

Fishing boat construction: 4

Building an undecked fibreglass reinforced plastic boat



Cover photo:

One stage in the production of an undecked fibreglass reinforced plastic boat in the Maldives.

Courtesy of Derrick Menezes

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Preparation of this document

This manual has been developed from information collected during a post-tsunami rehabilitation project of the Food and Agriculture Organization of the United Nations (FAO) funded by the Government of Japan and carried out in the Maldives after the 2004 Tsunami.

The 4.5 m fibreglass boat featured in this manual is the MDV-1. It was developed cooperatively by FAO and the Maldives' Ministry of Fisheries and Marine Resources to replace the traditional wooden *Bokkuras* lost in the Tsunami. Øyvind Gulbrandsen, FAO consultant Naval Architect, was responsible for the final MDV-1 design.

In 2005, while training local people in the Maldives to build their own boats, Thomas Anmarkrud made a preliminary record of the work. He has now revised and expanded this information and included additional photographs from Derrick Menezes, boatbuilding consultant for the FAO Fisheries and Aquaculture Department, who also worked on the project. Some photographs from Thomas Anmarkrud's own boatyard and his consultancy work in Sri Lanka, China and Poland have also been used to illustrate the procedures and techniques described.

Preparation of this manual was funded by the FAO Fisheries and Aquaculture Department and completed under the supervision of Ari Gudmundsson, Fishery Industry Officer (Vessels), Fishing Technology Service.

Abstract

In many areas of the world, finding the type of timber needed to build a good quality wooden boat is becoming a problem. As a result, fibreglass reinforced plastic (FRP) is beginning to be used by many wooden boatbuilders. The information provided in this manual relates specifically to the production of a 4.5 m open fishing boat called the MDV-1. It is a simple, easily-driven, seaworthy boat intended for both rowing and power propulsion. Its general-purpose design is suitable for inshore waters around the world.

A general basic knowledge in the use of FRP as a boatbuilding material is presented and step by step construction of a 4.5 m open fishing boat using FRP is set out in detail. In addition, the booklet describes how to maintain an FRP boat and how to recognize fatigue problems. Some simple guidelines on how to repair minor damage to FRP are also included.

The information is intended for less experienced boatbuilders who already have a plug or mould. (Making a plug is not easy and requires experience in reading line drawings and lofting frames.) It is assumed that people planning to build a boat already have a good, general understanding of basic hand tool use. This manual will also be a useful aid for maintaining and improving quality control practised by boatbuilders who already have some experience working with this material.

This manual should give boatbuilders and fishermen a better understanding of how FRP acts, how to recognize fatigue problems and more serious damage, and how to carry out needed maintenance and repair.

Anmarkrud, T.

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PART I – General information

INTRODUCTION

In many areas of the world, finding the type of timber needed to build a good quality wooden boat is becoming a problem. As a result, fibreglass reinforced plastic (FRP) is beginning to be used by many wooden boat builders; however, their skills in working with this material are not always as good as their woodworking skills.

Because FRP laminate is not transparent, it can be difficult to determine whether structural quality of the laminate is good or bad. When delivered from the boatbuilder, the surface appearance of the laminate could be good, while the deeper layers may be of poor quality or strained from fatigue. Too often such faults are only detected by fishermen suddenly and far out at sea, too late for preventive action.

What is fibreglass reinforced plastic?

Fibreglass reinforced plastic, or FRP, is a composite of several materials (mainly fibreglass fibres and resin) laid down in alternating layers and hardened to form a solid laminate. For comparison, wood fibres in a tree are held together by their natural glue, Lignin. Similarly in FRP, layers of fibreglass material are glued together with polyester resin. Both in a tree and in fibreglass reinforced plastic laminate, the fibres give strength to the structure, and lignin and resin hold the fibres together, creating stiffness, and distributing the load among the fibres.

If put together correctly, the laminate can be both strong and stiff with good resistance to fatigue and the influence of water. If constructed poorly, the laminate might still look good on the surface, but due to its poor quality, could degrade and collapse in half the expected lifetime or even less.

This basic manual concentrates on the process of preparing the mould and constructing an FRP boat by glueing together layers of bonded fibreglass fibres called chopped strand mat (CSM) with a resin called General Purpose Orthoptalic Polyester (Polyester). The fibreglass could also be glued together with other resins, like vinylester or epoxy.

The chemical, oil-based resin is toxic and flammable: therefore, safety considerations are important when working with this material. These precautions are set out in the following pages.

FIGURE 1



This boatbuilder is saturating the fibres of chopped strand mat (CSM) with polyester resin, using a resin roller.

He is also using a facemask respirator as protection against inhaling toxic fumes.

MATERIAL DESCRIPTION AND HANDLING

FIGURE 2
Fibreglass – CSM (chopped strand mat)

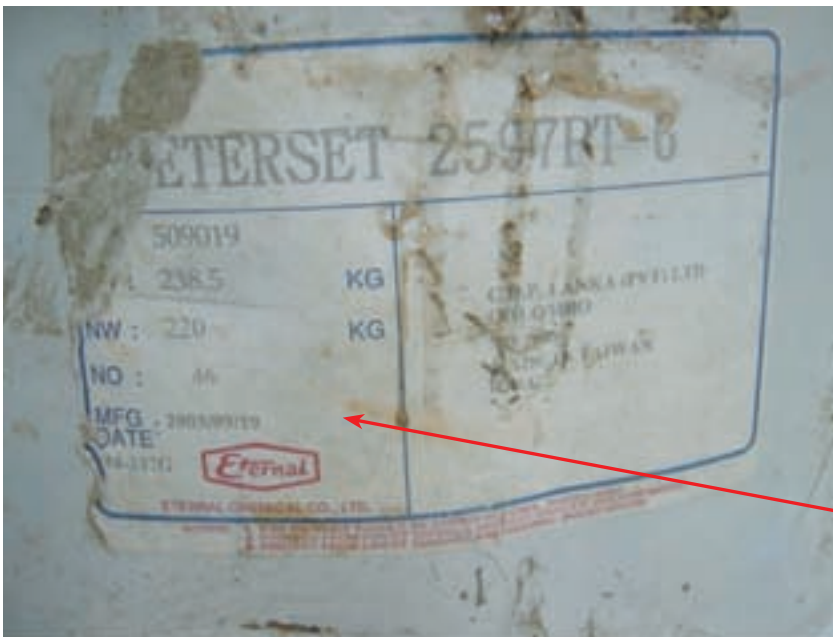


Chopped strand mat (CSM) consists of randomly oriented fibres from 25 to 50 mm (1–2 inches) in length, held together with a styrene soluble PVA binder.

The types of CSM to be used for the 4.5 m MDV-1 are 300 g/m² and 450 g/m². The 300 g/m² CSM is mainly used for the “skin coat” or “first layer”, instead of a surface tissue, and the 450 g/m² is used for the “bulk layers”.

It is very important to keep the CSM dry and free from contamination.

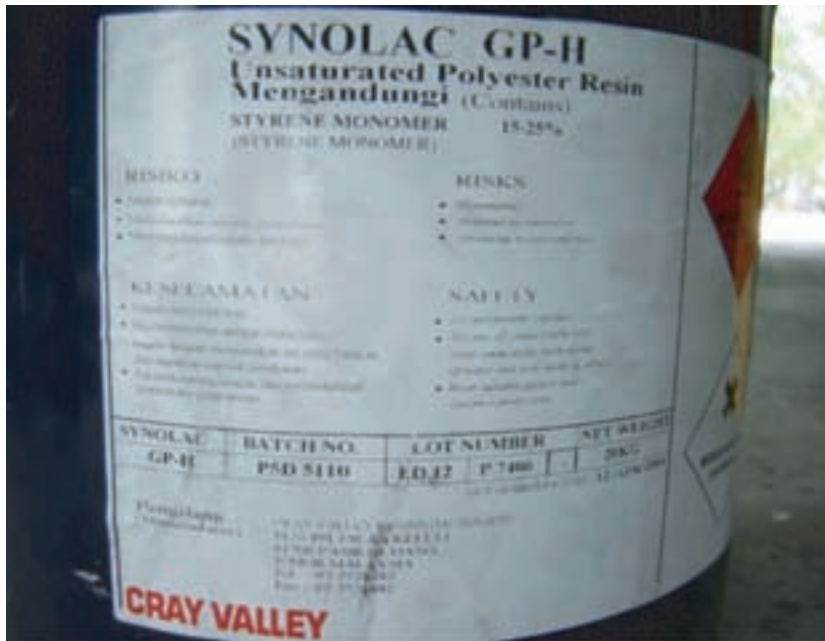
FIGURE 3
Polyester resin



The most commonly used polyester resin is a GP (General Purpose) Ortho-Polyester. This resin, when mixed with 1 percent of methyl ethyl ketone peroxide (MEKP) catalyst, typically has a gel time of 8-15 minutes at 30 °C. When stored in the dark and below 25 °C, the resin can remain stable for six months.

When stored at standard tropical temperatures, stability will be reduced to three to four months from production date (as shown on the label attached to the drum).

FIGURE 4
Gelcoat/topcoat

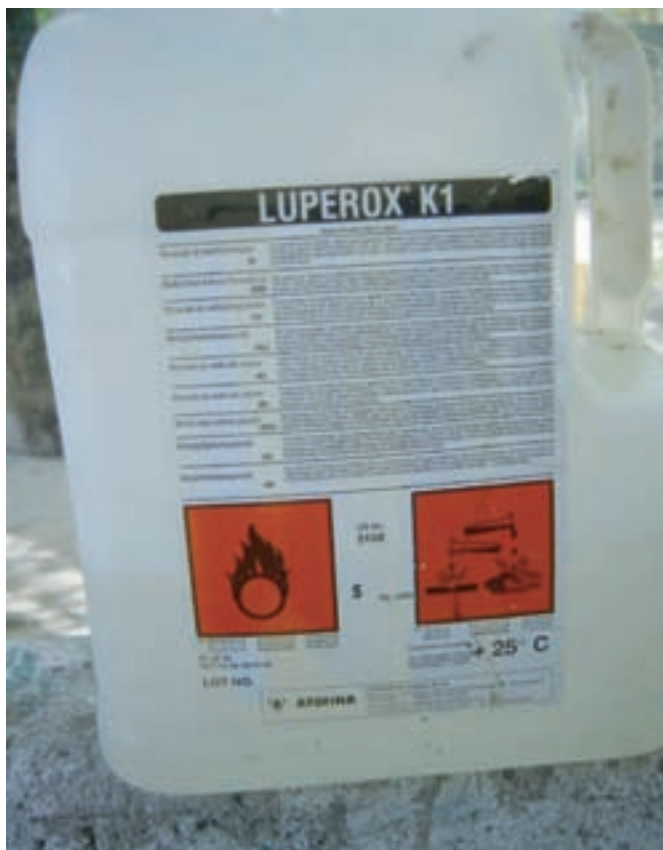


Date of production is written on the container label, and storing stability is the same as for polyester resin.

The gelcoat comes unpigmented but colour can be added. Use no more than 10 percent and mix thoroughly at slow speed using a “blender” attachment on a power drill, prior to application. Add no more than 2 percent hardener to the gelcoat.

Topcoat is made by mixing 4 percent of wax into the prepared gelcoat. Topcoat will air-dry on the surface and is often used as a finish coat.

FIGURE 5
Hardener/catalyst



The hardener, also called catalyst, is used to make the polyester cure. It is **extremely corrosive**, and special care must be taken in handling and storage. Wear safety glasses and rubber gloves for personal protection.

When hardener and resin are mixed, the chemical reaction generates heat (exotherm). If hardener is spilled in quantity, it may react quickly with other materials and cause a fire. Hardener should be stored separately from polyester.

If accelerator is used to make a fast-cure “fixing putty”, the accelerator must be mixed thoroughly with the putty before hardener is added. Mixing accelerator and hardener together will cause an explosion. When temperatures are near to 37 °C, follow the manufacturer’s advice and use a minimum 1 percent of hardener which will result in a shorter geltime. For ease of working, prepare this mixture in smaller batches.

FIGURE 6
Wax



When preparing a used mould for fibreglassing, a moderate amount of high quality paste release wax should be spread on the surface of the mould and then polished to a high gloss with a clean cloth.

When preparing (breaking-in) a new mould, apply five to ten layers of wax. Polyvinyl Alcohol (PVA) may also be used as a mould release before starting the first five products. A good quality mould should not require use of PVA, and should need only a light waxing and polishing after each demoulding. This gives the best finished results.

FIGURE 7
Buffing compound



Buffing compound or paste polish comes in different grades: coarse and fine or superfine. It is used when building up a new high-gloss finish in a mould or repairing an FRP hull. First, the surface is sanded with water and wet sandpaper in grits from 240 to 1 200 (see Figure 14). Second, a coarse paste is used to polish the surface. Finally, after a thorough washing, the surface is buffed with fine grade paste and polished with wax.

If repairing a mould, the repaired spot has to be sanded, polished and then broken-in as described above for a new mould.

Acetone

Acetone is a liquid solvent, much used to dissolve and remove polyester from brushes, rollers and other tools before the polyester sets up or cures. Acetone can be absorbed through skin and stored in the body. It also removes the natural oils that keep skin flexible and healthy. Extensive use of acetone over long periods without proper protection can have serious health implications. Direct contact should be avoided by the use of protective gloves when working with acetone. Hands should not be washed in acetone.

Styrene

Styrene is a standard ingredient in polyester resin. It is also a solvent and can be used to lower the viscosity of polyester and gelcoat. While styrene is also necessary for the curing process, more than 5 percent should not be used. Higher amounts can unbalance the curing process and weaken the finished laminate. When repairing old laminates, a light styrene wipe prior to laminating can improve the bond between old and the new polyester laminates. Styrene is also effective for cleaning moulds.

Polyurethane foam

Pourable polyurethane foam (PU) may be used inside thwarts and other hollow cavities for floatation. To make the foam, two liquids, delivered in separate cans A and B, must be mixed in equal amounts (1:1) for proper expansion and cure. The amount of liquid needed to achieve the desired volume should be confirmed before use. Typically, 1.6 kg of mixed liquid expands into approximately one cubic foot of foam. PU foam also comes in blocks and sheets in variable densities.

Polyester resin can be applied directly onto cured PU foam.

Expanded polystyrene (styrofoam)

This material can also be used for floatation. Styrofoam is generally the cheapest foam available and comes in blocks and sheets. However, it is easily damaged by solvents and melts on contact with acetone, styrene and gasoline. This means that it is not practical to laminate directly on Styrofoam without isolating it with solvent-proof plastic. Expanded Polystyrene also absorbs water when exposed for long periods. It therefore has to be waterproofed, for example, with bitumen emulsion.

BOX 1

GOOD VENTILATION IS EXTREMELY IMPORTANT WHEN WORKING WITH POLYESTER RESIN, STYRENE AND ACETONE! THE FUMES CAN BE HARMFUL TO HEALTH.

WHEN PU FOAM IS CURING, ISOCYANATE GASES DEVELOP THAT ARE ALSO HARMFUL IF INHALED.

Note that discarded chemicals, hardened resins, and foams all have short- and/or long-term negative effects on the environment.

Material storage

Precautions to be taken when handling and storing FPR materials include the following:

1. Materials received should always be checked against those ordered from the supplier. It should never be assumed that what arrives is what was ordered. Lot number and date of production and/or expiry must be checked as soon as the containers arrive. If the product is old or of a different quality than ordered, it should be returned at cost to the supplier. Such cross-checking is important because if the boat breaks down due to use of inappropriate raw materials, the boat owner will blame the builder not the supplier.

FIGURE 8
Information on FRP materials



Always check and write down the lot number and the production date when receiving storage-time sensitive products. This information should always be given on the container.

This example shows a 20 kg bucket of gelcoat with required information on the label.

2. The supplier should be asked for technical data sheets for each product which should then be retained for future reference (example given in Appendix 5). Data sheets should give all the physical and technical properties required by the boat designer to produce a quality product. Resins can vary widely in characteristics such as viscosity and strength. Data sheets also provide key information like proper mixing ratios and the critical temperature ranges suitable for laminating.
3. Fibreglass (chopped strand mat) should be kept dry and clean. This is of great importance but difficult to achieve in a hot and humid climate. The fibreglass mat should be kept in a dry and ventilated room. If there is much dust or contamination in the air or if there is a possibility of rain, cover the material in plastic.
4. Polyester and gelcoat should, if possible, be stored at less than 25 °C. The shelf life becomes greatly reduced at higher temperatures.
5. Thorough mixing of gelcoat and resins, in their original container, is required before use. According to existing standards, resin is supposed to be mixed for 10 minutes every day to keep additives from separating and settling to the bottom of the drum. If not stirred before use, additives in gelcoat sometimes separate and rise to the top of the container.
6. For best results when doing the lamination, the raw materials, the mould and the working environment, should all be at the same temperature.

