The C-Flex® Manual

FEATURES

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PREFACE

Because of the great adaptability of C-Flex®, there are many different approaches to consider when determining a construction method for a C-Flex® project. In the development of C-Flex®, Seemann Composites Inc. experimented with a broad range of construction techniques, many of which are practical for our uses, and some that could provide a good alternative for projects with a particular nature. The intention of this manual is to give some insight into the different capabilities of C-Flex®, while limiting it to a discussion of the basic approaches that are most suitable for a majority of boatbuilding projects and the fundamental information that can direct a builder through the fabrication of a C-Flex® structure.

Our objective is to reach the broadest possible spectrum of readers with this one book. We have included technical information for the experienced designer, as well as suggestions and outlines for the amateur. We have done our best to provide sketches and photographs to illustrate the text, and we hope that both the professional and novice reader alike will find the information presented here clear and concise.

This booklet is not intended to be a "complete boatbuilder's manual." There are countless sources that can be consulted for thorough and in depth information on working with fiberglass, lofting, building bases and framing interior finish, engine installation, etc. There is a brief recommendation of some sources that may be useful to any builder, found in the appendix.

We must express our thanks to builders and designers who have worked with us closely and patiently to help us in our development of the C-Flex® system. Our appreciation is directed towards many people, but we would especially like to single out Dave Sintes of Sintes Fiberglass in New Orleans, and Tom Dreyfus of New Orleans Marine, for their willingness to translate our ideas into practical applications in their construction shops. A large part of the C-Flex® building system evolved directly from Tommy's and Dave's efforts, and their contributions have certainly been instrumental in making C-Flex® a viable construction medium.

INTRODUCTION

There are obviously many advantages of glass reinforced plastics (GRP) that have made it such a vastly popular and lucrative construction medium. With GRP, strong and durable yet lightweight structures that require minimal maintenance can be fabricated. In addition, the versatility and accommodating nature of fiberglass reinforcements has made it possible to fabricate complex shapes out of GRP. However, the same traits that make fiberglass reinforcements so "workable", i.e. their softness and pliability, have made it necessary to use a full surface mold to shape the material in or over. The need for a mold, while an advantage to a company producing many pieces from the same mold, makes it extremely difficult and expensive to fabricate "one-off" custom-built structures of GRP.

After considerable research into custom building techniques, Seemann Composites Inc. has invented a fiberglass reinforcement, C-Flex® Fiberglass Planking, that has had a radical impact on "one-off" fabrication. The C-Flex® system is a unique development in glass reinforced plastic construction that may be utilized in a broad range of applications for the quick fabrication of low cost, low maintenance, custom-built structures. Among the many applications, C-Flex® has been used to build storage tanks, automobile bodies, sculpture, and of course, boats of all sizes and types. The use of C-Flex® is widely varied but the procedure involved is basically the same in all building applications, so it is our intention to illustrate the general nature of the material and the distinct advantages of the system by outlining the process followed in boatbuilding.

PHYSICAL PROPERTIES

C-Flex® is a unidirectional fiberglass reinforcement that is manufactured in long (250' or more), 12" wide "planks" in two grades. The heavier grade, CF-65 (CF-21), is used for most applications including cruising boats of all sizes, fishing boats, industrial items, etc. The lighter grade, CF-39 (CF-13), was developed for lightweight racing boats, canoes, and other special applications where light weight is important. (Refer to Table 1).

C-Flex® contains rigid rods of pultruded GRP (much like fishing rods) on 1/2" centers which give it a self-supporting nature when spanning an open framework. The rods have a very high glass/resin ratio, which means they impart high strength qualities to the structure in the direction which they run. The spacings between the rigid rods are filled with unsaturated strands of continuous fiberglass rovings, and when saturated, these also become excellent unidirectional reinforcements. A light fiberglass cloth holds the material together and gives C-Flex® the ability to bias, which enables it to follow the exact contours of most surfaces and to conform to compound curved shapes, such as round bottom boat hulls. Since C-Flex® retains a natural flexibility in all directions, no special tools such as heating ovens are needed to work with the material.

TABLE I PHYSICAL PROPERTIES OF C-FLEX®

	CF-65	(CF-21)	CF-39	(CF-13)
WIDTH	12"	(30.5cm)	12"	(30.5cm)
THICKNESS	.125"	(318mm)	.080"	(2.03mm)
MAXIMUM RECOMMENDED SPAN	18"	(45.8cm)	14"	(35.6cm)
WEIGHT (lbs/sq ft)	.5"	(2.1kg/m)	.33	(1.3kg/m)
RESIN REQUIRED (lbs/sq ft)	.4"	(1.68 kg/m)	.26	(1.05kg/m)
GLASS/RESIN RATIO	1/1	1/1	1/1	1/1

MECHANICAL PROPERTIES [1]

Although C-Flex® was originally developed as a simple method for building one-off boats, its strength properties as a unidirectional reinforcement have proven equally important. C-Flex® has been tested by itself and also in combination with chopped strand mat and woven roving reinforcements, and the results of the tests have shown a high tensile strength and modulus for the C-Flex® in the direction that the rods run (Warp[2]). For this reason, when oriented fore and aft in a boat hull, C-Flex® has been highly effective in increasing the longitudinal stiffness of sail and power boats.

How this property of high tensile modulus can improve a structure is well illustrated by "Swampfire", the 1974 3/4 Ton World Cup Champion. With a total displacement of 9,250 pounds, "Swampfire" has approximately 5000 lbs. of lead in her keel, meaning a ballast/displacement ratio of 54.2%. In spite of her lightness, (some of her competitors at the 1974 World's competition weighed as much as 1000 lbs. more), the apparent stiffness of her hull was so impressive in the heavy swells of the Gulf Stream, that a comparative test to measure the fore and aft deflection was run between "Swampfire" and conventionally molded GRP 3/4 Ton competitors. With "Swampfire", the amount of deflection was only 1/8", while on the more heavily constructed, molded hulls, the deflection was twice as much. Thus, C-Flex® does effectively increase the overall longitudinal stiffness and strength of a hull, and this fact should be taken into account when designing scantlings and structural reinforcements for a boat to be built of C-Flex®.

[1] see Appendix 1, Mechanical Properties

[2] see Appendix 1, Table 2

FRAMING

C-Flex® is used as a planking over a simple open framework, often very similar to the type used in traditional wooden boatbuilding. The framework should be constructed so that the material is supported by frames or lightweight battens running at approximate right angles to the rods. Since the material is usually used longitudinally, the framework should have transverse frames to support the material. Maximum recommended spacing for transverse frames is 18" on center when using CF-65, and 14"on center for CF-39. Close spacing of the lightweight frames provides a temporary support for the C-Flex® and laminate, and depending on the framing procedure followed, many or all of these frames may be removed from the completed hull.

There are basically three approaches to constructing a hull with C-Flex®:

1. **TEMPORARY FRAMEWORK**

Building over temporary wooden framing is a simple, straightforward procedure that is best for small hulls, because they don't need permanent framing. The first step here, as in all three of the framing procedures, is to set up a solid, level building base. Next, the builder should erect the temporary wooden frames on the building base, making sure that their alignment is as accurate as possible. The edges of the frames are then taped so that the resin will not stick to the wood and the frames can be removed easily from the completed hull. With the framework set up and aligned properly (faired), the builder is ready to start planking the hull with C-Flex®. Generally, planking begins at the centerline on round-bottom hulls and at the chine on vee-bottom boats, with the planks running longitudinally (fore and aft) over the framework in full length pieces.

After the C-Flex® is in place and wet out with resin, the outside laminate is finished and the hull is faired and then turned over. The hull shell is then braced from the outside, the temporary frames removed, and any "dry" areas of C-Flex® should be wet out with resin. The C-Flex® will then need to be sanded lightly to grind off staples, burrs, etc., and have the inside laminate applied. After the interior laminate is completed, the structural framing (bulkheads, stringers, etc.) can be constructed inside of the shell and bonded in place with fiberglass. In some cases, it may be practical to apply the interior laminate and permanent framing while removing only a few of the temporary frames at a time. This eliminates the need for a complex cradle to support the unstiffened hull shell.

Temporary framing is initially the cheapest approach when building just the hull or deck shell, and it is therefore the best way to build a male plug from which a cavity mold can be made. It may also be a good approach for an amateur who has limited funds to get started on his project. By using temporary framing, a minimal amount of preplanning is required because special problems can be worked out with the bulkheads and framing members positioned to suit after the hull is finished. In addition, the temporary framing may be saved so that it can be reused to build additional hulls, thus defraying initial set-up costs with subsequent hulls.

However, since all of the temporary frames have to be removed before work can begin on the interior of the hull, a cradle is required to hold the hull shell in shape. It may also take more time to position the bulkheads, frames, etc., inside the hull shell than it would if they were included as part of the building framework. For these reasons, we recommend fabricating larger boats and other structures directly over bulkheads and other permanent framing.

2. **PERMANENT AND TEMPORARY FRAMEWORK COMBINED**

This alternative could be the best approach to C-Flex® construction when considering material costs, labor, and end product. This technique incorporates the permanent structural framing into the framework, with only a few temporary additions, relative to the project, needed to properly define the shape of the hull and meet the recommended frame spacing requirement of 18" for the CF-65 and of 14" for CF-39.

