# The Use of Carbon Fiber/Epoxy Braided Composites in the Design of a Rowing Shell

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## Introduction

A composite is a material made of a polymer matrix, such as epoxy resin, and a fiber reinforcement like fiberglass, Carbon Fiber, and Kevlar (which is a type of Aramid Fiber). Fiber-reinforced composite materials are widely used in sports equipment such as rowing shells. A rowing shell is a very long and narrow boat that is designed for racing. An optimal rowing shell is lightweight, but it must also be stiff and durable to withstand forces in both the longitudinal and transverse directions. Hence, the outer shell of a rowing shell is typically made out of unidirectional (fibers lay in one direction) Kevlar or Fiberglass with epoxy resin as the commonly used matrix. However, carbon fiber, which is a strong, light, and stiff fiber that is typically used in aerospace as well as mechanical and medical fields, is a favorable material for composites that may also warrant investigation [1].

Figure 1: Single Sculls Rowing Shell

Composites can be produced by 2D braiding where fibers are bundled into yarn and woven together. 2D Braided composites offer added transverse strength, more damage tolerance, and are easy to mold to the curved shape of a rowing shell, hence their attractive potential for use in a rowing shell design. This study will examine the use of carbon fiber braided composites in a rowing shell in comparison to unidirectional Kevlar and Fiberglass composite parts.

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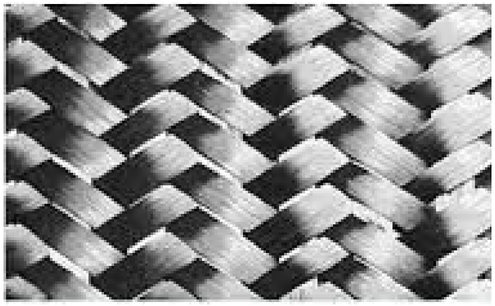

Figure 2: 2D Braided Composite

Source: Adapted from [2].

## Importance and Purpose

When looking at the material used to manufacture a rowing shell, the most important factors to consider are the stiffness, strength, and density of the material. Longitudinal stiffness is important because it maximizes the deformation resistance of the shell in the direction of motion; this can be measured from the longitudinal elastic modulus. A rowing shell that is not stiff is not favourable as it would absorb the energy and power of the rower. That power could have been used to accelerate the rower in the forward direction. Furthermore, a denser material translates to a lighter shell. A lighter shell is favourable as it means that there will be less load to move. Rowing is a sport which can be determined by a few thousandths of a second; for example, at the 2016 Rio Olympics, the difference between first and second in the men's single sculls was five-thousandths of a second. Therefore, an efficient rowing shell is important for high-performance athletes to maximize their performance.

However, rowing shells also need to be durable and strong to be able to withstand rough conditions or unexpected forces that do not come from the longitudinal direction. To account for these unforeseen forces, a 2D composite would be better suited than a unidirectional composite even though this will compromise the longitudinal stiffness of the boat. A rowing shell made with 2D Braided Composites is shown in Figure 3.

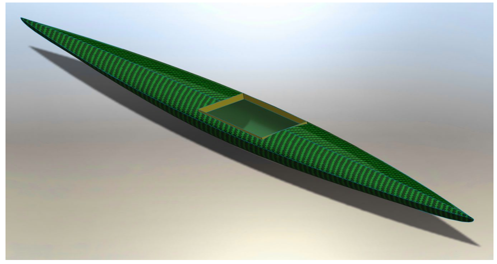

Figure 3: Braided composite rowing shell designed on Solidworks using dimensions of 7.09m lengthwise and 0.52m widthwise.

## Material Significance

Carbon Fiber, Kevlar, and Fiberglass have good tensile strength when combined with an epoxy resin matrix [3,4,5]. Carbon fiber's main advantage comes from its high longitudinal Elastic Modulus as shown in Table 1. Carbon Fiber's longitudinal elastic modulus is almost two times higher than Kevlar's longitudinal elastic modulus and more than three times higher than Fiberglass's longitudinal elastic modulus making it significantly stiffer, thus making it a much more suitable material for a rowing shell. Despite Carbon Fiber being more expensive than Kevlar and Fiberglass, its advantages overcome this making it the best material for a rowing shell [3]. Carbon fiber is also less dense (as shown in Table 1) than Fiberglass and has a comparable density to Kevlar allowing for minimal drag.

