VI.7 Development of Advanced Manufacturing Technologies for Low Cost Hydrogen Storage Vessels

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Subcontractor:
Boeing Research and Technology, Seattle, WA

Partners:
- Lawrence Livermore National Laboratory (LLNL), Livermore, CA
- Pacific Northwest National Laboratory (PNNL), Richmond, WA

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Project End Date: October 31, 2011

Project Objective

Develop new methods for manufacturing Type IV pressure vessels for hydrogen storage with the objective of lowering the overall product cost, which will:

- Optimize composite usage by combining traditional filament winding and automated fiber placement techniques.
- As a parallel effort, investigate emerging dry-tape technology which could drastically shorten the manufacturing time.

Technical Barriers

The project addresses the following technical barriers from the Hydrogen Storage section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) System Weight and Volume
(B) System Cost

Contribution to Achievement of DOE Manufacturing Milestones

This project is directed to develop a hybrid manufacturing process, which combines filament winding and automated fiber placement processes to save composite material usage in Type IV hydrogen storage vessels. Further efforts focus on a dry-tape technology having the potential to significantly reduce vessel production cycle time. It will contribute to achievement of the following DOE milestones from the (3.5) Manufacturing R&D section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 24:** Develop fabrication and assembly processes for high-pressure hydrogen storage technologies that can achieve a cost of $2/kWh. (4Q, 2015)

Accomplishments

- Investigated and selected candidate materials for use in both filament winding and automated fiber placement;
- Investigated an optimized liner dome profile; manufactured liners and measured their profiles;
- Designed and built robotic automated fiber placement system;
- Generated the first iteration of composite material design in the vessel structure; and
- Developed a cost model to assess cost sensitivities for different manufacturing techniques.

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Introduction

The goal of this project is to develop an innovative manufacturing process for Type IV high-pressure hydrogen storage tanks, with the intent to significantly drive down costs. Part of the development is to integrate the features of high precision automated fiber placement (AFP) and commercial filament winding (FW). As a potential, high-risk approach, 'dry-tape' technology is being investigated by LLNL, which could shorten production cycle time.

To achieve the goal of integrating AFP and FW, Quantum and Boeing have:

(a) Evaluated towpreg materials to address the material compatibility issue.

(b) Investigated liner dome profile optimization.

(c) Manufactured liners and measured liner profile for vessel production purpose.

(d) Assembled and integrated the AFP system, and further developed the control software.

Quantum and Boeing plan to build and burst test the first vessel by the end of this calendar year. Furthermore, we will continue to work on composite design iterations and refinement of the AFP process. Quantum and Boeing will supply manufacturing cost information to PNNL to refine the Cost Model, which will assess the cost sensitivities of this manufacturing technique. In a parallel activity, LLNL may conduct experiments to prove the feasibility of dry-tape technology. PNNL and LLNL will report their activities in separate reports.

Approach

Type IV pressure vessels are commonly made by FW with a limitation that the reinforcement has to be altogether continuous: the placement of material on the dome regions inevitably introduces materials on the entire cylinder region. Materials introduced this way are not needed and are called "parasitic". This parasitic material lowers the system storage efficiency and increases cost. The proposed process can locally reinforce the dome regions, eliminating parasitic waste. This is done by incorporating the AFP process, which can place non-continuous material on any region of the tank to supplement the FW process. Thus, this project is integrates the efficiency benefit of AFP with the speed of FW to create a new hybrid process which can optimize composite usage. Because these two processes typically use different materials, studies have been performed to address compatibility. Both materials have to cure completely within the existing processing window and the overlap between them must transfer load efficiently. A detailed composite design will determine the quantity and distribution of the materials in the vessel introduced by each process. The AFP process will be adapted to pressure vessel production to take advantage of its efficient material usage.

Results

Since the project started, Quantum and Boeing have built coupons and evaluated shear strength and fracture toughness. The test results have guided our composite design, by indicating how much overlap is needed between the AFP and FW placed materials. We have also studied the cure behavior for both materials to verify a complete cure.

We have developed an optimized liner dome profile for uniform fiber stress distribution, and have manufactured high-density polyethylene liners according to this derived profile. The liner surface profile was measured using a coordinate measuring machine to verify the accuracy of the liner production process. This same dome profile will be used in the path generation for AFP process, in order to place the material in the desired location. Quantum is working on the composite design using stress analysis and finite element modeling. We have generated the first iteration design, according to which the non-continuous materials will be laid down in the AFP process first on the dome region locally (shown in Figure 1), and then FW is used to cover continuous composite material all over the vessel surface. Based on our current composite design results, approximately 6 kg of materials may be eliminated from the current 76.5 kg design.

A graphic illustration of Boeing's robotic arm and revised head for AFP is shown in Figure 2.

