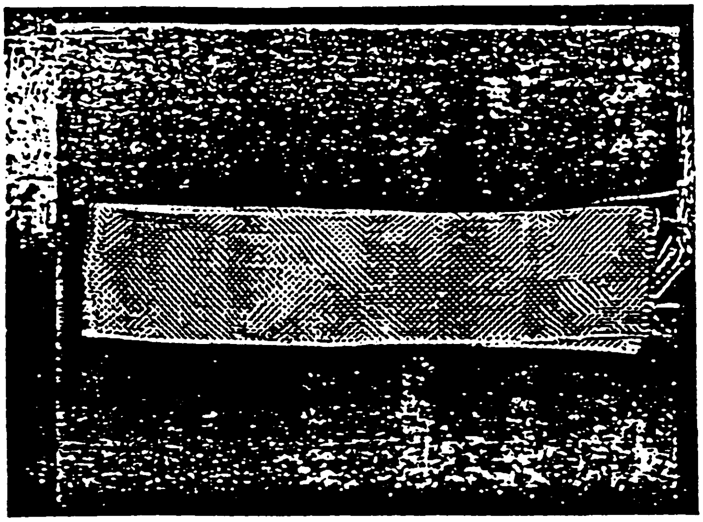

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FIGURE 1. *Woven glass cloth.*

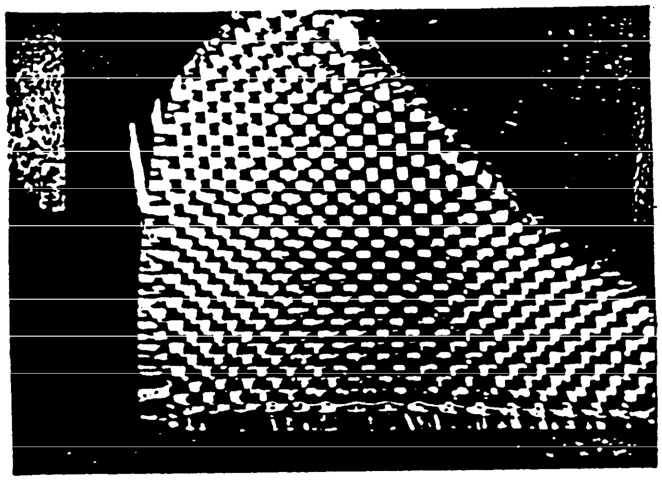

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FIGURE 2. *Woven roving.*

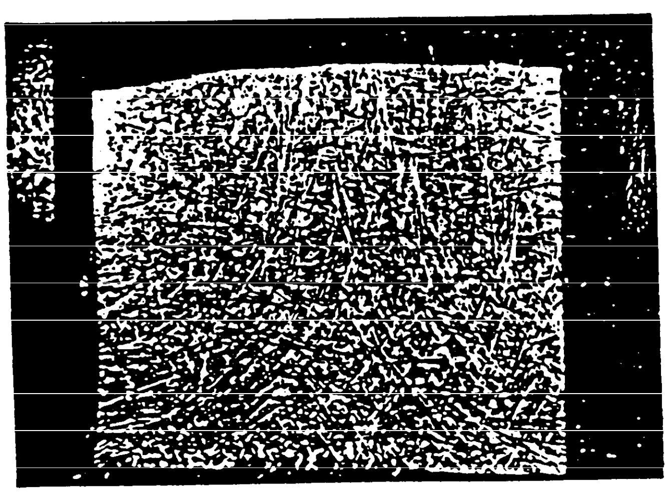

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FIGURE 3. *Chopped strand mat.*

5.1.1.2 Woven roving. Woven roving is similar to glass cloth, but it uses a coarse weave and is composed of bundles of continuous untwisted glass filaments as shown on figure 2. These bundles are known as rovings. Woven roving is much heavier than glass cloth and can be acquired in weights of 14 to 40 ounces per square yard. The standard weight used is 24 ounces and can be acquired in accordance with MIL-C-19663. This reinforcement has good strength characteristics and should be used in repair situations where thickness needs to be built up quickly.

5.1.1.3 Chopped strand mat. This is a felt-like material made from chopped strands of fiberglass filaments, pressed into a mat form and held together with a resin soluble binder as shown on figure 3. It is available in various weights, generally ranging from 3/4 to 4 ounces per square foot. (Note that the ounce designation for mat is per square foot, whereas that for woven fabric and woven roving is per square yard.) Mats weighing 1-1/2 to 2 ounces are most commonly specified for repair and construction purposes. Mat, in its unwetted state, is generally fairly stiff and will not conform well to a compound curve. However, when wetted-out with resin, the resin soluble binder holding it together dissolves, and the mat will then conform to various shapes and compound curves.

A laminate reinforced with mat only is much weaker than one made with cloth or woven roving, but it has good interlaminar (between layer) bonding strength due to its nonwoven (nondirectional) pattern. As with glass cloth, the finish and binder on the mat should be specified to be compatible with the resin to be used.

5.1.1.4 Glass materials combinations. In commercial boat manufacturing, it is a general practice to use alternate layers of mat and woven roving. This combination provides a good strength laminate that builds thickness quickly and is economical. However, the Navy normally specifies all woven roving construction because of its better strength to weight ratio, although a ply of mat is used against the mold to prevent print-through of the woven roving pattern and between secondarily-bonded surfaces to increase bond strength.

For small repairs, cloth is suggested instead of woven roving. Approximations for the various thicknesses using various weight reinforcement materials are shown in table I.

TABLE I. *Thicknesses (dry) for various glass reinforcements.*

Reinforcement	Unit weight (dry)	Number of plies			
		1	2	3	4
10 ounce cloth	10 ounces per square yard	0.019 inch	0.032 inch	0.044 inch	0.056 inch
1.5 ounce mat	1.5 ounces per square foot	0.048 inch	0.088 inch	0.145 inch	0.183 inch
24 ounce woven roving	24 ounces per square yard	0.038 inch	0.076 inch	0.115 inch	0.156 inch
24 ounce woven roving with 1.5 ounces mat	4.2 ounces per square foot	0.085 inch	0.150 inch	0.225 inch	0.300 inch

5.1.2 Special reinforcing materials. In addition to the standard reinforcing materials listed in the preceding sections, special types of reinforcing materials may be needed for repairs requiring a high strength-to-weight ratio or for repair of laminates originally made with this type of reinforcement. There are many types of high-performance reinforcements; however, only three will be discussed here.

5.1.2.1 Unidirectional glass reinforcements. This type of reinforcement, unlike the woven or mat type reinforcements, is manufactured as a tape consisting of unwoven, continuous glass fibers. Tapes are commonly available in widths ranging from 2 to 10 inches. The tape is held together by widely spaced glass fibers oriented in the fill (or transverse) direction. It is called unidirectional due to this construction in which nearly all the fibers are arranged in one direction. Unidirectional glass tape is used in areas where the load is oriented along an axis or in one direction thereby making maximum use of the glass fibers' strength.

5.1.2.2 Carbon fibers. Although other forms are available, carbon fibers used in repair and construction of boat hulls are usually acquired as a unidirectional tape, in widths ranging from 2 to 4 inches. Carbon fiber, originally developed for aerospace applications, has both high strength and high stiffness characteristics along with a low density. Applications for carbon fibers are similar to those of unidirectional glass, but where additional strength or stiffness is needed with less weight. Their use is very limited due to brittleness and high cost.

5.1.2.3 Aramid fiber. More commonly known as Kevlar (a trademark of Dupont Co.) aramid fiber is a man-made organic fiber having high strength, high stiffness (higher than glass, lower than carbon), and low weight. Aramid fiber is used in ballistic protection and high performance aerospace and marine applications. At the same stiffness, an aramid reinforced composite may weigh 30 percent less and have higher strength characteristics than a glass reinforced composite. However, aramid fibers require special tools for cutting and machining, are subject to compatibility problems with some resins, and are quite expensive.

5.1.3 Resins. In reinforced plastics, the term plastic refers to the resin matrix that holds the reinforcing material together. Structurally, the resin supplies most of the interlaminar shear strength of the laminate. However, the performance characteristics of the laminate are influenced most by the type of reinforcing material used. The percentage by weight of glass reinforcement and resin for typical laminates used in GRP repairs are listed in table II. Generally, three types of resins are used in repair and manufacturing of marine GRP products: polyesters vinylesters, and epoxies. Although other resins may be used in special applications, polyester, vinylester, and epoxy resins are well suited for marine applications and have shown good performance through many years of field experience. These resins are usually procured as two-part resin systems containing a resin and a catalyst or hardener to activate the chemical reaction that changes the liquid resin to a hard solid.

TABLE II. *Typical percentages by weight of reinforcement and resin for fiberglass reinforced laminates.*

Reinforcement type	Percent reinforcement	Percent resin
All mat	25	75
All woven roving	50	50
All cloth	55 plus	45 minus
Alternate mat and cloth	30	60
Alternate mat and woven roving	40	70

5.1.3.1 **Polyester resin.** Many commercial manufacturers have chosen polyester as their standard general purpose resin. Polyester is also used as the standard resin at most depot and intermediate maintenance activities. These resins may be obtained in a wide range of viscosities and character-istics from over 20 resin manufacturers. The consistency of the very high-viscosity resin resembles heavy molasses, while that of the low-viscosity resin is like light syrup. Usually, the low-viscosity resin will wet-out a glass reinforcement faster, but it will also drain more rapidly on a vertical surface. This drainage may be undesirable in some cases and may be minimized by the addition of a small amount of a finely divided silica (fumed silica). A highly viscous resin may be thinned by the addition of a small amount of styrene following the manufacturer's instructions. Many resins that have been specially compounded to the proper viscosity for repair use are available from commercial suppliers.

Polyesters are very versatile in cure (hardening) characteristics. The addition of a small amount of an organic peroxide catalyst (usually MEKP) and an accelerator (normally supplied premixed in the resin) will cause a cure to occur at ambient temperatures above 50 degrees Fahrenheit (°F) without the application of heat. If accelerator is to be added to the resin it should be added and mixed before adding the catalyst.

CAUTION

NEVER MIX CATALYST AND ACCELERATOR TOGETHER DIRECTLY.
THIS WILL RESULT IN A VIOLENT CHEMICAL REACTION.

The pot life (time within which the resin remains liquid and usable) and cure time may be varied by adjusting the proportions of catalyst and accelerator used. A general guide on catalyst measurement and the effect on pot life and gel time of various ambient temperatures and catalyst mix ratios are provided in tables III and IV. The resin manufacturer's data sheet must be consulted for specific details of catalyst ratios and gel times for a particular resin system. Polyesters have a limited storage life of about 6 months to a year. Standing in storage causes them to gradually thicken until they become unusable even though the catalyst has not been added.

TABLE III. *Catalyst requirements for 1 quart (32 ounces) polyester.*

MEKP catalyst percent	Approximate cubic centimeter	Approximate teaspoons	Approximate liquid ounces
1.00	9	2	1/3
1.50	13	2-3/4	1/2
2.00	18	3-3/4	2/3

TABLE IV. *Variation in polyester resin pot life and laminate gel time at differing temperatures and catalyst ratios (illustrative only).*

Ambient temperature (°F)	Percent catalyst	Working life (minutes)	Laminate gel time[1] (minutes)
60	1.0	50	50
60	2.0	12	12
70	1.0	30	32
80	1.0	20	22
90	1.0	15	18

[1]Laminates over 1/8-inch thick laid up at one operation will have faster laminate gel times. Working life is also affected by specific resin-catalyst systems (see manufacturer's recommendations).

5.1.3.2 Epoxy resins. Epoxy resin is used for the manufacture of GRP products to a lesser extent than polyester resin due to its cost; however, the superior adhesive characteristics of epoxy resin make it an excellent resin for repair work and it is the resin provided in the available GRP repair kits. The adhesive quality of epoxy is important in repair work, as all repair work relies on secondary bonding.

Epoxy resins are suited for room temperature cures by the addition of a recommended amount of a specific room temperature type hardener. For technical reasons, the term hardener is used with epoxy resins and the term catalyst is used with polyester resins. They both perform the same function in that they cause the resin to cure. However, it usually requires more hardener to cure an epoxy resin compared to the amount of catalyst needed to cure a polyester resin. Unlike the polyesters, the proportions of hardener should not be varied to change the cure time, since any change in concentration may adversely affect other properties. Cure conditions can be varied only by changing the ambient temperature or type of hardener, some of which will require an external heat source to ensure an optimum bond, or by cooling the resin below room temper-ature. There are many types of room temperature hardeners from which to choose. The resin manufacturer's data sheet must be consulted for specific details on hardener ratios, working time, cure times, and other information for a particular resin system.

Users are cautioned that room temperature hardeners are alkaline in nature, and should be handled with care. Rubber gloves and a respirator are recommended when handling both epoxy resin and hardener. The skin should always be washed immediately after any contact with hardener.

5.1.4 Core material. Traditional Navy practice in the design of GRP small craft and equipment has been to use only solid GRP laminate for construction of the hull. However, sandwich or cored construction is often used for flat surfaces such as bulkheads. In such structures, a core material is covered on both sides with facings or skins of GRP, resulting in a lighter weight and stiffer structure than a solid laminate would produce. Many different types of core material exist, but only four types will be covered in this handbook.

5.1.4.1 End-grain balsa wood. Balsa wood is a natural core very light weight wood obtained from balsa trees found in South America. The particular cut of balsa wood used for a core material is known as end-grain balsa. As the term implies, the grain of the wood is aligned at right angles to the face of the core. It is this orientation of the wood fibers that gives end-grain balsa its useful characteristics as a core material. By placing a skin of GRP on both faces of the core material, a structure similar to an "I" beam results (see figure 4). This type of sandwich construction can sustain damage over a large area and will still be capable of carrying a substantial portion of the design load.

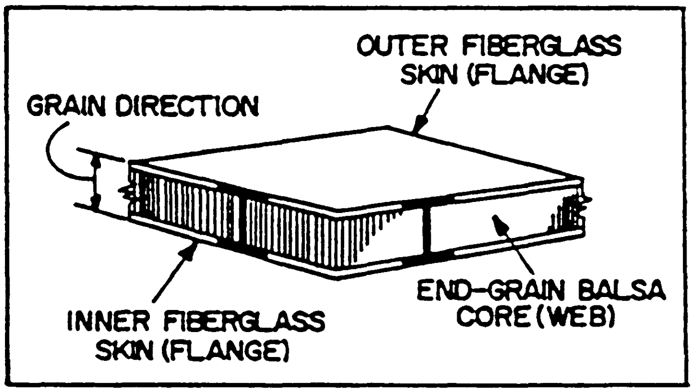

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FIGURE 4. *End-grain balsa wood or GRP sandwich construction.*

Balsa core is available in a range of densities from 6 to 15-1/2 pounds per cubic foot (lb/ft^3), and in various thicknesses. Mechanical properties of balsa are proportional to density. Balsa core performance is not affected by temperature. This property, along with its favorable compressive strength, has made balsa a popular choice for use in deck laminates.

5.1.4.2 Polyvinyl chloride (PVC) foam. PVC foam is a chemical foam material that is frequently used as a structural core material. PVC foam is manufactured in two different ways to produce either a rigid, cross-linked type on a tough but lower strength non-cross-linked type. The cross-linked foam can withstand higher loadings, but fails more dramatically than the rigid-elastic PVC type foams. Both foams are affected by temperature and have associated advantages and disadvantages. In construction or repair, the PVC foam may be heated to approximately 200 °F to facilitate forming complex or tight-radius surfaces. After a few minutes cooling time, the foam will be set and further laminating work may be done. The mechanical properties of the foam are affected by temperature. With increasing temperature, properties such as flexural modulus exhibit nearly linear degradation. Therefore, it is advised that PVC foams not be used in areas exposed to high heat. However, with their relatively high impact strength and flexibility in construction, PVC foams are well suited for structural core applications in small craft hulls and other equipment.

5.1.4.3 Aramid honeycomb. Aramid honeycomb is developed from the same chemistry that is used to produce the aramid fibers noted in 5.1.2.3. The major difference between the two materials is that one is manufactured as a fiber, while the honeycomb originates as a fiber but is processed into a paper type product. This aramid paper, commercially known as NOMEX (a trademark of Dupont Co.), is then bound together in a hexagonal cellular arrangement to form a honeycomb material. The honeycomb core is used in conjunction with various types of facing materials to form a structural composite (see figure 5). Attractive qualities of this material include high strength-to-weight ratio and good energy absorption and heat resistance characteristics. For these reasons, aramid honeycomb is used in some high performance structural applications; however, special techniques are necessary in repairing this material, as noted in 6.9.

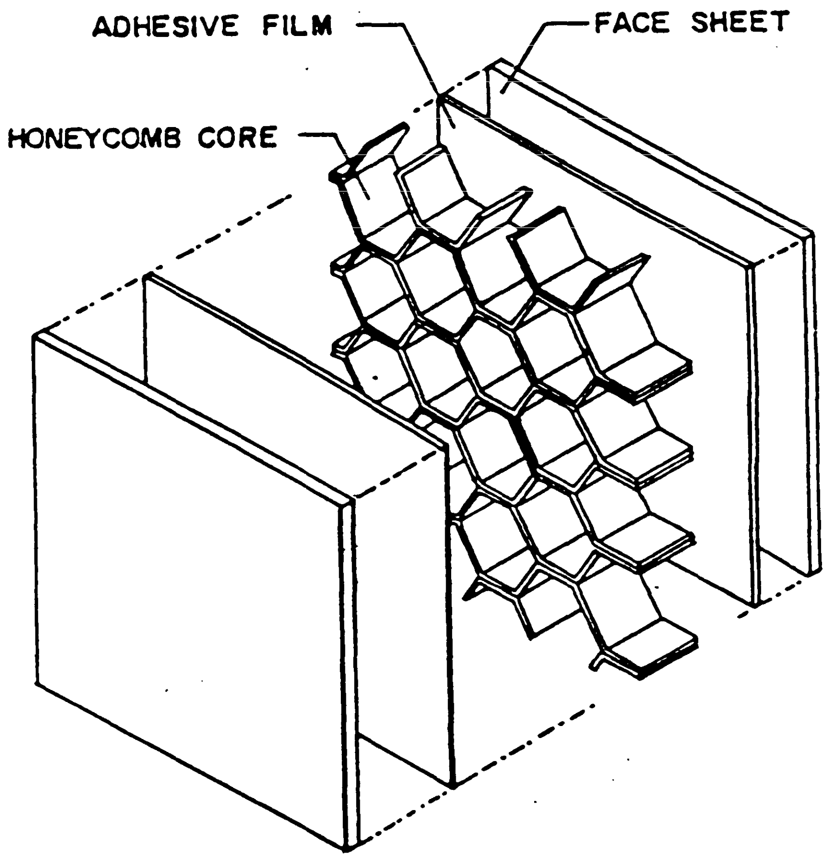

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FIGURE 5. *Typical honeycomb panel construction.*

5.1.4.4 Urethane foam. The type of urethane foam used as a sandwich core is a rigid, closed-cell type of about 6 to 8 lb/ft^3. It is provided in flat boards and is suitable only for flat panel work or slightly curved surfaces. It has been widely used in Navy boats as a sandwich core for bulkheads and seats, and as a form or core for hat-section stiffeners. It is closely related to the very low density foam-in-place floatation foam used in boats, but as a sandwich core it is not foamed-in-place.

