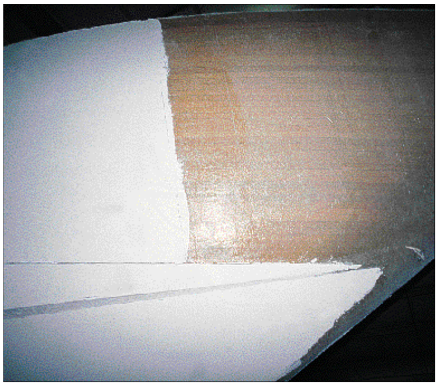
FIBER REINFORCED PLASTICS/COMPOSITES

The fundamental difference between fiber reinforced plastics (FRP) and other construction materials is that FRP is a combination of several products which are joined to result in a finished product/material, unlike wood planks or metal plates. It is fabricated by the laminator/builder with components that have extremely different physical, chemical, and mechanical properties and with various molding techniques. The materials selection, the laminating procedures or techniques and the quality control must conform to certain principles to achieve a good quality and high performance laminate.

There are two basic techniques used to fabricate FRP parts: the first one uses female molds for hulls, decks and small parts, and is widely used by production boatbuilding companies. The second method is used for the building of one-off hulls or decks for which the investment in costly molds would be difficult to amortize in small-scale production. A brief description of each of these procedures will allow one to identify and compare the **fibers**, **reinforcements**, **resins**, and **cores** used in the building of FRP or **composites** parts such as a hull or a deck.

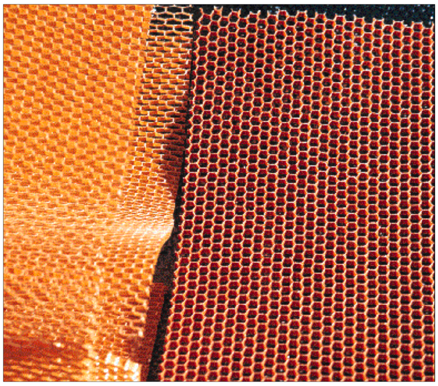
● In production boatbuilding, the molds used are of the female type, built and reinforced to endure the laminating of dozens and even hundreds of parts. They are also built to withstand the elevated temperatures associated with the **polymerization** of resins. The laying up of a FRP laminate begins with the application of **gelcoat** to the inside surface of the mold. It is usually sprayed with a so-called Airless gun to minimize the air inclusion. The spraying must be performed by a skilled operator to achieve the most uniform film thickness (usually around 20 to 22 mills) and to limit the microscopic air bubbles content that can make it porous. The gelcoat is a resin formulated and pigmented to improve the appearance and the resistance of the laminate against the environment and **hydrolysis**. Therefore the selection of the gelcoat and the quality of its application play an important role in the protection of a laminate against **osmosis**. The most resistant gelcoats are made of a **isophthalic** polyester resin, or even better, an **iso NPG** type. The use of orthophthalic type resins is not recommended for the gelcoat and the impregnation of the first two layers of the laminate. The first reinforcement next to the gelcoat is normally a surfacing veil or lightweight mat (.75 oz) made of **E-glass**, or even better, **C-glass** fibers with a powder **binder**. The characteristics of this reinforcement layer play an important role in the resistance of the protection barrier of the laminate. It is then impregnated with a isophthalic or sometimes vinylester resin. The **fiber/resin** ratio should be low (around 1 to 3) to ensure a good wetting out of the fibers and to limit the void content. It should be carefully rolled out to eliminate the air microbubbles while avoiding microperforations in the gelcoat caused by the fibers. These microperforations can let in sea water that travels along the fibers and creates the initial stages of osmosis. Next a slightly heavier second and/ or third layer of chopped strand mat (usually 1 oz and/or 1.5 oz) is applied and impregnated with the same resin. It should be noted that some boatbuilders use the **spray-up** method to deposit one or two layers of **chopped** fibers. This method is much faster in production but does not offer the same control over the laminate thickness and quality.

From this stage, the choice of techniques and reinforcements is wide. For hull construction, the builder can use a **single skin** or **sandwich** laminate, which is used for most of the decks. The builder could choose between **hand lay-up**, **vacuum bagging** or **infusion molding**; the choice

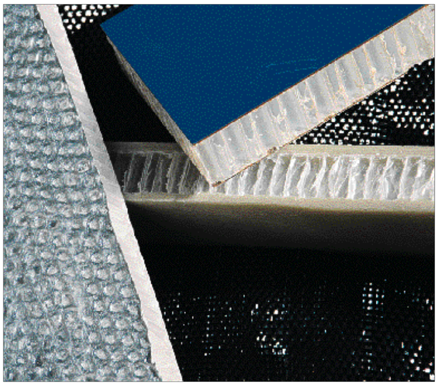


On a female molds, gel coat becomes the last layer.

Intregral tanks can be built in composites hulls.