If the temperature is much above 30 °C, for example 37 °C, geltime will be shortened. If the temperature is considerably lower than 30 °C, risk of insufficient curing is high. Lower temperatures and high humidity can also cause “aligatoring” (wrinkling) of the gelcoat.

If air humidity rises to above 80 percent, the binder in the CSM will absorb moisture and the reinforcement (CSM) will get “wet”, that is to say, lose its strength.

A common solution to many of these problems is for lamination work to be done in the morning before the sun gets too hot or the humidity rises.

FIGURE 9
Mixing of resin



If a drill with a proper mixing attachment is not available, the second best alternative is to roll the drum.

However, if the drum has been standing upright for some time, polyester resin near the bottom may already be of higher viscosity and rolling the drum for a full 10 minutes might not be enough to and fully mix the heavier and lighter resin. If not fully mixed, the first resin drawn from the drum tap may be of a different viscosity that that drawn later.

FIGURE 10
Measuring temperature and humidity



Even a simple workshop used for fibre reinforced plastics construction, should have a gauge showing temperature and relative humidity of air in the workshop.

The version shown here is sufficient and inexpensive.

Facilities

In a tropical climate, FRP materials must be stored in conditions as dark and cold as possible to ensure maximum shelf-life.

In colder climates, if the materials are stored near 0 °C or colder, remember that a drum of polyester takes approximately one week at room temperature (18 to 23 °C) to warm up to working temperature.

FIGURE 11
Storage of FRP materials



FIGURE 12
Work area



It is very important to protect the work area and FRP materials from the influence of the sun, wind and rain.

Similar care is important for storage of the raw materials.

If a shelter like the one shown at left is not possible, a temporary shelter should be constructed using for instance, canvas.

TOOLS TO BE USED

Apart from the moulds themselves a few specialized hand tools are necessary.

FIGURE 13



This picture shows examples of some tools used when building a 4.5 m fishing boat.

□ The brushes are best for applying gelcoat but can also be used for getting polyester resin into tight corners and onto small details.

□ Resin rollers of different sizes can be used. They should be made of materials that will not be damaged by solvents.

□ A variety of compacting rollers are employed for different applications. The rollers must be used firmly but not too hard. Compacting must stop as soon as the resin starts to gel. Continued use of rollers at this time will only create air bubbles not remove them.

FIGURE 14



The 60 (or coarser) grit sandpaper is used to sand the laminate first. The 80 and 120 grit sandpapers are used for medium finish work.

Wet sandpaper should be in these grits: 240, 400, 600, 800, 1 000 and 1 200. These are intended for finish work on the mould and on the gelcoat of the hull.

FIGURE 15



Funnels are handy for pouring polyester safely into smaller containers when larger buckets are not being used.

Transparent measuring containers of several sizes are useful for measuring polyester and gelcoat.

A weight scale is an alternative for measuring small amounts of gelcoat and polyester and also for weighing fibreglass.

FIGURE 16



A variety of syringes can be used for correctly measuring very small amounts of hardener.

A typical cap from a soda bottle can usually hold around 5ml of hardener.

FIGURE 17



Two sizes of masking tape are used for a variety of tasks. It can be used to keep two different colours of gelcoat separate on the hull during construction or when isolating an area for repair operations. Tape is also handy for securing a plastic cover used for protection against dust or rain.

Scrapers with handles are used for spreading putty.

The wider, soft steel trowels typically used for bodywork on cars can also work well for this purpose.

FIGURE 18



A regular knife or utility-type knife with extra blades can be used for cutting dry reinforcement (CSM) or "soft" laminate from edges.

Screwdrivers are needed for mounting stainless steel cleats and drain plugs.

CSM can also be cut with scissors or torn gently by hand.

A wood chisel is handy for removing bumps and cured strands of fibreglass.

FIGURE 19



Rubber mallets are useful for careful tapping of moulds to help with demoulding.

A regular hammer is more useful for driving in wooden wedges inserted around the edge of the mould.

Combination wrenches are used for mounting bolts and nuts on the fender and with cleats, eye bolts and u-bolt.

A spanner (adjustable wrench) is also handy for holding bolts and nuts during tightening.

FIGURE 20



A wood saw can be used for cutting foam.

A hacksaw can be used for cutting both cured laminate and stainless steel bolts.

FIGURE 21



An electric drill should be available with a full set of twist bits and flat wood bits of different sizes for countersinking the 6 mm bolts for wooden fenders.

Hard metal hole saw attachments are used with the electric drill for making larger holes in the FRP laminate.

FIGURE 22



Electric disc grinders are mainly used for sanding away damaged FRP, but also for abrading the laminate prior to assembly and to improve secondary bonding. They can be fitted with rubber backing discs for use with 40 grit sandpaper.

Carborundum cutting and grinding discs can be attached and used for cutting or grinding cured laminate and cutting off stainless steel bolts.

The machine at the right of exhibit is excellent for flattening large areas.

FIGURE 23



Belt sanders are excellent for sanding in preparation for repairs and for getting into tight corners.

FIGURE 24



A power saw with a laminated hard metal blade, like the one shown at here, is useful for cutting both wood and FRP laminate.

BASIC LAMINATE BUILDING

1. Prepare the mould by either applying release wax and polishing or applying mould release agent as described in Figure 6. The next step in building an FRP boat is the preparation and application of gelcoat. After the gelcoat has been mixed with

FIGURE 25



FIGURE 26

Brushing gelcoat on to the black surface of the mould is shown at left.

The picture below shows use of a gelcoat thickness or wet film gauge.



the right amount of hardener, as stated on the data sheet, it is important that the right thickness be applied either by rolling, brushing or spraying. An ideal total thickness of this layer of gelcoat is between 0.4 and 0.8 mm. Gelcoat thickness can be measured using a simple “wet film gauge” obtained from the gelcoat supplier. A gelcoat thickness gauge can also be made from a piece of metal. For practical reference, a generous layer of gelcoat applied by brush is around 0.25 to 0.3 mm so that two layers should be sufficient.

This initial layer of gelcoat must be properly cured before lamination can start. It is best to wait three to four hours for curing to be complete. If laminating starts sooner than one and a half hours after gelcoating, there is a danger that the polyester will soften up the gelcoat causing it to wrinkle. This effect is called “aligating”.

To achieve a good primary bond between gelcoat and polyester resin, the lamination process should be started as soon as possible after four hours and definitely within 24 hours of gelcoat application. This rule also applies for the “open time” (working time) of the polyester to ensure a good primary bond between laminate layers. (Primary bond is discussed in more detail in Part III – Maintenance and repair). Precautions should be taken against contamination of the gelcoat surface. If a mould with fresh gelcoat is left overnight in an open shed, the mould should be covered with light plastic. This is especially important in wet or windy weather or other conditions that might result in gelcoat contamination.

All required materials should be prepared before starting to laminate over gelcoat. The fibreglass resin should be thoroughly stirred and at room temperature before hardener is added and mixed. Once resin is mixed with hardener, all steps needed to build a layer of laminate must be completed quickly as the mixture can be worked for only 10–15 minutes. Suppliers should provide a technical paper detailing how long polyester at a certain temperature with a specific amount of hardener can be worked. An example of a technical data paper for general purpose ortho polyester is attached as Appendix 5.

2. Only mix as much polyester and hardener as can be applied to the fibreglass mat in the time available. A small amount of polyester mixed in large container, as shown in Figure 27, is less likely to start gelling early than if the same amount of polyester is mixed in a small container. The difference in gell time is caused by increased exotherm buildup. This problem can also occur if laminates are too thick.
3. Follow the initial steps set out in the section Material description and handling and make sure you use the correct amount of hardener for a good cure.

FIGURE 27



A handy tool for measuring hardener can be made by attaching a piece of steel wire to a bottle cap. A syringe can be used to measure the exact amount contained in the bottle cap.

A typical cap from a soda bottle will hold 5 ml of hardener. To measure 1 percent of hardener by volume, one capful is sufficient for 500 ml (1/2 litre) of polyester.

A coat of polyester resin should always be applied before laying on the fibreglass mat. The metal roller is effective for working out any air bubbles and for compacting the resin and fibreglass layers together.

If measuring polyester resin with a one litre instead of a one kilogram measure, the fractional difference between volume and weight is close enough to say one kilogram equals one litre. For either measure, there will be no significant loss of quality when working with these materials on a sturdy structure such as the MDV-1 boat.

4. The first layer, or “skin coat”, consists of resin and a 300 g mat. There should be no bumps or contamination on the cured gelcoat prior to starting the lamination. It is vital that all air bubbles are carefully worked out and the first layer is allowed to cure for 4 to 6 hours, maybe even overnight, before the next layer is added. For the skin coat, it is especially important that the fibreglass mat be torn (as shown in Figure 28), rather than cut. For this layer, the pieces of mat should be placed edge to edge with no overlap. This technique provides a smooth transition between the skin coat and subsequent layers, and does not interfere with the structure of the boat. Since the skin coat is not a structural layer, joining fibreglass pieces together in this way does not interfere with overall strength of the final product.

FIGURE 28



This picture shows how the first layer (skin coat) of fibreglass is applied.

The gelcoat is completely covered with a generous layer of polyester to make sure no air is trapped close to it.

Fibreglass mat with torn edges is then applied carefully over the polyester layer and rolled thoroughly.

FIGURE 29



Proper use of compacting rollers is very important. They are used to ease fibreglass mat into the underlying polyester and remove all air trapped between the two. This process must be completed before the polyester begins to set up and cure.

This boatbuilder is using a small compacting roller to push fibreglass into a tight groove and ensure that any trapped air is removed.

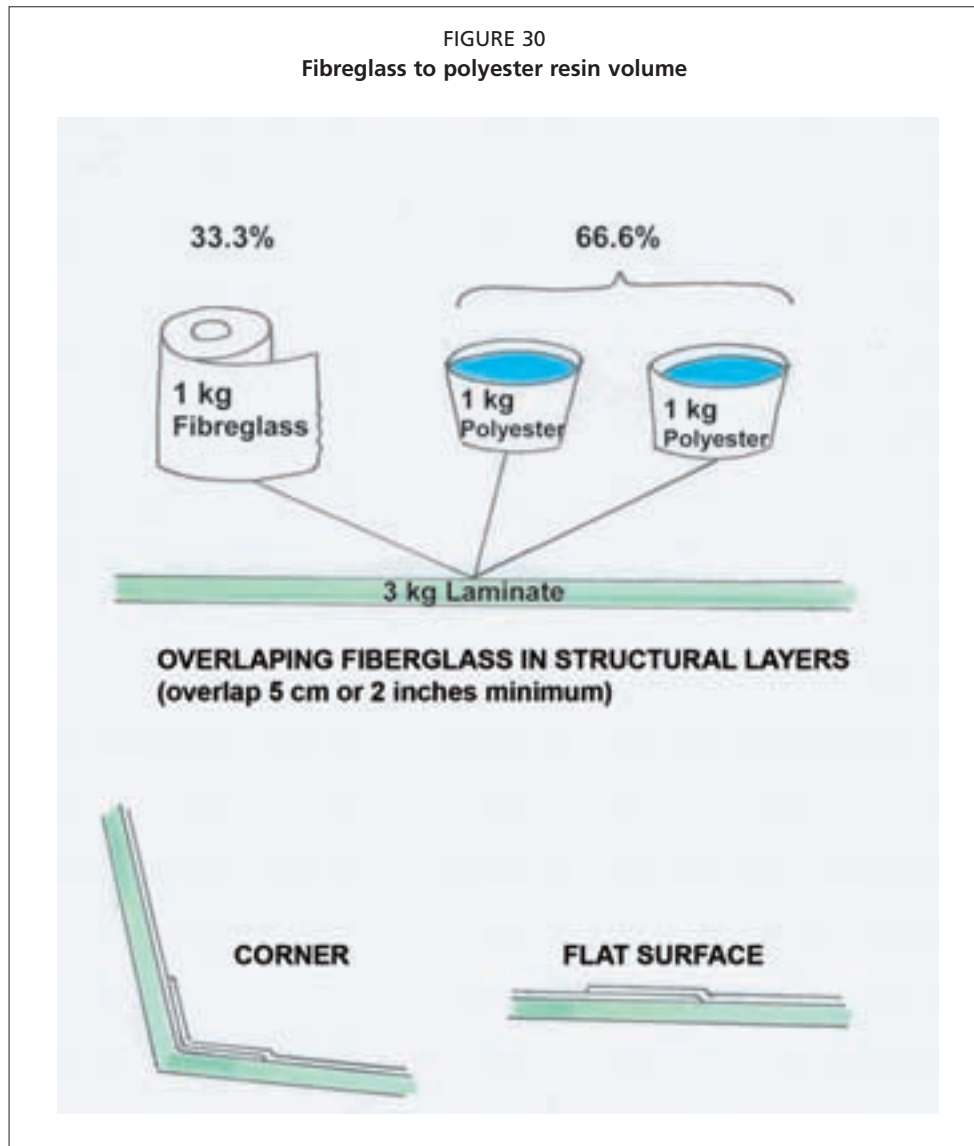
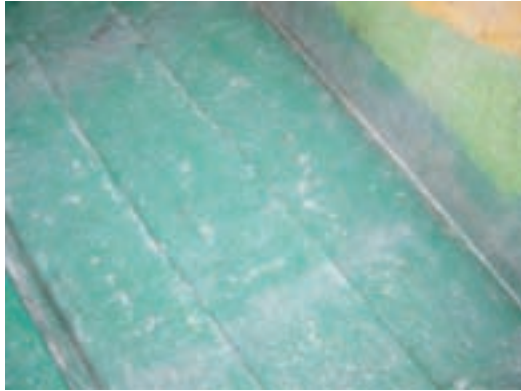


Figure 30 shows the right amount of fibreglass (chopped strand mat) and polyester to use in a CSM laminate, and how to stagger/overlap the pieces of fibreglass mat in a structural layer.

5. Continuous visual inspection is very important for quality control. A close watch must be kept to detect surface contamination and trapped air. If the fibreglass is too wet, the laminate will turn white. If the exotherm builds up too quickly, the color of the laminate will change and appear aerated/foamy. If too much polyester has been used, wet puddles will occur. The boat builder is usually the only person who can detect and correct such faults, and when the next layer of laminate is in place, the faults will be invisible. If such faults are not corrected immediately, the finished new boat will already have minor, or major, weaknesses.
6. For construction of the 4.5 m MDV-1 fishing boat, only CSM is used for ease of working and not woven roving. A main concern when laminating is to assemble each layer at the proper time interval. The laminate should be allowed to cool down after the curing process (exotherm) before starting on the next two layers but the work must be completed within 24 hours. The topic of primary and secondary bonding and preparation of the surface to be laminated are set out in more detail in Part III under “Repairing structural damage”.

FIGURE 31



This picture shows the results of poor quality control.

Large pockets of air have been left in the first fibreglass layer on top of the gelcoat.

HEALTH AND SAFETY ISSUES

Personal and environmental safety when working with fibreglass reinforced plastics

Personal safety

1. Eye safety

In all industrial environments, protection is needed to prevent objects or chemicals from getting into workers' eyes. When working with fibreglass reinforced plastics, care is needed to avoid both chemical hazards including anything from eye irritation to severe corrosion, and physical hazards such as irritation from airborne particulates.

For example, the catalyst/hardener (MEK peroxide) is a severely corrosive liquid. Grinders produce many dangerous airborne particles. In both cases, eye protection mainly in the form of goggles should be worn when working with FRP materials.

FIGURE 32



At left are examples of goggles for effective eye protection, ear protectors for hearing safety and a dust mask for lung protect during grinding.

2. Breathing safety

One of the most obvious and important organs to protect in a boatbuilding plant is the lungs. Most boatyards have mechanical ventilation to keep the levels of volatiles, or hazardous fumes, and dust, below an acceptable level. Even if fans/extractors are operating, a suitable respirator should be worn when there is direct

exposure to hazards such as Styrene fumes and fibreglass dust. There may be no immediate indication that exposure to such hazards is having an effect, but in the long term fibreglass dust will collect in the lungs, causing breathing problems and eventually result in lung collapse. The styrene fumes from polyester can cause nerve problems and possible brain damage while the isocyanides released by the curing of polyurethane are poisonous, and the amines released during the curing of epoxy have been linked to cancer.

When working with volatile fumes in a closed area with poor or no ventilation, such as inside a boat, respirators with an external source of fresh air must be worn for protection. Failure to use such protection can result in chemical lung inflammation.

FIGURE 33



The most commonly used respirator for protection against fumes is shown here. The filter in the front is disposable and should be replaced regularly. Different filters are available for specific fumes and also for dust.

The filter must be clean and of the proper type.

FIGURE 34



Here is a battery powered facemask. The battery pack is worn on the belt. Air is forced through the filters and pushed up into the mask which provides protection for both eyes and lungs.

This apparatus is comfortable to wear and facilitates communication since only the eyes and nose are covered.