5.1.4.5 Nonstructural foams. Occasionally, a nonstructural foam, such as urethane or syntactic, is employed in a structure to give added buoyancy or damping characteristics. Urethane foam may also be used to form a backing plate for hard to reach repairs and as a mold surface. Urethane foam is formed by the chemical reaction between two chemicals - polyol and toluene diisocyanate (TDI). A respirator and gloves are required when mixing this type of foam. Syntactic foam is formed by mixing a specified amount of microspheres or microballoons into a liquid resin and allowing the mixture to harden. Syntactic foam generally has higher strength than urethane foam and is often used in deep ocean applications. It could be considered a structural foam but it is not usually used as a core material because of its relative high density and high cost.

5.1.5 Surface fillers. Gouges and scratches in the surface of a GRP structure are normally repaired with a resin putty or filler made from resin and either milled glass fibers, glass microspheres, or powdered fillers, such as fumed silica (Cab-0-Sil or equal). Commercially available automobile body putties are also widely used for such repairs.

5.2 Tools. Tools necessary for the job should be assembled before starting work so that once the job is begun, unnecessary interruptions to obtain additional tools will be avoided. The particular tools used will vary from repair to repair depending on the nature of the damage, but the following list should be helpful as a starting point:

a. Chalk (for marking the area to be repaired)

b. Protective equipment and clothing, such as coveralls, goggles, gloves, and respirator

c. Ruler or tape measure

d. Saw (metal cutting hand saw, key hole, or reciprocating saw with hack saw type blade) for cutting away damaged area

e. Disk sander, cone sander, or file (for grinding away damaged portion and scarfing (beveling) edge of cutout area)

f. Cardboard, sheetmetal, or plywood panel (for use as backing or cover plate and mixing board)

g. Tape, shoring, or bracing (for attaching or supporting the backing and cover plates)

h. Acetone or other solvent (for cleaning surface and equipment).

Other necessary tools are contained in the standard repair kit (see 5.4). If such kits are not available, equivalent materials and tools should be assembled.

5.3 Safety. Caution must be observed when handling any chemicals or solvents. In making these repairs, the following general safety precautions shall be observed:

a. Cutting glass reinforcement causes small glass fibers to be released into the air. Protect hands and lungs by wearing gloves and a National Institute for Occupational Safety and Health (NIOSH) approval dust mask while cutting or trimming reinforcement.

b. Cutting and grinding of reinforced plastic laminates generates a fine dust. Since the dust is abrasive in nature, it can irritate the skin and eyes, and inhaling of the dust must be avoided. Protective goggles, coveralls, gloves, hood, and a dust respirator must be worn. Also, when equipment is available, air samples should be taken to determine dust concentration.

c. In handling plastic resins and associated chemicals, observe the following precautions:

   (1) Wear protective clothing and eye protection while handling chemicals and resins. Protect your hands by wearing the gloves provided in the repair kit. If available, a protective hand cream may be applied to all exposed skin.

   (2) Avoid chemical contact with eyes, skin, or clothing. Absorption of hardener or catalyst through skin may be harmful. In case of contact with eyes or skin, flush with water immediately. If eyes are involved, the worker should be rushed to a medical facility for attention, as MEKP and other catalysts will cause severe burns to eye tissue.

   (3) Prolonged or repeated breathing of vapors should be avoided. Be sure that there is adequate ventilation provided to draw fumes away from the worker, especially when working in confined spaces. Fans, blowers, or exhaust fans may be required. Organic vapor cartridge or organic vapor disposable type respirators are required for protection against fumes.

   (4) If clothes or shoes become contaminated with resin, remove them at once. If only a small amount of resin has been spilled, they should be thoroughly cleaned before reuse or else discarded.

   (5) Always wash exposed skin areas thoroughly when finished working with the resin.

   (6) Keep chemical containers covered when not in use and clearly label the containers, noting the hazard associated with the contents. In the case of a polyester-resin formulation, labels shall state that you never mix catalyst and accelerator together directly or a highly explosive mixture may result.

   (7) Do not work near hot surfaces or open flames. Never smoke when handling chemicals.

(8) Avoid grinding of metal near open acetone containers as fire may result.

(9) Do not use unprotected light sources in work area.

(10) If further questions exist after reading instructions, contact manufacturer. For specific guidance or unusual repairs, consult the safety officer for proper safety procedures.

d. Disposal of waste and scrap material, particularly unreacted resin, catalyst, hardener, and solvents, shall comply with Federal, State, and local environmental regulations.

5.4 Repair kits. Standard Navy repair kits may be obtained through the normal supply system (Ships Parts Control Center, Mechanicsburg, PA) under stock number 1H 2090-00-372-6064. These kits, which conform to MIL-R-19907, contain not only the basic materials, but many of the necessary auxiliary materials as well. The repair kits contain epoxy resin in several quart and pint cans with preweighed cans of hardener for each, as well as glass reinforcement in the form of mat and woven cloth. Resin cans are slack-filled so that hardener can be added directly to the resin and mixed in the same can.

Although either epoxy or polyester resins are satisfactory for most repairs, epoxies are generally recommended for use in repair kits, since they can be stored for long periods of time before becoming unusable. The auxiliary materials include separating film, kraft paper, protective gloves, wooden spatulas, resin-spreading tools, brushes, and a copy of a brief repair instruction. Sufficient quantities of these materials are provided in the kit to replace about 400 square inches of a damaged 1/4-inch laminate. In addition, the kit contains tubes of a paste resin for repairing minor surface imperfections.

Proper storage of repair kits is important. They should be stored in a cool, dry place. Ideally, temperatures should be kept below 70 °F and the relative humidity less than 50 percent. Kits should never be stored in temperatures below 32 °F. Storage life of the resin will vary as a function of temperature. However, if the resin is stored in a range of 50 to 80 °F, it should remain stable and usable for at least several years. Resins that have been exposed to elevated temperatures for long periods of time should be checked for lumps or excessive thickening. If these characteristics are found in the resin, it should be discarded.

6. REPAIR PROCEDURES

6.1 Introduction. The basic information on materials required to repair reinforced plastic items have been outlined herein. The following will deal with specific repair procedures for a selected number of common repairs. This is not intended to contain information on all types of repairs and materials. However, by studying the basic techniques illustrated here, and with some experience, it should be possible to carry out other types of repairs with relative ease.

The first step in repairing a damaged GRP item is to survey the extent of damage. Often, delamination will occur below or around even a small surface crack. This should be checked by tapping the laminate while conducting a close visual inspection. Also, if there is a stiffener near the damage, it is possible that this too could have separated from the damaged surface or hull. Survey the damaged area completely. Make a list of the tools, materials, and safety equipment that will be necessary to do the repair. Refer back to tables I through IV to help estimate the materials needed for the repair. Be sure to allow for wastage in the estimate for materials. Be thorough in estimating, since catalyzed resin will not wait for additional materials to be brought to the repair site. Temperature has a direct effect on the rate of cure of fresh laminate. Too high a temperature (plus 90 °F) might cause the laminate to cure too quickly. A shaded area and low humidity are ideal conditions for working with resins. If the repair cannot be made in a properly ventilated shop, a tarp should be rigged to prevent direct sunlight on the repair. With the materials and tools assembled, begin working on the repair doing as much as possible before catalyzing the resin. This includes cleaning and preparing the damaged area, cutting the reinforcement materials, assembling the backing plates, shoring, and so forth, and obtaining the required amount of resin. Once all the preparation work has been completed and the damaged area scarfed and cleaned of stray dust, catalyze the resin and begin laying-up the repair patch. Work quickly, but don't be rushed. The success or failure of the patch depends almost entirely on the person doing the lay-up. After the lay-up is finished, check for stray drops of resin and remove them using a solvent (such as acetone) before they harden. Clean up the area and set up heat lamps, if required, to aid in curing the laminate. When the patch has completely hardened, finish the repair by sanding, painting, or polishing the patch as required.

Illustrations of typical repairs are shown on figure 6. As can be seen, the basic method is to remove the defect and the affected area and scarf back to the edge of the laminate to a slope not steeper than 12 to 1, then laminate in a built-up patch. More detailed information is found in the following sections for particular types of repairs. These repairs are not complex, and inexperienced personnel should be able to perform this work with ease. Before any repair is made, read surface fractures (see 6.3), since details of many of the steps common to most repairs are contained in that section.

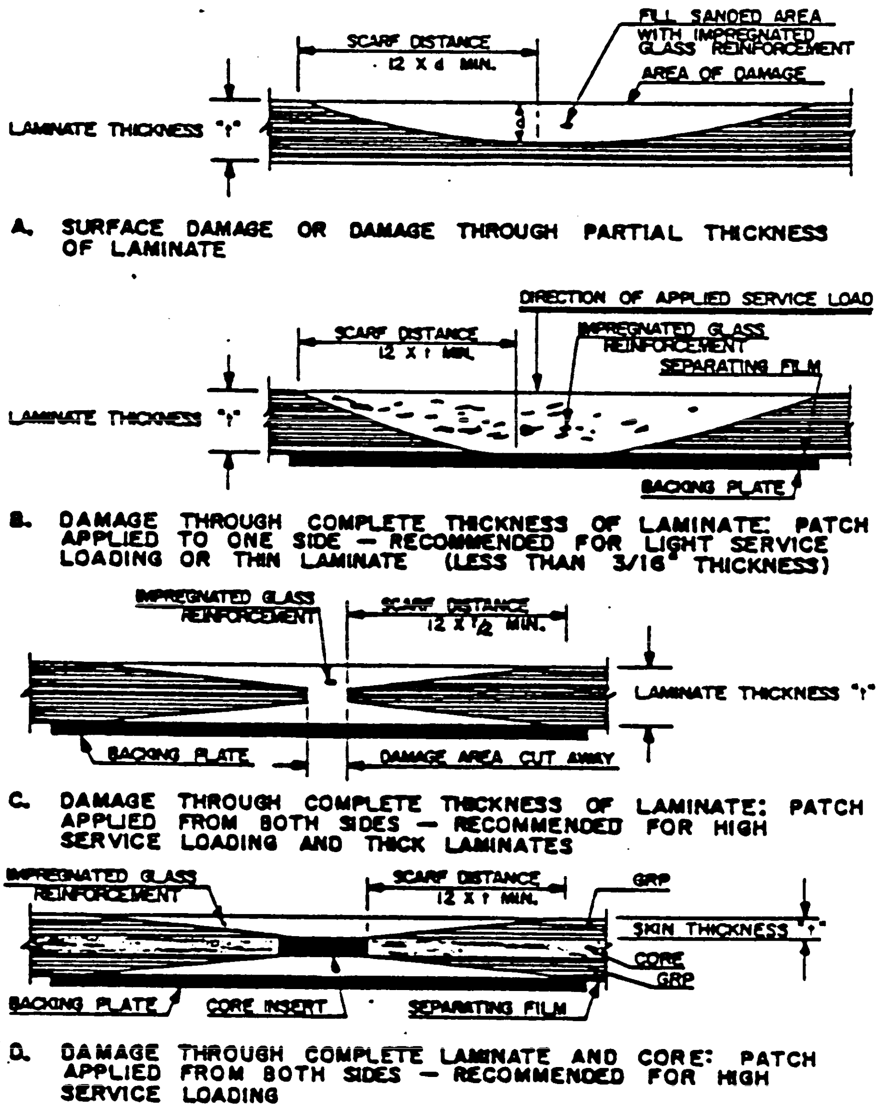

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FIGURE 6. *Illustration of repairs to solid and cored reinforced plastic laminates.*

6.2 Surface cracks and abrasions. Surface cracks and abrasions are the most common types of damage to GRP items. Though relatively harmless in appearance, they may lead to more serious damage due to water migration, and thus should be repaired promptly. Typical cracks and abrasions to a GRP boat hull are shown on figures 7 and 8.

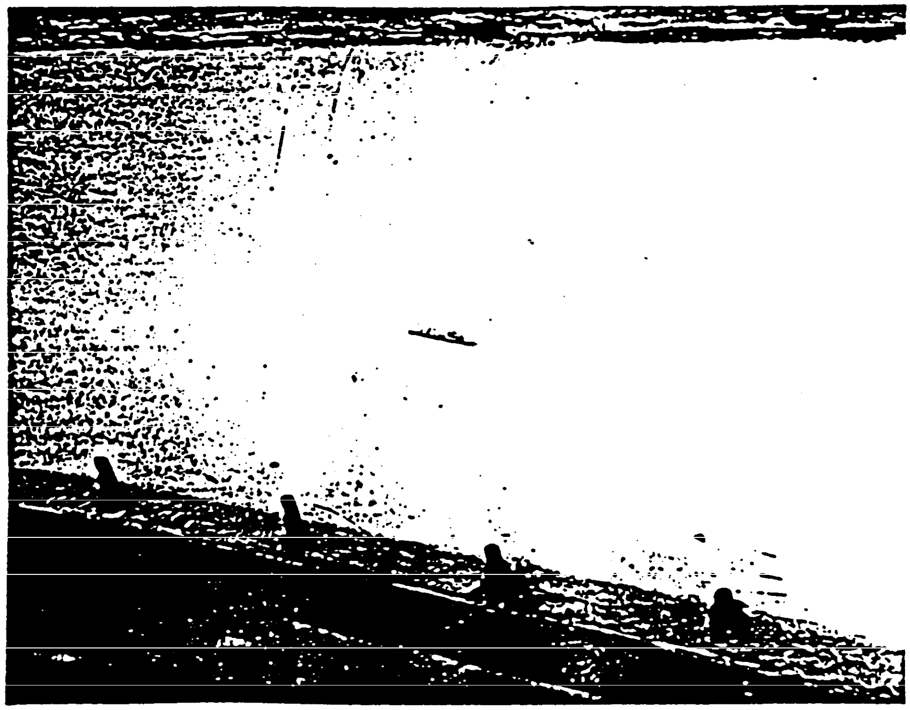

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FIGURE 7. *Small gouge in surface (less than 1/8-inch deep with no serious structural damage).*

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FIGURE 8. *Surface abrasion.*

If such cracks and abrasions are less than 1/16-inch deep, the following procedures apply (see figure 9). First, use a power drill with a burr, sanding sleeve, or disk sander to scarf back the material at the edges of the crack to the depth of the crack.

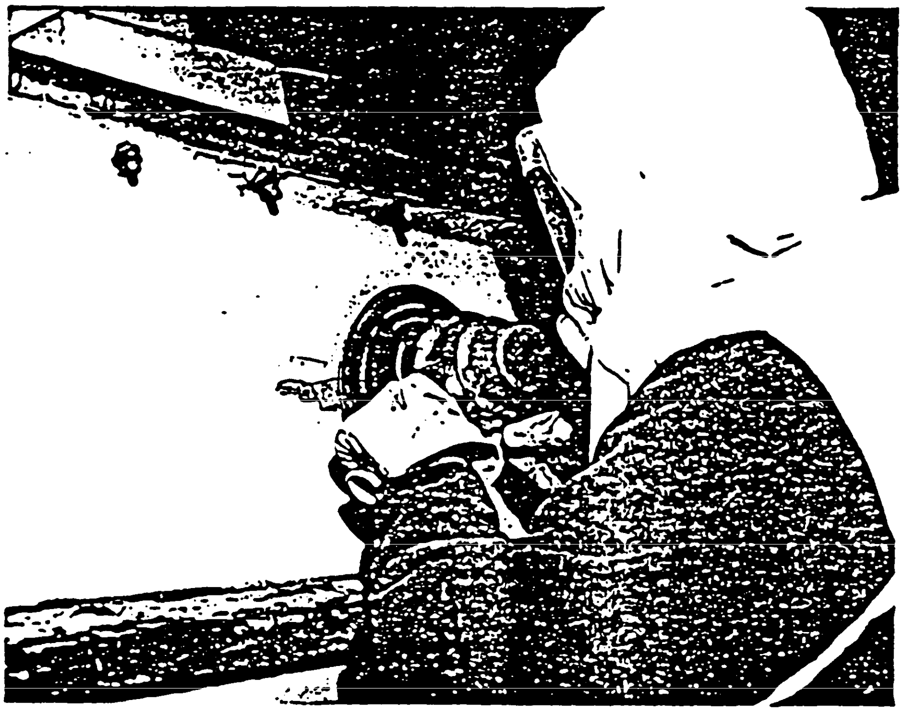

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FIGURE 9. *Smoothing surface crack.*

If the surface has been painted, remove all flaking paint and sand the area around the crack or [illegible]

Clean the area thoroughly of dust and particles and then wipe the area with solvent. Do not touch the area to be repaired as oils from the skin will prevent a secure bond. Mix the resin with a small amount of milled fibers or silica as required to thicken the resin, and the proper amount of catalyst or hardener. Mixing can be done more effectively in a container, but may be done on a smooth flat surface, such as a small square of plywood, sheet metal, or a wood palette. Alternatively, use a commercial, two-part fiberglass putty or the epoxy paste provided in the stock repair kit. Take a small amount of the mixed resin and apply it to the damaged surface with a squeegee, putty knife, mixing stick, or spreading tool (see figure 10).

