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Fiber Reinforced Composite Materials Used for Tankage

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Introduction

The Nonmetallic Materials and Processes Group is presently working on several projects to optimize cost while providing effect materials for the space program. One factor that must be considered is that these materials must meet certain weight requirements. Composites contribute greatly to this effort. Through the use of composites the cost of launching payloads into orbit will be reduced to one-tenth of the current cost. This research project involved composites used for aluminum pressure vessels. These tanks are used to store cryogenic liquids during flight. The tanks need some type of reinforcement. Steel was considered, but added too much weight. As a result, fiber was chosen. Presently, only carbon fibers with epoxy resin are wrapped around the vessels as a primary source of reinforcement. Carbon fibers are lightweight, yet high strength. The carbon fibers are wet wound onto the pressure vessels. This was done using the ENTEC Filament Winding Machine. It was thought that an additional layer of fiber would aid in reinforcement as well as containment and impact reduction. Kevlar was selected because it is light weight, but five times stronger that steel. This is the same fiber that is used to make bulletproof vests trampolines, and tennis rackets.

A braided structure was chosen because it is conformable to a variety (but not all) of shapes. The braided structure was manufactured by using the Wardwell Maypole Braider. This piece of equipment produces a braid by using the same principle as the popular children's game, "Braid the Maypole"; hence the name Maypole Braider. In this game children grab ribbons which hang from the top of a pole. They then move in a circular motion, some to the left and some to the right. As they meet, they go over the first person and under the second. This creates a braid. The Maypole Braiding machine has several carriers, which hold the yarn packages, on its front and the rear. They contain springs, which keep the yarns in constant tension. The carriers (like the children) on the front of this circular machine rotate. The carriers on the rear do not move. These rear carriers hold the yarns called axials. The axial yarns are pulled through the front side of the machine. They are held in a constant position. The carriers on the front of the machine are called wrapping yarns. They wrap around the axial yarns, thereby creating a braid. All of the yarns are pulled through a ring to a central location where they interlace, called the braiding point. This is the point where the mandrel or object being braided on is pushed through. This machine has a control box with the following controls: start/stop, emergency stop, stop motion on/off, run/jog, forward/reverse, auto/manual, braider/feeder/braider & feeder, traverse ratio, and master speed. The forward/reverse button controls the direction that the traverse moves. The traverse is the top part of the machine which moves in a horizontal direction. The traverse has a lower part that holds the mandrel after it is pushed through the braid point. The auto/manual button allows continuous operation of the machine when on auto, but non-continuous when on manual. The braider/feeder/braider & feeder button controls operation of the braider and feeder simultaneously as well and non-simultaneously.

The traverse ratio controls the speed that the traverse moves. The master speed controls the speed at which the machine braids. Both are unitless.

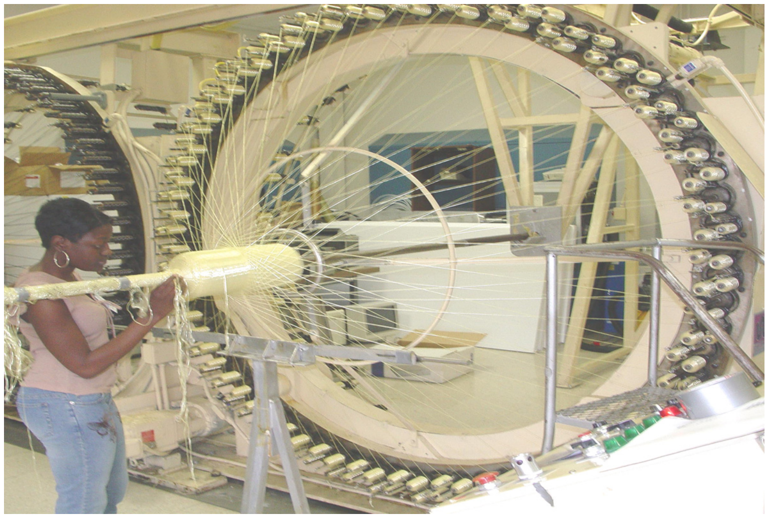

Figure 1: Wardwell Maypole Braider

Fiber Reinforcements Used for Tankage

Rubber bands were placed on the empty carriers. This was done to disable the stop motion and allow the machine to run continuously. Some of the rear carriers had to be replaced so that all eighteen operated by the same roller mechanism. Since the machine had been sitting idle for months, it was run to remove old surface yarns. Shafts were screwed into the ends of the pressure vessels and it was pushed through the braiding point onto the traverse. Several trials were done, but a useable structure was not produced. Some modifications had to be made to the braiding machine in order to produce a suitable structure. New springs were added to the carriers to provide better tensioning. Lubricants were applied to the machine so that the carriers released the yarns properly. The second ring was removed to prevent filaments from forming. After these adjustments were made the research was divided into three projects. Each project used a different technique of combining materials for the composite.

