SAND2013--2552

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Polymer and Composite Material Performance in Hydrogen

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2013 U.S. DOE HYDROGEN and FUEL CELLS PROGRAM
ANNUAL MERIT REVIEW, MAY 13-17, 2013

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

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Timeline

- Start date: 10/2012
- End date: 10/2013*
- 50% complete

Budget

- Total project funding:
  - DOE share: $50K
  - Contractor share: N/A
- FY13 funding: $50K

Barriers

- E: gaseous hydrogen storage and tube trailer delivery costs
- J: hydrogen leakage
- K: safety, codes and standards, permitting

Partners

- Jim Ohi, DOE consultant

*Project continuation and direction determined annually by DOE.

Relevance

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- Polymers and plastics are low-cost material solutions becoming more prevalent in hydrogen technology (e.g. tank liners, tubing, hoses, pipelines, seals and O-rings).

- There is little technical information [2,3,4] on polymer material performance at the extreme high pressures and low temperatures found in hydrogen fuel distribution, dispensing, and vehicle applications.

- Goal -- characterize polymer material mechanics at extreme conditions to help reduce cost, improve reliability, improve safety, and develop physically-motivated performance-based product standards.

Approach

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- Task 1: identify knowledge gaps and data needs for using polymers and composite material systems in hydrogen service, particularly at high pressures (up to 100 MPa), demanding duty cycles, and long service life – conduct an information sharing meeting between key stakeholders [1]; literature review [2]

- Task 2*: characterize failure mechanisms and discover mechanical behavior of polymer materials in high-pressure hydrogen gas at extreme temperature conditions

- Task 3*: place technical information in the hands of designers to positively impact performance, reliability, and safety -- participate in standards activities that concern the use of polymer materials and/or qualification of polymer materials

* Some tasks depend on future funding decisions by the Fuel Cell Technology Office

Accomplishment 1.a – preliminary assessment of knowledge gaps

Co-facilitated a panel session on *Assessing knowledge gaps for hydrogen vehicle and infrastructure codes and standards* at the August 2012 Composites Conference

- Conference hosted by NASA/WSTF and the Material Knowledge Foundation in Las Cruces, NM
- Panel co-facilitators: McColskey (NIST) & Moen (Sandia)
- Goal: increase diversity of knowledge base by seeking input from the aerospace community

Accomplishment 1.b – information exchange meeting to identify knowledge gaps

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Facilitated an information-sharing meeting on the use of polymer and composite materials in hydrogen applications, Oct 17-18, 2012:

- identified knowledge gaps and data needs for using polymers and composite material systems in hydrogen service, particularly at high pressures (up to 100 MPa), demanding duty cycles, and long service life;
- provided important input to enable lower-cost, higher-performance systems through improved knowledge and revised codes and standards;
- informed testing needs to better enable near-term applications of polymers and composite systems in hydrogen service, including components at high pressure and extreme temperatures.

Proceedings documented [1] in report SAND2012-10860P, available on the FCTO web-page (https://www1.eere.energy.gov/hydrogenandfuelcells/mtg_poly_comp_materials.html)

Accomplishment 1.b – meeting findings

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Participants identified material knowledge gaps in six different topical areas, motivated by safety, performance, and reliability concerns:

- thermal performance of polymers at service conditions and impact of thermal excursions;
- evaluation and minimization of gas permeation and absorption into polymers;
- polymer performance characterization tests considering significant material variability;
- characterization and performance of seals and O-rings;
- liner buckling in pressure systems;
- low cost composite material systems.

Accomplishment 1.b -- emergent issues in polymer material mechanics

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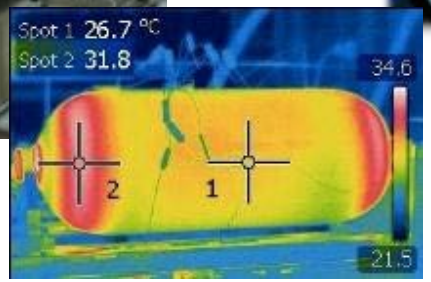

- Meeting participants identified polymer materials as having more significant knowledge gaps than composites
- Need to characterize local temperature excursions and correlate with certification tests
- Need to characterize material behavior at extreme pressure and temperature (including excursions)
- Need to correlate mechanical and permeation behavior of polymers at extreme conditions with leakage and other observed failures

Accomplishment 1.c – literature review

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Literature review on mechanical behavior (*e.g.* stress-strain, strength, ductility, fatigue resistance, failure) of polymer materials in hydrogen gas at extreme pressures and temperatures [2] to establish existing scientific knowledge base

- Limited permeability studies up to 2 MPa, but does not include temperature extremes
- Some studies on bubble formation and blistering at high pressure as an aging phenomenon; limited mechanical studies
- Limited mechanical studies up to 10 MPa
- Some unpublished work-in-progress on permeability and mechanics indicate pressure and temperature effects

Potential collaborations

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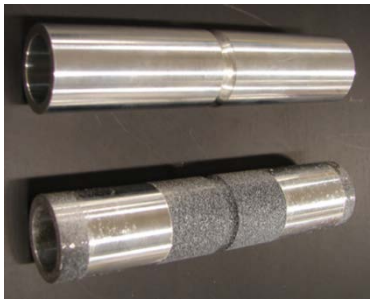
Peer research interactions that would be beneficial

- NASA/WSTF, leverage their research activities in non-destructive evaluation for composite material systems
- ORNL, leverage their research activities in hydrogen permeation in polymers at extreme conditions
- SRNL, leverage their standards development activities for polymer materials in pipelines
- PNNL, leverage their polymer aging (blistering) research
- International Symposium of Hydrogen Polymers Team, HYDROGENIUS, leverage research on seals and O-rings
- NREL, leverage their component testing and technology validation work
- SNL, Center for Infrastructure Research & Integration (CIRI), leverage testing of prototype components and new materials

Seek standards development partnerships such as (but not limited)

- CSA Compressed Hydrogen Material Characterization 1 Part 2 standard
- ASME B31.12, CSA HGV, SAE J2579

Proposed future work



Example of a notched tubular test article that could be used to characterize polymers exposed to high-pressure hydrogen at extreme temperatures, from the laboratory of Wei Yang Lu.

- (FY13) Collect information on specific polymer material failures at extreme conditions, partnering with Tech Teams and other technology validation activities
- (FY13) Design experiments to characterize mechanics and failure for polymers exposed to extreme conditions (Wei-Yang Lu and Brian Somerday)
  - 100 MPa hydrogen exposure
  - -70^{o}C to 120^{o}C
- (FY14) Execute characterization experiments for commonly-used polymer materials and develop mathematical models of mechanical behavior
- (FY14) Disseminate research findings through publications and standards engagement

Summary

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- A group of hydrogen technology stakeholders identified significant data gaps for the use of polymer materials
  - Need more material characterization information for extreme pressures and temperatures
  - Need to understand the impact of localized temperature excursions (e.g. in tanks during fueling) on the performance of polymer materials

- Some data gaps are being addressed by others (e.g. permeation, aging)

- Sandia has experimental mechanics capability and expertise to answer questions related to stress-strain and failure mechanisms at extreme conditions