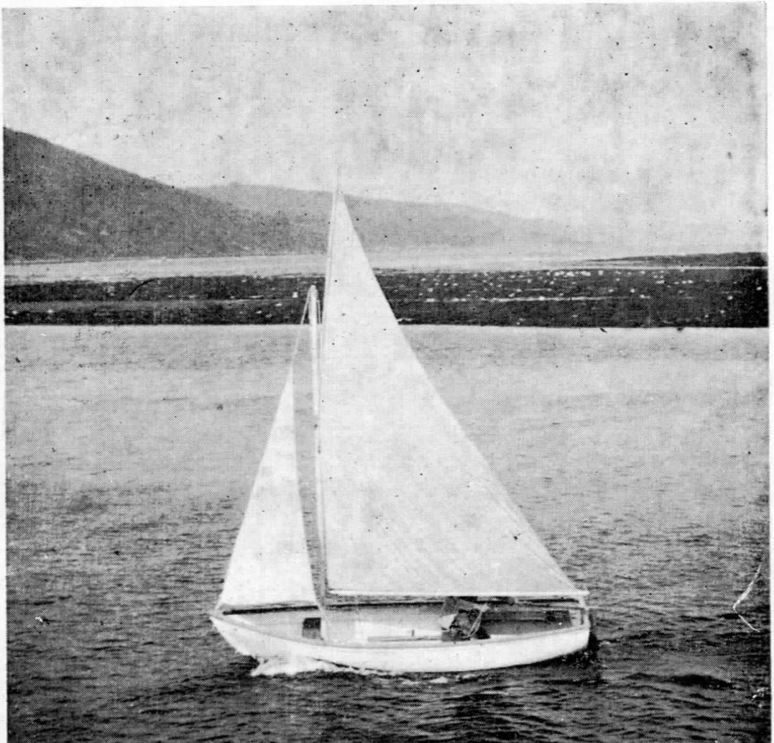
FIBREGLASS

A.Y.R.S. PUBLICATION No. 25



14 FT. FIBREGLASS DINGHY BY MOULDACRAFT

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EDITORIAL June, 1959. Reprint February. 1964.

Yachtsmen on the whole are divided into those who like the idea of fibreglass and those who don't. I take it that I am personally deficient in being addicted to wood as a boat-building material though this is prejudice. In fact, however, *Fibreglass*, despite its advantages, is not yet suitable for small boats which need to be built as lightly as possible, though epoxy resins and glass cloth can be as good, though much more expensive. On the other hand, the usual polyester resin/glass mat construction has some distinct advantages for boats of 6-8 feet and those of about 40 feet in length.

Roderick Macalpine-Downie has, I think, written this publication with great skill and has had to do a great deal of research to assemble the facts which give the background, the advantages and the faults of the material. These advantages and faults should form the basis for future research for the professional and help the amateur to understand a rather difficult process.

Though an account of laying-up of fibreglass is given, it is felt that the only way in which anyone can learn to make a boat of this material is by a practical demonstration first and then by re-reading this publication. Nearly all the amateur built fibreglass boats I have seen have had " orange peel effect," areas of " resin starvation " in the skin or surplus of resin at the stem or transom. Perhaps this publication will allow the amateur to build fibreglass boats with more hope of complete success.

The photographs of the moulding processes were taken at Messrs. MOULDACRAFT PRODUCTS, Inverness. Alex MacKenzie of this firm is thanked for permission to use them and for his co-operation with Roderick Macalpine-Downie in showing him all the commercial side of the business.

FIBREGLASS

BY

J. R. Macalpine-Downie

Introduction

By the waters of Babylon, we are told in the Bible, the Jews in their captivity sat down and wept. This, though understandable, is to be deplored ; since much earlier, during their exile in Egypt, they had occupied themselves more constructively in making bricks of mud from the banks of the river Nile. This they mixed, since it was not a true clay capable of being fired, with straw and reeds to give it the necessary strength and cohesion. These bricks are, so far as I can discover, the earliest known application of the very significant principle of reinforcing a brittle base with a strong fibre to provide the structural properties of both—to say nothing of a proverb.

Many centuries later we read of the Romans using human hair as the reinforcement in the springs of ballistic weapons with a range, according to contemporary accounts, of up to three thousand paces. Later still we find the Turks using horn as the main reinforcement in their formidable bows, with one of which the Sultan Selim achieved in 1798, a throw of 972 yards $2\frac{3}{4}$ inches, or nearly three times that of the traditional English yew longbow. With an eye, no doubt, to the scepticism of succeeding generations at so precise a figure, he very prudently had it witnessed by the British Ambassador of the time and ensured for his feat perpetual diplomatic immunity from the suspicions of the mean-minded.

In our own times a Mr. Norman Richards of Los Angeles has shot an arrow $842\frac{1}{2}$ yards with an " all glass laminated " bow of rather similar type.

The modern counterpart of the mud and straw brick is of course ferro-concrete, in which the reinforcement is steel. The great strength of reinforced concrete makes it suitable for many highly stressed purposes, including bridges, unsupported floors, beams and sky-scrapers ; and since its introduction nearly a century ago, it has become ever more widely used, particularly in France, and has caused a positive revolution in civil engineering.

The attractions of this principle for boat building, and of casting a hull in a homogeneous whole instead of laboriously building it up in strips, have naturally been appreciated for many years. Attempts have been made from time to time to develop a suitable material, and one at least, using asbestos-reinforced resorcinol, was marketed under the name of Durestos. It tended however to porosity and brittleness, and was somewhat expensive to produce since it required heat curing, and never found general favour. These attempts continue ; a Flying Fifteen, amateur built in laminated Tufnol (cloth-reinforced phenolic resin) was shown at the London Boat show last year (1958), and has since been extremely successful. More experimental yet is the cruiser reputedly building on the Clyde in reinforced concrete.

It was not, however, until the development of the glass reinforced polyester laminate, to which was given the trade name of Fibreglass, that a wholly reliable and satisfactory application of this principle became available for boat hulls. Despite its drawbacks, Fibreglass represents perhaps the greatest single advance in boat building since the introduction of steel, and one that may be no less far-reaching in its effects. With a properly made mould an almost unlimited number of hulls may be turned out with the minimum of time, skill and labour, all with unbroken skins of good finish, high physical properties and great durability.

Small wonder then that in a few years it has won such general acclaim; and small wonder perhaps that in the novelty and enthusiasm its disadvantages have tended to be glossed over. In writing this brief account, therefore, I have concerned myself especially with these drawbacks and with various approaches to circumventing them. If I appear at times to be biassed against it, it is only because I feel that it is its vices, rather than its well-known virtues, that require emphasis at the present time.