In the first project, Kevlar was braided over a bare pressure vessel. This was done to see if it was best to start the braid on the tank and move down toward the shaft or vise versa. It was also done to see if any additional adjustments had to be made. Several runs using a different number of axial and wrapping yarns were done. It was determined that the tightest structure was formed by using eighteen wrapping yarns in each direction. Eighteen axial yarns were used up until the point where the tank flares out into a disk shape.

This is the section just after the bottleneck of the tank. At this point an additional eighteen axials were pulled through. This increased the tension in the structure, which resulted in tighter braiding.

Figure 2: Braiding Over Bare Pressure Vessel

In the second project the vessel was wrapped with felt. The felt was also made from Kevlar. The felt was applied dry with double-sided tape. Rubber bands were placed on the end of the bottlenecks to hold the felt ends in place. The structure (also applied dry) was braided over the felt. Carbon fibers were then wet wound over the structure. The epoxy resin was allowed to cure.

Figure 3: Braiding Over Felt

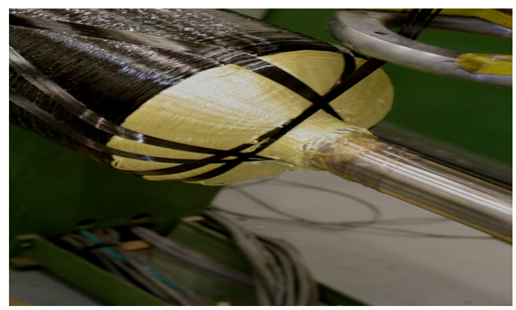

Figure 4: Wet Filament Winding Over Structure

In the third project, the carbon fibers were wet wound onto the tank first. The epoxy resin was allowed to cure. A layer of felt was wrapped over the cured carbon fibers of one tank. This was done so that one impact test could be performed with the felt and one without it. This will determine if the felt aids in impact reduction. The braided structure was applied over this layer of felt. The braided structure was applied directly on top of the cured carbon fiber for the other tank. A second layer of carbon fibers was wet wound on top of the braided structure for both tanks. The epoxy resin was allowed to cure.

Figure 5: Wet winding of carbon fibers

Testing and Results

Two tests are performed on the pressure vessels to see if they are more efficient with the addition of the structure. One test they undergo is an impact test. In this test the pressure vessels are shot with fifty caliber rifles. Observations will be made to see if the Kevlar structure and felt reduces the impact of the bullet. This test will also determine if the braided structure is useful for containment of metal fragments when the tank fails. The second test that is performed on these pressure vessels is a burst test. In this test, the tanks are filled with water. They are then placed inside of a machine where the pressure is increased to several thousand pounds per square inch until the tank fails. This test will also determine if the structure is useful for containment. The bare tanks burst at 1300 psi. The tank with carbon fibers and epoxy resin burst at 7800 psi. With the addition of the braided structure, the tanks should be able to withstand well over 8000 psi. (These tests have not been performed yet on the tanks with the braided structure and felt. Some of them have to be shipped to Utah, so there are no results to report.) The braided structure and felt material only add 800 grams to the tanks.

Figure 7: Bare tanks fail at1300 psi

Figure 8: Tank w/ carbon and resin fails at 7800 psi

Future Applications for the Braided Structure

The structure can be used in future space exploration missions and possibly the return to flight mission. It can be used to reinforce larger pressure vessels and other tankage. In the case of meteors or any other debris hitting the tank, it will reduce the impact. If by chance the tanks fail, it will serve as a safety and protective material by containing the metal fragments from tank. Possible future applications may include cryogenic research. Any lightweight high strength material can always aid in furthering the space exploration program. It may also be useful to the military and Department of Homeland Security to protect tanks containing explosive liquid from terrorist attacks.

Resources

This project required the use of a braiding machine and Kevlar fibers, which were provided by the United States Army. Aluminum pressure vessels, carbon fibers with epoxy resin, and a machine for filament winding were provided by Marshall Space Flight Center. A machine to perform the burst test was provided by the east testing area employees. The impact test will be done by engineers in Utah. A digital camera was used to take photographs of the different structures. These pictures were used to make observations, an analysis, and to determine the most proficient structure for this application.

Conclusion

This form of composite material is useful to Marshall Space Flight Center because it provides a very cost efficient mean of reinforcing aluminum pressure vessels. The material adds very little weight, but high strength. Therefore, the vessels are more durable and less susceptible to damage. If anything hits the tank, the structure will reduce the impact. Not only does the structure serve as a reinforcement and impact reducer, it can be used as a safety and protective material as well.

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