3. Hearing safety

Being exposed to loud sounds, constantly or even periodically, can eventually lead to permanent hearing loss. Ear protection should always be used whenever a power tool, such as a grinder or other noisy machinery is in operation. For safety reasons, extra attention to communications and location of co-workers is necessary when ear protection is in use otherwise you will not always hear if somebody tries to talk to you.

4. Walking and climbing safety

Uncured fibreglass and resin are very slippery. Spills on the floor, steps and scaffolding used for climbing can result in severe falls and other accidents.

Especially when working on larger boats, ease of access wet laminate without causing damage is important. Care is needed when construction and using steps and ladders. Electrical cables can also cause tripping.

FIGURE 35
Watch your step!!



Walking on narrow planks and stepping on wet slippery fibreglass must be done with great care.

5. Hand and finger safety

Fibreglass boat construction requires fully functioning hands and fingers. Boatbuilding careers can be lost once hands and/or fingers are damaged or lost.

Disc grinders and power saws should always be equipped with a suitable guard. Although wearing gloves is a very important protection from chemicals and abrasion, they can sometimes hamper the ability to work safely with power tools. It is necessary to balance work so that maximum protection against chemicals and power tools is achieved.

FIGURE 36



This photo shows proper use of long sleeved gloves when applying resin.

These workers are also wearing half-mask respirators for protection against volatile fumes like styrene.

Boatbuilders should always have available a generous supply of industrial gloves capable of withstanding the solvents being used.

6. Skin safety

Invisible threats can be just as dangerous as visible ones.

Direct contact with solvents like styrene and acetone must be avoided. They can be absorbed into skin and ultimately the bloodstream. This absorption can result from directly touching the liquids or when the air is heavily polluted with solvents during the use of spray equipment. The effects of repeated, direct contact with solvents are cumulative and long term.

7. Fire hazard safety

Smoking and open fire should not be permitted in a boatbuilding plant or boatyard.

Most materials used for FRP construction are highly volatile and can catch fire quickly. Everyone in the workplace must take responsibility for eliminating fire hazards. The combined effect of smoking cigarettes and inhaling volatile fumes greatly increases negative health risks.

Electrical appliances and power tools must be used with care. Electrical cables represent major risks, including poor wire condition and loose contacts that can cause explosions or start fires. Air powered tools are safer.

Any leakage or spillage of catalyst can pose a significant fire hazard whether spraying or hand laminating.

When too much catalyst is used, or when too much time is spent on some laminating details, resin may begin to set-up in the bucket (early “kick off”). In such circumstances, the exotherm can quickly build up and a fire might result unless the bucket is removed to a safe place and water is put on top of the resin.

Abnormal exotherm build up can also happen when saturated wet fibreglass is discarded into a waste container. Rags, wet with solvent, should not be discarded into the same container.

Mixing accelerator and catalyst (promoter and initiator) together causes explosions.

Workshop safety

1. Controlling dust and fumes

When sanding, the most effective way of controlling dust is at the source. An extraction fan/dust collector with a large hose diameter, or a vacuum cleaner (preferably a “HEPA VAC”) connected to a hose attachment on the grinder itself, is required.

FIGURE 37



The man on the left is spraying gelcoat and has a respirator with external air supply. This is good practice. The man on the right is preparing CSM and wearing no respirator even though the air is heavily loaded with styrene. This is not good practice.

In addition, with the activities this close, gelcoat overspray will contaminate the fibreglass on the cutting board. This could reduce quality and strength of the resulting laminate.

Because it is very difficult to eliminate all dust at the source, a combination of approaches can be useful in maintaining a good working environment in a workshop where several operations are being executed at the same time.

In a boatbuilding plant, the most effective approach is to carry out as much of the sanding and grinding as is practically possible in a separate room.

To control fumes, there should always be some sort of air extraction and ventilation in the area where work with painting, gelcoat or laminating takes place. This arrangement minimises the part of the boatbuilding plant where respirators are required.

2. Controlling fire hazards

FIGURE 38



One example of very dangerous conditions in a workshop.

The electric grinder is shown sitting on top of a full barrel of polyester, which is highly flammable!

The shop manager has overall responsibility for maintaining a safe working environment and reducing the risk of fire!

3. Reducing waste and disposal of material

Plans and good routines for waste disposal are necessary to minimize fire hazards and pollution. Local authorities have regulations on how to handle the hazardous waste. Money can often be saved by separating hazardous and non-hazardous waste.

Careful management of raw materials to avoid wastage also saves money!

4. Raw material storage

Ideally, all raw materials should be stored in separate rooms to retain quality prior to use and for safety reasons. In particular, it is important to keep the catalyst in a separate room from the polyester and gelcoat, to reduce the potential hazard of fire.

5. Documentation

All technical data sheets requested from and given by the supplier for each material purchased, should include everything needed to handle the chemical in a safe way. It is recommended that all technical data sheets be collected in a binder, kept in a safe place and be available to all personnel who may potentially be exposed to these chemicals.

PART II – Building the MDV-1

The MDV-1 is a simple, easily-driven, seaworthy boat intended for both rowing and power propulsion. Its general-purpose design is suitable for inshore waters around the world.

Because the boat is moderate in size and light in weight, it can be easily pulled up on the beach. One or two fishermen can readily handle the boat and, under normal conditions, a 5 hp engine provides sufficient power. For waters with more current, a 10 hp engine may be needed; however, since the boat was not designed for speed, there is little to be gained by using a larger engine.

To construct the MDV-1, a mould is required. If a mould does not already exist for this boat, one must be made. A mould is constructed using a plug that looks just like the finished boat on the surface. Since the plugs' only purpose is to provide a base for lamination of the mould, it does not have to be as rigid as a boat.

The boat plug consists of the main plug jig, or hull plug, and separate centre and aft thwart plugs, and a deck plug.

MAKING THE PLUG

A plug consists of a number of separate parts that can be made of wood, gypsum, metal or any other material which is not attacked by styrene monomer.

It is very important to remember that the surface of the mould (and the boat) is mirrored in the surface of the plug. The smoother the plug, the better the finished boat will be and look. Achieving a good finish involves the elimination of any imperfection by the use of putty and by sanding and polishing the resulting surface. When using a porous material like wood or gypsum, it is important to finish the plug with a good two-component paint which is resistant to styrene monomer.

An old wooden boat may also be used as a plug for an FRP design. Information on this approach is contained in Appendix 1.

The frames and sections of the 4.5 m MDV-1 are shown in the "LINES" drawings in Figure 39. The scale of the original drawings is 1:20. The offset table in Appendix 4 could also be used.

The principle of working with wood and setting up the frames is set out in the *FAO Fisheries Technical Paper 134, Rev. 2: Fishing boat designs: 2. V-bottom boats of planked and plywood construction*.

A stable structure can easily be achieved by building the frames, shown in Technical drawing "PLUG JIG" (Figure 40), out of plywood or fibre boards. See also the subsequent picture (Figure 41).

FIGURE 39
Technical drawing

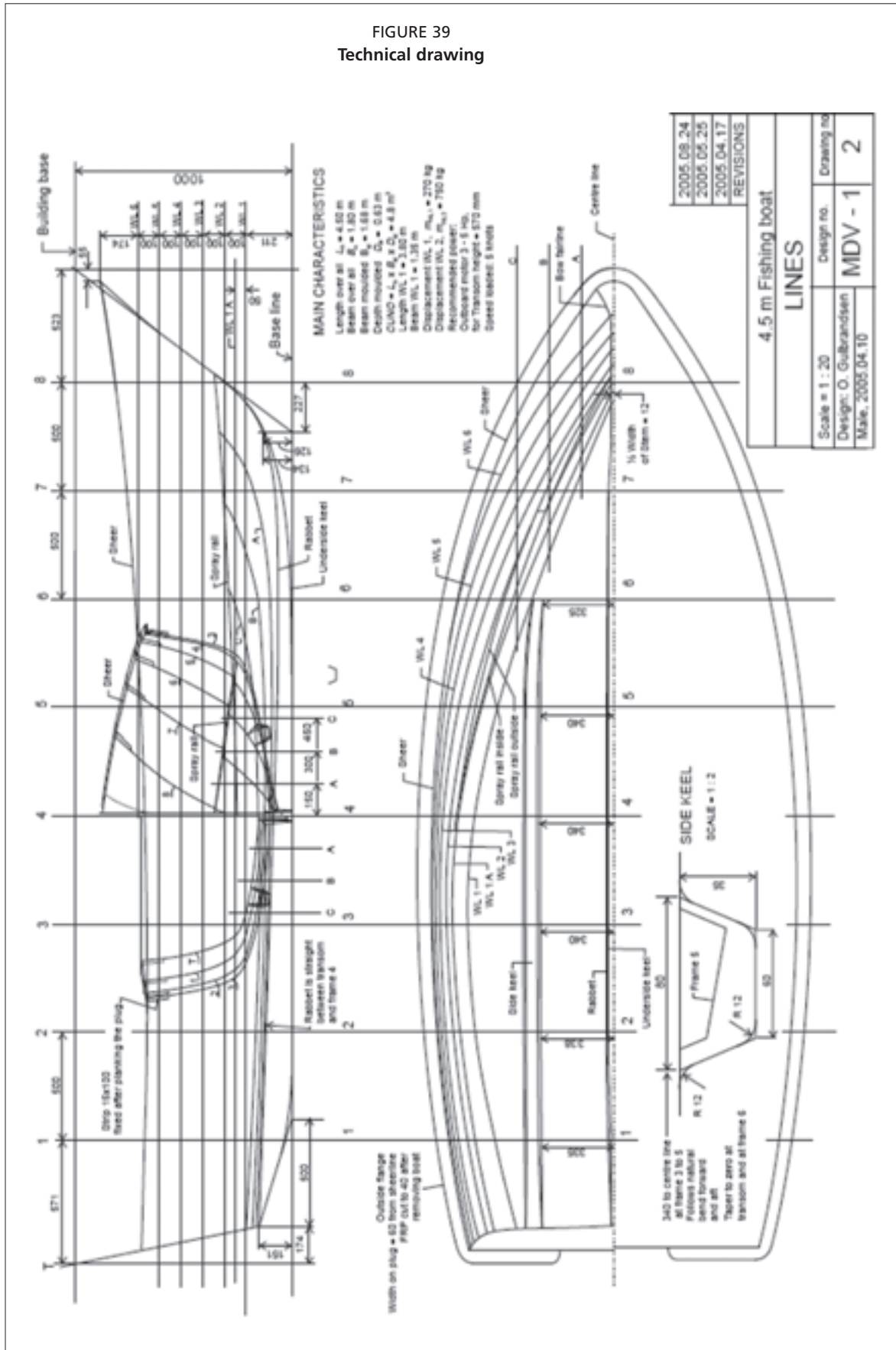
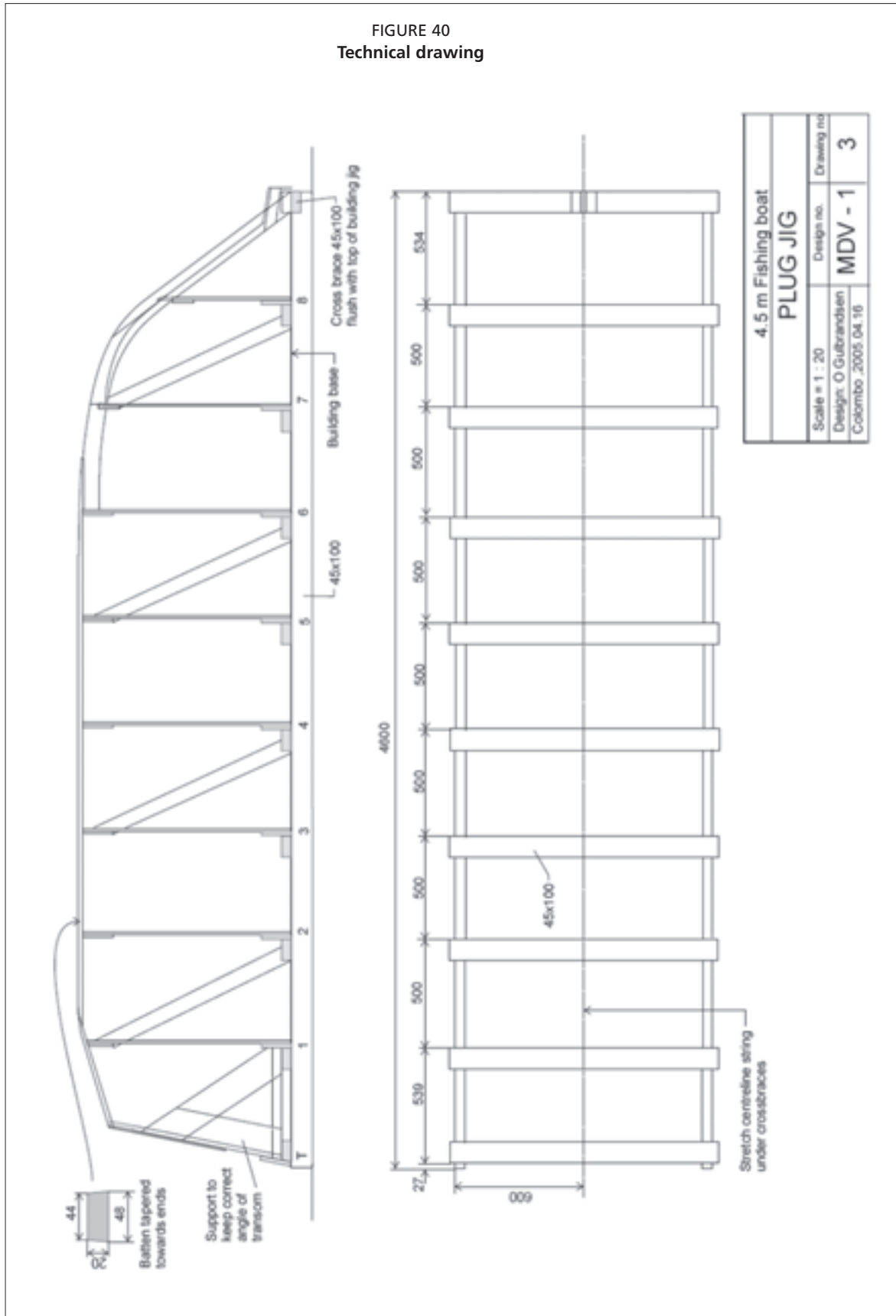


FIGURE 40
Technical drawing



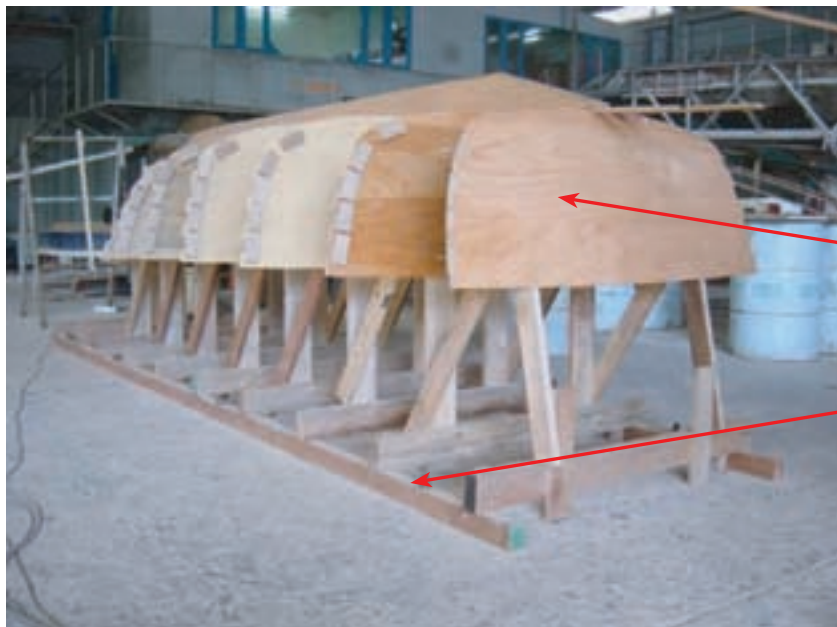
There are different preferences for the type and dimensions of the wood battens used to run horizontally along the surface of the plug. In this example, wooden strips have been used, 12 mm wide by 45 mm high on the relatively flat surfaces on the sides of the boat, and 12 mm wide by 30 mm high on the more curved surfaces where the sides become the bottom of the boat. The strips are fastened with small nails horizontally, at intervals of 5 to 10 cm, along the length of the boat just where the wooden blocks have been added on the frames.

The difference in height between the 45 mm and 30 mm battens must be roughly levelled out before beginning to put on the plywood.

Strips of 3 mm plywood (for example, Fancyply) should be attached diagonally to the battens (see Figure 45) for better surface stability and also because they shape more easily over the chine.

In addition to tacks, some glue should also be used to fasten the strips.