Large fiberglass boats need an internal framing system in order to be efficient structures. When they are designed with little internal framing, the hull shell must be made very heavy to take the stresses. This is expensive from a materials cost standpoint, and is inefficient from a weight standpoint. For many designs it may be more economical to develop an efficient framing system in which the frames can be made up outside of the boat and assembled in a skeleton form right on the building base rather than building them inside of the fiberglass shell. It demands more preplanning to know exactly where the bulkheads and frames will go, and more lofting skill if the boat is not built from full-size patterns, but this approach could represent a considerable cost and labor savings. Time and material that would be lost on discarded temporary frames can instead be used for the permanent stiffeners[3].

In a hull requiring bulkheads or transverse framing, these permanent members are fabricated in the initial stages of construction. They are then set into their designated positions on a sturdy building base along with intermediate temporary frames. These lightweight intermediate frames are necessary to support the C-Flex® within its maximum recommended span. For instance, if a hull is designed with permanent frames

[3] See Appendix 2 - Hull Framing Systems

On four-foot centers, then two temporary frames on 16" centers would be required between each pair of permanent frames. This would provide the minimal framework to support the C-Flex®, and when the laminate is finished and the hull turned over, the temporary frames would be removed.

If the structural design calls for longitudinal stiffeners, prefabricated longitudinal stringers of either wood or lightweight hollow hat sections of fiberglass may be laid in place in notches in the frames. The wooden stringers would be attached to the hull skin with mechanical fasteners (as detailed in the third framing section), while the fiberglass stringers would be bonded to the hull skin with angles of mat and woven roving when the hull is turned over. For wooden stringers, those made from hard woods should not be covered with fiberglass because the expansion of the wood from moisture absorption may rupture the fiberglass encasement. Most soft woods may be covered with fiberglass however, because their expansion strength is usually lower than the strength of the glass. Because of the possibility of moisture absorption and rot, we feel that any wood totally encapsulated with fiberglass should be considered as non-structural, and the fiberglass covering should be strong enough by itself to handle all structural loads.

When building over a set of temporary transverse frames on 14" or 18" centers, the C-Flex® is attached directly to the frame edges. For this reason, the edge of each frame must be faired into the complete framework. If the lofting and the fabrication of the frames are done carefully and accurately, fairing the frames should not be very time consuming. If however, the frames are rough and obviously unfair when erected, then some effort will be required to fair the framework.

Another approach, involving building over permanent stiffeners, eliminates most full size temporary transverse frames and simplifies the task of fairing the framework. First, the bulkheads, permanent transverse frames, longitudinals, etc. are set up on a stable, level building base. Then, temporary wooden longitudinal (fore and aft) battens (ribbands[4]) are attached to the frames on approximate 18" centers (or as required to define hull shape). Instead of having to fair (align) the frames according to the full edge of each frame, it is only necessary to work with the spots where the ribbands cross each frame. For a low spot, the builder shims up the ribband, while for a high spot, he merely grinds down the frame. With the "fairing" ribbands in place, transverse battens (running from centerline to sheerline) of either stock 1/4" x 1 1/2" wooden laths or 1 1/2" to 2" wide strips of C-Flex® are attached on the necessary spacings to support the planks of C-Flex®. Using wooden

[4] Ribbands-- Long narrow strips of wood attached longitudinally to frames of boat to temporarily hold framing members in position during construction.

battens is preferable because it allows that the C-Flex® planks may be stapled over them, while with C-Flex® battens, the planks would have to be wired in place. However, C-Flex® strips may be useful as transverse battens in areas of tight curvature, as the C-Flex® is more flexible than the wooden battens and will follow a fair curve where the wooden battens would break. With the longitudinal fairing ribbands and the transverse battens in place (both of which may be removed from the hull upon completion), the framework is ready for the planking to begin.

An interesting option when building over permanent framing for some particular designs is to set up a temporary deck building base, build the deck upside down, and then set up the bulkheads and frames directly on the deck.[5] The deck, whether single skin or balsa core, is planked with C-Flex® first, with the rest of the reinforcement following just as in hull construction. When the deck laminate is finished, deck beams and stiffeners may be fabricated onto the upside down deck. It is best to do as much finishing work as possible on what will be the underside of the deck now, while the deck is upside down. With the deck work completed, bulkheads are glassed in place on the deck, and the hull construction proceeds as detailed. Thus the deck simply becomes the building base for the construction of the hull. This method allows for a substantial labor and material savings in the building procedure and eliminates much uncomfortable and messy overhead work. Having the bulkheads, stringers, etc., already built into the hull will make the shell stiff and strong before it is turned over and no more than a simple cradle or blocking will be required to hold it upright while the boat is being finished. Also, there will not be any distortion, as occurs when removing a temporary framing system from a hull and fitting the permanent stiffeners afterward. Because there are fewer temporary frames to throwaway and no elaborate cradle to construct, little material will be wasted, thus adding to the overall efficiency of the project.

3. **TRADITIONAL WOODEN FRAMEWORK**

C-Flex® may also be used over fully permanent wooden frames. Here, the framing is erected in the same traditional manner of a planked wooden boat, but C-Flex® is used instead of wood for the planking. The rest of the shell laminate is laid up entirely on the outside surface, stopping before the last layer is applied to fasten the shell to the framework. This is accomplished by drilling pilot holes through the hull shell to the frames. Corrosion resistant mechanical fasteners (screws or anchorfast nails, etc.) are then used to bond the shell and framework together, with a final lay-up covering the

[5] For deck construction see Appendix 6

heads of the fasteners. No fiberglass bonding angles are required between the hull and framing when the hull is turned over, because of the mechanical fasteners. After the hull is turned, any dry areas of the C-Flex® should be wet out with resin. On some light laminates, to develop greater bi-directional strength on the inner surface of the hull, the builder should lay up a mat/woven roving combination over the C-Flex® between the frames on the inside. In any case, there needs to be at least a fiberglass mat laid up over the C-Flex® on the inside of all hulls.

In this approach to framing and construction, traditional boatbuilding skills can be applied to build the framework, and a minimum amount of fiberglass skill is required to do the "planking". In fact, more woodworking skill is needed for this approach than in either of the others. The fiberglass hull shell will be seamless, leak proof, and require little maintenance. Although the depth and number of frames may slightly take away space from the interior dimensions of the boat, this approach maintains the aesthetic look and feel of a traditional wooden boat on the interior. Also, the interior joiner work is easier to install because there are wooden frames to attach to. Because the boat is built right over the structural frames, there isn't any of the wasted material that comes with temporary framework.

Important Point to Consider:

For each boatbuilding project there are naturally special considerations which will help determine the best framing method. However, no matter which approach is used, the builder should make sure that after the framework is erected, he checks the fairness of the hull shape with a long batten and makes adjustments wherever necessary. The batten should touch each frame in a smooth line or arc and without any distortion. The finished hull will only be as fair as the framework, and the initial fairness will reduce difficulty throughout the duration of the build and help to determine the effort required for the final surface finish.

APPLYING C-FLEX®

As mentioned earlier, because of its high strength along its length, C-Flex® reinforces the critical longitudinal stress areas of the hull when it is run in a fore/aft direction. This fact is especially important for light laminates where the C-Flex® will be an essential part of the structural strength of the laminate. The C-Flex® should be applied in planks that span the full length of the hull and never using short pieces butted end to end. This is necessary to prevent fairing problems and weak spots relative to the rest of the hull. A builder should not concern himself with trying to conserve material in this way because there will, in fact, not be much material wasted. When using full length planks cut from 250' rolls, the left over short pieces can be used in the transom, in the deck, or at the centerline or sheer, where the material begins to run off the hull (depending on where the planking is started). A builder should determine where he will begin applying the C-Flex® based on the shape of his project. In this section we have included some guidelines to begin the application on round bottom and vee bottom boats.

On most round bottom boats the easiest place to start planking C-Flex® is with the first piece running along the centerline or keel. Because of the flexible nature of the rods, C-Flex® will bend sideways, allowing the planks to be butted alongside each other all the way to the sheer line. It may also be possible to start at the sheer line and work to the keel by the same manner if it seems better for a particular project.

On most vee bottom boats, particularly power boats, we have found that the easiest place to start is with the first sheet half on the bottom and half on the side, running right down the chine. The builder should try to keep the same two rods in the material straddling the chine batten so the hull will have a neat, fair chine edge. The planking is then completed on the bottom and sides, with the C-Flex® allowed to run past the centerline and stem. After half of the hull is planked, the C-Flex® is wet out with resin. When the resin has cured, the material is trimmed along the centerline and stem, and the other half of the hull is ready to be planked.

Of course, if it is not apparent what approach is going to be best for a particular boat, a piece of C-Flex® should be cut and tried different ways. It may even be advantageous to mark where each plank edge will fall and then check with the trial piece to see if there will be any difficulties as planking proceeds. Only on an unusually proportioned or shaped design should this approach be necessary, as the C-Flex® will lie in place with little effort on most hulls.

The reason that C-Flex® will conform to compound curves is that it will bias within itself. Usually it will conform to the shape of the hull easily, and all that is needed to hold it in place are ice picks or staples. However, if the builder tries to make it bend sideways beyond a point, it will not bias by itself and it will have to be helped. Two small clamps (1" or 2" C clamps) are fastened tightly to the ends of the single hard C-Flex® rod on the inside of the bend. The rod is then pulled from both ends. As long as the pull is in line with the strand and kept on the proper part of the clamp (so it doesn't twist and bend the strand) the material can really be cinched down. However, C-Flex® will tend to follow fair lines in the hull, and only in unusual circumstances should it be necessary to pull it excessively.

