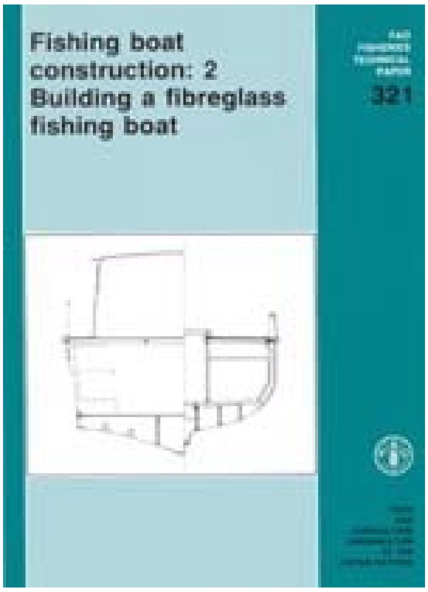


FAO FISHERIES TECHNICAL PAPER 321

Fishing boat construction: 2 Building a fibreglass fishing boat

CONTENTS

Prepared by
Ned Coackley
Y. Bryn
Glan Conwy
Clwyd LL28 5SL, UK

M-41
ISBN 92-5-103116-9

PREPARATION OF THIS DOCUMENT

This document has been prepared on the basis of the author's practical experience of FRP boatbuilding in North America, Europe and the Developing World.

It is the second Technical Paper within the series dealing with Fishing Boat Construction destined for fisheries officers and selected boatbuilders who want to develop their knowledge of various boatbuilding methods.

The Organization is debted to the following Institutions who have allowed the reproduction of selected parts of their literature and/or illustrations:

Lloyd's Register of Shipping
Owens Corning Fibreglass
Sea Fish Industry Authority
Pittsburgh Plate Glass
Venus Spray Guns
Ferry Boatyard
Scott Bader Co.
Dept of Boatyard Management
Southampton Institute of
Higher Education
Cygnus Marine Ltd

Distribution:

FAO Fisheries Department
FAO Regional Fisheries Officers
FAO Fisheries Field Projects
Selected Naval Architects and Boatbuilders

Coackley, N.
Fishing Boat Construction: 2. Building a fibreglass fishing boat.
FAO Fisheries Technical Paper. No. 321. Rome,
FAO. 1991. 84p.

ABSTRACT

The contents are intended to give the reader a sound basic knowledge of FRP and it's possibilities and limitations in boatbuilding. Any person using the document is likely to have some technical or management capacity upon which to base the information.

It is not intended to describe all aspects of FRP, but attempts to cover most subjects applicable to small vessel construction and setting up a new boatyard. The publication leads up to and deals mainly with the single skin manual layup technique, however, other FRP technologies are also presented.

Sections such as Design and Construction Considerations, Planning for Construction and the Production Flow Chart are intended to stimulate appraisal of the requirements of FRP boatbuilding while others such as Workshop, Equipment and Tools and Basic Vessel Construction offer practical guidelines.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 What is FRP ?

The term FRP is generally accepted to mean fibre reinforced plastic. The names fibreglass reinforced polyester, resinglass, and glass reinforced plastic (GRP) are also used. This material is a plastic and is unique in that it is made by the user in situ. It is composed of a series of reinforcements and liquid chemicals which when brought together in specific proportions can be formed into strong, solid but flexible shapes. By varying the quantities of the main components, the finished product can achieve different properties to suit the desired application.

The material has been developed over the last forty years to have many varied characteristics. A crude use is the casting of ornaments in slow setting, filled resin with no reinforcement, aviation is at the other end of the technology spectrum where whole wings of military fighters are made of carbon fibre reinforced plastic. At the low technology end the property of faithful reproduction is employed while at the other a very strong lightweight structure is made to exacting standards. In between are manufacturers of motor car bodies, furniture, pre-fabricated buildings and boats who use combinations of the properties of faithful reproduction and strength to varying degrees.

By changing the chemical composition of the resins and varying the reinforcements, properties of finished FRP may be designed to suit different applications. These may be heat or fire resistance, resistance to acids and fuels, or to be taste and odour free for water or fish tanks.

Historically, FRP as a boatbuilding material was developed for military purposes in North America in the late 1940's. Early hulls were made by draping the reinforcement over a pattern or former made of wood (male mould) and painting on the resin. This was an era before catalysts were developed when strong sunlight was used to make the composition harden. This is called “curing”. From these crude beginnings faster curing resins were developed followed by contact moulding with female moulds (materials laid on the inside) for mass production.

Soon decks and interiors were being made of FRP so that boats were no longer hand crafted in wood piece by piece but bolted and bonded together on an assembly line. The cost saving was realized by the boatbuilding industry in the developed world to the extent that today yachts, motorboats and small workboats in FRP are more popular than wooden boats. FRP boats now available range in size from rowing boats of 2 m to naval minesweepers of 80 m length and types from yachts through commercial fishing boats to harbour tugs. In terms of materials and modern production technology Sweden, France, United States and Great Britain have the most to offer.

The prime reason in developed countries for the change to FRP was lower production costs for small boats built in series. Industrialized countries have the advantage of low raw materials costs (resin and reinforcement) but the disadvantage of high labour costs. Therefore the opportunity to change from labour intensive methods to a faster and less skilled productions system was attractive.

In the developing world the reverse is the case where any FRP boatyard must import all raw materials and is therefore subject to attendant problems of foreign currency and continuity of supply. This major disadvantage must be weighed against labour costs and carefully considered before any decision is taken to embark on investment in FRP production.

It must be emphasized that a certain level of technical expertise is needed when attempting to build boats in FRP together with a basic understanding when embarking on a boatbuilding programme.

1.2 Equipment and Materials

The fundamental tool for the production of FRP vessels is the mould. The most common type is the female mould which can be described as a reverse or mirror image of the finished hull which allows the FRP materials to be laid up on the inside. It too is made of FRP and is cast from a “plug” which is a reproduction of the hull or deck, faithful in size, shape and every detail.

The plug is the beginning of the whole process and is an exact hand crafted replica of the final hull. Normally it is made from wood and used only for casting the mould and is then discarded. It requires high skill levels to achieve fairness and a smooth finish. But this is reproduced faithfully each and every time a hull is made, so the better the mould, the better the hull.

It can be said that the first hull made from a new mould has been built three times:

WOODEN PLUG→ FRP MOULD→FRP HULL

This gives some idea of costs and effort needed in setting up FRP production. Therefore it is important to choose the most suitable design and to produce at least a minimum number of boats to recover the investment made for the production of the plug and mould.

For larger vessels the tooling-up phase (plug and mould building) is repeated for the deck, wheelhouse and interior moulds which increases further the investment costs before a single vessel is produced. The sequencing of these tasks is complicated and it is emphasized that thorough planning and careful choice of vessel must be undertaken before commitments are made.

The main material components previously mentioned are the reinforcement and resin. The most popular reinforcement used is a form of glass. It is processed into filaments then woven or chopped and supplied in rolls similar to bolts of cloth. The thickness of the cloth varying with the weight of the glass in grams per square metre. The two main types are “chopped strand mat” and “woven roving”. At a working level, there are two main types of resin - “laminating” and “gelcoat”. The former is a translucent liquid of various pale colours with a strong smell of styrene which is characteristic of resins. The latter is a more viscous liquid with a similar smell. The difference is in use where the gelcoat is applied directly to the mould without a reinforcement and is mainly to provide a smooth, coloured finish to the outside of the hull while the laminating resin provides the matrix within which the reinforcement is bedded. These and other components will be explained in the following sections.

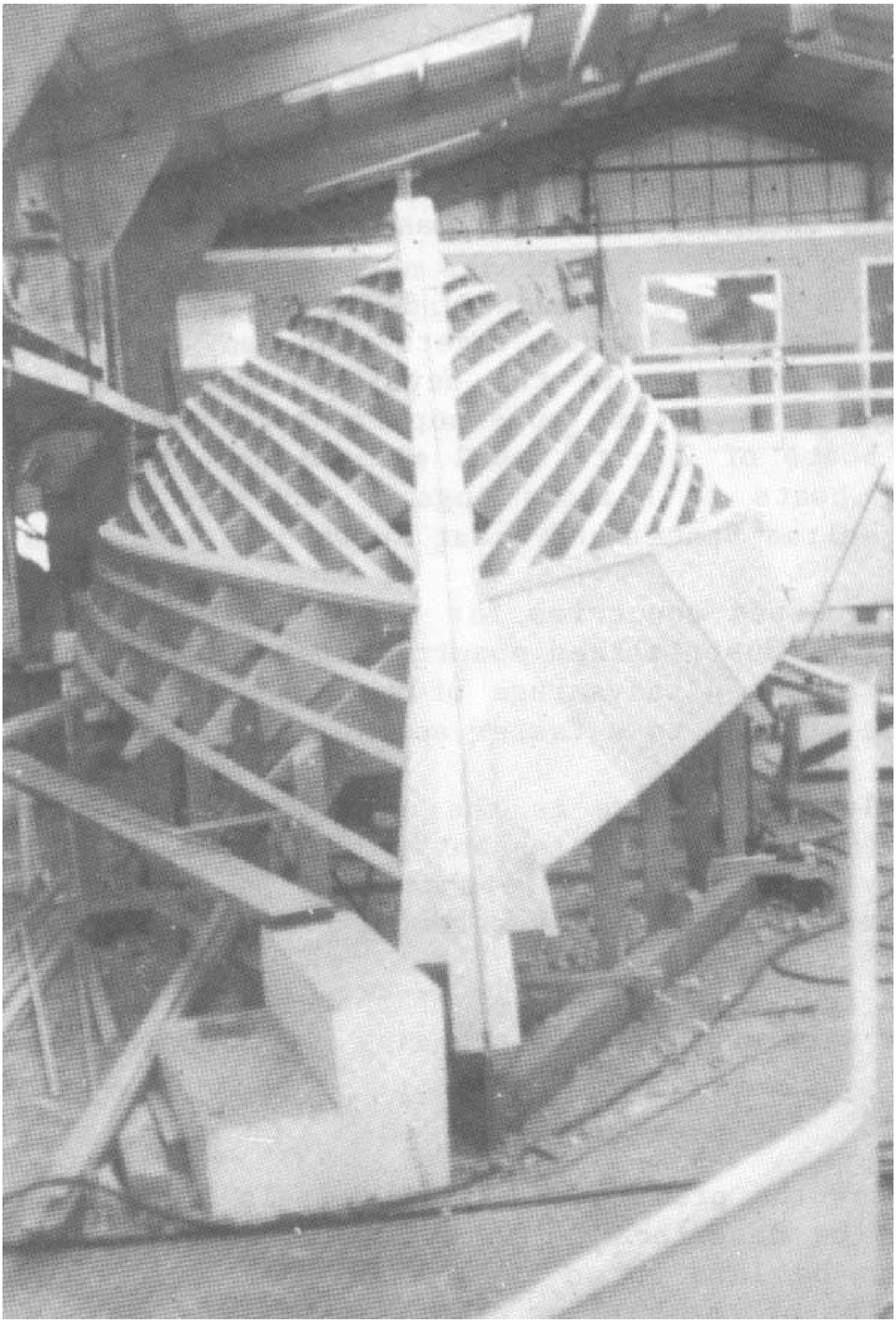


Figure 1 Hull plug

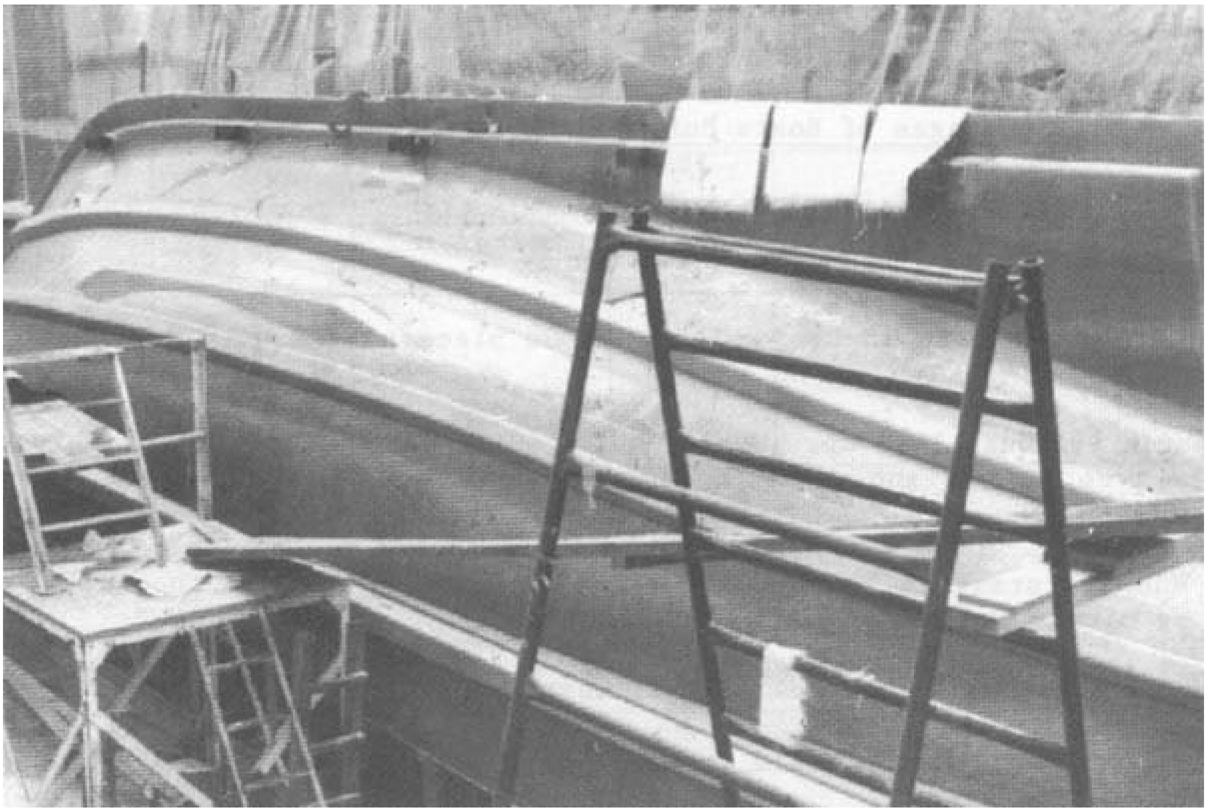


Figure 2 Hull mould

(See also Figure 29)

Figure 3 Hull

Figure 1 shows the wooden plug for a 15.0 m Sambuk (typical inshore fishing boat on the Red Sea), Figure 2 the FRP mould laid over this plug and Figure 3 the FRP hull released from mouldwith all internal stiffeners installed.

1.3 Advantages and Disadvantages of Boats Built in FRP

1.3.1 Advantages

1. Reduction of maintenance

No caulking, no leaks. Hulls are one continuous piece of FRP with no joints or gaps to allow water into the hull.

No plank shrinkage when laid up. Wooden hulls suffer from plank shrinkage when brought out of the water and laid up in the sun. FRP does not shrink or swell so leakage and re-caulking are avoided.

Rot proof and resistant to borers. FRP is non-organic and will not rot. As a plastic it cannot be eaten by marine borers.

Corrosion and electrolysis reduced. FRP is inert. As a plastic it will not corrode.

2. Simpler construction. Once a mould is made, identical copies of a hull can be made many times over and in a shorter time.
3. Reduction of skill levels required once a basic training is received.

1.3.2 Disadvantages

1. Total dependance on imported materials and foreign currency availability.
2. Choice of vessel fixed once design is chosen and moulds made.
3. Must retain core group of qualified technicians.
4. Fire and health hazards from chemicals.
5. Large start up investment.

1.4 Comparison with Other Boatbuilding Materials

The main materials used in boatbuilding are wood, steel, aluminium, ferrocement and FRP. Each has its optimum use just as each has advantages and disadvantages.

Wood is the best known traditional material but depends on a shrinking forest resource and highly skilled carpenters. Marine grade aluminium is lightweight, long lasting and requires a skilled labour force whereas ferrocement uses low cost materials and a large labour force, each has its applications.

Steel is easier to obtain than aluminium, is more rugged but corrodes if unprotected, it is the prime material for shipbuilding. FRP is the newest arrival and will be discussed at length in the following chapters.

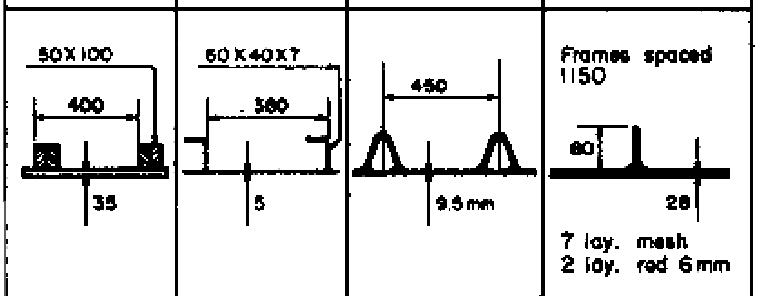
Table 1 and 2 compare some physical properties and costs per unit weight of FRP, wood, aluminium and steel used for boatbuilding. Table 3 compares weights.

Table 1
Comaprison of ultimate strengths

Material	Specific weight		Tensile strength	Compressive strength	Elastic modulus
	1b/ft^3	tonne/m^3	kN/m^2 × 10	kN/m^2 × 10	kN/m^2 × 10
FRP (CSM)	94	1.5	100	100	6
(WR)	106	1.7	240	170	14
Wood spruce	42	0.7	55	40	8
ply	40	0.65	16	12	11
Aluminium	170	2.7	120	85	70
Steel	485	7.8	210	190	200

Table 2
Comparison of thickness and costs for equal strengths

Material	Cost/unit Weight	Equal tensile strength		Equal bending stiffness	
		Thickness	Cost	Thickness	Cost
Steel	1	1	1	1	1
Aluminium	6.3	1.8	1.3	6.6	3.2
FRP	5.4	3.0	3.0	3.0	3.0



	Wood	Steel	FRP	Ferro-Cement
Specific gravity	0.75	7.8	1.5	2.6
Weight of skin per m^2	26 kg	39 kg	14 kg	70 kg
Weight of frame per m^2	19 kg	17 kg	7 kg	6 kg
Weight of panel per m^2	45 kg	56 kg	21 kg	76 kg

Note:: Based on the scantlings as given by Lloyd's Register of Shipping for FRP, Rajendran and Choudhury (1969) for wood, Hanson (1960) for steel and New Zealand Ministry of Transport for ferro—cement

---

2. FRP AND ITS COMPONENTS

The major components have been outlined. This is a more detailed look at those items and a description of materials secondary but integral to FRP construction. Figure 4 shows the manufacturing process of various fibreglass reinforcements.

2.1 Glass Reinforcement

Glass is normally encountered as flat sheets such as windows or formed into containers such as drinking glasses and test tubes. If the chemical composition of this same material is altered when it is in a molten state and it is processed into filaments of 8–14 microns, it can gain an ultimate strength higher than that of steel. A material of this tensile stress obviously has structural potential. For the boatbuilder the specification of the glass is denoted by the type designation. Type A, E or S are generally offered by manufacturers and for tropical marine use Type E only should be used. Figure 5 shows some glass reinforcements.

2.1.1 Chopped strand mat (CSM)

It can be seen from Figure 4 that the continuous filament forms the basis of most reinforcements. With no further processing other than cutting to lengths of about 50 mm, these short pieces are deposited by machine on a moving conveyor belt and held and held together with a gluing compound (Powder or Liquid Binder) to form a continuous sheet of chopped strand mat of variable thickness. This material is specified by weight: 300, 450, 600 and 900 g/m^2 are popular weights of CSM. The boatbuilder purchase it in rolls of 30–35 kg which are about 1 m in width. Note that as total weight and width of rolls is similar, the length of mat will decrease as the weight per square metre increases. The side of the material is slightly smoother than the other which reflects the smooth side of the conveyor belt on which the mat was made. It is the rougher side which should be placed down when laminating.

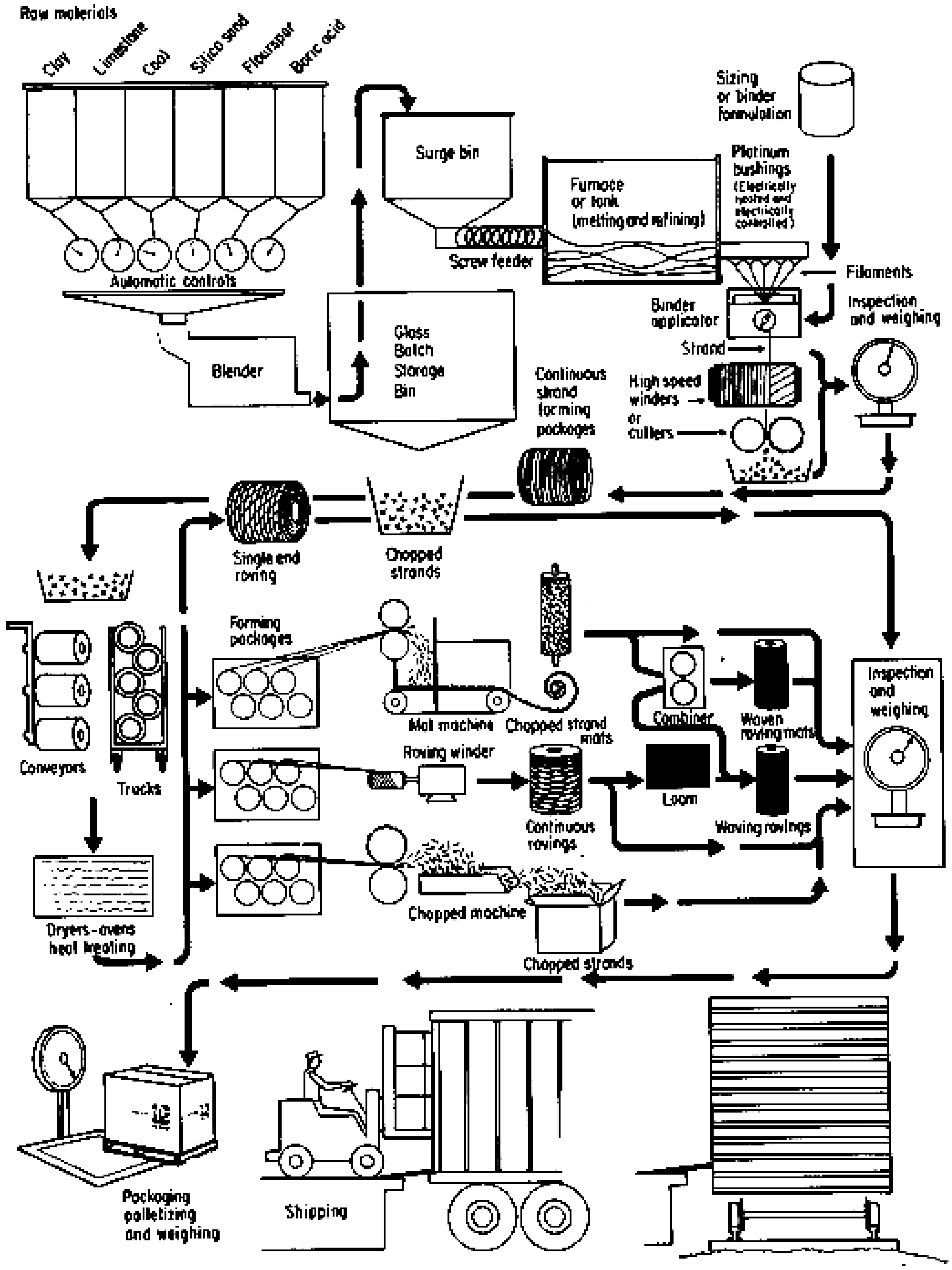


Figure 4 Reinforcements manufacturing process

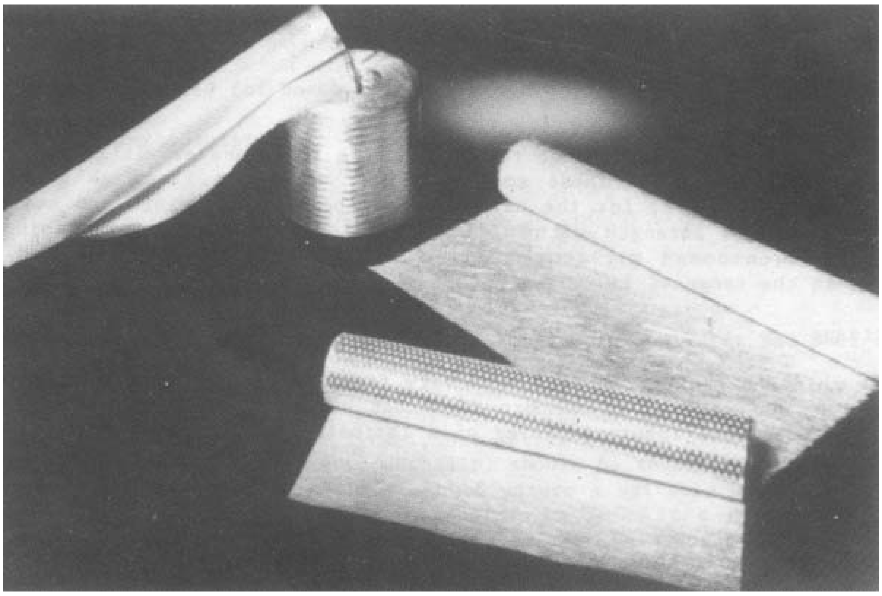


Figure 5 Glass reinforcements

2.1.2 Continuous roving

The alternative step in the processing of filaments is their formation into strands which are loosely twisted into rovings. The normal range is 60–120 strands per roving. These rovings resemble loose glass rope which can be coiled up into reels or further processed into woven roving. The reels of roving may be used to provide short lengths of glass reinforcement to strengthen areas where access is difficult or used with a spray chopper machine as a magazine supply of glass reinforcement for spray lay up. This is an automated process combining a chopper gun which reduces the roving to short lengths and sprays it with catalysed resin onto a mould (Figure 18). This achieves the same result as a layer of CSM but faster. For a uniform rate of deposit, the operator of this expensive machine should possess similar skills to a paint sprayer. It is useful in mass production situations.

2.1.3 Woven roving (WR)

This is the other popular reinforcement. It is purchased in a similar form to CSM and is again specified by weight. Standard specifications are 18 oz per square yard (600 g/m^2) and 24 oz (800 g/m^2). As in the case of CSM, other weights are available but boat designers will normally specify a laminate which is composed of commonly available materials as it passes on a cost saving to the builder.

During manufacture, the roving is woven into a cloth such that roving in the "warp" direction (length of the cloth) is continuous for the whole length of the roll which results in a high tensile strength. WR also gives a higher glass per unit volume ratio than CSM which reduces the amount of resin needed. Approximate resin to glass ratio for CSM is 2.5:1 by weight (30% glass) and for WR is 1.25:1 (45% glass). So for a large vessel whose hull shell weight is measured in tons, inaccurate resin/glass ratios or a laminate with too much CSM and not enough WR may waste substantial amounts of materials and money.

However, it is rate to find any WR in vessels of less than 6 m and equally rare to find vessels built wholly of WR. CSM laminates are normally adequate for smaller boats while wholly WR laminates do not provide a good inter-laminar bond (adhesion of successive layers) at any size. For these reasons experience has shown that normal hull laminates are best made of alternate layers of CSM and WR with extra CSM near the outside.

2.1.4 Unidirectional roving

This is available in standard widths as previously described. It is characterized by continuous roving in the warp direction only with no transverse roving except a light glass thread at widely spaced intervals to prevent the cloth from falling apart when handled. It is rarely found in workboats as it is difficult to keep in shape, expensive and needed only where high strength and light weight are requirements.

2.1.5 Glass cloth

This has a similar appearance to woven roving but on a finer scale. It is available in various widths from rolls down to 25 mm. These smaller sizes, which are known as glass tape, give an indication of its uses which are, for the narrow sizes, bonding of joints and small repairs or in full sizes for giving high strength with a smooth finish and where good draping qualities are required in areas of compound curvature. It is more expensive than WR and normal weight specifications are in the range of 110–400 g/m^2.

2.1.6 Surface tissue

This is very thin and can be compared to a very fine, smooth CSM but is made from blown glass staple. It is rarely used except to support a gelcoat of above average thickness or to produce a smooth cosmetic finish on the innermost layer of a laminate. It is non-structural and unnecessary on workboats.

2.2 Resins

Polyester resin is the main type used in the boatbuilding industry worldwide. “Unsaturated” polyester resin is a more correct term for the liquid state in which it is supplied. When cured to the solid state during the laminating process it becomes “saturated”. Terylene is another example of a saturated polyester resin and is clearly a plastic and non-organic material.

Resin is derived from coal and oil. The industrial base for the production of resins is an oil refinery and petro-chemical works which are rarely found in developing countries. The characteristic smell of polyester resin is given by styrene which is added to the polyester base at a late stage in production.

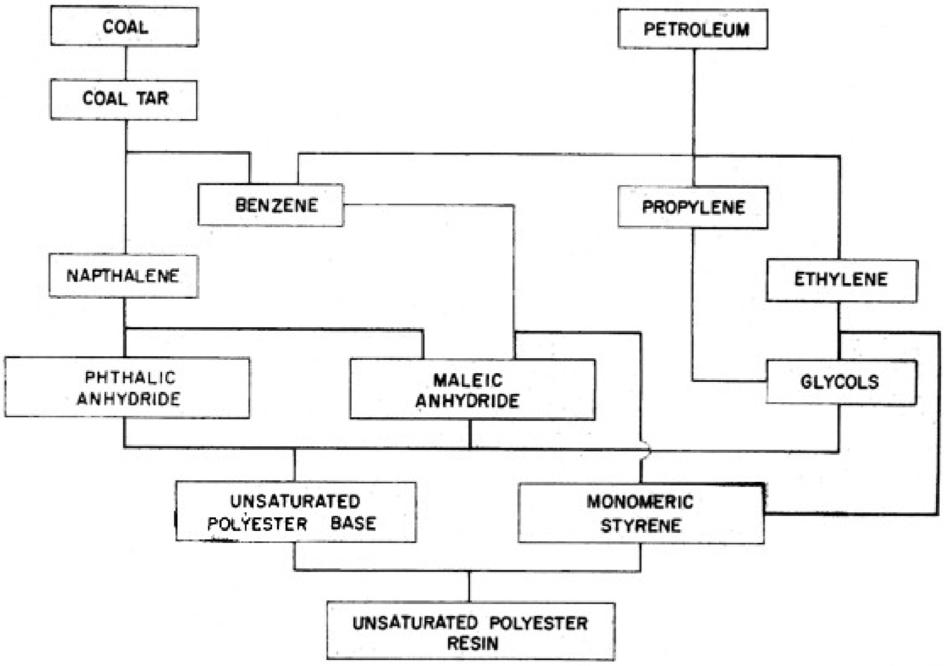


Figure 6 Manufacture of polyester resin

2.2.1 Lay-up or laminating resins

After the basic polyester resin has been produced various changes may be made by the manufacturer to alter the properties so that the resin gains characteristics required for a particular application. For example, improved weather resistance where exposure to a harsh environment is foreseen or resistance to chemical attack if the final product is to be used for a fuel tank.

Properties to be considered for boatbuilding lay-up resin are:

- Resistance to water absorption;
- Strength;
- Adhesive qualities;
- Resistance to ultra-violet radiation and weathering;
- Reaction to and from other liquids and solids, e.g. drinking water and fuel oil or wet fish.

When direct contact with the supplier is not possible, a “Marine General Purpose” resin should be ordered which has been previously approved by a Classification Society such as Bureau Veritas, Lloyds Register of Shipping, Nippon Kaiji Kyokai, Det Norske Veritas or American Bureau of Shipping. An Iso (Isophthalic) rather than Ortho (Orthophthalic) should be requested, better again is an Iso - NPG (Neopentyl Glycol). These qualifications should ensure a suitable material. Lay-up resin for boatyards in developing countries will be supplied in 200-litre drums and to achieve cure (hardening) it requires a catalyst and an accelerator and can be ordered with or without the latter pre-mixed.

The addition of the catalyst is always the absolute final step immediately before applying the resin onto the mould and is ordered in separate containers. It is recommended that pre-accelerated resin be ordered for two reasons:

- A more precise and thorough mix is made by the supplier;
- It is one less step to be made by the user. Inexperienced personnel can make mistakes in calculating quantities to be used which may result in wasted resin or weak laminates.

2.2.2 Gelcoat resin

This is the other type of resin commonly referred to in the boatbuilding industry. When cured it forms the shiny, smooth outer surface of the hull and as such is the first layer to be applied to the female mould during the laminating sequence. The name refers to use rather than any fundamental chemical difference. It also is usually a polyester resin but is more viscous as it must not drain off vertical surfaces when applied to the polished inner face of the mould. When cured it is usually harder than laminating resin and has greater weather and chemical resistance as it forms a protective barrier between the environment and the reinforced laminate of the hull itself.

2.3 Resin Putty

This material is commonly used for car body repairs and on boats is used for similar purposes. It possesses little strength as it is composed mostly of a filler powder such as chalk dust which is water absorbent and should not be used on underwater surfaces unless based on an epoxy resin. In new construction it can be used for bedding deck fittings or radiusing internal corners on joints which require bonding.

2.4 Catalysts and Accelerators

The three items described above can all be supplied pre-accelerated but to cure, the addition of a catalyst is needed. It is the catalyst which changes the monomeric unsaturated polyester resin to a polymeric saturated resin that is, the hardened state, by the production of an exothermic reaction (heat expiration).

This begins IMMEDIATELY on adding the catalyst and once again it is emphasized that the addition of the catalyst to the resin MUST BE THE VERY LAST ACTION before it is applied to the mould.

The accelerator governs the speed of the reaction and without the catalyst the accelerator has no effect on resin. This is why it can be pre-mixed months before use. The catalyst however, cannot, as it will cure the resin in a matter of hours in a hot climate without any accelerator being present. The addition of a specified amount of catalyst to a set quantity of pre-accelerated resin should, if following manufacturer's instructions and in line with worldwide industrial experience, allow working times of 20–40 minutes.

If accelerator must be purchased separately, a purple liquid (Cobalt Naphthanate) is usually offered for use with Methyl Ethyl Ketone Peroxide (MEKP) catalyst. When using unaccelerated resin the accelerator should be thoroughly mixed in first. Accelerator and catalyst must never be mixed directly together as they can cause an explosion. The flashpoint for both can be as low as 20°C. Other combinations are available for special circumstances.

When using materials from separate suppliers or when mixing batches, caution should be taken to ensure the concentration strength of the catalyst purchased agrees with the percentage volume required for catalyzing the resin, 40% MEKP is standard and should have been checked as correct by the supplier/manufacturer if ordered at the same time as other materials from his product range.

3. GENERAL PRECAUTIONS

3.1 Fire Hazard

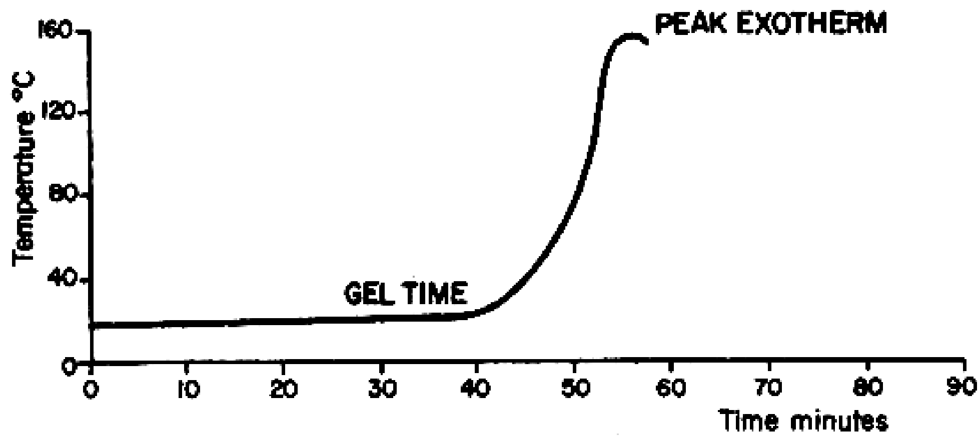
The most serious danger is probably the risk of fire from the incorrect handling of resins and catalyst. It has already been stated that catalyst and accelerator when mixed directly form an explosive mixture but as all resins are coal and oil base.

THEY ARE HIGHLY FLAMMABLE. SMOKING IN THE MOULDING SHOP IS TOTALLY FORBIDDEN.

Great care must be taken to mix the correct amount of catalyst to the resin to avoid a “HOT MIX” which could produce so much exotherm (heat) that it self-ignites. Any bucket of resin producing smoke should be immediately taken outside the moulding shop and filled with water, likewise any spillage should be diluted with water. Other fire hazards are solvent cleaners, styrene monomer and rags contaminated with flammable liquids. Small fires may be dealt with by Carbon Dioxide or Dry Powder extinguishers or by water spray.

Table 4

Exotherm with time



Exothermic fraction of a typical polyester resin

3.2 Health Hazard

All these materials are toxic if swallowed. Special care should be taken with catalyst as it is an organic peroxide and will cause burns to skin and possibly blindness if in contact with the eye. Readily available fire extinguishers of the correct type and patent eyewash should be at hand in the mould shop as well as a First Aid Kit in the yard office. The local hospital should be briefed at the beginning of operations about the nature of the chemicals being used in case of extreme emergencies as should Fire Services.