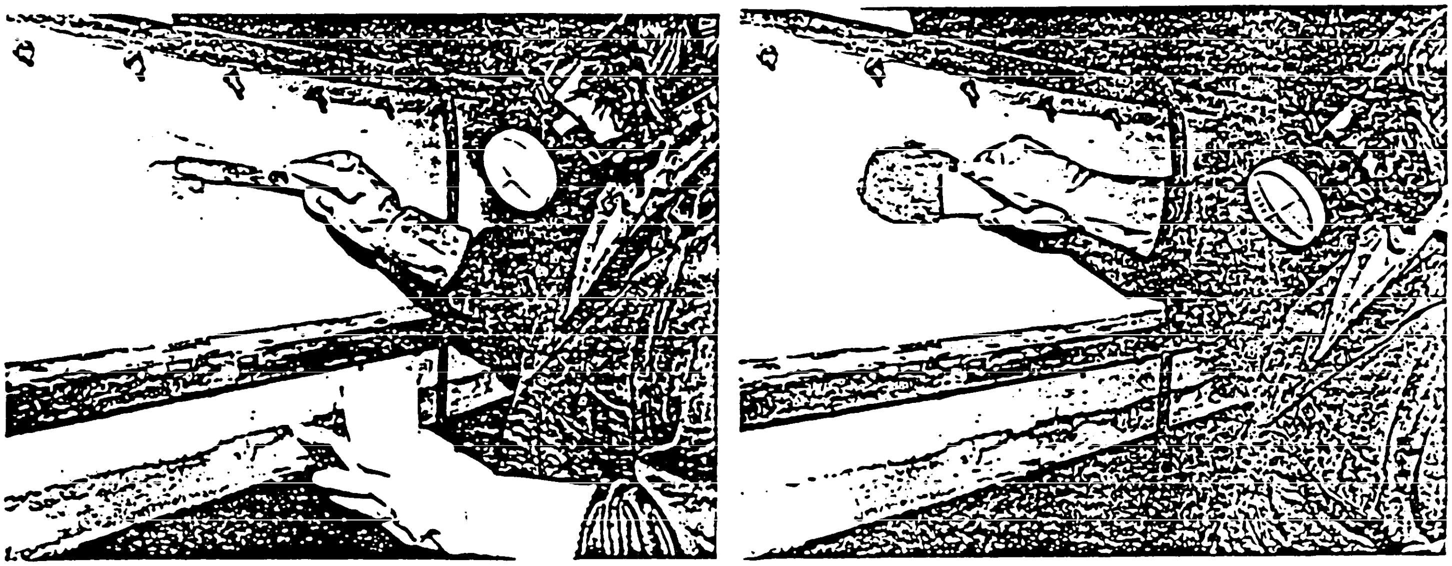

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FIGURE 10. *Working resin into damaged area.*

Work the resin into the damaged area with a circular motion to work out any trapped air bubbles. Apply enough resin to overlap the undamaged area by 1/2 inch and then apply either a PVA or plastic wrap film over the patch. Squeegee the patch to remove any air bubbles and allow to harden. After the resin has hardened, remove the film and sand the patch with fine sandpaper to match the original surface. If any voids appear, lightly sand the area, reapply the resin mixture and continue as outlined above. Painting or other finish work should be accomplished as specified in 7.1 through 7.3.

6.3 Surface fractures. Two types of surface fractures can occur as a result of impact loading or high stress. The first is an open fracture where the surface resin has chipped away exposing the glass plies. The second is a hairline fracture extending into the laminate but not penetrating the back side of the laminate where no appreciable amount of resin has chipped away. Both of these types of fractures should be repaired immediately as stress concentration and weathering of the damaged area will cause further failure (see figures 11 and 12).

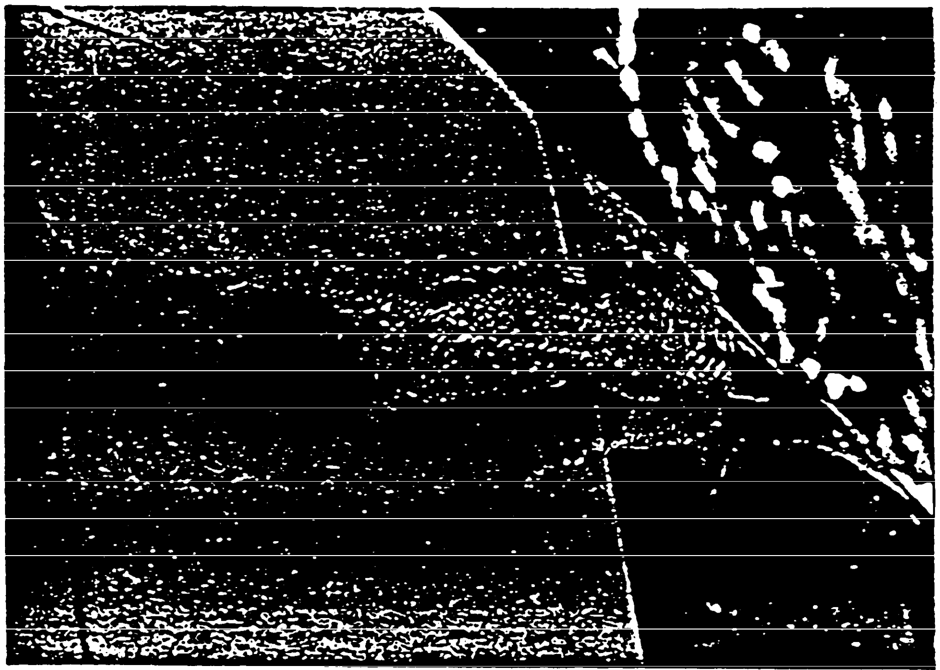

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FIGURE 11. *Open type surface fracture.*

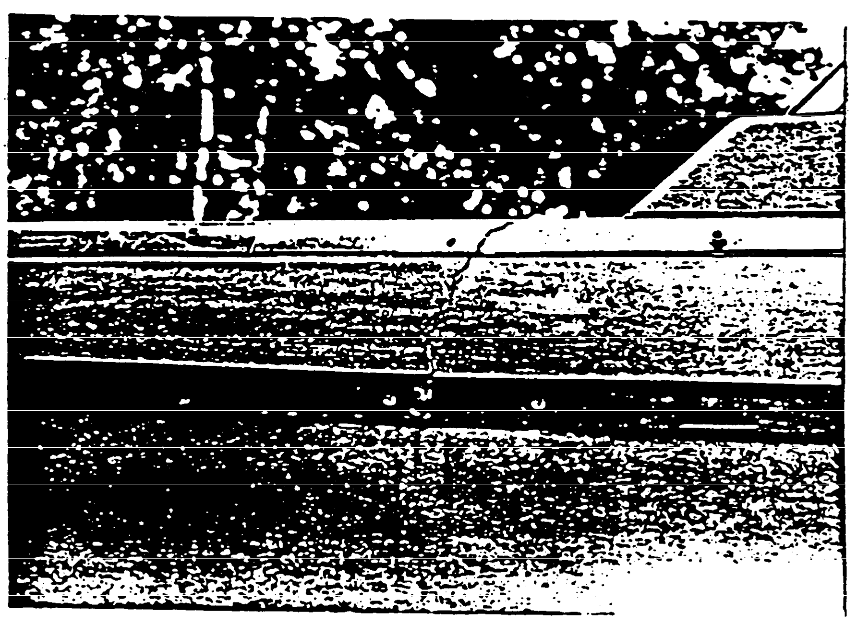

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FIGURE 12. *Hairline fracture on pleasure craft.*

For the open fracture, the first step after surveying the damage is to clear away any loose or broken glass and resin. This will help eliminate the possibility of glass and resin fragments flying loose during the sanding operation. The next step for both types of fractures is to begin sanding away damaged laminate and scarfing the edges around the damaged area. For thick laminates, the damaged area may be chiseled away by cutting around the damage, but not through the laminate, with a sharp chisel and hammer. When sanding, work evenly around the damaged area to avoid creating sharp corners that may catch the sanding disk. Keep the area free of dust by using a vacuum attachment or by blowing the dust away at frequent intervals. Sand until solid laminate is reached, taking care not to break through the back of the laminate (see figure 13).

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FIGURE 13. *Removing damaged fiberglass from outside area smoothly and evenly with heavy-duty sander.*

After the damaged laminate has been removed, chalk mark the scarf area surrounding the damage to a distance of at least 12 times the depth of the damage removed, (for example, for a 1/4-inch depth, the scarf distance would be 3 inches). (See figure 6, example (A) for an illustration of the scarf distance.) Then begin to sand from the damaged area back to scarf line in smooth easy strokes (see figure 14).

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FIGURE 14. *Damaged area with scarf.*

Avoid putting sharp edges or corners in the laminate while sanding as this will make the lay-up of the reinforcement more difficult and lower the strength of the repair. Once the scarfing has been completed, tap the sanded areas to ensure that all of the laminate is solid. If the characteristic solid ring sound is not found throughout the area, a delamination may be present. Mark the dull sounding area and sand until solid laminate is found. Mark and then increase the scarf around the newly sanded area while fairing the new scarf into the old. Clean the area of dust and grit and place a sheet of paper over the scarfed area. Trace the outline of the scarf and the damaged area onto the paper. This tracing will serve as a guide in cutting the reinforcement material (see figure 15).

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FIGURE 15. *Cutting paper template to proper size.*

Knowing the depth of the damaged area, the type of laminate, and the strength required of the item, use tables I and V to estimate the number of plies and type of reinforcement required. If the original laminate reinforcement type is known it should be used in the repair instead of the guidance of table V. In all cases the first ply contacting the substrate is mat. The number of plies can also be estimated by counting the layers of reinforcement showing through the scarfed area. Trace the shape of the required plies on paper by evenly reducing the ply size from the largest to the smallest, using table VI as a guide. Then, calculate the amount of reinforcement necessary by measuring each ply using this template.

TABLE V. *General guide to reinforcement selection.*

Laminate thickness	Required strength	Required reinforcement
1/8-inch or less	All cases	Begin with mat and add glass cloth until sufficient thickness and end with mat
Greater than 1/8-inch	Normal[1]	Alternate mat and woven roving beginning and ending with mat
	High[1]	Begin with mat and add woven until sufficient thickness and end with mat

[1]Normal strength requirements are usually placed on light or nonstructural items, such as boat decks or flag boxes. High strength requirements are generally placed on laminates in areas of high stress such as boat hulls, stiffener connections, mounts, and so forth. High strength is also required from safety related items, including lifelines, stanchions, safety net frames, ladders, and so forth.

TABLE VI. *Guide for step-back in making reinforcement template.*

Type of reinforcement (ounce)	Reduction in size of ply measured form edge (inch)
Mat (1.5)	9/16
Woven roving (24)	7/16
Cloth (10)	3/16

Begin cutting the reinforcement material using light work gloves, a NIOSH approved dust mask, and a sharp pair of shears, starting with the largest ply first. Then, trim the template to the next ply, cut that ply, and continue to the innermost ply. While handling and cutting the reinforcement, take care to keep the reinforcement clean and free of oils. Protective clothing should be worn to prevent skin irritation by stray glass fibers. Table VII is provided as a guide in estimating the amount of resin necessary for repairing an average laminate of 3/8-inch thickness.

TABLE VII. *Guide to estimating amount of resin for a 3/8-inch thick repair.*

Average area of repair (square inches)	Amount of resin (pints)
35	1
144	3
288	9

Clean the scarfed area of all dust and particles with solvent and mask off the scarfed area, leaving several inches between the edge of the scarf and the tape. This will help prevent any runs or drips from running down the full length of the item. With the damaged area now prepared, organize the reinforcement materials within reach of the damaged area with the plies to be used first on top. Combine the amount of resin and catalyst or hardener required or the amount that can be used in 20 to 30 minutes, whichever is less. This will help to reduce resin wastage resulting from large batches that kick over or begin to gel before they can be used. Adding the catalyst to the resin slowly and stirring continuously will assure that the two parts are thoroughly mixed (see figure 16).

The repair lay-up process begins by applying a thin coat of resin to the sanded area and placing the first ply of reinforcing material (glass mat) on to the resin wetted surface.

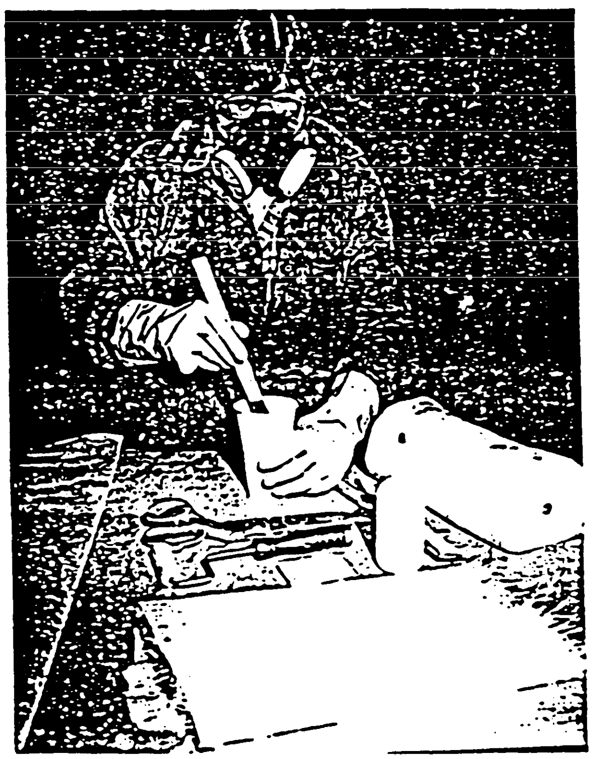

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FIGURE 16. *Materials for repair and mixing resin.*

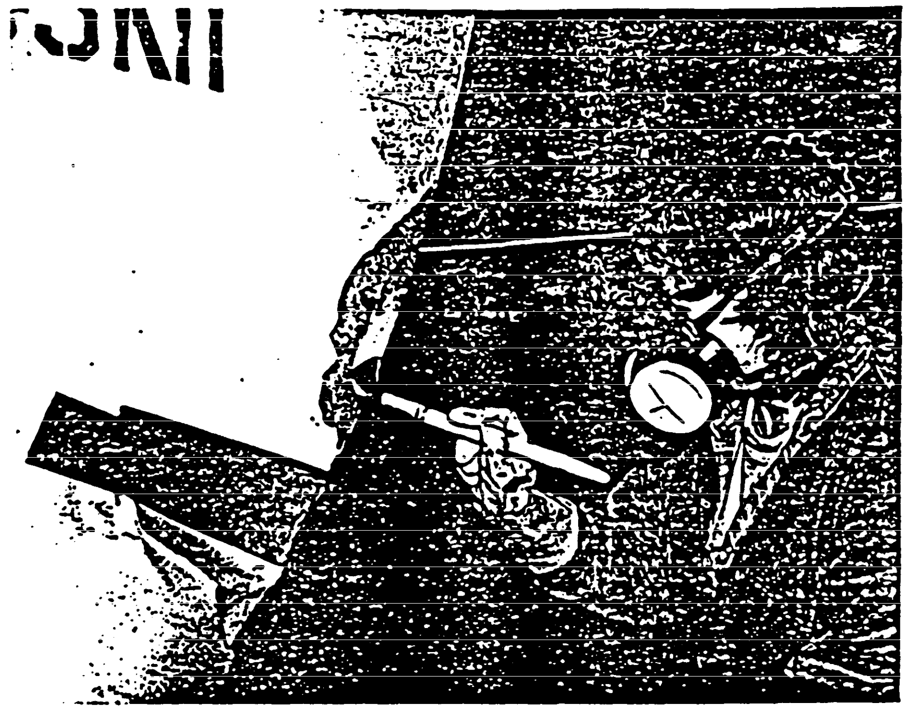

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FIGURE 17. *Reinforcement being wetted out with resin.*

Using a brush, paint the resin onto the mat thoroughly wetting-out, but not oversaturating the mat, (see figure 17). Be careful not to pull the reinforcement away from the damaged area. Work as much air as possible out of the laminate with a roller or by using short dabbing strokes with a brush (see figure 18).

Apply the succeeding plies in a similar manner. Work quickly but do not rush. If the laminate is greater than 1/4-inch thick, do the repair in stages by building up the laminate to about 3/16-inch thick and then allowing the patch to cure to a leather-like, but still tacky, consistency. This two-step process will prevent excessive exothmeric heat build-up in the laminate from the heat generated by the curing resin. When the cure is complete to this stage, mix a new batch of resin and continue the lay-up procedure by spreading a thin coat of resin on the patch and applying the next layer of reinforcement. Build the patch up until it is slightly above the normal surface. Work out any air bubbles using a small aluminum roller (6 inches long, 1/2-inch diameter). Apply a piece of separating film to the fresh laminate and roll or squeegee out any trapped air bubbles. If an epoxy resin is used the parting film is not necessary but may be used to provide a smoother surface or to keep the surface clean.

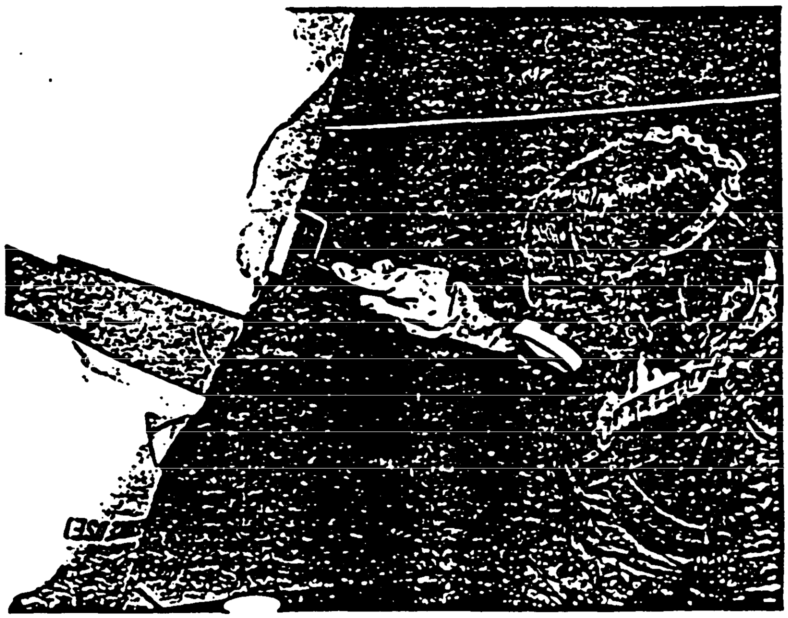

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FIGURE 18. *Working out air and excess resin with roller.*

Allow the laminate to cure to a hard, tack-free finish (the separating film will then easily peel away). This may be aided by heat lamps, but use them with caution as the repair may be easily ruined by too much heat. After the patch has fully cured (a few hours to overnight depending on the resin), pull off the separating film and inspect the patch for voids and subsurface air bubbles. If surface voids are found, fill them using the resin paste. Subsurface air bubbles are permitted if they are scattered pin bubbles. If large air bubbles or voids are found they must be sanded out and repaired as an open fracture or the repair may be redone. After full curing, sand the entire laminate flush with the surrounding surface. Clean the dust from the patch using a blower or vacuum and solvent. Now complete the patch following the instructions found in 7.1 through 7.3.

6.4 Delamination. There are three basic types of delaminations, but all involve separation of the individual plies from the laminate as a whole. An edge delamination is illustrated in figure 19. Stiffener delamination and bubble delamination are the two other common types of delamination. Bubble delamination occurs when plies become separated in the interior of the laminate without breaking the surface. Stiffener delaminations generally appear as if the stiffener bonding flange has been peeled away from the boat hull or attached area.