Of course, even with the use of C clamps there is a limit to the amount that the material will bend sideways. If the hull has a very straight sheer, a reverse sheer, or if it is really beamy for its length, the material may reach a point where it will not bend enough to conform to the hull shape. There are two ways to handle this situation. First, if the builder can foresee that there is going to be a problem, he may start the sheeting somewhere in the middle of the girth of the boat, perhaps at the waterline area, and let the sheeting run out both along the sheer batten and the keel batten. The other approach is if the builder has already started with the C-Flex® parallel to the centerline or the sheer line and finds that the curve is becoming too tight, he should stop, wet down the C-Flex® which is already in place with resin, and wait for it to cure. He should then take a sheet of unsaturated C-Flex® and place it over the frames, letting it fall naturally in place. The unsaturated sheet of C-Flex will be butted alongside the cured C-Flex® in the middle of the boat and allowed to fall across the cured C-Flex® at the end or ends of the boat where the curve is tight. The C-Flex® plank on the hull is marked along the edge of the unsaturated C-Flex®, and the builder then removes the unsaturated sheet and cuts along the mark using a power hand saw with an abrasive cut-off blade. It is important that the blade of the saw be set so that it just cuts through the C-Flex® and not into the frames. After the two wedge-shaped pieces are removed, the next unsaturated sheet of C-Flex® will fall naturally in place when butted alongside the newly sawn edge, and the builder can proceed with the rest of the "planking".

CUTTING THE "PLANKS"--Tin snips will cut unsaturated C-Flex®, or the unsaturated plank may be bunched together and cut with a hacksaw. A hand power saw (circular saw) with an abrasive cut-off type blade may also be used. This type of saw may be used to cut both the unsaturated material and the saturated, fully cured material. To make a long diagonal cut on the unsaturated C-Flex® plank, it should be set on a scrap piece of wood which will support the material as the saw cuts through it, being given a straight, clean cut. When cutting the C-Flex® along a distinct line on the hull (i.e. stem, sheer, centerline, chine, transom, etc.) it is easier to get a neat, even edge if it is trimmed after it has been wet out and the resin has cured.

ATTACHING THE C-FLEX® TO THE FRAMEWORK--Either ice picks or staples may be used to hold the C-Flex® in place over the framing. It is probably best to have both available, using the ice picks to hold the material roughly in place, and then using the staples during the final fitting. Generally, it is necessary to staple only the two (2) outside rods in each plank, although some areas (i.e. transom, stem, and areas of concavity) may need more. The staples we recommend are 3/8" long with a narrow crown (3/16"), and are either monel, for corrosion resistance, or steel. These fit tightly over the rods in the C-Flex®, eliminating the chance of slippage. After the resin on the C-Flex® layer has cured, the staples may be removed, but most often they remain in the hull and the protruding points are knocked off with a grinder after the temporary frames are removed. On many boat hulls there are areas of concavity (flare, etc.) and the C-Flex® could require as much as a staple over each rod to hold it flush against the frames in those areas.

A good alternative to using a lot of staples is to strip a single "rod" from a piece of C-Flex® and lay it transversely (same as the frame) on top of the C-Flex® on the hull. When the "rod" is stapled to the frame in the lowest point of the concave section, it holds the C-Flex® (which is sandwiched between frame and rod) properly against the frame. A few additional staples over the "rod" will hold it and the C-Flex® securely in place. Wooden battens (taped so they won't adhere to the resin) may also be used to hold the C-Flex® in place in areas of flare, but they won't conform to the hard curves that the "rods" will. The rods or wooden battens are removed from the surface after the C-Flex® has been "wet out" and the resin has cured.

It is usually not necessary to bevel the frames in the framework, as it is possible to staple or ice pick into the edge of the frame that is contacting the C-Flex®. Care should be taken not to cause a hollow spot (distortion) by pulling any of the little rods down over the frame edge. The staples are placed where the C-Flex® plank first touches the edge of each frame to insure fairness. The planks should be butted side to side and not overlapped. Overlapping creates irregularities in the hull surface and does not increase the strength of the initial C-Flex® layer. Since C-Flex® is a unidirectional reinforcement with its strength running the length of the rods, an attempt to increase transverse strength by overlapping would be pointless. Transverse strength is achieved through the subsequent laminate and the structural framing, and not in the C-Flex® layer.

When "planking" the C-Flex® over the framework, we have found that in boats with a lot of curved surfaces, a gap may exist between the edge rods of two adjacent planks in some areas of the hull. This can be corrected by tying the edge rods in the butted planks together with either monofilament or twists of wire in the sections where the gaps exist. Only a few "ties" should be necessary to keep the edge rods butted where there are gaps. After the C-Flex® has been "wet out" and the resin has cured, the C-Flex® will hold its "set" form and the wire or monofilament may be removed. Another way to handle the gaps is to pull the two planks together at the gap and staple over the outside rods of the planks and into a small piece of wood fitted against the inside surface of the C-Flex®. The small block of wood can be removed when the hull is turned over.

After all of the C-Flex® is in place the surface should be checked carefully. The builder will find that by putting in a few extra staples where needed and pulling on a few hard rods in the C-Flex® planks to remove ripples, he can make things easier for himself and prevent more work later. Also, by sighting along the hard strands in the material, it will be possible to check the fairness of the hull, because the rods in the C-flex® act as tiny fairing battens when spanning the framework. It is important at this early stage to find and correct any frames or planks of C-Flex® that are out of alignment, as problems later discovered will inevitably be time consuming.

SATURATING THE C-FLEX®

Once the C-Flex® is in place, the material is saturated from the outside with a coat of resin that has been catalyzed, to cure slowly. The resin does not always wet through the C-Flex® completely, but it is very easy to finish wetting the C-Flex® from the inside after the boat is turned over. We have found this technique to be completely satisfactory, as well as easy and fast.

It is important to mix the resin that will be applied to the C-Flex® so that it will cure slowly with little shrinkage. A "hot", quick-curing resin will shrink excessively and pull the sheeting down, creating flat spots between the frames where there are tight convex curves in the hull. If this happens, it will not affect the strength of the hull, but more fairing will be necessary to obtain an excellent, yacht-type finish. We have found that this problem can be avoided if a polyester casting-type resin is used to “wet out” the C-Flex®. There are many available, and we recommend any slow curing, low shrinkage type that is formulated for making artificial marble. These cost about the same as an orthophthalic general purpose laminating resin.

Generally, the viscosity on the casting resin should range between 800 cps and 1000 cps. so that the C-Flex® gets an acceptable saturation. Resins higher than 1000 cps will be too viscous for practical use, while resins below 600-800 cps will tend to shrink too much as they cure. Most of these casting resins are more viscous than regular laminating resins, but they will saturate well if you give them enough time because they are non-thixotropic. This means they do not have the additive that laminating resins usually have to keep them from draining out on a vertical surface.[6] (See Appendix "Polyester Resins").

However, as mentioned earlier, the builder need not worry about totally saturating the C-Flex® with the casting resin. After the exterior laminate is finished and the hull is turned, the remaining dry areas of the C-Flex® can (and must) be wet out. The unsaturated glass on the inner surface will allow for an excellent bond between the hull and the structural frames when they are glassed to the hull skin.

It is possible to use a laminating resin, but only a light brush coat should be applied to the "dry" C-Flex®. This will provide a stiff surface as needed for the subsequent laminate and reduce the possibility for shrinkage. When the skin laminate is completed and the hull is turned, the rest of the C-Flex® may be saturated from the inside after removing the temporary frames. However, when permanent stiffeners exist in the formwork, the C-Flex® over these will have to be completely saturated from the outside, since those areas won't be accessible from the interior. This technique is only suggested for the experienced C-Flex® builder.

[6] See Appendix 3 - Polyester Resins

We strongly recommend using casting resin on C-Flex® in any application. Since the proper casting resin will insure a C-Flex® surface as fair as the framework in a carefully done job, we feel that it's simply not worth the risk of creating the fairing problems (scalloping, flat spots) on the C-Flex® surfaces that can be caused by the curing shrinkage of general purpose resin. Please check the suitability of a particular casting resin, as there is a wide variety of casting resins, many of which are unsuitable for the C-Flex® system.

To apply the resin on the C-Flex®, we have used spray guns, rollers, and brushes. All of these techniques will work, but we recommend a long nap paint roller because it is the simplest and quickest way. We usually catalyze two or three gallons of resin at a time in a five gallon, open-top pail, and dip the roller right into the pail. Generally, a coat is rolled over an area, and allowed to soak in for five minutes or so while other areas are coated. After it soaks, more is rolled on the dry spots, again left for five minutes, and then the excess is squeegeed off. The saturation cannot be forced by vigorous rolling, as this will not hasten penetration of the resin, but could instead loosen the staples and disturb the fairness of the planks. Another common mistake is to use too much resin. Once the material is saturated and wet through completely, it doesn't need any more. Excess will only add weight and cause the laminate to be brittle and shrink. For this reason it is essential that any extra resin on the C-Flex® be squeegeed from the surface.

LAYING UP OVER THE C-FLEX®

After the C-Flex® has been wet out and the resin has cured, (which will take overnight for casting resin), the hull should be sanded lightly to knock off any high spots and resin build-up. A 7" or 9" disc sander with a 16 or 24 grit disc is best for this. The sander is held with one edge of the disc raised up slightly- just enough to keep the sander from bouncing-and should be kept moving so it doesn’t "dig in" at any spot. (The C-Flex® at the transom, stem, and sheer should be trimmed and sanded also). We recommend that a dust mask and safety glasses always be worn when sanding work is being done.