Occasionally some individuals show a skin reaction to handling glass reinforcements and more rarely to resins. Use of a patent barrier cream may allow the worker to continue but if the problem persists then transfer to another department should be considered. Rubber gloves can be worn but these tend to restrict manual dexterity and cause other skin problems if worn for long periods. Workshop ventilation should allow a complete air change 1–1.5 times per hour and an upper limit of 100 ppm (parts per million) of atmospheric styrene which evaporates during the gelation of resin. Face masks may offer some relief when laminating in confined areas and when grinding or sanding cured laminates.

3.3 Delivery and Storage

3.3.1 Resins

It has been explained that heat is the agent which cures resin from the liquid to the solid state. Resins are designed and manufactured primarily for use in northern countries, and as tropical temperatures are higher, some effort will be needed to maintain a reasonable shelf life (storage life) of the raw material.

The source of resin for use in a developing country may be many thousands of kilometres away and delivery may involve a long sea voyage. This may expose the drums of resin to weeks of lying in direct sunlight on the deck of a cargo ship as such flammable cargoes are usually carried in well ventilated areas. It is essential therefore that the supplier despatches new stock to ensure that the exported resin arrives in the best possible condition. The duration between manufacture and use is termed shelf life. Often 6–12 months are quoted as the normal shelf life but resin can be considered useable as long as it is liquid. Three months for rotation of stock is a prudent period to aim for. Time spent in ports while the resin is being transhipped or awaiting customs clearance should not be overlooked.

Storage temperatures should not exceed 20°C as higher temperatures even for a few days will reduce shelf life. Resin specifically ordered for tropical use should contain a higher level of inhibitor in which case a higher storage temperature may be acceptable. Flashpoint is about 31°C.

On delivery the resin drums should be opened and checked for quality and contact made with the supplier and shipper if it is not up to expected standard. Following acceptance it will be the responsibility of the user and should be stored in as cool, shaded and ventilated place as possible.

All raw materials for FRP can be airfreighted. However, for reinforcements airfreight costs may soon outweigh the purchase price and for combustibles such as resin, accelerator and catalyst special airline approved containers will have to be used. This will require transfer from the manufacturer's container which will again add substantially to costs. The airfreight option is best avoided.

3.3.2 Reinforcement

Reinforcement materials are supplied in rolls sealed in heavy duty polythene bags inside strong cardboard boxes. During handling these are prone to damage and on delivery the glass reinforcement should be checked for contamination by dirt, oil or water. If spoiled, the material is unusable. Once rolls have been checked they should be resealed to prevent contamination by high humidity.

The consequence of using damp reinforcement is that the bonding properties of the resin to the mat are reduced introducing the possibility of a weak interlaminar bond. It is for this reason that Classification Societies are reluctant to survey and classify new vessels built by yards in tropical climates except for those which have fully air conditioned moulding workshops or can show proof of moulding in a controlled environment.

The difficulties of arranging insurance for a vessel built without Classification Society approval has influenced the continued import of large FRP vessels by developing countries and partly explains why the advantage of low overheads has not been used to promote exports. Nevertheless boats are being produced and used successfully in the developing world.

---

4. WORKSHOP, EQUIPMENT AND TOOLS

4.1 General Conditions

The moulding of plastic boat hulls should be carried out under controlled conditions if quality work is to be maintained. Workshop conditions are of vital importance if resin is to gain its maximum mechanical properties. It is not possible to lay down hard and fast rules for workshop conditions as each must be considered individually taking into account layout, type of production, local climate, etc.

An FRP yard can be broadly divided into two sections:

- The plastic section comprising the moulding shop and its associated shops and stores handling the resins and reinforcements;
- The fitting out shed and its wood machining shop, paint and general stores and a machine fitter's shop.

This chapter will only deal with workshop conditions of the FRP department.

The layout and facilities of the plastic section will be dependent on the type of production. For instance, separate rooms are provided for the gel spraying, trimming and post cure operations in works which mould hulls on a production line basis but are not found in smaller yards. In the early development of FRP boatbuilding some yards converted an old shed into a moulding shop and success came with experience. Newer entries to the industry have benefitted from advice given by technical sales staff of resin suppliers and Classification Societies and have been able to erect better equipped moulding shops.

4.2 The Building

4.2.1 Construction

It may be one or more bays of a larger work or may be a separate building. The exterior walls will be of some weather resistant material in association with a substantially framed structure, of steel, reinforced concrete or timber. Corrugated steel sheeting can be used for roof or walls but must be insulated against solar heating. Sometimes roof girders are increased in strength to carry additional loads from handling equipment, such as pulley blocks used to lift the moulding from the mould. The floor should be a damp-proof and dust-free material such as concrete or bituminous composition.

4.2.2 Insulation, air conditioning and humidity control

The insulation's function is to assist in maintaining a satisfactory working temperature. In very warm climates full use should be made of foil-faced insulation boards, spun glass insulation and corrugated aluminium. Windows, walls, doors and roofs need to be addressed as well as accounting for daily passage of the sun, natural shade and wind direction.

It is recognized that 18–21°C is the most suitable range for working temperatures in the mould shop when approval by a Classification Society is to be sought. Temperatures should not normally exceed 25°C but where a short moulding cycle of up to three days is used temperatures of up to 33°C may be satisfactory provided attention is paid to resin/catalyst ratios. Relative humidity should not exceed 80%. Above this level glass fibres may pick up moisture which will affect the cure and bond. In areas where humidity is consistently 70–100%, shift working may overcome these problems with moulding carried out at night. If approval by a Classification Society is sought, the question of an air conditioned mould shop should be addressed. A hygrometer and wet and dry bulb thermometer will allow the yard management to build up a record of local conditions and to allow for climate in production planning.

4.2.3 Ventilation and dust extraction

The shop atmosphere should be reasonably free from fumes and dust to permit comfortable and efficient working conditions. Up to about 5% styrene is evaporated during moulding and for 6–8 hours afterwards. The fumes are heavier than air and have to be drawn from the mould to the roof of the shop. The higher the roof, the less air changes are required. A ventilation system of several exhaust fans along the roof will also be required to remove solar heat.

Adequate ventilation should be provided in the spray area which is often in a separate area for gelcoating. Fans should not play on the moulding nor cause undue evaporation. In trimming and sanding areas, down draught ventilators which pull rather than blow overcome the problem of blowing dust over workers and wet laminates. Dust will retard and often inhibit resin cure and trunked extraction may have to be used with flexible suction ducts that can be held over cutting and sanding tools. A canvas pipe fitted to one of the roof extractors may be adequate. Dust removal from all surfaces prior to gelcoating and moulding is fundamental.

4.2.4 Lighting

The shop should be adequately illuminated at moulding level by either natural or artificial lighting or by a combination of both. If allowed to play on a moulding or resin, direct sunlight will tend to cause premature gelling and excessive evaporation of the styrene both of which may cause permanent undercure. Fluorescent lighting should be installed well above mould surfaces as it emits ultra-violet radiations and has a similar effect to sunlight. Supplementary portable lighting may prove useful where fixed shop lighting does not illuminate secondary FRP work such as interior bonding.

4.2.5 Electrical and compressed air systems

The number of power points depends on the number of tools being used. Cables and hoses should be as short as possible to give better and easier handling of the equipment and will result in a less obstructed floor. Compressed air tools are usually lighter and more rugged than electrical power tools, they are also less likely to cause fire but are more expensive and require a constant source of compressed air. Equipment for resin spraying will need a compressed air system which should have a very low humidity level so that it does not contaminate the resin.

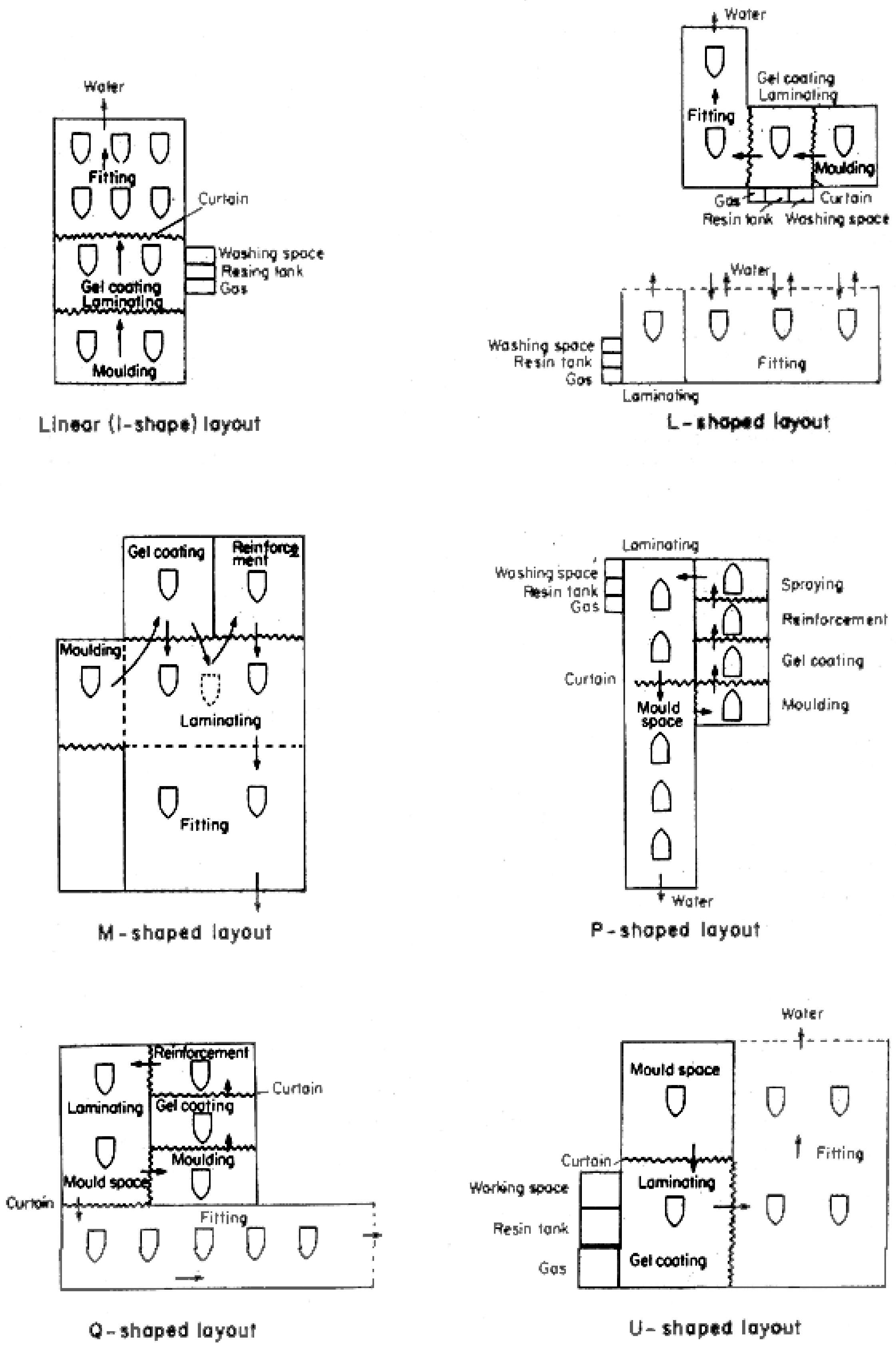


Figure 7 Examples of plant layout

4.2.6 Access to the workshop

The main shop doors should be large enough to allow the boats to be removed by handling equipment without the risk of damage. Steel doors are normally insulated to prevent heat gain. A heavy canvas curtain will prevent draughts but allow passage.

4.2.7 Cleaning

Cleaning in an FRP yard is a laborious and expensive business. It is essential for high quality work and the health of the worker, an untidy workshop will reflect itself eventually in the quality of workmanship. General cleaning may be carried out by one man dedicated to the task or by the work crew at the end of a shift.

The main problem is small pieces of discarded resin and glass which stick to footwear and are carried everywhere. Large pieces can be discarded directly into waste containers. Waxed hardboard panels can be positioned around spray equipment to prevent overspray adhering to walls and floors (particularly appropriate in rented accommodation). Entire floors waxed before operations commence and then covered in sections with a sacrificial layer of CSM is a means of scraping off congeled FRP. Covering with hardboard panels which can be thrown away is another method.

The cleaning of resin pots and moulding equipment is generally carried out in the resin preparation room by the resin mixer or his assistants so that they can be prepared for re-use. An extractor fan will be necessary for the styrene and acetone fumes. Brushes and rollers are also cleaned in acetone before washing in soap and water, but this time by the laminators themselves immediately after finishing a section.

4.3 Tools and Equipment

For high technology laminating and mass production methods, some special equipment is necessary. For the general purpose moulder however, apart from the moulds themselves and lifting and moving equipment, no expensive equipment is required. A few specialized hand tools are necessary such as rollers for consolidating the wet laminate and catalyst or accelerator dispenser bottles.

Following tools are usually used for working FRP:

Electric drilling machine 13 mm chuck industrial quality
Hole saws 25 mm – 100 mm
High speed twist drills 3 – 18 mm
Jigsaw industrial quality with metal-cutting blades
Angle grinder hand held with 100 mm disc
Grinder discs carborundum for cutting
Grinder discs carborundum for grinding
Grinder discs disposable aluminium oxide 40 grit
Hacksaw 18/24 point blades
Rasp 250 mm half round
Files 250 mm flat, half round and round

Stanley knife and standard blades
Wood saw for foam cutting
Scissors tailoring quality for reinforcement cutting
Wet and dry abrasive paper 100 – 1 000 grit
Cork sanding blocks
Padsaw handles to accept hacksaw blades
Spirit levels 250 mm and 750 mm
Plumb bob
Chalk line
Tape measures 3 m and 5 m
Rubber mallet 1 – 2 kg for mould release
Brushes 25 – 100 mm plain wood handles
Squeegees metal, rubber and plastic for resin and putty spreading
Masking tape 12 mm – 50 mm
Weighing scales to 20 kg
Buckets plastic or 5 L cans
Cleaning rags
Soap powder
Mohair rollers in various sizes for applying resin.
Laminating rollers, paddle or washer type for consolidating laminate.
Squeegee - flat, hard rubber pad 150 mm × 75 mm with tapered edge, replaces both of above.
Plastic graduated dispenser bottles for catalyst and accelerator.

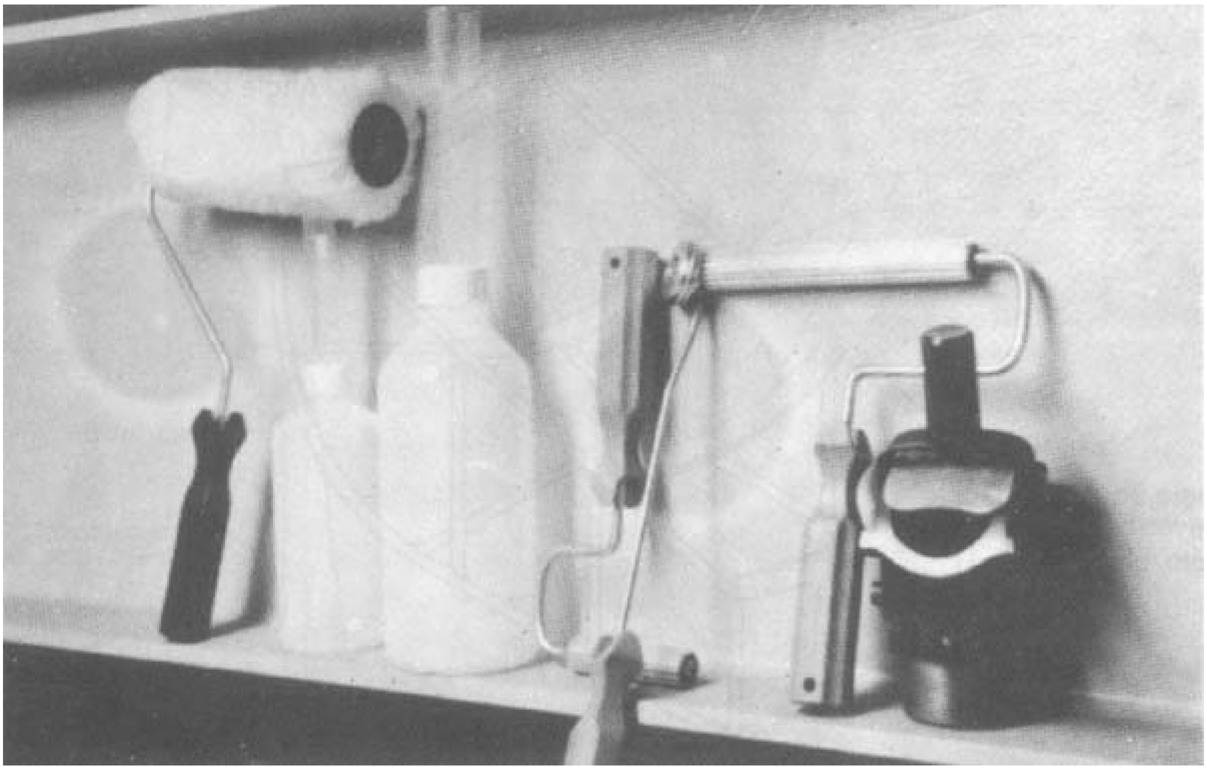


Figure 8 Some hand tools

5. FRP HANDLING AND USE

5.1 Mixing Resin and Gelcoat

Resin is stored in drums in a cool, shaded part of the yard preferably a separate resin room. The drum in use will be laid horizontally off the ground on a steel cradle (Figure 9) with a transferrable brass tap (Figure 8) screwed into the drum lid.

There should be a drip tray beneath the tap. Between the tap and the tray will be enough room to place a 5–10 1 plastic bucket which can be filled with resin for use by a laminator. Outside the resin room should be a separate store cupboard for catalyst and a second cupboard, well distanced from the first, for accelerator if the resin is not already pre-accelerated. Accelerator can be added during the preparatory phase and well mixed in with a clean, disposable wooden stick. Catalyst is only added AT THE VERY LAST MOMENT before laminating commence and when the laminating crew have agreed that EVERYTHING is ready.

Both these additives are supplied in 20 l plastic drums (not in steel containers because resin reacts with rust) and are used to refill one litre plastic bottles fitted with a graduated pourer for final mixing. This preparation is relevant to gelcoat and laminating resin, but in the case of the former a colour pigment will have been added to “unpigmented” (uncoloured) gelcoat according to supplier's mixing ratios. Standard white pre-pigmented resin is widely available as it is the most popular hull and superstructure colour.

5.2 Application

After the mould has been cleaned, waxed and polished, the first step in the moulding process is the application of gelcoat by the laminating team of 2 persons with mohair paint rollers or by spraying. Some rollers have handles extended to 2 m to gain access to distant areas. A single heavy coating of 0.6 mm thickness or 2 medium coatings of 0.5 mm each is required on all surfaces which may curve from vertical topsides to the horizontal bottom area. Paint brushes with unpainted wooden handles can be used to cover restricted corners. A pot life of 20–40 minutes will be planned which will require a 1 % catalyst content in the tropics.

It is preferable to have a follow-up bucket of resin ready for use immediately the first is emptied so that a good molecular bond between the two separately mixed batches is achieved. The second laminator can take care of this or a labourer may be employed if the mould is large and requires many buckets of resin. At the end of the gelcoating the tools will need cleaning. Buckets should be left to drain out and any resin which remains will harden and can be cracked off some hours later. Rollers and brushes need more care and will need washing in acetone. This liquid is also HIGHLY FLAMMABLE and evaporates quickly. Personnel should rinse any exposed skin in clean acetone followed by the tools in the same liquid before washing skin and tools again in soapy water then fresh water. Brushes and rollers must be dry before re-use.

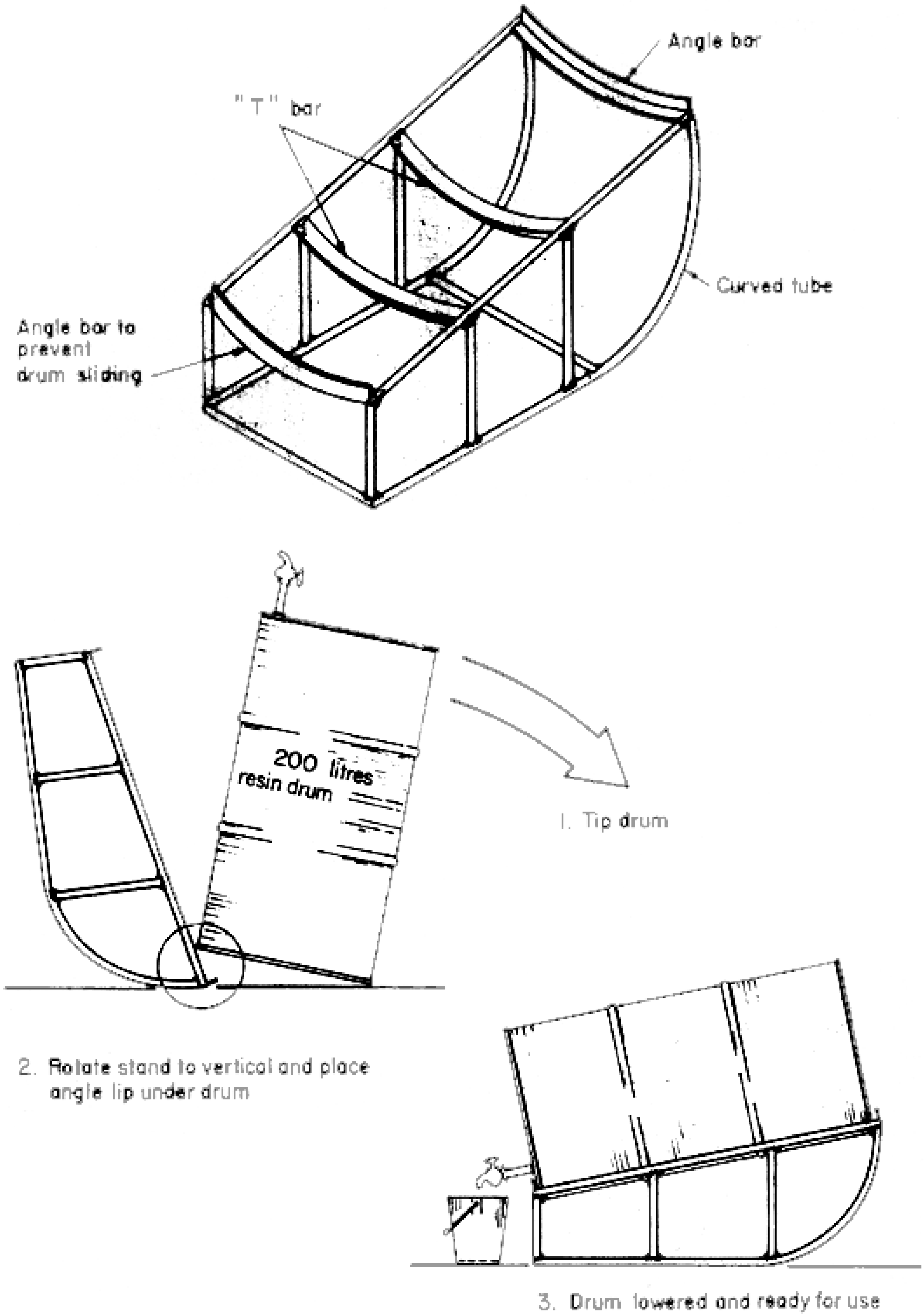


Figure 9 Drum cradle

5.3 Preparing reinforcement

Reinforcements also deserve to be stored in a separate room or at least a section of the moulding shop which is kept dry, dust free and clean. It is quite usual to allot the task of storing and tailoring the reinforcement to one labourer who then becomes skilled at this task. It is initially stored in its delivery cartons thus kept free from most contamination. For preparation, a cutting table is needed with a vertical rack for the rolls of different types of reinforcement from which appropriate lengths can be drawn and cut and then re-rolled and labelled with a felt tip pen to indicate to the laminators precisely what it is for. The cutting tailor will prepare the reinforcement for a whole vessel according to a cutting list which has been previously written for each type of vessel in production.

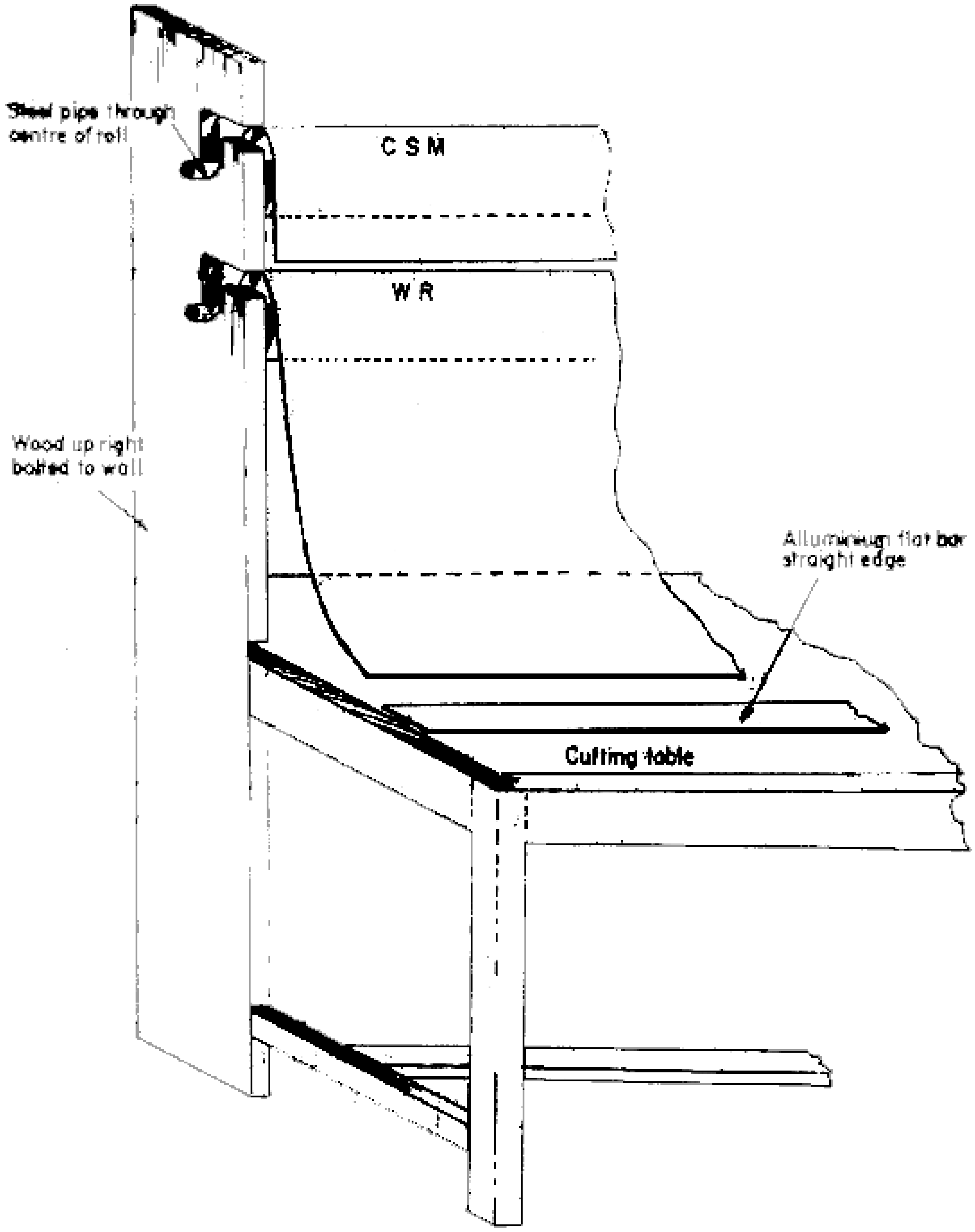


Figure 10 Reinforcement dispenser

Lengths up to 10 m can be prepared on a shorter cutting table by folding the reinforcement. The table edge should have graduations at 10 cm intervals to ensure precise measurement. A sharp knife is needed for cutting and as glass reinforcement blunts steel blades very quickly, they should be sharpened often. A straight edge is needed to cut the glass to length, and aluminium strip is best as it is light to handle and does not contaminate the cloth.

For cutting curves, a felt tip pen or chalked line can be drawn for guidance and the cut made freehand whilst allowing a 10 cm margin. Straight cross cuts in mat and cloth should be made using the straight edge but for WR a transverse strand can be pulled out which will indicate the line to be cut even if the material has deformed in the unrolling process. Industrial quality scissors may also be of use.

5.4 Laminating (also termed laying-up or moulding)

Once the resin, reinforcement, mould, personnel, and tools are ready, the catalyst can be added to the resin and the laminating begun. This assumes that the gelcoat has been applied to the mould already, has cured, has been checked for flaws and is considered acceptable. If gelcoat has been applied at the end of the working day it will be ready the following morning, if it has been applied in the early morning, it may have achieved sufficient cure to be overlaid at the end of the working day. If an attempt is made to laminate over gelcoat which is not cured sufficiently, the exotherm from the lay-up resin may deform the gelcoat and leave problems which will only be visible when the hull (or deck) is released from the mould. If the gelcoat is left for too long (a weekend) it may harden to a point which will not provide good bonding with the subsequent laminate. Reference to the manufacturer's instructions and experience will soon further define these broad outlines.

Inspection of the gelcoat may indicate contamination by rain or sand and this should be remedied before any new resin is applied. Any rough areas may need to be lightly sanded and any dust removed. Any overcured areas can be lightly washed with acetone or styrene to regain some tackiness. The designer and manager will have decided if reinforcement is to be laid transversely or fore and aft, the latter is recommended as it more easily accommodates changes of skin thickness required between topsides and bottom and is the faster method.

A sequence should be worked out so that the binder is dissolving in CSM reinforcement laid in one part of the mould while previously laid CSM with now dissolved binder is being consolidated in another part. While a layer is curing in one side of the mould, the other side can be worked on. This allows application of resin and reinforcement, consolidating and curing to take place in rotation.

APPLY RESIN BEFORE REINFORCEMENT!!

It is usual to lay up CSM alone for 1 or 2 layers next to the gelcoat. Subsequent layers should be applied as soon as the resin hardens. These subsequent layers may be augmented by the inclusion of a cloth or WR layer which can be laid in the mould at the same time as CSM and which are consolidated together. This saves time and achieves a superior bond as both layers of reinforcement are using the same batch of resin. WR is applied after its associated mat layer has been lightly rolled into the resin. If there are large dry patches, further resin can be applied before the WR is laid on as better impregnation is achieved if the resin is drawn up and not forced down through the reinforcement. Being of a woven nature, WR is less prone to disintegration than wet CSM during rolling out, it can be consolidated using rollers, but a “squeegee” is probably the best, quickest and simplest tool to use. The sequence for subsequent layers has been described, but it should be clearly understood that the opposite side of the hull should be moulded in sequence with the first side.

On returning to the first side, the laminate may have become too hard and parts of it may need sanding to remove any protruding pieces of resin and glass which would prevent the following layer from achieving a void-free bond. These cured surfaces can be walked on to achieve access to restricted areas of the mould, but this risks contaminating the next bond. Walking on the FRP in barefeet is one solution, but even slight perspiration from skin in contact with the FRP can lead to a weakening of the bond in that area. Lightweight shoes should be provided to the laminators to eliminate this risk. Further protective clothing such as an overall is also a good idea as the inevitable contact between clothing and wet FRP cn rapidly render a laminator's own clothes unwearable. Filter face masks should also be worn to counter long-term respiratory problems but in practice these are usually declined by experienced laminators as the discomfort while wearing one is greater than the short-term unpleasantness of breathing styrene fumes.

For any job which requires working in a confined space such as a fish or fuel tank, the laminator should be ordered to wear a face mask. The work should be in short periods and the space should be force ventilated or exhausted. An electric fan may be used to BLOW fresh air via a long pipe but it should NOT BE USED TO EVACUATE a space nor be placed directly in the space as fire may result from the flammable styrene in contact with the electrical contacts of the fan.

5.5 Stages of Cure

Storage or shelf life	While pourable Up to one year if stored correctly
Pot life or gel time	20-40 min Depends on age, catalyst and accelerator
Hardening time[1]	30 min
Fully cured[1]	Three weeks from addition of catalyst

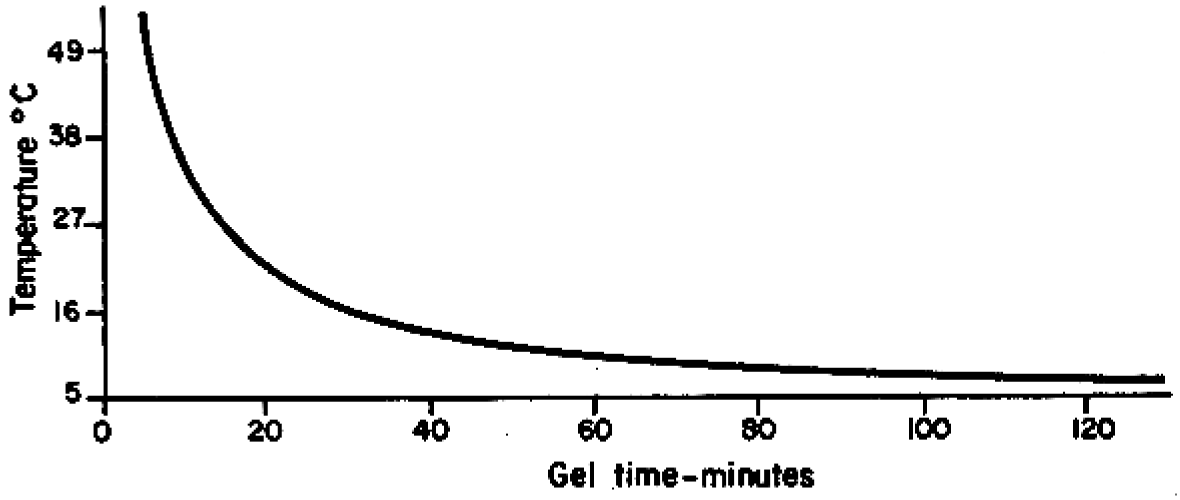
5.6 Using Tools on FRP Mouldings

No special tools are needed on FRP after it has set hard, but metalworking rather than woodworking tools should be used. It can be drilled, filed, sawn and polished but not hammered or bent and not easily punched or sheared. The basic shape cannot be altered and the resin component shows a tendency to fracture and chip. It should be remembered that apart from trimming and drilling very little work is usually required because all the shaping and forming is done while the plastic is soft and uncured in the mould. In this respect it is like concrete.

[1] Hardness to be tested by using a “Barcol” Impressor model 934 or equivalent method

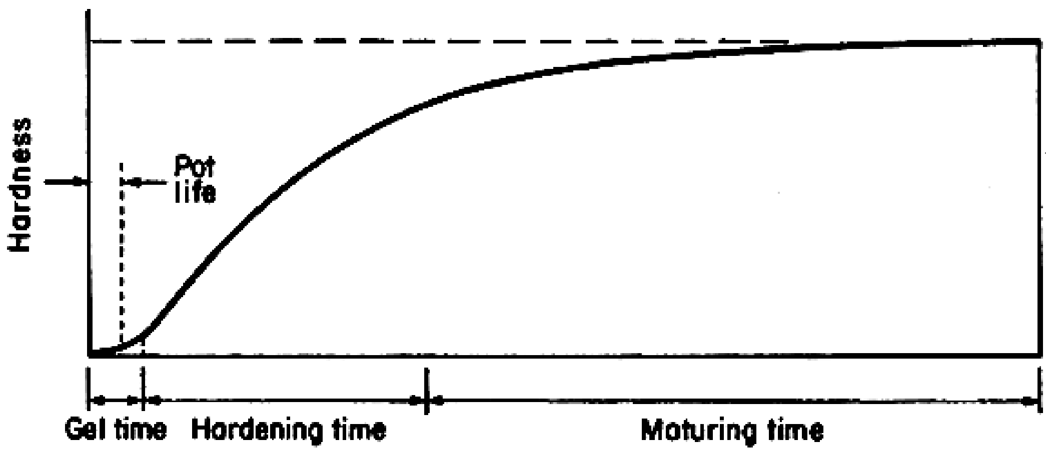
Table 5

Gel time and temparature



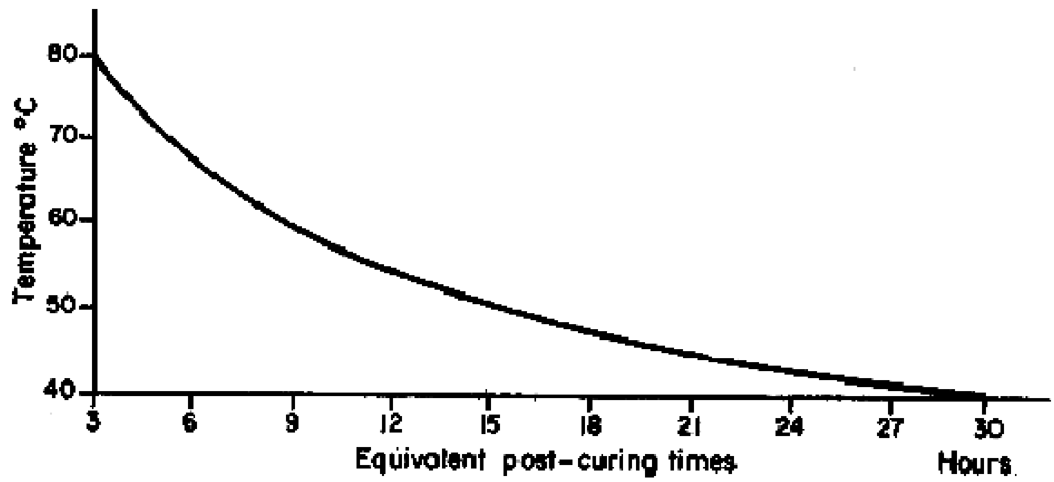
<u>Table 6</u>

Hardening time with hardness



<u>Table 7</u>

Cure times



The resin component cracks and shatters if overstressed. It has little ductility and it does not deform and yield like a metal, or even like wood. Any fastening which depends on deforming or denting the material will not hold satisfactorily, e.g., a wood screw or nail, and bending is as impracticable as bending concrete. Although the basic shape cannot be altered the natural springiness allows a certain degree of minor distortion. The extent of this will depend on the framework and the age of the moulding. It is much more flexible when newly moulded and still in the gel state than when fully cured. A sawn, ground, or sanded surface will have a matt finish and cannot be polished until recoated with resin.