The repair techniques for these three types of delaminations are different only if the edge delamination is limited in size. If the area of the damaged edge is large (greater than 6 inches in length) or at the surface, then it is recommended that the bubble delamination technique be used.

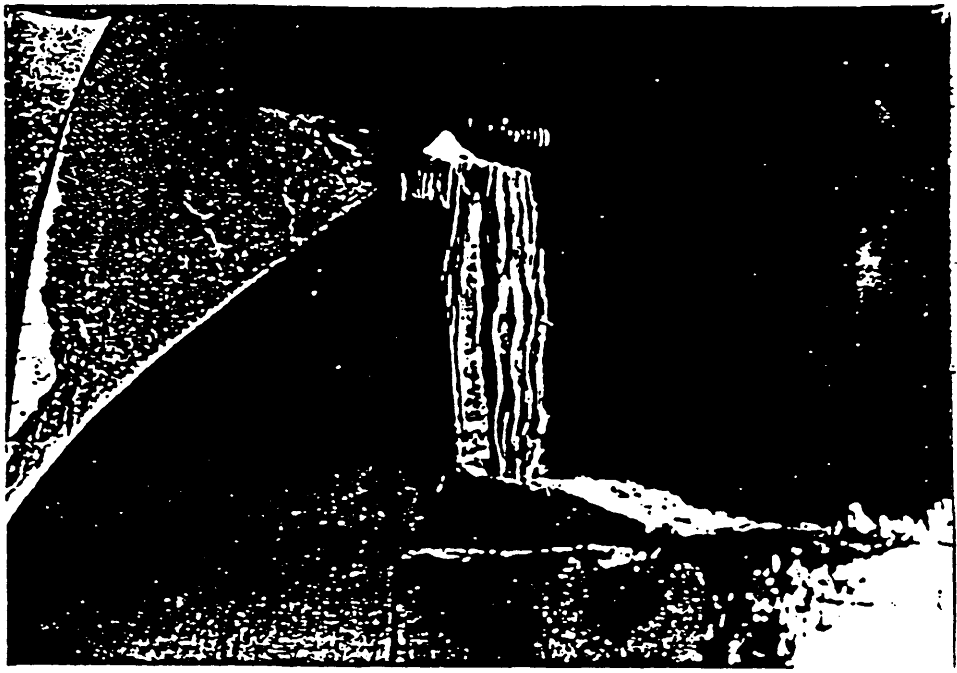

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FIGURE 19. *Edge delaminations.*

6.4.1 Small edge delamination. Edge delamination is characterized by large or small separations in the laminate caused by the breakdown of the bond between the individual plies that make up the laminate. The procedure used to repair small edge delaminations not exceeding 6 inches in length and 1 inch in width, with both top and bottom plies of the laminate intact, is relatively simple.

First, clear away all stray glass fibers and broken pieces of laminate. If, by clearing out these broken pieces, the laminate has been hollowed out, use the techniques described in bubble delamination (see 6.4.2) to make the repair. Otherwise, obtain separating film, two sturdy backing plates (such as plywood), clamps, 1/2 pint of resin, the necessary amount of catalyst and a plastic syringe or stiff brush (see figure 20). Clean away any dust or particles from the damaged area. Mix the resin and catalyst and pour mixture into syringe, if available. Take the syringe or a resin soaked brush and insert it deep into the damaged area and squeeze or dab resin liberally into the laminate. If a brush is used, a resin paste will be more effective in depositing the resin than the resin alone (see figure 21). Continue depositing resin into the laminate, working from back to front and top to bottom between the separated plies. Deposit resin evenly so as to minimize air bubbles. With all separated plies covered with resin, cover backing plates with separating film and clamp them in place on the top and bottom of the laminate (see figure 22). Do not clamp too hard as to squeeze all the resin out of the repair. Remove excess resin coming out of the laminate with a rag. Allow to cure for 12 hours or more at 70 °F (longer if temperature is lower) to assure a strong enough cure.

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FIGURE 20. *Materials for edge delamination repair.*

After the resin has fully cured, check for air pockets by tapping the laminate. A hard, solid ring will indicate a solid repair. Clean the edge by sanding smooth any excess resin drops or squeeze-out. Surface blemishes should be filled with a resin paste and then sanded smooth.

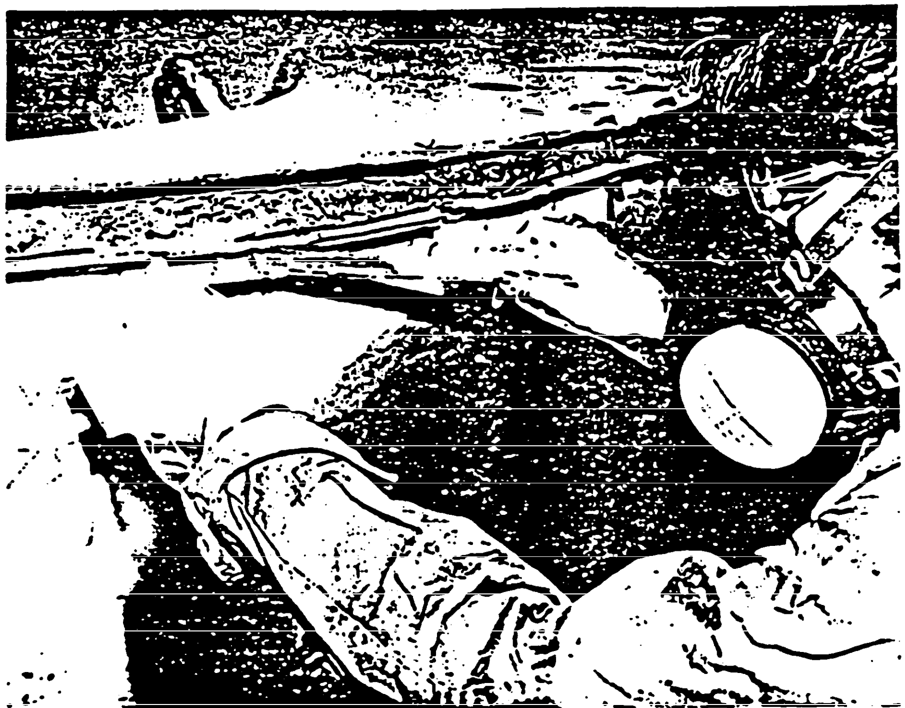

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FIGURE 21. *Applying resin paste to edge delamination.*

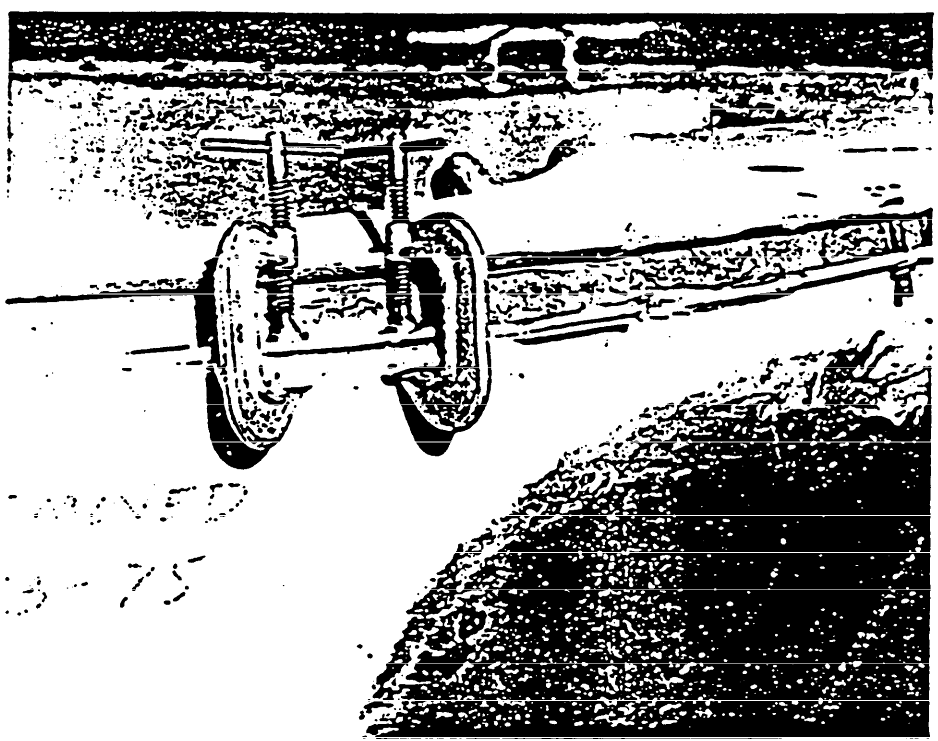

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FIGURE 22. *Clamped laminate.*

6.4.2 Bubble type delamination. This type of delamination is generally due to a breakdown of a small area of resin within the laminate or a pocket of uncured resin or air. A milky color is a sign of this type of delamination, and when tapped, a delaminated area will produce a dull, soft sound as opposed to the strong ring of solid laminate. To repair this type of damage, remove the delaminated portion either by cutting or sanding. If the bubble is near the surface, sanding is recommended, but if the delamination is further down, cutting the laminate may be necessary, especially if the laminate is thick. The idea of cutting the laminate is to peel off only the damaged section and leave the sound laminate intact. This can be done using a sharp chisel.

After the cuts have been made, remove the surface and delaminated plies. If water or uncured resin is found, clean the area thoroughly with acetone and allow to dry completely. The solid laminate should be sanded to provide a fresh, uncontaminated surface and the scarf area laid out as shown on figure 6. The repair procedure is identical to that specified in 6.3. The reader should refer to that section for completion of the repair.

6.4.3 Stiffener delamination. This type of delamination is characteristic of secondary bond failure usually occurring when a craft is subjected to unusual or excessive operating conditions. The telltale signs of this delamination are similar to the other types of delamination, as well as clear separation of the stiffener from the hull. The most effective repair for this damage is to sand or cut away the parted laminate and reform the bonding flange by applying fresh reinforcement. The actual process is similar to repair of a surface fracture (see 6.3), except that as the laminate is applied, care must be exercised to ensure all air is removed from the corner areas of the stiffener. This is accomplished by working each ply from the corner to the edge while applying each resin coat. Should a core be present, consult with fractures in foam core structures (see 6.6). The basic steps for repair of a delaminated stiffener are shown on figure 23.

6.5 Laminate punctures. Laminate punctures are the most common type of damage to GRP equipment. There are two repair procedures for laminate punctures. The first can only be used if the damage is accessible from both sides. The second deals with punctures accessible only from the outside (see figure 24).

A. Delaminated portion of stiffener has pulled away from base laminate. Laminate appears "whiter" in color and has dull or hollow sound when tapped.

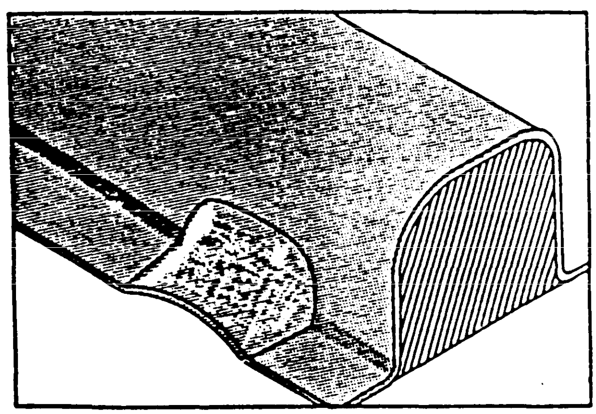

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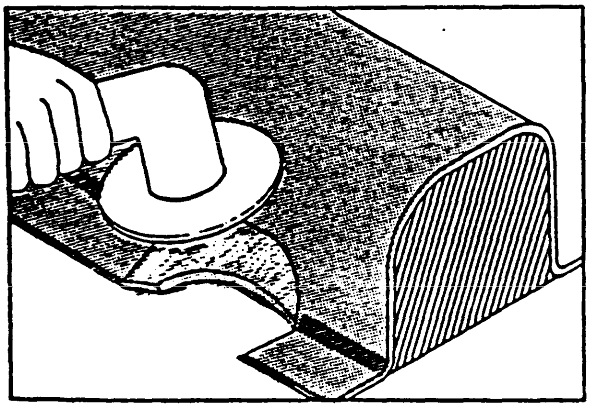
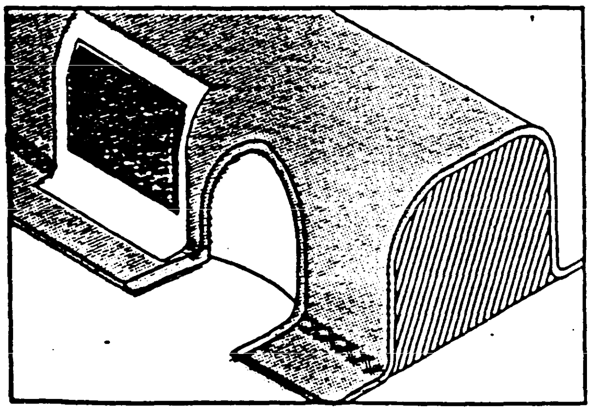
TABLE 23. *Repair of delaminated stiffener.*

B. Sand away delaminated portion back to sound laminate. After sound laminate is found, scarf back edge a distance at least 12 times the thickness of the laminate. Also sand surface of laminate about 2 inches beyound the edge of scarf. Remove any damage or unsound core material.



C. For stiffener with core proceed to step E. For hollow stiffener a backing plate must be formed. Place separating film over stiffener adjacent to sanded area. Cut three plies of glass cloth to form backing plate. Plate should be longer than damage by 2-4 inches and nearly as high. Wet out glass cloth in successive plies with resin and allow to harden.



D. After plate has hardened remove from separating film. Trim stray pieces of glass and square sides with heavy-duty scissors or sharp knife. Trim the height so that it will just fit through the damage opening. Check fit of plate by trial placement. Obtain resin, hardener and filler (Cab-O-Sil or equal) in an amount sufficient to coat edges of plate (1-2 inches each edge). Obtain thin wire and wood batten to secure plate to stiffener. Follow procedure in section 6.5.3.1 to attach plate to stiffener.

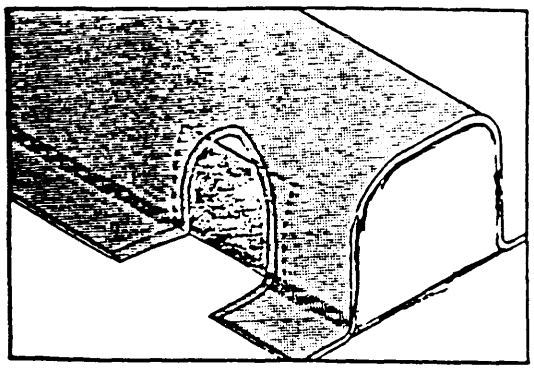


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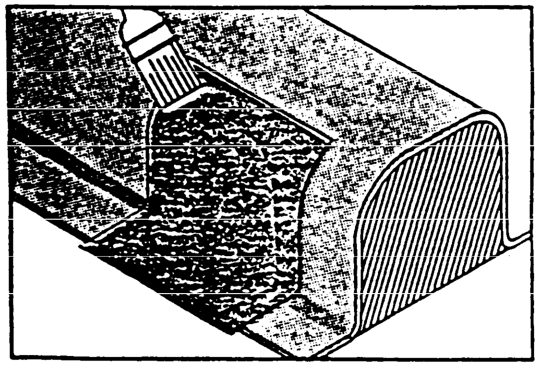
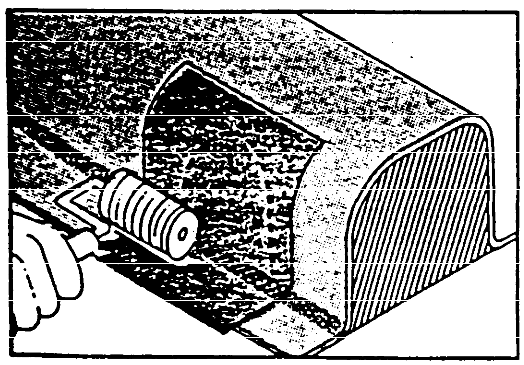
FIGURE 23. *Repair of delaminated stiffener – Continued.*

E. For core filled stiffeners, replace any large pieces of core with new core using resin as an adhesive or form a new core patch using mixed resin and microballons as paste core material. Small depressions in core should be filled with resin paste. With patched core or backing plate hardended (remove wires and batten from plate) estimate amount of resin and reinforcement required to make patch allowing for 1 to 2 inches of overlap of scarfed edge. Mix and apply resin to damaged area followed by reinforcement. Wet out reinforcement using brush.



