IV.E.2 Advanced Concepts for Containment of Hydrogen and Hydrogen Storage Materials

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Objectives

- Design, fabricate and test optimum designs for filament wound conformable pressure vessels
- Design, fabricate and test optimum designs for macrolattice conformable pressure vessels
- Design, fabricate and test optimum designs for replicant conformable pressure vessels
- Develop innovative concepts of hydrogen storage to meet DOE goals for improved performance

Technical Barriers

This project addresses the following technical barriers from the Storage section (3.3.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) System Weight and Volume
(D) Durability
(E) Charging/Discharging Rates
(H) Balance of plant (BOP) components
(J) Thermal management
(L) High-Pressure Conformability

Technical Targets

Table 1. Lawrence Livermore Filament Wound Conformable Vessels Progress Toward Meeting DOE On-Board Hydrogen Storage Targets

Storage Parameter	Units	2007 Target	2010 Target	2005, 1st prototype	2006, 2nd prototype
Specific Energy	kWh/kg	1.5	2	0.53*	1.1*
Energy Density	kWh/L	1.2	1.5	0.16*	0.48*
Storage System Cost	$/kWh	6	4	-	-

* Vessel only, no accessories included

Accomplishments

- Designed, fabricated and tested prototype macrolattice conformable vessels
- Designed and built parts for second generation macrolattice vessels
- Analyzed and designed filament wound conformable container
- Built and burst tested two filament wound pressure vessels
- Built parts for replicant conformable vessel

Future Directions

- Complete fabrication and pressure test second generation macrolattice containers with potential for much improved (~30%) volumetric efficiency over regular cylindrical tanks
- Build and test improved filament wound container prototypes
- Design end segments for filament wound vessels
- Analyze thermal management capability of macrolattice and determine performance advantage with respect to other available means for hydrogen storage material thermal management
- Complete design and construction of replicant vessel and determine capacity, degree of conformability and evaluate against 2007 targets

Introduction

One of the fundamental hurdles limiting the broad applicability of hydrogen vehicles is storing enough hydrogen on-board for a reasonable range (over 300 miles for the US market). Several approaches are being pursued, including physical storage (liquid or compressed hydrogen), chemical storage, hydrogen absorption in metallic hydrides, or hydrogen adsorption in carbon compounds. All these approaches present fundamental limitations in weight and volume densities. Some forms of storage (hydrides and carbon structures) also require thermal management (heating during desorption and cooling during absorption or adsorption). Regardless of which form of hydrogen storage is ultimately selected by the vehicle manufacturers, there is a great need to develop high performance low-cost containers for hydrogen or hydrogen storage materials. For best performance, these containers should be conformable, meet the pressure and temperature requirements for the different forms of hydrogen storage, and provide efficient means for thermal management.

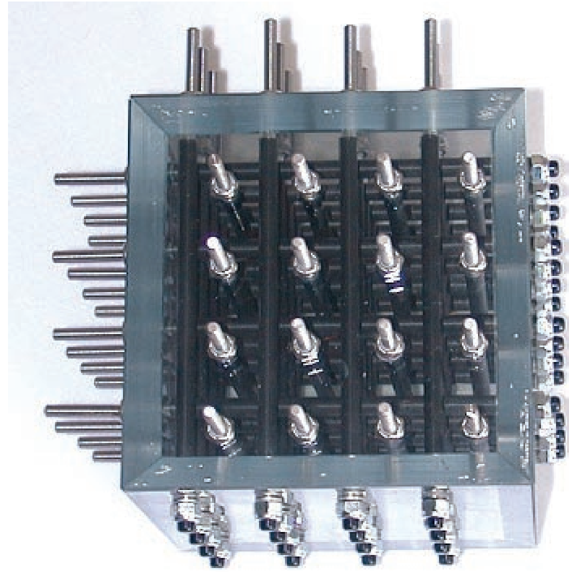

FIGURE 1. Prototype First Generation Conformable Macrolattice Container

Approach

We are working on many approaches for high performance containers. We have designed and constructed and pressure tested two filament wound conformable containers. We have designed and built parts for the second generation of macrolattice conformable vessels. We have also designed and made parts for replicant pressure vessels. All our container work can efficiently be applied for all forms of hydrogen storage, including hydride and carbon storage in addition to physical storage.