Drilling

Holes can be drilled easily with ordinary twist drills. Wherever possible drill from the smooth face towards the rough side as this prevents chipping the resin-rich gelcoat. Masking tape or a punched mark will help prevent scratch marks from skidding drills if a hole has to be drilled from the gelcoat side. For large holes use a tank cutter or hole saw or drill perforations around the circumference of a large holes with a drill bit wide enough to accept a jigsaw blade, then saw it out.

Sawing

A hacksaw, padsaw or jigsaw should be used for sawing and trimming. Always saw on the face opposite the gelcoat to avoid chipping. Heavy duty electric jigsaws with metal cutting blades or diamond wheel compressed air cutters are the most effective.

Filing

FRP files easily much like aluminium. An open pattern file is less liable to clog particularly when the resin is not fully hard. On edges, the cutting stroke should be in the direction away from the gelcoat once again to avoid chipping. Extra care is needed on corners.

Hammering

Light hammering to encourage mould release or alignment of two mouldings should be carried out with a rubber mallet. Hammered fastenings or blows with a metal hammer will shatter the laminate.

Sanding

Avoid sandpaper (sand or gold coloured) as it will clog badly particularly if the resin is wet. “Wet and dry” (black colour) is the only suitable kind and it must be used with plenty of water. A small amount of liquid soap added to the water will reduce friction. For power sanding, a very open grade of disc will clog least. Resin bonded discs must be used. Care must be taken as disc edges can make deep scars in a moulding before an operator realize what is happening. Face masks should be worn and dust removed before applying the next layer.

Cleaning

Files, drills, saw blades and discs can be cleaned with acetone when clogged. If left overnight the resin will harden and render the tool useless.

Effect of Fillers

The workability of resins can be affected to a large extent by fillers. Talc has a lubricating or anti-clogging effect. Hard fillers such as quartz, silica, or slate render the operation similar to drilling rock. Where hard fillers are encountered a masonry drill should be used for drilling and a diamond wheel for cutting if the opportunity to trim with a knife during the gel stage was missed.

Trimming

The easiest stage to trim is just after the resin has set, when the moulding is rubbery and can be cut with a sharp knife. A large moulding must be trimmed in stages as each layer sets. The rubbery “gel” stage lasts only about thirty minutes depending on the type of resin used. Do not trim too soon as the laminate will not have set enough and will be disturbed. During fitting out hard untrimmed areas will be encountered and should be treated as described in the note on sawing.

Sealing Edges

All FRP working will leave a rough, shattered edge where water can penetrate and eventually cause delamination. All such edges must be sealed either with resin painted on or bonded over during assembly. Holes for deck and underwater fittings should be treated carefully in the same manner. Working on sandwich mouldings demands special care as there will be the likelihood of causing delamination between the opposite face and the core. If possible work from the gelcoat face and support the inside with a wooden pad. Seal the hole edges thoroughly.

---

6. CONSTRUCTION METHODS

Variations in the structural properties of a laminate can be achieved by altering the type and quantity of reinforcement that it contains. A fishing boat needs to be tough and impact resistant while the wing of an aircraft needs to be light and rigid.

The item to be produced may be as simple as a fishbox where there is little financial outlay in tooling costs or a more complex project where an FRP prototype is needed for structural and marketing tests. Each application will have its optimum construction method.

6.1 Single Skin Laminate

This is achieved by contact moulding resin and reinforcement onto a former such as an open mould which when cured produces a solid FRP laminate. It may or may not need to be stiffened depending on the size and purpose of the finished item. Unstiffened means that no additional stiffening members are added to the solid laminate, the strength of the hull being derived from the skin laminate and hull curvature. This is found only in very small craft. Stiffened hulls have transverse and/or longitudinal stiffeners similar to frames and stringers bonded to the laminate to reduce the flexibility of large panels.

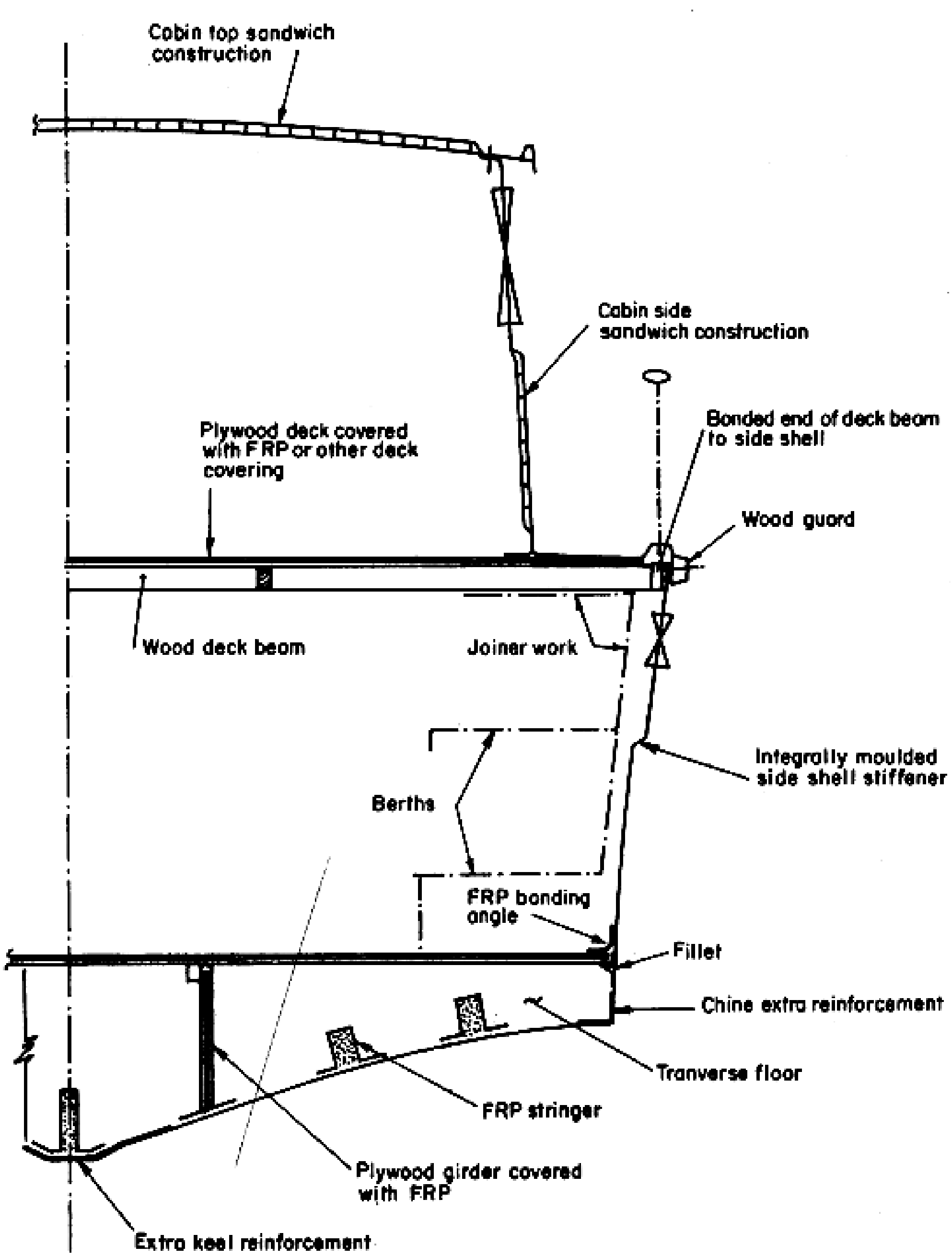


Figure 11 Single skin construction for large planing hull

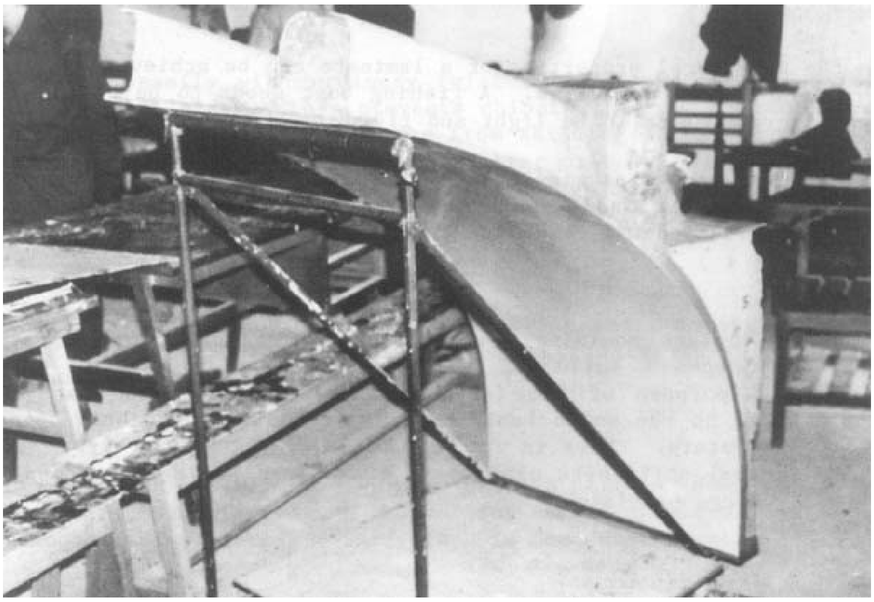


Figure 12 Example of bilage and keel, 18 m trawler

6.2 Double or Sandwich Skin Construction

Two thinner laminates are separated by a lightweight core which increases the rigidity of the panel by increasing effective thickness without the use of solid FRP laminates. Because of inherent rigidity, decks, cabintops and bulkheads are usually built as a sandwich. This type of laminate begins in a similar manner to the above but after the first few layers of reinforcement a sheet core material is bedded on and allowed to form a solid bond. When the bond is checked and judged void free the FRP lamination is continued on the exposed surface of the core material. Popular core materials are plywood, balsa wood and plastic foams such as Poly Vinyl Chloride (PVC) and Urethane.

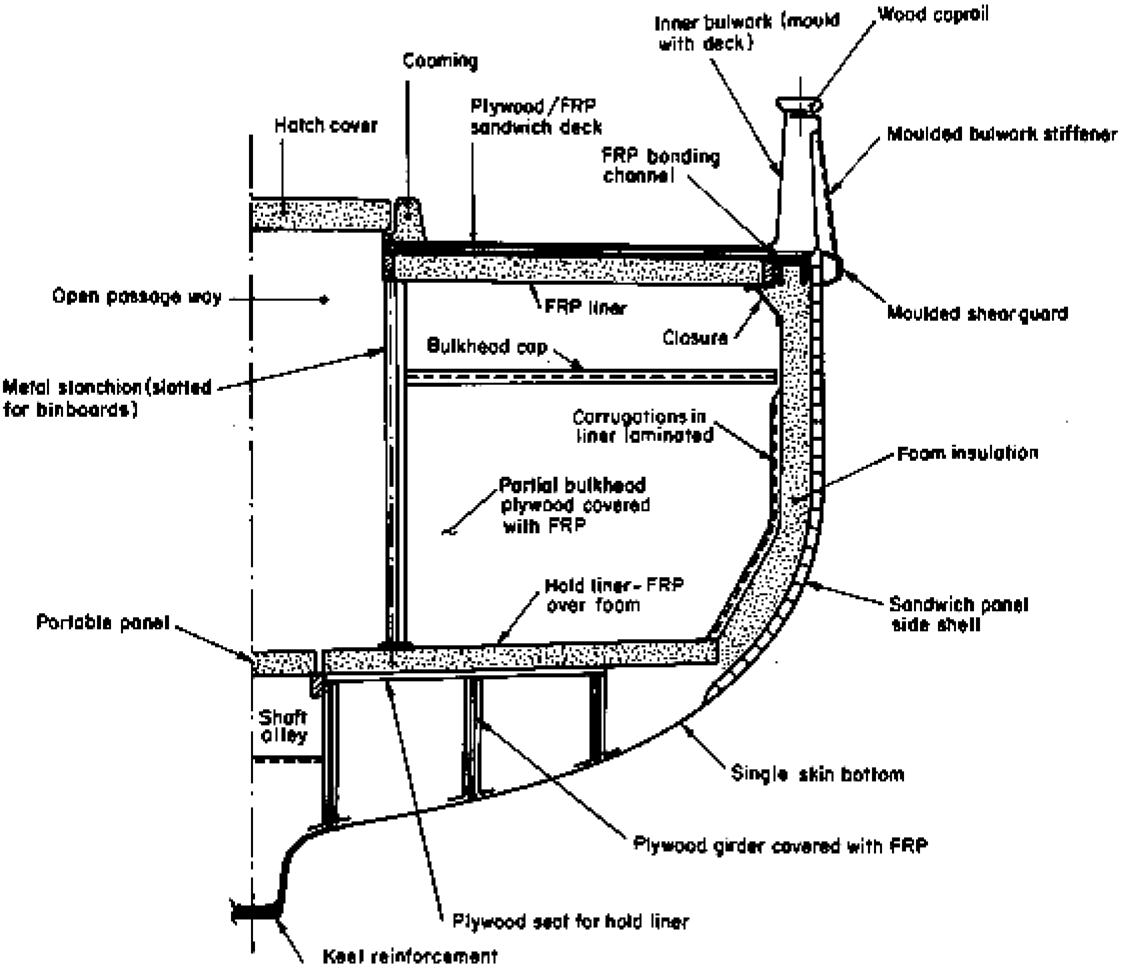


Figure 13 Cross-section of a double skin shrimp trawler

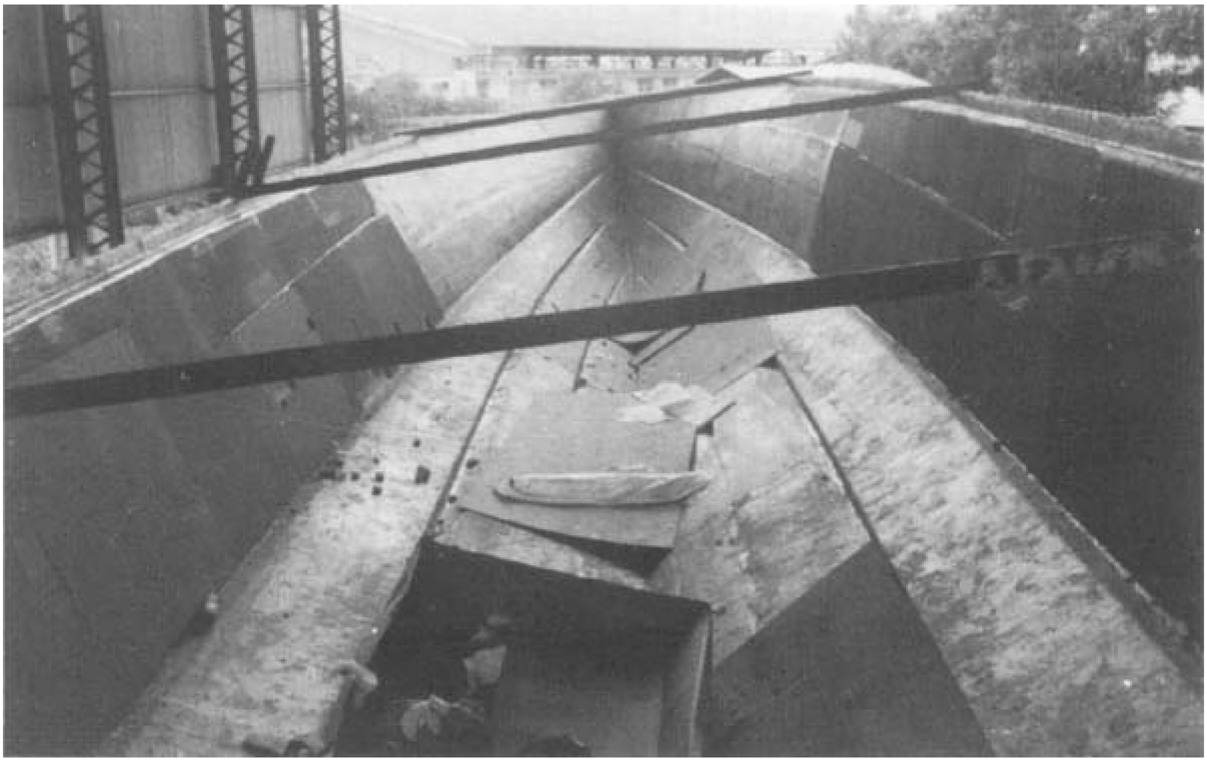


Figure 14 Sandwich skin patrol boat

Table 8
Relative rigidity of sandwich laminates in bending

Total thickness (mm)	Single FRP skin	Two FRP skins each 1.5 mm thick with centre core	Two FRP skins each 3 mm thick with centre core
1.5	0.018		
3	0.2	0.2	
6	1.6	1.3	1.6
10	5.3	3.7	5
13	12.5	7.3	10
19	42	18	29
25	100	34	58
32	195	52	94
38	337	77	143
44	536	104	197
50	800	145	266

6.3 Mouldless Construction

Because of the rigidity of the cores mentioned above, they also lend themselves readily to prototype or single model construction as FRP can be applied directly to the self-supporting core material. In this case sheet foam is laid over an open framework of the hull shape and covered by an FRP skin. After removal of the framework an interior skin is laminated to finish the double, or sandwich hull. In this type of application, cured laminate surfaces either side of the core will not have a gelcoat smooth finish and will require hand finishing. This is in effect the same process as plug making. Occasionally after trials have been completed a prototype hull may be considered for use as a plug if conversion and preparation are judged less costly than making a new plug.

6.4 <u>High Technology Developments in FRP</u>

High technology (hi-tech) developments can be divided into materials advances and developments in production methods. The former are used to reduce weight or to increase strength for the same weight by using sophisticated reinforcements such as carbon fibre in combination with other resins such as epoxy and have mainly military or racing applications. They are all more expensive than materials previously described and are rarely used by production builders in northern countries. Developments in production methods are directed at mass production, particularly to reduce the expensive labour content of any item subject to a competitive market and are not suitable for initial entry into FRP boatbuilding in a developing country.

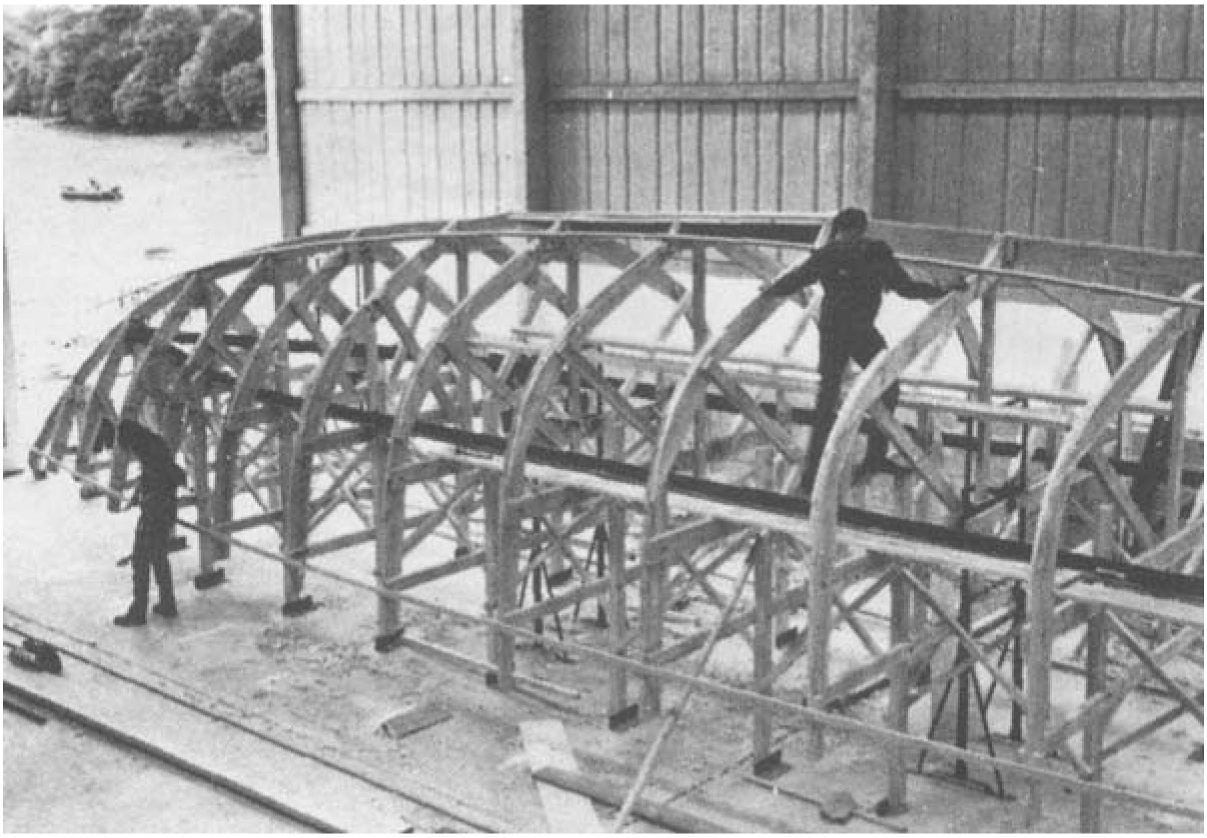


Figure 15 Wooden framework for mouldless construction

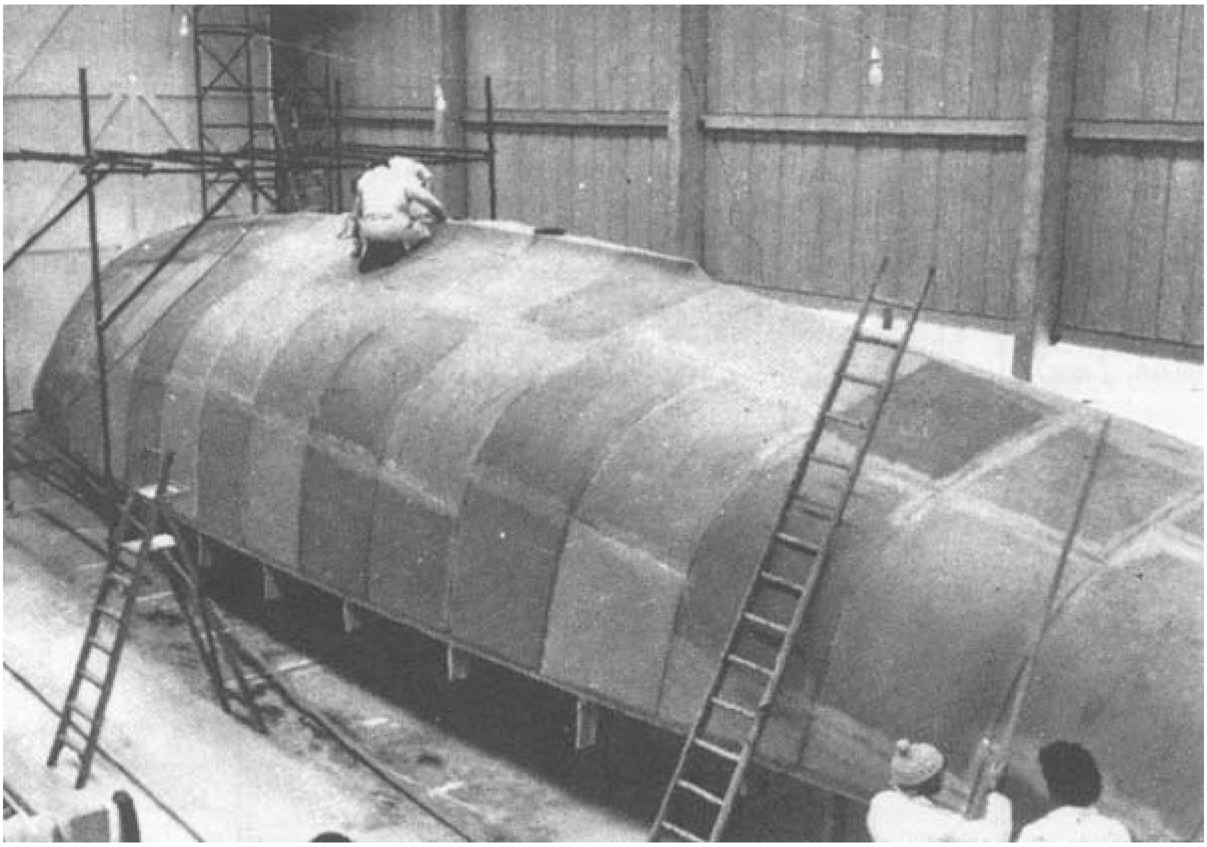


Figure 16 Foam sheets on framework

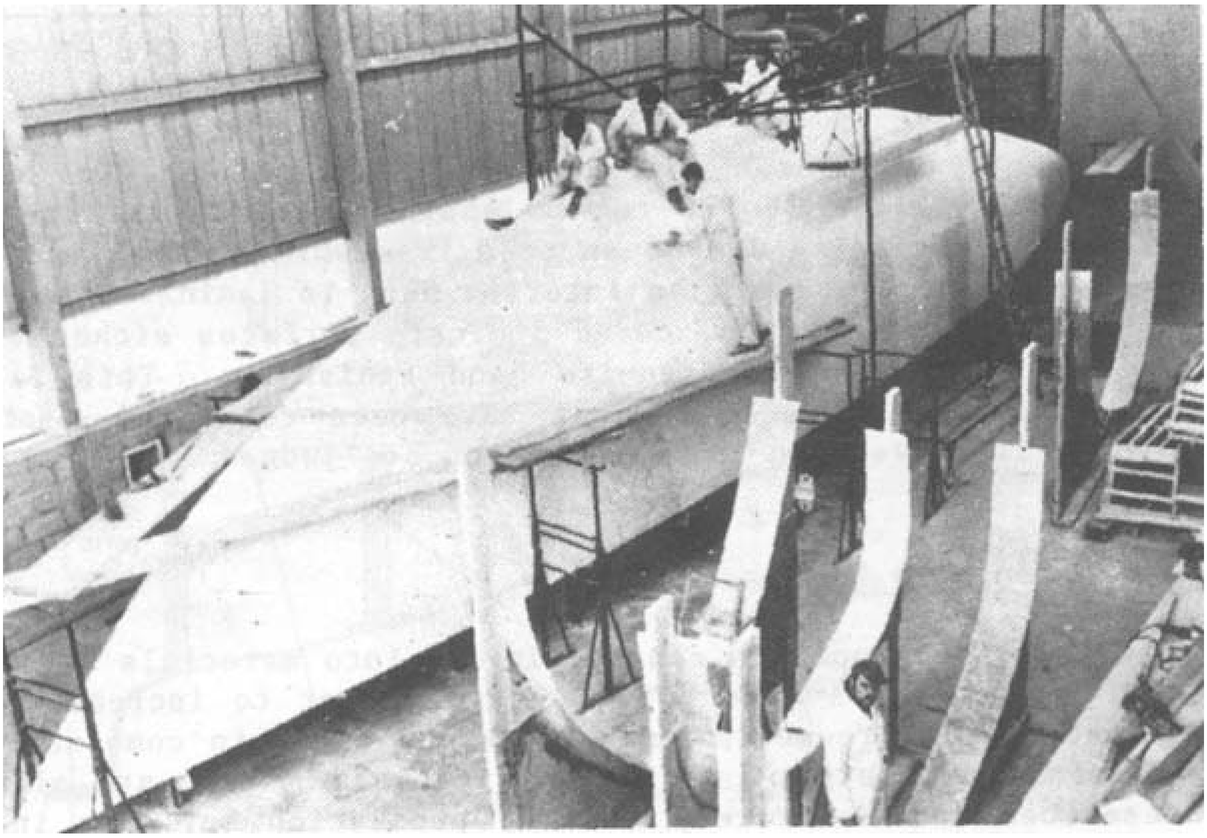


Figure 17 Outer FRP skin

6.4.1 Materials

These all have in common restricted use and the need for care and experience when handled. Some require special solvents; some can be used only in certain temperatures and humidity ranges or production sequences. They are unlikely to be tolerant of normal misuses encountered on the shopfloor.

Resins

Epoxy resin is often encountered in developing countries as a filled resin in the form of a two part glue. It possesses superior abrasion resistance, less water absorption, greater bonding strength and much lower shrinkage. Vinyl Ester resin is a further improvement on epoxy but neither are judged cost effective for workboat building.

Reinforcements

Conventional glass reinforcements have advanced beyond CSM and WR mainly in ways in which they can be combined. It is apparent that if a layer of WR is needed on top of a layer of CSM then production time can be saved and a stronger inter-laminar bond will be achieved if they are laid simultaneously. More time could be saved if they were bound and could be cut, together. This principle of combination leads to a whole range of possibilities using different types, weights and sizes of reinforcement and even to tailor made reinforcements for some larger boatyards or special applications.

Pre-Impregnated Reinforcement

This is a glass reinforcement with an uncatalyzed paste resin impregnated into it. It is used for the mass production of precision industrial or domestic items with a closed or two sided mould and rarely for the boat industry.

Kevlar

An aramid fibre, gold coloured and difficult to cut with a steel blade. It is used where extremely strong, lightweight structures are needed or to reinforce specific areas. Hi-tech resins must be used with kevlar as it does not bond well with polyester.

Carbon Fibre

This is not as strong as kevlar but neither is it as expensive. The price of carbon fibre has come down to the extent that it is offered as a woven part of cloth reinforcements by some manufacturers. It is sold in similar roll sizes as glass tape and has a silky black appearance.

Cores

A core in a laminate makes it stiffer with little weight penalty. If a hull laminate has been reduced in thickness by the use of hi-tech reinforcements, the stiffness lost due to thickness can be re-gained to the same or greater extent by the use of a core. Lightweight hi-tech cores can be aluminium or treated cardboard honeycomb panels applied in the same way as other cores but rendering the laminate very difficult to repair if damaged.

Fillers

Chalk powder is cheap non-toxic and easy to use. It is also water absorbent and relatively heavy which is not acceptable in the search for speed and light weight. Hi-tech fillers include glass or silicone bubbles which are so fine that they resemble a white dust. Micro and macro bubbles are hard, blown resin bubbles ranging in size from 2 mm to 8 mm and are used for coarse filling when the weight of solid FRP is unacceptable.

6.4.2 Advanced boatbuilding methods

These usually have as an aim the refinement of the manufacturing technique to obtain the best possible laminate from the components. This may include machine mixed resin, air conditioned moulding shops and pressure compaction of the laminate by vacuum bagging.

6.5 Production Methods

6.5.1 Production line

The fabrication of a boat from FRP mouldings reduces the need for highly skilled carpenters to hand craft each component. This allows the possibility of production line methods where boatbuilding can be accomplished by separate teams of moulders for the FRP components, carpenters for the fitting out and mechanics for the machinery installation.

For yards where wooden boats are normally built, a production line is a radical change from the traditional system. It can lead to higher productivity from specialization of tasks but Production Management skills will be required to maintain both a flow of orders and supply of materials to keep the system running at its optimum speed.

6.5.2 Mass production

Spray Lay-up

Large items such as shower stalls and baths which require a good cosmetic finish but do not have critical strength requirements can be spray gel-coated and use spray application of reinforcement. Spray lay-up is a very fast method of applying chopped strands. In principle it is a pneumatic powered spray gun (Figure 18) hand operated and fed from a bulk store of raw materials. When triggered by the operator the boomed out gun mechanism draws on separate supplies of resin and catalyst which are mixed together at the spray gun head similar to paint or gelcoat spraying, whilst at the same time drawing on bulk rovings which are “chopped” or cut to 50 mm lengths alongside the resin spray nozzle and applied together to the mould surface. A contrasting coloured thread (e.g. red against the white of the roving) gives a colour tone to the sprayed chopped strand so that when the experienced operator judges the colour appropriate to the required weight of reinforcement per square metre he ceases operations and consolidates the laminate by roller. These “chopper” guns need to be cleaned every time they are used to prevent resin curing in the fine nozzles and spray head. As this is laborious, the machine should be kept in use continually and only cleaned out at the end of the working day. This tool is used where there is a high constant workload.

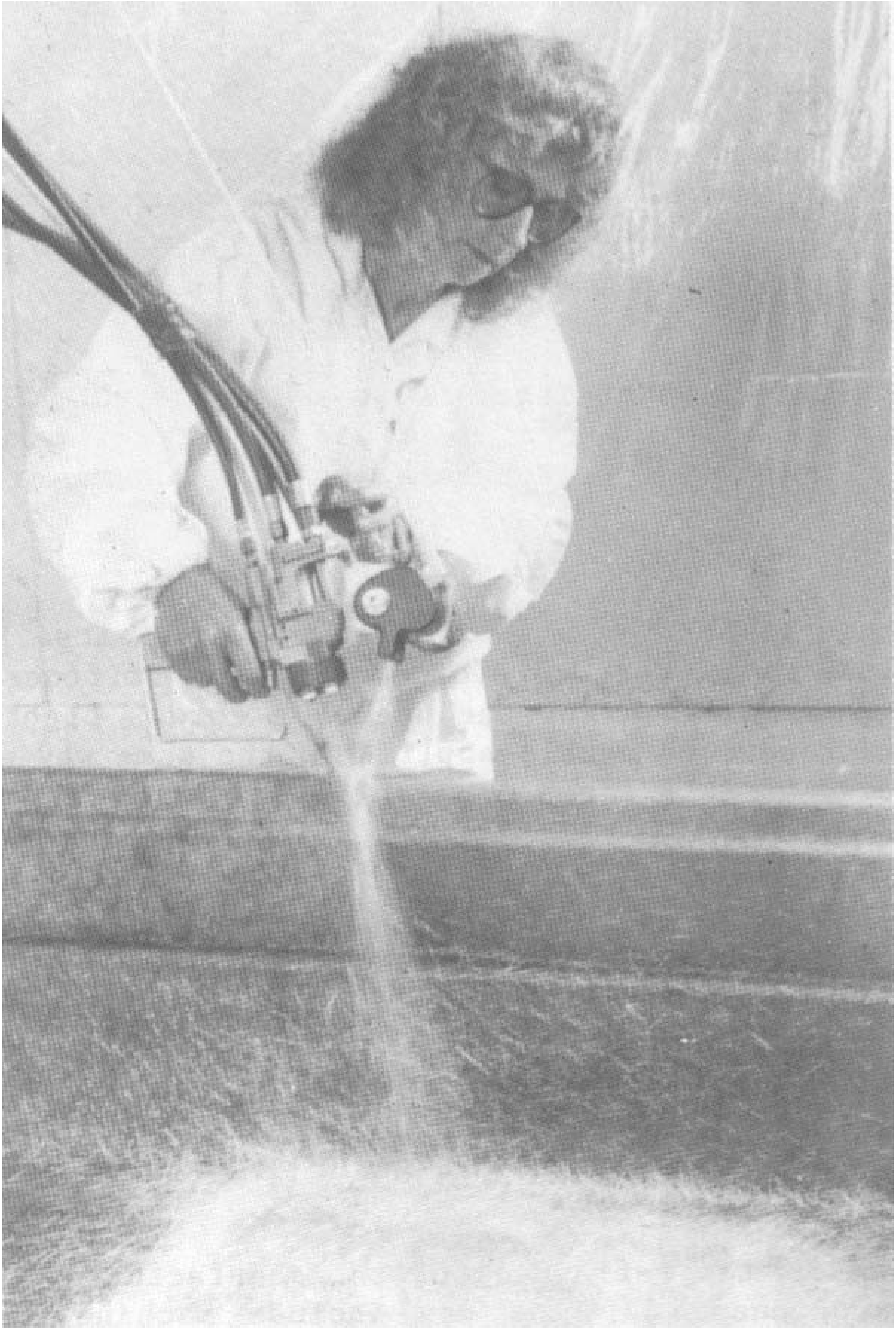


Figure 18 Spray gun laminating

Injection Moulding

This is used for small precision items. High quality tooling is required possibly in steel to withstand the pressures and cycles required of the mould. Boat hulls up to 10 m have been made using conventional reinforcements in matched male and female moulds with resin injected between them thus removing the need for hand consolidation. Equipment costs are very high.

---

7. SIMPLE CONSTRUCTION

7.1 FRP Applied to Core Material

FRP can be used other than with a mould. For example, if an owner required a vessel with a non-standard deck layout, his requirements could be accommodated by moulding that part of the deck which remains standard and using it as a foundation to which new structures could be attached either in wood or FRP. On a simpler level, fish tanks, hatches, ice containers, etc., can all be made by coating a plywood or plastic foam core with resin and reinforcement. Balsa wood can also be used when it is prepared for such a purpose but is more prone to water absorption than other cores.