F. Roll out air and excess resin from patch with roller after each application of reinforcement.



G. Allow patch to harden. Inspect for voids and unbonded areas.

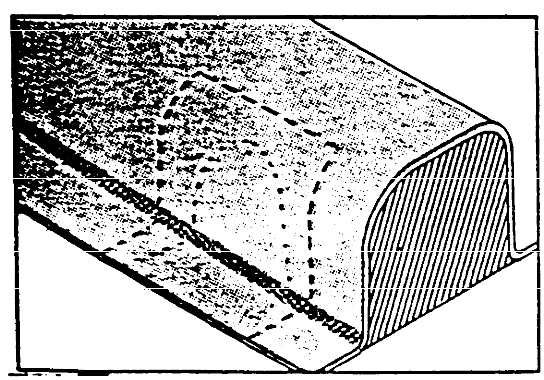


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FIGURE 23. *Repair of delaminated stiffener – Continued.*

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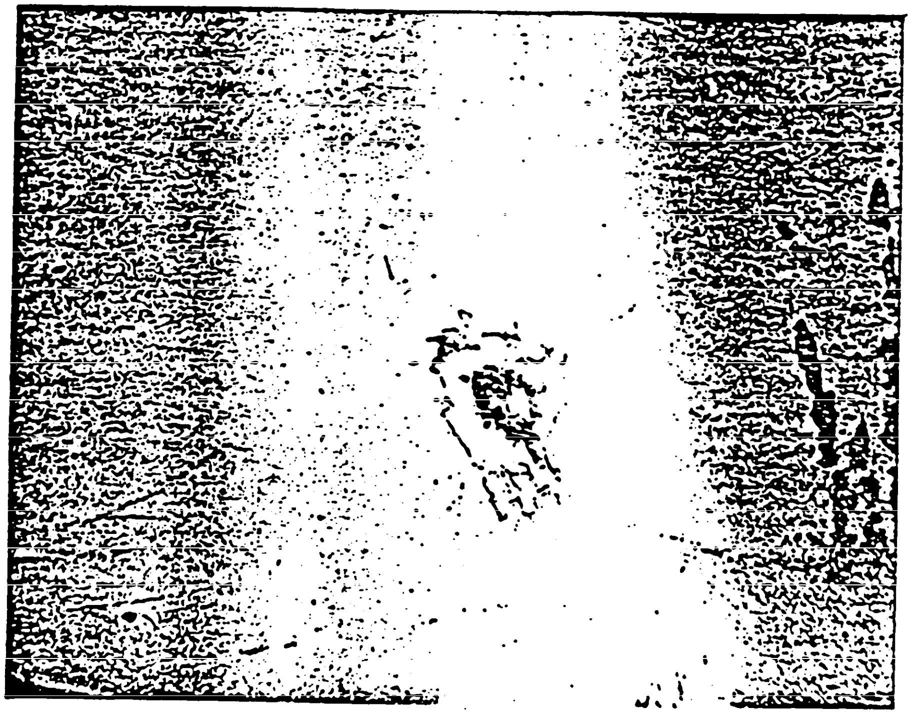

FIGURE 24. *Typical puncture.*

6.5.1 Laminate punctures accessible from both sides. Before starting the repair, carefully examine the damaged area using visual and sound inspection procedures to determine the full extent of the damage. If the damaged equipment is small and the cracks are extensive, replacement should be considered. However, if damage is confined to a reasonable area, follow the safety requirements of 5.3 and repair as follows:

a. Assemble the necessary tools as discussed in 5.2, plus any auxiliary tools (squeegee, mixing sticks, and so forth).

b. Mark an area around the damage that contains solid laminate to serve as a cutting line for removing damaged laminate.

c. Cut along the line and remove damaged laminate using a power saber saw or hand key-hole saw. Cut back to solid laminate, even if it requires enlargement of the original hole.

d. Determine the type of scarf repair to be used, based on the guidelines of figure 6. For laminates less than 1/4-inch thick or where access is possible from only one side, use the single scarf repair shown in type B of figure 6. For laminates 1/4-inch or thicker or where access is possible from both sides, use the double scarf repair shown in type C of figure 6. The recommended length of the scarf is at least 12 times the thickness of the laminate or 12 times the thickness to be laid-up on one side.

e. Begin scarfing using a disc sander (see figure 25) and smooth, easy strokes, to avoid leaving any hard corners or deep ridges. Ensure that no stray glass fibers or jagged corners remain.

f. Clean the sanded area of dust and particles, and estimate the required amount of reinforcement and resin needed (see 6.3). With a double scarf, estimate the total materials for each half-thickness, and assemble two material packages which will be laid-up separately.

g. Assemble repair materials, and materials to form the backing plate (glass cloth, plywood, sheet metal, stiff cardboard, or other).

h. Construct the backing plate so that it is several inches larger than the feather edge of the scarf. This will ensure proper support. (NOTE: Since the backing plate of the double scarf will be contacting the sloping surface of the second scarf face, it will need to be flexible and probably somewhat smaller.)

i. Trace the outline of the scarfed area on paper, to be used as a template for cutting the individual plies of reinforcement. The number of plies can be estimated from table I. Cut out each ply and place in order of use on a clean surface.

j. Clean the sanded area with solvent.

k. Cover the backing plate with separating film and place on the appropriate side of the laminate, using tape or shoring to hold in place. The backing plate must lie as tightly as possible to the feather edge of the scarf to prevent the reinforcing materials from running under the plate to the opposite side of the laminate.

l. Slowly add the catalyst to the resin while stirring constantly. Mix thoroughly.

m. Begin laying-up the patch, using a brush to apply a thin coat of resin to the sanded area and backing plate, followed by the first layer of mat reinforcing material. Thoroughly wet-out this layer with resin. Work out any air bubbles before placing the next ply. (NOTE: Do not pour resin on to the reinforcement, as this will produce excess resin and air bubbles.) Continue applying layers of reinforcement, thoroughly wetting-out each layer with resin and ensuring that no air bubbles are trapped within the laminate. Build up the patch until it just exceeds the height of the surrounding surface.

n. Work out any air pockets or bubbles with a roller or brush. If using a polyester resin, apply a sheet of separating film over the patch and allow patch to cure. After curing, remove the separating film and backing plate.

o. Inspect the patch for voids and soundness. If surface pits or blemishes are found, fill with putty or polyester paste. After allowing the putty or paste to dry, sand the surface smooth and clean the area of dust with acetone.

p. If a double scarf is used, remove the backing plate and wipe the scarf face with acetone to remove residue. Build the second side of the patch as described in "m." above. The second side should be laid-up as soon as the first side is cured sufficiently to preclude damage by the follow-on work. (NOTE: if the second lay-up is not begun within 24 hours, the second scarf face and the visible back side of the first lay-up should be lightly sanded and wiped with acetone to provide a fresh bond area.)

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FIGURE 25. *Scarfing area around punctured area smoothly with power sander*

After removing the backing plate of single scarf repairs, there will probably be a slight depression in the area of the newly applied patch. This depression should be very shallow and if required for appearance, it can be easily filled with a resin and milled fiber paste. Apply this paste with a putty knife or squeegee, leaving as smooth a surface as possible (see figure 26).

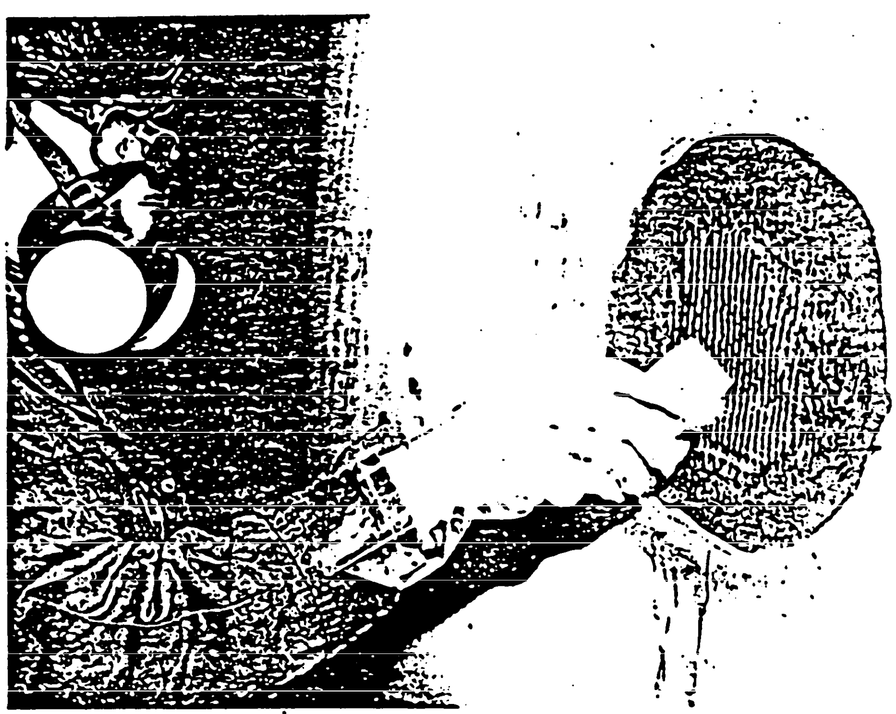

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FIGURE 26. *Working air out of woven roving with squeegee.*

After allowing the putty to harden, sand the surface using fine grade sandpaper to remove any rough areas. Final finishing of surface should be done as specified in 7.1 through 7.3.

6.5.2 Punctures through complex surfaces. Occasionally, a puncture will occur on a surface that has a tight radius or complex curve. In these instances, it may be beneficial to build a mold to serve as a backing plate so that the repaired surface is as close a match to the original surface as possible.

To build the mold, first inspect and clean the damaged area of stray broken glass and resin. Any jagged pieces of glass and resin that protrude above the normal surface must also be removed. After determining the extent of damage, obtain some modeling clay and rebuild the exterior surface, making sure the clay is as smooth as possible. Mask off the area surrounding the damage, leaving about 5 inches excess around the damage as a work space and to allow for cutting the damaged area back to sound laminate later. Spray the masked off area with a mold release agent (usually PVA) and allow the film to dry. Obtain enough 10-ounce cloth to make a laminate 5 plies thick and cut the cloth to the outline of the masked area. Mix up the corresponding amount of resin and begin building up the mold one layer of cloth at a time. After the mold has hardened, remove from the damaged piece with gentle pressure. Wash the damaged piece with water to remove the PVA and allow the area to dry thoroughly. Cut away the damaged area (still filled with clay) and use the repair procedure for a single scarf from the opposite side with the mold as a backing plate. Spray the mold surface with mold release before attaching it as a backing plate to avoid any possibility of accidently spraying it on the scarfed bonding surface. As an alternative, a mold can be laid up using an identical undamaged boat as a plug or molding surface.

6.5.3 Laminate punctures accessible from the exterior only. This type of repair often requires patience and creativity, since only one side of the damaged item is accessible. The key to success of this repair is forming and securing a backing plate that will facilitate a smooth, well bonded patch. With only one side available for inspection, it is especially important that this repair begin with both visual and sound inspections to check for delaminations and subsurface cracks. After the extent of damage has been determined, gather the necessary tools and cut away the damaged area with a power saber or hand keyhole saw. Be sure that only sound laminate remains after the damaged area is removed. Also do not leave any sharp corners, which may cause small gaps in the patch laminate and cause stress concentrations. After the damaged area has been removed, feather or scarf the area surrounding the hole with a power disk sander. The scarf should be taken back a distance of at least 12 times the thickness to ensure a good bond between original and patch laminate. Work the sander in smooth, even strokes so no ridges or corners remain. Clean the area of dust, particles and stray glass. Estimate amount of repair materials to be used for patch using surface fractures as a guideline (see 6.3). Once the repair materials have been obtained, a backing system must be chosen to support the patch. Several different types can be used, some of which are as follows:

6.5.3.1 Glass laminate backing. This form of backing employs glass mat or cloth as a backing material and is especially useful for flat surfaces (see figures 27, 28 and 29). A wood batten is used to support the backing plate, which shall be constructed before the lay-up of the patch. The batten length should be 6 to 8 inches longer than the widest dimension of the scarfed area. Two small blocks of wood can be nailed at both ends of the batten to keep the batten off the surface 2 to 3 inches.

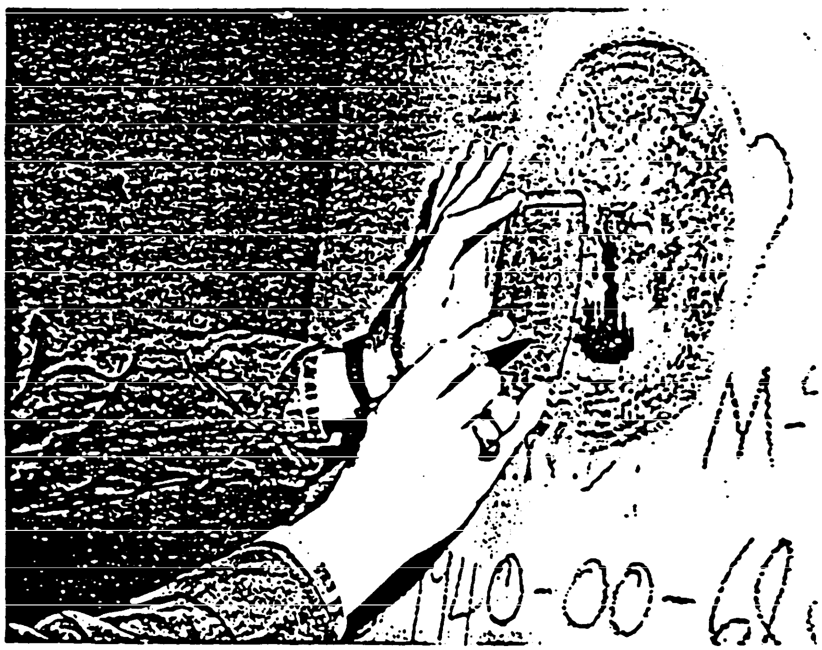

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FIGURE 27. *Measuring for back-up plate size.*

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FIGURE 28. *Cutting out backing plate material.*

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FIGURE 29. *Wetting out backing material.*

To form the backing plate, cut a template of paper 3 inches larger all around than the hole size. Using this template cut 2 or 3 plies of mat or cloth, which will become the backing plate. Measure the proper amount of resin and catalyst to be used and mix them together. Begin laying-up the plate on a piece of separating film using a brush to apply the resin. All air bubbles should be removed using the brush bristle ends in a tamping action or by using a roller. After all the plies have been laid-up and the air bubbles removed, set the plate aside to cure (see figures 30 and 31).

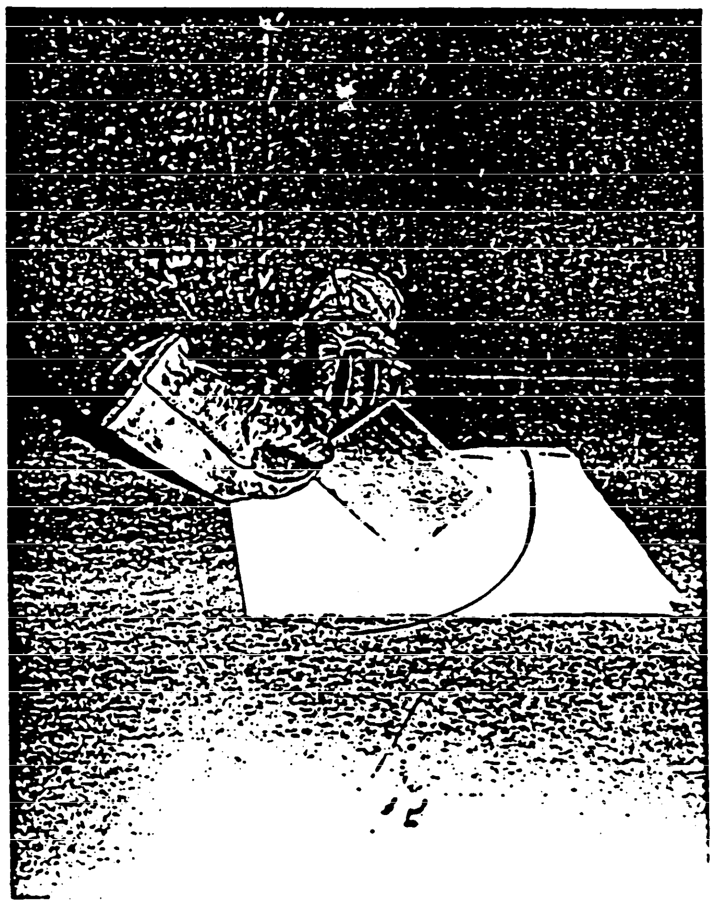

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FIGURE 30. *Backing plate and retaining wire.*

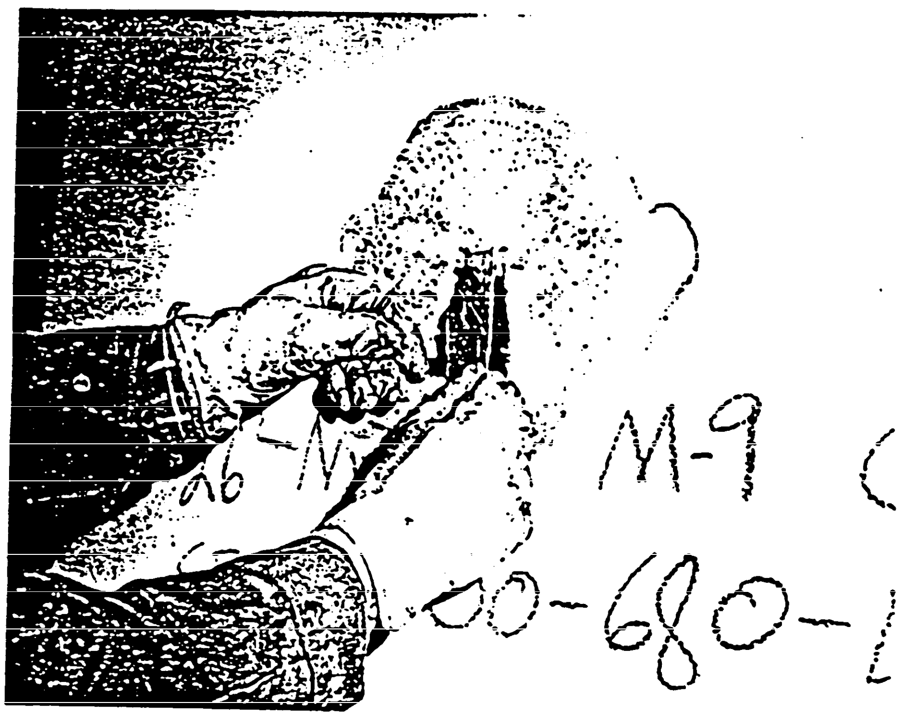

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FIGURE 31. *Placing backing behind original laminate.*

When the plate has cured to a leather-like consistency, punch holes through the back side of the laminate so that thin stiff wire loops can be inserted from the back and left extended out the front through the laminated plate. Holes should be punched in pairs, with the number of pairs the same as the number of wire loops. Take the laminate with the wire loops attached and carefully slip it through the cut-out hole, leaving the ends of the wires extending through to the outside. While maneuvering the piece sideways through the hole, the wires will allow you to hold onto the piece and prevent it from falling inside (see figure 32).

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FIGURE 32. *Securing backing plate.*

Position the plate on the inside of hole so that the edges of the plate have a 2-inch overlap on the inside of the damaged laminate. Pull wires toward you to temporarily hold the plate in position. Take the prepared wood batten and place it to straddle each pair of extended wire ends so each pair of wires can be pulled and twisted around the support to hold the plate firmly in place. If desirable, small strips of masking tape can be used to hold the support in place while working. Ensure that the plate is secure against the damaged piece (see figure 33). This method has the disadvantage that in laying-up the patch the support wires are in the way. Reinforcement must be worked around the wires, by cutting slits in the layers. The slits should be staggered from layer to layer to avoid having them occur in the same plane through the thickness.

A variation of this method is to use milled fiber paste or epoxy paste resin (see 6.2) and "butter" it on the backing plate where it will contact the back of the damaged laminate. Place the plate, tighten up hard on the retaining wires and let the putty cure and bond the plate in place. Wipe off any paste that oozes onto the scarfed surface. When cured, remove the remaining wires, clean the scarf surface and lay up the patch.