FIGURE 41



This picture shows the plug jig set up and ready for the addition of horizontal wooden strips or "battens".

Small blocks of wood are fastened to the perimeter of each frame to provide better attachment for the nails holding the battens in place.

In this boatyard, the frame has been bolted to the floor. This improves the frame's three-dimensional stability and makes working easier to apply pressure during puttying and sanding.

FIGURE 42
Technical drawing

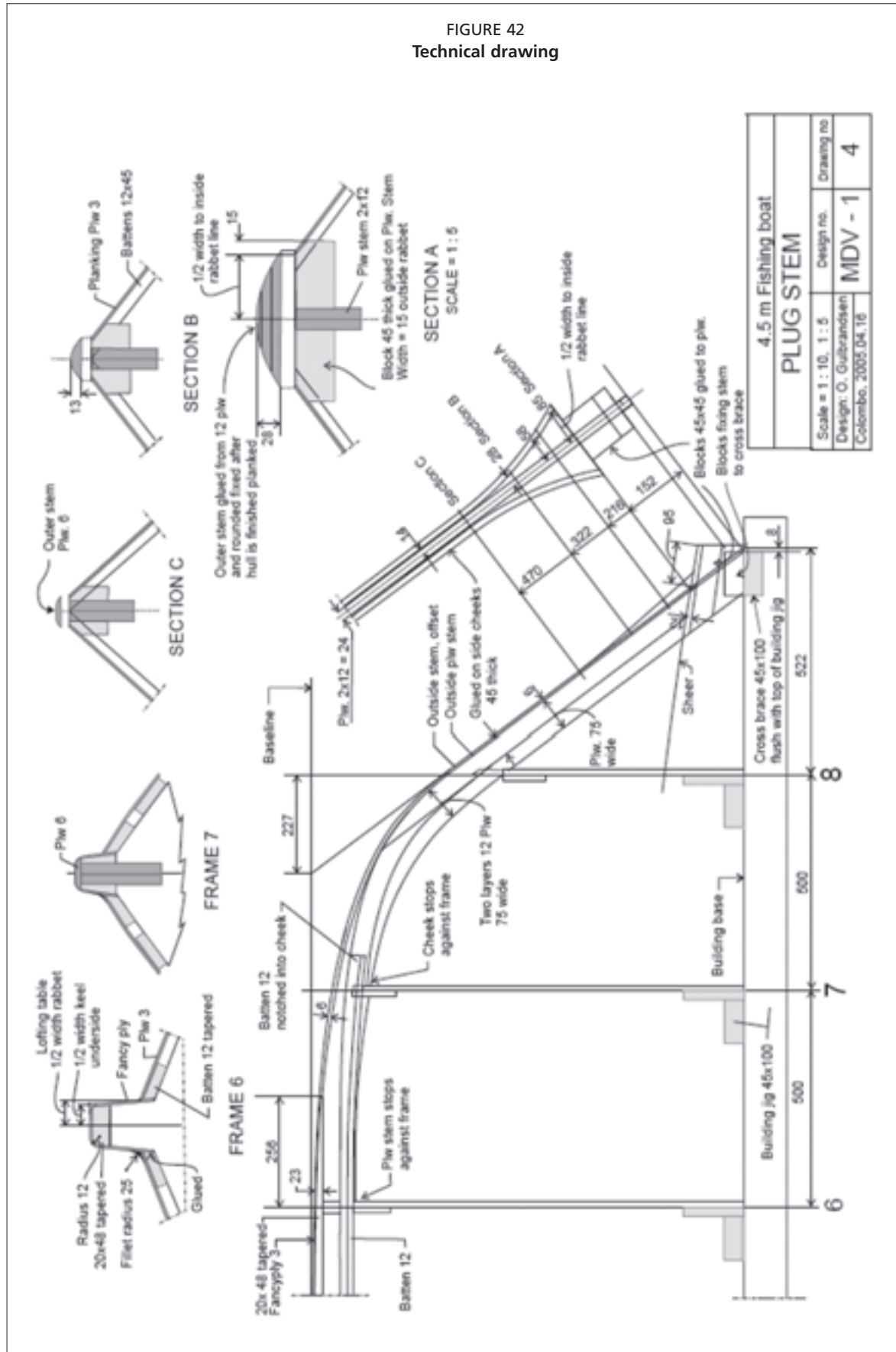


FIGURE 43
Technical drawing

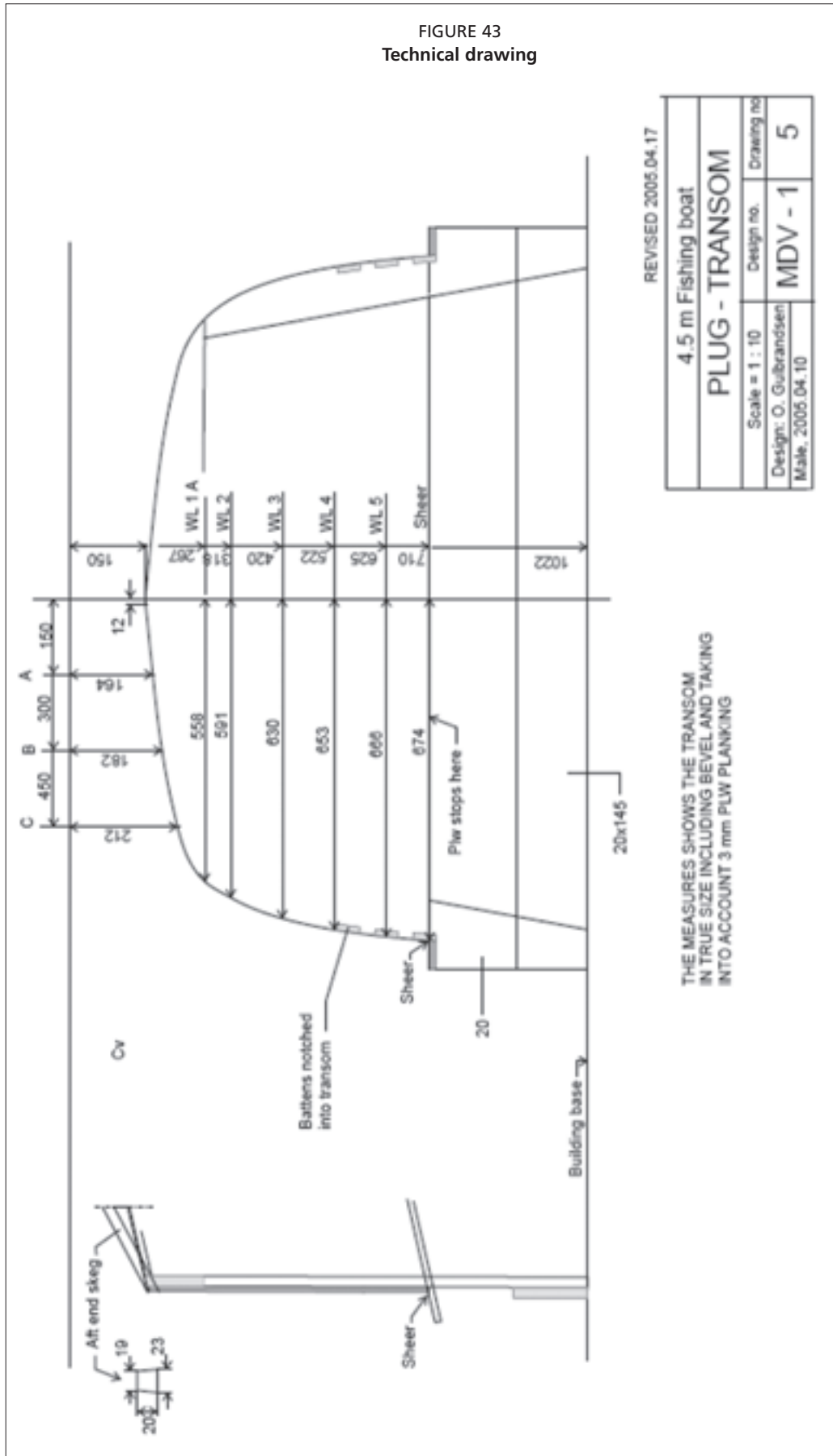
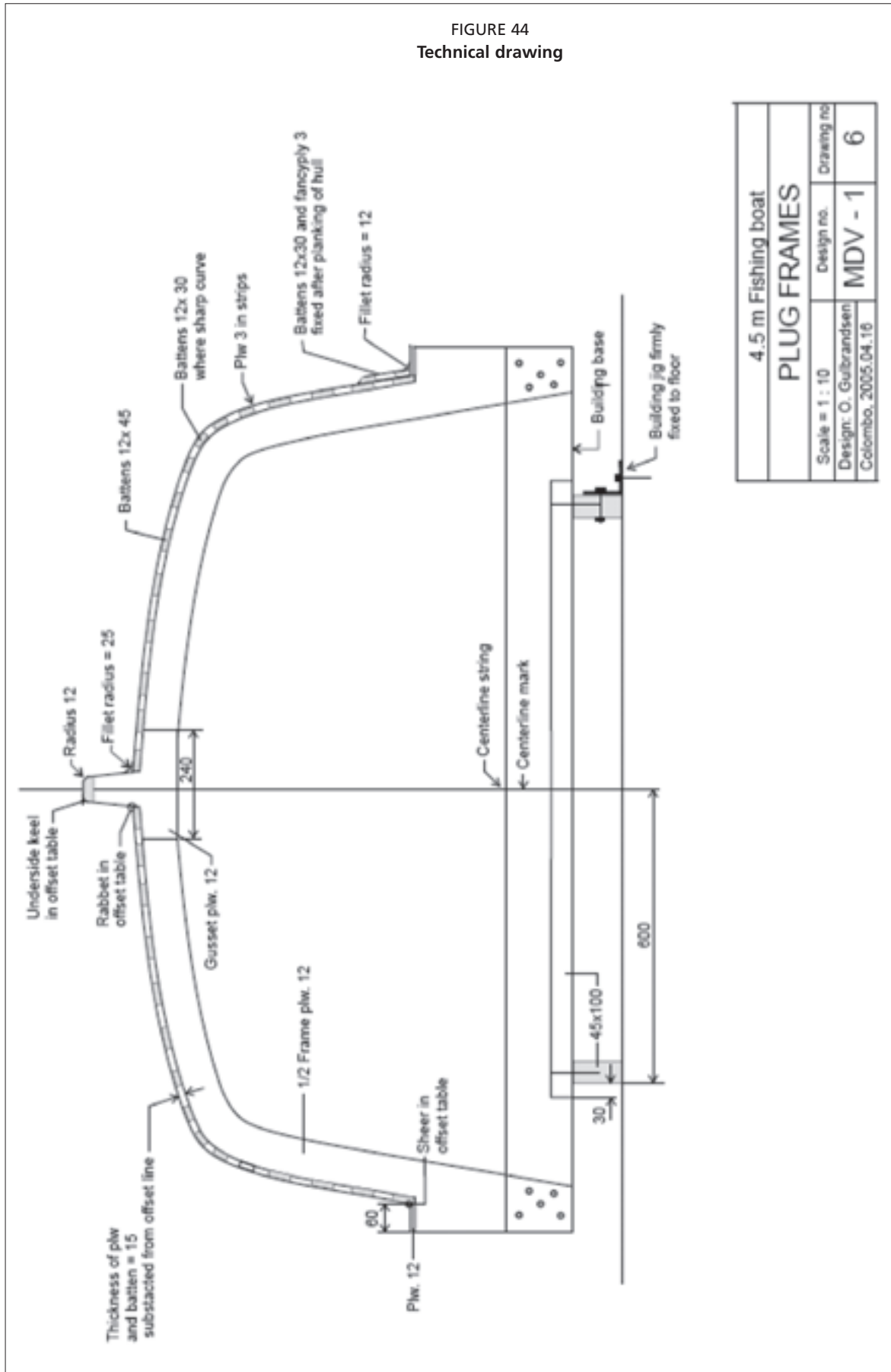


FIGURE 44
Technical drawing



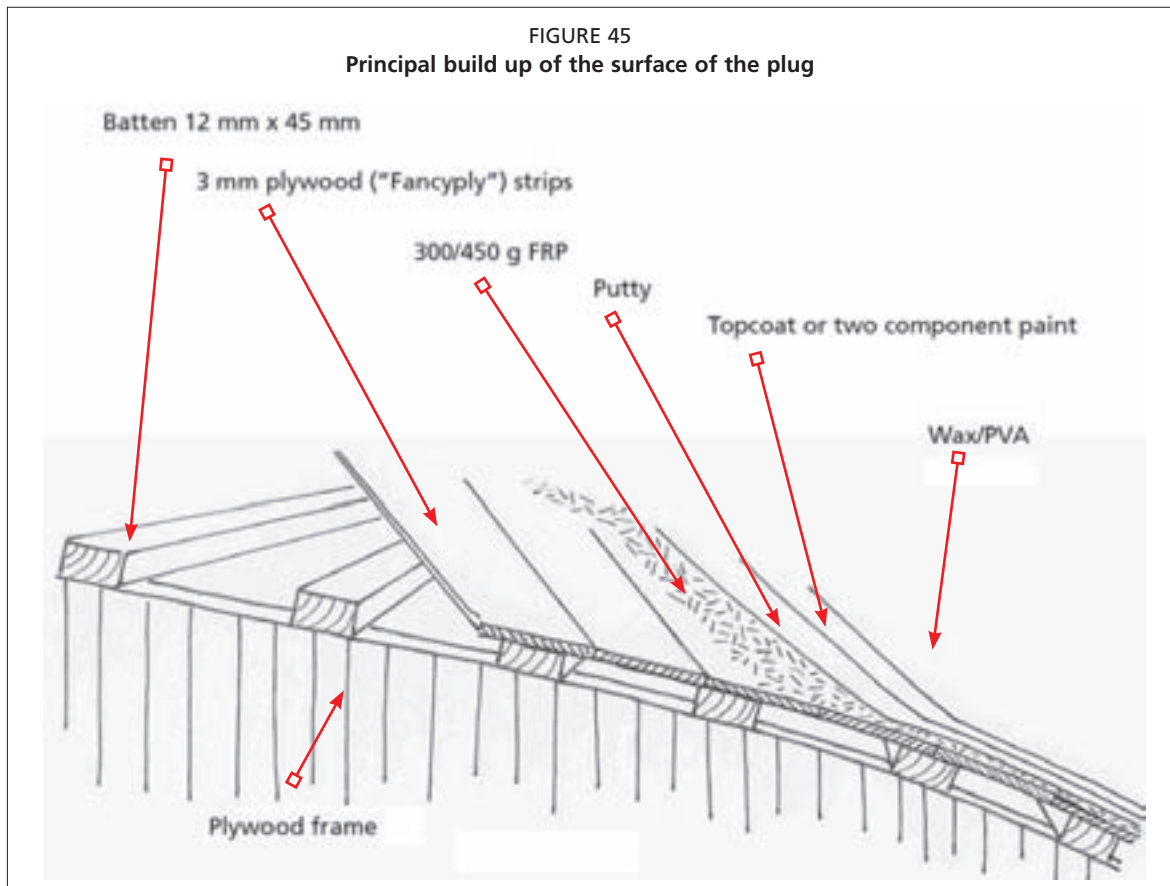


FIGURE 48



Sometimes, the battens (wooden strips) are placed further apart, and a thicker plywood "skin" is used on top.

When a thicker plywood skin is used, it is necessary to take an equal measure off the frames to compensate for the extra thickness.

Once the plywood is securely in place, the surface has to be evened off and smoothed with sandpaper.

FIGURE 49



After sanding is complete, the wood surface is sealed / primed and prepared for the laminate layer.

If only one mould is to be made from this plug and/or if the plug is to be painted with two-component paint, there is no need for the layer of fibreglass laminate.

FIGURE 50



A layer of 300 or 450 g fibreglass mat is laminated over the plug to ensure its strength and stability.

The surface of the plug is then built up with several layers of putty, and sanded to even out any imperfections in the lines.

FIGURE 51



Here is the plug almost ready for gelcoating. Only the side keels need to be fitted on and blended in. Different colours of putty are used to make it easier to recognize locations of imperfections.

For best results in achieving an even surface at this stage of the finishing, hand sanding with long boards should be used rather than power tools.

FIGURE 52



To achieve a proper high-gloss finish, topcoat or two component paint has to be applied over the putty.

If topcoat is chosen it has to be water-sanded, starting with a grit no coarser than 240 and ending up with grit sizes of 1 000 to 1 200 or even as high as 2 000.

The hull plug is finished off by buffing and polishing with wax.

NB! A flange for connecting the hull to the deck has to be made on the hull plug as shown on Technical drawing 44.