The requirements for use as a core are that the material have a surface to which the FRP will form a mechanical bond, and that the core material is dimensionally stable so that it will not distort and consequently throw off the FRP sheath. New plywood is the only form of wood which can be expected to give a reasonably sound bond which will last. The bond is mechanical (gluing effect between two dissimilar materials) rather than a chemical bond which implies a joining of the materials on a molecular level. To assist the bond, surfaces should be roughened so that resin can grip as well as possible. Ply and balsa should be pre-coated with an unreinforced resin to which the reinforced layers may obtain a good bond.

Corner joints may be simplified by butt jointing and coating the internal and external angles with a single layer of glass tape. This is then left to cure. Such a joint will hold sheets of ply and foam in shape while the main reinforcing sheath is applied. In lightweight construction it may be strong enough to be all that is necessary. Another material to which FRP forms a good and reliable bond is PVC in solid form e.g. PVC pipe. This property is useful when making tanks and the like, as PVC pipes and ducts, etc., can be bonded directly to the FRP.

The construction of on-board insulated fish containers for canoes is a good example of a small production run where the insulating material itself (sheet polyurethane foam) has been bonded together to give the basic container shape and then coated with a protecting and strengthening FRP skin.

7.2 Making a Simple Plug and Mould

Simple moulds may include small portable moulds for items such as buckets, hatch covers, chairs or fish boxes. The simplest mould is a flat panel, FRP mouldings from which can be used for a customized wheelhouse for example. Any mould:

- Must be rigid to retain its shape and resist distortion;
- Must possess positive release angles which do not resist release;
- Must posses a surface layer which will release the moulding when appropriate pressure is applied (see Figure 21).

The plug should always be regarded as disposable and only to be used once; so repair work to cover any blemishes made during construction is governed by smoothness of the finish and not by any visual or long lasting quality, e.g., a little resin putty would grip slotted screws long enough for the mould to be made. When it has been made smooth the whole unit can be given 3 coats of wax and a coat of PVA (Poly Vinyl Acetate) release agent before the gelcoat is applied.

By convention, plug and mould gelcoat is usually black and is a harder finished surface than hull gelcoat. This is because it is subject to repeated overcoating, but does not have to be as pliable. Once the mould gelcoat is cured, a surface tissue is used to strengthen it and then FRP is built up to twice the thickness of the moulding to ensure rigidity. It is usually CSM only to remove the risk of roving print being transferred permanently to the mould surface. After the FRP laminate has been completed and has cured beyond the gel stage, stiffening can be bonded to the outside before release from the plug. This may include some legs to raise it off the floor. The stiffening can be of wood, foam or rolled newspaper to give a former for the FRP framing. The whole assembly should then be left for up to 3 weeks to become fully cured before release. Small wooden wedges gently hammered between the mould and plug should achieve release, a few blows to the flat areas with a rubber mallet can also help on occasion. Once the plug has been removed, the mould can be inspected for flaws and damage and any repairs made and blemishes removed before it is polished with 5–7 coats of wax to render it serviceable (see simple mould - Figure 22).

Figure 19 Insulated FRP/foam fish container

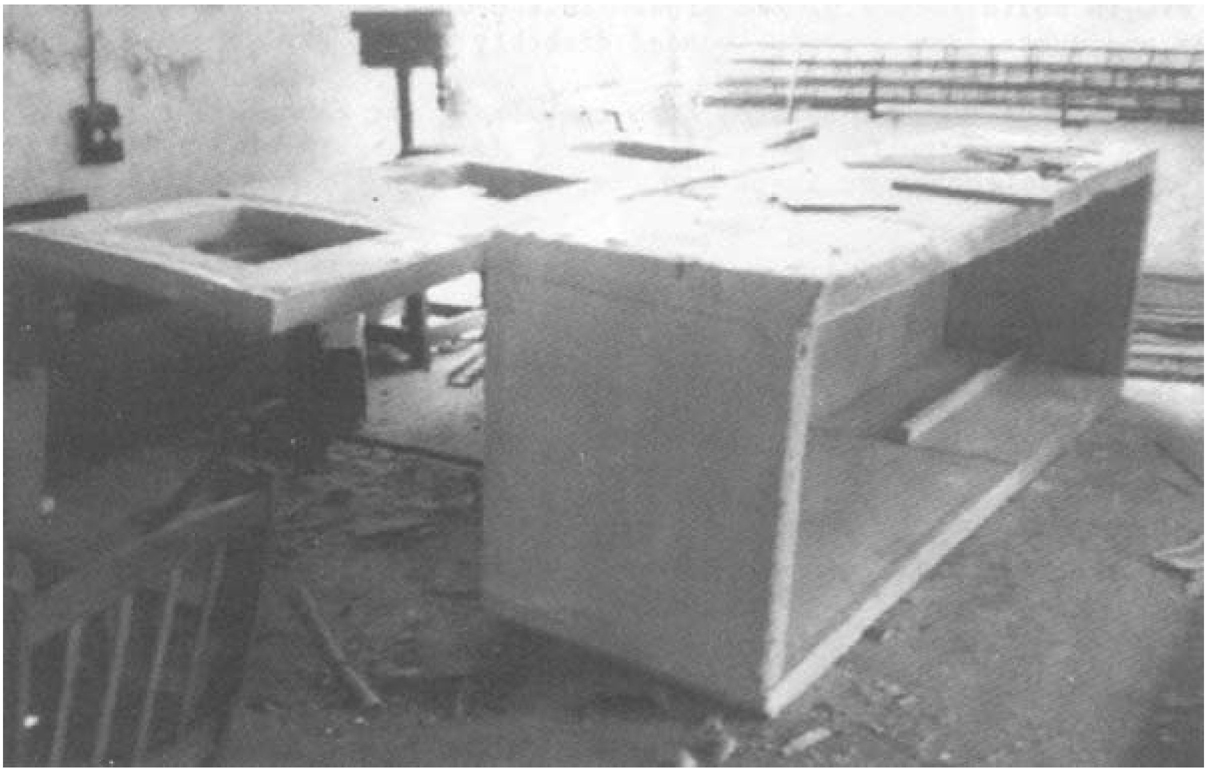


Figure 20 Free standing insulated container

Some moulds need waxing each time they are used, high quality moulds may need waxing after every third cycle. A wax build up shows as a dull sticky area and should be washed off.

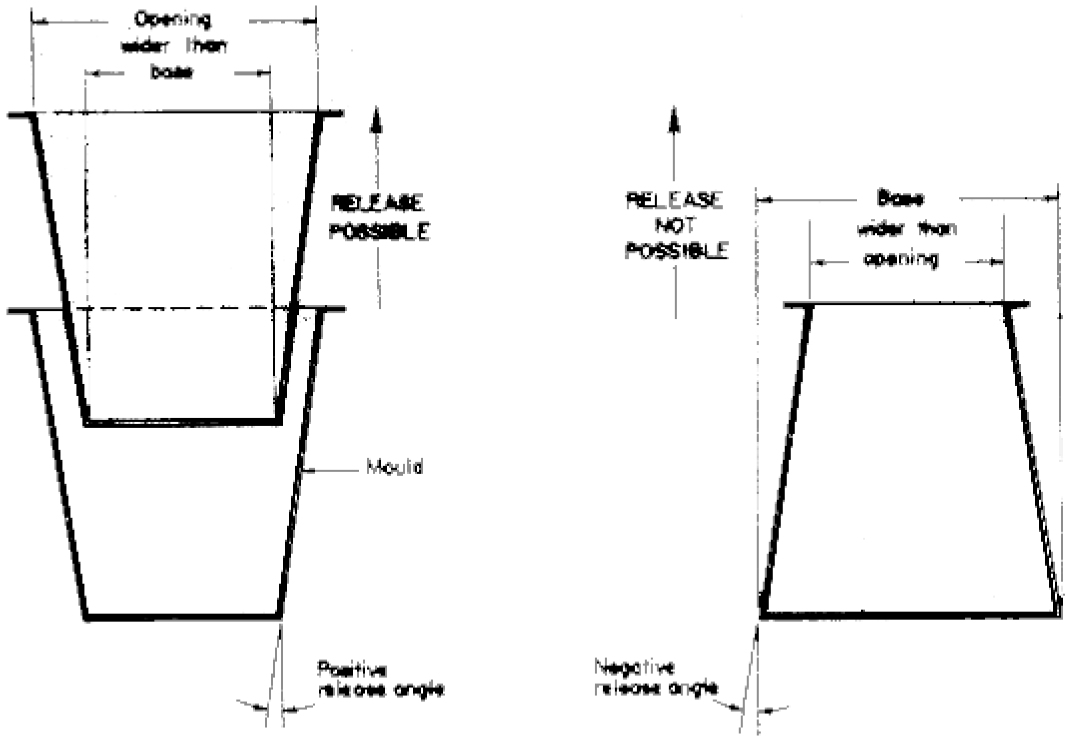


Figure 21 Release angles

7.3 FRP Practice Panel

This exercise allows practice in basic skills such as gelcoating, laminating and repairs.

1. Obtain flat sheet 800 mm × 1 000 mm which will be the mould for the exercise. Formica covered plywood is best but hardboard or other smooth surface will do. Polish surface with silicone-free wax.
2. Apply white gel coat to one half of surface. Use masking tape to give a straight line, remove it during gel stage and apply clear gelcoat to other half.
3. Check for flaws when cured and laminate one layer 300 g CSM on top.
4. Check for air bubbles, sand smooth if necessary and laminate one layer 300 g CSM and one layer woven cloth AT SAME TIME. Use rollers.
5. Repeat checks and judge whether resin ratio is correct by sheen. Laminate one layer 450 g CSM AT SAME TIME as one layer 800 g WR using squeegee. All edges should be trimmed with a sharp knife to shape of mould when each layer is at the gel stage.

6. Leave for at least 24 hr and release panel from mould using wooden wedges. Trim edges by hand sanding.
7. Cut panel to 800 mm × 800 mm, using jigsaw with metal cutting blades or padsaw with hacksaw blade.
8. On non gelcoated side scribe lines at 150 mm from two opposite edges so that scribed lines cross gelcoat divide line at rightangles.
9. On one line place sheet of newspaper rolled to 30 mm diameter and hold in place with 2 – 4 strips of masking tape.
10. Sand offcut to remove gloss from both faces and place on-edge on other line. Prop in place and cement with dabs of resin putty.
11. Along gelcoat join line (seen from working side) place dabs of resin putty and bed-on foam stiffener (cross section shown below). Arrangement now provides working practice for two types of panel stiffener and panel-to-panel bonding.
12. Work on foam former first. Coat with resin. When cured, prepare piece of CSM to cover foam and give 25 mm overlap onto FRP panel. When cured roughen surface with sandpaper and prepare CSM and woven cloth to give overlap 25 mm beyond first overlap. Repeat with CSM and WR.
13. Vertical web. Round off internal angle at panel/web joint with resin putty. The radius is obtained by running the rounded end of flat stick through the putty. Reinforce joint both sides with CSM only, first layer 5 cm width, second 10 cm, third 15 cm.
14. The paper stiffener cannot be expected to be as resilient as the first two. It is included to demonstrate the non-structural nature of cores and the use of paper when a stiffener is needed urgently. The first problem occurs in that being of a circular nature, the lower half of the paper tube cannot provide any support for wet reinforcement. To overcome this, a tailored piece of CSM should be wet out on top of a corresponding piece of woven cloth away from the tube, then carefully laid on the tube and gently smoothed out to remove air bubbles. To prepare the WC/CSM lay the cloth down first with the CSM on top and wet it out. To apply it, the cloth should be uppermost to facilitate smoothing out probably by hand. Continue lay up when first layer is hard.
15. There should now be two areas above and below the crossbar of the “H” formed by the framing. These are for practicing repair techniques. One with a white gelcoat and one with clear. Holes about 150 mm dia should be made in these areas and conventional and blind hole repair techniques practiced according to methods described in Chapter II. An effective method to obtain holes is for the student to attempt to punch a hole through the laminate with a hammer. This will adequately demonstrate the strength of his creation. If a hole is not obtained the cracked area can be cut out to give an asymmetric hole. Impact testing of the bonded web can also be carried out.

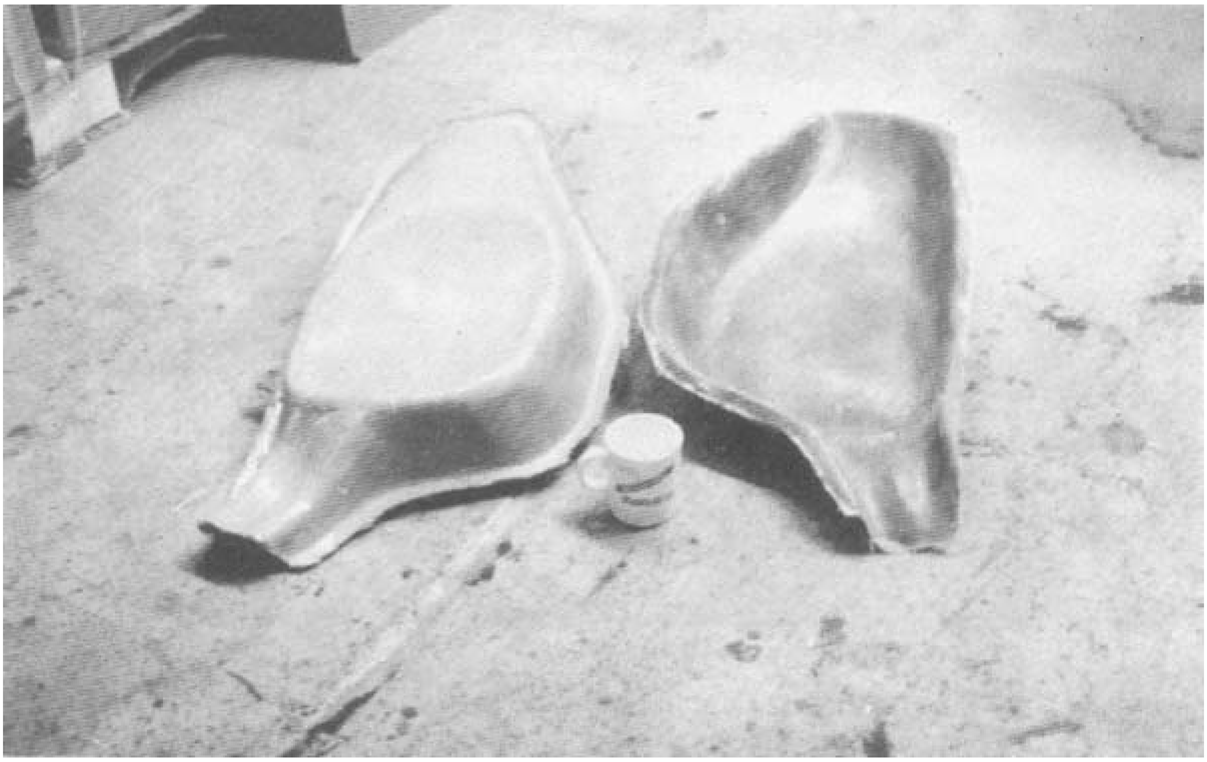


Figure 22 Simple mould

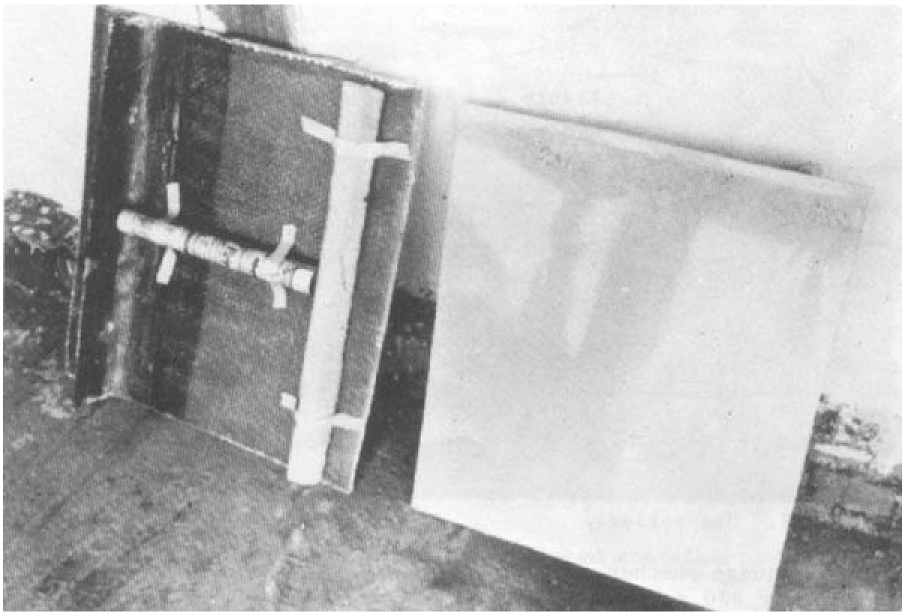


Figure 23 Practice panel showing working face and gelcoat face

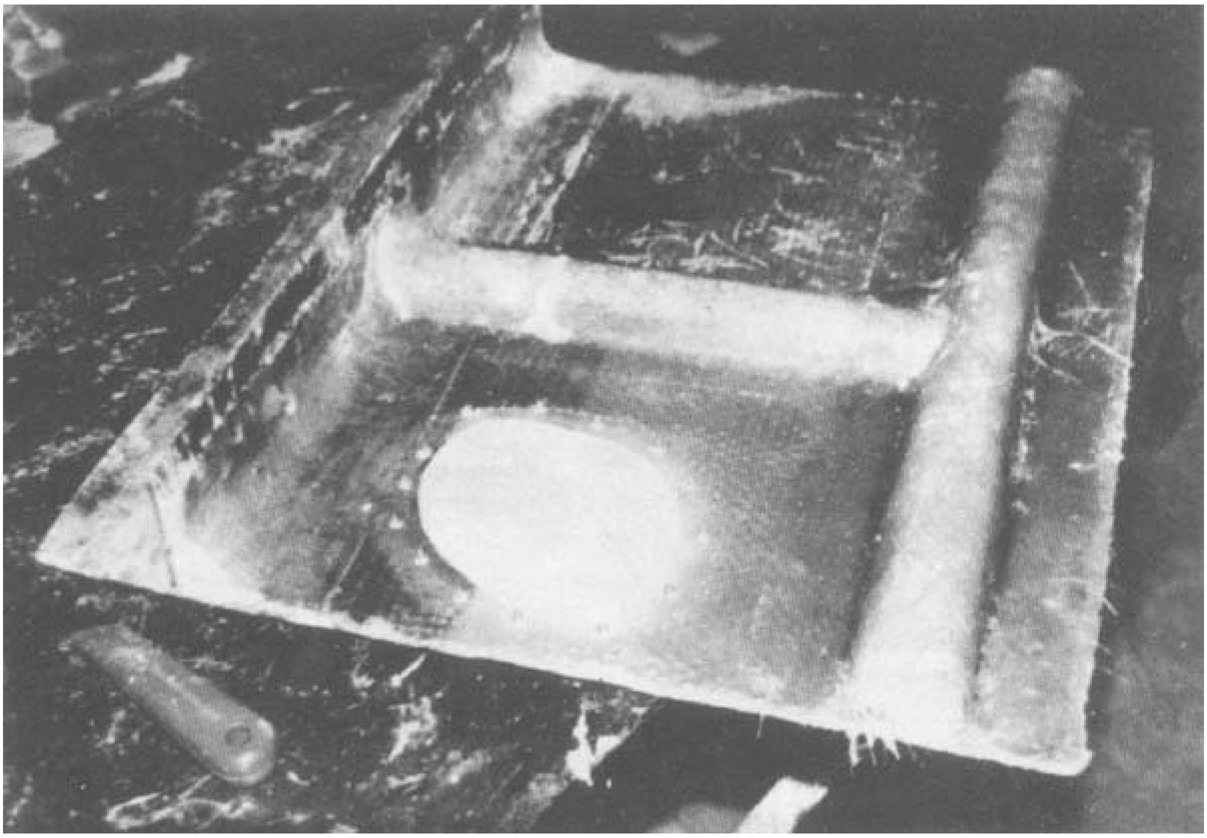


Figure 24 Panel with framing reinforced and hole repaired

Figure 25 Repairing one-side access hole

8. BASIC SINGLE SKIN VESSEL CONSTRUCTION

This chapter deals with the most common method which has been used to produce a large proportion of the FRP vessels existing today. Single skin construction using the PLUG - MOULD -HULL sequence is the simplest and cheapest method to build a number of boats from the same mould.

8.1 Plugs and Moulds

The principles described for the construction of small plugs and moulds equally apply to large. In the case of a new vessel design construction of the plug calls for the traditional skills of a boat builder. Wood is the principle material for construction but foam or balsa can be used as well as other less common materials such as C-Flex. Though traditional skills are required, if carpenters have not built a plug before new demands will be made in terms of accuracy and quality of workmanship. This aspect is particularly relevant in developing countries where a conservative approach to new demands leads to slow progress and requires constant encouragement by an experienced technician.

Three aspects need particular attention for the construction of a good plug:

1. Building the plug upside down. Even though the plug is virtually a wooden hull, for reasons of access and mould release it is better built in this position.
2. Finishing the surface to a high standard. A mirror finish is often quoted and this is true in terms of sheen, smoothness to the touch and fairness of hull lines.
3. Achieving the finish in FRP once the basic woodwork has been completed.

It needs to be made clear once again that the plug is NOT a boat but a means to building a mould ONLY. It will be used once and thrown away.

Figure 26 Mould construction

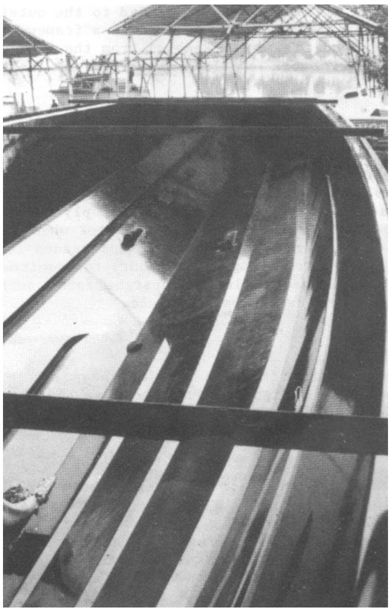


Figure 27 Polished surface of new mould

8.1.1 Hull plug and mould building

To begin, the frames of the plug are erected in an inverted position on a solid foundation. This is usually a heavy wooden frame laid on a level concrete floor. When all framing is erected, the skeleton can be strip planked or completed in any material judged suitable to achieve the shape of the vessel. At the deck edge which is in this case near the floor while the keel is some distance above it, a plywood flange is attached so that later during the moulding process, gelled FRP can be trimmed back to leave a solid laminate with a clean cut edge. It is usual to cover the plug with a layer of FRP as soon as the crude shape of the vessel is achieved to reduce distortion due to any shrinkage of the wood. This layer can then be filled where necessary with resin putty to remove the shallow indentations which will show up once the FRP skin is consolidated.

Likewise, any irregularity which spoils fairness can be removed by grinding or by hand sanding. This process of hand finishing is repeated until the foreman considers the plug smooth enough to receive a layer of hard tooling gelcoat. This especially formulated gelcoat is the beginning of the coating which will eventually give the polished surface from which the mould will be lifted. There is no shortcut at this stage, the more time that is spent hand sanding the plug with wet and dry abrasive paper, the better the plug will be. Further filling with resin putty and overspraying may be necessary before a satisfactory finish is achieved.

For a 10 m hull, five persons for a week is about the minimum time that is needed for the final preparation of the plug. This will include polishing with rubbing paste after the sequence of wet and dry paper has run its course. Polishing with a non-silicone wax to give 5–7 coats and a brilliant sheen precedes a coat of PVA release agent which is the final step before the mould itself is begun. A dust cover is useful in the final stages.

When the time comes to make the mould, the process is a reverse of plug building without the need for final finishing as this obtained by the faithful reproduction of the plug surface. Mould the thickness can be up to twice finished hull thickness. There is little point in using WR in a mould as the thickness provided by solid CSM layup gives the required dimensional stability. Once the mould has cured, reinforcing stiffening can be bonded to the outside so that external bracing is present to support the mould when released and to provide a framework for the attachment of wheels, etc., to allow it to be moved about the yard. Removal from the plug may be tortuous and cause minor damage to the mould. Any repair work should be carried out before the mould is prepared for service.

8.1.2 Deck and interior

Preparation of plugs and moulds for deck and interior follows similar methods. As the deck contains few compound curves but many flat panels and tight radii, some differences should be mentioned. Use should be made of sheets of hardboard, or plywood covered with formica to provide large flat areas of decks and bulkheads with a final surface which requires little hand finishing. Tight corners are generally made from resin putty and hand sanded to shape. Moulded - in textured surfaces are possible (non-skid) as are flanges and mounts for equipment. The most important factor to remember is to obtain good release angles on upright faces such as bulkheads as it will not otherwise be possible to release the deck from the mould.

8.2 Plug and Mould Details

A one piece mould lifted directly from the plug may be possible in the case of a small vessel but some complications arise if the design has tumblehome, a reverse transom, a deep narrow keel or is simply very large.

8.2.1 Water/air inlets

In the case of large vessels it may not be possible to overcome the vacuum between the mould and the moulding by the use of wedges alone. In areas which may be suspected of poor release, pipe inlets can be cast into the mould during plug/mould construction so that compressed air or mains water pressure can be introduced to encourage the separation of mould and hull. This is accomplished as follows: before the gelcoat which will form the surface of the mould is sprayed on to the plug, inlets are fixed to the plug with modelling clay. The gelcoat and laminate are laid up around it leaving the connector part of the inlet protruding through the finished laminate.

The release of the mould from plug is similar to the launch of a new boat. It is the day all the work is seen to come to fruition. It is likely to provide one or two problems during separation as well as needing some heavy lifting gear to roll the mould over once it is clear of the plug.

8.2.2 Split moulds

If the mould has acute release angles created by the hull form, then there is little alternative but to use a “split mould”. This is a mould which is in two or more pieces which allows easier access to areas foreseen as difficult to mould and to release mouldings where form would not permit release from a one piece mould.

A flange is needed to bolt together the two or more pieces of the mould. To create it, a pattern of the flange has to be made on the plug on each side of the joint line in a similar manner to the sheer flange previously described. This may cause some damage to the plug which must be repaired before the corresponding flange on the opposite side can be made. It is possible to use the first mould flange as the pattern for the second half; this will provide a very accurate joint and will allow bolt holes to be through drilled in situ before release.

8.2.3 Care and use of moulds

Preparing the mould for service has already been discussed and this forms the basis for care and use. Any purchaser of an FRP vessel will expect a first class vessel so the mould should be kept in a first class condition - AS NEW. Between mouldings it should be checked for damage and receive a coat of wax. Every five - ten cycles it should be thoroughly checked and any repairs carried out to wear on flange bolt holes, or damage caused by hammering during release. Wax can build up in some areas to form a thick layer which gives a dull gelcoat, this should be washed or polished off. The priority here is to maintain the inside surfaces as smooth and polished as possible.

During periods of long inactivity mould need to be stored undercover. Exposure to the sun and wind is not recommended as the shiny gelcoat surface will soon become dulled. Coating it with a protective layer is advisable. This could be a gelcoat and supporting surface tissue or a latex rubber paint which can be easily peeled off. Smaller moulds can be turned over or covered with a dust sheet.

Figure 28 Deck mould

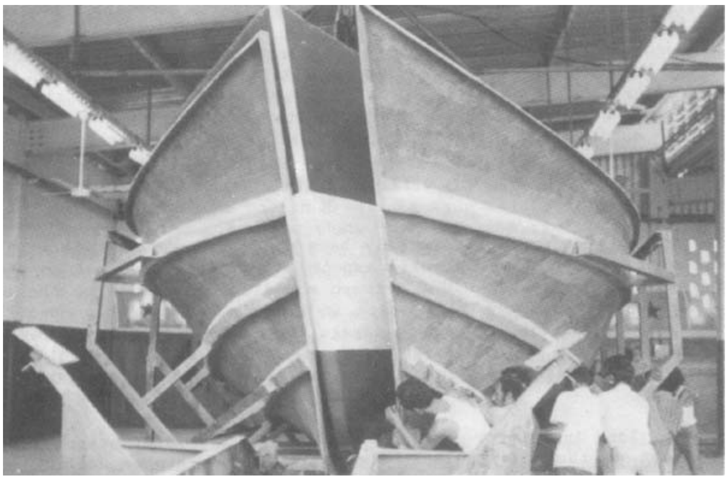


Figure 29 Split mould

8.2.4 Variations to a standard product

It has been emphasized up to now that once the design has been chosen then the yard is “locked” into a standard vessel. This is true but variations can be made within reason. The hull itself can be made longer or shorter or have its topsides raised and lowered provided it is done so with the Naval Architect's agreement and that he has checked the stability of what is virtually a new design. The mould can be changed in length if there is a region of fairly constant section such as in a hard chine power boat where aft of midships little cross sectional change occurs. Topside changes require the cutting down of the moulding to give a lower sheerline or the attachment of an extension to the mould sheer to build them up. Changes to the form of round bilge vessels are not recommended and in general the standard hull should be used unaltered unless consequences are very thoroughly calculated by the designer.

The deck offers more possibilities. A one-off or custom made deck would have to be built in the traditional manner or in plywood and sheathed in FRP. It is not unusual for yards producing workboats to offer a standard hull with a range of engine and deck options to suit different tasks. This is an acceptable mode of operation but the yard now becomes a producer of individual vessels and complications arise trying to satisfy each customer's needs. At long distance from equipment suppliers this might prove difficult as well as missing the point of offering a standard cheaper vessel.

8.2.5 Component assembly

One moulding which has not been discussed is the interior. In a workboat this may not be very large, possibly only comprising the accommodations areas. Depending on the vessel there may not be one at all as it could be fitted out entirely in wood. Another use for interior moulds is the wheelhouse. To use interior mouldings and to produce plugs and moulds for them requires the yard to have a sound market for the vessel over which to spread this extra development cost. However, the advantage of an interior moulding is that the whole unit can be fitted out on the shopfloor BEFORE it is placed into the hull.

It is not unusual for a 20 m vessel to have FRP cabins, toilets, galleys and stores fitted out, piped, wired and lowered into the hull while the hull is still in the mould. The advantage to a carpenter to work unrestricted by the confines of a hull is translated to a saving in production time and therefore a lower cost. Shorter overall production times are also achieved as the hull can be moulded at the same time as the deck and interior are undergoing fitting out operations which then require only assembly of the three large components to produce an almost finished vessel.

This is an over-simplification but the principle of using large FRP components fitted out by carpenters specializing in one task can enable the yard to achieve greater productivity.

Figure 30 Production line/component assembly

8.3 <u>Construction Details</u>

8.3.1 Keels and areas requiring extra stiffening

A keel is formed by laminating additional material along the centreline of the hull and is to extend forward to the stemhead and aft to the transom boundary, so forming a structural backbone. This backbone can be maintained at the midwidth throughout the length and be reduced in weight towards the ends, or can be constant in weight and reduced in width, or can be a combination of both.

In boats with deep keels, restricted access makes moulding difficult and split moulds are used. About the joint line a scarphed laminate should be made with succeeding layers 25 mm shorter than the preceeding layer. The laminate is completed when the mould halves are bolted together. Topsides are increased in thickness to form a strong sheer in powered vessels and further increased in local areas to take mast rigging or deck hauling equipment loads.

The boundary of the transom is to be increased to support and stiffen the sides, bottom and transom laminates. A typical boundary layup is formed by overlapping the side and bottom with the transom reinforcements, but as with the backbone the increase can also be achieved by the addition of strips of material laid around the boundary.

8.3.2 Framing and stiffening sections

The stiffener former is placed in position on the gelled laminate and the reinforcement is built up layer by layer as a continuous process. Frames are usually a solid or hollow core former covered with several layers of reinforcement forming a closed box or semi-circular section when combined with the hull laminate. These are known as “hat” and “half round”. The material of the former is chosen for light weight, workability, intertness, ability to withstand laminating pressure and economy. Solid cores are normally of foamed plastics of the desired profile and do not contribute to the strength. They are bedded on resin putty. Paper rope former is to be used only on small boats.

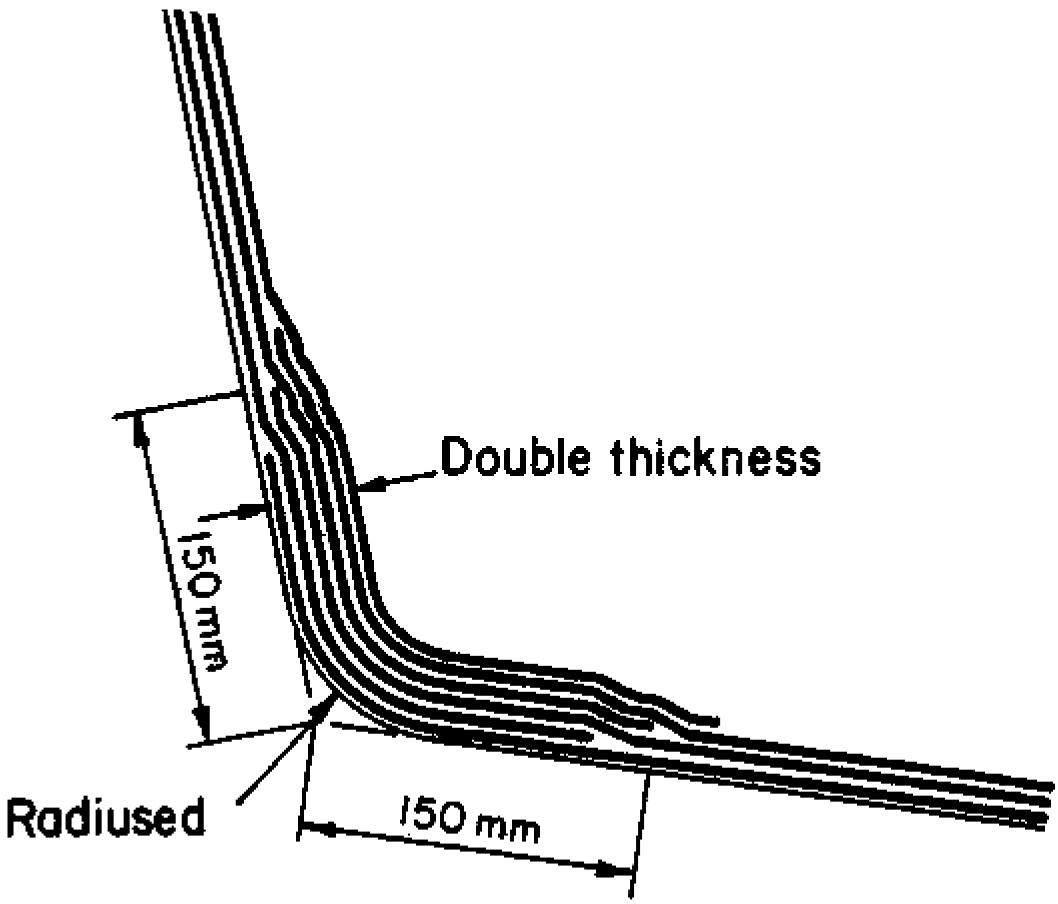


Figure 31 Typical lay-up along chine and transom boundaries

Hollow cores are plastic, cardboard or a single layer of FRP from a hat shape mould made by the yard itself which can be cut to allow a fit to hull curves. Frames can be tapered off in shape and weight at the upper and lower ends.

The strength and stiffness of the section can be varied by adjusting the section depth and retaining a constant lay-up or by increasing the lay-up where the stiffener depth cannot be increased. The lay-up can be increased by additional layers of the same material or by incorporating higher strength materials such as uni-directional or woven rovings on the face. The bonding of the section should be as neat as possible with good overlaps of basic and high tensile face material. The last layer of hull reinforcement can be timed to cover the framing to give a more finished appearance.