Failure to appreciate and allow for these weaknesses is still widespread among both amateurs and professionals. I recently met the head of a firm making Fibreglass dinghies who had never even heard of the " cold-flowing " of plastics (he mugged up and later gave me an excellent little homily on it). A considerable, though happily diminishing, number of professionally built fibreglass boats are little short of disgraceful and suggest either complete ignorance or disregard of the principles of its use. On the fringes of the trade there are a number of concerns that are still absurdly ill-qualified as either boat builders or fibreglass workers ; there are woefully few who are genuinely competent in both. All too many fibreglass boats on the market at the present time resemble ill-fashioned bathtubs.

This opinion is by no means mine alone ; I recently enjoyed a positively vitriolic conversation with the representative of a reinforcements manufacturer. His comments on a shell he had seen, made by one of the leading moulders in the land, might have been recorded and played at intervals throughout the last Boat Show, alternating with the management's warnings to the public against predatory photographers.

In evaluating and trying to improve on existing materials we must remember that the qualities of the laminate, despite occasional inanities in the popular press, are in no wise magical ; they are merely logically compounded of those of the constituents, with an overall factor dependent on their mutual adhesion. Negative weaknesses in the one will be masked by the equivalent positive qualities of the other ; the lack of tensile and bending strength in the resin, for instance, is countered by the tenacity of the glass fibres. Positive weakness, on the other hand, will remain ; combination with glass fibres will not, for example, protect the resin from excessive heat or from chemical attack to which it is normally liable. The combination is, in other words, purely physical and not in any degree chemical, with all that this implies. The only apparent exception to this is the increase in bending that the resin can accept in the laminate without cracking.

The improvement in resins and reinforcements, continues steadily; it is in any case, with the possible exception of fillers, outside the realm of the amateur. In designing for fibreglass, on the other hand, and in the choice of materials and their arrangement within the laminate, there is tremendous scope. With imagination and care, particularly in the making of the mould, the amateur can produce results to rival the best, and to excel the great majority of, professional mouldings.

The Reinforcement

Glass fibres are made from a mixture of sand, alumina hydrate, burnt lime, borax and a miscellany of minor components. The molten glass is attenuated by extrusion into fast moving gas streams or onto drums spinning at speeds up to 100 m.p.h. Glass fibres for plastics reinforcement are made almost exclusively by the latter method, which yields a continuous filament, in contrast with the short " staple fibre " of the former. For marine purposes they are made from a low-alkali borosilicate glass ; this gives a fibre that is reasonably cheap, completely fire and rot proof, and has high resistance to moisture and chemical or microbiological attack. It has great strength and dimensional stability, and low extensibility. It has a specific gravity of about 2.5 and a diameter between 0.0001 in. and 0.0004 in. ; when Ariel undertook to " set a girdle about the earth in thirty minutes " he omitted to mention that he could do it with little more than a pound of glass filament. Its tensile strength runs from 180,000-300,000 lbs./sq. in., or up to five times that of structural steel. Figures as high as 2,000,000 lbs. (893 tons) per square inch have been recorded.

The filaments when extruded and attenuated are treated with a lubricant and size to prevent them from abrading each other, and to enable them to be drawn together into a cohesive but tack-free strand. The diameter of the filament, within the range available, has little effect on its strength. Its length, on the other hand, is critical, the strength of the laminate falling off abruptly with fibre lengths below about $\frac{5}{8}$ in. ; above this figure, the strength remains constant. This is due to the adhesion between the fibre and the resin becoming less than the tensile strength of the former ; the effect is so marked that the excessive mixing of a chopped strand/resin gunk (dough) may reduce its strength, by breaking down the fibres, to as little as 10%.

This strand, of 102 or more commonly 204 filaments, is the basis of all forms of glass reinforcement. The latter is available, in two main types : cloths, in which the strands, severally or together, are twisted up into yarn from which the cloth is woven ; and mats, in which the strands are bound together in short lengths and in a more or less random manner. The following is a brief description of the characteristics of these types of reinforcement.

Cloths

Cloths in general give high glass/resin and strength/weight ratios to the laminate. Weight for weight, they are considerably more expensive than mat. The strength/weight ratio of the laminate varies inversely with the weight of cloth used, except the impact strength which varies directly with the cloth weight. This is due to the crimp, or deviation of the yarn within the cloth, and is readily understood if the individual yarn is considered as a column under load.

The cloths vary in weight, in yarn, in threads per inch warp (longitudinal) and weft (transverse), in finish—of which more later—and in weave. By the strength of the cloth, in this account of weaves, I mean the strength that the cloth confers on the laminate.

Plain weaves, also known as square weaves, in which the warp and the weft go alternately under and over each other, offer uniformity of strength pattern and high impact strength. Drape qualities, or ability to accept compound curvature, are only moderate. Weave stability is good ; the regular interlock of warp and weft reduces to a minimum the slipping of the yarn and consequent irregularity in the reinforcement.

In all cloths, a fine yarn and close weave increase weave stability : decrease ease of impregnation, or wetting out.

Loosely woven plain weaves, with inferior strength and weave stability, but superior wetting out qualities, are also available and are known as Scrims.

Twill weaves, in which the weave, instead of going alternately under and over, " floats " over two threads at a time, offer better drape qualities, tensile strength and flexural strength, at the expense of weave stability and smoothness of the laminate surface.

Satin weaves are an extension of the twill weave, and have a standard float of 7 ends (warp) and 7 picks (weft). Due to the long float and absence of crimp it gives a laminate of great strength and stiffness. Drape and surface smoothness are excellent.

Mock leno weaves give an open fabric with the warp and weft drawn together in bundles. Weave stability and wetting out properties are excellent, even in the heavier weights. Strength is good, but the surface is strongly patterned.

Unidirectional weaves are made with a large number of heavy warp ends held together by a very light weft. They are used where all the strength is required in one direction, but may also be laminated up in cross plies to obtain any required characteristics in the laminate.

Woven roving. Continuous filament can also be woven, without being spun into yarn, into an easily wetted reinforcement of exceptional strength ; weave and weight can be altered to suit the application.

Tapes, commonly of plain weave, are also available and are useful for local reinforcement and occasionally in the making of tubes by wrapping round a male former.

Mats

In the second major form of reinforcement the strands are chopped into standard lengths of 2 in. and bound together in a random fashion. Binding is achieved either by mechanical interlocking of the strands or by the application of a resinous material, additional to the original size, which is itself soluble in the laminating resin.

Chopped strand mat is the standard reinforcement in marine use. It gives a laminate of all-round strength and is the most economical reinforcement in both material and labour costs, providing in one layup the equivalent weight of several layers of cloth. This thickness helps to give the stiffness which, for marine use, is more often required than outright strength. It has, when wet, the best drape qualities of any reinforcement, due to the solution of the binder in the resin and distintegration into strands, though trouble may be experienced in dry handling with marked compound curvature. It is readily obtainable in weights of from 1-2$\frac{1}{2}$ oz. per square foot in $\frac{1}{2}$ oz. increments, with a choice of pre-treatment. It is widely and satisfactorily used as the sole reinforcement in small hull manufacture.