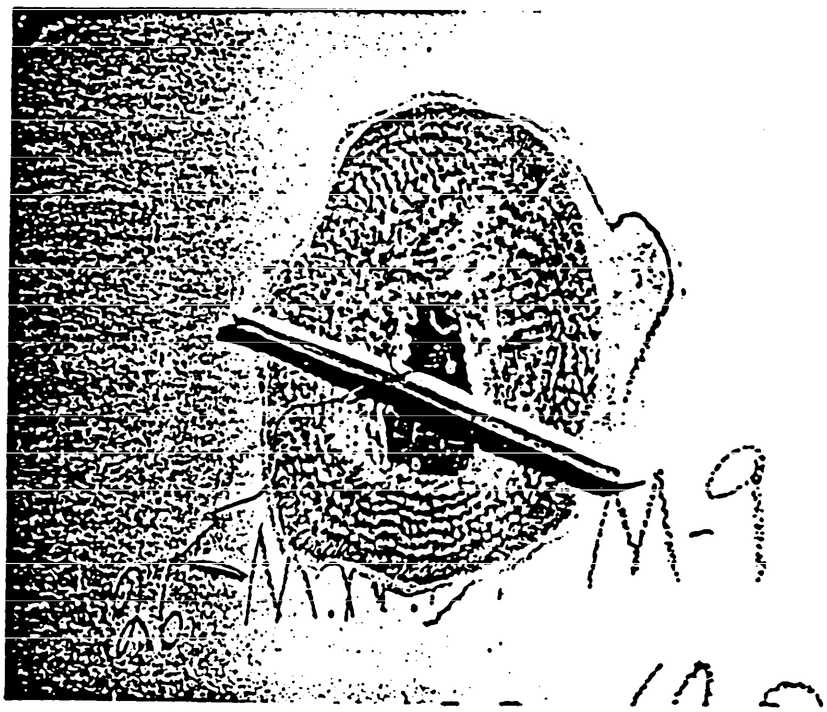

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FIGURE 33. *Batten and backing plate in place.*

6.5.3.2 Screwed-in-place backing. This type of backing is especially useful for complex surfaces, since it can be shaped and uses no support brace as in the previous method. The steps for constructing this type of backing plate are as follows:

a. Cut a backing plate slightly larger than the hole from sheet metal or heavy, stiff cardboard.

b. Punch a pair of holes near center of plate so that a thin piece of wire can be slipped through.

c. Place a wire of sufficient length to extend out 3 inches through the punched holes.

d. Supporting this backing material on a loop of wire, slip plate through the hole in the laminate and pull it against interior surface of the item.

e. Fit and shape the backing plate until you get a good fit between the plate and the interior surface of the item.

f. Remove the plate from the interior of the item and place it over the damaged area and drill several holes through the plate and into the scarfed laminate.

g. Place the plate behind the laminate and align the holes.

h. Holding the backing plate with the wire loop, insert sheet metal screws through the predrilled area into the plate. Once these screws are holding the plate in position, remove the wire loop.

i. Obtain required reinforcement and resin. Cut reinforcement into proper shapes, mix resin, and begin repair. Build up the layers of reinforcement until it slightly overlaps the scarfed area. After the patch is partially gelled, remove the screws supporting the backing plate. Then allow the patch to harden completely. If the screw heads are well below the finished surface of the patch they can be left in place especially if they are of a corrosion resistant material (metal or plastic).

j. A variation of this method would be to apply paste resin to the patch to bond it to the back of the damaged laminate. After curing, the screws can be removed before laying-up the patch.

6.5.3.3 Foam backing. If the damage has occurred in a foam filled buoyancy chamber or in an area where there is a small void, filling the void with foam-in-place urethane foam provides convenient backing for the patch lay-up. The space should be fully investigated using design drawings as well as a visual inspection to make absolutely certain that the space can be safely filled with foam. After the foam components have been properly mixed and placed within the void, allow the reaction to take place and the foam to harden. Then, cut away the excess foam from the damaged area and work the surface with a file or sander to bring it flush with the inside face of the damaged laminate. This process is illustrated in figures 34 through 38.

After using any of the above methods to fabricate and secure the backing plate, the repair procedures are identical to those in surface fractures (see 6.3). Ensure that the scarfed area is fresh and clean before laying-up the repair patch. If it is contaminated by handling or spillage, dust, and so forth, sand the area lightly again and wipe with acetone.

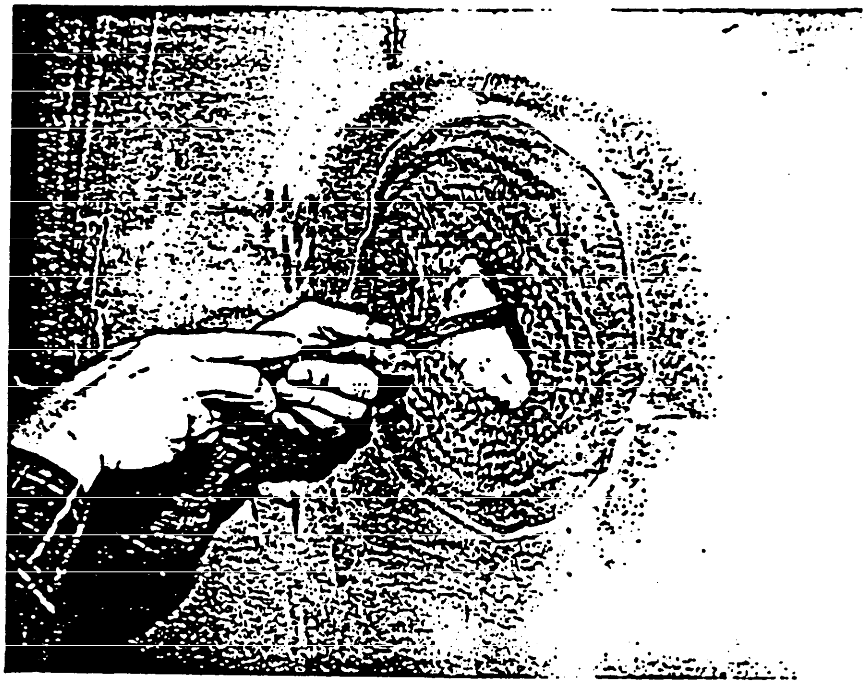

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FIGURE 34. *Removing fractured foam from damaged area.*

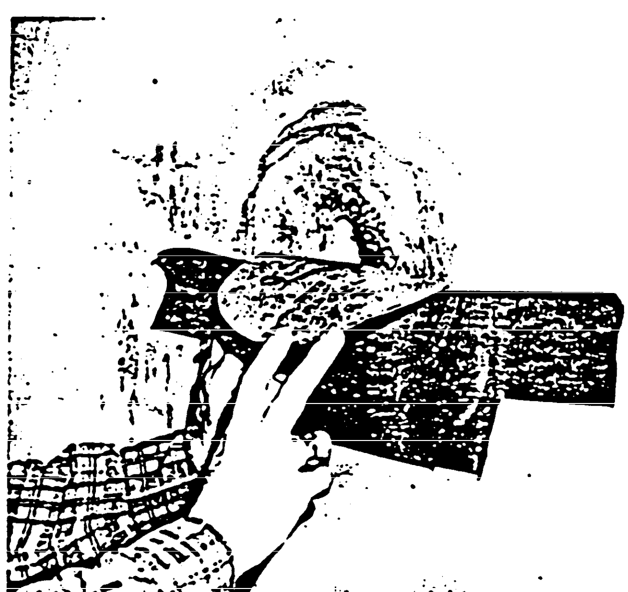

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FIGURE 35. *Retaining plate taped to hull.*

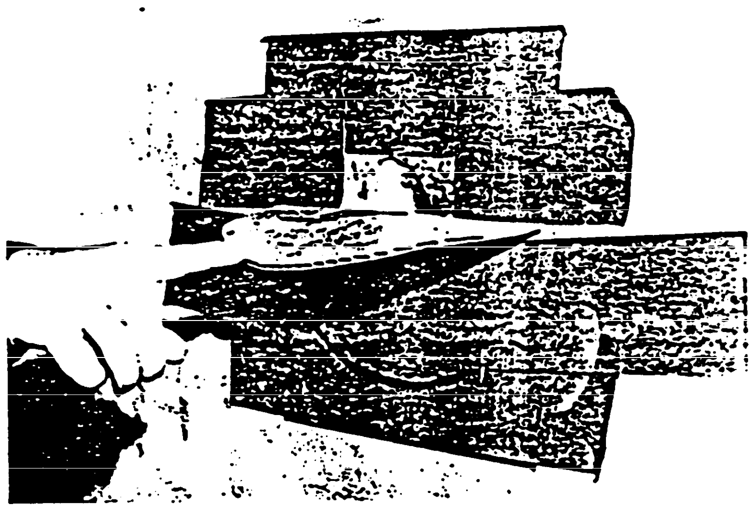

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FIGURE 36. *Tape placed around damaged area.*

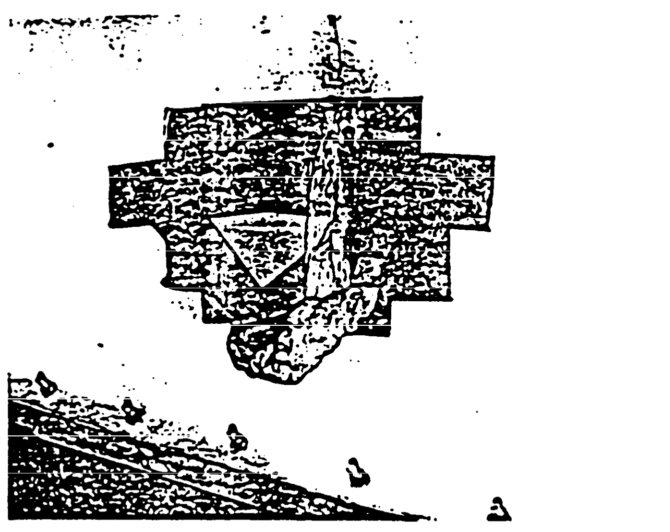

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FIGURE 37. *Excess foam leaking through retaining plate.*

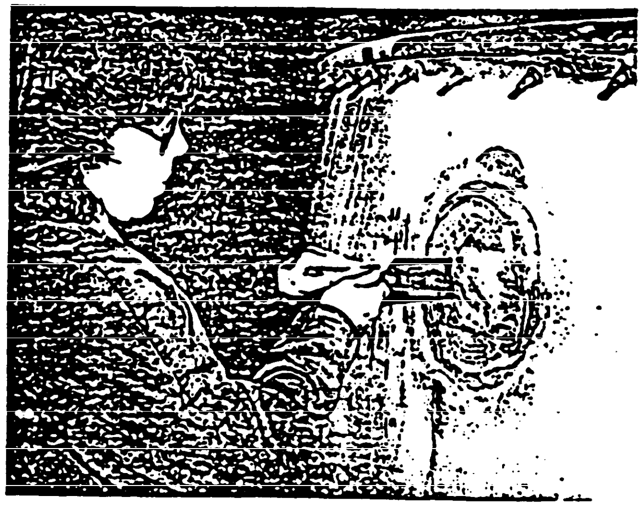

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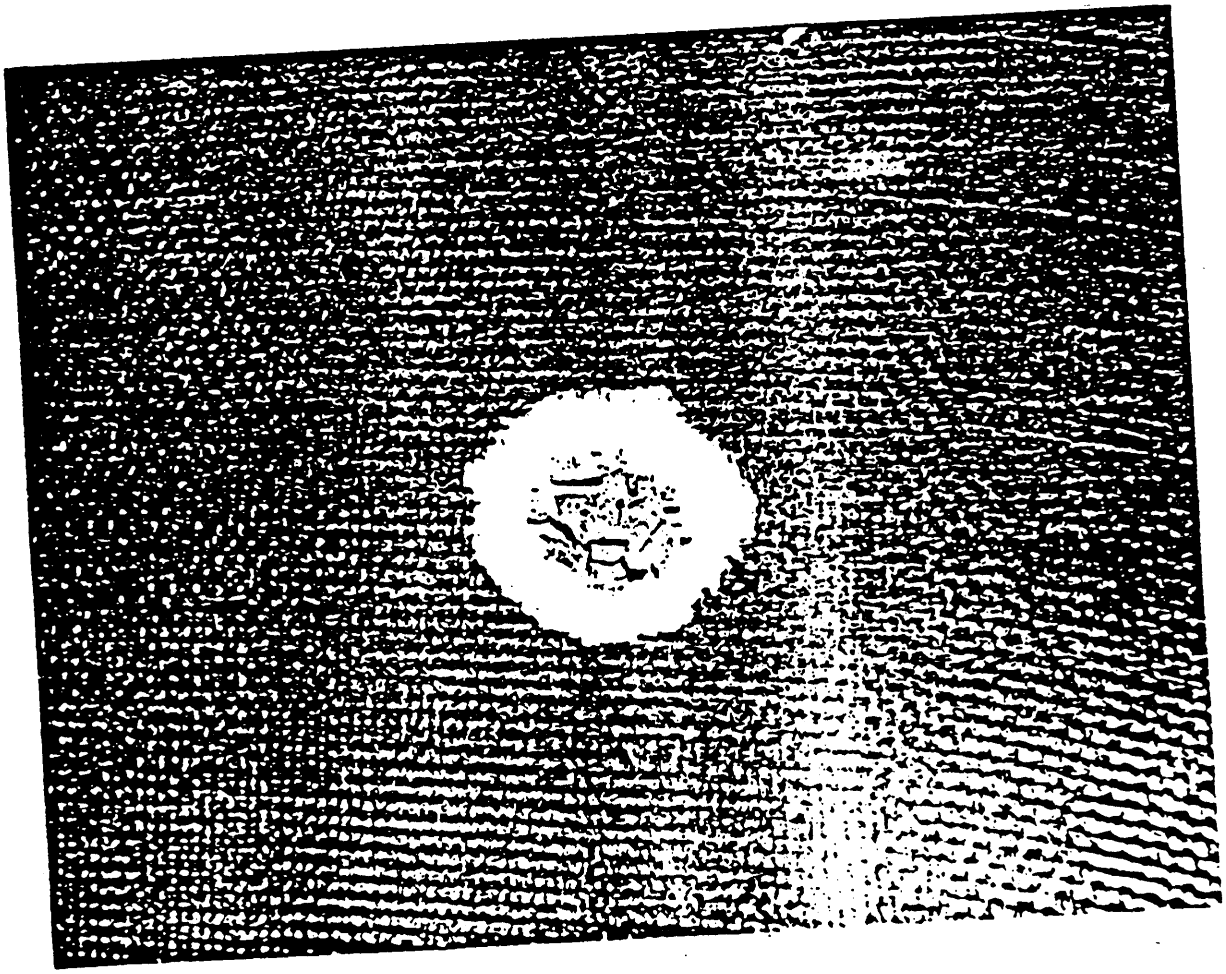
FIGURE 38. *Excess hardened foam removed with chisel.*

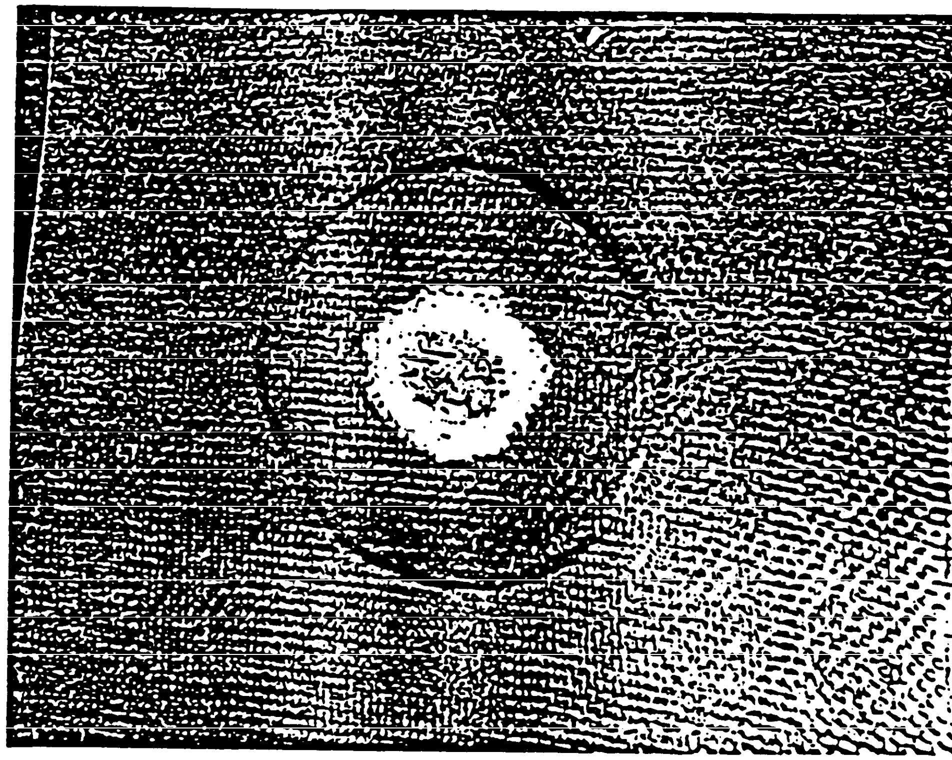
6.6 Fractures in foam core structures. Foam core structures (stiffeners, bulkheads, topsides, and so forth) add a slight complication to reinforced plastic repairs. For surface fractures that do not penetrate the core, repairs are much the same as for solid laminate. Fractures that penetrate the core should be taped over immediately to prevent water infiltration and migration, which may lead to further degradation of the laminate or core. When an appropriate time can be found to make the repair, the tape should be removed and the laminate allowed to dry out so that all trace of water has evaporated (see figure 39).