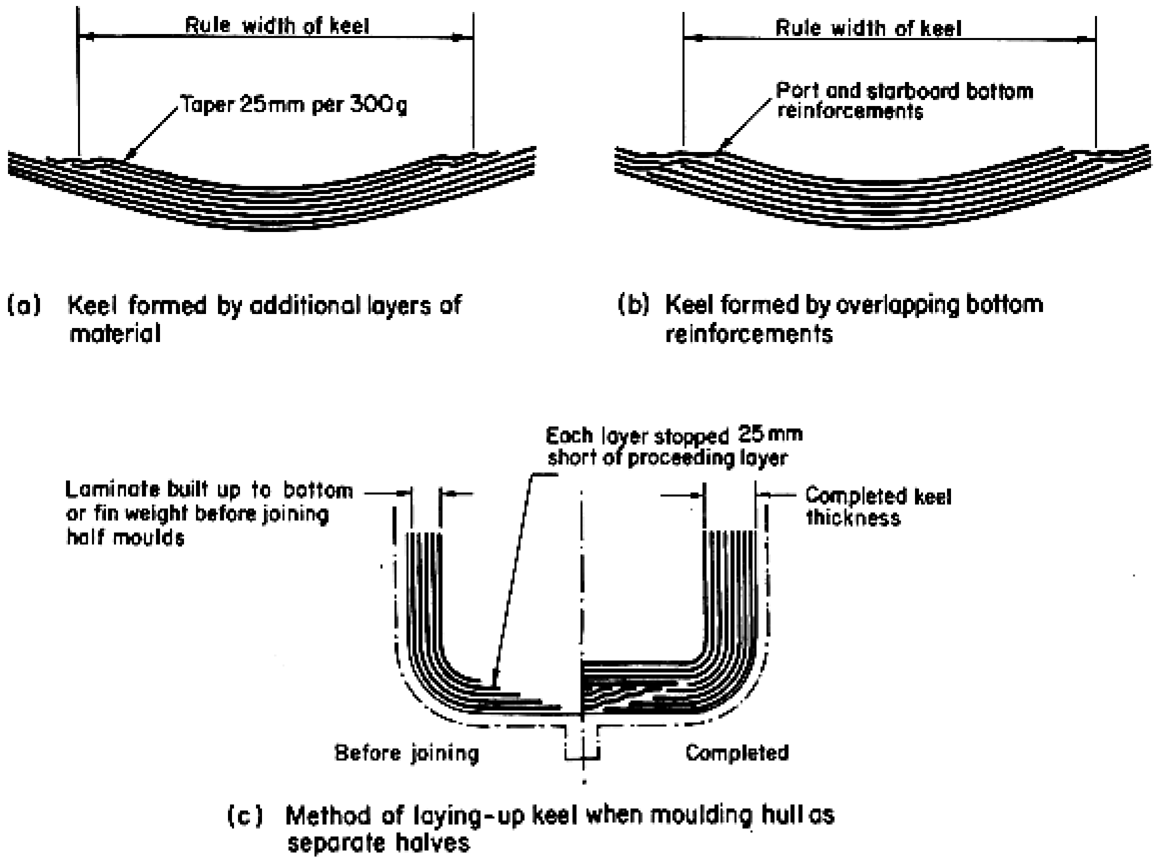


Figure 32 Methods of laying-up keel

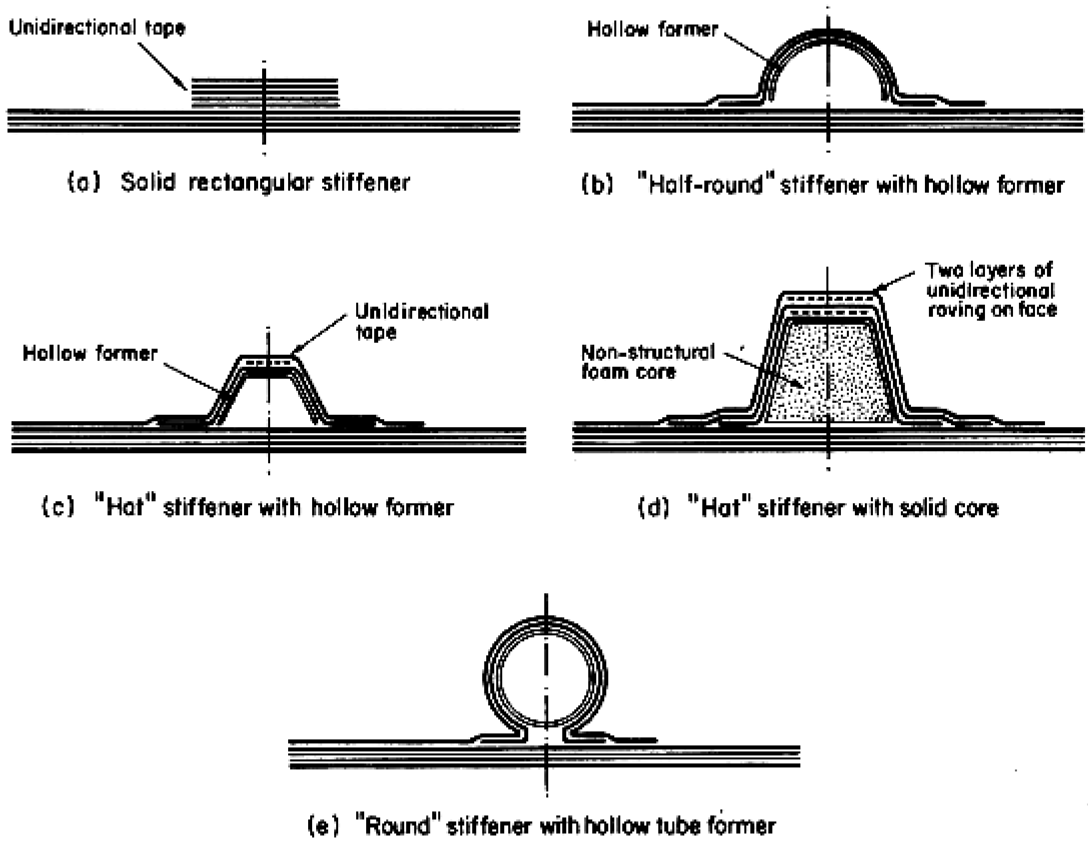


Figure 33 Typical framing and stiffening section

8.3.3 Bulkheads

Bulkheads play a greater part in a plastic hull than they do in wood or metal boats. Apart from separating compartments, they are essential in providing transverse rigidity necessary for maintaining form in the comparatively flexible FRP hull. A collision bulkhead should be installed forward and machinery space bulkeads should be watertight. Other bulkheads may replace strongbeams and be required to support masts or deck loads. Exterior grade plywood is usually used for bulkheads and should be fitted while the hull is still in the mould. The plywood should have a roughened border to improve adhesion of the resin when the bulkhead is bonded into the hull. In small boats the thickness of the plywood is normally adequate for stiffness but some pillaring may need to be added in larger boats. All openings in bulkheads should be radiused to avoid local stress fractures. Separate sandwich construction bulkheads may be used but these will be more expensive. Bulkheads can be built as part of an interior moulding to gain a moulded gelcoat finish or resin painted (flowcoat) if the visible face shows the reinforcement such as when the core is made from plywood sheets.

8.3.4 Decks and superstructures

It is standard practice to fit FRP decks and superstructures to production line craft. Custom made decks based on a standard moulding have been discussed. The moulding may be single skin or more usually sandwich construction. Ply is the favoured core for working boats where weight is less critical while allowing fastenings to be applied to the deck with little fear of crushing the core. Because of its relative inflexibility ply should be sawn to blocks of 150 × 200 mm and installed individually to achieve a void-free bond.

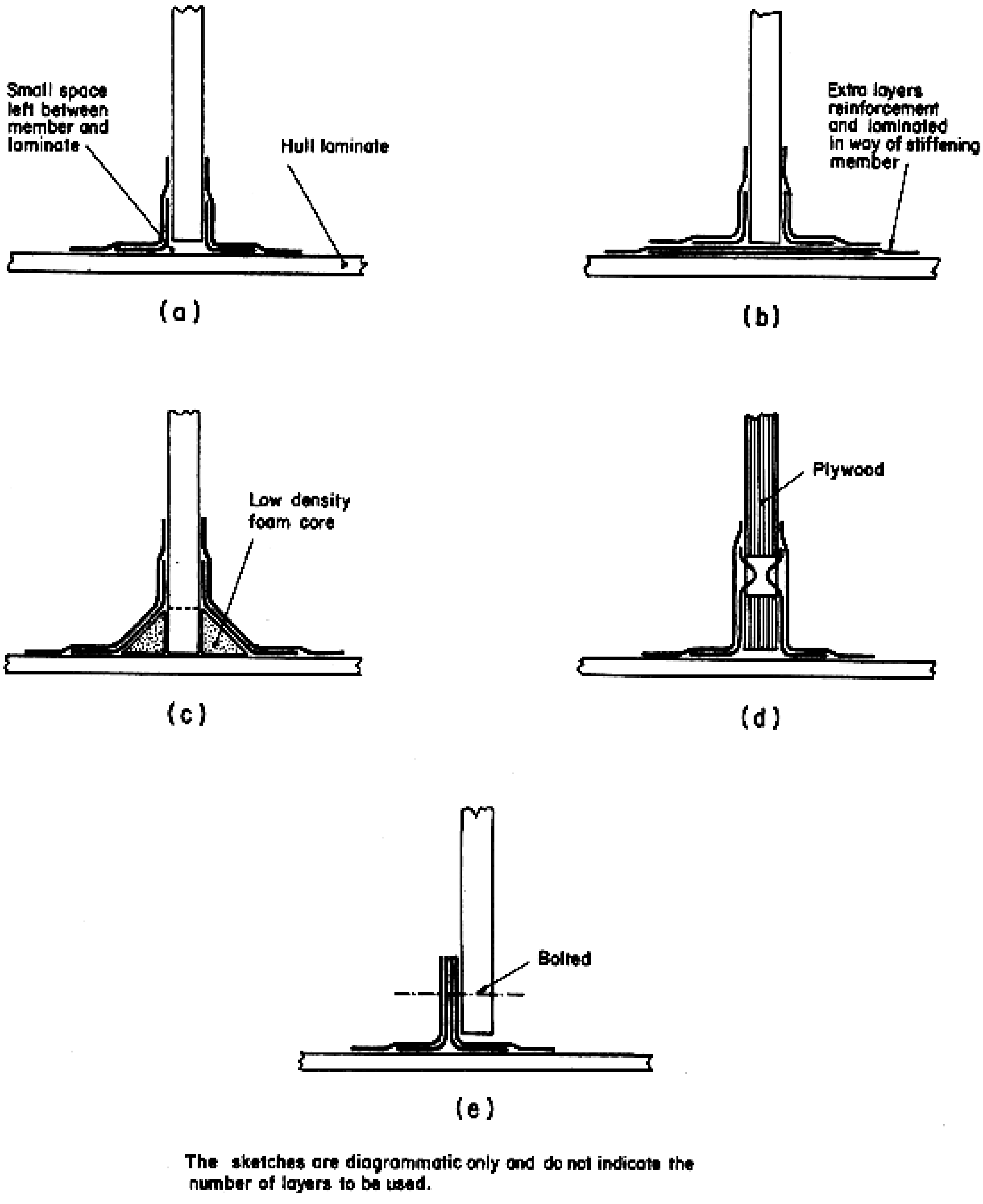


Figure 34 Typical bulkhead to hull connections

The deck laminate should be increased locally to take loads such as deck machinery or at hatch corners, etc., which may be subject to impact damage. A pad on the underside of the deck is recommended to spread the load of a through fastening.

As with other applications of sandwich mouldings, 60% of the laminate should be on the outside and 40% on the inside. Advantage can be taken of the gelcoat to mould in a non-skid surface, also to design-in mountings for deck equipment which may be cast in at the plug stage.

8.3.5 Deck to hull connection

The choice of type of connection is based on the following requirements:

1. The joint should be as strong as the weaker of the two mouldings being joined.
2. It must be easily moulded and simple to bond.
3. It should allow sufficient tolerance that the joint need not be forced into place.

Normal loads produce shear and tension at the joint. Exterior bonding would be more suitable to resist these loads but interior bonding is used for reasons of appearance. Weight of the bonding reinforcement varies with designs but should be 25% more than the lesser of the two mouldings being joined. It may require extra layers in areas of possible impact or extra local loading.

If the deck is to be of wood construction it is normal practice to fit a beam shelf around the inside of the hull to carry the beam ends. This can be done by fitting an outwhale and the beam to the outwhale by through bolting in the conventional manner. Top of frames need to be of wood so that beams may be through fastened. A moulded in knuckle at beam height running the length of the hull can accommodate a beam shelf, and simplify the process if wooden decks are standard.

8.3.6 Fuel and water tanks

FRP tanks are popular in larger craft as they do not rust, corrode or contaminate the contained liquid. They are of relatively simple construction, space saving and may be integral or separate. Tanks should be arranged so that they are not positioned at the widest part of the boat, above shaft brackets and sterngear nor at the deck to hull connection. Fittings through fastened near the tanks should be designed to fail before the tank and not to fracture the tank.

Construction should be as simple as possible with adequate access to the tank's internals to guarantee good quality joints when the final panel is bonded in place. For a separate tank normal procedure is to mould the bottom and sides as one piece then to bond on a separate top. Integral tanks can be fabricated from panels as necessary. Before either type is closed off any internal work should be completed such as fitting baffles, drains or gauges. Access is via a hole cut in the top. This will serve as access during bonding and later as an inspection hole with a strong cover and well sealed.

If possible, special gelcoats should be purchased with increased resistance to fuels for the diesel tank and an odour and taste - free gelcoat for the water tank. If these two types of tanks are in a continuous run then a cofferdam should be installed by doubling the separation bulkhead and leaving a space between.

8.3.7 Connections and fastenings

<u>Bonding</u>

Interlaminar bonds can be defined as the achivements of strong, solid connections between successive FRP layers and can be classified as follows:

1. Primary bonds are those between successive layers of reinforcement laid and cured at the same time.
2. Secondary bonds are those made between a cured laminate and successive lay-up in place.
3. Bonded joints are those between two previously cured laminates by applying new mat and resin which when cured forms a solid connection.

The laminate of the hull, deck, tanks and other assemblies will always be either primary or secondary bonds depending on the size of the moulded unit and the phasing. The bonding-in of the interior mouldings should be secondary bonds and completed during the “gel” stage of the laminate which will be a maximum of 24 hours in a tropical climate. Any bonding area should be as large as possible and designed so that the resin bond is shear. Lapped joints are preferred. In butt and scarph joints the bond is in tension and the joint should be reinforced on one or both sides. Whatever type of joint is chosen, the bonding area should be rendered free from release agent, grease, dust and dirt and then roughened to expose glass fibres. A wipe with acetone will remove fine dust and make the resin tacky once more. Gelcoat should be totally removed.

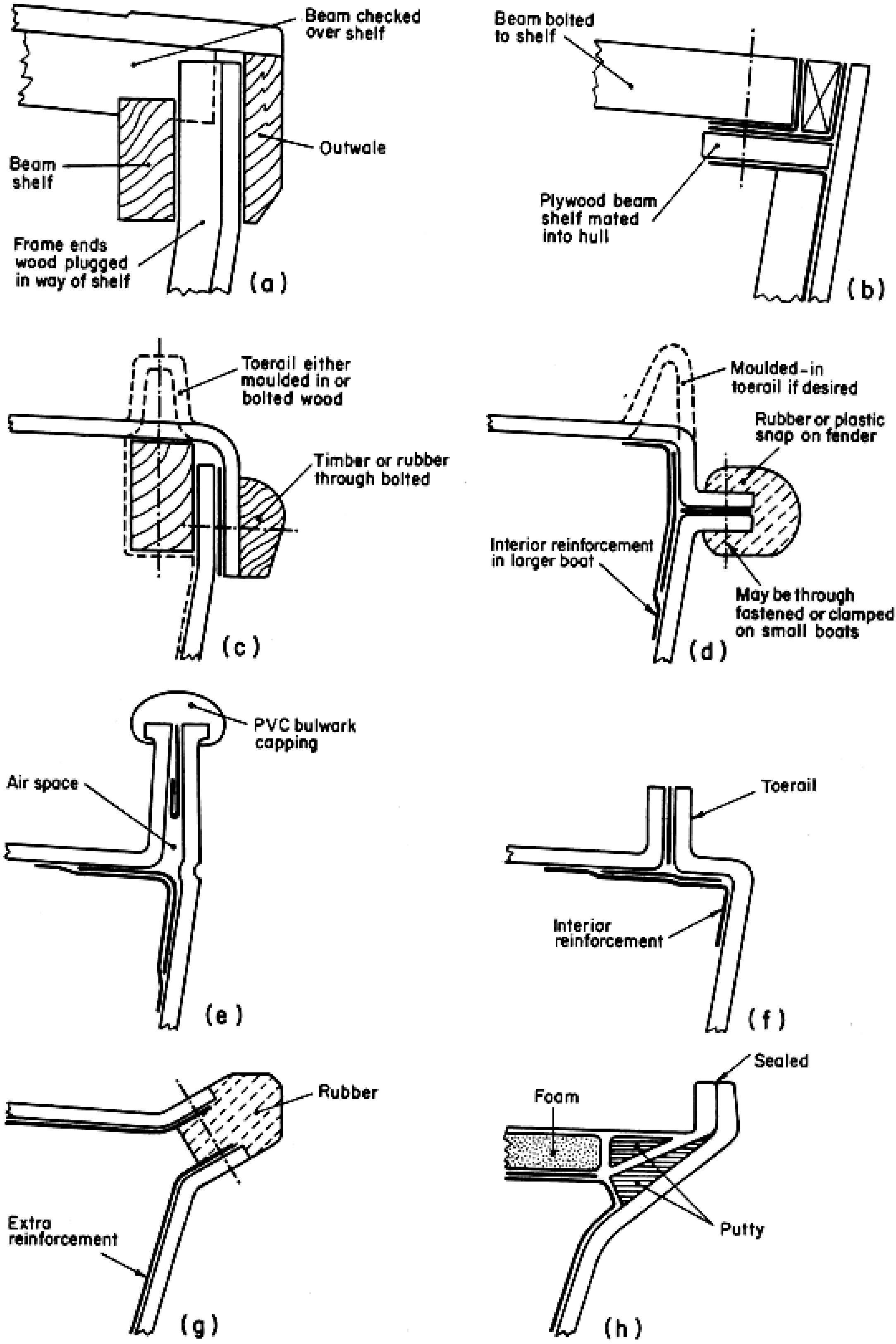


Figure 35 Typical deck to hull connections

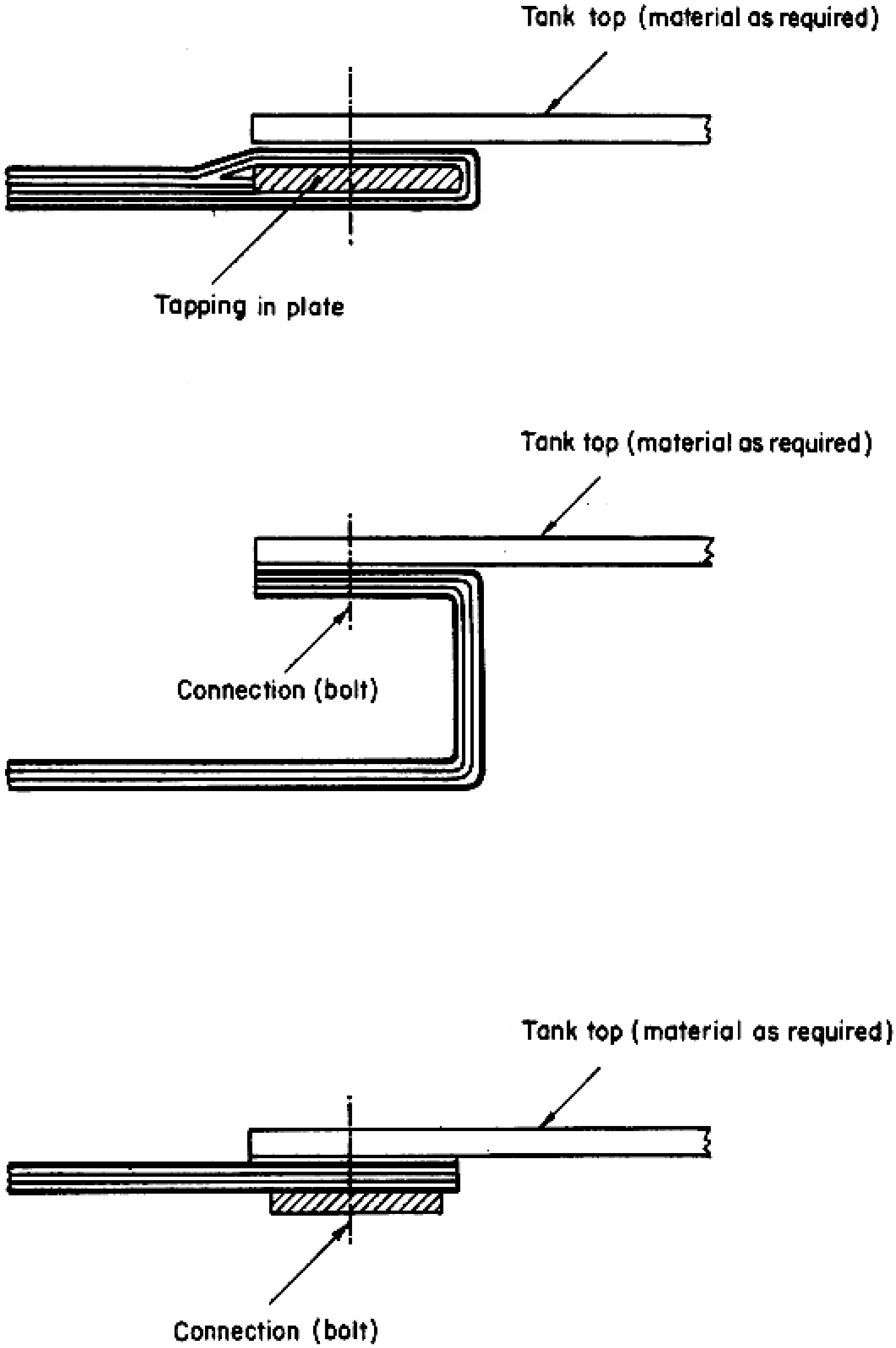


Figure 36 Tank manhole details

Metal Fasteners

Laminates can be satisfactorily fastened with bolts or screws. They should be corrosion resistant or resin coated if made of plain steel. Rivets are sometimes found as the hull to deck connector in very small boats. Bolts should be fitted with large washers under the head and nut but should not be used in a laminate of less than 450 g weight. As a general guide, bolt diameter should be the same as laminate thickness. Self tapping screws may be used if the load is not heavy and machine screws can also be used in a pre-threaded hole. They should have their long axis perpendicular to the reinforcement layers and should never be screwed into the end of a laminate. Not to be used when laminate weight is less than 450g.

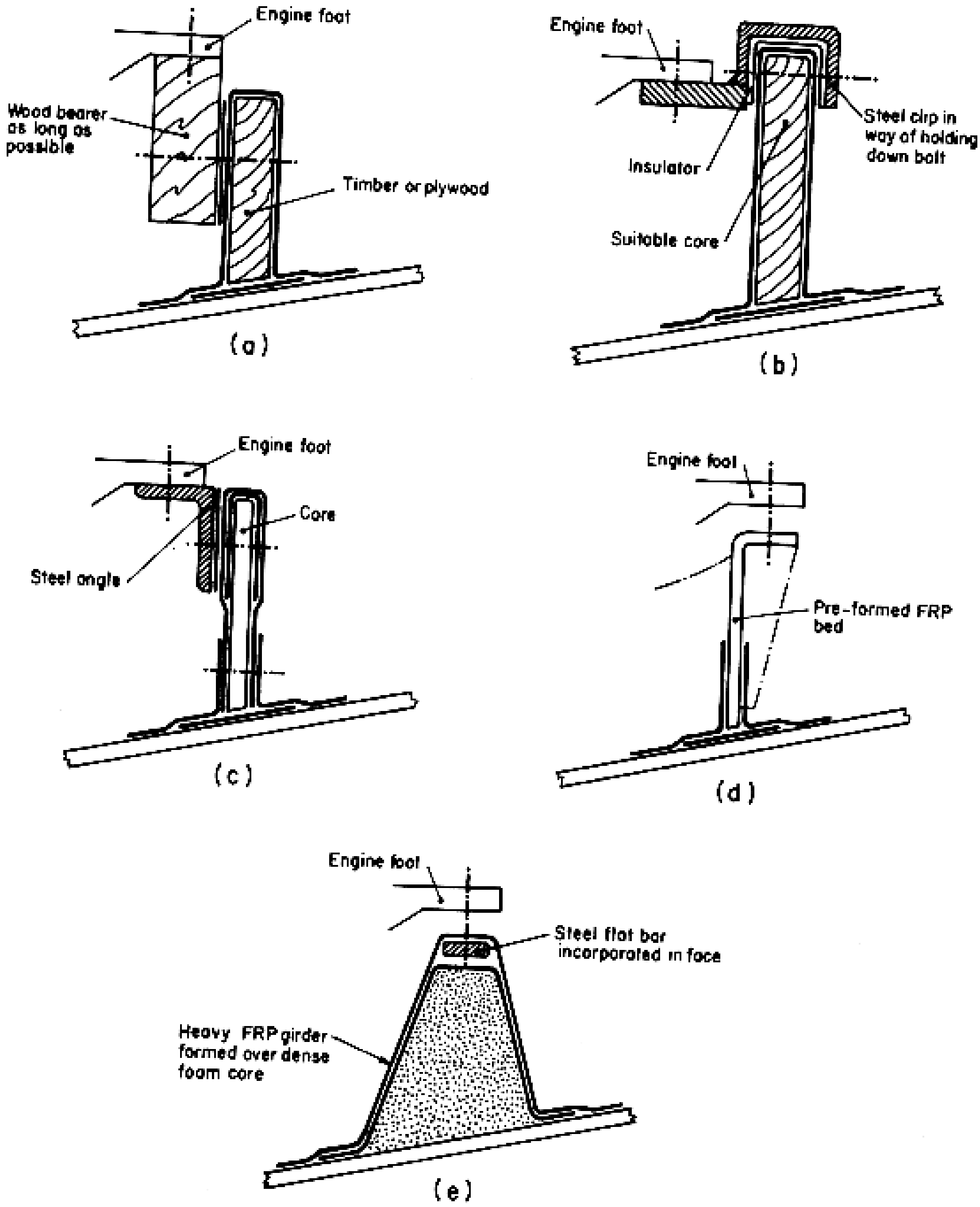


Figure 37 Typical designs of engine bearers

<u>Attachment of Metal Fittings</u>

A metal fitting may be bolted on in the conventional manner or may be bonded on. Through bolting of the hull should be kept to a minimum and avoided where possible. For propellor brackets and other loaded fittings however, it is advisable. The holes should be just sufficient to accept the bolts which should be dipped in catalyzed resin to prevent leaks just before insertion. Copper alloy bolts will inhibit the resin cure. A mastic sealant should be used if the bolts are required to be removed later. Drilled and tapped metal plates can be moulded into the laminate to take heavy loads such as engine holding down bolts. The plates should be bevel edged and have a large area for load spreading. All rust should be removed from steel and keying can be improved by cutting perforations or scoring the surface. Watertightness should be ensured to prevent the formation of any corrosion which could break the resin to metal bond.

Deck fittings such as bollards and cleats should be bedded on a flexible sealing compound. The laminate should be increased by 25% and a wood back up-pad placed on the inside to spread the load. If the deck core is foam or balsa then compression tubes or a solid ply core should be inserted locally to prevent crushing.

8.3.8 Bonding to materials other than FRP

One of the sources of problems in an FRP vessel is delamination and the ingress of water due to material incompatibility, that is the bonding of FRP to materials other than FRP. Polyster resins are not good adhesives and an approach which achieves a good mechanical bond should be employed. That is where the resin has a physical grip or lock on the adjacent material.

Bonding to Wood

Debonding of FRP angles securing structural members such as bulkheads and frames is a common fault. Wood should be roughened, dry, dust free, unpainted and given as big a contact area as possible. Resin thinned with 10% styrene or 5% acetone will allow a keying coat to better penetrate a wood surface than a more thixotropic straight resin. Any wood which has been treated with preservative should not be used, but if unavoidable then a joint using screws or bolts should be substituted. Oily hardwoods such as teak and iroko should be degreased with acetone and the moisture content of all woods checked before use. Delamination through resin contamination or movement caused by wood shrinkage will render the joint useless. Epoxy resin has better adhesive qualities.

Bonding to Metal

Some metals accelerate gelling time, others slow it down. Copper or its alloys are to be avoided unless of small pieces, completely encapsulated and above the waterline. Brass or bronze fittings should receive a coat of epoxy resin before being overlaid with any structural polyester resin. Aluminium and steel are best etch primed before coating. All metals should be degreased before use, even finger marks or sweat from a hand can render the bond inffective. Roughened surfaces provide better keying. It is generally advisable to avoid metal to wet resin joints as a faultless bond can only be achieved under conditions of laboratory cleanliness which are not present in a boatyard. Sooner or later corrosion will appear on the metal fitting and cause delamination and leaks.

Other Materials

Glass, polythene, formica, aluminium and the like will not bond and can be used to mould flat panels of FRP. Cardboard, hardboard, cement, and canvas all have rough porous surfaces and can be expected to give some degree of bonding.

Foams used for cores have been discussed and each treated in its own way. Scored and scrim-backed cores are superior as they provide a grossly keyed surface which is the basis of a mechanical bond.

---

9. DESIGN AND CONSTRUCTION CONSIDERATIONS

9.1 Choosing the Right Design

A wooden or steel boat can accommodate the purchaser's detailed design changes up to a very late stage in construction. An FRP boat cannot. The shape is a faithfull reproduction of a mould which has been designed and usually made long before the purchaser appeared. Production is therefore locked into a single type of vessel, a “Standard Design”.

It is emphasized that a wrongly chosen design, or design with features unsuitable for a tropical environment, would not find buyers and would cause the yard to fail at an early stage. Some research into fishermen's needs would allow a person to select plants to begin from an informed position.

It may be tempting to purchase a licence to copy vessels already in production elsewhere, but fishermen would not be thankful if the design were inappropriate. A design specifically commissioned for the local area combining traditional requirements, appropriate technology for construction and use, which has a regard to the climate and probable lack of maintenance, will take longer to arrange but is more likely to produce acceptable results.

9.2 Choice of Construction Method

Methods for the construction of plugs, moulds and hulls have been described in previous sections and the reader must judge which route is most suitable for local conditions. Factors influencing choice include:

- Yard facilities
- Materials availability
- Labour skills
- Size of vessel
- Number to be produced

In the early stages of the life of an FRP boatyard in a developing country when experience is in short supply, it is advisable to obtain as much technical assistance as possible and begin with a project of manageable size.

Importing moulds and an example of a finished model which has been designed for the local environment is recommended for the start-up of an

FRP boatyard. Subsequent local production initially under the guidance of an accredited expert will ensure well built boats while building up experience. This transfer of technology is vital as it provides the basic “hands on” experience of building boats in a new way and with new materials. A joint venture with an established overseas builder is another method whereby moulds, FRP materials and technology transfer are provided by the foreign company for a longer period on a more stable basis.

9.3 Structural and Design Requirements

It is unlikely that a newly established yard will attempt to introduce a wholly new design until experience has been gained. Even then it is advised that the opinion of a third party be sought to check the hydrodynamic and structural calculations of a new vessel. This procedure is normal in northern countries where Classification Societies are employed to conduct such tasks. A list of recognized societies who undertake this work worldwide is given in Annex 3. In the case of a yard which has been set up with the assistance of an Aid Agency then this on going contact should be used for advice.

Another example of where design understanding may be of use is in the case of foreign built vessel requiring repairs when the laminate schedule information is not available. The construction rules of the original Classification Society may be requested and used to maintain the vessel within class after repair, but if not available the laminate schedule of the Sea Fish Industry Authority (SFIA) UK, should prove adequate and not difficult to follow.

The SFIA recommends that the amount of FRP needed for the skins of hulls of various sizes be based on a SCANTLING NUMERAL obtained as a product of multiplying:

$L \times B \times D$ which are defined as follows:

L: The length shall be measured in metres on a straight line from the fore part of the stem at the top to the aftermost side of the hull shell.

B: The breadth shall be measured in metres at the greatest breadth of the vessel to the outside of the shell moulding.

D: The depth shall be measured in metres at the middle of the length L from the underside of the keel moulding to the top of the shell moulding.

Weight of laminate given in Table 9 is CSM only. However, a WR/CSM laminate can be calculated by substituting some CSM with WR in the ratio of 2:1 by weight/unit area. Alternate layering of CSM/WR MUST be maintained.

For example lets take from Table 9 a Scantling Numeral equal 200. The required shell weight is 5 100 g/m^2 (CSM)

CSM Only Laminate

Layer	
1	300 g/m^2
2	300 g/m^2
3	450 g/m^2
4	450 g/m^2
5	600 g/m^2
6	600 g/m^2
7	600 g/m^2
8	900 g/m^2
9	900 g/m^2
5	100 g/m^2

Totals: 9 layers requiring 9 applications given 5 100 g/m^2

CSM/WR Combination

Layer		CSM Equivalent
1	300 g/m^2 CSM	300 g/m^2
2	300 g/m^2 CSM	300 g/m^2
3	300 g/m^2 CSM}	300 g/m^2
	600 g/m^2 WR}	1 200 g/m^2
4	300 g/m^2 CSM}	300 g/m^2
	600 g/m^2 WR}	1 200 g/m^2
5	300 g/m^2 CSM}	300 g/m^2
	600 g/m^2 WR}	1 200 g/m^2
	3 300 g/m^2	5 100 g/m^2

Totals: 8 layers requiring 5 applications giving 3 300 g/m^2 which is equivalent to the required 5 100 g/m^2 of CSM.

This realizes savings of:

- Reinforcement
- Resin
- Application time

---

10. FRP IN THE TROPICS

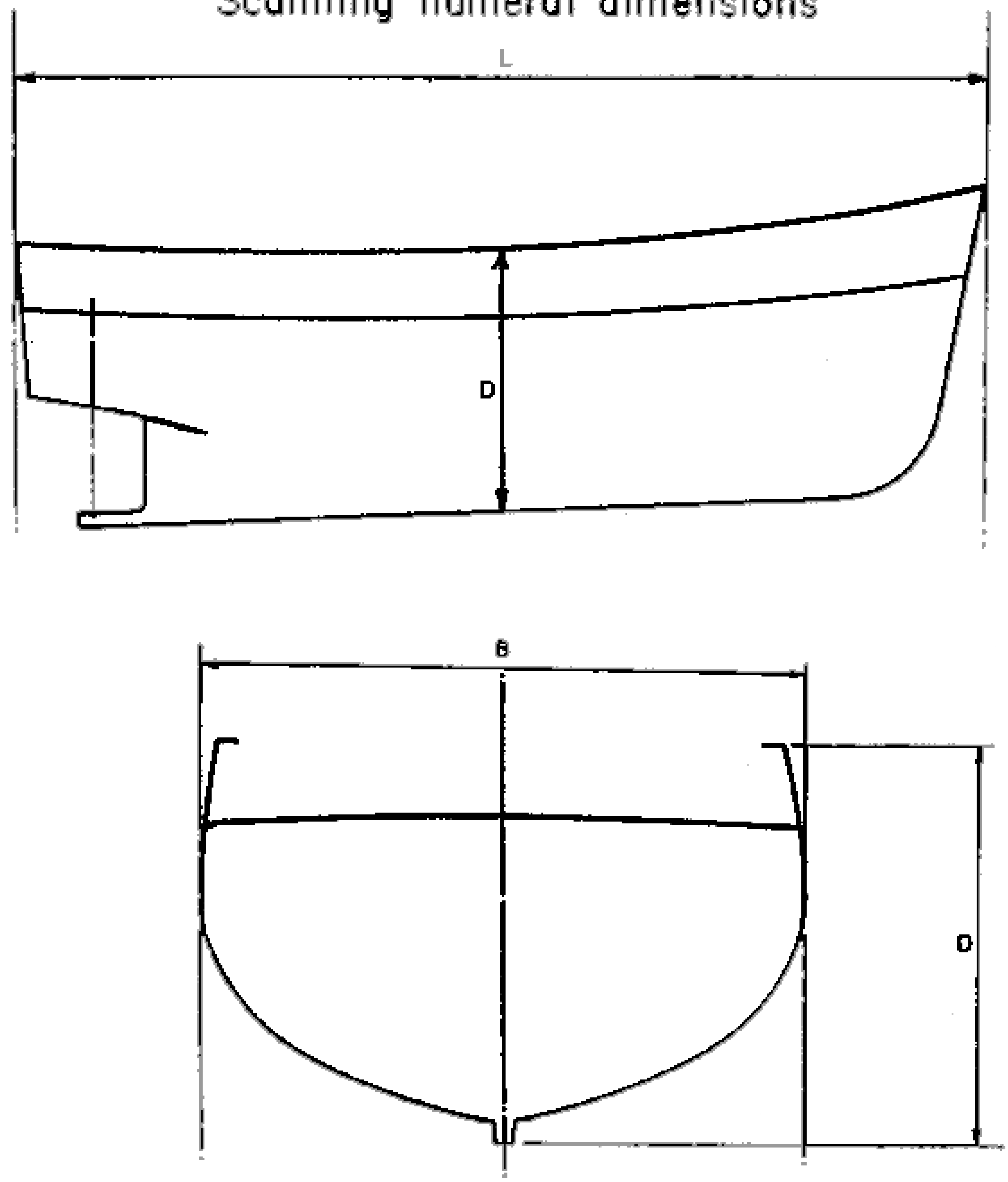
10.1 Heat and Humidity

For FRP to cure some form of heat is needed. This is conventionally achieved by the addition of a catalyst to the accelerated resin. It should be understood that if the resin is treated exactly as instructions for European or North American use dictate, then very short gelling times are likely. This is because the resign is well into its shelf as it has been in transit probably for months and because of the higher ambient temperatures of tropical countries. Each batch of resin should be tested to find an acceptable gelling time by fabricating a test panel typical of laminates in day to day use at the yard.

Table 9

Sea Fish Industry Authority Laminate Schedule

Scantling numeral dimensions



Length L measured in a straight line from fore part of stem at top to aft side of stern/transom

Breadth B the greatest breadth of the vessel outside of the shell moulding

Depth D measured at the middle of length L from underside of keel to top of shell moulding or gunwale

Hull laminate

	HULL	KEEL		SHEER	
SCANTLING NUMERAL	WEIGHT grammes/	WIDTH millimetres	WEIGHT grammes/	WIDTH millimetres	WEIGHT grammes/

	metres²		metres²		metres²
10	3000	400	5400	250	3000
15	3300	450	6000	300	3600
20	3600	450	6000	300	3900
25	3900	480	6300	330	4200
30	3900	520	6600	380	4200
45	4200	560	6900	400	4500
60	4500	620	7200	460	4800
80	4500	660	7500	460	4800
100	4800	680	7800	540	5400
150	4950	700	8100	540	5400
200	5100	720	8100	620	5700
250	5400	760	8400	620	6000
300	5700	840	8700	680	6300
400	5850	840	8700	680	6600
500	6150	920	9300	760	7200
600	6300	920	9300	760	7200
700	6600	920	9300	760	7200

An extreme example of water content/humidity is that of a piece of reinforcement dropped into water which becomes soaked. This piece would obviously be rejected. Yard management should be just as aware of the possibilities of weak laminates if moulding is carried on in conditions of high humidity. Relative humidity of 80% is the maximum recommended level which may be temporarily tolerated and precautions should be taken when 70%–95% is experienced during certain times of the day or seasons of the year. This may mean ventilating or dehumidifying the moulding shop, moulding only during the cooler times of the day or arranging annual production so that moulding work is not undertaken during, for instance, the monsoon season. A hygrometer in the mould shop should be monitored and a record kept of daily humidity levels.