Diamond mat is a variant in which the strands are laid regularly, crossing over each other at an angle of approximately 15 degrees, giving a mat of almost unidirectional strength without losing its other qualities. The angle of crossover, within the range available has little effect on the strength along the lay, which may be as much as thirty times the transverse strength. It is usually used in combination with ordinary mat.

Mechanically interlocked mat, or needle mat, has much superior dry handling and drape qualities. It wets out very easily, but some pressure is required to ensure a smooth interior surface, and it appears to offer little to the amateur.

Surfacing tissue mat, is an exceedingly fine and light mat that has been recently introduced for the intimate reinforcement of the gel coat, or finished surface of the moulding, to produce a tougher and more durable finish. It also helps, in the less opaque laminates—where, for instance, a clear colour precludes the use of normal fillers—to suppress the reinforcement pattern. It may be applied either with the gel coat, or on top of it ; the former gives the toughest finish and dispenses with the separate impregnation of the tissue, but the latter is likely to prove easier, especially with large areas and marked compound curvature. It is extremely cheap and should not be ignored if the highest quality of moulding is desired.

Chopped strands, without binder, may be had for gunks or doughs for the repair of holes ; they may also be used for moulding, but the strand should not be too short and the dough should be carefully mixed if strength is required in the laminate.

Rovings consist of a number of basic strands of continuous filament wound up parallel. Properly applied, they give the highest possible glass/resin ratio and unidirectional strength. They are mainly used for lapping into tubes, and due to their unsuitability for application to large surfaces seem to have little future in marine moulding.

Size, Binder and Finish

In the production of strand for mat the strands may be sized with a polyvinyl acetate and chrome or silane complex pretreatment which itself increases the bond between glass and resin and improves the wet strength retention of the laminate. For binding the strands into mat a resinous binder is used to give adequate dry handling strength without loss of the " key " promoted by the stranding size. Binders are classified by their high, medium, or low solubility in polyester resins ; mat for marine use is made with a medium solubility binder, to allow time before distintegration for thorough impregnation and to ensure sufficient softening thereafter for the mat to adapt itself to the contours of the mould.

For the greater degree of working involved in the making of cloth, an oil/starch size is required. This has an adverse effect on the bond between resin and fibre, and must be cleaned off by heat treatment or aqueous desizing. In this state an adequate bond will be attained for many purposes, but its further treatment with a chrome (Volan) or silane complex finish, or resin acceptor treatment, results in still further improvement.

With the silane treatment, dry strength is similar to that with the chrome, but wet strength may be increased as much as 30%, and be very little below dry. It is about 10% more expensive than the chrome, and is strongly recommended for marine use.

Improvements

The basic properties of glass leave little to be desired, and it would appear that improvements may be expected mainly in the finish, resulting in still further increase in bond and wet strength ; and in the form of the reinforcement, to give better drape and handling and a higher glass/resin, and hence strength/weight ratio with lower cost/weight. This is cumulative, and would allow of a lighter laminate for the same strength and, because of this and the lower resin content, the possible economic use of an epoxide resin—which would in turn give greater strength and so restart the cycle. This all savours somewhat of pulling oneself up by one's own shoestrings.

An interesting development is the experimental work at present being done with glass in thin ribbons. This gives a notable increase in glass/resin ratio, and may prove to be the most important advance in this field for some time.

Resins

Of all the resins used in combination with glass reinforcement only the polyesters have achieved general acceptance in the marine field. They are tough, rot proof, relatively cheap, easily worked and suitable for cold wet layup since they cure without the application of heat or pressure. The only other resins at present suitable for marine use are the epoxides, which offer markedly superior physical properties, but have not found much favour on account of their high cost.

Polyester resins are standard for boat building, as for cold wet layup generally, and are the most generally suitable of those presently available. They are supplied as transparent syrups, slightly heavier than water, and should have a storage (shelf) life of at least six months if kept cool and shielded from direct sunlight. A large number of resins are available, differing mainly in handling, impregnating and bonding qualities, and in hardness and brittleness when cured. *Thixotropic resins* are used for vertical or overhanging surfaces and resist drainage while curing. They may be mixed with other resins or, if a greater degree of thixotropy is required, used alone. Alternatively, *thixotropic pastes* may be added to normal resins.

Manufacturers market a wide range of polyesters for different purposes and supply comprehensive information about their properties. A typical specification may call for the use of perhaps 80% of one resin and the rest of one, two or more others, and they are usually very helpful about advising on and supplying these small quantities for specific purposes. Minor improvements and innovations are so common that specifications are constantly changing and can give rise to confusion.

Polyesters are thermosetting ; that is, they set to a hard, infusible, transparent mass as a result of chemical change following the addition of a catalyst and heat. For cold layup the necessary heat is supplied by the violent reaction between the catalyst and an accelerator (also known as a reactor or promoter). Temperatures as high as 200 C. have been recorded during cure. The time the resin takes to gel, or set to a soft but non-fluid state, varies with the quantity of accelerator and the temperature, and is commonly arranged for convenience at about 20 minutes. Cure is accelerated by the application of external heat. It should be remembered that the purpose of the accelerator is to supply the heat necessary for the catalyst to take effect. In a thin coat of resin, as in a gel coat, the high rate of heat loss may call for increased quantities of accelerator, unless the mould is heated.

In many cases, and according to manufacturers recommendation, the resin and all components except the catalyst may be made up into a stock batch and still retain an adequate shelf life. Heat will shorten the life of any resin, and even an unactalysed resin may gel if exposed to direct sunlight.

The fully cured resin may have the following properties : S.G. 1.2-1.4, tensile strength 1,000-10,000 lbs. sq. in., water absorption (24 hours) up to 2%. It is relatively brittle and may be readily scratched with a brass woodscrew.

Epoxide resins, or epoxy resins, offer certain notable advantages over the polyesters. They have excellent adhesion to most materials, including metals, glass and many plastics, and are very much harder and tougher. They may give a laminate with 50% more flexural strength and higher wet strength retention, both due probably to a better bond to the fibre. Like the polyesters they can be used for unpressurised cold curing, and have the additional virtue of negligible shrinking on cure. On account of their excellent adhesion they may be used for bonding preformed polyester/glass structures to each other or to other materials. They have very low flammability. They are inclined to be toxic and require ventilation during laminating. Different release agents are required, and Crystic and silicone varnishes and emulsions are recommended.

Unfortunately they are from three to five times as expensive as the polyesters, and have for this reason little application in the field of boat construction at present.

