

High-Tech Fibers for Marine Applications

The majority of improvements in marine composite construction over the last fifty years have been through better resin chemistry. However, fibers have also played an important roll in the development of advanced composite laminates for marine applications. Specifically, weight, strength and stiffness optimization can be enhanced by using fibers with properties superior to E-glass. However, what we've found is that often a judicious use of high strength and/or modulus materials in combination with E-glass can often result in an efficient, cost-effective composite structure.

GLASS

Glass fibers account for over 90% of the fibers used in reinforced plastics because they are inexpensive to produce and have relatively good strength to weight characteristics. (see Table 1) Additionally, glass fibers exhibit good chemical resistance and processability. The excellent tensile strength of glass fibers, however, may deteriorate when loads are applied for long periods of time E-glass (lime aluminum borosilicate) is the most common reinforcement used in marine laminates because of its good strength properties and resistance to water degradation. S-glass (silicon dioxide, aluminum and magnesium oxides) exhibits about one third better tensile strength, and in general, demonstrates better fatigue resistance. Because the cost for this variety of glass fiber is about three to four times that of E-glass we don't see it used too much in the marine industry. Table 2 shows some comparative fiber performance data.

CARBON

The terms "carbon" and "graphite" fibers are typically used interchangeably, although graphite technically refers to fibers that are greater than 99% carbon composition versus 93 to 95% for PAN-base fibers. All continuous carbon fibers produced to date are made from organic precursors, which in addition to PAN (polyacrylonitrile), include rayon and pitches, with the latter two generally used for low modulus fibers. Carbon fibers offer the highest strength and stiffness of all commonly used reinforcement fibers. The fibers are not subject to stress rupture or stress corrosion, as with glass and aramids. High temperature performance is particularly outstanding. The major drawback to the PAN-base fibers is their relative cost, which is a function of high precursor costs and an energy intensive manufacturing process.

Carbon fiber use for marine structures is most useful for designs that are limited by how stiff we can make them, such as long, slender bodies that don't have much Section Modulus. That's why catamarans and trimarans often use carbon. Vessels with a lot of surface area, such as hovercrafts or the M-Ship concept also can benefit from sandwich laminates with carbon skins. Carbon is also used exclusively for composite masts, rudder posts, and other sailboat hardware as well as in the caps of stringers when height of the stringer is limited..

Earthrace

The Earthrace project was established to break the outright world record for circumnavigating the globe in a powerboat, which currently stands at 75 days, but has a loftier goal of promoting the use of renewable fuel. Circumnavigating the globe is the world's longest race at 24,000 nautical miles, and represents the pinnacle of powerboat challenges. The Earthrace team plans to make this trip in 65 days using only bio-diesel fuel made from renewable sources such as canola and rape, hoping that the high profile nature of the project will significantly raise awareness about the use of sustainable resources.

M-Ship

M-Ship has built The carbon fiber Stiletto, a Twin M hull vessel that is 80 ft in length with a 40 ft beam. The vessel's draft fully loaded is 3 ft and is designed for a speed of 50-60 kts. Its superior performance is based on M Ship Co.'s proprietary, globally-patented technology that recaptures the bow wave to create an air cushion for more efficient planning. The M80 Stiletto is also notable because it is the largest U.S. Naval vessel built using carbon fiber composite and epoxy building techniques, which yields a very light, but strong hull. Figure 2 shows the M80 underway with a low radar cross signature.

High Modulus

The High Modulus Company of New Zealand is a world-leading supplier of composite technology and structural engineering services to the marine industry. I asked Michael Eaglen, Vice President of Engineering about recent projects they're working on that involve carbon fibers. "The first is a 37m (121') 60-knot vacuum infused carbon/epoxy/foam motoryacht. The designer is Rob Humphreys Yacht Design in England; the builder is McMullen and Wing in New Zealand. This project used quite a bit of ultra high modulus fiber for very light inside skin of deck panels and the like.

"The second is a 40m (130') luxury day-sailor in prepreg carbon with foam and honeycomb cores. The designer is Javier Soto Acebal in Argentina; the builder is Wally in Italy. The project uses quite a bit of intermediate-modulus fiber in the hull and deck shells for global stiffness. It also has a combination of standard, intermediate and high modulus fiber in the rudder stock.

"Finally we are currently doing a lot of work with Rhebergen Composites in Amsterdam on mast structures for very large (80-120m) motoryachts. These are primarily governed by their vibrational behavior, so we use increasingly high modulus carbon fibers (mostly M46J and HS40) to lift stiffness without increasing weight in order to tune the natural frequencies of the structure."

POLYMERS

The most common aramid fiber is Kevlar[®] developed by DuPont. This is the predominant organic reinforcing fiber, whose use dates to the early 1970s as a replacement for steel belting in tires. The outstanding features of aramids are low weight, high tensile strength and modulus, impact and fatigue resistance, and weavability.