10.2 Appropriate Technology

In a developing country it is rare to have regular access to foreign currency for the purchase of imports. As boatbuilding in FRP would be dependent on imported raw materials and in the beginning an inexperienced workforce, it makes sense to keep imports down and technology at an appropriate level. That is, to be self reliant and do without complicated equipment which may need many spare parts. Materials described so far have been basic but still demand substantial technological appreciation and a technology jump when compared to traditional wooden boatbuilding. A labour intensive approach is appropriate with overmanning compensating for any lack in productivity.

Simple tools are adequate for the main part, with some specialized containers required for dispensing catalyst and other imported hand tools for spreading resin during the laminating process. These are not expensive nor do they need maintenance beyond cleaning.

When the laminating process is complete hulls and decks are released from the moulds and require fitting out as do traditional vessels. At this stage traditional carpentry skills will be needed as cutting and drilling FRP is similar to wood. It is now that a source of electricity will be useful for fixed and hand power tools.

It is a common error to be over-impressed by a new hull being released from a mould and believing that the vessel is almost finished. This is far from reality and traditional boatbuilding requirements during the fitting out stage should not be underestimated when switching to FRP construction. In some boatyards in northern countries FRP hull shell costs for larger vessels are considered as low as 10% of total costs which emphasizes the amount of work needed to convert an FRP moulding into a completed vessel.

10.3 The Workforce, Skill Levels and Training

The setting up of a new FRP boatyard in a developing country will probably be at the request of a government department who foresees the need for an alternative source of vessels. Once external expertise has advised on outline planning of site, choice of vessel, market analysis, etc., construction or extension of the boatyard should take place as design selection and tooling-up for production. Assuming some external expertise has been present to guide the development of the FRP boatyard, towards the end of this phase the point will arrive where staffing and managing the yard will have to be addressed. It is usual in these circumstances to recruit carpenters or boatbuilders as their work experience is probably the most relevant to FRP construction. It is also usual that early on in the life of the yard a natural division of labour takes place where the more skilled carpenters concentrate on the fitting out and woodworking aspects of construction while the less experienced become full time laminators. There is also a tendency for older workers who are used to relatively clean woodworking to decline to use the strong smelling and messy FRP materials. For a yard employing a shopfloor staff of about 30 people, which will include 2–4 charge hands or section leaders, the management structure may contain an overall general manager, a secretary/clerk, an accountant and a foreman.

Management skills will not be discussed here but the Manager in overall charge should have an awareness of his product at the outset and would benefit from exposure to FRP construction which may require secondment to a boatyard abroad. Likewise the foreman must be thoroughly trained in all technical aspects of FRP construction which will require a longer period of training either abroad or under the guidance of an acknowledged expert at the new boatyard. This technology transfer is most important. The “know how” required for the day to day running of an FRP boatyard is a valuable asset but can be wiped out with serious consequences for the yard if the technicians are insufficiently trained or if the knowledge is concentrated in one person who may return, for example, to his village at a moment's notice. The training effort should be concentrated on the practical use of FRP with “hands-on” experience gained by the trainee laminator before he is allowed to work on a real boat. Carpenters and mechanics can be expected to fit out a hull in a conventional manner once some wood has been attached to the moulding.

11. MAINTENANCE AND REPAIR

11.1 Arrangements and Obligations

Before techniques are considered, the question of logistical support and obligations should be addressed. If the new FRP boatyard is the only one in the country and particularly if it is set up using scarce government resources, then it will have an obligation to look after the national interest and investment by taking on FRP repair work no matter how difficult or distant from the yard.

It takes considerable courage on the part of an owner to spend borrowed money on a vessel built of an unfamiliar material. He deserves to be supported by the national repair facility even if considerable effort is needed. In the case of a small boat this will not prove too difficult, but if a 15 m vessel is hauled and immobilized 150 km away, then these obligations need to be addressed seriously.

Figure 38 Hauling out a fishing vessel

Small vessels can be considered as those which can be manouvered by a reasonable amount of manual force into a position in which they can be repaired. These include canoes, outboard powered boats and others which are brought ashore daily. Repair work on the beach is not unusual but vessels which have been severely damaged and require much repair are preferably moved to the yard where a more comprehensive range of skills and equipment will be available. In a remote location it is unlikely that there will be any source of electrical power so all work will be manual. If a large vessel has to be repaired at a distant village then a small team may have to live and work at that village for several weeks. Logistics should not be underestimated but neither should the owner be exploited by any monopoly held by the yard.

Once a survey has been carried out and a price has been agreed between owner and repairer, then the work can begin. The boat should be manouvered into a position away from the water and arranged so that good working access is available. Shade will keep temperatures reasonable for both men and materials. The environment should be as clean, tidy and dry as possible and kept so.

11.2 <u>Maintenance</u>

Maintaining the skin of an FRP vessel in good condition means keeping the surface gelcoat sound so that it protects the reinforcement layers below. “Maintenance free” is often seen in advertising FRP products and this is true within limits. An FRP boat left unused and unattended for a number of years will remain unchanged except for some dulling of the gelcoat shine which may be restored by polishing. Depending on the type of gelcoat and colour pigment used an otherwise sound gelcoat may require spray painting when polishing no longer restores a shine. Further than this, regular checking for damage due to abrasion, impact damage, or attack from fuels or chemicals is all that is required. Anti-fouling paint is applied in a similar to wooden boats but new boats may need de-waxing and etch priming. Burners should not be used to remove old paint and any scraping must not damage gelcoats.

11.3 <u>Gelcoat Repairs</u>

Repairs to FRP vessels all have in common the necessity of removing old, damaged material back to areas of sound FRP to which a bond can be made. Beginning at the outside of the vessel, the gelcoat can have the following faults, most of which can be repaired simply by sanding back the gelcoat and painting new on.

WRINKLING this is caused by the heat released by the following laminate immediately attacking an undercured thin gelcoat (Figure 39).

PINHOLING small air bubbles trapped during the cure show up on release (Figure 40).

POOR ADHESION occurs when a gelcoat is left unreinforced for too long. A weekend is long enough (Figure 41).

SPOTTING all over the gelcoat layer small spots will indicate poor mixing of one of the components.

STRIATIONS indicate inadequate mixing of the colour pigment.

FIBRE PATTERNS if the gelcoat is thin or the reinforcement is applied before the gelcoat is sufficiently cured the roving pattern may “print through” and be visible in the gelcoat when the hull is released (Figure 42).

FISH EYES caused by the gelcoat “de-wetting” from the polished mould surface in spots. Occurs mainly when silicone based waxes are used. These, in particular car waxes, should be avoided (Figure 43).

BLISTERS an indication of delamnation between layers on older vessels. Of various causes and potentially the most serious of problems (Figure 44).

CRAZING usually indicates a gelcoat which is too thick and has crazed during flexing of the hull (Figure 45).

STAR CRACKING once again due to an overthick gelcoat but this time it must have received an impact from the inside (Figure 46).

INTERNAL DRY PATCHES areas where resin has not penetrated (Figure 47).

LEACHING a serious fault. Severe weathering can remove a poor resin from surface of a laminate (Figure 48).

YELLOWING discoloration of clear or light gelcoats.

It is apparent fro this list that great care must be taken in the formulation and application of the gelcoat and that it is the barrier between the environment and the structural laminate of the hull and not simply the shiny coloured surface of mouldings. Wearing away of the gelcoat is caused by abrasion. This occurs when materials harder than cured polyester consistently rub on the same area. This may be the anchor chain or heavy gear being hauled over the side of a fishing boat. It does not take long to scratch the thin gelcoat below which the laminate will be revealed. At this point, particularly if the damage is below the waterline, corrective action should be taken as descpite FRP being a plastic material, water can slowly penetrate the laminate and render it “rotten” by seeping along pathways created by the fibres of the reinforcement. A correctly designed vessel should have adequate protection in areas where abrasion can be predicted but problems can occur when a boat is inexpertly converted from one fishing method to another.

11.4 Repairs to FRP Structures

Accidental damage is relatively easy to repair by the hand lay-up or contact moulding methods. If the vessel is locally built then the technicians performing the repair can be expected to be familiar with its construction and be able to put back the rquired reinforcement. If the vessel is imported and unique to the country, then samples may have to be cut out to ascertain exactly what the hull is made of. A sample is taken by drilling with a hole saw and burned to remove the cured resin to reveal the reinforcement it contains. If it is found to contain a core such as balsa, then a suitable replacement must be found. In an emergency, a solid laminate can be used but would be heavier and more expensive.

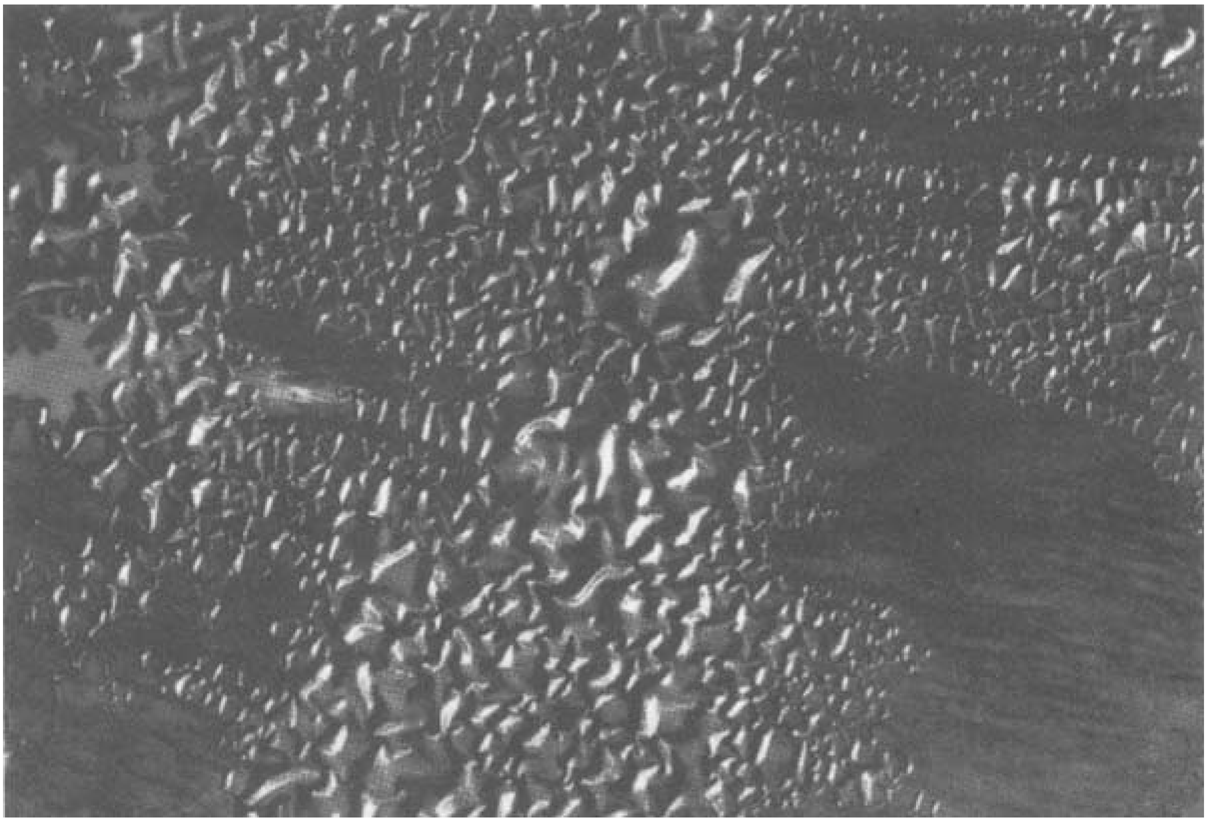


Figure 39 Gelcoat fault - wrinkling

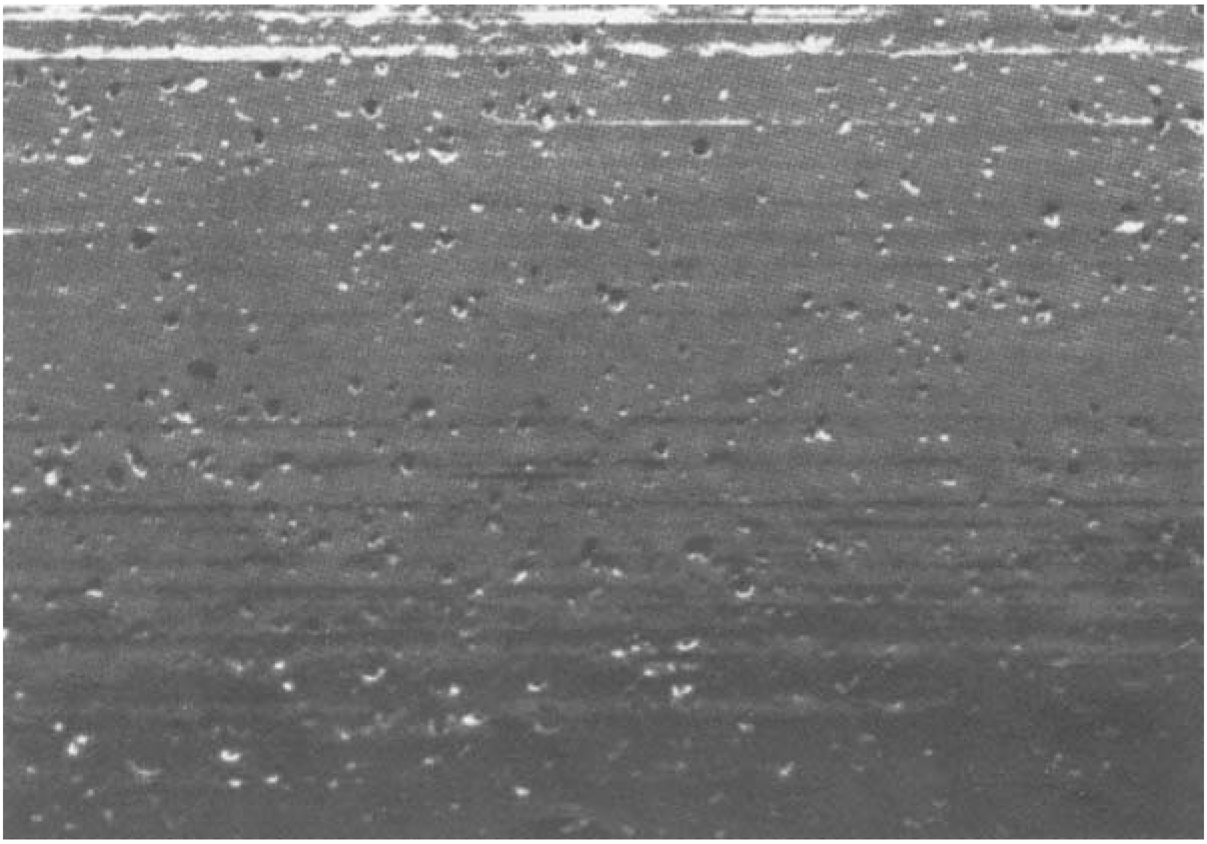


Figure 40 Gelcoat fault - pinholing

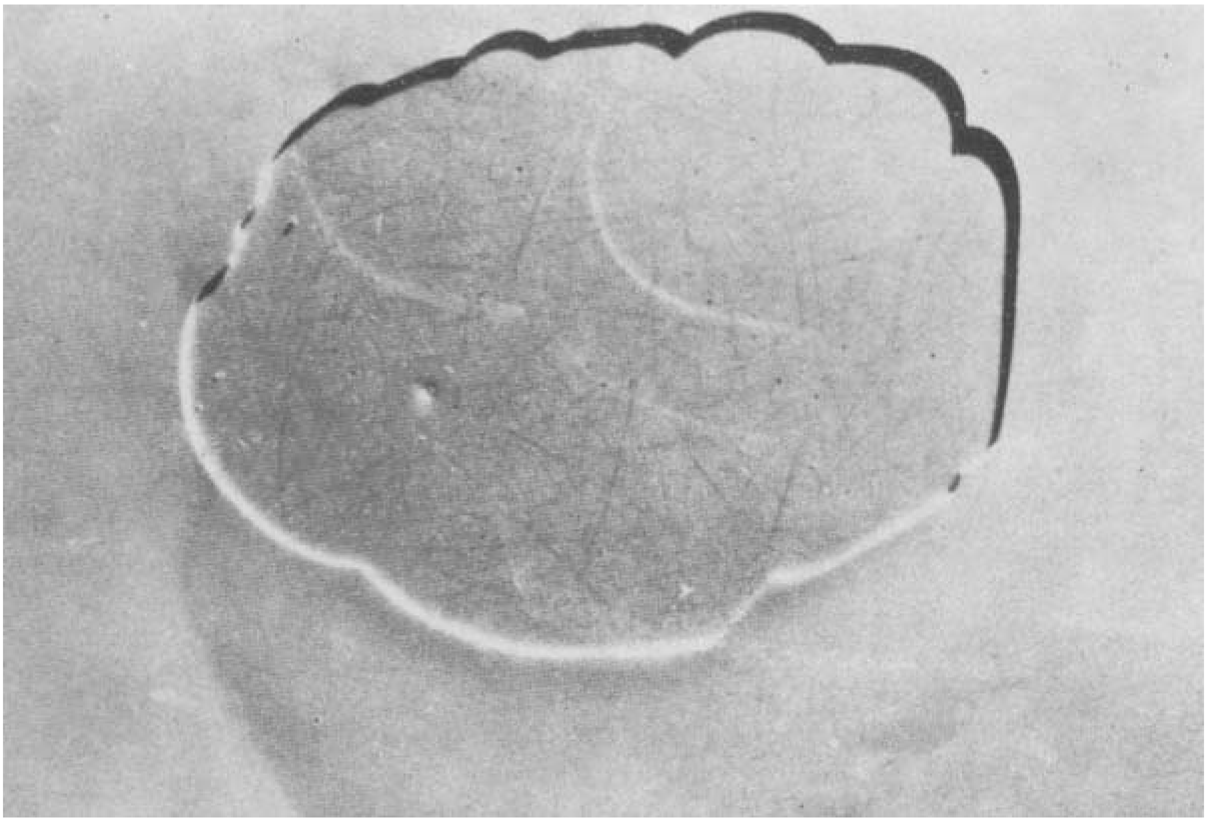


Figure 41 Gelcoat fault - poor adhesion

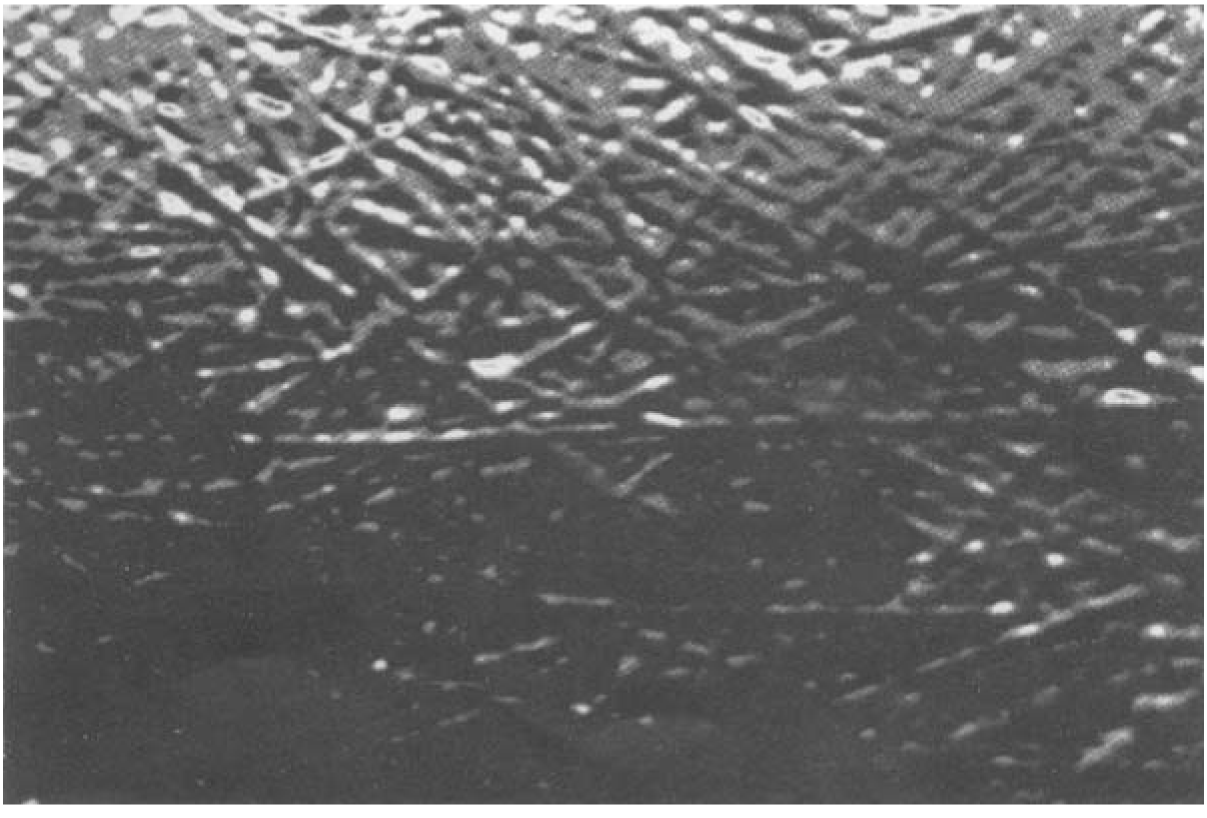


Figure 42 Gelcoat fault - fibre patterns

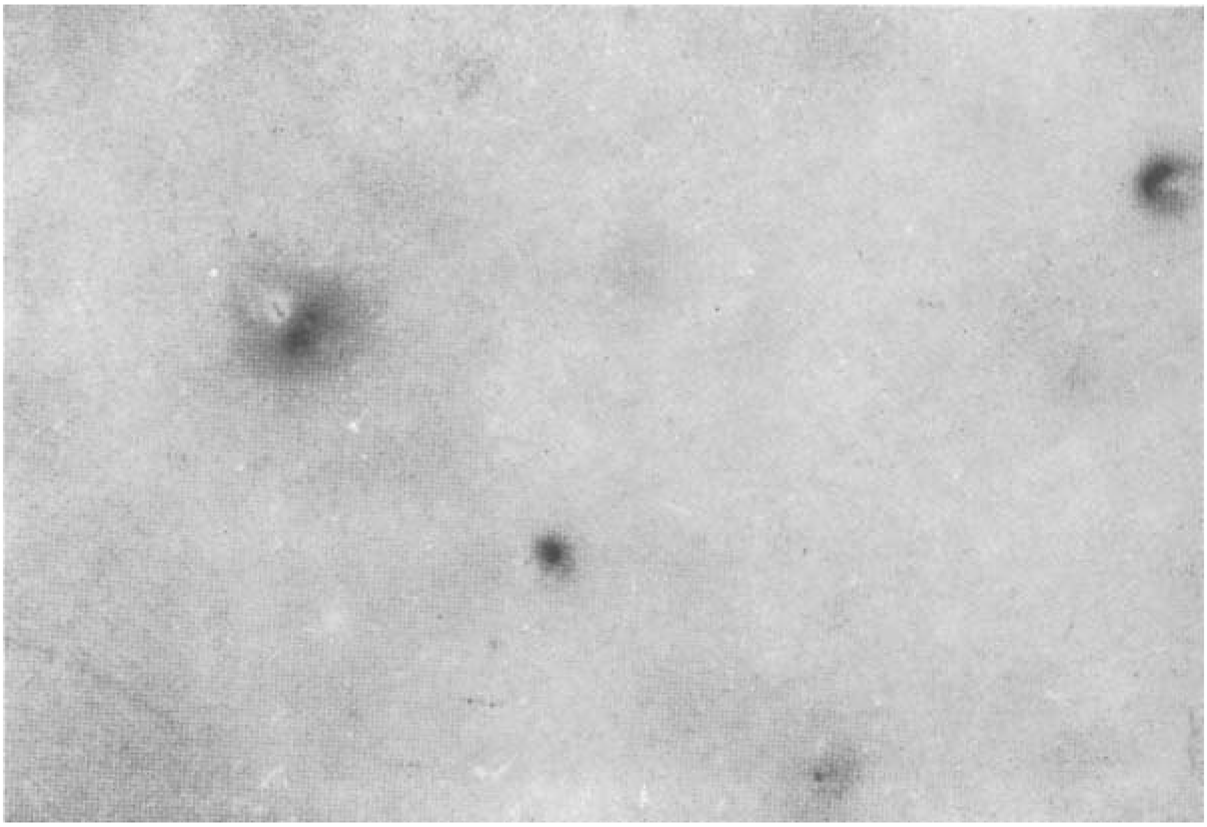


Figure 43 Gelcoat fault - fish eyes

Figure 44 Gelcoat fault - blisters

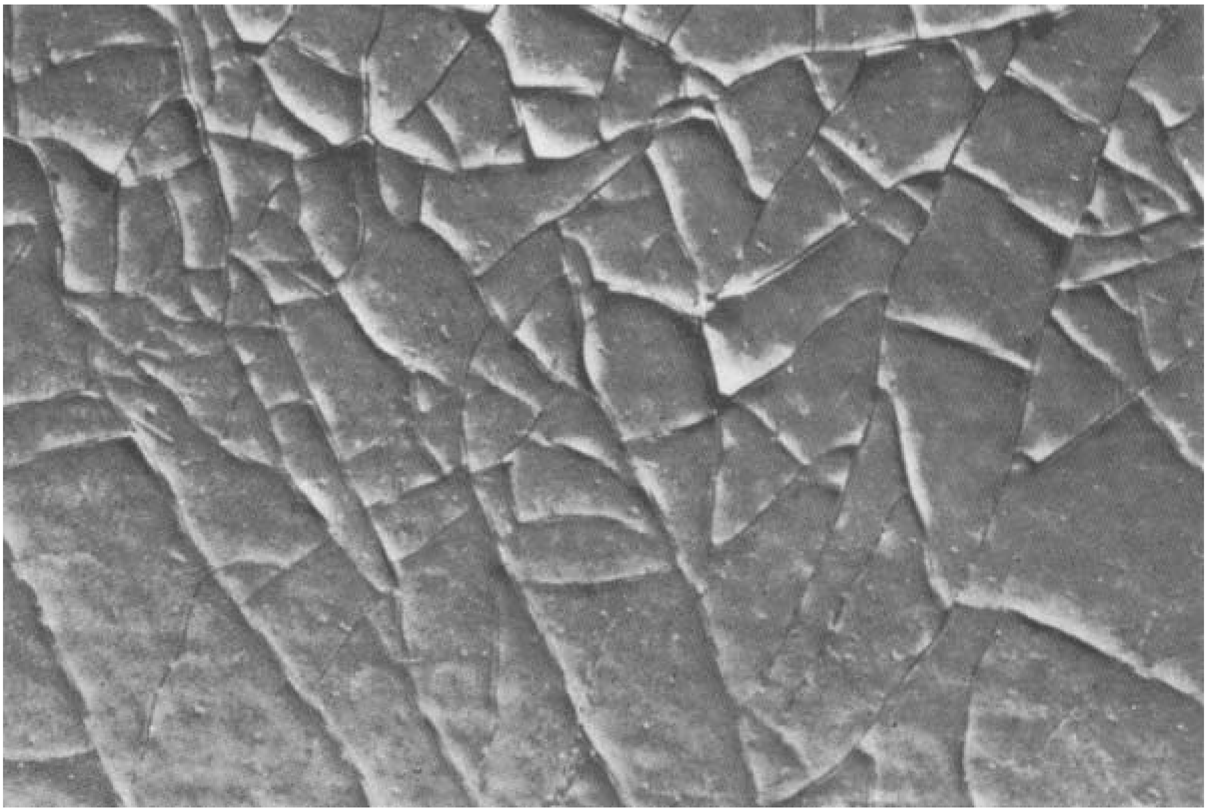


Figure 45 Gelcoat fault - crazing

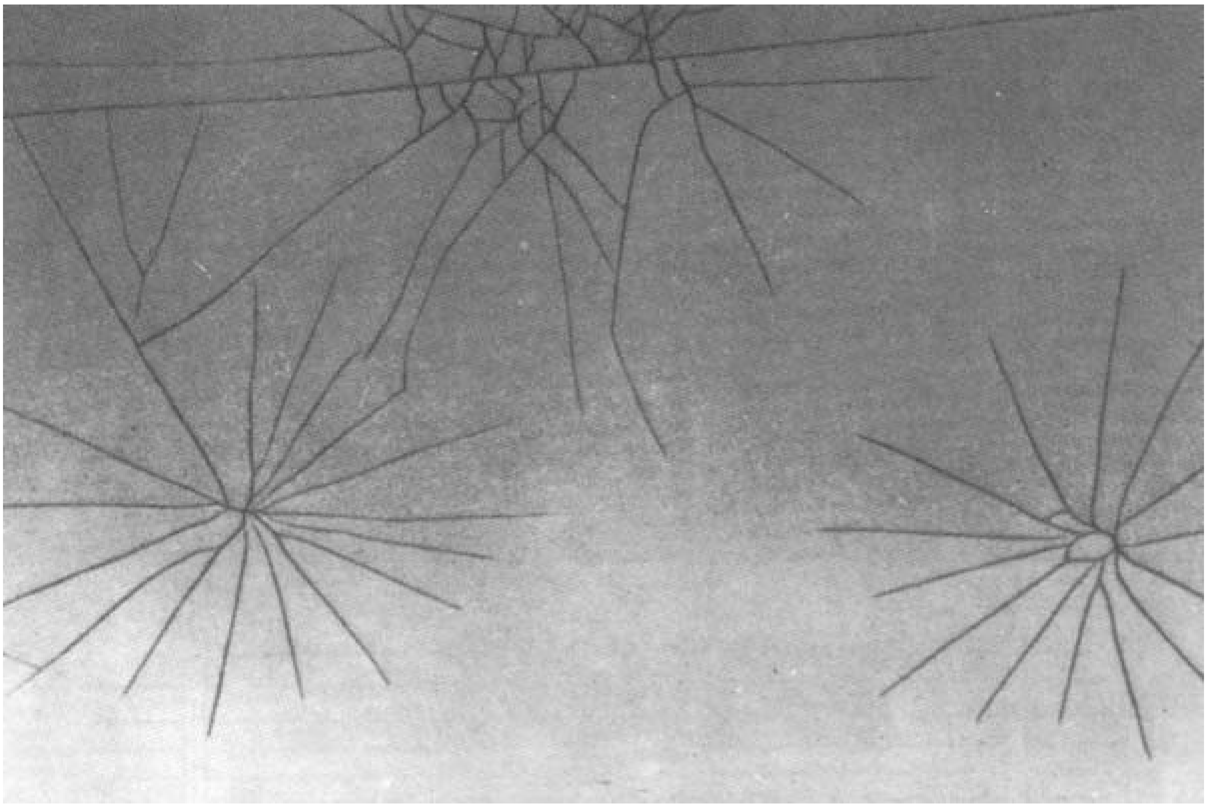


Figure 46 Gelcoat fault - star cracking

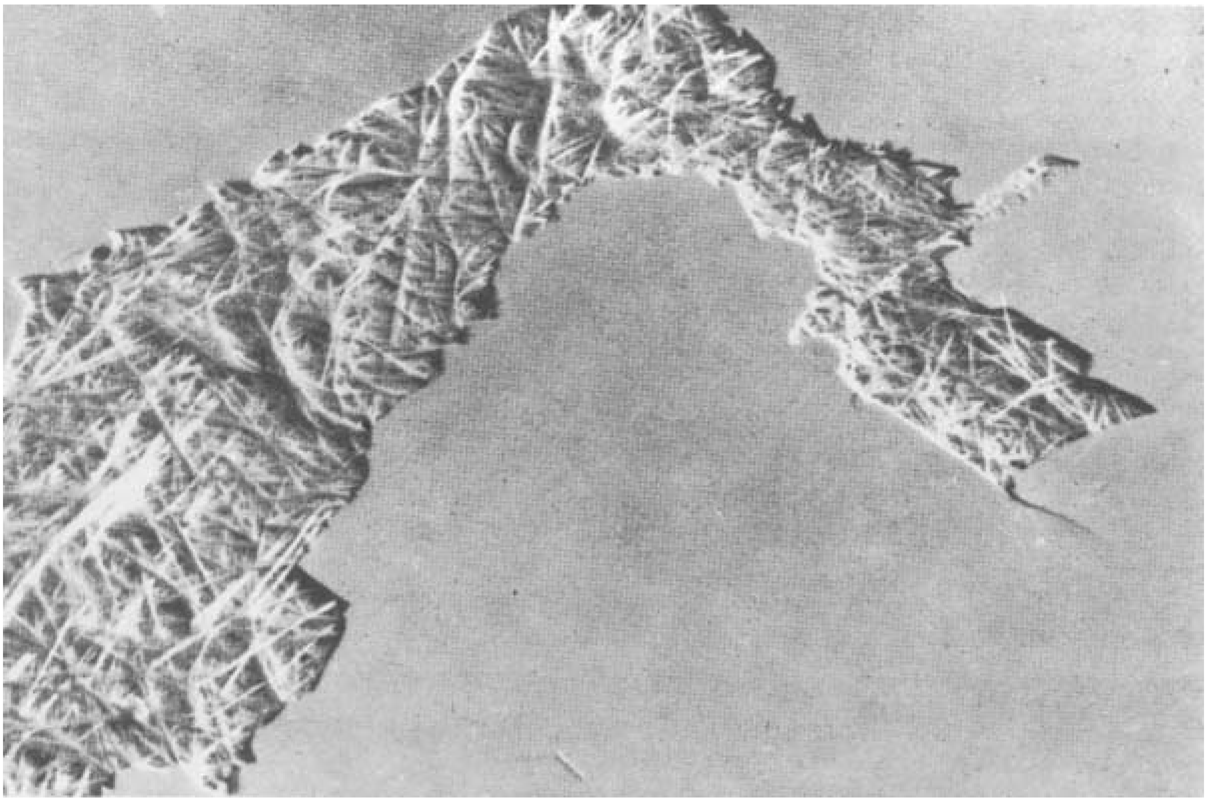


Figure 47 Gelcoat fault - internal dry patches

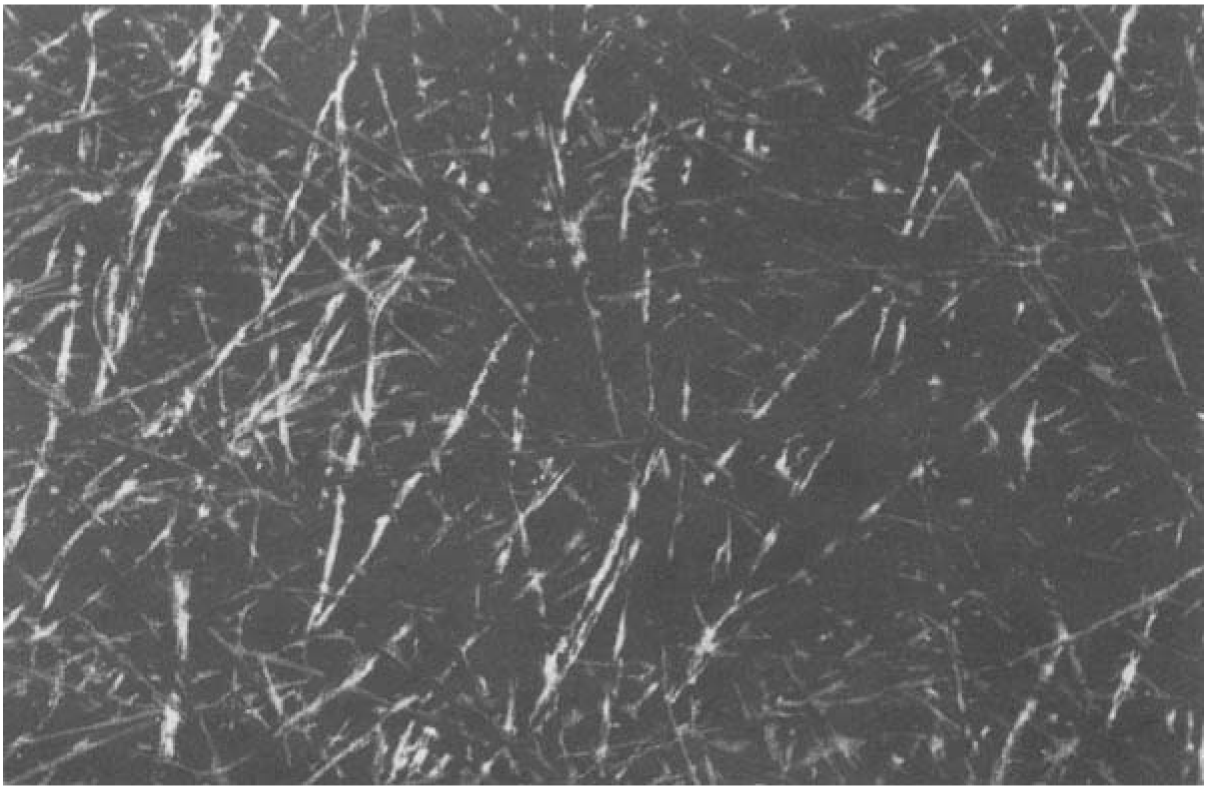


Figure 48 Gelcoat fault - leaching

Some typical damages of vessel hulls are shown in Figures 52, 53, 54 and 55.