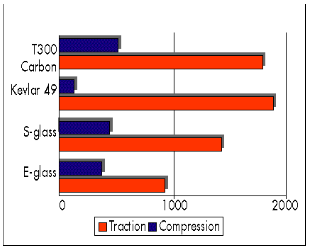


Honeycomb can be used on tight curved surfaces.

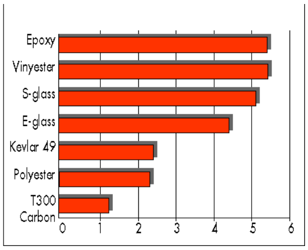


Tubulam is a honeycomb with cylindral cells. It has a wide range of applications.

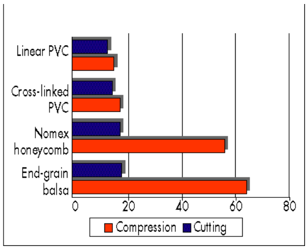
will determine the selection of components to be used. In the early days of FRP, the reinforcements used were E-glass chopped strand mat (CSM), cloth or woven rovings . Since then the industry has seen the introduction of high performance fibers, such as **R and S glass**, **aramid**, and **carbon/graphite**, whose properties are higher but are more costly to use (see graph 1). These fibers are stitched, bonded or woven together as combined **mat/roving**, **unidirectional** or **multiaxial** reinforcements of various **weight** and construction. Some builders have been using some glass/Kevlar hybrids with properties substantially higher that the all-glass **combination mats** or which have shown some labor savings compared to the more traditional laminate with alternating layer of mat and woven roving. Today designers and builders have a large array of resin systems to choose from. The three main types of resin used in the marine industry are **polyester**, **vinylester** and **epoxy**. Epoxy is primarily used for the building of one-off boats. Resins and fibers have elongations which vary from 1.4 to 5.5 % (see graph 2), it is critical that the elongation of all components of a laminate match each other to optimize the composite performance and properties If a sandwich laminate is used, the core material must have good shear and compression resistance. **End grain-balsa** has been successfully used for many decades by a vast majority of production builders because of its high mechanical properties. **PVC foams** and **honeycombs** are used for applications where weight saving is essential, their mechanical properties vary substantially with their density (see graphs 3 and 4). Honeycombs are made out **Nomex** and aluminum, their use and bonding require extreme care and quality control. There are primarily used for the molding of high performance one off boats where the weight saving can justify the cost increase. To conclude on the subject of production building, we will briefly review the main



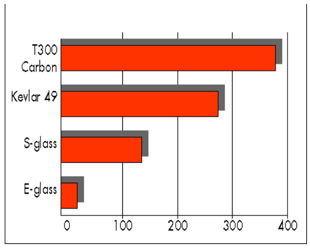
1 - Fibers specific mechanical properties



2 - Elongation (%)



3 - Core materials specific mechanical properties



4 - Reinforcements average prices (FRF / m2)

molding techniques. Hand lay-up is obviously the most well known and widely used method. The reinforcements are manually placed onto the mold, the resin is either rolled or sprayed and rollers are used to thoroughly **roll-out** the reinforcements. The quality and voids content depend entirely on the laminators' skill and experience. The other method is vacuum bagging of which several types have developed. Several North American boatbuilding companies are now using different vacuum assisted techniques. Vacuum is applied between the mold surface and a flexible membrane placed over the dry reinforcements, then the resin is "injected" or infused. This technique allows the builder to control accurately the fiber/resin ratio and therefore the properties of the laminate by eliminating excess resin, these techniques are known as **VARTM** or **SCRIMP**.

The hull bottom laminate is molded on a male mold while the topsides have fabricated on temporary female molds.

Foam cored sandwich bulkheads improve both sound and thermal insulations.

● The building of one-off motor yachts of all sizes, uses the same techniques and materials, the main difference is the size of the mold. To minimize the tooling costs, the hulls are generally built on a **plug** or male mold made out of wood strips or plywood depending on the complexity of the shapes. The high performance hulls are built with sandwich composites using high properties cores, fibers and resins. Some builders have been using low temperature **prepregs with post curing** to improve the properties. Only a few builders have the know how and can afford the equipment to use this method of construction. Theoretically, the ongoing developments of materials and computerized design tools will allow the designers to optimize the type and orientation of the fibers, the resin system and the core material based on the actual stresses. In reality however the actual forces and stresses are not accurately known and the mechanical properties are too often based on laboratory made samples within high quality control environment of the aerosapce industry. The actual properties of composites manufactured by the marine industry are lower than the data published. The unexplained damage and/or fracture of marine composites may be attributed to this difference, but this debate could be the subject of an entirely different article.

Fairing and finishing can only be achieved manually by very skilled workers.

GLOSSARY...