Chemistry of polyester resins. Ethylene glycol and succinic acid react initially (I am told) as follows : $HO.CH_2$, $CH_2.OH + HOOC.CH_2.CH_2.COOH$—$HO.CH_2.CH_2.O.CO.CH_2.CH.COOH + H_2O$, subsequent polycondensations leading to the formation of chains with the general formula $HO_2(CH_2\,CH_2.O.CO.CH_2.CH_2.CO.O)n$ with possibly small proportions of $CH_2.CH_2.O.CO.CH.CH_2.CO.O$.

Possibly indeed. How much happier the lot of the boat-builder than that of the organic chemist!

Ancillary Materials

Catalysts and accelerators : resin makers recommendations should be followed.

Fillers

There are three main reasons for the use of fillers :

1. To reduce the cost of the laminate.
2. To facilitate laying up.
3. To increase the stiffness and abrasion resistanceof the laminate.

A wide variety of substances have already been developed. China clay, chalk and alumina are commonly used and have the effect of increasing the stiffness of the laminate, its hardness and its weight, and of decreasing its cost and its shrinkage during cure. From translucent it becomes opaque and more or less white ; if pigments are added the fillers tend to dilute the colour to pastel. Certain fillers also affect the gelation time.

In addition to the above, special fillers are used to obtain qualities like fire-resistance, electrical conductivity, resistance to tracking etc., though these seem to have little application to marine use. I have also heard of a small firm moulding kitchen sinks who have developed their own filler which, they claim, gives the polyester the toughness of an epoxide ; though what it is, naturally enough, they are not divulging.

Some fillers, particularly the metallic oxides, impart to the resin a certain degree of thixotropy, though this is normally best achieved by the addition of a proper thixotropic paste. Tremendous properties are claimed for certain proprietary fillers ; undoubtedly the choice of filler, on structural, economic and ornamental grounds, warrants more careful thought than it sometimes receives, and there appears to be considerable scope for amateur research.

Release agents

There are many different types available, each with its own specific uses. *Fibreglass* moulds may be carefully polished with two coats of wax (a carnauba, like Simoniz, is considered best) and finished with a cloth very slightly dampened with Polyvinyl Alcohol solution (PVA). Wax alone is sufficient on *all-metal moulds* except for aluminium, which requires a special release agent as well ; wax should not be used alone on fibreglass moulds. *Plaster moulds* should be allowed to become thoroughly dry and sealed with shellac or repeated applications of wax, followed by the PVA solution. It is vital that the release agent should be scrupulously dry before layup is commenced. Quick-drying solutions of cellulose acetate are also of use for plaster and other porous surfaced moulds when speed is important.

For surfaces without compound curvature and for the repair of small holes, waterproof grade cellulose sheet may be used—it is used commercially for the production of translucent roof panels on moulds of corrugated iron.

Resin manufacturers will advise on and supply the necessary release agents.

Pigments

A very wide range of pigments is now available. Unfortunately, despite claims to the contrary, they are not yet in all respects perfect. Some are prone to fade or discolour with time, and some pale shades tend to come out in streaks on the moulding. Dark, clear shades preclude the use of normal fillers, and without fillers there is a tendency for the reinforcement pattern to show through, particularly with a poor gel coat. This is of course minimised by the use of surfacing tissue or cloth.

When no filler is used, approximately 5% of pigment, by weight, will be required ; where fillers are indicated, a considerably higher proportion will be needed to give a strong shade. Attractive shades can be had, but most fibreglass boats are readily apparent as such.

Pigment manufacturers are a little cautious about committing themselves to percentages and a little experimentation is often called for. They are however very helpful about supplying small samples for this purpose.

It should be remembered that the vaunted permanent finish will rapidly acquire no less permanent scratches, and trouble should be taken to match the colour of the main laminate as closely as possible with that of the gel coat. The practice of using colour in the gel coat only, or even on the inner surface of the hull as a " paint " coat, should be most violently eschewed.

Properties of the Laminate

Polyester/glass

The cured laminate has properties intermediate between those of the resin and the reinforcement ; it is hard, heavy and relatively flexible, with great strength, but relatively easily delaminated. It has a very high impact strength, commonly 10 ft. lbs. (notched Izod) or more ; figures as high as 70 ft. lbs. have been recorded. Its flexibility limits its suitability for compression loading unless it is stabilised by curvature or applied stiffening, and makes it ill-suited for large flat planes. It cannot be dented, and will either recover completely or fail. Although it may lose some strength through weathering this is likely to be offset by a gradual increase in stiffness that may continue for years after curing. It is unaffected by climatic conditions, and is believed to be immune to all sea borers, though some doubt exists in one or two localities. It fouls less readily than enamel or metal, and fouling may be readily removed—in the early stages with a nylon pot-scourer. Its water absorption is very low. It will survive extremes of rough usage, but is readily scratched. The surface, unless intimately reinforced, may be cracked or chipped by impact without structural damage, particularly where there is a tendency to resin richness as at the stem and edges of the transom ; sharp corners should for this reason be avoided whenever possible. When failure occurs, it is usually in the nature of a tear, with softening and delamination of the edges of the damaged area. Its fatigue resistance approximates to that of Duralumin. If subjected to prolonged load it may cold-flow (plastic deformation) especially on flat and unsupported surfaces.

The following table is based on average values for silane treated reinforcement, but is only a guide, and figures may in practice vary widely with different materials and techniques.

	Mat laminate	*Cloth lam.*	*Makore ply*
Specific gravity	1.6	1.9	0.75
Ult. tens. lbs./sq. in.	25,000	40,000	12,000
Ult. compr. lbs./sq. in.	25,000	34,000	6,000
Cost/lb.	5/-	8/-	2/-
Glass/resin (wt.)	1:3 appr.	1:1.5 appr.	——

The principal factor affecting the fibreglass values is the glass/resin ratio : the dry strength increases approximately with the square root of the glass content expressed as a percentage by weight. Wet strength, on the other hand, decreases with increasing glass content, though this is minimised by the use of a silane finish.

The laminate may be worked with a hacksaw, surform and metal twist drills, and sanded—though laboriously—by hand or by machine. It works readily and, except in the plane of the reinforcement, reasonably cleanly. It may if necessary be planed on the edge with a metal plane, but will rapidly blunt the blade and eventually groove the sole.

It is not recommended to use screws bearing directly on the moulding ; a sandwich construction is the ideal, with the laminate through-fastened between two pieces of wood and bedded in Seelastik or wet polyester and chopped strands. Where this is impracticable, round headed screws should be used, with washers. If bright-plated, these give quite a neat, bathroom appearance.

I have, nevertheless, seen ordinary screws countersunk into fibreglass and showing no signs of deterioration in any way after some years, but they were in every case quite lightly stressed.

Cured fibreglass is not particularly pleasant stuff to work. An edge can dig a painful groove in a careless hand, and the dust from sanding is pernicious stuff and it is advisable to wear a mask.

Epoxy/glass laminates are harder, stiffer, stronger and much more expensive. They have excellent wet strength retention and great resistance to delamination. Their principal use at present is for quantity-production moulds, where their great durability shows up to advantage.