11.4.1 Tools

Hacksaw, chisel, file, mallet, grinder/sander, wet-and-dry paper, wax and polishing cloth, plastic sheeting, plastic bucket and small mixing containers, laminating brushes, sharp knife, tape measure, paint scraper, acetone, catalyst measuring bottle.

11.4.2 Procedures

Impact Fractures

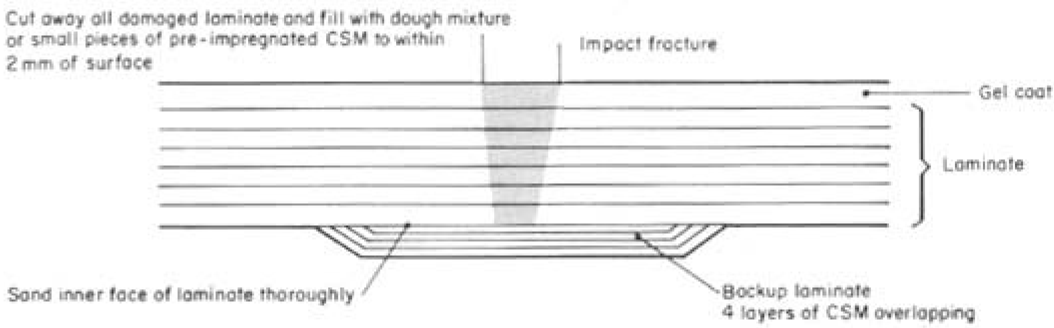


Figure 49 Repair technique for impact fracture

These appear as a crack which may extend as far as the reverse side of the laminate.

1. The fracture should be enlarged from the surface of the impact into a V-shaped groove, ensuring that all the damaged area is removed to the full depth of the crack. It may be necessary to penetrate the slot fully.
2. Abrade the back surface of the original laminate for about 75 mm in all directions from the slot and remove loose material.
3. Cut four strips of CSM each 20 mm larger than the previous. The smallest should be 20 mm larger then the repair.
4. Prepare resin 2.5 × weight of CSM.
5. Apply resin and CSM to the back of the repair area starting with the smallest piece. Caution not to push the CSM through the slot when consolidating. Allow to cure.
6. From the gelcoat side fill the slot with overlapping strips of CSM to just below gelcoat level. Allow to cure.
7. Sand smooth and fill with pigmented gelcoat. Sand and polish smooth when cured.

Holes (Access to Both Sides)

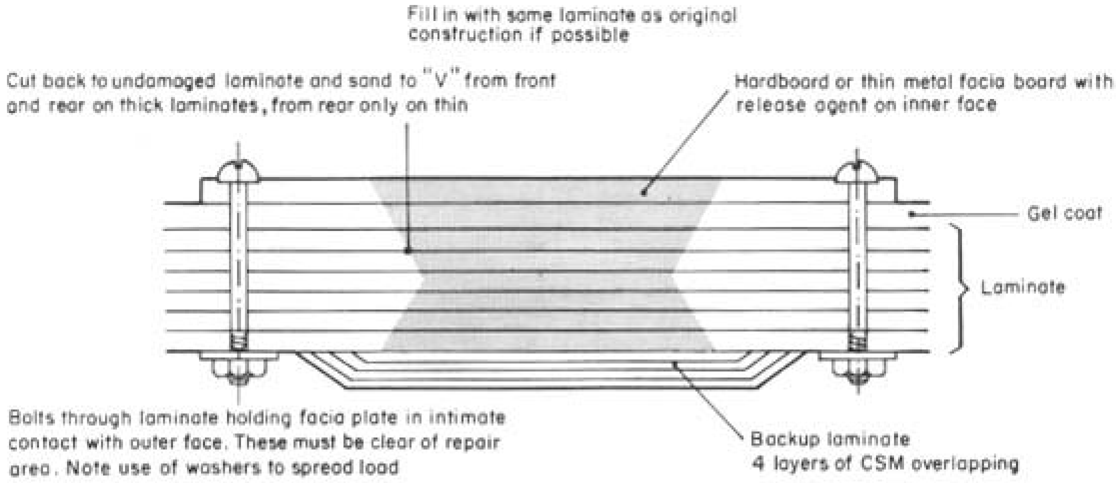


Figure 50 Repair technique for punctures

1. All jagged edges and damaged laminate must be cut out to leave a clear hole in sound FRP.
2. Edges must be filed down to form a wedge with the fine edge towards the outside. The interior surrounding area is sanded down and dust, grease and damp removed.
3. Reinforcement equal to the original laminate is cut to shape and layered and the correct weight of resin is prepared. Further layers are prepared to cover the patch and surrounding sanded area on the inside.
4. The essence of obtaining a good repair is to arrange a smooth surface flush with the gelcoat on which to work. For small repairs a piece of formica, aluminium, hardboard as well as a thin laminate offcut can be used and secured firmly to the gelcoat side of the repair with self tapping screws. For larger holes the curvature of the hull complicates the process and may require a facia board or "splash" to be moulded from an identical vessel to achieve a compound curved surface which will fit the repair area exactly. The facia board, no matter what size, must fit exactly over the edges of the repair area with no gaps. Fastener spacing should suit the application and for large holes with a heavy FRP facia board bolts may need to be used. If the required area of a sister vessel is not available because of a skin fitting for example, then an area immediately adjacent might be used to lift a splash which, with a little persuading, can be fastened flush with the hole. This is possible as hull shape usually changes only gradually along the length of the hull. The opposite side of the same vessel cannot be used.
5. Before fixing over the hole the facia board should be well waxed. If PVA release agent is used also to aid release of the facia board after the repair is complete, then care should be taken that it does not contaminate any prepared surface to which a strong bond is to be made.
6. The repair is then continued as if a hull were being laid up in a mould, which is what the facia board is providing. The join line on

the inside should be overlaid as in the previous repair once the board and any fastenings are removed.
7. If the board was tightly fastened around the join line little gelcoat repair will be required. Any remaining gelcoat imperfections and fastening holes should be hand finished and polished.

Repairs to Blind Panels (One Side Access)

In some cases it will be impossible to reach the reverse side of a laminate.

1. The hole should be cut out as before and the blind (unseen) side cleaned and sanded as much as possible by reaching through the hole. The edges are beveled with the fine edge innermost.
2. THE NEXT 3 STAGES REQUIRE GOOG TIMING. A small laminate the size of the sanded surrounding area is prepared comprising of two layers of light CSM and no gelcoat. A third piece of light CSM is prepared but not used at this stage.
3. At the gel stage the double layer is released from its formica sheet mould and with some speed, the third previously prepared piece of CSM is applied to the double layer's rough side with an over-catalysed or “hot mix”. A screw or wire is then inserted side to form a grip or handle protruding through the rougher wet side. WORK FAST!
4. Utilizing the flexibility of the double layer at its gel stage, it is slightly folded and pushed through the smaller hole. When it springs back into shape, the screw or wire handle is used to hold it against the inaccessible sanded area until the hot mix is cured and the patch adheres to the inside face. Grip can then be released (Figures 24–25).
5. The screw is then removed or sawn flush or the wire withdrawn or clipped and the repair continued as previously described. This method requires that the accessible side receive heavier overlaying than simpler methods.
6. Where the hole is larger, the laminate very heavy and the panel has little curvature, the method illustrated above may be used. In this case a rectangular hole is cut and a ply pad used instead of the thin flexible CSM panel. It can be only very slightly larger than the hole as it must pass through diagonally.

11.5 Osmosis

FRP vessels have a lifespan proportional to the amount of care and attention that is given to them. However, a recent development in some older FRP vessels is the blistering of under water gelcoat surfaces. This is referred to as osmosis.

No gelcoat is entirely waterproof and it is possible for water to collect in small air bubbles which are formed during the moulding process. Water in contact with soluble substances in the gelcoat forms an acidic solution and an osmotic process then attracts seawater through the outer gelcoat membrane which leads to a blister on the hull surface. Water can also be drawn down glass strands which are too close to the surface also causing blisters as does a gelcoat which has been over mixed and aerated before application to the mould. Both of these can be confused with osmosis. To remove any offending gelcoat requires either grit or slurry blasting the underwater surfaces. A solventless epoxy paint should then be applied in its place. Use of an Iso-NPG resin gelcoat (Isophthalic neopentyl glycol) during original manufacture should prevent osmosis.

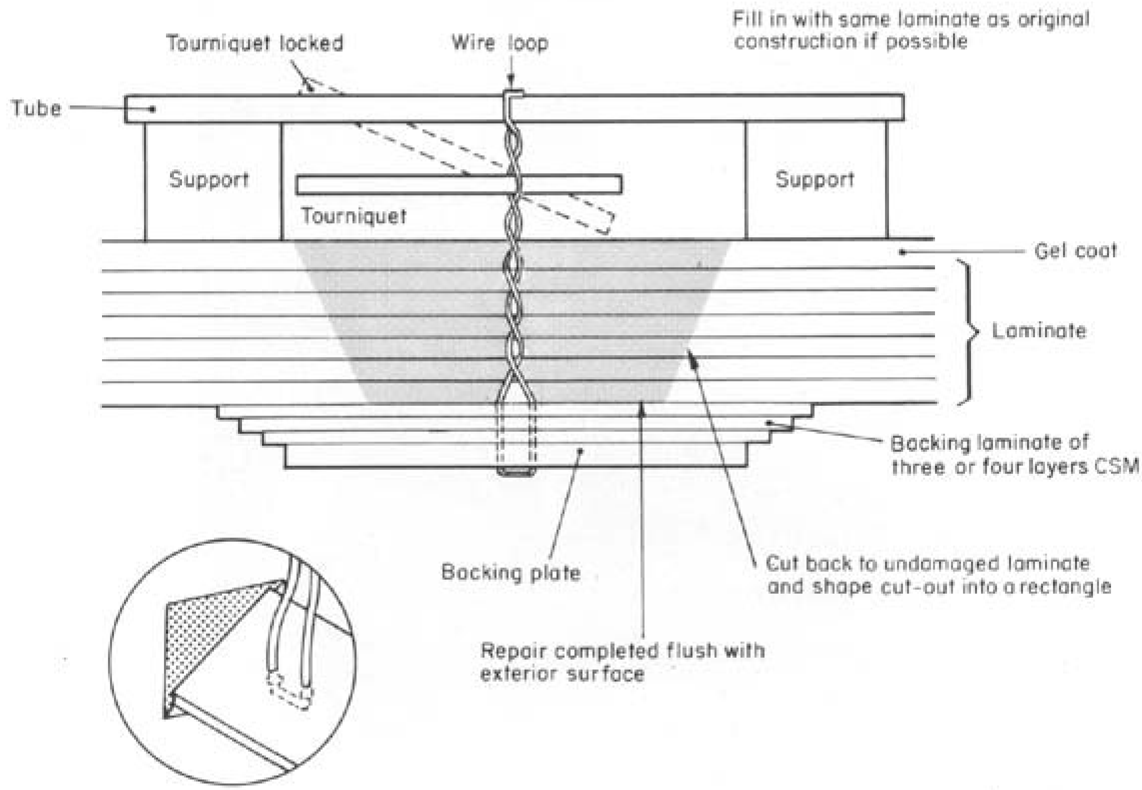


Figure 51 Repair technique for blind panels

Figure 52 Hole due to grounding on anchor

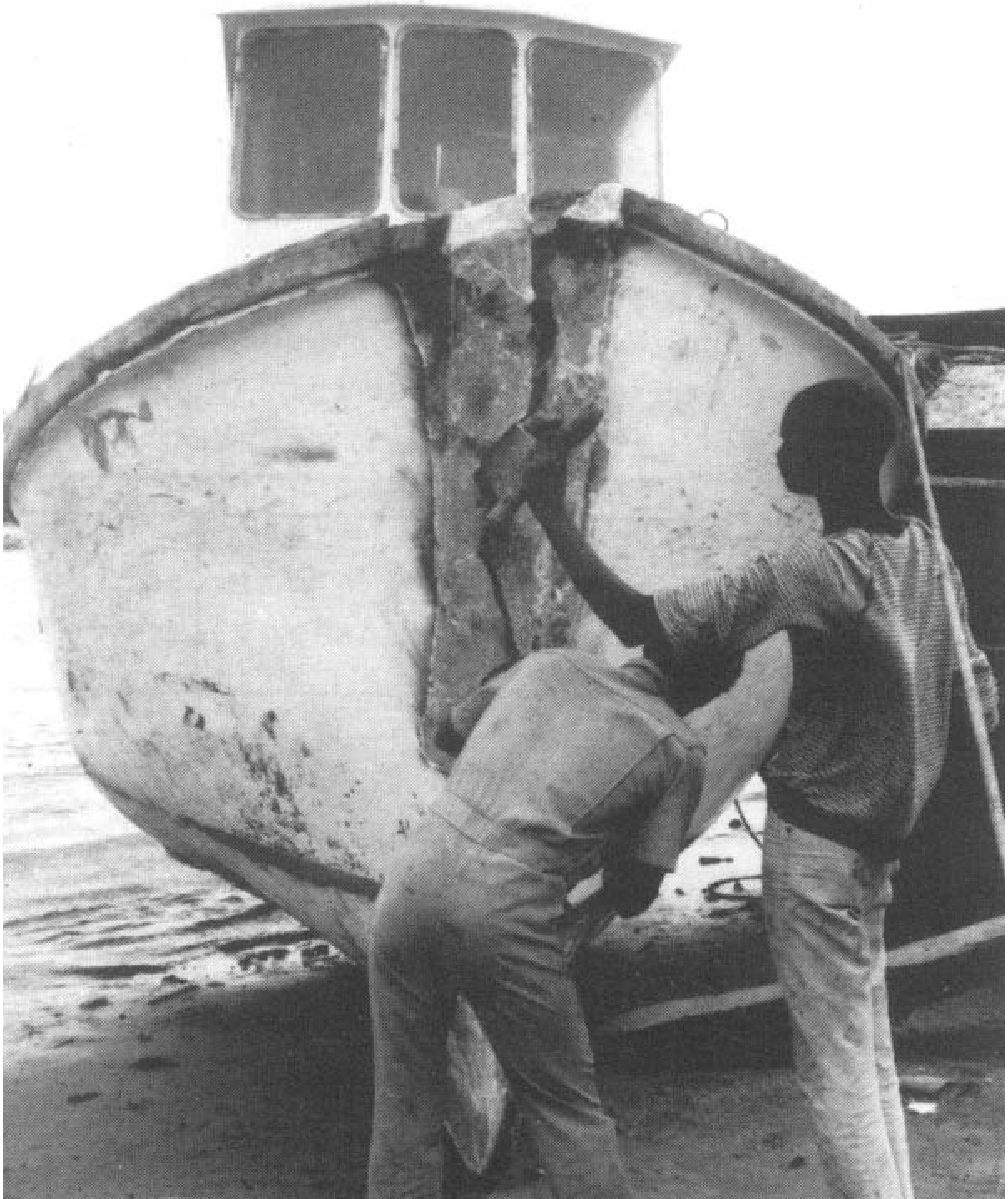


Figure 53 Collision damage to bow

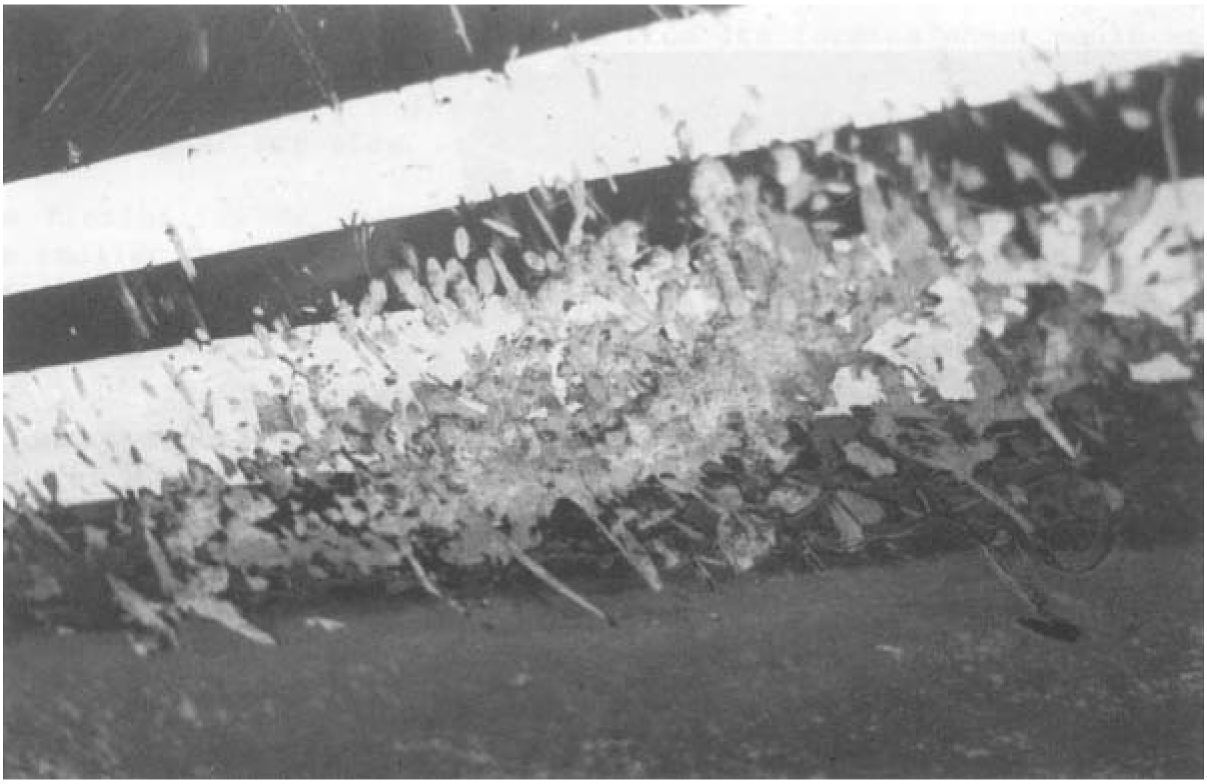


Figure 54 Abrasion damage to gelcoat and laminate

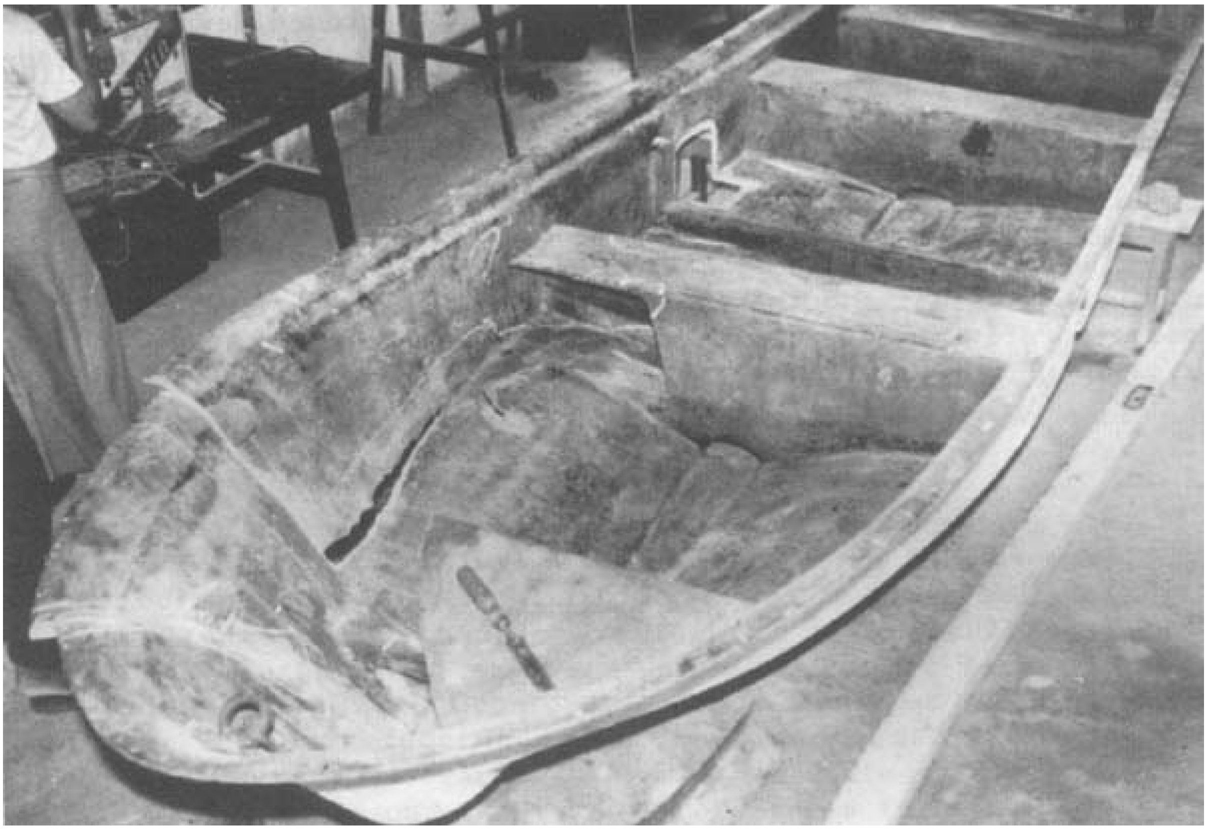


Figure 55 Severe impact damage to side

11.6 Lifespan of FRP

Twenty years is often quoted as the lifespan of an FRP vessel. However, there are many vessels older than this still very sound and in service. It is also obvious that an FRP pleasure boat which is well maintained and rarely used will have a longer service life than an FRP trawler in daily use and repaired only when something breaks. The fact is that an FRP trawler is more likely to become worn out through rough handling, lack of maintenance and breakages than any sudden structural failure of the hull laminate after a fixed period of time.

11.7 Sheathing of Old Wooden Vessels

It is tempting to sheath an old, planked wooden boat in FRP to stop persistent leaks, prevent rot or extend its life but this is generally not recommended. In this form and condition the many pieces of wood which make up the hull have varying moisture contents both from the inside to the outside and particularly from deck level to keel. A sheathed hull may appear an improvement when first coated but it is only a matter of time before it begins to del aminate. Rot can be accelerated by the sealing in of moisture.

---

12. PLANNING FOR CONSTRUCTION

12.1 General

Planning for construction requires to know:

- What you are going to build
- How many units
- Who is going to buy them
- How much it will cost
- Where the materials will come from

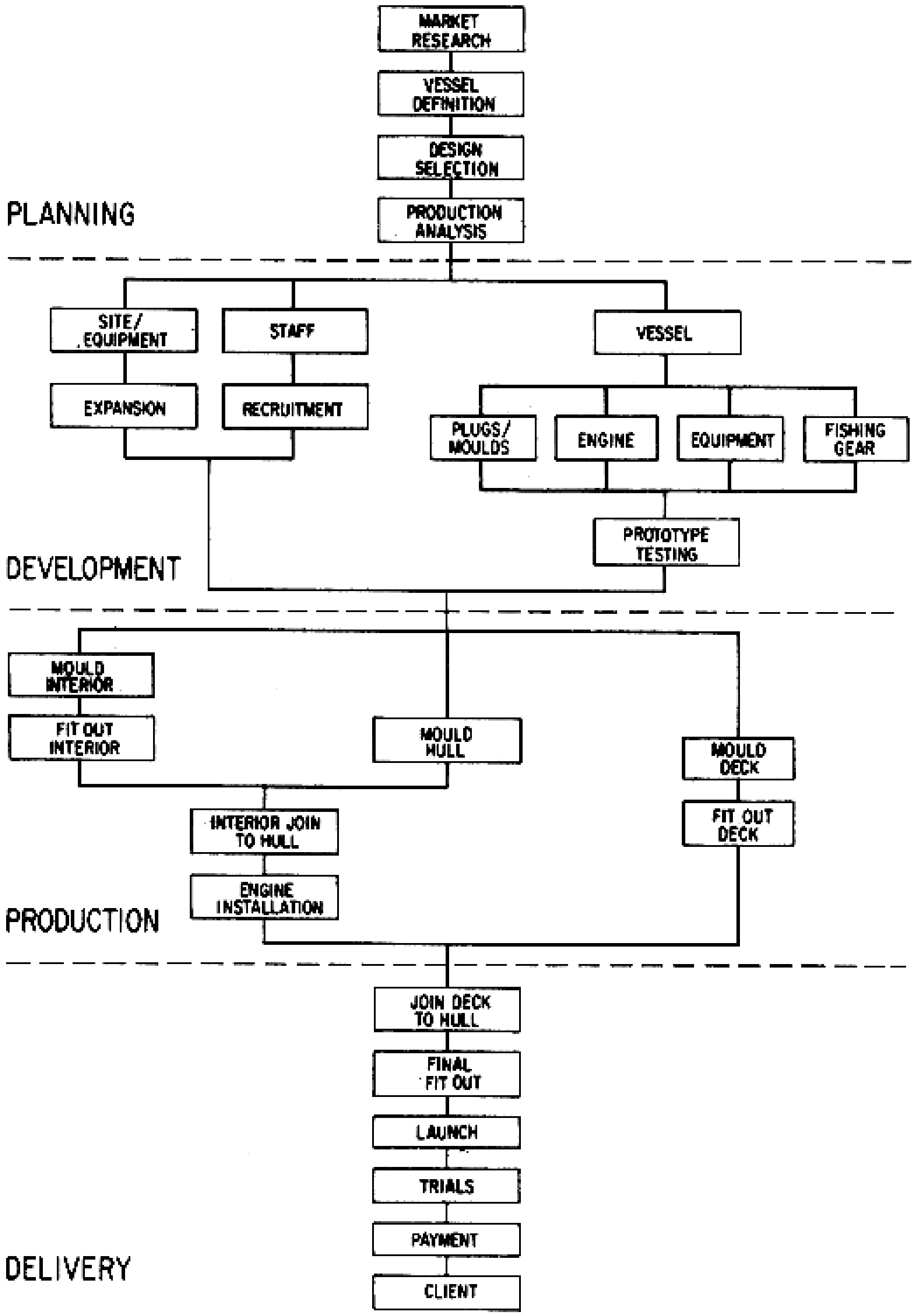
The first three topics concern the market for the vessel. As a starting point, the decision to build FRP boats in a developing country will be taken at government level following a requirement to augment traditional vessel sources. Outside assistance is usually called in at this stage to guide the officials delegated with the task of putting the plan into effect.

The type of vessel required will be one of the first questions to be addressed. The answer in this instance will be taken to be an FRP version of the local artisanal inshore fishing vessel. A combination of information from the national fisheries extension service and other departments within the Ministry of Fisheries will show what kind of vessels exist and in what quantities, how many people are employed in the industry, what percentage of the national catch this sector produces, and what is the source of new traditional boats, gear and motors. With this information, a plan can be made of what the new boat will look like, how many need to be built each year, the target price that owners might be prepared to pay and credit schemes devised as FRP boats are likely to be more expensive than traditional ones. Following agreement on the type and numbers of the vessel to be built, decisions can be taken on putting the vessel into production.

It is rare for the Government of a developing country to have sufficient foreign currency to risk competing in the commercial boatbuilding industry and requests for funding are usually addressed to an Aid Agency. To process this request a techno-economic study is required to support the proposal. It is normal for the funding agency to send in their own study team for confirmation before committing funds. Assuming only minor changes are required and that stage funding has been agreed, the recipient government and executing agency can put the plan into effect.

Table 10

Flow chart for development and production



For the private sector market entrant the buffer of government support is removed. In this case involvement with FRP boats may begin with repairs, import of complete vessels or a joint venture/licensing agreement. Market research, a knowledge of import regulations and coordination with the local Fisheries Department are important in this case.

12.2 <u>Selection of Design, Material and Equipment</u>

Because of long lead times design and equipment sourcing should begin at the same time as site construction or conversion. An acknowledged expert should be asked to provide a set of plans for the new boat following a visit to the region for direct talks and briefing. It is normally several months before plans are presented by the naval architect to the parties who will use them. A decision will have been taken previously on whether to build the tooling (plugs and moulds) locally or have it all prepared abroad by an experienced boatyard together with a completed example of the final vessel. This decision will be influenced by the size of the boat to be built and the competence of the local staff who would otherwise have to build it. In completely new enterprises it is adviseable to begin with small open boats and build up a level of expertise before attempting any complex craft.

If all the tooling is to be imported, then the contractor who receives the order should also be expected to train the foreman and manager who will eventually run the new yard. If the decision is taken to build all the tooling locally then this will need to be under the guidance of an expert and the whole procedure treated as a training exercise. It is unlikely that the cost effective production will be achieved during this start-up period which may necessitate funding subsidies before the yard can continue unaided. It cannot be understated that it is vital to the credibility of the boatyard that the first production design be a success. If a traditional and highly conservative fishing community decides against the early products of the yard then it could be an irreversible set back. For this reason, the likely choice of a first design will be an FRP vessel which will resemble as closely as possible the most widely used traditional boat. It is tempting to make technical innovations which inevitably make the boat more complex than the original, but this should be resisted until the yard has proved its product and has a good reputation. Once a basic model has entered the market and is well accepted then it can be used as a foundation on which the yard can develop a wider range of vessels.

12.3 <u>Foreign Currency Problem</u>

It has been established that there is much to be needed by a developing country from overseas during the early stages of the boatyard. Import requirement will continue with each vessel ordered as resin, reinforcement, engines and equipment all come from abroad. The yard must then have steady access to foreign currency which will entail early discussions with the National Bank to explain this long term and continuing need. Without the Bank's agreement to provide this facility the yard is in difficulties before it has begun.

Between the yard and the vessel purchaser deals are struck in the local currency. Any agreement made can be much affected by currency fluctuations during the long lead times between order and delivery and should not be underestimated. It is also normal that FRP vessels cost more than wooden equivalents which requires much explanation to prospective purchasers who often have little understanding of offsetting the extra cost over the much longer life of an FRP vessel.

Credit schemes may be called for. Yards should not enter directly into offering credit as they are not banks. One solution is to arrange with the local Agricultural Development Bank for loans to be made to a fishermen's cooperative so that the yard receives payment without undue delay.

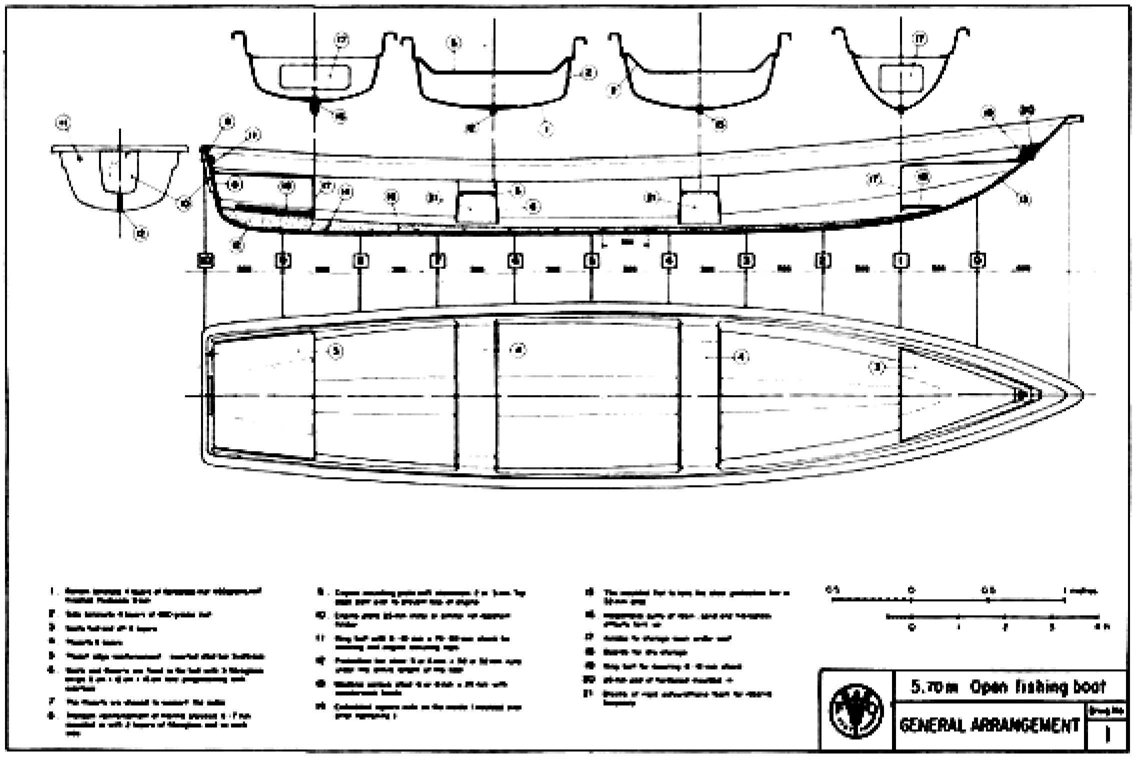
ANNEX I

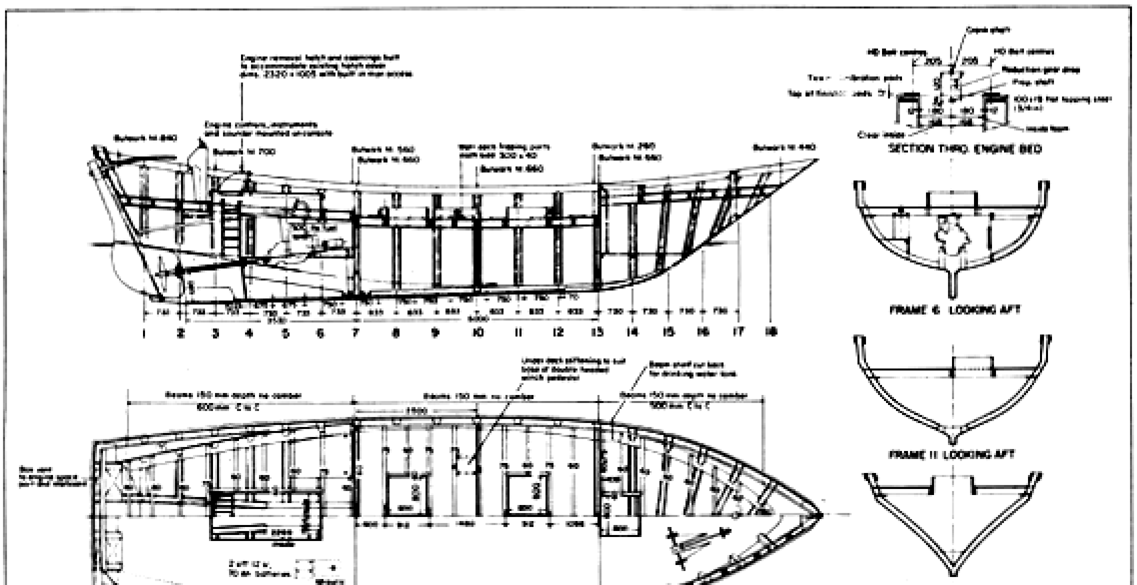
5.7 m Open Fishing Boat
15.0 m Decked Inshore Fishing Vessel (Sambuk)

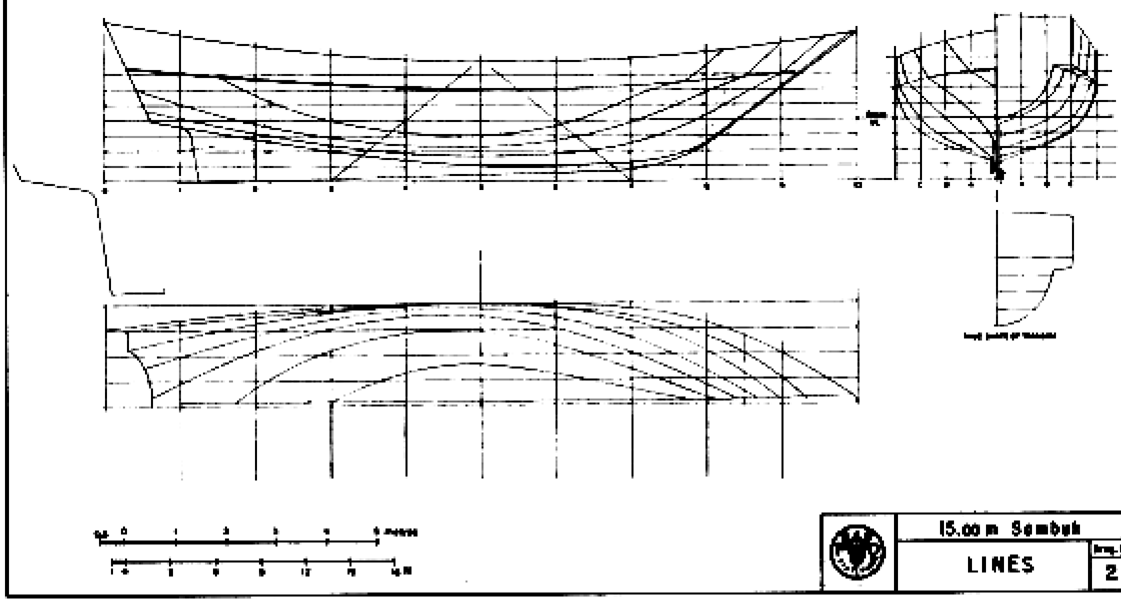
This provides typical examples of design information which should be provided for the construction of, in this case, a small fishing canoe and a larger inboard powered inshore fishing boat.