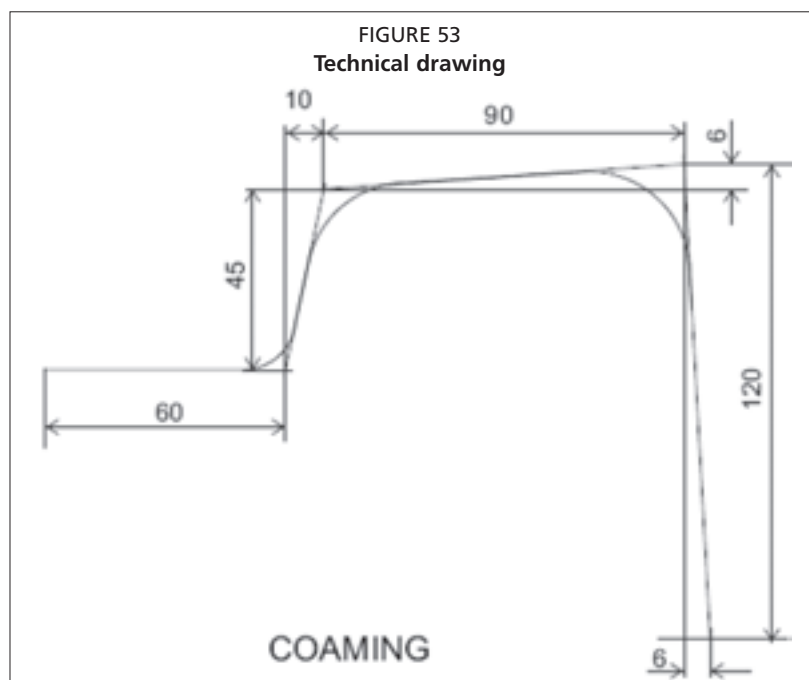
FIGURE 53
Technical drawing

FIGURE 54



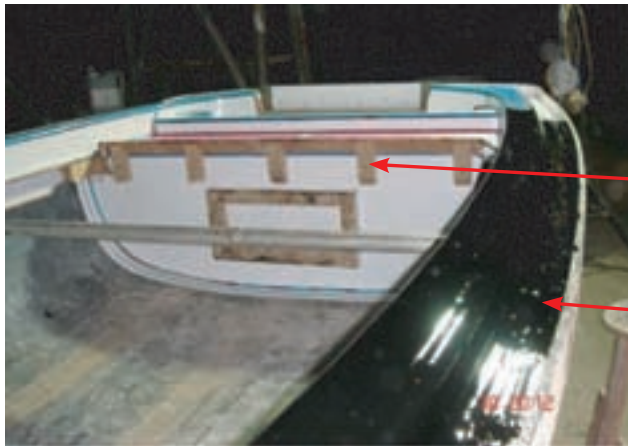
Before making the deck plug, the hull plug and mould have to be finished and a hull to be laminated (to be used to make the deck plug).

Next, steel pipe braces are laminated into the hull to keep the sides in position.

The coaming measurements are provided in Figure 53.

Vinyl anti-skid patterns are also glued in place to make a perfect "negative" print in the mould.

FIGURE 55



All the parts of the plug are shaped and fitted carefully to make sure all the laminated parts of the resulting boat will fit together.

In this picture, the aft thwart, containing a locker, is being fixed in place.

The first black layer of tooling gelcoat is also being painted on the deck plug in preparation for building the deck mould.

FIGURE 56



Separate thwart plugs also need to be constructed before beginning to make the mould. The centre thwart plug is shown at left.

The fit of the separate plugs must be checked against the hull plug before any of the moulds are built.

MAKING THE MOULD

Most moulds in common use are “female” moulds. This ensures a really smooth finish on the outer surface of the resulting boat when the cured product is pulled out of the mould.

To achieve such a finish, the plug must be worked up to a smooth finish and a perfect gloss before the mould is built. Being a mirror of the plug, every blemish is transferred to the mould and will show on the final product.

The lifespan and value of a mould is largely determined by the surface quality of the plug. If improvements or repairs to the surface of the mould are needed after the mould is pulled off the plug, valuable time will be lost. As long as the surface of the mould remains unbroken, only polishing or buffing is needed between uses and more products can be pulled off the mould in a shorter period of time.

Prepare the surface of the plug with 5 to 10 layers of wax to achieve a perfect finish. If the quality of the finish is in any doubt or if the gelcoat on the plug was not given sufficient time for a proper pre-cure (2 to 3 weeks), a PVA anti-release agent should be applied to the surface of the plug.

FIGURE 57



Real tooling gelcoat must be used on the plug, not just regular gelcoat with a black color. Tooling gelcoat is generally harder than regular gelcoat and can hold a higher gloss. It also shrinks less.

A decently thick layer must be built up by applying at least 3 coats of tooling gelcoat with a 3 - 6 hour cure in between.

When all the coats have been applied, let the gelcoat cure for 3-6 hours, and then apply a surface layer.

FIGURE 58



The first thin layer of tissue mat /surface veil has to be put on carefully, worked completely free of air and left to be cured separately. If a tissue mat is not available, a 300 g mat can also be used or both can be used wet.

It is important to apply a good coat of resin to the surface of the mould before the surface mat is added. This will ensure that the mat is impregnated from the bottom, “pushing” the air out.

□ Careful butt-jointing of torn edges is preferable the overlapping of cut edges as shown in this example.

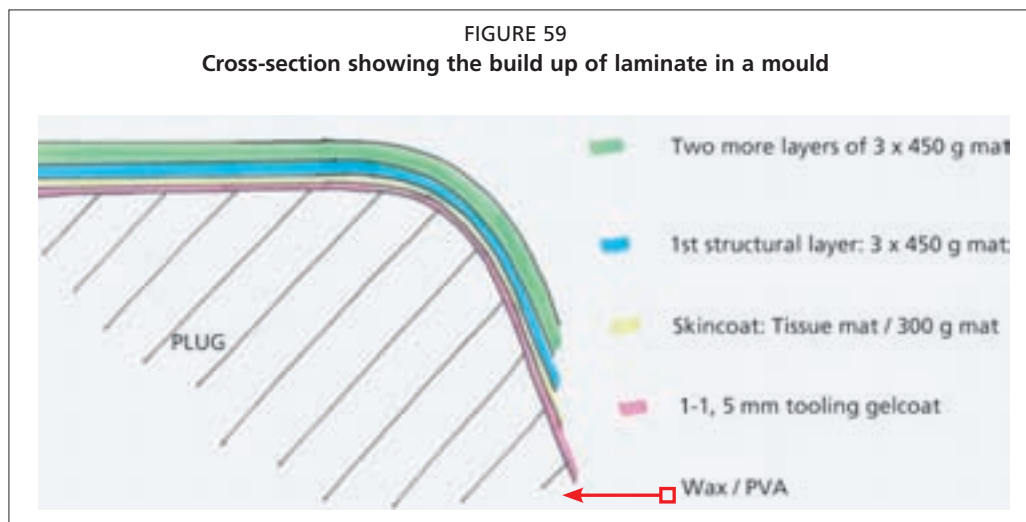
The last wax layer must have been left to dry for at least 12 hours. After this drying period, apply one layer of mould wax and let it dry for at least 4 hours. Then, apply the PVA release film. This should be done with a piece of chamois, wettex or similar material. The chamois or cloth should be saturated with PVA solution, carefully squeezed out and applied lightly to build up a thin and even film.

NB! If the surface of the plug has been treated with fully cured two-component paint and the waxing has been done with care, the release film should not be used.

The procedure for building up the laminate to create a mould is more or less the same as for building up the laminate to create a boat (see Basic laminate building). It is **very important** to ensure that the surface layer is totally free of trapped air.

Special tooling resins are also available that are formulated to withstand better the repeated heat from exotherm during curing of successive laminate layers and the strain of demoulding.

When using common GP polyester, no more than 3 layers a day should be laminated to allow the styrene to evaporate and avoid heat build up and excessive shrinkage. For this size of boat, a 10 mm thickness of laminate should be sufficient for the mould.



Stiffeners made of FRP, plywood or steel must be laminated to the mould to ensure that it retains the intended shape after being pulled off the plug. The stiffeners and frames should not be fitted until the surface layers of the mould have cured for at least two weeks. This avoids them printing through.

FIGURE 60

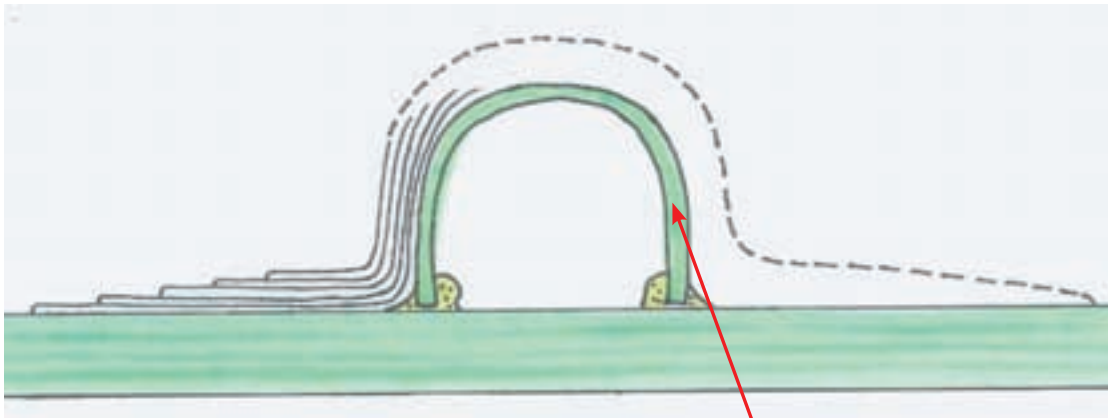


FIGURE 61



These figures show how stiffeners made from preformed tubes of FRP are fixed in place with putty and then laminated in with at least 5 layers of 450 g mat.

These additions greatly improve the rigidity of the mould while not adding much weight.

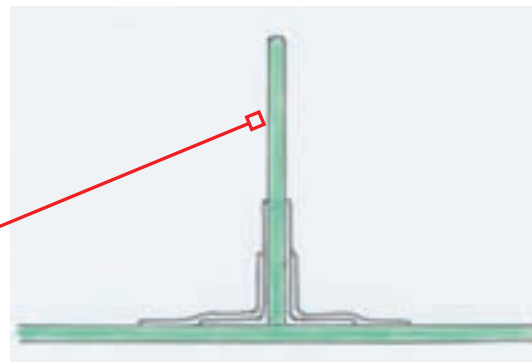
FIGURE 62



Here the finished mould is shown with stiffeners attached and a "cradle" beneath it.

The cradle is made of plywood supports, laminated in place in the same way as the FRP tubes were attached to the mould (see Figure 63).

FIGURE 63



A layer of gelcoat and fibreglass has already been applied inside the mould – the beginnings of the first boat to be made.

FIGURE 64



The deck mould ready for use.

FIGURE 65



A finished mould for the centre thwart. All the separate parts (structurals and other items) of the boat need their own mould.

Ideally, a new mould should be placed in a tent, heated to maybe 40 °C, to pre-cure for a couple of days. In a tropical climate, maintaining the high temperature should be an easy task. The pre-cure should drive off most of the active styrene on the tooling surface and help prevent the fresh mould from sticking to the gelcoat on the first boat produced. After the first boat is completed and freed from the mould, prepare the mould's surface by wax, as described earlier in this chapter, before starting work on the second boat.

An inexpensive way of “breaking in” the mould involves construct of two “throw away” products built with extra hardener to create a “hot” gelcoat and two layers of laminate. This will help to prevent the first real boat getting stuck in the mould.

While an easy precaution, the use of PVA mould release gives a poor surface finish. More rubbing and polishing will be required to achieve a proper finish on this boat.

NB! Tooling gelcoat is not UV stabilized so the mould should be protected against direct sunlight when it is being stored.

BUILDING THE BOAT

Prepare the mould as described in the previous section “Making the mould”. Building the actual boat starts with the application of the proper thickness of gelcoat to the prepared mould. Two layers applied by brush (0.4 to 0.8 mm) are sufficient.

Laying down the skincoat laminate and bulk (structural) layers are the next steps. The processes for this work are described in an earlier section called “Basic laminate building” and according to the lay-up schedule set out in Figure 69. Appendix 3 may also be used.

FIGURE 66



The mould is prepared with wax.

Two layers of gelcoat are applied.

A skincoat laminate layer is added.

The main (structural) laminate layers are built.