While the builder sands the C-Flex®, problems caused by unfairness in the framework that may have escaped earlier notice may now become apparent. Although slight irregularities can be easily corrected during the laminating stages, if any serious unfairness exists it may be a good idea to correct it before proceeding. Low areas in the rigid C-Flex® surface can be shimmed up, while high areas can be pulled down with wire or monofilament tied from the C-Flex® to the framing. It is possible to sand down high spots to an extent, but if the rods in the C-Flex® are sanded too thin, the high area may become more prominent rather than more fair.

Several things should be considered to determine the laminate schedule of fiberglass reinforcement to be used with C-Flex®, including the size of the boat, the type of structural framing, and the spacings of the permanent frames. There are many books available that outline the general procedures of fiberglass lay-up work. We have limited this section to a brief outline of these, as necessary, to illustrate some special techniques that we suggest for achieving a superior hull finish.

We recommend using a chopped-strand mat and woven roving combination for the fiberglass laminate. This is more or less standard commercial practice in the U.S. for hand laid-up hulls. The chopped-strand mat develops superior adhesion and builds up bulk, while the woven roving develops tensile and impact strength. The two materials should always be applied together. Generally, the surface that will be covered is first wet out with resin, the mat is laid in place next to the C-Flex®, and then it too is coated with resin. By this approach the material absorbs resin from both sides, increasing the speed of saturation. Air bubbles and irregularities must be worked out of the mat (usually with a grooved roller) before the woven roving is laid in place.

It's not necessary to worry about the little valleys between the pre-hardened strands of the C-Flex® that exist before the lay-up begins. If the mat layer is worked down with a grooved metal or plastic roller before fitting the woven roving, it will fill in the valleys with no trouble. Another option is to lay down a 3/4 or 1 oz. mat over the C-Flex®, wet it out with resin, and work it down completely with grooved rollers. After the resin cures, the hull is ready for the rest of the CSM/WR lay-up. However, this step is not normally necessary as the "ribbed" effect will disappear with the first layer of the laminate.

It is best to run the woven roving at right angles to the C-Flex® (i.e. from centerline to sheer). The C-Flex® needs more strength "across the grain" because its layer develops strength in the direction of its fiber orientation. It is for this reason that a builder wants to see the joints in the woven roving running across the joints in the C-Flex®. When the woven roving is fitted over the mat, it should be rolled down with a grooved/ paint roller before more resin is applied to it. This pushes the rovings into the mat surface and helps them absorb resin from the resin-rich mat layer.

We suggest at this point in the procedure that the builder include an extra step in his lay-up. After each combination of laminate is fitted and saturated with resin, the wet lay-up should be evenly and firmly troweled or squeegeed with a wide steel putty knife. We prefer to use either a 12" wide sheet rock finish knife or a 24" steel bladed painter's shield. This step takes out the excess resin and air bubbles in the lay-up, which means a better glass to resin ratio and a stronger, lighter hull. Squeegeeing the excess resin from the lay-up actually pulls the laminate down tighter over the male plug (framework). In contrast, excess resin cannot be squeegeed as effectively from the lay-up in a cavity mold as it would pull the laminate away from the mold surface. This is why custom boats properly built over male plugs are often structurally superior to hulls built in cavity molds. Squeegeeing also effectively trowels (fairs) the boat with each lay-up. If this step is done carefully, it will be surprising how smooth the final surface is, and the time spent on achieving a good finish in the final fairing stage will be significantly reduced.

As the additional fiberglass is laid up over the C-Flex®, the builder should be careful to keep lumps from developing in the laminate as he works. If he is working with an all mat lay-up, he should try to judge where the lumps are and work them down with the grooved roller by rolling more and with more pressure in the areas that seem high. Another technique that is used to eliminate bumps in the hull is to butt the layers of reinforcement and stagger the butts through the laminate. The builder can overlap the fuzzy edges of the woven roving and lap the mat about 1/2" (this will roll and squeegee out smooth). With the butts staggered there is no place in the resulting laminate where a cross-section will show more than one layer butted, and usually a butt in only one layer of the total laminate will not decrease the overall strength of the laminate enough to be of any concern. However, with some very light laminates, since there aren't enough layers of reinforcement to permit butting, it may be necessary to overlap the reinforcement at the joints.

It is possible, when the lay-up crew is experienced and well organized, to lay up more than one combination at a time (apply a second lay-up before the first begins to cure). The joints must be staggered so that the second lay-up is not directly over the first, and the standard lay-up procedure is followed. With several plies of material laid up at once, the heat generated by the curing resin can build up and cause over curing, making the resin brittle and weak. (This is apparent when the cured resin is dark brown with hairline cracks throughout). Therefore, the builder should be especially careful when trying to lay-up more than one combination at a time, and in most cases a "wet" lay-up probably should not exceed two combinations of mat and woven roving.

For the difficult places in the hull that undergo greater stress (i.e. the stem, the joint at the transom), it is best to lap the laminate around these areas. When the lay-up on one side gets to the stem, for instance, it should be lapped over to the other side of the stem, 6 inches or so. On the same layer of laminate on the opposite side of the hull, the lay-up is butted along the edge of the 6 inch overlap. The next layer of laminate is lapped to the opposite side of the stem in the same manner (6"). The same approach is followed on subsequent layers, alternating the overlap, but varying the amount of lap so that the butted joints are staggered throughout the laminate. By lapping only one side per layer the lay-up remains fair, as opposed to building up a thick "bulb" by lapping both sides in the same layer around the joint. If extra reinforcement is desired in these joints, it may be added to the inside of the hull where fairness isn't a concern.

In fiberglass work, the reinforcements will not sit flat in hard angles, as might be found at the stem, chine, or transom. Unless a slight "round" is sanded into these joints, air bubbles will form under the laminate. It is only necessary to sand a slight round in the sharp corner with a grinder, with the sharpness, when desired, being redefined with fairing compound during the finishing stages. Similarly, fiberglass will not fit snugly into hard inside angles, for instance where the hull and bulkheads meet. Here it is necessary to create a slight "round" with a fillet (i.e. milled fiber/resin putty) troweled into the corner so that bonding angles fit smoothly from hull to bulkhead without air bubbles under them.

Another point should be mentioned for a builder using with fiberglass for the first time. While woven materials will bias to fit complex shapes, the chopped strand mat will not bias at all when dry because of the resin binder that holds it together. Although it is often helpful to cut the mat to make it fit properly, this is not always necessary. For some surfaces the mat can be roughly fitted in place and then saturated with resin. The resin causes the binder to break down, and the mat may then be "stretched" a bit and worked into or around the difficult shape. Ridges of excess material should be worked down smooth with a grooved roller or in an extreme case, cut away with shears or torn`1. This approach is often effective in areas of compound curvature, and it can be considerably easier and faster than trying to cut and fit the mat in place.

As is described in the section on deck construction[7], core materials may be used along with C-Flex® if sandwich construction is needed. The core may either be fitted over the outside of the hull at the midway point of the laminate, or it may be added to the inside surface of the shell after the exterior laminate is completed and the hull is turned over. The advantage to laying the core over the outside of the hull is that the builder can construct the hull over the permanent structural framing. This approach makes fairing more difficult than in single skin construction. When laying the core material on the inside of the hull, all of the framing must first be removed from the shell, lengthening the construction procedure. The builder can be selective about the areas in which he chooses to use a sandwich construction by laying the core material on the inner face.

Since C-Flex® hulls can achieve excellent strength to weight ratios and good stiffness with a single skin structure, it is often considered unnecessary to make the hull a sandwich structure when lightness is required. Although sandwich hulls may initially have better sound and thermal insulation properties than a single skin hull, these characteristics can be easily equaled in the single skin hull with conventional foam or fiberglass insulation where a builder feels it is necessary.

After the required number of mats and woven rovings have been "laid up" (with each woven roving squeegeed with the wide putty knife while it is still wet, and excess resin, rough spots, and overlapped areas sanded after each portion of the laminate cures), the hull should be covered with a 3/4 oz. or l oz chopped strand mat. This acts as a fairing mat for sanding high spots without damaging the structural laminate, seals the laminate from water penetration, and provides a good base for the finishing procedure. If there are obvious voids or low spots, some milled glass fibers mixed in resin can be used as filler as the lay-up proceeds. As mentioned previously, it is important for the builder to watch for fairness throughout construction, rather than accumulate problems to be handled in the fairing/finishing stages.

[7] See deck construction, Appendix 6

FAIRING THE HULL[8]

The final surface finish has traditionally been the most time consuming step in building fiberglass custom hulls and plugs. The C-Flex® process requires considerably less time for this step and yields hulls with outstanding results.

Fairness should be maintained and improved from the initial framing to the completion of the laminate. From the beginning, fairing battens (long wooden battens) should be used to check the fairness of the framework to get the project off on the right foot. During the laminating stages, steel bladed squeegees should be used on the woven roving or cloth to keep the material smooth, eliminate air bubbles and excess resin, and to provide better glass/resin ratios. As the lay-up proceeds, some milled glass fibers mixed in resin can be used as filler for any obvious voids or low spots. It is very important to remember that while irregularities in the hull surface may be corrected in the final fairing stage, by working on fairness throughout construction, time and expense may be kept to a minimum in this last stage.