Indications for Use

For small boat construction the main indications are as follows :

1. Where the higher material and mould costs are offset by reduced and only semi-skilled labour costs.

2. For survival under extremes of rough usage and climatic conditions.

3. Where hull shape is suited to simple moulds and inherent stiffness.

4. Where, except in very small craft, weight is not paramount.

5. For very small light craft, below about 8 ft. over all, where the marked curvatures and lower loads permit the use of a thinner skin and consequently low material, as well as labour, costs.

6. Where the superior appearance and feel of wood is not required.

7. For shapes that would be difficult or impracticable in wood.

8. For anyone who wishes to sail in a magnetic minefield.

In order to help in the choice between fibreglass and moulded ply, I have set down a comparison of some of their characteristics in tabular form, as follows :

Fibreglass	*Moulded Ply*
Cost approximately 5/- lb.	Cost approximately 1/6d. lb.
Mould expensive.	Mould cheap.
Same mould does many hulls.	Same mould does many hulls.
Mould labour heavy.	Mould labour light.
Very strong, flexible.	Very strong, stiff.
Tremendous resistance to piercing.	Good resistance to piercing.
Surface almost immune to other than light scratches.	Surface more readily damaged ; less so if plasticised.
Difficult to keep to minimum weights where light.	Usually lightest possible construction for small boats.
Takes up almost no water.	Takes up as much as 40% by weight with prolonged immersion and poor protection.
Readily repaired.	Can be tricky to repair.
Readily added to, bond imperfect unless with epoxy.	Readily added to, bond perfect if correctly done.
Often excessively flexible.	Pretty stiff for most uses.
Rot and borer proof.	Not prone to either ; borers seldom penetrate glue line.
May coldflow (deform).	Will not set or deform.
Finish mediocre and liable to scratches. Very tricky to repair.	Enamelled or varnished; blood, sweat and tears.
Feels " plasticky."	Elegant and grateful.

Some Design Considerations

The two dominant considerations in fibreglass boat design are the excessive flexibility of the material and the need for the hull form to be suitable for moulding. There seem to me to be three main approaches to stiffness, which I shall attack point by point :

1. " Designing in," by the use of curvature, simple or compound, and integral stiffening in the form of bulkheads, buoyancy tanks, bunks, etc.

2. Adding stiffness with ribs or extra plies, and

3. Increasing the skin stiffness by choice and arrangement of reinforcement, fillers, extra thickness, sandwich construction, etc.

1. In the use of *curvature* one is of course limited by the requirements of hull form. Simple curvature will help, but compound, even in small degree, has a much greater effect. Care should be taken, however, to ensure that the latter is not too slight, or " the last state of that man may be worse than the first " ; the skin, instead of being either adequately stiff or free to flex as it will, may in bad weather start bumping in and out like the sides of an oilcan with a noise and general effect that I can only describe, from first-hand experience, as heart-stopping.

A good example of *integral stiffening* is to be seen in the moulded side-deck buoyancy of the International 505 ; the side-deck, itself already necessary, provides also stiffening for the hull and buoyancy in the best possible place, both without extra weight or cost.

The idea of " designing in " stiffness is obviously attractive and offers great opportunities for simplicity, lightness, economy and ingenuity.

2. Before going into the actual methods of " adding " stiffness, we must examine briefly some of the principles involved. It is, for a start, fundamentally unsound to stiffen a weak skin with a rigid reinforcement. It results in the entire load, which should be shared between skin and stiffening, being borne entirely by the latter ; in the risk of severe damage to the skin in quite minor impact due to inflexibility and localisation of stress ; and in a tendency for the stiffening to project through the skin under hydraulic pressure to the marked detriment of appearance and, if transverse, performance. If this appears childishly obvious, I must apologise ; I have seen a shell by one of our leading moulders with an extremely flexible skin reinforced by four-inch-deep transverse diaphragms which stuck out like the ribs of a starved cow.

Should it be desired to utilise existing and rigid transverse members—bulkheads, for instance—they should bear mainly on longitudinal " stringers " moulded onto the skin proper. Rigid longitudinal stiffening will protrude no less, though it will of course be far less detrimental to both appearance and performance.

The normal method of stiffening boat hulls is by the addition of ribs and stringers moulded over formers of semicircular or rectangular section. These formers may be of a variety of materials including PVC paper, expanded metal, balsa and well-waxed soft rubber tubing. The latter may be withdrawn after curing. Since the resin makes an imperfect bond to itself once fully cured, not less than $1\frac{1}{2}$ in. of material should be laid each side of the rib proper.

It is a common practice to use wooden stiffeners (as opposed to formers) covered with a layer of the laminate. Since the covering laminate is in these circumstances normally both stronger and stiffer than the wooden core the latter contributes nothing whatsoever to the mechanics of the matter and merely tends to absorb water, adding further to its parasitic weight, and eventually to rot. Wood is commonly included in the laminate where anchorage is required for screws, as for instance in the hog to allow of the fitting of a keelstrip. If a treated wood is to be used care should be taken that it does not inhibit (poison) the resin. Some paint removers, incidentally, attack polyester very vigorously.

For heavily loaded fastenings it is best to embed a drilled and tapped metal plate in the laminate, spreading the load with stiffeners or extra plies.

3. The other attractive approach is through the stiffening of the skin itself by the use of a sandwich construction, or by the gradual improvements in the resins, fillers and reinforcements that are continually taking place. The use of epoxides in lieu of polyesters would also make a great difference. In larger hulls diamond mat might be laid up in crossplies to give an increase in specific stiffness of up to 60% over normal mat.

Unfortunately sandwich construction in the small sizes involves extra labour and the use of cloths to avoid unnecessary weight ; and if the weight is to be kept down to the minimum allowed by moulded ply construction the outer skin becomes so thin as to be somewhat vulnerable. Boats have been built with polystyrene or polyurethane foam between the skins, often at considerable expense, but the unpalatable fact is that, in the small sizes at least, a method of construction has still to be devised that will show any overall advantage over moulded veneer. Mr. Austin Farrar has built canoes with a skin thickness of 3/16 in. in moulded veneers ; this works out at a trifle over half a pound per square foot and will take a deal of beating. Many of those who speak of the simplicity of the sandwich construction would be agreeably surprised at the ease, speed, and simplicity of cold-moulding.

Passing on from stiffness to moulding considerations, we find that the main effect this has on the designer is to force him to make allowance in the hull form for its withdrawal from the female mould. This involves, with a normal mould, the provision of " draw " or taper, as in foundry work. Withdrawal may be greatly assisted by jarring with a rubber mallet and by the incorporation of compressed air nozzles in the mould.

If a tumblehome is required, a split mould must be used, and this is dealt with in the section on moulding methods.