FIGURE 67



FIGURE 68
Technical drawing

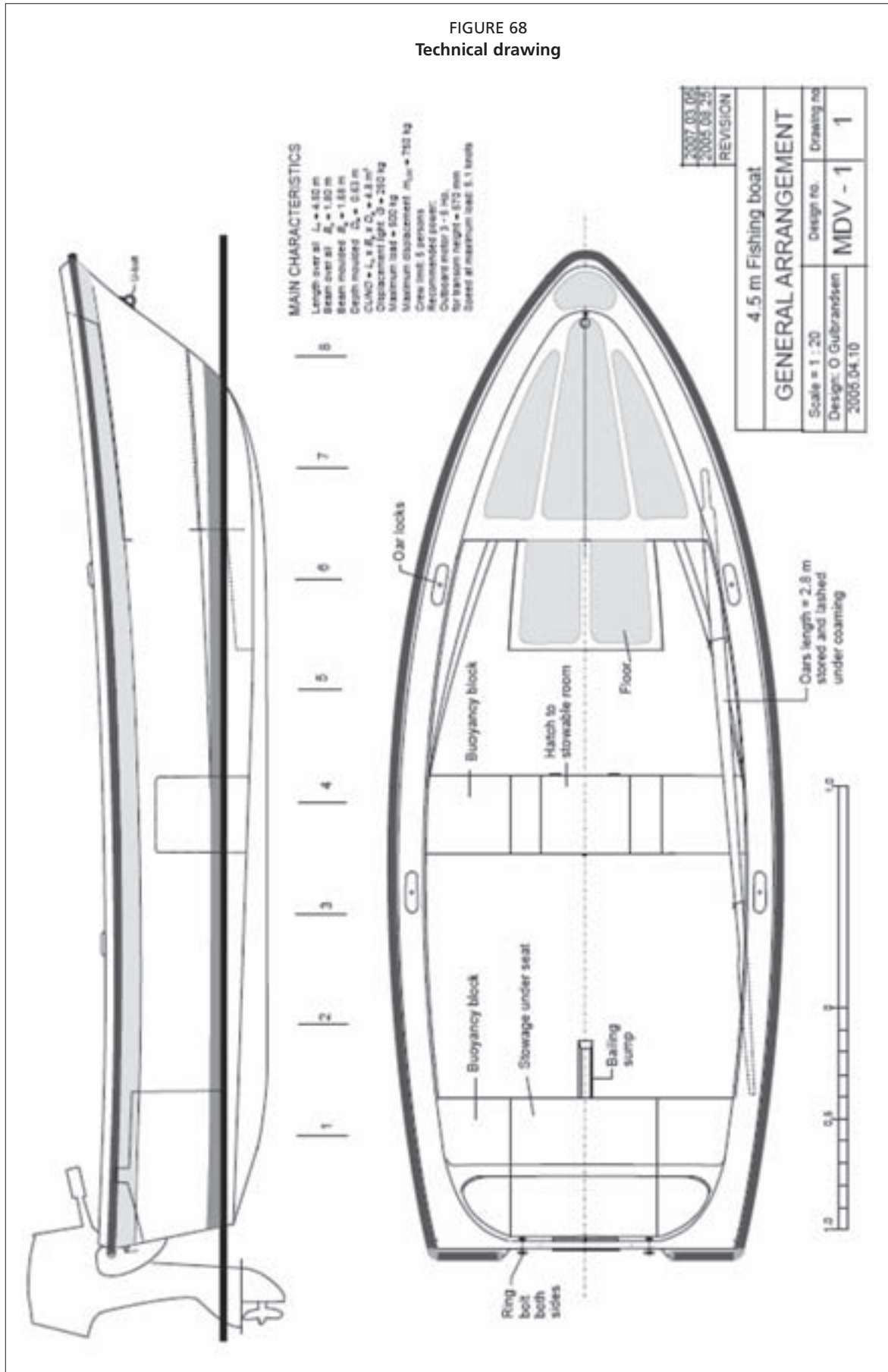


FIGURE 69
Technical drawing

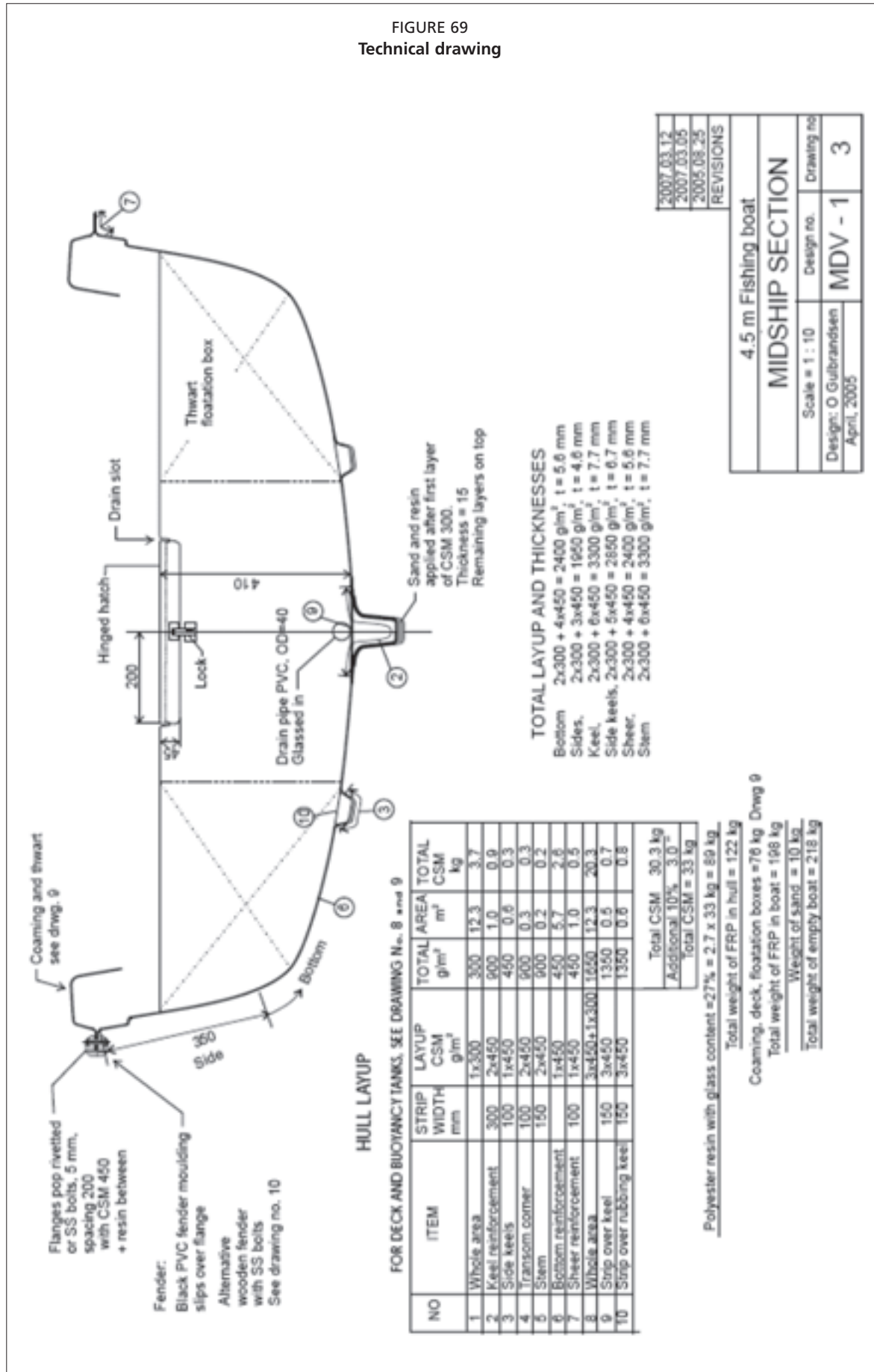


FIGURE 70



The transom is strengthened by adding two layers of 18 mm plywood bonded together for a total of 36 mm.

The sides must be tapered at least 45° before being laminated with 3 layers of 450 g mat.

Any drain holes for the engine well must be properly sealed to prevent water from coming in contact with the plywood.

FIGURE 71



The deck is strengthened by laminating stiffeners into the deck as shown at left.

In this example, the stiffeners are dried wood. Make sure the end pieces of the wood are cut and properly sealed with FRP.

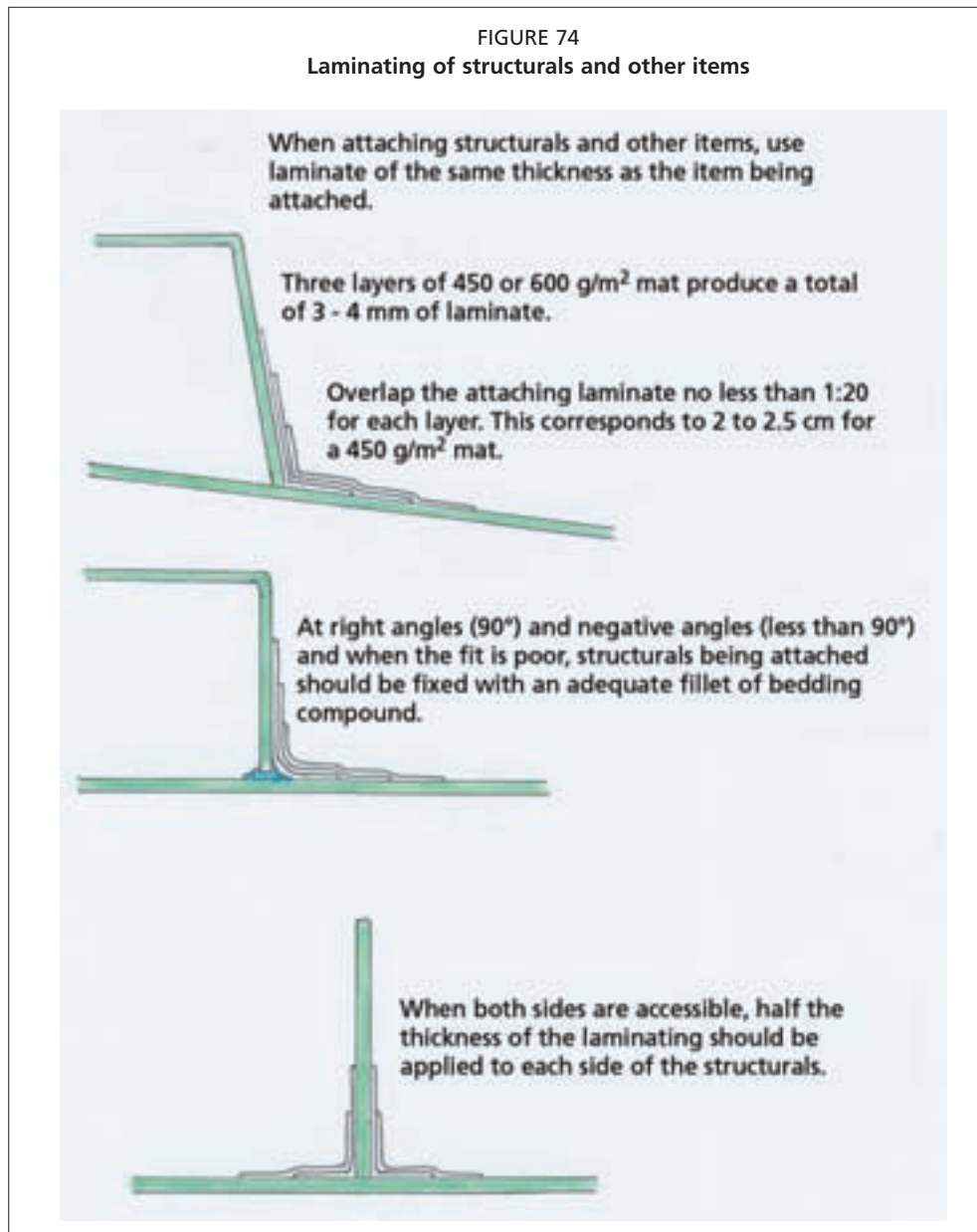
Plywood, PU foam and preformed FRP tubes can also be used as moulds for FRP stiffeners. Another option is to make a sandwich with structural foam.

FIGURE 72



In both these pictures, inserts of plywood can be seen laminated into the deck.

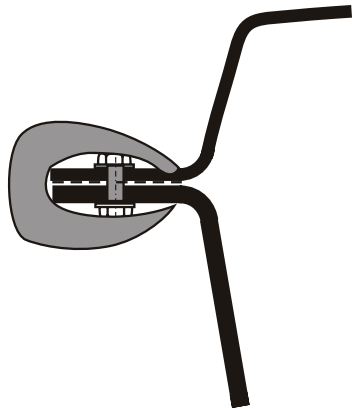
These inserts will support the fastening of necessary deck hardware and also increase the stiffness of the structure.



When preparing to attach the deck to the hull, a disc grinder should be used to grind the two flanges very flat and produce a rough finish. Two layers of laminate using 450 g CSM must be applied on the flange and the two parts clamped together to cure.

An even better, but slightly more expensive way, of fixing the two halves together would be by using Polyurethane or MS construction glue as a bedding compound. This glue should also be used to seal/bed the hardware, bolts and screws while mounting them. If mechanical fasteners are not used, a simple clamp could be made and used to keep the two halves together while the FRP or bedding compound is hardening.

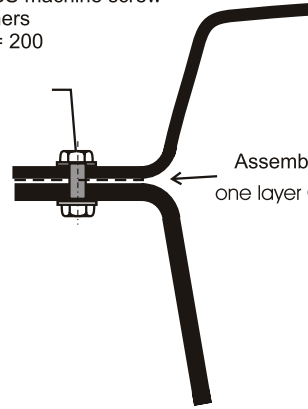
FIGURE 75
Technical drawing



ALTERNATIVE PVC FENDER

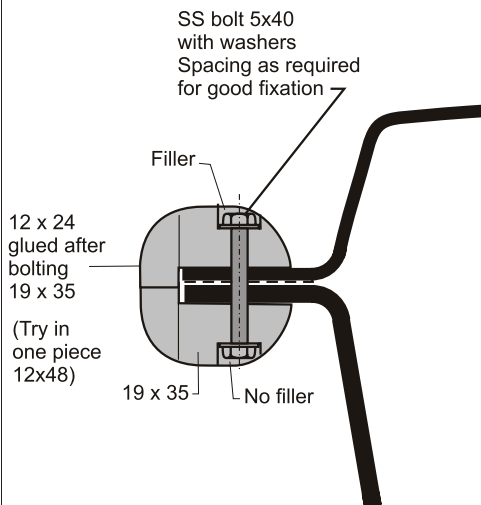
Heated in hot water before application

Marine type pop rivets
or 5x20 SS machine screw
with washers
Spacing = 200



FLANGE ASSEMBLY

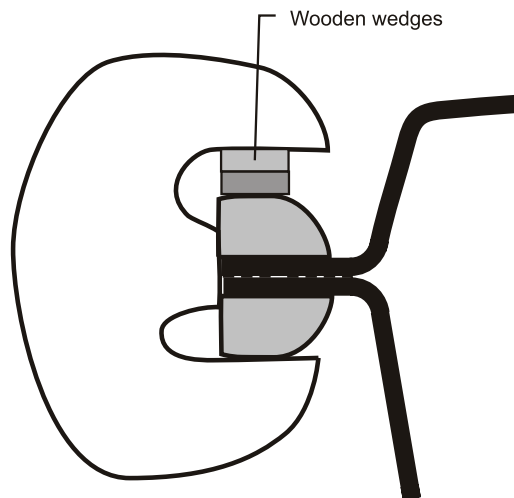
Assembled with
one layer CSM 450 wet



ALTERNATIVE WOODEN FENDER

Fixed after assembly of flanges

Use hardwood with
high rot resistance



Clamp from 18 - 20 mm plywood

4.5 m Fishing boat		
HULL - DECK JOINT		
Scale = 2 : 1	Design no.	Drawing no.
Design: O Gulbrandsen	MDV - 1	10
Date: 2005.08.25		

FIGURE 76



This picture shows details of the storage area in the forward part of the boat.

PU foam can be poured into the flotation space below the storage area.

The edges have been ground in preparation for laminating.

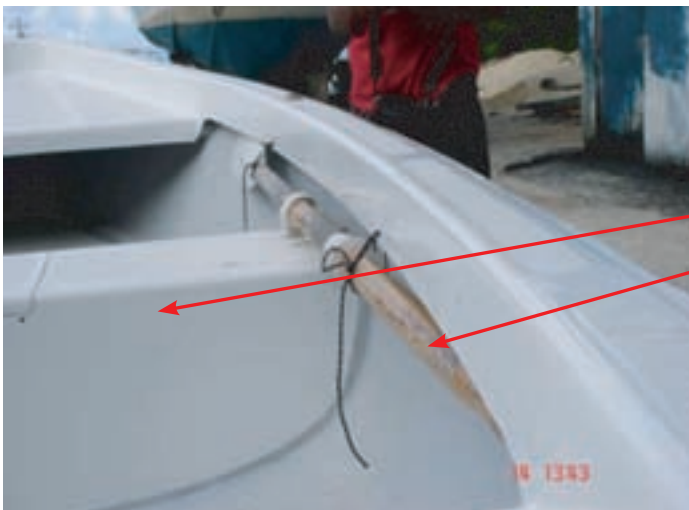
FIGURE 77



This photo shows PU being poured into the flotation space. The correct volume of foam needed to fill the space must be carefully calculated. Manufacturer's directions concerning temperature, mixing ratio, and rate of expansion of the foam should be understood and carefully followed.

Approximately 1.6 kg of liquid PU makes 0.028 m³ (1 ft³) of foam.

FIGURE 78



Thwart fixed in place, with oars stored out of the way.

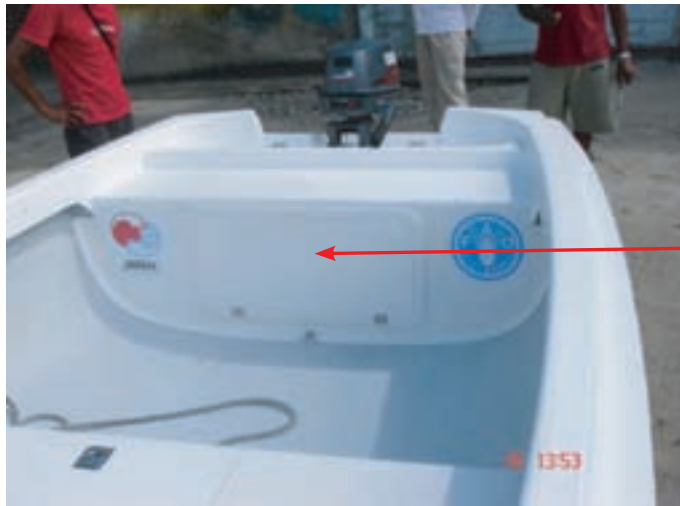
FIGURE 79



Weighing the boat is a good way to calculate how much polyester and fibreglass has been used during construction.

□ This picture shows the flotation spaces and the storage area aft.

FIGURE 80



□ The aft storage area is closed with a weathertight hatch in the finished boat.

FIGURE 81



□ A reinforcement plate made of steel or aluminium is added to provide extra support for the engine mount.

□ Installed location of U-bolts shown in Figure 82.

FIGURE 82



Eight (8) mm stainless steel U-bolts to be mounted in the bow and the transom as shown in Technical drawing 73.

FIGURE 83



Oarlocks can be made in different ways.

This is an example of one made locally in the Maldives.

FIGURE 84



The drain plug is mounted in the transom with two ½ inch number 8 taper head screws.

The drain plug must be completely sealed with bedding compound when mounting.

FIGURE 85



A 5 hp outboard engine is sufficient for use in calm waters. Where stronger currents are common, a 10 hp engine could be more suitable.

The cavitation plate must be in line with the bottom of the transom, as shown at left.

FIGURE 86



A completed boat without fender is shown in the foreground of the picture at left.

PART III – Maintenance and repair

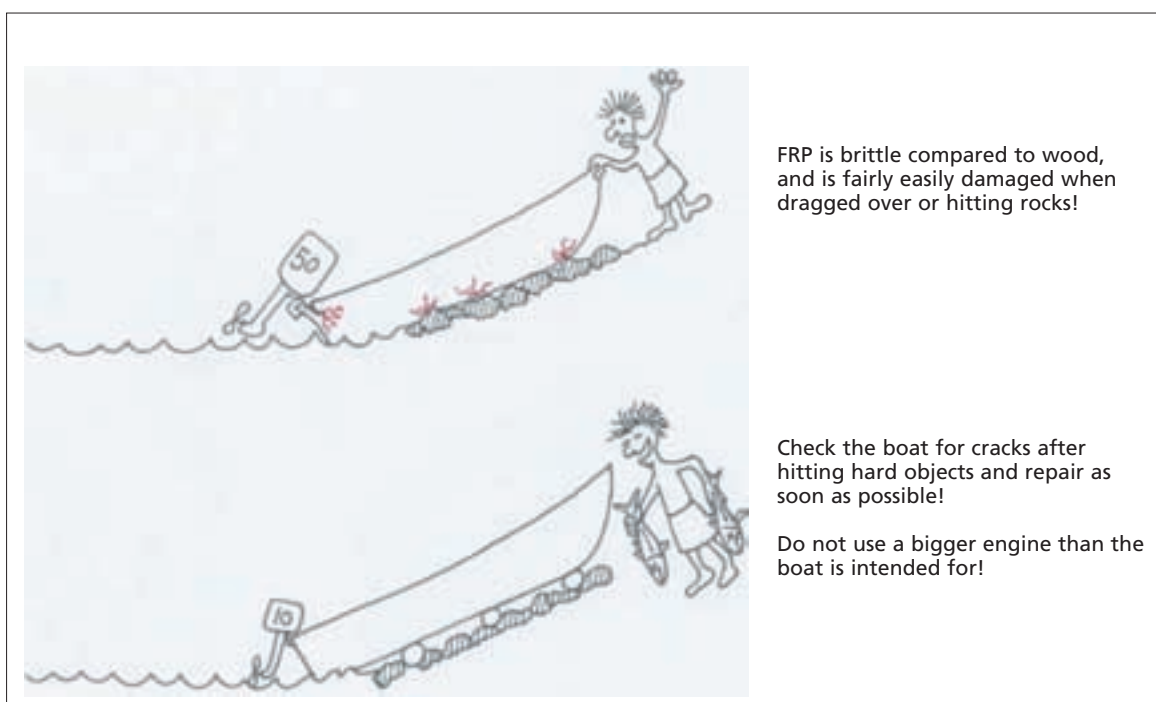
MAINTENANCE

What to look for and how to take care of your FRP boat

For everyday use, fibreglass reinforced polyester generally does not need much maintenance but this does not mean the boat will last forever. Wear and tear and the absorption of water do affect the lifespan of an FRP boat. The challenge is to determine if what can be observed on the surface is just cosmetic or more serious structural damage.