If the weight of the hull is not a critical concern, we suggest applying a ¾ or 1 oz. chopped strand mat at the end of the structural laminate step. It acts as a moisture barrier for the hull shell and provides a surface that prevents the sanding from creating weak spots in the laminate. After the mat is in place, the builder should sand as many high spots as possible. If necessary, a troweling/fairing compound is used to build up the low areas in the hull and make the surface fair. However, if the high spots in the final mat layer are sanded well, the builder will need much less fairing compound to achieve a quality finish, hence, less cost, labor, and additional weight.

The amount of time and energy spent on the finishing stage depends, of course, on the function of the boat and the personal preference of the builder. On a trawler hull for instance, the object is to get the boat in the water as fast as possible, hence the time spent finishing the surface will be considerably less than that spent on a high performance Two Ton Class sailboat, where the fairness of the hull is a critical factor in her performance.

The fairing procedure for commercial hulls, where a yacht or plug type finish is not desired, is relatively quick and easy and yields good results. After the final mat layer has been sanded (with a heavy, 16 or 24 grit sanding disc), a flood coat of resin is applied over it to

[8]Fairing- the act of producing a smooth or flowing outline or surface without sudden or angular deviation or distortion.

reseal the glass fibers against moisture absorption. The resin is allowed to cure, and then a filler compound is trowelled into the low spots in the hull. A filler that we have found suitable for commercial hulls is made with equal volumes of talc and Glass Bubbles® (a product of the 3M Company), mixed in resin to a fairly thick, plaster-like consistency. This mixture is easy to trowel and sand and imparts qualities of toughness and durability to the surface when it cures. It is ideal for commercial hulls, but because of the talc, it is too heavy to use on lightweight hulls. The filler can be made without the talc, and just "Glass Bubbles", micro spheres, or micro balloons mixed in resin, but the addition of talc makes the mixture harder and increases abrasion resistance. Usually the compound is sanded smooth with a heavy (24 or 36) grit disc. If obvious unfairness still exists in the hull, the low spots should be filled and sanded again. A slow speed (1500-3000 rpm) sanding machine (polisher) and a soft foam rubber backup pad with heavy (40) grit sandpaper should then be used to get the smoothest finish on the fairing compound. Next, a high build polyester or epoxy paint is either sprayed (preferable) or rolled on the hull. This coat seals the fairing compound and fills the pinholes and sanding scratch marks. For work below the waterline, a high build, two-part epoxy primer seems to yield the best results. This coating is sanded with the slow speed machine and soft pad with medium (80-100) grit paper. It is important when using the slow speed machine to keep it moving on the hull and not let it work too long on one particular area where it would "dig in" and cause a low spot or sand completely through the coating. Since the high build paints also serve as primers, the hull is ready for its final paint system when the sanding is completed. From the completed laminate to the painted, finished surface, good commercial finishes can be achieved at an average rate of 10 square feet per man hour.

The fairing process for a custom hull is similar to that for a commercial hull, with the addition of the fairing/troweling compound as a general surfacing agent. This is perhaps the most important element in achieving a superior, “plug” type finish. Ideally, the compound must be easy to mix; it must have a smooth, creamy texture so that it will trowel well, but it must not sag on vertical surfaces; it should be relatively easy to sand, and it should be lightweight yet durable and tough. This is obviously a tall order, and we at Seemann Composites have experimented with a wide variety of "fillers" in an attempt to find the one most suitable as a base for a fairing compound. We have found that a combination of several fillers yields a fairing compound that most nearly meets the rather stringent requisites that we have established. A filler that we have found satisfactory by itself is the same that we recommend for commercial hulls, Glass Bubbles®, manufactured by 3M Company. When the Glass Bubbles® are mixed in resin at a ratio of approximately 20% bubbles by weight, the result is a smooth textured, easy to trowel, lightweight putty that sands well. If sanding is begun before the putty paste cures completely (when it is still slightly "green"), the compound will "cut" much faster and with less effort than is necessary after it has fully cured.

As with commercial hulls, if a "fairing" mat has been used the prominent high spots should be sanded; taking care not to sand beyond the mat layer, and a flood coat of resin should then be applied over the surface. If the hull is generally fair at this point, the few obvious low spots should be filled with the fairing compound. (If the hull has many irregularities, it may be best to begin with a screed coat of the fairing compound applied to the surface with a 3' or 4' batten. The obvious high spots are sanded with a grinder using heavy (16 or 24) grit discs, and the low spots are filled again with compound). A long batten may be useful to find the bumps and hollows on the hull. After all of the rough areas are sanded smooth, a coat of compound is applied to the hull with a notched (\") plasterer's trowel, which insures a consistently thick coating over the hull. With every few strokes of the notched trowel, the "furrowed" fairing compound is smoothed out with a wide (12" or 24") steel bladed putty knife, leaving an approximately 1/8" thick coat on the surface of the hull.

Disc and belt sanders are generally not used to do the finish sanding on the troweling compound, because their sanding area is relatively small and it takes exceptional skill to get a fair hull surface with these machines. In unskilled hands the machines would follow the existing contours of the hull, indiscriminately reducing high and low spots alike. Most builders prefer to use either traditional sanding boards (long boards) or a material called Foamglas® (product of Pittsburg Corning Corp.). Many builders prefer to use these sanding boards (long (3' to 5') narrow "boards" with strips of heavy grit floor sandpaper glued to them) to fair the hull surface, but we have found that Foamglas® (a rigid insulation material that acts as a self-cleaning abrasive when rubbed on the fairing compound), works very well. A two foot long block of Foamglas®, when rubbed at an angle from keel to sheer, reduces high areas while spanning the low spots in the hull. The Foamglas® shapes itself to the contours of the hull, while a sanding board is flat and relatively inflexible in more than one direction. In addition, with the sanding board one must contend with the problem of the "build" on the sandpaper while there is no such problem with the Foamglas®. On an average 32' sailboat hull, two boxes of Foamglas® should be adequate to achieve an excellent finish.

When the resin surface of the hull begins to show through the surface, foamglasing should cease. Unfair sections will develop if the rubbing continues because the resin and mat abrade at different rates than the fairing compound; there is also the possibility that the structural laminate could be damaged. The remaining low spots will be evident by the patches of dye on the hull. These should be filled again with the fairing compound and foamglased. If there are many irregularities remaining on the hull, it may be necessary to recoat it entirely and go through the process a second time. At any rate, when this stage is complete the hull should be fair and ready for the finish coats. The high build polyester or epoxy paint, which seals the fairing compound and fills any pinholes or slight irregularities in the surface, can be sprayed (recommended) or rolled on the hull with a short nap roller. If spray equipment is used, it must be a pressure pot system, since the paint is too heavy to get satisfactory results from a syphon gun. When the paint cures, it is sanded with a slow speed (1500-3000 rpm) polisher with a foam rubber backup pad and medium (80-100), then light (180-220) grit sandpaper. An orbital sander may also be useful at this stage as it won't leave sanding swirl marks. Any remaining pinholes should be filled with putty, and small irregularities spray coated again. These areas are then sanded as before. For an excellent, "plug" finish, completely smooth and devoid of scratch marks, the hull should be hand sanded with 360 waterproof paper and rubber blocks.

The painting system that has yielded the best gloss finishes in our experience is the two-part polyurethane enamels. These are the same type of paints that are often used on automobiles and airplanes to get a tough, durable finish. These paints generally must be sprayed for best results, although there is a "brushable" two-part polyurethane available.

Although a quality finish on a custom hull requires much more effort than a commercial finish, virtually perfect finishes have been achieved in little time using these fairing techniques. Depending on the fairness of the hull skin upon completion of the laminate, "plug" type finishes have been achieved at a rate of better than three square feet per man hour, with "yacht" finishes averaging four to five square feet per man hour.

CONSTRUCTION EXAMPLES

We feel that the most obvious and important advantage of C-Flex®, and indeed the original purpose in its development, is the ease and speed that it affords a builder in constructing a one-off GRP boat. The building procedure is straightforward and relatively simple and inexpensive when compared to other one-off construction processes. While these points make C-Flex® well suited for the amateur builder with little or no experience in fiberglass construction, the same advantages make it attractive to professional custom boat yards and plug builders. Table 4 illustrates the speed with which C-Flex® can be used by citing a variety of application examples.