A further consideration at this stage is the avoidance of sharp angles and edges, which are difficult to lay up and prone to resin richness and even a completely unsupported gel coat where the reinforcement bridges the corner. Careful tailoring of the reinforcement is required where sharp edges are *de rigeur*, as at the transom, and the use of surfacing tissue can also be of great assistance. The use of polyesters as paints on wooden members is to be deplored ; they rapidly crack, chip and flake off. Wooden inserts in stressed members relying on the endfibre adhesion of the resin are equally useless ; stresses should be carried by further reinforcements laid around or over the insert.

This seems to be as good a time as any for a little digression on—if I may be pardoned the phrase—the Morality of Design. Just how far is a designer justified in subordinating good looks to material considerations, and who shall define good looks?

To take the latter point first, there can be little question that the greatest single influence on accepted taste is that of familiarity ; the spoon bow, the Bermudian rig and the reverse shear, now often so pleasing to our eyes, were all in their time anathema to the faithful.

But not all will wish to conform solely to accepted standards ; design, from an aesthetic point of view, would stand still if they did. Fewer still, perhaps, will be prepared to sacrifice entirely all present concepts of beauty on the altar of efficiency—though, above the waterline at any rate, some rather exotic shapes could be employed to reduce windage. Functional and unaffected design must be at least valid ; if it is allied to a sense of line and proportion, the freak of today may well be the criterion of the morrow. On the other hand, the self-conscious aiming at " modernity," so evident in the exaggerated and usually pointless fins stuck onto so many runabouts, is deplorable. It is the Victorial concept of a weak basic structure embellished with pointless detail, and in a few years will surely look as ugly and dated as the early attempts at streamlined car bodies do to us now.

The yachting public knows what it wants, and it wants what it knows ; it may be led, but only slowly. He who will do so must be an artist, and even then it may be questioned how far he is justified in going at any one time. Some say that the ultimate in modernity stands as a shining example to the age (sic) ; others that, by losing touch with the mass of opinion entirely, he invalidates his work and ceases to have effect either on popular taste or on current design. An occasional eye opener keeps the blood running, but it may be that a man's place is in the van of his own age rather than in someone else's age altogether, whether past or present.

This is a problem for the individual designer ; he sails between the Scylla of a timid subservience to his public and the Charybdis of the merely esoteric. The economics of the matter are plain enough; the merits less so.

And finally a word about " feel." Quite apart from appearance it is most important to include wooden members in a fibreglass boat if it is not to feel like a plastic bath. In open boats even mahogany gunwales and thwarts can make an enormous difference and alter the whole character of the craft. A fibreglass boat with a wooden deck may be elegant and graceful where the same craft with a fibreglass deck feels—and looks—like a public convenience.

Moulding Methods

There are of course two main methods of producing a fibreglass hull : directly off a male mould, or indirectly off an intermediate female. For large boats it may be more economical to make a wooden female, commonly of plywood strips on battens and stripmetal frames, which can be dismantled for storage, but for the size of hull with which this article is concerned it will normally be best to use a plaster male and a fibreglass female. A direct female mould of plaster is also occasionally practicable.

Despite the complication and cost of a female mould, authorities on both sides of the Atlantic are unanimous in recommending it. The essence of the matter is that fibreglass accepts the surface finish of its mould, and it is of course the outside of the hull that needs to be smooth. A smooth inner side is not merely unnecessary but possibly actually worse than a rough one, which affords an excellent grip even when wet and is not spoiled by normal wear and tear.

There appears at first sight to be much less work in moulding the hull on a male, but this is less apparent in practice. The natural roughness of mat usually forces the builder to use several laminations of more expensive cloth for the equivalent strength and stiffness, and the extra cost may even exceed that of the additional female of mat. Nor are his troubles over yet ; the necessary overlaps of the cloth cause bumps over and above the cloth texture and must be sanded out, which takes a deal of doing.

Even then, he is faced with problems in finishing. He may use a final layer of cloth and accept the poorer finish, or he may apply a thick coat of resin and expect brittleness due to the mediocre adhesion and lack of intimate reinforcement. It may be that surfacing tissue could be of advantage. A further method is to fill and enamel the hull in the normal way, and this may in the end be the most generally satisfactory.

With a female mould, on the other hand, the shaping and surfacing of the final hull is done on the easily worked male and the final moulding, apart from shrinkage, is a true replica of the original. Materials for both the female and the final moulding may be chosen for strength, convenience and economy, and it may prove not only more satisfactory but quicker and even cheaper in the end.

Mould Construction

The first stage, whether for the making of an intermediate female or for the direct moulding of the final hull, is the construction of a male. Where the male moulding method is to be used, the only differences are that surface finish is unimportant and allowance must be made in the mould for the thickness of the final moulding. Tumblehome may be incorporated, but the mould will then have to be destroyed to free the moulding.

The male mould will in any case normally be of plaster on a wooden framework and mounted on a substantial wooden horse ; two $2\frac{1}{2}$ in. x 5 in. beams of any cheap, reasonably stable wood will do. These are best mounted, on edge, on legs ; they should have enough overlap at each end to minimise sagging in the span ; 2 ft.-3 ft. transverse spacing is suitable. If the floor is uneven, it is worth while marking the position of the legs on it.

Crossmembers, about 2 in. square, are then put at each station, all forward of the midship section lying for'ard of their line, and all aft, aft. They are then planed exactly level, and a taut line is carefully used for checking them and for marking in their centrelines.

Sections, preferably of thick ply, are next cut out exactly to the plans, with *all* reference lines marked in ; a bushman saw blade makes an admirable fairing batten. They are lightly screwed to centres of the crossmembers, aligned vertically by eye with panel pins along the hog, and tightened down. They will now be mounted with one edge to the finished surface of the mould, and the other below it rather than proud, (see Fig. 1).

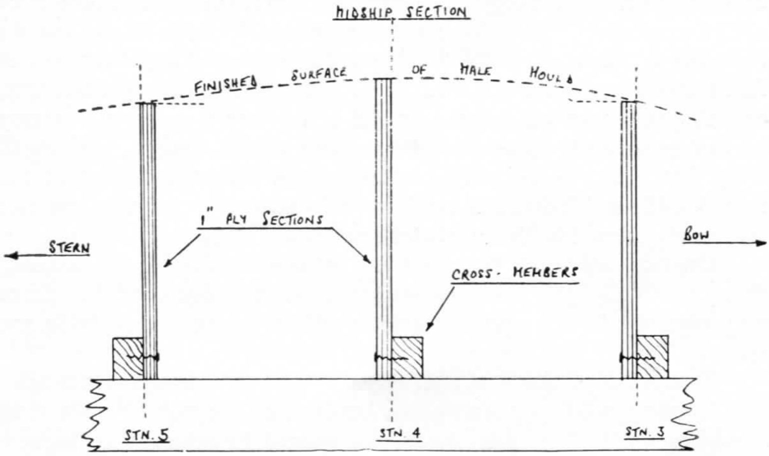


Fig. 1 *showing method of positioning sections*

Stiff wires may now be run through holes in the sections to provide a base for the plaster layup, which is extremely strong and need not be very thick. Hessian or expanded metal is then laid over the wires followed by plaster-soaked fibre mats. Slow-setting plaster of paris is ideal ; it costs about 3d. a pound and 60 lbs. sets to approximately one cubic foot. More plaster is applied over the mats in layers of decreasing thickness, fairing each with a spline across not less than three sections at a time. The final coat of plaster should be very thin and should just cover, and be quite fair between, the sections. The mould is then most meticulously sanded to absolute accuracy and smoothness, and sealed with shellac varnish before applying the release agent.