SH 13202988

FIGURE 39. *Damage to foam cored panel.*

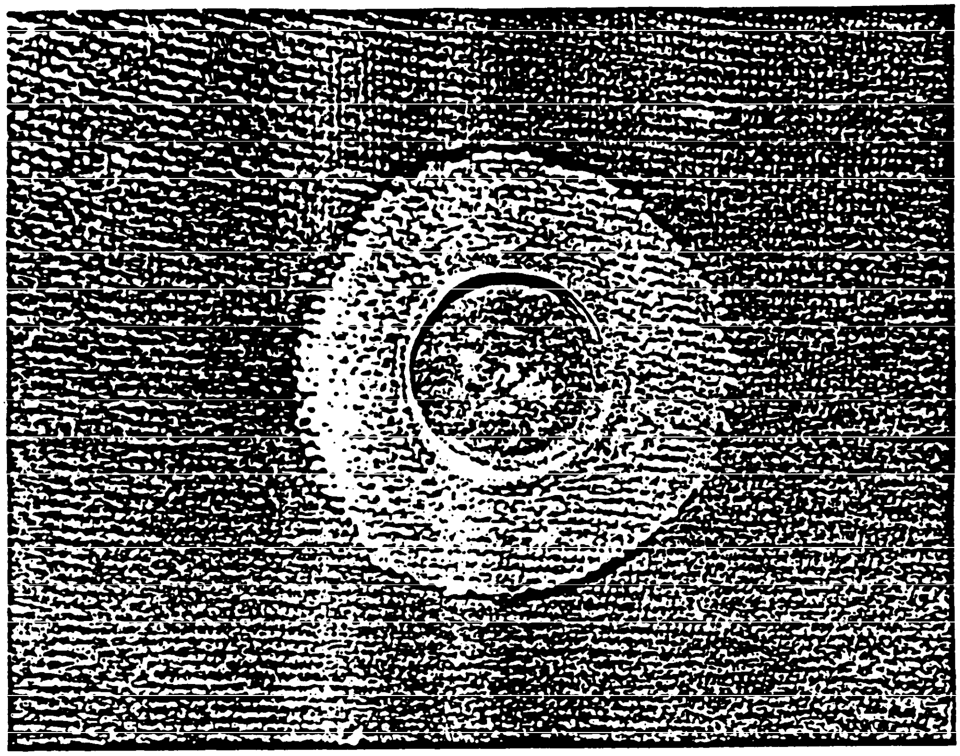
After drying out the laminate, inspect the damage thoroughly to determine its extent (see figure 40). The damaged area should be ground away using a disk sander as opposed to a power or hand saw. Sanding foam core material will produce a fine dust in addition to the glass dust; therefore, wear protective equipment and clothing.



SH 13202989

FIGURE 40. *Damage and scarf line.*

Clear away the damaged laminate back to sound laminate, exposing the damaged core. Inspect the area for subsurface cracks, further delamination, and water. If more water is found, heat lamps may be used as an aid in drying out the laminate, but extreme care should be used to avoid "scorching" the damaged area. Continue sanding the laminate until a scarf has formed a distance of at least 12 times the thickness of the GRP skin onto sound laminate. Clean the area of dust and particles and again inspect the core. If all damaged core has been exposed, cut away the exposed core along the edge of the scarf with a knife or saw, taking care not to harm the bottom laminate (see figure 41).



SH 13202990

FIGURE 41. *Damage sanded and cleared of fractured core.*

Clear away excess foam with a chisel or file and make the edges (walls) of the core as vertical as possible. Core materials need not be scarfed like damaged skins.

Estimate the amount of repair materials necessary for the laminate and measure the amount of foam necessary to replace the damaged core. If only a small amount of foam is required, a putty made from a large amount of microballoons mixed with resin may be sufficient. However, a piece of replacement core is recommended for areas greater than 1 or 2 square inches. Assemble all the materials at the repair site and clean out the damaged area with solvent to remove any fine dust. Now measure and cut the replacement foam so that a tight fit is achieved between the new piece and the existing core (see figure 42).

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FIGURE 42. *Sizing replacement core material.*

Next, place a piece of paper over the damage and trace over the damage and the outside scarf edge. Use this paper as a template for cutting the various plies of reinforcement (see figure 43).

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FIGURE 43. *Template for reinforcing material.*

Cut an extra piece of 1.5 ounce mat that will fit the bottom of the replacement core. All the reinforcement materials should now be cut and set aside on a clean space ready for use.

Estimate the small amount of resin that will be required to set the core in place and saturate the piece of mat. Mix the resin and catalyst together and spread a thin coat of resin in the hole where the replacement core will be fitted. Lay the extra piece of 1.5 ounce mat onto the resin and coat the mat with resin using a stiff brush (see figure 44).

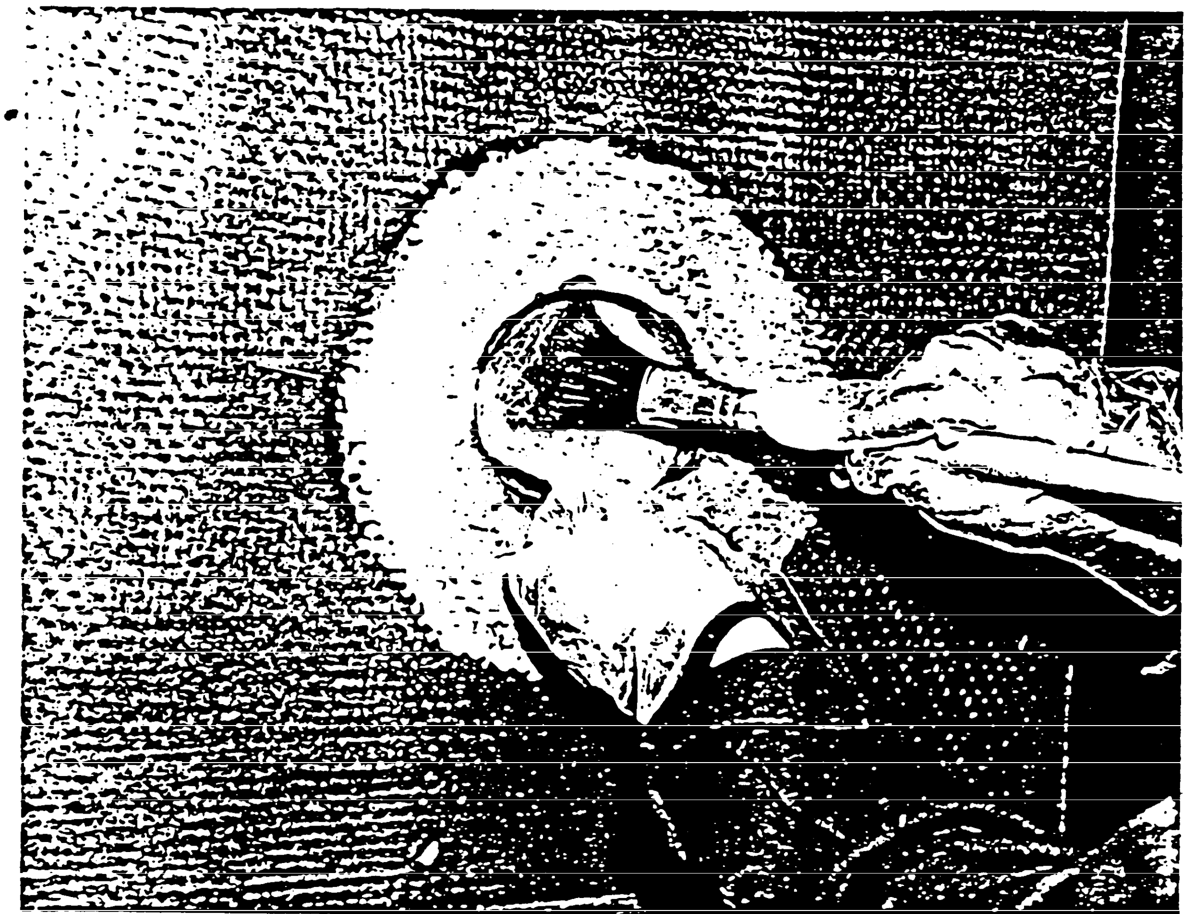

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FIGURE 44. *Applying mats to core replacement area.*

The mat will help bond the foam to the bottom laminate, and should be well saturated, but not oversaturated, with resin. Prepare the rest of the cavity by coating the sides of the original and replacement foam with a thin coat of resin and gently press the replacement foam into place, allowing any trapped air to escape (see figure 45).

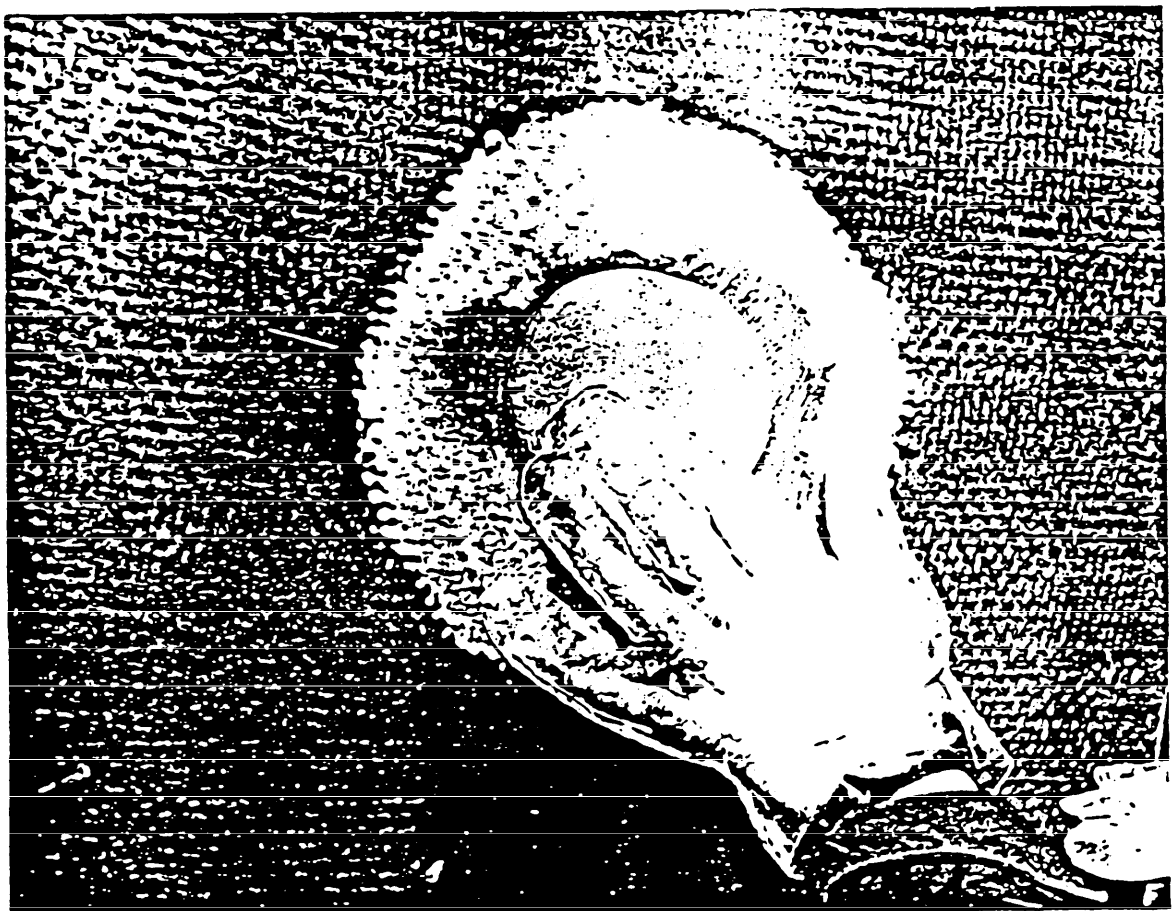

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FIGURE 45. *Placing replacement core into position.*

Allow the resin around the core to set and cure. When fully cured, check the bond by scraping the foam with a coin and visually inspecting the bond line. Any difference in sound or gaps in the bond line will signal an insufficient bond and the core may have to be removed and a new one reset. If the bond appears solid, the top laminate skin is now ready to be applied (see figure 46). Remaining steps to this repair are identical to those specified in 6.3 and should be followed to complete the repair.

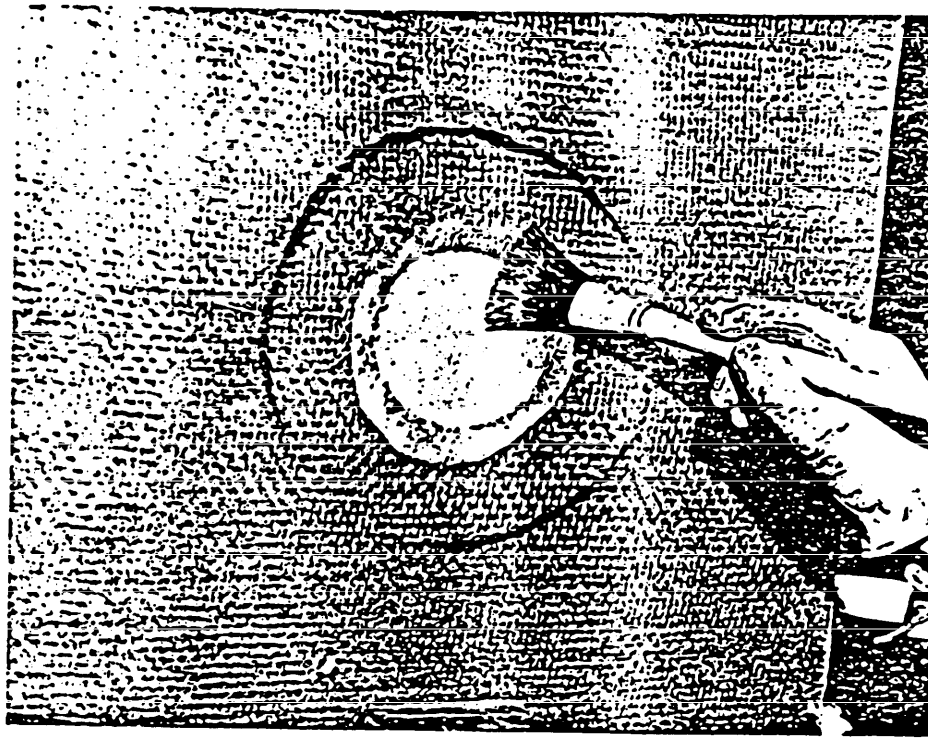

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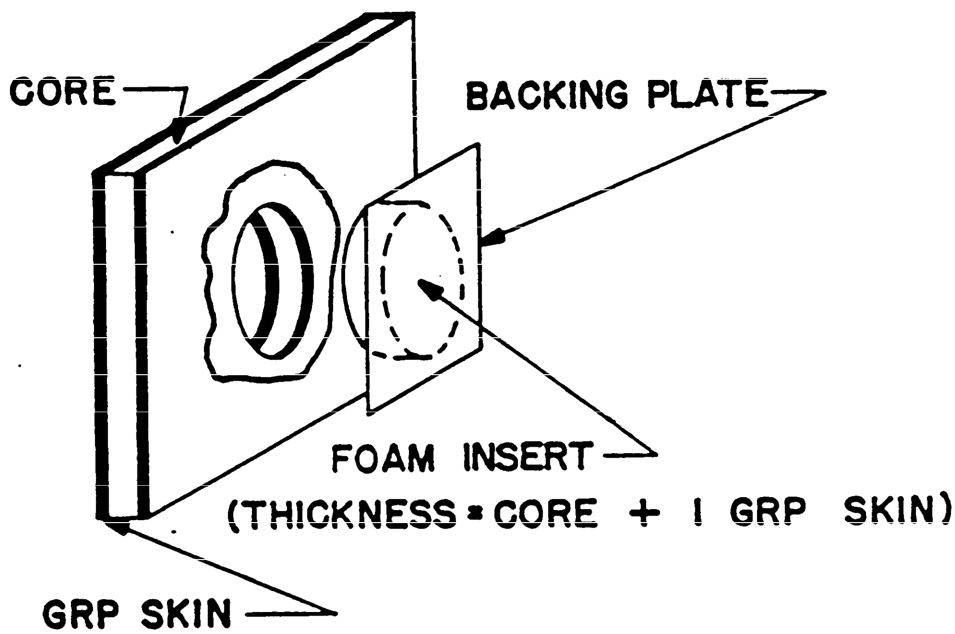
FIGURE 46. *First layer of mat with resin being applied to patch.*

6.7 Punctures through foam core structures. Punctures through foam core structures should receive the same first-aid treatment as fractured foam core structures. Be sure to check the damage carefully. If the damaged item is a structural member, watch for further cracking or other types of failure. The damage should be sealed to prevent water or moisture from seeping into the laminate, which would weaken it further. When beginning the repair, first survey the damage to check for subsurface cracks or hidden delamination. A sound test (tapping with a coin) is an excellent assist to a visual inspection. A dull, dead sound or an almost crackling sound will indicate a crack or delamination against the solid ring of sound laminate. After surveying the damage, clear away all the stray glass and core material from the damaged area. Assemble the necessary tools (saber saw, keyhole saw, and knife) to cut the damaged area away from the sound laminate. After cutting away the visible damage, check the laminate and core for hidden cracks that will also have to be cut away.

With all damaged structure cut back to sound laminate, scarf back the front and back reinforced plastic skins a distance of at least 12 times the skin thickness using a disk sander. While using the sander, use protective equipment such as goggles and respirator as well as long sleeved clothing to prevent irritation from dust particles. Clean resulting cavity of dust and other particles. At this point, measure the amount of core that will be required to replace the damaged core. Cut the proper thickness replacement core slightly larger than necessary so that it can be sanded or filed to a snug fit. Alternately sand and fit the replacement core until the core fits snugly with no significant gaps (see figure 47).



SH 131779

FIGURE 47. *Foam core backing plate.*

To make sure the replacement core will stay aligned in the damaged area, a simple backing plate will be required. A piece of thin cardboard covered with separating film will do. Form the cardboard against the scarfed laminate so that it is flush against the damaged core. Remove the plate and place several strips of tape around the edges. With the backing plate ready and the replacement core cut, mix a small amount of resin sufficient to coat the edges of the damaged and replacement core. It will be helpful to add a small amount of fumed silica or other filler to the resin to make a light paste. Spread a thin coat of the mixed resin on all edges, taking care not to allow any excess to drip onto the laminate or the top and bottom of the replacement core. Place the replacement core into the damaged area and use excess resin to fill any gaps around the core patch. Wipe away any excess resin that has dripped and place the backing plate into position. The plate will keep the core from slipping out of the damaged area until the resin has gelled. At that time, when the resin has taken on a leather-like texture, remove the backing plate, gently scrape away any excess resin and then allow the resin to fully harden. From this stage, the repair is similar to surface fractures (see 6.3). For very thick lay-ups, the repair laminate can be built up in stages, so as to avoid excess heat buildup during cure, as explained earlier.

6.8 Balsa core structures. End grain balsa wood has been used for many years as a core material, especially for deck structures. As balsa is a wood, it is more susceptible to water migration and seepage than foams. Therefore, any punctures or fractures in a balsa cored item should be sealed immediately. Also, whenever fittings are attached to balsa cored panels, the fasteners should be set in a liberal amount of sealant, such as bedding compound or resin, to prevent any seepage through the fastener hole. Repair procedures for balsa cored structures are similar to those for foam core structures, and those techniques specified in 6.6 and 6.7 can be directly adapted by substituting balsa for foam. One difference, however, is that the end grain surfaces of the balsa must be coated with catalyzed resin and allowed to gel before patch lay-up is begun. This is to seal the wood surface to prevent excessive wicking of the patch resin into the wood grain and causing an internally resin-starved patch.