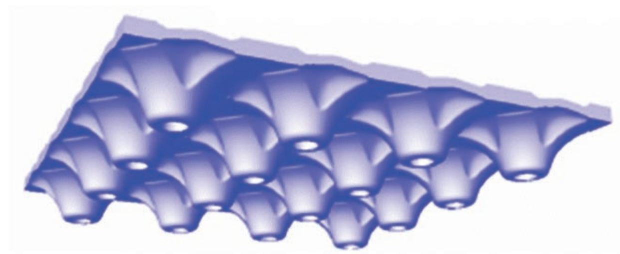

FIGURE 2. Improved "Egg Carton" Surface Shape for Generation Two Macrolattice Container

Results

In FY 2005 we built and tested the first ever macrolattice conformable container (Figure 1). This is a cubic container with polycarbonate surfaces held together by metallic struts. The arrangement of the struts is inspired by crystallography tables, and was selected to facilitate manufacture and improve volumetric efficiency. The container was pressure tested in our high pressure laboratory and then demonstrated in the poster session at the review meeting. The strut arrangement has the additional advantage of providing heat transfer paths for efficient thermal management of hydrogen storage materials (hydrides and carbon adsorbents). If more intense thermal management is required, the metallic struts can be made hollow, allowing the circulation of a coolant fluid into the vessel.

This year we went beyond the initial macrolattice design with flat outer skin and created new designs for the outer surfaces that minimize bending stresses. These surfaces for the second generation macrolattice designs have an "egg carton" shape (Figure 2). These parts have been designed with computer assisted design (CAD) software and built in a rapid prototyping machine. With future funding we will build a complete generation two macrolattice vessel with much improved structural performance.

We have also been working on filament wound conformable pressure vessels. Last year we designed conformable pressure vessel container segments with a "pillow" shape. In this year we designed, fabricated and pressure tested two pillow container segment prototypes (Figure 3). The segments were tested between two parallel plates for replicating the results that would be obtained if segments with elliptical ends were added to our design. The first prototype failed at a relatively low pressure (800 psi) at an unreinforced corner. The second prototype with reinforced corners had a boss failure at 1,600 psi. The tank fiber held up at this higher pressure, indicating good structural performance.

FIGURE 3. Prototype Filament Wound "Pillow" Conformable Pressure Vessel Segment

Finally, we also designed and fabricated components for replicant vessels, which also use an internal structure to hold the pressure, along with a thin outer skin that contains the hydrogen. The internal structure is made of "replicants," which are small structural members that fill the interior of the vessel (Figure 4). It is believed replicant vessels will have a mass production advantage for large sizes (e.g. delivery trucks for pressurized hydrogen) where individual macrolattice struts would be very large. Mass production of the replicants and robotic assembly could result in large scale vessels with reduced manufacturing costs that would be time consuming to produce by conventional methods (filament winding).

Conclusions

- We have designed and fabricated optimum skin designs for second generation macrolattice containers. These new macrolattice containers are being designed for much improved structural performance
- We designed, fabricated and tested two prototype filament wound conformable vessel segments (pillow tanks)
- We have designed and fabricated components for replicant vessel designs

FIGURE 4. Internal Structure Made of Replicants for Conformable Pressure Vessel

FY 2006 Publications/Presentations

1. Advanced Concepts for Vehicular Containment of Compressed and Cryogenic Hydrogen, Salvador M. Aceves, Gene D. Berry, Andrew H. Weisberg, Francisco Espinosa-Loza, Scott A. Perfect, Proceedings of the 16th World Hydrogen Energy Conference, Lyon, France, June 10-15, 2006.

2. The Use of Hydrogen Combustion for Power Generation, D. Walther, C. Fernandez-Pello, and R. Dibble, S. Aceves and D. Flowers, Paper AIAA-2005-5753, 3rd International Energy Conversion Engineering Conference and Exhibit, San Francisco, California, Aug. 15-18, 2005.

3. The Case for Hydrogen in a Carbon Constrained World, Gene D. Berry and Salvador M. Aceves, Invited discussion paper, ASME Journal of Energy Resources Technology, Vol. 127, pp. 89-94, 2005.

4. Vehicular Storage of Hydrogen in Insulated Pressure Vessels, Salvador M. Aceves, Gene D. Berry, Joel Martinez-Frias, Francisco Espinosa-Loza, In press, International Journal of Hydrogen Energy, 2006.

5. Hydrogen Absorption in Fluids: An Unexplored Solution for Onboard Hydrogen Storage, Gene D. Berry, Lawrence Livermore National Laboratory Report UCRL-TR-209650, Livermore, CA, February 2005.

6. Advanced Hydrogen Containers, Andrew Weisberg, Invited presentation, American Physical Society, March 2005.

7. Cryogenic Hydrogen Storage, Salvador Aceves, Invited Presentation, Materials for the Hydrogen Economy, September 2005.

Special Recognitions & Awards/Patents Issued

1. Lightweight Cryogenic-Compatible Pressure Vessels for Vehicular Fuel Storage, Salvador M. Aceves, Gene Berry, Andrew H. Weisberg, U.S. Patent 6,708,502 B1, March 23, 2004. World Patent WO 2004/029503 A2, April 8, 2004.

2. Storage of H2 by Absorption and/or Mixture within a Fluid, Gene Berry and Salvador Aceves, World Patent WO 2005/015076 A1, February 24, 2005.