Table 1: Comparison of the modulus of different composites [6].

| | **Carbon Fiber/Epoxy** | **Kevlar/Epoxy** | **Fiberglass/Epoxy** |
|---|---|---|---|
| **E_11 (GPa)** | 135 | 75 | 40 |
| **E_22 (GPa)** | 10 | 6 | 8 |
| **G_12 (GPa)** | 5 | 2 | 4 |
| **Poisson's Ratio** | 0.3 | 0.34 | 0.24 |
| **Fiber Volume Fraction** | 0.6 | 0.6 | 0.6 |
| **Density ($g/cm^3$)** | 1.6 | 1.4 | 1.9 |

*E_11= Longitudinal Elastic Modulus, E_12= Transverse Elastic Modulus, G_12 = Shear Modulus

## Significance of Braid Angle

After concluding that the carbon fiber epoxy composite is optimal to manufacture a rowing shell, the equations shown in Figure 4 were used to find the most effective braid angle when using a Carbon Fiber/Epoxy Composite. The braid angle is the angle formed by the longitudinal axis and the fiber.

$$S_{11} = \frac{1}{E_{11}} \quad S_{22} = \frac{1}{E_{22}} \quad S_{12} = -\frac{v_{12}}{E_{11}} \quad S_{66} = \frac{1}{G_{12}}$$

$$S_L = S_{11}cos^4\theta + (2S_{12} + S_{66})sin^2\theta cos^2\theta + S_{22}sin^4\theta$$

$$S_T = S_{11}sin^4\theta + (2S_{12} + S_{66})sin^2\theta cos^2\theta + S_{22}cos^4\theta$$

$$S_G = 2(2S_{11} + 2S_{22} - 4S_{12} - S_{66})sin^2\theta cos^2\theta + S_{66}(sin^4\theta + cos^4\theta)$$

$$E_L = \frac{1}{S_L} \quad E_T = \frac{1}{S_T} \quad G = \frac{1}{S_G}$$

$E_{11}$ = Longitudinal Elastic Modulus of Composite, $E_{22}$ = Transverse Elastic Modulus of Composite, $G_{12}$ = Shear Modulus of Composite, $v_{12}$ = Poisson's Ratio, $E_L$ = Longitudinal Elastic Modulus of Braided Composite, $E_T$ = Transverse Elastic Modulus of Braided Composite, $G$ = Shear Modulus of Braided Composite

Figure 4: Equations used to calculate $E_L$, $E_T$, and $G$ of the braided composite [7].

The results are found in Figure 5.

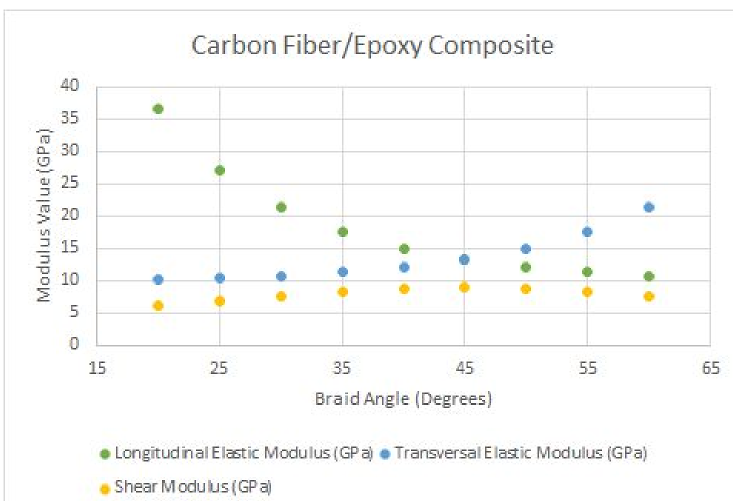


Figure 5: Plot of the modulus values of the composite as a function of the braid angle.

Since most of the forces present will be in the longitudinal direction, it is most important to have a higher elastic modulus in that direction. Therefore, a braid angle of 20 degrees would have the highest stiffness in the direction of motion while also making the shell durable enough to withstand potential unexpected forces.

## Conclusion

Fiber-reinforced composites are used for a variety of different sports equipment one of which is the outer layer of a rowing shell. After comparing the properties of Carbon Fiber to what is typically used to manufacture rowing shells (Kevlar and Fiberglass), it was evident that Carbon Fiber was a more optimal material to manufacture a rowing shell due to its high elastic modulus. To maximize the longitudinal elastic modulus while increasing the transverse elastic modulus, a braid angle of 20 degrees was determined to be best. Although this decreases the longitudinal elastic modulus from 135 GPa to 36.6 GPa, it is still comparable to the longitudinal elastic modulus of the commonly used fiberglass. It also increases other factors such as the transverse elastic modulus and the torsional strength. This subsequently increases the overall stiffness of the shell, such that the shell will be more durable when facing unexpected forces that may occur on the water. While carbon fiber is more expensive than typical fibers, the quality is much higher and it is more durable and lightweight, which allows for decreased drag. Ultimately, using 2D Braided Carbon Fiber/Epoxy Composite to manufacture a rowing shell will result in a more efficient boat that will have a longer lifespan.


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