With the canoe drawing is a basic but adequate specification from which a list of materials and a construction sequence can be derived. For comparison, the drawings No. 1, 2, 3, 4, 5 and 6 of the larger vessel are accompanied by a full specification which includes details of materials to be used, the construction sequence, machinery description and all equipment necessary to operate a vessel of this size.

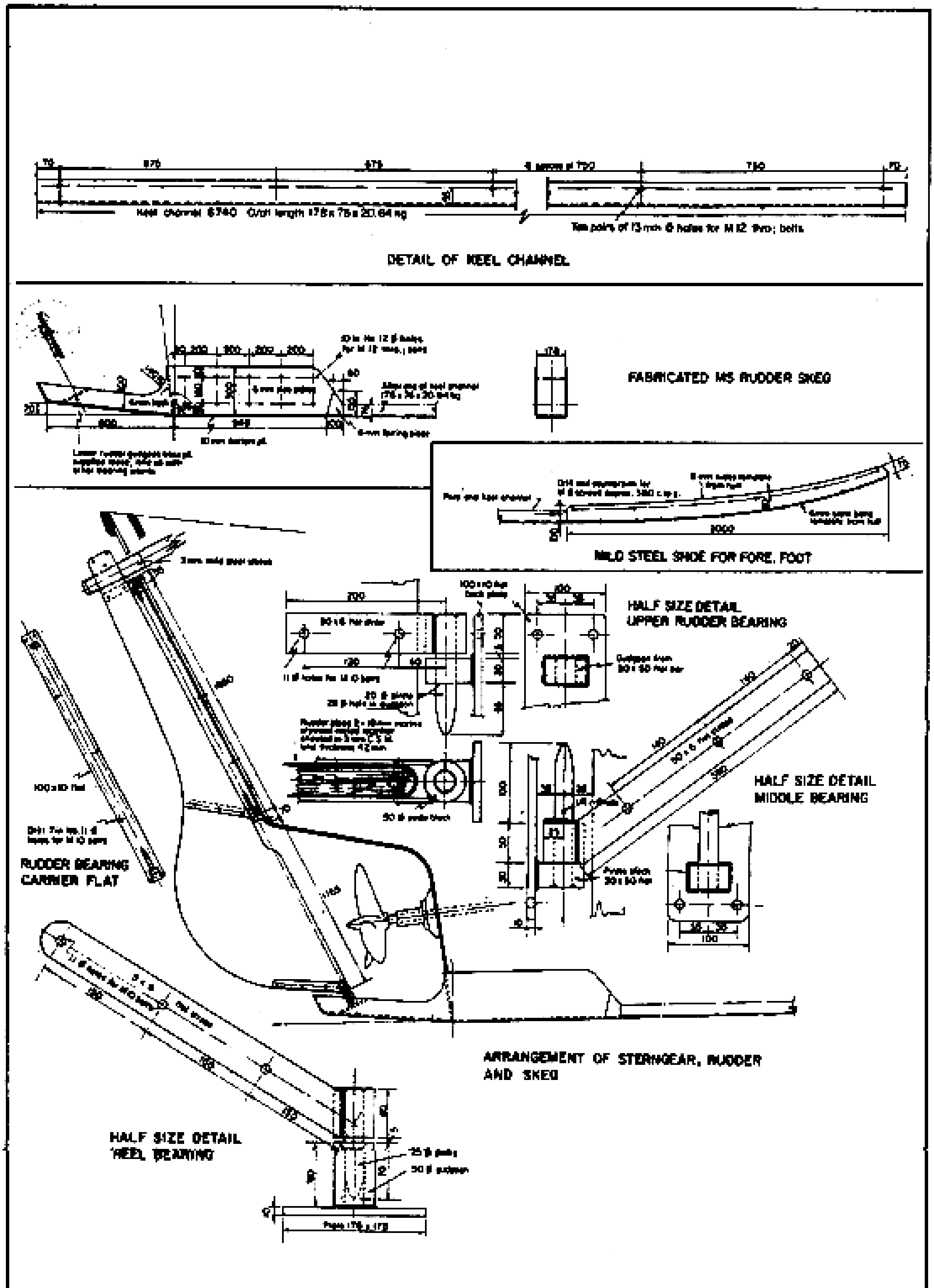
LIST OF DRAWINGS


5.70m Open fishing boat
GENERAL ARRANGEMENT
Drwg No
1


SECTION THRO' ENGINE BED
FRAME 6 LOOKING AFT
FRAME 11 LOOKING AFT
FRAME 14 LOOKING AFT
AFTER BHD ON FRAME 13 SHOWING F. WATER TANK
15.00m Sambuk
GENERAL ARRANGEMENT
Drwg No
1
metres



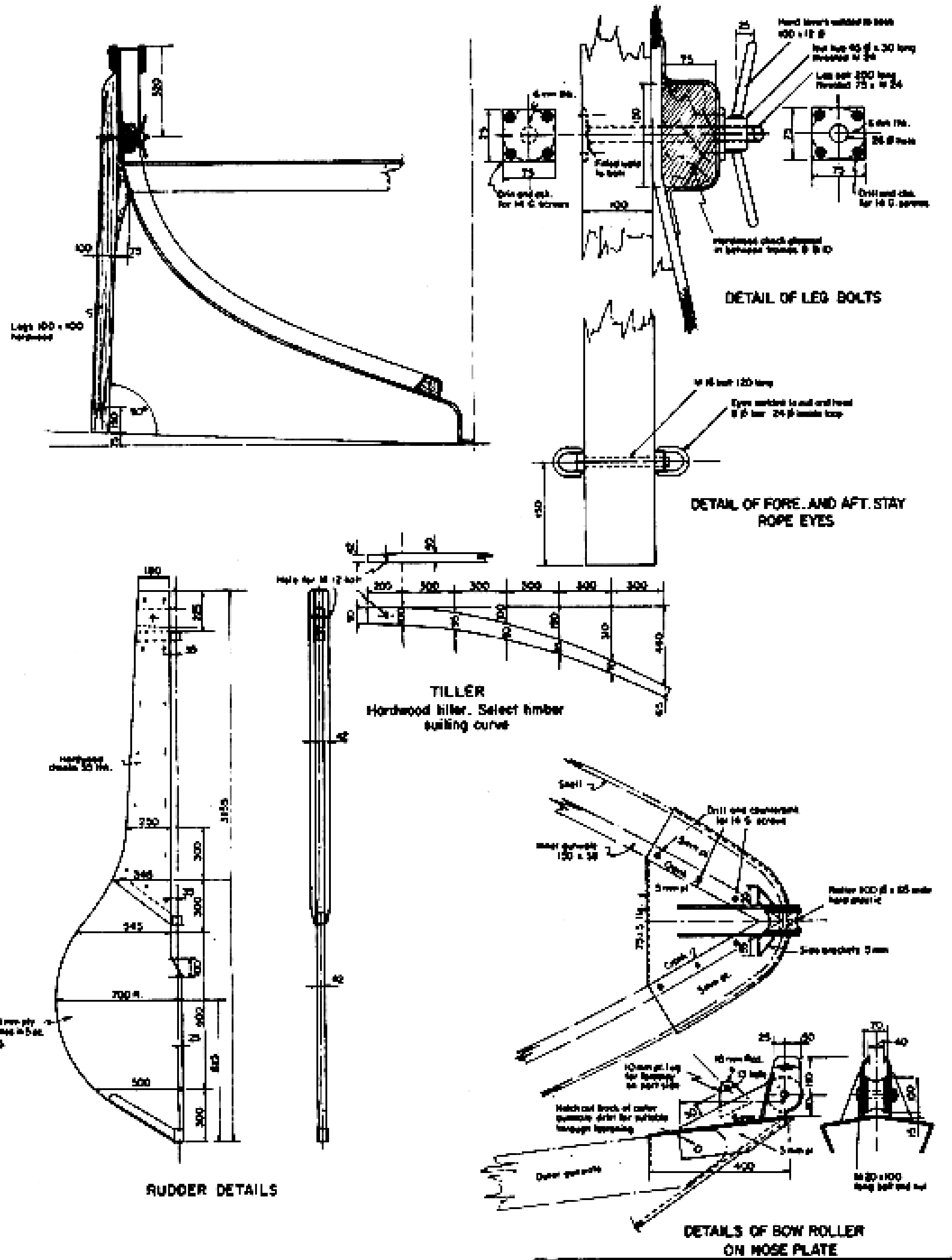
15.00 m Sambuk	
LINES	Drwg. No. 2



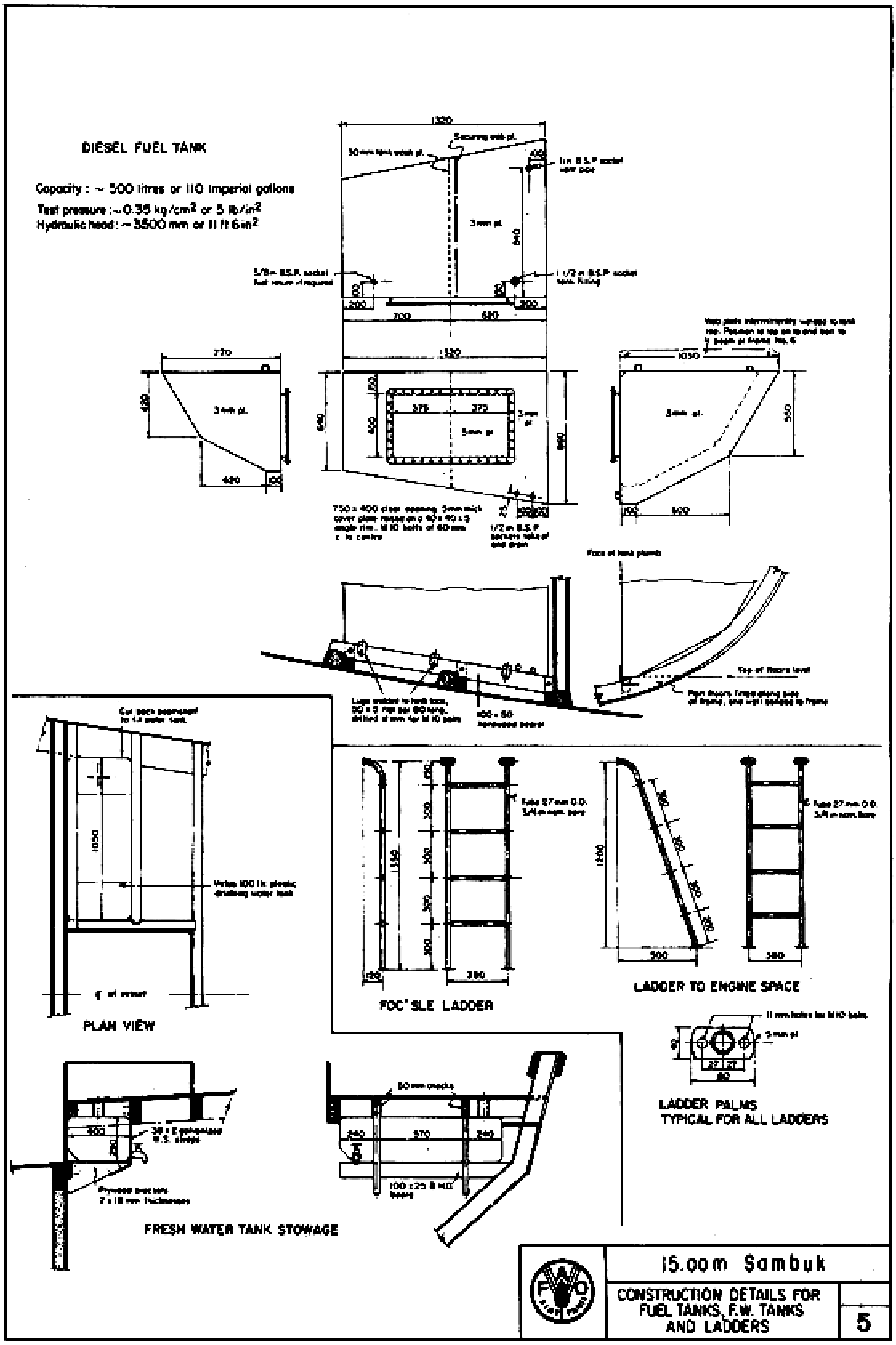
15.00 m Sombuk

CONSTRUCTION DETAILS FOR SKEG, KEEL CHANNEL AND RUDDER FITTINGS

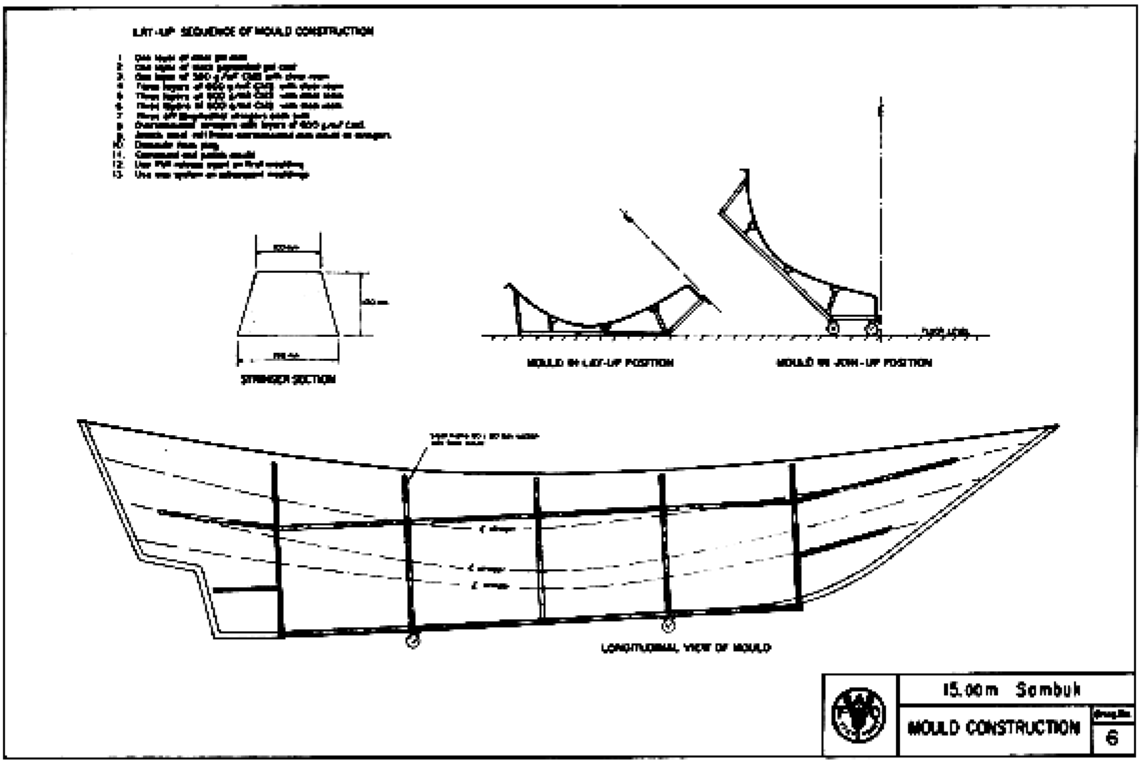
Drwg. No. 3



15.00 m Sombuk		
DETAILS OF BEACHING LEGS, RUDDER AND TILLER AND BOW ROLLER NOSE PLATE	Drwg. No.	4



DIESEL FUEL TANK
Capacity : ~ 500 litres or 110 imperial gallons
Test pressure : ~ 0.35 kg/cm² or 5 lb/in²
Hydraulic head : ~ 3500 mm or 11 ft 6 in²
PLAN VIEW
FOC'SLE LADDER
LADDER TO ENGINE SPACE
LADDER PALMS
TYPICAL FOR ALL LADDERS
FRESH WATER TANK STOWAGE
15.00m Sambuk
CONSTRUCTION DETAILS FOR FUEL TANKS, F.W. TANKS AND LADDERS
5



SPECIFICATION FOR 15-m SAMBUK

1. GENERAL

1.1 Description

The vessel to be of a displacement type with round bilge hull form based on traditional design, constructed in modern materials with a self-draining main deck, raked stem and transom stern. In general, the vessel to have a clean, modern and distinctive appearance for coastal fishing.

1.2 Arrangement

The vessel to be sub-divided by watertight bulkheads into the following compartments:

Forecabin crew space
Fish hold in two sections
Engine room

1.3 Drawings

Upon completion, the builders to supply one set of construction drawings.

1.4 Dimensions

Length overall:	15.0 m
Length waterline:	11.2 m

Beam:	4.1 m
Draught aft:	1.2 m
Displacement :	12 t approx.

1.5 Quality and Supervision

Building of the vessel to be carried out under cover protected from sun and rain premises.

All resins to be of highest quality and all glassfibre to be “E” type. All materials used will be of marine grade. All timber to be seasoned and hard-wood; all steel to be well coated; stainless steel to be EN58J (BS 316 SIG); all aluminium to be NB; all bronze to be BSI 400: all dissimilar metals to be isolated from each other. All materials to be stored under controlled conditions and monitored throughout building cycle.

1.6 Certificates

A builder's certificate will be issued to the owner upon completion of the vessel.

1.7 Stability

Upon completion, the vessel to be inclined to obtain particulars on stability. A stability booklet to be issued to the owner including hydrostatic particulars.

1.8 Trials

Upon completion of the vessel, full sea trials to be carried out as follows:

Speed runs over a measured mile
Manoeuvring trials
Astern trials
Engine system tests including fuel consumption
Bilge system tests
Electronic equipment tests if applicable
Compass adjustment

The builder to be responsible for the supply of all necessary crew, fuel, oils, technicians and provisions required for the trials.

2. CONSTRUCTION

2.1 Hull

Hull moulding to be two piece structure laid up using split mould technique as follows:

> a. Two gel coats all over, applied by hand using “mohair” rollers and 100 mm paint brushes. Nominal thickness 0.5 mm gel type isophthalic. The whole of one side to be laid in one operation with no break, one gel after the other, then immediately onto:

b. One layer of 225 g/m^2 chopped strand mat emulsion bonded, laid with isophthalic resin. Resin to glass ration 1.8:1 by weight laid by hand using “wolly rollers” and aluminium “paddles” rollers.

Operations (a) and (b) to be carried out in one shift of work, i.e., within 24 hours. Cure time of 30 min minimum between gel coats and cure time of 60 min for 225 g/m^2 layer.

c. Main hull laminate to commence not more than 24 h after application of 225 g/m^2 layer.
d. Three layers of 600 g/m^2 chopped strand mat (CSM) emulsion bonded. Laid with orthophthalic resin all over. Resin to glass ratio 2:1 by weight. All three layers laid simultaneously in mat width strips transversely applied, stepped back by 50 mm steps from previous layers on the keel stem and transom join edges.
e. One complex of 600 g/m^2 (CSM) and 600 g/m^2 woven roving and 600 g/m^2 CSM laid simultaneiously in mat width strips transversely applied, stepped back by 50 mm steps from previous layer on keel, stem and transom join edges.
f. Three layers of 600 g/m^2 chopped strand mat CSM emulsion bonded, laid with orthophthalic resin all over. Resin to glass ratio 2:1 by weight. All three layers laid simultaneously in mat width strips transversely applied, stepped back by 50 mm steps from previous layer on keel, stem and transom join edges.
g. Bring mould halves together, bolt up all round, arrange internal access and staging as required.
h. Apply one layer of resin proof tape to join line all round.
i. Repeat operation (a) to (f) throughout length of join line ensuring 50 mm overlaps increasing by 50 mm for each layer.
j. Mark off hull with chalk or wax pencil for position of hull frames maximum spacing longitudinally 900 mm.
k. Insert frames constructed of low density closed cell polyurethane foam, trapezoidal section base size 150 mm, tapering over 100 mm to top face of 100 mm. Frames to be contact adhesive bonded to hull.
l. Overlaminate frames with three layers of 600 g/m^2 CSM with orthophthalic resin. Layers to lap over frame and onto hull with 50 mm, 250 mm and 400 mm laps each side.
m. Frames to be extended through keel in way of bulkheads, fishroom, forefoot where practical. Frame to stop short in way of engine to allow fitting of engine bearers.
n. Insert hull lifting blocks/plates for release from mould.
o. Insert two main bulkheads constructed of 19 mm thick marine grade plywood vertical to datum and square to centreline. Plywood to be butt strapped on joints and glued and screwed. Bond bulkheads to frames on both sides with three layers of 600 g/m^2 CSM with laps as per (1).
p. Hull moulding is now ready to release from mould provided lifting blocks/plates have cured for 48 hours since insertion. Section (n) refers.
q. On release from mould hull to be placed in fitout cradle or suitably chocked to prevent any distortion.
r. Construction to take place protected from sun, rain and in well ventilated dust-free atmosphere. All materials to be stored in similar

conditions and to be suitable for use in tropical environments if appropriate and to be marine grade.

s. Ballast to be located in the keel and bilge section in the form of steel punchings set in resin and overlaminated. Final trimming to be carried out after launch and inclining test.

t. Hull protection to include a stem shoe, keel iron and skeg.

u. Galvanized steel strips to be fitted to bilge keels.

2.2 Deck

The main deck to be constructed of cambered, hardwood, transverse beams nominally 150 mm × 75 mm and 60 mm as required and sheathed with 19 mm plywood overlaminated with 1 800 g/m^2 of chopped strand mat, and to incorporate a non-slip finish. The deck to incorporate an engine removal hatch and access hatches to fish hold. All hatches to be fitted on coamings of at least 300 mm.

Freeing ports to be cut in the bulwarks to allow free drainage of water overboard from deck. Bulwark height to be 610 mm minimum at side.

2.3 Gunwales

Gunwales to be constructed in hardwood as follows:

Outer section: 150× 50 mm

Inner section: 150× 38 mm

Outer to be bolted to inner at approximately 900 mm centres using spacer blocks 120 mm deep × 100 mm thick. Bolts to be 10 mm diameter cup square on outside nut and washer inside recessed. All edges of timber to be rounded to prevent snagging of nets. Quarter knees to be fitted at transom. Forward mooring post of 100 × 100 mm to be fitted. Finish to be oiled.

3. FITOUT

3.1 Crew Cover

Space under foredeck to be allocated as occasional crew cover. Top of foredeck to be finished in non-slip and to be fitted with heavy duty either steel or hardwood mooring post 100 mm square taken through deck to hull forefoot well bonded in and secured at main deck level. Stowage bins for crew's provision/food, etc., to be fitted.

3.2 Fish Hold

The fish hold to be nominally 4.9 m long × 1.1 m deep × internal beam of vessel. Access through hatches on deck 0.8 × 0.8 m. Fish hold to be contained between two insulated bulkheads with central fixed division. Hull sides and overhead to be insulated.

Insulation to be in the form of low density rigid foam covered on inside with plywood sheathed over with FRP pigment and finished in white gelcoat, nominal insulation thickness 100 mm. The sole of the fish hold to be non-slip finish.

The hold is to be fitted with 4 pound boards on centreline, 200 mm high each. Boards to be removable and to fit into slots at each end to prevent catch from moving from side to side in seaway.

3.3 Engine Room

The access to engine space to be via deck hatch, set in larger hatch. The engine can be removed through a large hatch. This hatch to be FRP bolted down and only used in the event of main engine failure or replacement.

The engine space to be well ventilated by air vents set in bulwarks transom and in control console.

3.4 Deck Fittings

a. Foredeck mooring post, 100 mm square × 1
b. Forecabin hatch cover, lid type × 1
c. Fish hold hatch covers, FRP, lid type × 2
d. Fuel oil deck filler plate × 1
e. Engine room hatch cover, lid type × 1
f. Aft moring post/goal post gantry 100 mm square, steel
g. FRP moulded control console on after deck
h. Forward "A" frame mast in galvanized steel with unloading derrick for 0.5 t
i. (i) Sun awning to be rigged from forward "A" frame to after goal post. Awning to be PVC on stainless steel wires
j. (j) Bow roller

4. MAIN ENGINE

4.1 Main Propulsion Engine

Marine propulsion engine complete with all standard equipment, for example, type YANMAR 3 SME. Engine to be solidly mounted on Tico anti-vibration pads.

Engine to be generally as follows:

Three cylinders, in-line 3 117 1, wet liner diesel engine cooled by salt water circulating through engine. Engine to be continuously rated at 45 HP at 2 200 rpm for 24 h running. Engine start to be electric;

Engine to be directly coupled to a 2.60: 1 reduction gearbox. Gearbox to be hydraulically operated, mechanical drive type. Dry weight of the engine 530 kg.

4.2 Stern Gear

Fixed propeller system to be installed in accordance with the manufacturer's recommendations. Shaft to be stainless steel or manganese bronze and stern tube in manganese bronze. Stern tube to be fitted with water lubricated cutless type bearing and to have a lignum vitae inboard stuffing gland. Propeller to be three bladed in manganese bronze, turbine section designed for optimum free running condition with half load. Diameter approximately 740 mm (29"), pitch approximately 410 mm (16").

4.3 Instruments and Alarms

Full engine instrumentation to be installed on or adjacent to the engine as recommended by the engine manufacturer, normally as follows:

- Tachometer
- Lubrication oil pressure gauge for engine and gearbox, or indicator lamp
- Ammeter or indicator lamp
- Engine stop control

4.4 Power Take-off

A power take-off drive from the front end of the main engine to be made. The following equipment to be driven:

- Hydraulic pump for net/line hauler and purse seine winch
- Bilge/deckwash pump

4.5 Fuel System

Fuel tank to be constructed of steel, fully baffled and fitted with sump, inspection plates and vent pipe. Tank to be fitted so as to allow manual content dipstick to be used. Tank to have a total capacity of 500 1. Fuel lines to be in continuous drawn copper piping to the main engine with short, flexible connecting pipe.

One shut-off valve to be fitted in supply line. One in-line water separator. Fuel oil tank to be cleaned prior to filling.

4.6 Exhaust System

A wet exhaust system to be fitted, to include an injection elbow at engine. Pipe diameter and details to be in accordance with the engine manufacturer's recommendations.

Exposed pipework to be fully insulated with an approved material.

Exhaust to terminate at transom, well above waterline.

4.7 Cooling System

A heavy duty seacock and strainer to be located close to the water circuit on the main engine and to be easily accessible. Pipework to be suitable for application. Seacock strainer to be one size larger than engine circulating pump.

4.8 Controls

Power (throttle) and gear controls to be located on control console. Control to be of the cable type suited to the enghine installed.

5. STEERING

5.1 Rudder Gear

The rudder mechanism to be constructed as follows:

- Rudder blade, wood sheathed in FRP
- Rudder pintles in galvanized steel
- Jumping collars, stainless steel pins
- Tiller arm in wood

6. BILGE AND DECKWASH SYSTEM

6.1 Bilge and Deckwash

Bilge to be drained by a clutch type power pump belt driven from main engine. The valve chest, 32 mm pipe diameter, to have three-way alternative suction as follows:

i. Engine room bilge suction
ii. Fishroom bilge suction
iii. Seawater suction through independent seacock with strainer.

The delivery side of the pump to be fitted to a hose connection for fire and deckwash purposes.

Deckwash/fire hose to be 3 metres length and to have a nozzle.

6.2 Piping

All piping to be of galvanized steel or copper or reinforced hose. All valves to have open and shut indicators. Non-return valves to be fitted where necessary. Strainers to be fitted to bilge and salt water suctions.

All pipework to be well designed and adequately supported.

6.3 Hand Pumps

The following hand pump to be installed:

- One Whale 25, hand pump to main valve chest with handle fastened to pump.

6.4 Auxiliary Pump

One off engine mounted, standard bilge pump plumbed to engine space bilge, constant running type with outboard discharge.

7. HYDRAULIC SYSTEM

7.1 Deck Machinery

1 off double headed capstan purse-seine winch

1 off gill net hauler with long line sheave and capstsan

7.2 Pumps and Installation

One hydraulic pump mounted on the main engine PTO and fitted with a clutch. Capacity to suit deck machinery, with changeover valve to either set of equipment.

7.3 Piping

Hydraulic piping specification to be in accordance with recommendations laid down by the manufacturer of the hydraulic machinery.

Net hauler to be fitted with quick release connectors to allow removal from boat when not in use.

8. ELECTRIC SYSTEM

8.1 General

The electrical installation to be 24 volt DC only. Battery charging by engine mounted, 400 w alternator.

8.2 Cables and Wiring

Generally all cables to be suitably insulated. Screened cables to be used on electronic equipment where necessary. Cables to run on perforated galvanized steel tray plate or through galvanized tube as necessary. Water-tight glands to be fitted in way of all watertight bulkheads. Cable to be colour coded as necessary and circuits clearly labelled.

8.3 Main Switchboard

Main switchboard to be fitted in the engine room. The circuit breaker board to be fitted with MCB units of the correct amperage for each circuit loading. Each circuit to be fused in the positive pole.

8.4 Batteries

Two lead acid batteries, 24 Volt and approximately 100 Amp hour capacity to be fitted. The batteries to be installed in an FRP lined and ventilated box with lid. An isolating switch to be fitted.

8.5 Switches

All switches to be of the heavy duty marine type and splash-proof. Switch panel to be clearly labelled. Interior lights to be individually switched.

8.6 Lights

The following lights to be fitted:

- Engine instrument lights, one set
- Compass light × 1
- Fish hold lights × 2 recessed into overhead
- Engine room lights × 2
- Deckflood lights × 2 halogen forward
- Deckflood lights × 2 fluorescent over aft deck
- Crew accommodation light × 1
- Electric socket adjacent to helm position × 2
- Bicolour navigation light
- Stem light
- Steaming lights

8.7 Electronics

Paper trace echosounder complete with transducer in hull and metric display mounted in console on aft deck. Spare stylus and box of paper rolls to be provided.

9. FRESH WATER

Two tanks for storage of fresh water to be fitted in forward end complete with taps, approximate capacity 100 1 each.

10. LIFE-SAVING APPLIANCES

The following equipment to be supplied on board:

- Lifebelts × 4
- Distress flares, offshore pack × 1
- Lifejackets× 10
- First aid kit

11. FIRE-FIGHTING EQUIPMENT

The following equipment to be supplied on board:

- Fire extinguishers× 2

12. MISCELLANEOUS EQUIPMENT

The following equipment to be fitted or supplied on board:

- Anchor, 60 kg × 1
- Anchor rope, 100 m × 20 mm
- Mooring ropes, 25 m × 19 mm × 2
- Tire fenders × 4

- Beaching legs × 2 with rope strops
- Compass, 100 mm
- Cathodic protection

13. HULL AND DECK PAINTING

- Hull below waterline to be anti-fouled red
- Decks to be non-slip grey
- Hull pigment white with brown topside
- Hull internal of white gelcoat
- Timber external oiled, timber internal painted.

ANNEX 2

Glossary

ACCELERATOR
Liquid or powder which decreases the curing time of a synthetic resin.

ACETONE
Cleaning agent

AIR INHIBITION
Undercuring of exposed resin surface. Sticky.

BINDER PVA
Emulsion or powder used to hold chopped strands together

BLISTER
Moulding flaw where air or water is trapped

BLANK
A ready shaped foam core requiring application of FRP to complete

BONDING
The joining of two panels by an FRP joint cured in situ, or of two layers of FRP

CARBON FIBRE
A light weight, high-tech reinforcement

CHOPPED STRAND MAT
A lightly compressed and bound mat formed from filaments of glass which have been chopped to short lengths and bound together

CATALYST
A chemical which initiates polymerisation of a resin

CURE
Chemical hardening of the resin mixture

COBALT ACCELERATOR
Chemical additive to accelerate curing based on cobalt naphthanate

CORE
Foam or wood layer between inner and outer FRP skins

COMPRESSIVE STRENGTH
Ability of laminate to withstand crushing

CONSOLIDATING (a laminate)
Wetting out and removing air bubbles from resin/glass layer

CONTACT MOULDING
Casting of FRP by the use of a mould

DELAMINATION
Separation of one layer of a cured laminate from another

DRY LAMINATE
Resin to glass ratio below specification

EPOXY
Resin with adhesive, resistance and stability qualities superior to polyester

EXOTHERM
Heat generated during curing process

FEMALE MOULD
Mould where contact laminating is on the inside

FILLER
Inert material which reduces the volume of resin

FILLET
Bead of filled resin at a joint

FLEXURAL STRENGTH
A measure of bending resistance

FLOWCOAT
Gelcoat with high wax content for cosmetic finishes

FOAM
Lightweight, aereated plastic core material

FORMER
Non-structural item to give shape to panel stiffeners

FRP
Fibre reinforced plastics

GEL TIME
Interval between adding catalyst and laminate becoming hard

GELCOAT
Viscous, coloured resin used to give smooth outer hull skin

GRP
Glass reinforced plastics

HARDENER
Catalyst

HAND LAYUP
Hand applied resin and glass laminate

HONEYCOMB CORE
Cardboard or aluminium frame spacing core material

HOT MIX
Over-catalysed resin mix

ISOPHTHALIC
Improved polyester with good wear and flexibility properties

INJECTION MOULDING
Introduction of resin to reinforcement pre-applied between matched male and female moulds

LAMINATE
Consolidated and cured layers of FRP

LAY UP
The moulding process

KEVLAR
High tech aramid fibre reinforcement

MALE MOULD
Mould where the FRP is laid up on the outside of the mould

MONOMER
Styrene monomer. Liquid thinner, gives characteristic smell

MATURING TIME
Follows gel stage. Up to 3 weeks

MEKP
Methyl ethyl ketone peroxide. Standard catalyst

MOULD
Tool in which FRP is cast

POLYMER
Fundamental molecular chain formed when FRP chemical reaction is initiated

PVA
Polyvinyl alcohol. Basic release agent

PLUG
Original and faithful pattern used to cast mould

POLYESTER
Basic resin component of FRP

POLYURETHANE FOAM
Orange or cream coloured rigid foam. Friable

POLYSTYRENE FOAM
White colour, for insulation. Large beads

PVC FOAM
Polyvinyl choride foam. Flexible, high quality

POTLIFE
Interval between addition of catalyst to resin and hardening

PRE-PREG
Previously impregnated reinforcement

PIGMENT
Colouring agent for resins

PRE-ACCELERATED
Resin with accelerator added precisely at chemical works

RESIN
Viscous liquid component of FRP system

RELEASE
Removal of moulded unit from mould

RELEASE AGENT
Liquid or wax compound to ease release

RESIN RICH
Resin ratio higher than specification

ROVINGS
Continuous strands of glass loosely bound together

ROLLER
Tools for compacting laminate and applying resin

RESIN PUTTY
Heavily filled resin mix, paste like

SHELF LIFE
Length of time material remains useable while in store

SANDWICH CONSTRUCTION
Double skin moulding with core material separating skins

SCRIM
Open weave cloth used to bind other type of cloth

STIPPLING
Use of paint brush to chase out individual air bubbles from laminate

SHEATHING
Application of FRP skin to previously existing item

SPLIT MOULD
Mould in more than one piece

SPRAY LAY-UP
Application of chopped roving and resin by spray gun

SURFACE TISSUE
Fine cloth applied after gel coat

SQUEEGEE
Alternative tool for laminating

TENSILE STRENGTH
A measure of strength in tension

THIXOTROPIC
A liquid of high viscosity

TWO-PART MIX
Two liquids requiring mixing together to cure

TOOLING
The plugs and moulds

UNIDIRECTIONAL
One-way. Unidirectional rovings-sheet of roving loosely bound as cloth

VACUUM BAGGING
High tech-method of applying pressure to laminate in order to achieve high quality bond

VINYL ESTER RESIN
With qualities superior to polyester

WETTING OUT
Process of applying resin to reinforcement

WARP
Transverse strand of a cloth

WEFT
Lengthways strand of cloth

WOVEN ROVINGS
Cloth woven from rovings

ANNEX 3

FRP Construction Rules

Construction rules for FRP vessels are available from the following institutions:

American Bureau of Shipping
45 Broad Street
New York
NY 10004
USA

Bureau Veritas
Services Maritimes
31 rue Henri Rochefort
75821 Paris Cedex 17
France

Det Norske Veritas
P.O. Box 300
1322 Hovik
Norway

Lloyds Register of Shipping
Small Craft Dept.
69 Oxford Street
Southampton SOl IDL
UK

Nippon Kaiji Kyokai
17-26, Akasaka 2-Chome
Minato-ku
Tokyo
Japan

Sea Fish Industry Authority
10 Young Street
Edinburgh EH2 4JQ
UK

REFERENCES

POLYESTER HANDBOOK Scott Bader Co. Wollaston Northants UK

FIBREGLASS BOAT DESIGN AND CONSTRUCTION
R.J. Scott, John de Graff
Inc. Tuckahoe New York

FIBREGLASS BOATS
H. du Plessis, Adlard Coles Ltd. London

GLASS REINFORCED PLASTIC BOATBUILDING
McInnes and Hobbs, Lloyds
Register

CONSTRUCTION OF ON-BOARD INSULATED FISH CONTAINERS FOR PIROGUES
FAO Fisheries Circular, No. 775

GRP BOAT CONSTRUCTION
F. Figg and J. Hayward, Butterworth and Co. London

NEW GRP BOOK
R.H. Waring, Model and Allied Publications, Watford UK

ONE-OFF FIBREGLASS SANDWICH CONSTRUCTION
Airex Ltf., Sins, Switzerland