TABLE 3

Finishing Procedure followed by New Orleans Marine to achieve a plug finish on a 35' LOA 3/4 Ton rated hull (approximately 600 sq. ft.):

OPERATION	MATERIALS	MAN HOURS
grind and patch	16 grit disc, troweling compound, large trowel	16
screed	troweling compound, screed batten	16
grind and screed	16 grit disc, troweling compound, screed batten	16
grind and patch	16 grit disc, troweling compound, large trowel	16
north trowel	notch trowel, troweling compound	16
grind and foam glass	soft pad, 40 grit, foam glass	48
check with batten & patch	batten, troweling compound, large trowel	16
primer	spray, and pressure pot gun, featherfil	4
soft pad and block sand	80 grit soft pad, 180 grit hand block	48

spot patch	regatta surfacing compound, small trowel	16
sand spot patches	180 grit hand sand paper, rubber blocks	16
primer	spray, pressure pot gun, featherfil	4
hand wet-sand primer	360 waterproof paper, rubber block	48
paint	2 part polyurethane, siphon gun	4

Total: 4, 334 hours

Table 4

ACTUAL TIME FOR APPLICATION OF C-FLEX®

25' LOA MORC Sailboat: C-Flex® applied and wet out	(Florida)	7 man hours
32' LOA Powerboat: Frames set up, C-Flex® applied and wet out, first laminate applied	(New Orleans)	18 man hours
37' LOA Sailboat: C-Flex® applied and wet out	(New Orleans)	14 man hours
38' LOA Powerboat: C-Flex® applied	(Clyde, Scotland)	18 man hours
42' LOA Sailboat: C-Flex® and all laminate applied	(New Orleans)	108 man hours
44' LOA Sport fisherman: C-Flex® applied	(Biloxi, Miss.)	20 man hours

With the durability, strength, and low maintenance requirements of GRP structures already well established facts, the only limits to the size of boats have been the high tooling costs and structural feasibility of large molds. C-Flex® enables the construction of GRP boats of virtually unlimited size with a substantially reduced initial investment of money and labor. This makes C-Flex® an ideal building material for not only one-offs and prototype craft, but also for the production of large commercial vessels such as fishing trawlers.

Many boats over 50' in length have been built with C-Flex®, including both pleasure and work craft. The largest constructed to date has been an 84 foot pilot boat built in France which was designed for service off of the Cape of Good Hope where heavy weather is the rule rather than the exception. In her trials, this boat exceeded design expectations by reaching a speed of 23 knots.

In a project involving the construction of a heavy displacement commercial trawler, a builder erected the framework and applied the C-Flex® and laminate for the 84 footer in 576 man hours. Even while including the time spent on setting up the frames, the deposition of the C-Flex® and the laminate was accomplished at an average rate of approximately 17 pounds per man hour.

At Seemann Composites, we have also experimented with the concept of building a one-off fiberglass boat upright instead of upside down. We constructed a 1/3 scale model of a 50 foot LOA heavy displacement trawler in much the same manner as if the boat were built out of wood. We set up a bearer to support the hull and fabricated the keel out of GRP right on top of the bearer. We then set up floor timbers, bulkheads and permanent frames directly on top of the keel. The C-Flex® was planked over the framing and fastened in place by staples. For the laminate, to avoid difficult and messy overhead work that would have been encountered on the bottom of the hull, we "rocked" the boat to one side, and with the keel still resting on the bearer, and the hull resting on its chin we applied the laminate to the exposed side. When the first side was completed, we "rocked" the hull the other way and laid up the second side. Even while the exterior work was still underway, work progressed on finishing the interior of the hull. Building certain C-Flex® boats upright could be a reasonable approach for a small yard that does not have the means to turn a relatively large hull over, or for constructing a hull so large that turning it would be difficult for even a well equipped yard. In addition, many hulls are built in sheds that are barely large enough for the hull, let alone turning it. By building the hull upright, it would not be necessary to remove it from the shed until it was fully completed. However, there should be enough room in the shed to rock the hull to each side and make all surfaces fully accessible. The pilot project went very smoothly and was quite encouraging, and we feel that on the full size hull of this particular boat, the project would have been equally feasible.

Another interesting project involving C-Flex® was the construction of the 65 foot replica of the "Providence", the first ship commissioned in the fledgling U.S. Navy back in 1776.

The hull shell of the "Providence" was constructed over her permanent framing, a network of transverse stiffeners and longitudinal stringers. Since she was built over a permanent framing system, there was no chance for hull distortion when she was turned over, and no need or a complex cradle to hold the upright hull. Nearly 3000 square feet of C-Flex® was planked over the framework in approximately 96 man hours, and all but the last layer of the exterior laminate required approximately 400 additional man hours.

Perhaps the most striking C-F1ex® success story is that of the 1975 3/4 Ton World Cup Winner, an English entry named "So1ent Saracen". With a deadline of six weeks to have the boat in the water and sailing, no custom yard in England was interested in building the Doug Peterson design. The owner, a construction contractor named John McCarthy who had never built a boat before, decided that his only alternative was to do the job himself. In a determined effort, the project progressed from the plans to the framing, the C-F1ex®, and the completed laminate in only eight days. Within the six week limit, the boat was completed inside and out and sailed with the obvious1y successful results.

Any construction yard with experience in GRP should have no trouble using C-F1ex® if they are careful to follow the techniques that we have developed. Even builders of traditional wooden boats should be able to adapt quickly to C-Flex® construction, as wooden framing skills and techniques are an integral part of the construction process. Similarly the amateur with little or no experience in GRP fabrication should be able to achieve excellent results with C-F1ex®. A major portion of C-F1ex® production goes into "backyard boatbuilding" projects. Since the production of the first C-F1ex® planking on an experimental basis in 1972, the development of the C-F1ex® system has been patiently developed and studied to insure that application procedures and design considerations were tested and evaluated properly. Consequently Seemann Composites has the necessary experience to draw on to recommend the easiest and most logical utilization of C-F1ex® and can offer advice and answer the many questions that may arise out of particular projects. In recognition of the fact that we are presenting a unique new system, Seemann Composites encourages users of C-Flex® to feel free to contact the company at any time to consult with experienced C-Flex® personnel. However, it must be remembered that in any project, careful planning and forethought coupled with patience and common sense are essential ingredients for success.

APPENDIX 1

MECHANICAL PROPERTIES - C-FLEX® FIBERGLASS PLANKING

Tests have been run on both the C-Flex® itself, and on C-Flex®/mat/woven roving laminates to determine their strength properties. In the tests quoted in Table 2 the test sample of C-Flex® had a glass content of only 42-43%, which is lower than in actual usage (50%) due to the procedure by which the sample was prepared. Instead of the normal process of laying the C-Flex® out, saturating the dry fibers, then squeegeeing away the excess resin, the test procedure required that the sample be flooded with resin and sandwiched between two pieces of glass. This result accounted for considerable excess resin between the rods in the C-Flex®.

Results of the tests were very similar to those of tests run on conventional unidirectional fiberglass reinforcements with similar glass/resin ratios.

TABLE 2: MECHANICAL PROPERTIES: C-FLEX®, WOVEN ROVING, CHOPPED STRAND MAT

Material	Glass Content % by Mass	Density lb/ft^3	Tensile Strength 10^3lb/in^2	Tensile Modulus 10^6lb/in^2	Compression Strength 10^3lb/in^2
C-Flex*	43**	93	67.6 (466 N/mm^2)	3.2 (21,700 N/mm^2)	46.5 (321 N/mm^2)
Woven Roving	40-55	93-112	19-37	1.4-2.3	24-27.5
Chopped Strand Mat	20-30	89-93	5.6-12.4	0.7-1.0	19-22

* Tests performed by SCOTT BADER CO., LTD., Wellingborough, England.

Mechanical Properties of CF-65 and CF-39 are similar.

** Under normal circumstances, the glass content should be over 50%, with mechanical properties improved accordingly.

The results in Table 2 were achieved in tests run on the longitudinal strength of the sample (i.e. parallel with the rods). Like all unidirectional reinforcement, C-Flex® has low strength when tested transversely (at right angles to the rods), and the transverse strength properties should be considered negligible when engineering with the material. In most cases, therefore, it is recommended that additional layers of the fiberglass reinforcement be laid up on both sides of the C-Flex® to ensure adequate cross-breaking strength.

Since the C-Flex® is most often "sandwiched" in the laminate, we ran tests on samples that consisted of the C-Flex® with a mat-woven roving layer on each side of it. With these samples, the bend strength tests, which reflect the characteristics of the surface fibers in a laminate, naturally reflected the fiber strength of the material in the faces of the sample, (i.e. the woven roving) and not the C-Flex®. The flexural strengths achieved, were comparable with those of a mat/woven roving laminate.

It is interesting to note that the tensile-modulus was 2.8 x 106 psi, or approximately 50% greater than the average mat/woven roving laminate. This means that C-Flex® adds stiffness to a laminate, and when C-Flex® is oriented fore and aft in a boat, the hull will have greater longitudinal stiffness than a hull using only conventional mat/woven roving.

APPENDIX 2

TOOLS

Useful tools for a C-Flex project:

CUTTING TOOLS:

For cutting "dry" planks of C-Flex®, aviation snips (tin snips), a hack saw or an abrasive cutoff wheel in a circular saw may be used. More expensive is a diamond chip wheel in a high speed air tool, but it can be very useful and easy to handle, and this consideration could justify the extra cost. The abrasive cutoff wheel, the hack saw and the diamond chip blade may also be used to cut cured GRP, as may a saber saw with either a fine toothed blade or a special carbide grit blade for cutting plastics. A razor knife is useful for cutting conventional fiberglass reinforcements, especially chopped strand mat, and a pair of heavy-duty shears is suitable to cut woven materials. The razor knife may also be used to trim the edges of a laminate when it is still "green" (gelled but not fully hardened).

FASTENERS:

A staple gun for attaching C-Flex® to the framework should be the type that shoots narrow 3/16") crown staples, since these fit snugly over the hard rods in the C-Flex®. We use the Duo-Fast model #CT-8541. The staples should be at least 3/8" long and if they are to remain in the hull, it is a good idea to use monel, as they will resist rust corrosion. A number of ice picks are useful in holding the C-Flex® in place temporarily as the staples are being applied.