If unattended for a long time, a good quality FRP boat has the advantage of not requiring as much maintenance as a wooden boat.

A boat's smooth shiny surfaces can be protected by a good polishing with wax. This polish repels water and helps to keep the surface clean. Polishing is not a realistic option for rough surfaces like the inside surface of a boat. Wear and tear is often heaviest in these areas where the only protection is a layer topcoat.



It is important to watch out for new cuts and crushing on the surface. Any such areas should be examined and sealed temporarily especially if the cracks are deep. As soon as possible, the damage should be repaired properly to prevent the areas from developing into more severe structural damage as a result of material fatigue during continued use of the boat.

When the surface becomes too worn, it should be degreased, cleaned and abraded properly to give good adhesion for a fresh layer of topcoat or paint. Above the waterline, a good quality marine paint is often a quicker, short-term solution than applying new topcoat. Paint has a glossier surface, and more easily repels dirt. However, gelcoat builds up thicker and generally resists mechanical wear better.

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

FIGURE 88



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

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

If the gelcoat is intact, osmosis blisters might occur.

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

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

FIGURE 89



This photo shows typically worn interior of a fishing boat. The topcoat is worn off, and even FRP laminate covering the longitudinal stiffeners is gone.

The damaged laminate should already have been repaired to regain original strength and the surface recoated with topcoat or paint.

FIGURE 90



This photo shows what happens when laminate has not been maintained or repaired for too long.

□ The laminate has lost its strength and stiffness and, due to fatigue, the frame has broken.

◇ At this spot the longitudinal stiffener is no longer supported by FRP laminate and, as a result, the bottom laminate can flex.

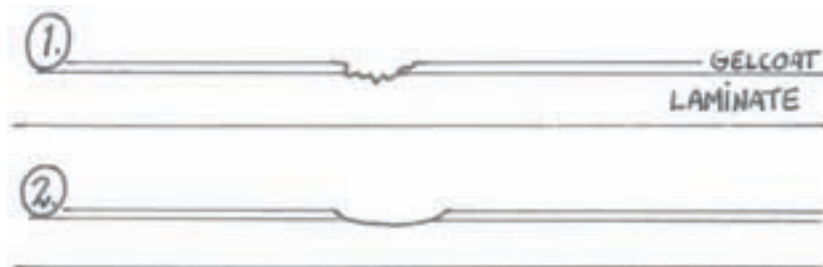
For fishing boats and workboats making and maintaining a glossy surface finish is not always realistic. However, such surfaces repel water more easily and take longer to deteriorate.

The goal of regular maintenance is to keep the vessel in a state of good repair and help it last as long as possible. The next two chapters focus on how to repair a damaged boat so that it is sound and as close to the original in strength and stiffness as possible. If such action is needed suggestions for improving the boat, compared to the original, are also given.

REPAIRING SMALL DEFECTS

The following notes refer to the repair of minor damage to FRP boats where the gelcoat has worn away or been chipped or cut but the laminate has not been seriously abraded. Figures 91 to 93 show an example of superficial damage and the steps needed in preparation for making the repair.

FIGURE 91



First of all, make sure it is really just a minor defect.

If the laminate is damaged, the site needs structural repair (as described in the section titled "Repairing structural damage").

FIGURE 92



Dirt, oil from the engine, grease, and blood from fish must be cleaned off before sanding begins!

Soap and water are used first followed by washing with available strong detergent.

FIGURE 93



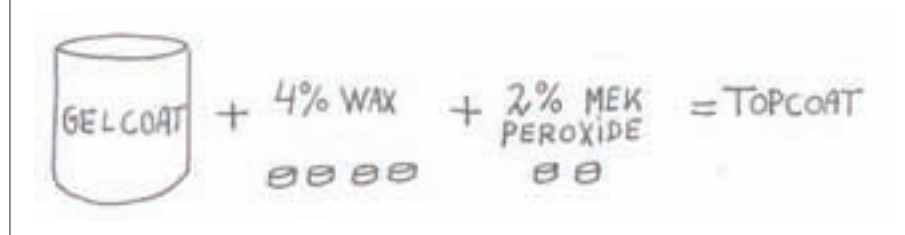
All broken gelcoat must be sanded away and any broken edges like the ones shown in Figure 91 must be smoothed.

A small piece of sandpaper (60 to 100 grit) should be used and size of repair area kept to a minimum.

Once sanded, no further washing or degreasing should occur before applying topcoat to the damaged area!

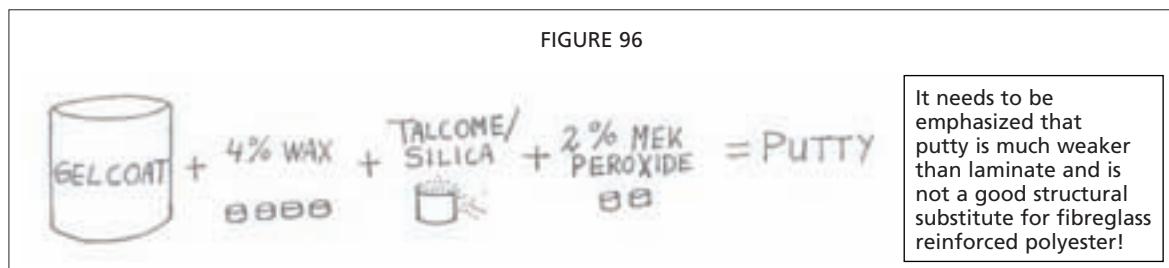
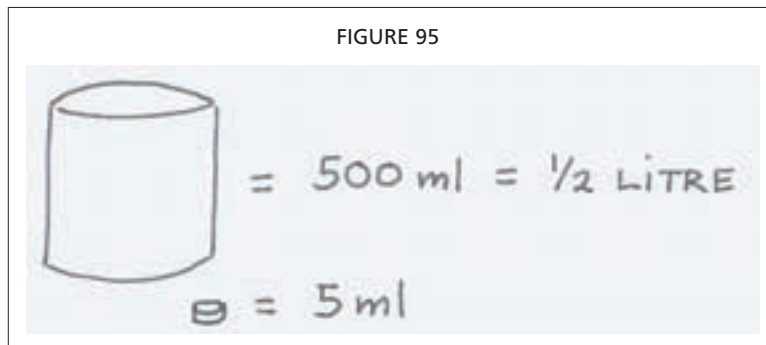
Topcoat should be prepared by combining the following ingredients in the proportions shown (half a litre of gelcoat, 20 ml of wax and 10 ml of MEK peroxide).

FIGURE 94



Figures 94 to 96 were copied from a repair folder. In Figure 94, the formula for topcoat is shown graphically. Figure 95 explains the two measures used in the above formula where a plastic bottle is cut down to hold half a litre (500 ml) and each bottle cap holds 5 ml (see Figure 95). Such measuring devices are readily available and provide a simple way to get the right ratio of materials for a good cure.

If there is a very thick layer of gelcoat and/or the damage extends slightly into the laminate but is not deep enough to be considered structural damage, the area can be repaired faster using putty. To make putty, mix in Colloidal Silica, the preferred option, or Talcome, if this is what is available, according to the formula in Figure 96. The amount of talcome/silica required depends on how much is needed to achieve the viscosity suitable for repairing the damaged area.

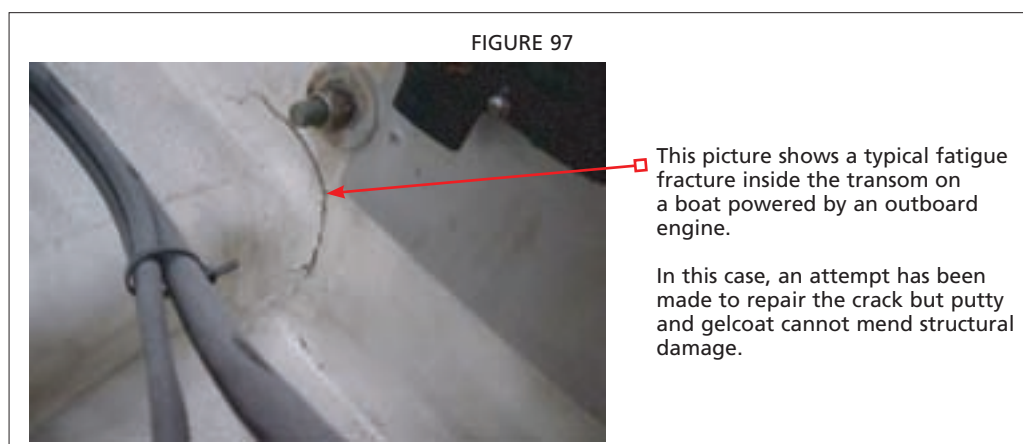


To create a lasting finish on the surface, the putty should be sanded down and a layer of topcoat added. At this stage, the appearance of the cured topcoat will be slightly rough and dull. To get a smooth and shiny finish, it is necessary to water sand the topcoat with an 800 grit (or finer). This should be followed by buffing and polishing to the same standard used for making plugs or repairing moulds.

REPAIRING STRUCTURAL DAMAGE

Practical guidelines for structural FRP repair

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



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

FIGURE 98

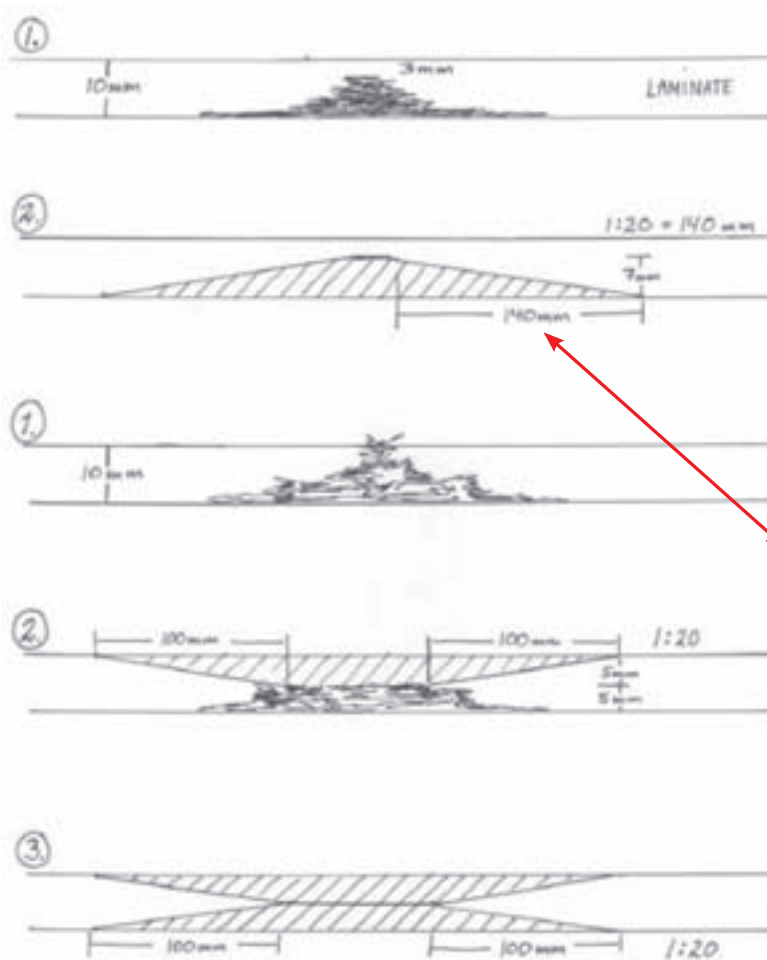


Prior to grinding, all surface contamination like oil and silicone should be washed off and removed with a suitable solvent. For grinding, 40 grit sandpaper is a good choice.

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

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

FIGURE 99



These schematic drawings illustrate the principle of laminate repair.

The first two images show damage which has not penetrated the whole laminate. The next three show a two sided repair.

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

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

FIGURE 100



When the grinding is complete, the area to be laminated will likely be much bigger than suggested by the initial visual inspection.

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

Primary bonding

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

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

Apart from sanding off bumps and fibres which could cause defects and air pockets in the laminate, a fresh (green) polyester laminate requires no preparations before adding another layer.

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

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

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

Secondary bonding

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

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

Choosing a resin for structural repair

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

For more critical structural repairs, laminates made with epoxy resin are generally stronger (but not stiffer!). Epoxy resins are highly adhesive and have a longer shelf life

than polyester and vinylesters. These characteristics make epoxy ideal for emergency repair kits. As they require no solvents, epoxy resin does not contaminate the surface of the original laminate and shows no shrinkage when curing (less tension).

Epoxies do not hydrolyse and this together with good adhesion, low shrinkage and high ratio of elongation to break, makes them more liable to perform well as a primary bonded laminate. However, epoxies are intolerant of bad mix ratios and the setting time cannot be shortened or lengthened by altering the amount of hardener. In addition, an epoxy surface is definitely not active with styrene; therefore, any further rework on an epoxy boat or an epoxy repair will have to be made with epoxy.

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

As part of the repair process, a secondary bonding test can be made as follows.

BOX 2

A SECONDARY BONDING TEST FOR RESINS

1. Prepare a small piece of the laminate to be repaired.
2. Apply 3 layers of reinforcement and resin.
3. Cure for one day.
4. Separate new laminates. This may require use of a chisel.
5. If the new laminate pulls fibres out of the old laminate, the bonding is good!
6. Another simple testing method is by using small dry wooden blocks as shown in Figure 101.

FIGURE 101



Choosing reinforcement for structural repair

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

Meanwhile, remember that there will be no continuous fibres attaching the old to the new laminate, and strength of the joint will depend solely on adhesion of the new laminate to the old. Almost 100 percent of stiffness can be recovered if the laminate is

built up to its original thickness; however, the strength and fatigue properties of the repaired laminate will be weaker than the original. Dimension of the fibre bundles is critical for the repair to perform well because large bundles and heavy mats/fabrics obscure air and resin-rich pockets that are more likely to form at the borderline between the old and new laminates.

It is important to take all these matters into consideration when designing the repair laminate (see Figure 102). If additional reinforcement is required to maintain the boat's overall strength, be careful to avoid excessive laminate build-up as this can increase the risk of developing stress concentrations.

FIGURE 102



In this example, the resin chosen for use was epoxy, but vinylester might also have performed well. Bear in mind that this was a single-sided repair and the original polyester laminate was already showing weakness from fatigue.

The reinforcement was a mix of 290 g woven twill and 450 g Double Bias fibreglass, chosen because of its drape ability and good performance with epoxy.

Surface preparation

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

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

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

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

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

FIGURE 103



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

Putty has a short "elongation to break" ratio, and will break up and crack much faster than a laminate.