Compressive performance of aramids is not as good as glass, as they show nonlinear ductile behavior at low strain values. Water absorption of un-impregnated Kevlar® 49 is greater than other reinforcements, although ultra-high modulus Kevlar® 149 absorbs almost two thirds less than Kevlar® 49. The unique characteristics of aramids can best be exploited if appropriate weave style and handling techniques are used.

KEVLAR®

Tawainese Patrol Boats

Among the many duties of Taiwan's Seventh Peace Preservation Police Corps, shown in Figure 5 is patrolling this island nation's vast coastline to deter smuggling, drug trafficking, piracy and illegal immigration, along with search and rescue missions. This is effectively handled thanks to Lung Teh shipbuilding's new, 92-foot patrol boat.

The Taiwan-based shipbuilder has constructed six patrol boats to date, all of which use a combination of Kevlar®/E-glass in all main structures including hull and wheelhouse. Use of Kevlar® fiber/e-glass hybrid in these boats to strengthen hulls and other structures in order to reduce speed-sapping weight. "There has never been any fault with advanced composites; just a lack of understanding how to get the best out of them," says Ken Raybould, the British consultant to DuPont that helped launch Kevlar® into the marine industry. In his crusade for Kevlar®, Raybould scientifically addressed each of the perceived shortcomings of the fiber, such as wet-out, compression strength, water absorption, UV resistance, and handling (cutting and machining). The wet-out issue goes away with the use of E-glass/Kevlar hybrids, as shown in Figure 6. This also reduces overall material cost by optimizing Kevlar®'s advantages with the lower-cost E-glass in a hybrid weave. Water uptake is mostly a function of resin performance. Coatings can handle the UV issue and tools have been developed to cut Kevlar® before and after its laminated. Figure 7 shows a fast Customs boat from Spain made with Kevlar®. Figure 8 is a Kevlar® catamaran workboat

Sails and High Tech Fibers

Newer sails on racing sail boats are another place where high strength fibers are becoming more prevalent. According to Doug Stewart, Production Manager at Quantum Sailmakers, "Fiber currently being used in high end sails is Carbon and Twaron. Currently in the highly competitive TP 52 class sails are 100% carbon. Low modulus carbon has great strength to weight and is very flexible fiber as long as it is not saturated in the lamination process. At this point in the process of high end sails the key is the perfect mix of fiber, pressure and heat. Not enough fiber, you have a sail that is light but will not hold its desired shape. Not enough glue, you have a sail that is light but will probably delaminate long term.

"What will the next sail making revolution bring? There is no doubt that there is another super fiber like carbon right around the corner! Mylar, the outer skin of the sail which is really used to hold the fiber and glue in place probably is the next area where we will see changes. Films will get stronger which means sailmakers will be less reliant on fiber. My opinion is that within 10 years we will see a sail just made of film. Initially very

expensive and not very durable but in the high end arena of America's Cup (AC) and TP 52s, money certainly is not the issue."

OTHER HIGH TECH FIBERS

Other high-tech fibers have yet to establish themselves in the marine market. Basalt was investigated by High Modulus, but they concluded from their testing that "...[t]he Basalt unidirectional material was not significantly stronger or stiffer than the E-glass unidirectional." The M-5[®] fiber development effort received a boost when DuPont bought a majority share of the company making the fibers marketed as having "... potential as an ultra-high strength, ultra-high thermal and flame resistant alternative to products currently available in the advanced fibers market."

Nova Craft Canoe has developed a laminate that combines a leading edge Kevlar[®]/Carbon material combined with Spectra[®] and applied through an infusion process. The result is a tough, rigid canoe that's surprisingly light and easy to handle. Once plasma-treated surfacing helped improve resin adhesion, Spectra[®] has mostly been limited to canoe applications.

So although carbon and Kevlar[®] have made significant inroads into the marine composites world, E-glass remains the workhorse of the industry. Certainly when weight is at a premium, Kevlar[®] or carbon fiber laminates can be justified. For stiffness-limited designs, carbon unidirectional can help optimize a laminate.