LAMINATING TOOLS:

For brushes and rollers, we definitely recommend getting the type that are solvent resistant. They may cost slightly more initially, but they can be cleaned in acetone solvent and used repeatedly as long as resin doesn't harden in them. Long nap (0/4" to 1") rollers hold more resin and are better for laminating than the short nap type which may be preferable when applying a light sealing coat of resin or when working with lightweight cloth which doesn't require much resin. Grooved rollers are important to have when working with chopped strand mat, as they help work resin into and air bubbles out of the mat, and they also work down lumps and overlaps in the mat layer. Metal squeegees are used to get excess resin out of the "wet" woven layup and to smooth (fair) the laminate. Either a 12" plasterer's troweling knife or a 24" painters shield works well as a squeegee, and they are also suitable for spreading the fairing compound. The rubber type squeegee may be useful for spreading the resin evenly when laminating, but it is generally too flexible to use to fair the laminate or trowel the, fairing compound.

Drum racks that holds 55 gallon drums of resin and acetone, and resin gates that fit into the drum's bunghole, make the resin and acetone more accessible, while plastic resin buckets are cheap and can be easily cleaned, even when resin has hardened in them.

SANDING TOOLS:

A high speed (4500-6000 rpm) 7" or 9" disc sander is a must for a boatbuilding project as it will be useful throughout construction. With the grinder use resin bonded "open-kote" discs. These don't collect "build" as quickly as the "close-kote" type when sanding glass reinforced plastics, and they may be cleaned in acetone and used repeatedly until the grit wears dull. A slow (1500-3000) speed machine with a soft backup pad is good for working on the surface finish. The soft pad uses paper discs from a relatively heavy (40) grit to very fine grit. An orbital sander may also prove useful in working on the surface finish, as it won't "dig in" and doesn't leave sanding swirl marks. "Foamglas", a rigid abrasive, works very well in fairing a hull when sanding the troweling compound due to its self-cleaning nature and its ability to span low areas while reducing high spots. Its a good idea to wear a particle mask when sanding, and also safety glasses when using a high speed machine. Lightweight masks and glasses are easy to grow accustomed to, and not only reduce hazards, but also make sanding much more comfortable.

There is, of course, a vast assortment of miscellaneous tools that have been designed for working with GRP, and although there are many that aren't necessary, there are others that could be helpful in some facets of the project by making construction easier and the work higher quality. It is, of course, useful to have a good kit of basic hand tools along with such items as: masking tape, chalk line, cleaning rags, carpenters square, level, electric saber saw, etc.

APPENDIX 3

POLYESTER RESINS

POLYESTER RESIN: Thermosetting plastic, (solidifies with heat and cannot be reliquified). The variety of mechanical and chemical properties available in polyester resins, the relatively low cost, and the ease of handling make polyesters suitable for most boatbuilding projects. When the polyester resin, a monomer, and a catalyst are mixed together, a chemical reaction known as polymerization occurs and the resin hardens.

ORTHOPHTHALIC/ISOPHTHALIC: A description of the basic chemistry of the polyester resin. Isophthalic resins are slightly stronger, have higher chemical and heat resistance, and are slightly more expensive than orthophthalic resins. (Sometimes referred to as "ortho" and "iso" resins).

MARBLE CASTING RESIN: A low shrinkage polyester resin recommended for saturating C-Flex Fiberglass Planking (particularly in fabricating boats, etc. with a lot of rounded surfaces). As it cures, general purpose laminating resin can shrink considerably and cause distortion if used on the C-Flex® layer. Viscous (800-1000 cps) marble casting resin eliminates this possibility of distortion of the C-Flex® layer from shrinkage. Casting resin is used only on C-Flex® and not on the rest of the laminate.

LAMINATING RESINS (wax-free): Most polyester resins are air-inhibited; that is, the surface of the resin that is in contact with the air will not cure completely and remains "tacky". For laminating application, this is to an advantage because subsequent laminations will bond better to a slightly "tacky" surface than to a completely cured surface. The "tacky" surface can be harder to sand than a completely cured surface, and to remedy this on final coats a "wax solution" can be added to the laminating resin. The "wax solution" seals the surface of the resin from the air and allows for a complete cure.

FINISHING RESIN: This resin contains a wax additive which floats to the surface as the resin cures and seals the surface so that the resin will cure fully at the surface. This will eliminate tackiness and make final sanding easier. It also makes it more difficult to obtain the best bond for subsequent laminations, so this resin should be avoided until the very last. Wax-free laminating resin may be made into a finishing resin by adding the proper amount of surfacing agent (wax solution) to the resin. Isophthalic or orthophthalic, pre-promoted, contains wax, thixotropic.

PRE-PROMOTED: In order for polyester resin to be able to cure properly at room temperature, a small quantity of a chemical called an accelerator is added to the liquid polyester resin. The most commonly used accelerator is cobalt napthenate and is most convenient when pre-mixed with the resin so that the user only needs to add only one chemical, the catalyst, in order for the resin to cure.

THIXOTROPIC: Polyester resin sometimes will drain out from the fiberglass reinforcement and run on vertical surfaces. There are additives which can be used that will make the resin remain easily workable, yet will help keep it from draining out on vertical surfaces. Thixotropic resins have these additives already mixed in them.

APPENDIX 4

FIBERGLASS REINFORCEMENTS

The boats that we commonly call "fiberglass boats" more properly should be called fiberglass reinforced plastic boats or, in industry terminology, FRP boats (in England GRP for glass reinforced plastic). The glass gives the basic strength to the laminate, the plastic holds it all together. Today, with the advent of the "exotic" reinforcements such as carbon fiber, Kevlar, etc., a better name might be simply "reinforced plastic boats". In most "reinforced plastic" boats, fiberglass is still the basic reinforcement and polyester is the basic plastic. As there are different types of polyesters for different purposes, so also are there different types of fiberglass reinforcements. The way in which the reinforcement is arranged in the plastic and the amount of reinforcement per unit volume will greatly affect the strength properties of the finished laminate.

If we arrange the reinforcement so that it is "stacked" neatly so we can pack lots in a given volume and it all runs in one direction, we will have a material which is extremely strong in one direction but correspondingly weaker in other directions. A piece of wood is like this; all of the fibers run in essentially one direction and so it has what we call "a direction of grain" in which it is strongest. In the direction 90 degrees to the grain it is weak and it will easily split "along the grain". We make wood strong in the direction by laminating layers together to form plywood; we do the same in reinforced plastics by using various different types of reinforcements arranged in what we hope is an intelligent fashion.

The basic types of reinforcement which are available for use in reinforced plastics are:

> Chopped Strand Mat (CSM)--Consists of chopped strands of fiberglass up to 2" long randomly deposited to form a sheet and held together by a resin binder which is soluble in polyester resin. The random "hay stack" arrangement of the fibers does not allow efficient stacking of the fibers and the fiber loading or glass content in an all CSM laminate is low.

Advantages of CSM:

Low cost per unit volume of laminate. This is because the resin is still less expensive than glass, and therefore the less glass and more resin, the cheaper the finished product will be.

Also there are equal physical properties in all directions. This is because of the random arrangement of the fibers.

CSM offers the best bonding characteristics because the random orientation of the fibers gives good strength in all directions and allows the reinforcement to conform to the irregularities of the surfaces to be bonded. One of the main reasons for weak bonds is resin rich pockets which are weak and brittle. This is the reason why it is a good idea to always use a layer of CSM or something similar, between layers of woven reinforcement. The mat fibers tend to work up into the weave pattern and hold everything together. For this reason, whenever anything is bonded to an already cured reinforced plastic surface, a layer of CSM should be used first, then woven reinforcements. The same is true when bonding to any surface, such as plywood, etc.

Easily conformable to complex shapes. The binder which holds the CSM together is soluble in polyester resin and once it has dissolved, all that is left is unconnected, loose strands which can be pushed and pulled wherever you want. This is a disadvantage as well as an advantage because it is easy to develop thick and thin areas in the laminate and therefore weak spots.

A CSM laminate is more resistant to chemicals and water. Basically we depend upon the resin to keep chemicals, including water, away from the reinforcements. The more resin, the better protection. For this reason, it is recommended that the outside layer of all laminates exposed to the weather should be covered with a layer of CSM. The same applies for the inside of fuel and water tanks.

Disadvantages of CSM:

The resulting laminate has much lower mechanical properties, especially impact resistance, than laminates which are made with oriented, continuous fibers.

Quality control is more difficult, because consistent resin/glass ratios are hard to maintain and thick spots can result from reinforcement migration due to careless workmanship.

Unidirectional Reinforcement (UDR)--Continuous strands of fiberglass filaments arranged in bundles and oriented in a single direction with a minimal number of cross strands to hold the bundles together.

Advantages of UDR:

With the full strength of UDR running in a single direction, the material can be used in a laminate to provide reinforcement against specific stresses.

High glass/resin ratios (up to 60%) yield high strength and modulus properties.

Disadvantages of UDR:

It is useful in limited applications since strength runs only in a single direction.

It has higher cost than standard reinforcements.

Saturation with resin may take longer.

Cloth (Fabric)-Woven from continuous fiberglass yarn and ranging in weight from 2 to 40 ounces per square yard. Numerous styles are available to fit the requirements of virtually any application. In most boat projects a plain weave cloth of 6, 7.5, or 10 ounces per square yard is used.

Advantages of Cloth:

Many weaves and styles are available but the most common is a plain basket weave which is bidirectional (orthotropic) reinforcement that provides nearly equal strength in warp and fill directions (0° and 90°).