To ensure a solid edge to the moulding it is necessary to allow an overlap of a few inches at the sheerline. The sheerline must be defined either by marks on the mould or by leaving a constant excess to be trimmed off ; to mark a sheerline on a shell off-mould is a truly Oriental conundrum.

The female is then laid up over the male in a normal manner. After curing, and before release from the male, scrap glass and resin is used to bond on frames of ply or scrap timber to keep it to its true shape and to provide a base for it to sit on. The female should be thick enough to ensure fairness between the stiffeners.

Where a tumblehome is required on the finished hull, a split female mould is necessary. The mould should normally be split longitudinally with flanges moulded onto each half. Moulds can be split transversely, but a joint mark that would be unnoticed on the keel-line is most unsightly passing around the hull. There was in fact a canoe in the last Boat Show with its deck moulded in this way, and the joint was very apparent and in no way decorative. It may be that some form of expendable gasket could be devised, perhaps of wax, that could be polished perfectly flush with the surface of the mould with a cloth moistened in solvent. Split moulds are not commonly used for the production of boat hulls.

On removal from the male the female should have a smooth, glossy surface. It is, however, not yet quite ready for use and requires very careful sanding with the finest wet-and-dry before applying the release agent.

The finish of the final hull depends entirely on that of the male and female moulds. Nothing can be done to the finish on the final moulding and no trouble should be spared to achieve the highest possible standard on both.

LAYUP

1. PREPARATION

Working conditions

For reliable results a steady temperature of 65°F. should be aimed at. Workshop and reinforcements must be absolutely dry and reasonably draught-free, and layup should be avoided in damp weather.

Tools required are simple and relatively inexpensive. Components of the resin mix must be accurately proportioned ; a small spring balance will do nicely for resins and fillers but will not be sensitive enough for catalysts and accelerators. It may be more convenient to measure these by volume, but whatever method is used accuracy is essential for consistent results.

Very thorough mixing is also necessary and an electric drill with mixing tool attachment is very convenient ; the high-speed fluted disc type is very good and introduces the minimum of air.

Brushes and rollers are used for working the resin into the reinforcement and consolidating it to eliminate air pockets. Ordinary paint brushes will do, but rollers should be of the wirecage, ribbed, "hedgehog" or split washer variety to avoid lifting the wet laminate. A rubber squeegee is also useful for initial spreading.

All tools must be cleaned before the resin cures ; hot detergent solution, styrene or cellulose thinners may be used but must be carefully dried out of brushes before they are used again.

Precautions

Many substances can inhibit (prevent from curing) polyesters ; among those more likely to be met with are hard rubber, resorcinol glues, some copper salts and even small traces of moisture. Various sorts of composition board can also give trouble, and many catalysts and accelerators may inhibit, and inhibitors catalyse, in excessive and highly specific concentrations.

The accelerator must be thoroughly mixed with the resin before the catalyst is added ; under no circumstances may they be allowed to come into direct contact as they are violently and even explosively reactive.

When fillers are used the resin mix should be allowed to stand for some hours before adding the catalyst, to ensure thorough wetting of the filler particles.

Draughts, direct sunlight and localised heat or cold in any form should be kept off the moulding during layup for fear of uneven curing and the appearance of " orange-peel " and other stress marks on its surface.

The moulding should be left in the mould for at least 12 hours after curing, and should not be subjected to severe stress for at least five days unless heat is used to hasten maturing. Polyesters, in common with most commercial chemicals, may cause dermatitis and a barrier cream should be used for the hands.

2. RESIN MIX

Proportions vary with the job in hand. No fixed rules can be laid down, but the following table may serve as an indication :

Resins	100 parts/wt.
Catalyst	1-3 parts/wt.
Accelerator	1-3 parts/wt.
Fillers up to	50 parts/wt.
Monumeric Styrene up to	10 parts/wt. to dilute and extend if required.

Pigments and Thixotropic paste as required.

It may be noted at this point that a thixotropic resin mix is not merely more viscious, but has the unusual and useful property of being thick at rest and thin in motion. The working it gets during application thins it and makes it impregnate readily, but as soon as this ceases it rapidly thickens again and resists drainage even on overhung surfaces.

If fire-retarding properties are required, 5-15% each of finely ground antimony oxide and a chlorinated hydrocarbon such as Aroclar or Cereclor, based on the total resin mix, can be added.

A major cause of variation in the laminate properties is uneven application of the resin. It should ideally be spread by weight per square foot, and the following table gives an idea of the approximate amount of mix required for the normal laminating processes :

For gel coat	$1\frac{1}{2}$-2 oz. per sq. ft.
Surfacing Mat	1-$1\frac{1}{2}$ oz. per sq. ft.
Glass cloth	$1\frac{1}{2}$-2 times glass weight
Woven rovings	$1\frac{1}{2}$-2 times glass weight
Mat	2-3 times glass weight

Gelation time is controlled by the quantity of catalyst and accelerator, though the proportions of one to the other normally remain constant. Fillers and pigments may increase it and it is decreased by higher working temperatures. It should be remembered that the function of the accelerator is to cause the necessary heat, by its reaction with the catalyst, to allow the latter to cure the resin, and anything that causes a change in the temperature of the mix will affect this process. A gel coat, due to its high rate of heat loss, is given an increased quantity of catalyst and accelerator ; while the heavier the reinforcement being applied the greater the heat that is likely to be generated and the smaller amount of each that is required.

The more skilled the worker the shorter the gelation time that may be employed ; $\frac{1}{2}$-1 hour is normal, and no more should be catalysed than can be used up within this time.