Figure 1. Earthrace Long Distance Trimaran Runs on Bio-Diesel [Eric Greene photo]



Figure 2. M-Ship was built by Knight & Carver for U.S. Navy [M-Ship]



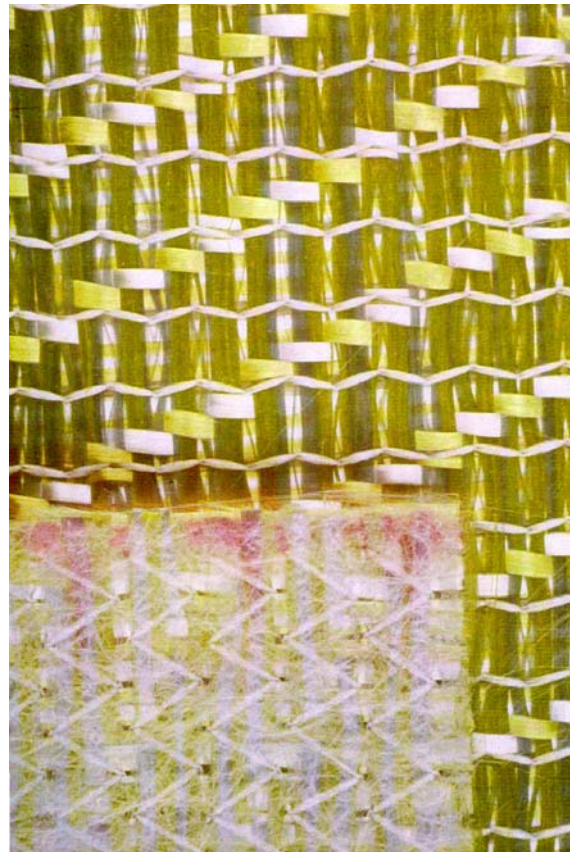
Figure 3. 121 foot Humpries Motoryacht [Humpreys Yacht Design]



Figure 4. 130 foot Wally Daysailor [Javier Soto Acebal]



**Figure 5..Tiawanese Patrol
Boat Built with Kevlar®
[Raybould, DuPont]**



**Figure 6. Hybrid Weave
of Kevlar® and E-glass
[Raybould, DuPont]**



**Figure 7. 60+-Knot Spanish Customs Boat Built with Kevlar®
[Raybould, DuPont]**



**Figure 8 Catamaran Work Boat Built with Kevlar®
[Raybould, DuPont]**

Table 1. Fiber Usage in the Marine Industry

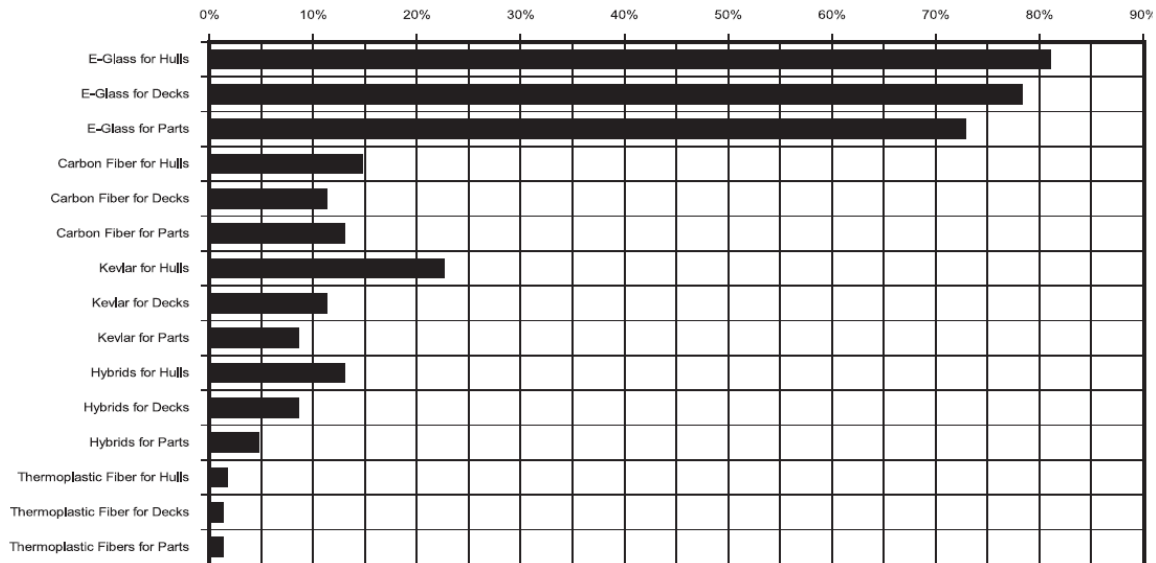


Table 2. Fiber Mechanical Properties

Fiber	Density lb/in ³	Tensile Strength psi x 10 ³	Tensile Modulus psi x 10 ⁶	Ultimate Elongation
E-Glass	.094	500	10.5	4.8%
S-Glass	.090	665	12.6	5.7%
Aramid-Kevlar [®] 49	.052	525	18.0	2.9%
Spectra [®] 900	.035	375	17.0	3.5%
Polyester-COMPET [®]	.049	150	1.4	22.0%
Carbon-PAN	.062-.065	350-700	33-57	0.38-2.0%



Figure 9 Laminated Sails use Fiber in Areas of Predicted Stress [Quantum Sails]