Aramid *: a yellow/golden fiber, mostly known as Kevlar, a trademark of Du Pont de Nemours. It has very good tensile strength.*

Binder *: Bonding powder or resin applied to glass fibers to hold them in position in a mat structure.*

Carbon *: Black and shiny fibers produced by oxidation and heating of acrylic filaments.*

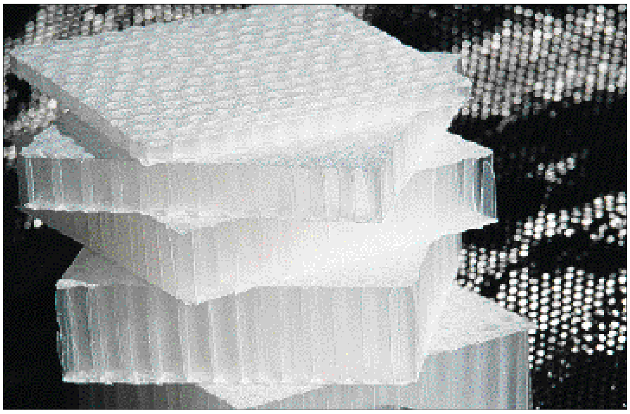
C-glass *: (Chemical grade) it has a good chemical resistance.*

Combination mat *: one ply of woven roving chemically bonded to a chopped strand mat.*

Composites *: materials created by the synthetic assembly of two or more material a matrix (the resin) and reinforcement*

E-glass *: (Electrical grade) is by far the most widely used reinforcing fiber. Originally used for electrical application because of its low resistivity.*

End-grain balsa *: lightweight tropical wood, the average specific weight of the marine grade varies between 8 and 10 lbs/cu. ft. It has been introduced in 1963 by Baltek Corp. under the trade name of Contourkore.*



Epoxy *: Resin produced by the reaction of glycol with materials such as alcohols. It has good mechanical and adhesive properties, better corrosion resistance and low shrinkage.*

Finish *: material applied to the surface of fibers in a fabric to improve the physical properties.*

Fiber/resin ratio *: glass or fiber content, either in volume or in weight, it determines the mechanical properties of a laminate.*

Gel coat *: layer of pigmented resin applied to the mold to improve surface appearance.*

Hand lay-up *: open-mold process which includes spraying or brushing resin followed by hand lamination.*

Hydrolysis *: chemical reaction causing the degradation of polyester resin exposed to water.*

Injection or infusion *: Molding is by injecting or infusing the resin between a plastic membrane and the mold where the dry reinforcements have been laid up and vacuum applied.*

Isophthalic *: polyester resin based on isophthalic acid*

Iso NPG *: Isophthalic-Neopentyl-Glycol acid based resin. It has the best resistance to hydrolysis.*

Mat *: A randomly distributed felt of glass fibers held together with a binder. Also chopped strand mat or CSM.*

PVC foam *: lightweight closed cell structure of rigid polyvinyl foam.*

Honeycomb *: Manufactured product of resin impregnated sheet material of metal formed into hexagonal-shaped cells.*

Multiaxial *: reinforcement with fibers oriented in various directions. Usually made of unidirectionals stitched together.*

Nomex *: Aramid paper developed and patented by Du Pont de Nemours*

Orthophtalic *: Polyester resin based on orthophthalic acid*

Osmosis *: Degeneration process within a laminate caused by a chemical reaction between unreacted substances and water.*

Polyester *: A resin formed by the reaction between dibasic acid and dihydroxy alcohol. Modification with some unsaturated reactants permit cross-linking to thermosetting resins.*

Polymerization *: the reaction that takes place when resin is activated or iniated*

Prepregs *: Reinforcements which are pre-impregnated with catalyzed resin. The resin/fiber ratio is controlled. The curing process is initiated by a temperature elevation.*

R glass *: European version of S-glass.*

Reinforcement weight *: for chopped strand mat in ounces per sq ft and for cloth and woven roving in ounces per sq yd.*

Rolling out *: thoroughly wetting the reinforcement, densifying the laminate and removing entrapped air.*

Sandwich *: FRP skins bonded to thicker, lightweight core (end grain balsa, PVC foam, honeycomb). It increases the stiffness of the panel.*

SCRIMP *: Seaman Composites Resin Infusion Molding Process, infusion molding process developed by Bill Seaman.*

S glass *: High performance glass fiber developed by Owens Corning, its mechanical properties are between 20% and 40% higher than E-glass*

Single skin *: laminate made up of various layers of reinforcements only without any core material.*

Spray-up *: Technique in which a spray gun is used to simultaneously deposited fibers and resin in a mold.*

Unidirectional *: Strands of fibers running in one direction held together by single fibers that are glued or sewn laterally.*

Vacuum bagging *: An air bag, usually a simple flexible film is placed over the curing laminate and air is removed to draw a vacuum. Atmospheric pressure eliminates voids in the laminate and forces out excess resin and air.*

VARTM *: Vacuum Assisted Resin Transfer Molding*

Vinylester *: a modified epoxy acrylates resin with better mechanical properties and higher corrosion resistance than polyester.*

Wet-out *: condition of an impregnated reinforcement where all voids between the fibers and filaments are filled with resin.*