The DOE target for system storage efficiency is based on the assumption of producing 500,000 units per year. A system considered here consists of a single 129L type IV H_2 tank (approximately 5 kg hydrogen capacity) with a solenoid valve, a set of high pressure and low pressure regulators, a mid stage valve, a receptacle with filter, all tubing and fittings for this system, a frame, a wire harness, a pressure sensor and a balance of parts (consisting mainly of fasteners etc.). The end-user cost efficiency of such a system based on the assumption of 500,000 units/year as well as the assumption that 1 kg hydrogen is able to generate 33.3 kWh energy, is estimated to be $45.9/kWh, with a weight efficiency of 1.50 kWh/kg. The 6 kg of composite savings will improve the storage system weight efficiency

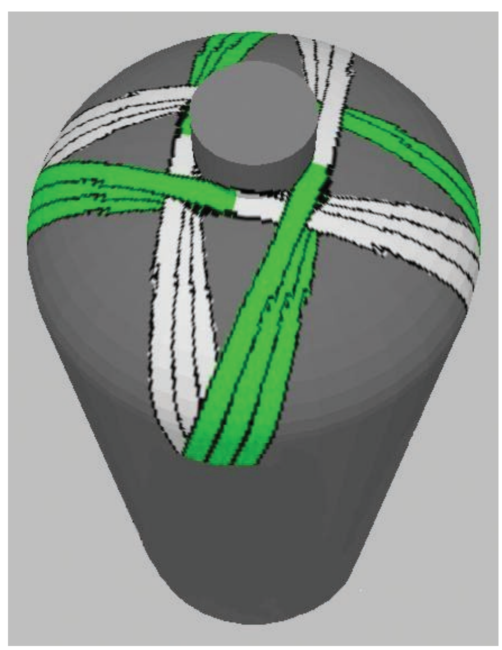

FIGURE 1. Local Dome Reinforcement

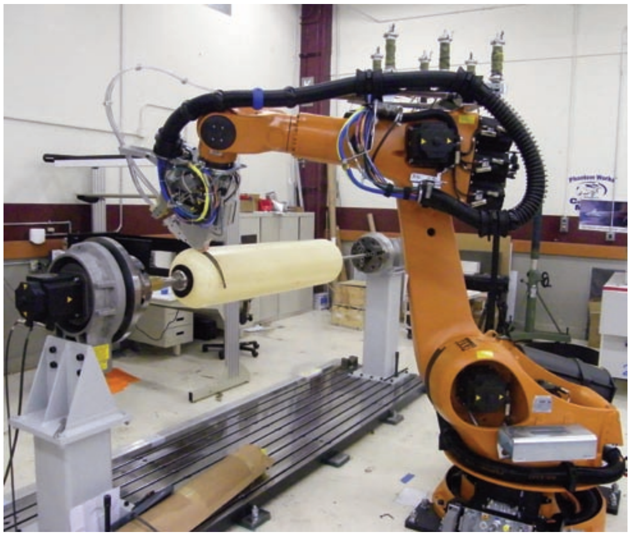

FIGURE 2. Kuka KR100 Robot Platform with AFP Integration

approximately to 1.58 kWh/kg, and will possibly improve the system cost efficiency as well.

The overall AFP robotic system is 90% complete for this project. Key to this system is a Boeing designed tow-placement head having a low-profile that allows for a tight clearance to the end bosses. The head uses six-tows, each 0.25-inch wide producing a 1.5-inch band. The machine can add an individual tow independently from each other. The integrated system includes a 6-spool creel mounted on the upper arm of the robot. The robot's path is driven by CGTech-VCP software adapted for a hybrid fiber-placement/filament-winding process. The post-processor for the path generation software has been completed. Boeing has further completed the liner mounting system, which will be used for future development activities. Final tasks prior to first tank build include:

(1) Reworking a limited number of creel components.

(2) Completing the Kuka controller's input/output mapping .

(3) Testing programs and end-dome material lay-down. Once the system has been demonstrated, Boeing will begin increasing rates to evaluate productivity goals.

We will build the first hybrid process vessel and perform the burst test according to European Integrated Hydrogen Project standard before the end of the current calendar year. After the test, we will continue composite design iterations and improvements in the AFP process capabilities.

We also supply manufacturing cost information to help PNNL assess cost sensitivities of different manufacturing techniques.

Conclusions and Future Direction

- Material study, initial composite design, and liner dome investigation have been finished.
- The AFP equipment and software is 90% complete; completion of this task will allow the manufacture of the first hybrid AFP/FW pressure vessel.
- Further composite design iterations and AFP process development will be required to refine the process (Phase II activities).
- Identified and prioritized the significant manufacturing costs with consideration of process steps, materials, equipment, factory space and labor for compressed hydrogen storage tank (details reported separately on "Design of Advanced Manufacturing Technologies for Low Cost Hydrogen Storage Vessels" by PNNL).

FY 2009 Publications/Presentations

1. Development of Advanced Manufacturing Technologies for Low Cost Hydrogen Storage Vessels, Annual Merit Review, Department of Energy, May 18–22, 2009, Arlington, VA.