6.9 Honeycomb structures. Honeycomb construction provides a lightweight high strength structure for many high performance applications. Due to its construction, much of the core area is empty space. This void area is a key to the structure's light weight, but also makes it more susceptible to water seepage when damaged and resin entrapment when being repaired. The repair procedures for honeycomb structures are similar to those for foam cored structures. However, some special instructions should be followed for repair of a puncture or when replacing the core material for repair of a fracture.

For either a puncture or a fracture to a honeycomb structure, the method for clearing away the damaged area, preparation of the core, and laying-up an interior skin is identical to the method for foam core structures. Picking up from the point where either the interior skin of the structure has been laid-up and allowed to fully cure (puncture), or where just the damaged core has been removed and is ready to accept the replacement core (fracture), precise measurements should be made to cut and shape the new core. Care should be taken to shape the new core section so that a maximum of the flat honeycomb walls of the original core mate with the replacement core walls. This will allow a maximum amount of surface area to bond the new core into the existing laminate.

With the core cut and shaped, trace the damaged cavity and outer edge of the scarf onto a piece of paper to be used as a guide for cutting the plies or reinforcement material. Estimate the amount of reinforcement material necessary for the repair of the skin using table I as a guide. Determine the number of plies necessary to build up the skin and trace their outline on the paper making each ply proportionally larger than the previous one, beginning with the innermost ply. Cut out each piece of reinforcement, using the paper as a template working from the largest to the smallest ply.

Estimate the amount of resin required for the patch, allowing a bit extra for the seating of the core. For this phase of core repair, use a commercially available fast setting epoxy resin to minimize the possibility of resin seeping or running into the core. Because this type of resin must be used, it is especially important that all materials and tools be laid out and ready to go. With everything prepared and the cavity cleaned with solvent, spread a thin layer of resin on the bottom of the cavity and lay a piece of glass mat in the space. Thoroughly wet-out the mat along with the sides of the cells of the original core. Carefully place the core into the cavity and press it firmly into the saturated mat. Wipe up all excess resin. On a separate flat area covered with separating film, wet-out a piece of mat that has been cut to cover the core and overlap onto the scarfed skin. Roll excess resin out of the mat. Carefully place this mat onto the core. Continue laying-up the reinforcement taking care not to use an excess amount of resin in wetting-out each ply. When the final layer of reinforcement has been applied, allow the laminate to cure at room temperature or use heat lamps as an aid. After the laminate has cured, inspect the patch for bond quality and voids. Fill the surface voids with epoxy resin or resin combined with silica or microballoons as a filler. Poor bond quality, usually detected by a change in sound when tapped, must be investigated and, if extensive, the repair must be torn out and redone. Complete the repair by following appropriate instructions as specified in 7.1 through 7.3.

6.10 Tubular structures. Tubular structures, such as liferails and stanchions, are sometimes made from GRP material. These GRP structures are usually made by pultrusion process that tends to orient most of the glass fibers in axial direction. Because the fibers are not woven, a damaged item will generally exhibit more stray fibers than a woven reinforcement laminate.

For solid pultruded structures such as lifelines or liferails, the tensile strength is so great and the end use so safety critical that repair of this type of structure is not considered structurally adequate or reliable. For tubular structures such as lifeline stanchions, adequate repair is difficult but may be possible. The critical nature of the life safety features of these articles is such that before approval of the repaired item it must be load tested as prescribed for a new installation. There must be no compromise in performance of these structures.

In general, it is better to replace than repair tubular structures. As a guide, if the damage length exceeds the diameter measurement, it would be more prudent to replace than to repair the tube. In repairing these damaged structures, the important factor is to regain the structural reliability of the article. Often this will necessitate the use of a plug or high density core placed in the area of the damage. These types of repairs can be looked upon more as splices than patches.

Begin the repair by examining the causes and failure mechanism of the damage. This will help in determining where to concentrate the reinforcement and place the plug, if required. Point failures, such as cracked bolt holes or impact failures, may be repaired more effectively using plugs, whereas bending or compression failures may require more reinforcement at the surface to increase the moment of inertia of the item. These conclusions must be reached by examination of the damaged item and a bit of deductive thinking. Once the problem, or at least the symptom, has been determined, begin planning the repair. Glass cloth, due to its high glass content and pliable nature, is generally the best bet for a reinforcing material. The epoxy resin contained in the issued GRP repair kits is also recommended for repairs to tubular structures for its adhesive and strength properties. For most repairs, only a few plies (2 or 3) will be necessary as more extensive damage would imply that replacement may be more efficient and effective than repair. Estimate both the reinforcement and resin required on a square area basis, with table VI as a guide for resin quantities. Assemble all tools and materials before actually working on the repair so that time need not be spent searching for materials as a batch of resin is kicking-off.

Begin by clearing away damaged laminate and any paint using a power or hand saw or a disk sander to grind back to solid laminate. Care should be taken to avoid dust and particles produced in this process. Use a respirator and goggles. After clearing away the damaged laminate, examine the item to see if a plug will be necessary. Any damage length greater than one-half the tube diameter will require a plug. If so, fashion one from a piece of solid wood, or high density foam, cutting four to eight grooves around the outside 1/16-inch deep. These will serve to form a foothold for the resin, thus making a more secure bond between plug and tube. The length of the plug should be equal to the damage length plus three tube diameters. Be sure that the plug will fit snugly. Sand down the edges around the damage to form a scarf that is 15 to 20 times as long as the thickness of the laminate. Assemble the various pieces (damaged item and plug) and cut out the reinforcing material using a paper template as a guide (see figure 48).

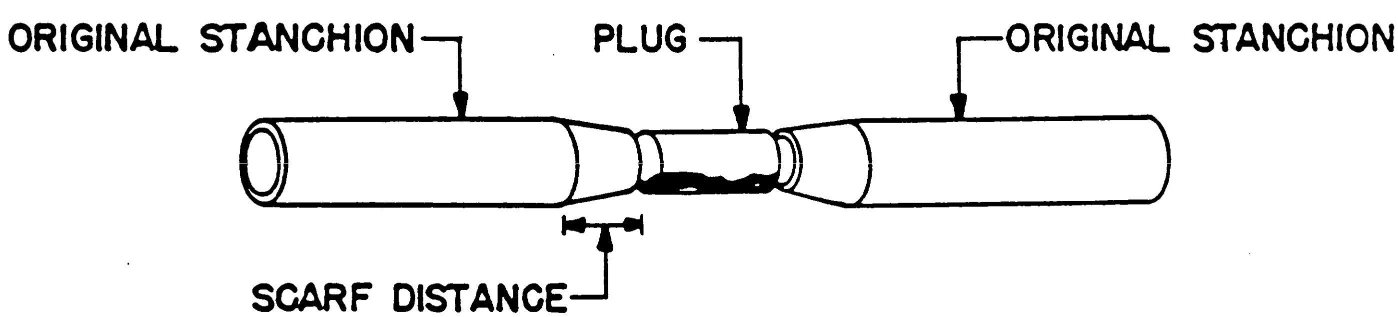


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FIGURE 48. *Schematic for a repair to a hollow stanchion.*

A length of unidirectional or glass cloth tape long enough to wrap the damaged area with an overlap of one diameter at each end will also be required. For thin wall, small diameter tubing, this tape will be sufficient reinforcement with use of a plug. With all materials and pieces assembled, mix the catalyst and resin together by stirring the resin while slowly adding the catalyst. If a plug is required, coat inside of the tube and exterior of plug with resin. Place the plug in the damaged tube and wipe away any excess resin. With a brush, coat the patch area with a thin film of resin and apply the cloth, wrapping or placing it over the damage as required. Wet-out this layer, making sure that all edges of the reinforcement are faired into the original piece and that no dry edges remain. Remove excess resin from the ply using a tamping action with the brush. Apply subsequent layers of cloth in a similar manner.

If the damage occurred on one side of the tube rather than completely through, apply a thin coat of resin to the undamaged tube surface opposite the patch. While holding the leading edge of the tape, slowly wrap the tape around the tube overlapping each wind by one-quarter the width of the tape. Wrap the laminate with separating film and work out trapped air bubbles with a squeegee and allow the laminate to cure. After the laminate has fully cured, remove the separating film and inspect the laminate for soundness and voids. Fill any voids with resin or a resin putty made with the addition of silica. Sand the patch smooth and apply a protective coat of surface resin to seal the patch. If the patch is to be painted, see 7.1 through 7.3 for instructions.

7. FINISHING

7.1 Introduction. Often, an excellent repair can be ruined by improper finishing techniques. Surface voids, peeling paint, and so forth can all lead to increased maintenance or premature failure. This section will present guidance on a few common finishing techniques that are applicable to a wide range of situations.

7.1.1 Surface finish. Before any true finish work can be done, the repaired surface must be in a workable condition. This means that the surface must be smooth, void-free, with no stray fibers. A fair, smooth surface is achieved by sanding and filling. High spots should be sanded down with fine sand paper using a disk sander (see figure 49). Voids and low spots should be filled with a resin putty made from resin and silica to ensure workability, while retaining a smooth surface. This putty is best applied with a putty knife or a squeegee. A squeegee works best for final filling. Use small amounts of putty on the squeegee when filling voids, as large amounts can be cumbersome to work with. When sanding, begin with a hard disk and a reasonably fine grade of abrasive paper, such as 100 grade. Use this combination for initial sanding of high spots and excess putty. After removal of these rough spots, shape the area using 150 grade sandpaper and the hard disk.

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FIGURE 49. *Removing high spots with power sander.*

For final preparation, use a soft padded sanding disk or flexpad and 220 grade sandpaper. This combination will give very good results; however, where high quality is required, hand sanding may be necessary. For best results with hand sanding, a sanding block is required. Sanding blocks made from rubber or a block of rigid foam have proven to work the best. Initial hand sanding should start with 320 grade sandpaper and move up to 400 grade wet-dry sandpaper. A 400 grade sandpaper should be used only if a very fine finish is necessary; otherwise, 320 grade should be sufficient, especially if only a final surface coat of resin is to be applied. When sanding, use smooth even strokes and check the paper often to catch buildups that could mar the surface. Change paper often to maintain efficiency (see figure 50).

7.2 Coatings. The two most prevalent coatings used on Navy GRP equipment are paint and surface resin. Both will provide protection for the item if properly applied and maintained (although surface resin will not protect against ultra-violet light as paint does). Improper application will, however, result in drastically reduced service life for the coating and possibly for the equipment as well. Gel coat, used on some Navy GRP equipment, is a type of surfacing resin containing pigment for appearance and to provide protection against ultraviolet light (see 7.3). Note that a continuous layer of resin (or gel coat), over the repair is required even if it will be painted, to prevent possible migration of water into the laminate.

7.2.1 Surface resin. Surface resin is applied to a repair either as a final coating or as an undercoat for paint or gel coat. It provides a seal for the repair against moisture pickup by exposed glass fibers. The key to a good bond with surface resin is a surface that is clean and oil free. Surface cleaning is best accomplished by light sanding and wiping with acetone. This solvent will dissolve oils and remove dust better than many solvents and evaporates completely, leaving no residue which might affect the resin. Great care must be exercised when using acetone. It is very volatile and highly flammable. Safety personnel should be consulted for advise on proper and safe usage. The surface should be fair and slightly roughened using 320 grade sandpaper. Mix the proper amount of resin and catalyst to just cover the repaired area. The resin should be applied evenly and smoothly with a brush. Remember to discard any resin if it prematurely gels as it will ruin the finish by spreading in lumps (see figure 51).

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FIGURE 50. *Roughening surface by hand sanding.*

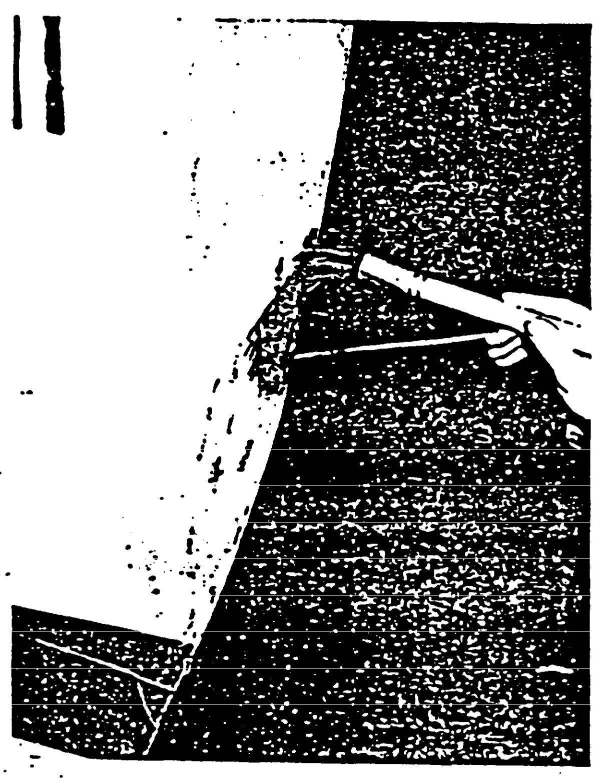

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FIGURE 51. *Applying finish coat of resin.*

7.2.2 Paint. Despite the fact that standard haze-gray paint comes in one can, it takes two parts and a proper surface to do the job effectively. As with surface resin, the repair surface must be even, slightly roughened, and clean. Paint is less forgiving than resin. Extra care in preparing the surface is required so that any irregularities or resin drips are removed. A coat of formulation number 117 pretreatment is required for GRP surfaces before painting. The pretreatment chemically interacts with the plastic surface so that a good bond will result between the paint and the surface. Only one coat of the pretreatment is necessary. Follow this with either topside or antifouling paint, as required by original specification or repair procedures. Use a roller or spray as appropriate. Paint helps provide protection for the GRP laminate by shielding it from the sun's ultraviolet rays. A poor paint job will result in flaking paint and shorter service life for the GRP item.

7.3 Gel coat. Gel coat is a specially formulated resin to provide good surfacing characteristics, a high gloss, and pigmentation. Being a resin, gel coat requires a catalyst to provide the necessary chemical reaction so that it will harden. Gel coat comes in two forms - one with wax added and one without wax. The wax additive is used to seal the final layer of gel coat to ensure a proper cure. Where multiple layers will be required for a repair, the gel coat without wax should be used to ensure a proper bond. The gel coat resin manufacturer should be consulted on any questions concerning the addition of wax or method of final cure of gel coat.

Surface preparation is important for a good finish with gel coat. A roughened clean surface is more important than an even one as slight hollows can be easily filled in with gel coat. After wiping down the surface with acetone, mix in the required amount of catalyst in a manner similar to laminating resin. Mix catalyst thoroughly with the resin, then spread a small amount on a squeegee. Apply gel coat to the prepared surface with even pressure and smooth strokes. Several thin coats are preferable to one thick coat, helping to prevent cracking due to brittleness of the gel coat. After the final layer of gel coat has been applied, allow it to cure by covering it with separating film (working out trapped air as it is covered) or, preferably, by spraying the gel coat with PVA. If a gel coat with added wax is used, PVA or separating film are not required. Should additional coats be required, remove the separating film or wash off the PVA (soap and water will do) after the gel coat has fully cured. Then, roughen the surface using 320 grade wet-dry sandpaper and water. When using wet sandpaper, be sure to keep the area flushed with water to carry the sanded particles away so as not to clog the paper. Clean the surface after it dries with acetone and reapply the gel coat as necessary. Smooth the final coat with 320 and 400 grit wet-dry sandpaper and water. A small quality of soap will prevent clogging of the sandpaper. Be careful not to sand away the gel coat in areas adjacent to the repair. Masking these areas with tape may be necessary. A final buffing with polishing compound will bring out a high gloss (see figure 52).

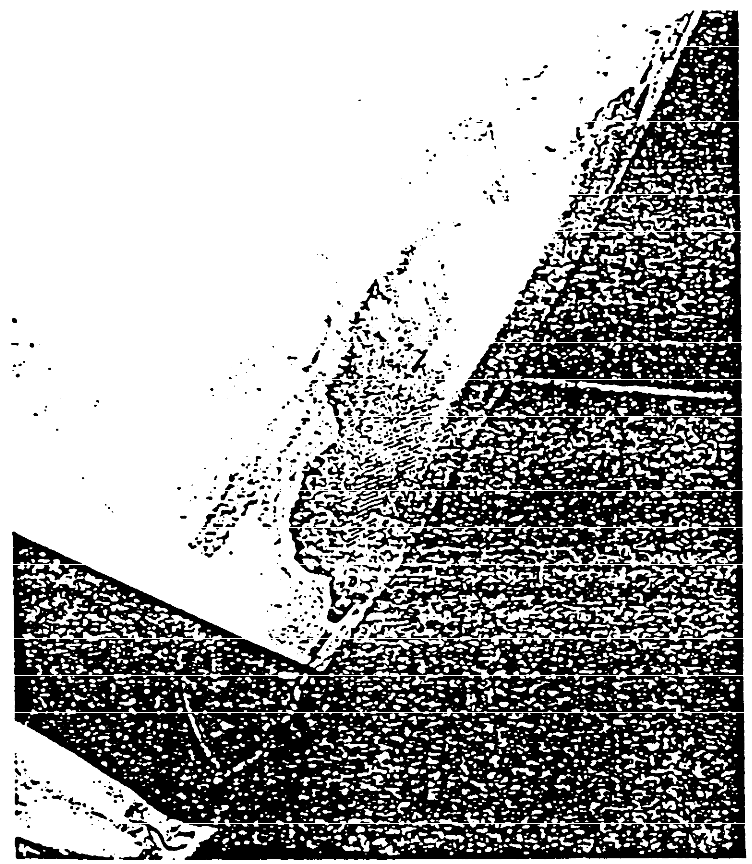

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FIGURE 52. *Finished bow repair.*

8. SUMMARY

8.1 Previous sections of this handbook have attempted to expose personnel to various techniques of reinforced plastic repair and preventive maintenance. Not every technique is covered, but with this handbook as a guide and some experience, most repair situations can be dealt with in an effective manner.

9. NOTES

(This section contains information of a general or explanatory nature which may be helpful, but is not mandatory.)

9.1 **Intended use.** This handbook is intended for use as a guide for preventive maintenance of glass reinforced plastic items and repair techniques for minor damage to reinforced plastic structures.

9.2 **Issue of DODISS.** When this handbook is used in acquisition, the issue of the DODISS to be applicable to this solicitation must be cited in this solicitation (see 2.1.1).

9.3 **Subject term (key word) listing.**

Accelerator
Adhesion
Alligatoring
Chine
Crazing
Cross-linking
Cure time
Delamination

Preparing activity:
Navy - SH
(Project 9330-NB17)