FIGURE 104

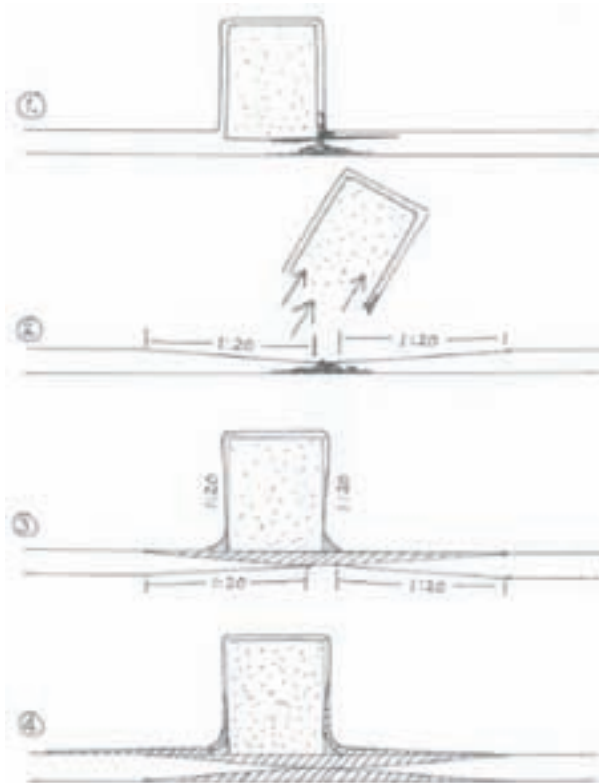


This picture shows the finished product. Topcoat has been applied, water sanded, buffed and polished to a decent gloss.

Polyester topcoat can be used on top of epoxy as long as the epoxy is cured properly before the topcoat is applied.

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

FIGURE 105



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

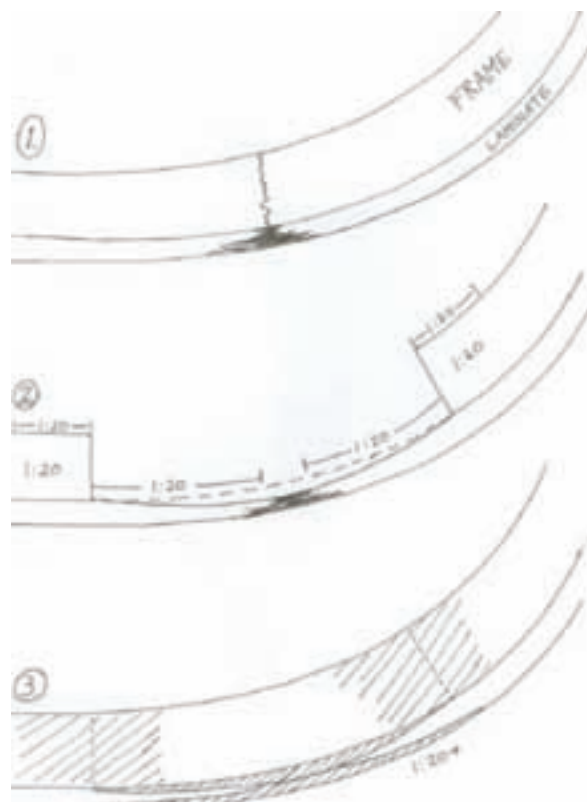
1. A fracture in the outer skin has penetrated the whole laminate, and caused delamination in the framework.

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

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

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

FIGURE 106



Side view

1. This represents almost the same structural damage as shown in Figure 105, but viewed from the side.

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

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

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Appendix 1

Copying old boat designs for construction with fibreglass reinforced plastics

It is possible to use an old wooden boat as a plug by first drying out the wood and then covering it with fibreglass reinforced polyester (FRP). The rest of the process of building up the surface is the same as described in the section Making the Plug.

It should be noted that not all old boats or canoes are of a suitable design to be copied directly in fibreglass. Wood and FRP have different mechanical properties. It is dangerous to think that, since FRP is stronger, it can easily be used to make the hull of any boat thinner and lighter.

If the design does not take into consideration the properties of FRP, the copied boat may lose stiffness quickly and be more exposed to fatigue.

The combination of an original wooden boat shape and the lighter weight of FRP could result in vessel instability and other less favourable seagoing characteristics.

This type of large traditional wooden canoe has demonstrated its seaworthiness and durability for generations, successfully going out to sea from shore through the surf, heavily loaded with nets.

FIGURE 107





This FRP boat was copied from a wooden canoe and was not old but already had broken frames and fatigue cracks in the bottom laminate.

The shape, size and use of these wooden boats make them unsuitable for exact reproduction as FRP copies. FRP is too brittle to survive such regular bending and the thinner walls make the structure vulnerable to fatigue.

The FRP version would have to be built much more heavily than this copy and with better designed and stronger stiffeners in order to withstand the stresses involved in carrying their typical load of fishing equipment and men out to sea through the heavy swell.

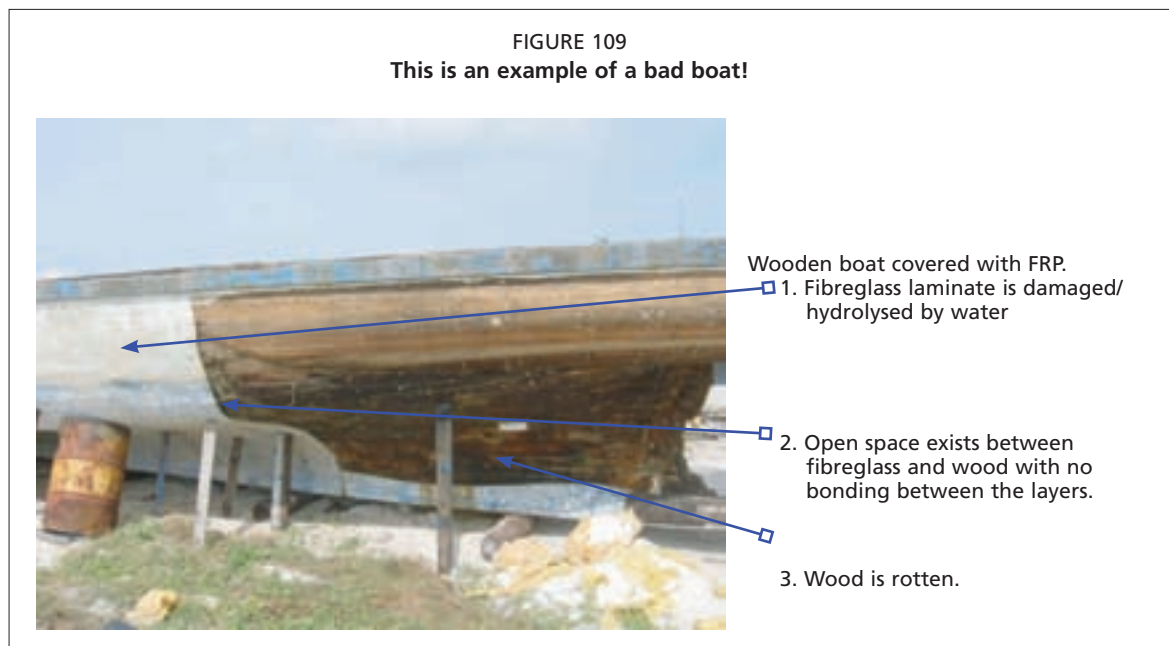
Appendix 2

Covering old boats with FRP

Choosing to cover an old worn-out wooden boat with fibreglass reinforced polyester to keep it floating on the water is a big risk. Even if the old wood can be dried out completely, the likelihood of keeping rot away for any reasonable length of time is not very good.

There is a good chance that, within a few years, rot will eat up the boat from the inside!

Adding two to three layers of FRP on the wood will seem to produce a stiff and dry boat, but after a few years problems will start. To be safe at sea for a longer time, a new boat should be built.



Appendix 3

Material list and hull lay-up for MDV-1

TABLE 1

HULL LAYUP FOR DECK AND BUOYANCY TANKS, SEE ALSO FIGURE 73

NO	ITEM	STRIP WIDTH mm	LAYUP CSM g/m ²	TOTAL g/m ²	AREA m ²	TOTAL CSM kg
1	Whole area		1 x 300	300	12.3	3.7
2	Keel reinforcement	300	2 x 450	900	1.0	0.9
3	Side keels	100	1 x 450	450	0.6	0.3
4	Transom corner	100	2 x 450	900	0.3	0.3
5	Stem	150	2 x 450	900	0.2	0.2
6	Bottom reinforcement		1 x 450	450	5.7	2.6
7	Sheer reinforcement	100	1 x 450	450	1.0	0.5
8	Whole area		3 x 450 + 1 x 300	1650	12.3	20.3
9	Strip over keel	150	3 x 450	1350	0.5	0.7
10	Strip over rubbing keel	150	3 x 450	1350	0.6	0.8
Total CSM						30.3 kg
Additional 10%						3.0 kg
Total CSM						33 kg

TABLE 2

COAMING, DECK AND FLOATATION BOXES

	ITEM	LAYUP CSM	g/m ²	AREA m ²	WEIGHT kg
1	Coaming	300 + 3 x 450	1650	3.07	5.06
2	Deck aft, engine well	"	"	1.09	1.80
3	Deck forward	"	"	0.95	1.57
4	Floatation boxes aft	"	"	1.00	1.65
5	Thwart boxes	"	"	1.20	1.98
6	Floatation forward	"	"	0.74	1.22
7	Floor forward	"	"	0.46	0.76
8	Strip in flange, assembly	450	450	0.40	0.18
CSM					14.22 kg
Waste 10 %					1.42
CSM Total					15.6 kg
Polyester, 30 % glass content: 2.40 x 15.6					37.4 kg
Total deck and floatation: FRP materials					53 kg
Wood fender and thwart					14
TOTAL					67 kg

Polyester resin with glass content = 30% = 2.4 x 33 kg = 79 kg

Total weight of FRP in hull = 112 kg

Coaming, deck, floating boxes = 67 kg

Total weight of boat = 179 kg

Total layup and thicknesses:

Bottom	$2 \times 300 + 4 \times 450 = 2\,400 \text{ g/m}^2$	$t = 5.6 \text{ mm}$
Sides	$2 \times 300 + 3 \times 450 = 1\,950 \text{ g/m}^2$	$t = 4.6 \text{ mm}$
Keel	$2 \times 300 + 6 \times 450 = 3\,300 \text{ g/m}^2$	$t = 7.7 \text{ mm}$
Side keels	$2 \times 300 + 5 \times 450 = 2\,850 \text{ g/m}^2$	$t = 6.7 \text{ mm}$
Sheer	$2 \times 300 + 4 \times 450 = 2\,400 \text{ g/m}^2$	$t = 5.6 \text{ mm}$
Stem	$2 \times 300 + 6 \times 450 = 3\,300 \text{ g/m}^2$	$t = 7.7 \text{ mm}$

These are approximate figures of the total amount of material needed:

Gelcoat:	20 kg
Polyester:	150 kg
MEK Peroxide:	4 kg
300 g/m ² CSM mat:	14 kg
450 g/m ² CSM mat:	50 kg
Acetone:	10 kg
Mould release wax:	0.3 kg
PVA release agent:	0.2 kg
Buffing compound:	0.2 kg
PU foam:	As required
Polystyrene foam:	As required

Hardware:

Oarlocks
 Oars
 PVC or wooden fender
 Reinforcement plate of steel or aluminium
 Two to four stainless steel U-bolts
 Drainage plug
 Bolts and nuts for fastening

Appendix 4

Offset table MDV-1

TABLE 3

LOFTING TABLE FOR 4.5 M MDV-1 In mm to outside planking

½ width from centre line	Keel underside	12	12	25	25	25	25	25	19	12
	Rabbit	12	23	35	35	33	32	31	25	12
	Sprayrail, inner						618	466	275	31
	Sprayrail, outer						640	506	314	35
	Sheer	669	762	817	843	838	801	722	587	367
	WL 1	450	549	641	675	643	536	379	183	
	WL 1 A	553	640	710	746	718	611	438	228	
	WL 2	586	676	741	773	754	667	519	274	12
	WL 3	625	718	777	802	790	717	576	360	64
	WL 4	648	738	796	821	810	755	629	420	121
	WL 5	661	754	811	836	826	782	677	486	188
WL 6							719	553	271	
Height from baseline	Keel underside	151	35	0	0	0	0	5	47	307
	Rabbit	151	137	120	102	85	67	63	78	307
	Sprayrail					251	267	290	316	353
	Sheer	694	680	668	669	679	697	724	762	815
	Buttock A	164	146	127	110	101	91	100	176	
	Buttock B	183	162	142	126	126	126	157		
	Buttock C	211	188	165	147	155	173	272		

Appendix 5

Technical information on GP polyester

EXAMPLE OF TECHNICAL DATA PAPER FOR GENERAL PURPOSE ORTHO



POLYLITE® 440-M850

Standard orthophthalic polyester resin

DESCRIPTION

POLYLITE® 440-M850 is a medium reactive orthophthalic polyester resin. POLYLITE® 440-M850 is thixotropic and has a built-in accelerator system giving medium gel time, rapid curing combined with relatively low exothermic temperature and short demoulding time.

POLYLITE® 440-M850 contains special additives which improve the working environment during and after application due to substantially reduced styrene evaporation. The resin contains wax which gives the cured laminate a tack-free surface.

APPLICATION

- POLYLITE® 440-M850 is a hand layup/sprayup resin.
- POLYLITE® 440-M850 is designed for marine, industrial and transport application.

Recommended laminate thickness applied wet-on-wet: 2-8 mm.

FEATURES

- Excellent application properties
- Medium reactivity
- Approvals

BENEFITS

- Short application time
- Good fiber wetting
- Higher fiber content
- Good curing
- Short demoulding time
- Det norske Veritas, DNV, grade 2
Lloyd's Register of Shipping
Bureau Veritas
Germanischer Lloyd
Russian Maritime register

REICHOLD**[PRODUCT BULLETIN]****TYPICAL PROPERTIES****PHYSICAL DATA IN LIQUID STATE AT 23°C**

Properties	Unit	Value	Test method
Viscosity			
- Brookfield Model LVF, Spindle 2 at 12 rpm	mPa·s(cP)	1100-1300	ASTM D 2196-86
- Cone & Plate	mPa·s(cP)	170-200	ISO 2884-1999
Specific gravity / Density	g/cm ³	1,10	ISO 2811-2001
Acid number (max.)	mgKOH/g	24	ISO 2114-1996
Styrene content	% weight	44 ± 2	B070
Flash point	°C	32	ASTM D 3278-95
Gel time: 1% NORPOL PEROXIDE 1 (MEKP)	minutes	35-45	G020
Storage stability from date of manufacture	months	6	G180

TYPICAL NON-REINFORCED CASTING PROPERTIES

Fully post cured.

Properties	Unit	Value	Test method
Tensile strength	MPa	50	ISO 527-1993
Tensile modulus	MPa	4600	ISO 527-1993
Tensile elongation	%	1.6	ISO 527-1993
Flexural strength	MPa	60	ISO 178-2001
Flexural modulus	MPa	4000	ISO 178-2001
Impact strength P4J	kJ/m ²	5.0-6.0	ISO 179-2001
Volume shrinkage	%	5.5-6.5	ISO 3521-1976
Heat distortion temp.	°C	62	ISO 75-1993

STORAGE

To ensure maximum stability and maintain optimum resin properties, resins should be stored in closed containers at temperatures below 24°C/75°F and away from heat ignition sources and sunlight. Resin should be warmed to at least 18°C/65°F prior to use in order to assure proper curing and handling. All storage areas and containers should conform to local fire and building codes. Copper or copper containing alloys should be avoided as containers. Store separate from oxidizing materials, peroxides and metal salts. Keep containers closed when not in use. Inventory levels should be kept to a reasonable minimum with first-in, first-out stock rotation.

Additional information on handling and storing unsaturated polyesters is available in Reichhold's application bulletin "Bulk Storage and Handling of Unsaturated Polyester Resins." For information on other Reichhold resins or initiators, contact your sales representative or authorized Reichhold distributor.

SAFETY**READ AND UNDERSTAND THE MATERIAL SAFETY DATA SHEET BEFORE WORKING WITH THIS PRODUCT**

Obtain a copy of the material safety data sheet on this product prior to use. Material safety data sheets are available from your Reichhold sales representative. Such information should be requested from suppliers of all products and understood prior to working with their materials.

DIRECTLY MIXING ANY ORGANIC PEROXIDE WITH A METAL SOAP, AMINE, OR OTHER POLYMERIZATION ACCELERATOR OR PROMOTER WILL RESULT IN VIOLENT DECOMPOSITION

POLYLITE® 440-M850

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In many areas of the world, finding the type of timber needed to build a good quality wooden boat is becoming a problem. As a result, fibreglass reinforced plastic (FRP) is beginning to be used by many wooden boatbuilders. The information provided in this manual relates specifically to the production of a 4.5 m open fishing boat called the MDV-1. It is a simple, easily-driven, seaworthy boat intended for both rowing and power propulsion. Its general-purpose design is suitable for inshore waters around the world. A general basic knowledge in the use of FRP as a boatbuilding material is presented and step by step construction of a 4.5 m open fishing boat using FRP is set out in detail. In addition, the booklet describes how to maintain an FRP boat and how to recognize fatigue problems. Some simple guidelines on how to repair minor damage to FRP are also included. It is assumed that people planning to build a boat already have a good, general understanding of basic hand tool use. This manual should give boatbuilders and fishermen a better understanding of how FRP acts, how to recognize fatigue problems and more serious damage, and how to carry out needed maintenance and repair.

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