Cloth has high glass/resin ratio which means excellent mechanical properties. (high glass content = high strength)

Cloth is thin and relatively lightweight reinforcement good for small boats (canoes, prams, etc.) and projects where weight is critical. These qualities also make closely woven cloth useful as a protective covering.

TABLE 5

WEIGHTS AND RESIN REQUIREMENTS OF FIBERGLASS REINFORCEMENTS

Material	Weight lbs/sq ft	Resin/Glass ratio	Resin Required lbs/sq ft	Total Weight per Ply lbs/sq ft	Thickness per Ply inches
¾ oz. CSM	.047	2.64	.120	.167	.024
1 oz. CSM	.062	2.64	.160	.222	.032
1½ oz. CSM	.094	2.64	.240	.334	.048
2 oz. CSM	.124	2.64	.320	.444	.064
7½ oz. CLOTH	.052	1.0	.052	.104	.013
10 oz. CLOTH	.070	1.0	.070	.140	.017
18 oz. WR	.125	1.0	.125	.250	.031
24 oz. WR	.167	1.0	.167	.334	.041
C-FLEX CF-39	.35	1.0	.28	.63	.080
C-FLEX CF-65	.51	1.0	.40	.92	.125

Disadvantages of Cloth:

The fact that cloth builds bulk slowly and because of the higher cost per pound of this reinforcement make it impractical and uneconomical for use in large applications, such as boatbuilding.

It decrease in mechanical properties at 45° to weave.

A heavy cloth can be difficult to saturate with resin.

Woven Roving--bundles of continuous fiberglass filaments woven into a relatively coarse, open, heavy fabric. A bidirectional (orthotropic) reinforcement. Although weights vary from 14 to 40 ounces per square yard, the 18 oz. and 24 oz. material are most commonly used.

Advantages of WR:

WR yield high glass/resin ratios that translate into excellent mechanical properties.

Although many styles are available the most common is a basket weave which is orthotropic (bidirectional) reinforcement that provides nearly equal strength in warp and fill directions. (Usually slightly higher in warp because more strands per inch)

It builds bulk relatively quickly at reasonable cost.

An open weave makes it pliable and easy to work with.

Disadvantages of WR:

Coarse, open weave means a poor bonding surface with resin rich pockets, resulting in a weak bond between plies of woven roving or onto a flat surface. To attain a good bond, either chopped strand mat or milled fiber paste should be used in conjunction with the woven roving.

Woven roving can be difficult to saturate with resin.

WR has lower mechanical properties at 45° to weave.

Course weave yields roughly textured surface.

APPENDIX 5

HULL FRAMING SYSTEMS

Without a permanent framing system to support the hull skin, GRP boat hulls would not be very flexible and unstable, or they would necessarily be very thick and heavy. Also, it is very expensive to build such an impractical structure. With a properly designed framing system, a fiberglass hull skin can be relatively lightweight, and this will not only mean a savings in material costs, but also better performance. The selection and design of a framing system for a particular hull can depend on many factors, such as hull shape, type, usage, accomodation plans, etc.

The structural systems that support the hull skin may be either transversely or longitudinally oriented, or a combination of the two. Longitudinal framing runs fore and aft to support the hull skin, while transverse frames are oriented at right angles to the centerline of the hull. Although most hulls have elements of both systems (i.e. bulkheads and longitudinal stringers) usually one will support the skin, while the other supports the framing. The type of framing that supports the hull skin is the basis for how the structural system of a boat is designated. For instance, a hull with longitudinal stringers running uninterrupted on l8" centers supporting the skin, and bulkheads on 7' centers supporting the stringers is called a longitudinally framed hull. A hull with transverse framing 14" or 18” o.c. and longitudinal chine logs or engine stringers notched over the transverse frames is "transversely framed." Some hulls with nearly equal numbers of longitudinal and transverse frames may be recognized as having hybrid structural systems combining the best elements of each type. Large hulls would require relatively closely spaced frames if only one type were used. By combining the two, fewer and lighter frames are needed to support the hull skin.

BASIC FRAME TYPES:

"Hat sections"--either longitudinal or transverse; these can be hollow

GRP sections premolded over a shaped form and then added to the framework, or they can be molded in place in the hull over any number of formers including urethane foam, plywood, or an acceptable softwood. (The wood core of an encapsulated frame should, in most cases, be considered non-structural due to the possibility of rot, and hence adds unnecessary weight to the structure).

Bulkheads-Vertical partitions that effectively divide open areas into compartments. Bulkheads may be either structural (integral parts of the framing system of the hull) or non-structural partitions. In boat hulls, bulkheads are usually designed in conjunction with the accommodations plan. Plywood is most often used for bulkheads in GRP hulls. Traditional hardwood framing--either longitudinal or transverse framing that is usually attached to GRP hull skin by mechanical fasteners. It is generally recommended that hardwood framing should not be encapsulated in GRP.

Various "T", angle and bulb sections can also be used as both longitudinal and transverse stiffeners.

APPENDIX 6

DECK CONSTRUCTION

Decks may also be constructed using C-Flex®, generally over temporary framing. Usually, though not always, the deck is constructed upside-down over plywood forms set on 14" or 18" spacing, depending on which grade of C-Flex® is used. The forms are shaped to give the deck its proper crown. The edges of the frames are taped so that the resin won't adhere to the wood, and the C-Flex® is then planked over the framing and saturated with resin.

At this point in the deck construction, with the C-Flex in place and before the rest of the laminate is applied, we recommend that the builder have cockpit molds ready to be put in place on the deck. These male molds are made from particle board or plywood to the desired dimensions of the cockpit. The corners must be rounded, and all cracks and holes must be filled with putty to give a completely smooth surface. The surface is coated with a primer, preferably a high build type such as "Featherfil®", and covered with a release agent (i.e. wax, polyvinyl alcohol).

The molds are then bonded into place on the C-Flex® deck surface and coated with gelcoat. The conventional fiberglass laminate is applied over the C-Flex® deck with the same techniques employed in hull construction, with the laminate, covering the cockpit molds also. Whenever a sandwich structure is preferred, the core material is added at or near the halfway point of the laminate, so that solid reinforcement exists on both sides of the core. For the core, the most popular material for decks is end grain balsa, as it is lightweight and will not distort in heat.

When the laminate is completed, the deck is removed from the temporary framework and turned upright. The C-Flex® over the cockpit is cut away and the wooden plugs are removed. The edges of the cockpit are trimmed and rounded and the dry areas of C-Flex® are wet out with resin. In any additional laminate is required, it is then applied to the deck, with a "fishing" mat as the last lay-up. The deck surface is then finished by the same procedures outlined in the section on fairing the hull.

APPENDIX 7

SPECIAL PROCEDURES - USE OF MILLED FIBER PASTE

For very lightweight hulls where strength/weight ratios are of the utmost importance, we have found that a milled fiber paste (1/16" milled glass fibers mixed with resin to a "brushable" consistency-approximately 77% resin to 23% milled fibers by weight) can be substituted for the chopped strand mat. This paste serves the same purpose as the mat in filling voids and providing for a good bond between layers of woven roving (or cloth), and it does so without the bulk and weight that the mat adds to the structure. (For example, 1oz. chopped strand mat weighs approximately .222 lbs./sq. ft. when saturated with resin, while in a test sample, the milled fiber mixture required in one sq. ft. of a WR laminate weighed only .094 lbs.) This means that more bidirectional (or unidirectional) reinforcements can be used to achieve better mechanical properties in the laminate than could be achieved in a CSM-WR laminate of the same weight. By using the milled fibers instead of the CSM, the laminate has a much higher glass content, hence higher modulus, making lighter laminates possible. For instance, while the average flexural modulus of a CSM-WR laminate tested at 0° is approximately 1.1×10^6 psi, that of a laminate is nearly 2.0×10^6 psi. In fact, because of the higher glass content of the laminate when using milled fibers instead of CSM, all of the tensile and flexural strength characteristics are higher than in CSM-WR laminates (as is the compressive strength except when tested at 45°, at which instance the mat-WR laminate is slightly stronger due to the isotropic nature of the chopped strand mat.) The milled fiber paste may also be used to fill low spots as the laminate progresses, rather than saving such problems for the final finishing stage.

APPENDIX 8

GENERAL REFERENCE SOURCES FOR GRP BOATBUILDERS

This is a basic list of possible sources for a builder to consult on both general and specific design and construction problems. There are, of course, many books available on boatbuilding, and naturally there is much duplication from book to book. These are a few of the books that we are familiar with, which between them, cover all facets of a boatbuilding project.

Chapelle, Howard I., Boatbuilding, A Complete. Handbook of Wooden Boat Construction, W.W. Norton & Co., Inc. New York

General information on lofting, framing and fitting out, that is readily applicable to C-Flex construction.

du Plessis, Hugo, Fibreglass Boats, Adlard Coles, Ltd., London

Excellent source for detailed information pertaining to fitting out and finishing a GRP boat.

Hankinson, Ken, Fiberglass Boatbuilding for Amateurs, Glen-L Marine Designs, Bellflower, Ca.

Good basic information on working with fiberglass for the inexperienced builder as well as a good introduction to custom building systems

Nicolson, Ian, Designers Notebook, Adlard Coles, Ltd., London

Full of detailed drawings on fitting out a boat.

Scott, Robert, Fiberglass Boat Designs ~ Construction, John de Graff, Inc., Tuckahoe, N.Y., 1973

A good introduction to the design of GRP boats.