Fiber Reinforced Composite Pressure Vessel – Carbon Fiber

RUTGERS School of Engineering

MAE Design and Manufacturing

Jaritza Rodriguez, Jonathan Burnley, Daniel O'Rear, John Bastardo, Benjamin Fiedler, Marco Lopez

Advisor: Dr. George Weng

Abstract

In a conventional household or major company, pressure vessels are used for storing liquids, gases and vapors at high pressures. Most vessels currently available are constructed from steel and other types of alloys. The problem with these kinds of vessels is they have a much lower strength to weight ratio, meaning these vessels weigh more while not being able to withstand as much pressure. Our goal is to construct a cylindrical pressure vessel that is fabricated from carbon fiber, which is a well known fiber reinforced composite.

Figure 1: Anticipated use of Pressure Vessels U.S market

Proposed Solution

In designing our pressure vessel, we had 3 targets:

- Be able to withstand a maximum internal pressure of 3000 psi.
- Contain a cylindrical washer adding extra strength to the nozzle.
- Be made up of no more than three layers of carbon fiber, each being oriented to specifically maximize pressure capacity.

Figure 2: Pressure Vessel Solidworks design and drawing schematic

Background

When coming up with a design for the pressure vessel, the major constraints that were assessed include weight, strength, and cost. Composite materials such as carbon fiber have high strengths and low weights compared to metals. In the case of carbon fiber, the strength to weight ratio can be as high as 20 times greater than that of metals. This means that when incorporating carbon fiber into the structure of our pressure vessel, we can expect to see these improvements.

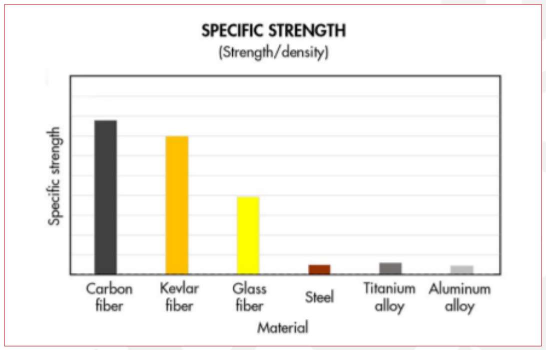

Figure 3: Specific Strength Comparison Amongst Materials

The overall dimensions and the thickness of a pressure vessel is important when trying to determine the theoretical stress it experiences.

Equation 1: The longitudinal stress experienced due to internal pressure. Here, p is the internal pressure, t is the wall thickness, and r is the radius of the vessel.

$$\sigma_{longitudinal} = \frac{pr}{2t}$$

Equation 2: Hoop stress experienced due to internal pressure.

$$\sigma_{hoop} = \frac{pr}{t}$$

Figure 6: Final Carbon Fiber Pressure Vessel

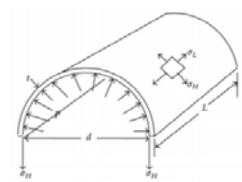

Figure 4: Hoop and longitudinal stress modeled visually

$$[T] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & 2\sin\theta\cos\theta \\ \sin^2\theta & \cos^2\theta & -2\sin\theta\cos\theta \\ -\sin\theta\cos\theta & \sin\theta\cos\theta & \cos^2\theta - \sin^2\theta \end{bmatrix}$$

Figure 5: T Matrix

The three carbon fiber layers will be oriented in a specific direction. Theta represents the orientations of the carbon fiber layers with respect to the horizontal plane. This will result in a maximized pressure capacity for the vessel when all three are combined. It is intended to optimize the reinforced strength in longitudinal and hoop directions. A T-matrix is to be used to transform the stresses from the normal longitudinal and hoop directions to set of new orthogonal directions.

Equations five and six will then be used to calculate the overall strengths in the hoop and longitudinal directions. In these equations, the superscripts 1 and 2 denote either the first or second layer.

$$\frac{1}{2}(\sigma_x^{(1)} + \sigma_x^{(2)}) = \sigma_x = \frac{pr}{2t}$$

Total longitudinal stress capacity from examining the individual stresses of layer 1 and layer 2

Total hoop stress capacity from examining the individual stresses of layer 1 and layer 2.

$$\frac{1}{2}(\sigma_y^{(1)} + \sigma_y^{(2)}) = \sigma_y = \frac{pr}{t}$$

Fabrication Process

Figure 7: (1) Melting the wax used to create the mold for the pressure vessel (2) the solidified cylindrical mold made of wax (3) the metal washer unique to this design that adds structural stability

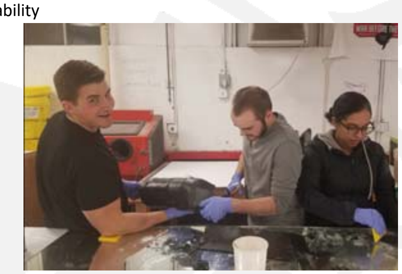

Figure 8: Dan, Ben and Jaritza wrapping the wax mold

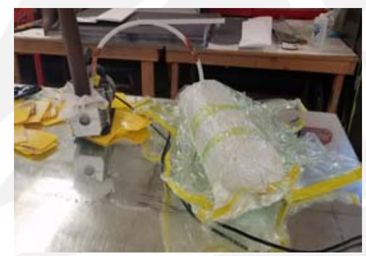

Figure 9: Curing the carbon fiber

Conclusion

Utilizing carbon fiber, an effective composite known for its strength, to tackle the problem of high pressure storage, resulted in the conception of the cylindrical composite carbon fiber pressure vessel. Carbon fiber has a superior tensile stress compared to steel as well as it being lighter in comparison. These properties stage carbon fiber to make a large impact on the aerospace industry. compared to traditional pressure vessels.