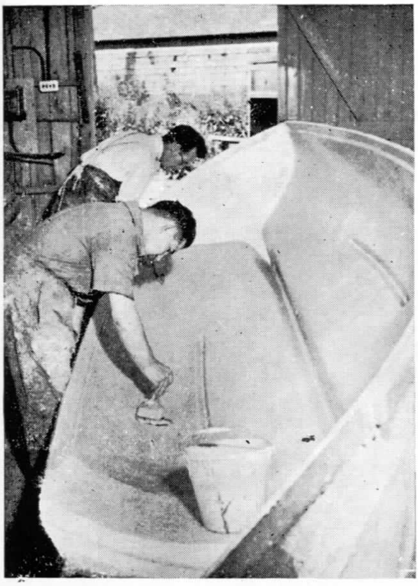
Normal Wet Layup Sequence

1. Final release agent, usually PVA, is applied very sparingly and thoroughly dried off.
2. The glass reinforcement is tailored to shape ready for use.
3. Either

(a) The special *Gel coat* mixture, according to makers' specification, is applied all over the mould as evenly as possible. A thickness of 0.012 in. is to be aimed at, and application by spray is ideal ; if brushing is used instead, it should be carefully laid off (crossed) like an enamel. On the evenness of the gel coat depends much of the finish, durability and colour of the final surface, and care at this stage will be well repaid.

or

(b) If the *Surfacing Mat* method is being used, a heavy coat of the ordinary laminating resin mix is applied to the mould and the surfacing tissue pressed into it. Careful consolidation is of the greatest importance to eliminate air bubbles and ensure a good finished surface.



" *Layup in female Mould ; note tilted mould for ease of application and reduced tendency to drainage, also integral bilge rubbers.*"

"*Layup in female Mould; note stiffeners on mould and mould surplus above sheerline.*"

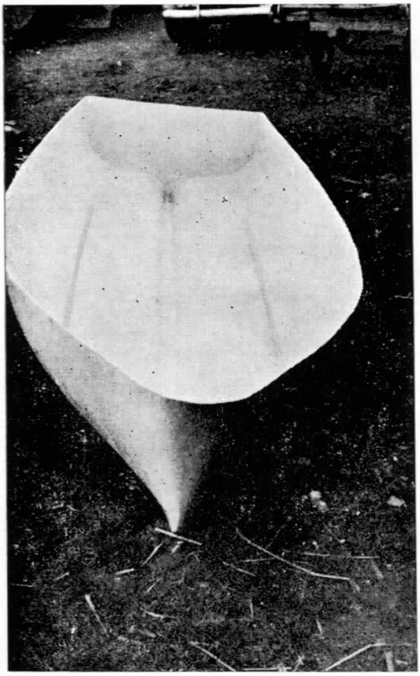
4. *The main laminate* is now built up as follows : a thick coat of resin is applied to the part-cured gel coat by spraying or by a stippling action with a saturated brush. The reinforcement is pressed into this and rolled down most thoroughly, and more resin applied on the outer surface as required, with any combination of pots, sprays, brushes, rollers, wedges, squeegees, fingers and bits of stick suited to the dire necessity of the moment.

This process may be repeated indefinitely if the laminate requires it and the nerves can take it.

5. Stand back and admire handiwork. Weep, gnash fangs, tear hair and vow to prepare thoroughly and follow instructions next time.

Dry Layup

Another method is fortunately available, using reinforcements which are supplied already impregnated with the complete resin mix except accelerator. They have initial tack, which helps in positioning them in the mould, and have the advantage of an exactly predetermined resin content. Unfortunately the range of resin mixes and pigments is limited and they are much more expensive ; they also require a heated mould for curing and have found little favour in the marine field.



" *Finished shell* "

"*Operator moulding separate gunwales*"

Repairs

Sooner or later you may be unfortunate enough to be faced with repairs to the fibreglass shell which—ever one to profit from experience—you have bought from a reputable manufacturer.

There are three likely degrees of damage :

1. *Severe bruising* and softening, with whitening of the resin due to crazing. The interior surface should be thoroughly roughened and an overlay, or tingle, of mat bonded on with the normal laminating resin.

2. *Localised cracks* are more likely in thicker laminates. They should be forced open and filled with a resin mix containing a higher proportion of catalyst and accelerator than normal.

3. *Broken stiffeners* may be caused by collision etc., or even by the impact of waves, particularly when the member is too stiff for the skin, and should be treated as for bruising.

4. *Holing*. The main damaged area should be cut back to sound laminate. Small cracks surrounding it are filled and left to cure as in item 2. The hole is then chamfered away from the inside, and the surrounding edges roughened and cleaned. Cellophane sheet, backed with cardboard, is held against the outside of the shell in the curve of the skin and a normal laminate, overlapping the damage by at least two inches all round, is applied from the inside.

Should it be impracticable to work from the inside, the repair may be applied from the outside leaving an excess thickness to be ground down to shape after curing.

Faults

Though most common sources of faults in the final laminate have already been mentioned, the following brief list is included for convenience :

Fault	*Cause*
" Orange peel " or other surface defect of like type.	Uneven curing: draughts, sunlight, uneven gel coat, etc.
Surface breakdown.	Release agent inadequate or damp.
Resin stays tacky.	Inhibited, usually by damp. For inside surface tackiness only, wipe with acetone or scrub with Vim or similar.

Fault	*Cause*
Laminate lacks strength, stiffness, etc.	Look to standardisation of materials, proportions, working conditions, applied weight and technique.
Resin starvation.	Poor consolidation.

Costs

The following figures are approximate only and are included only for initial guidance :

Mats, silane finish, 5/- lb.
Surface tissue, £3 per 100 yds.
Polyesters, around 4/- lb.
Epoxides, 10/-, £1 per lb.
Slow setting Plaster of Paris, £1 per cwt.
Fillers usually around 4d. per lb.
Preimpregnated materials up to twice normal cost.

Acknowledgement

My thanks are due to my grandmother for reading this manuscript and for her summing up :

" I don't understand one word of it."

Appendix. List of Suppliers

Resins

Bakelite Ltd., 12-18 Grosvenor Gardens, London, S.W.1.
BIP Chemicals Ltd., Popes Lane, Oldbury, Birmingham.

Reinforcements

Turner Brothers Asbestos Ltd., 14 Finsbury Circus, E.C.2.
Fibreglass Ltd., Ravenhead, St. Helens, Lancs.

Fillers

Witco Chemical Co. Ltd., Bush House, Aldwych, W.C.2.
Croxton and Garry Ltd., 16-18 High St., Kingston-on-Thames.

Colour Concentrates

Reeves and Sons, Ltd., Greyhound Works, Lincoln Road, Enfield, Middlesex.

Fire Retardants

Monsanto Chemicals Ltd., Monsanto House, 10-18 Victoria Street, S.W.1. (Aroclor).

Associated Lead Manufacturers Ltd., 14 Finsbury Circus, E.C.2. (Antimony oxide).

Polystyrene Foam and Polyurethane Foam-in-Place plastic

Baxenden Chemicals Ltd., Paragon Works, Baxenden, Nr. Accrington, Lancs.

Open Rollers

Shawcraft, Iver, Bucks.

Barrier Cream

Rosalex.

Wax (for release agent)

Simoniz or Car Plate.

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