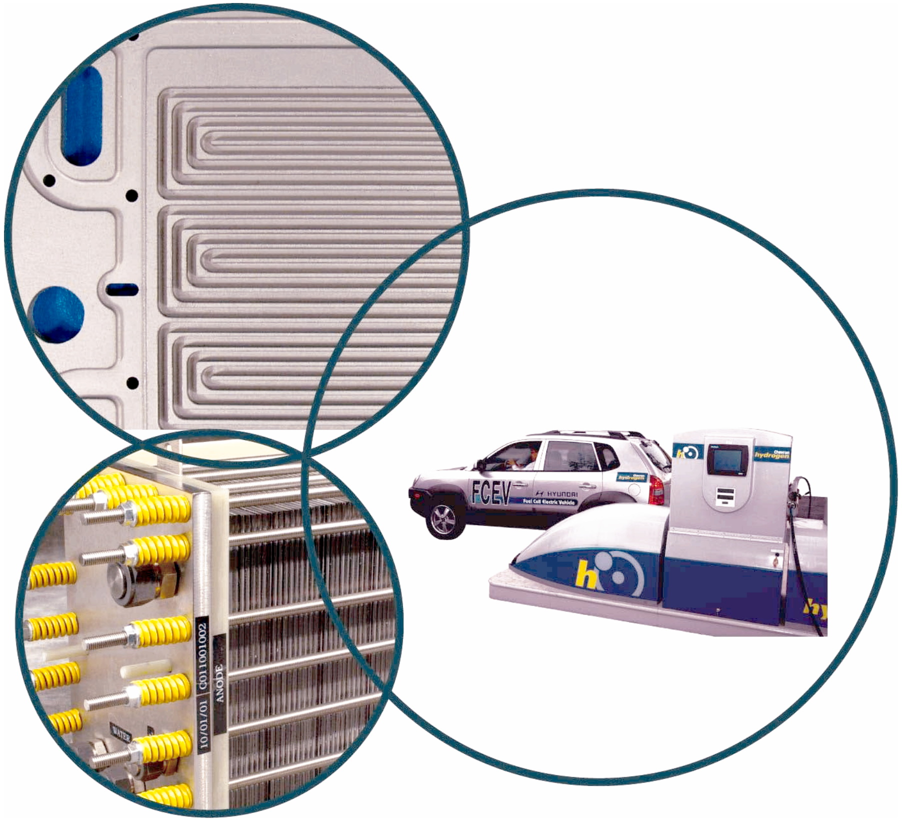
Composite Technology for Hydrogen Pipelines



Barton Smith, Barbara Frame, Lawrence Anovitz

Oak Ridge National Laboratory

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Project ID #: PD024

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Overview

Timeline

- Start: Jan 2005
- Finish: Project continuation & direction determined annually by DOE

Budget

- Total project funding
  - DOE: $1.95M
- Funding for FY 11
  - $100k

Barriers

- D. High Capital Cost and Hydrogen Embrittlement of pipelines
- Technical Targets on next slide

Partners & Collaborators

- Fiberspar, PolyFlow, Flexpipe
- Arkema, Ticona, Fluoro-Seal
- Pipeline Working Group

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Overview

Technical Targets

Category	2005 Status	2012	2017
Pipelines: Transmission			
Total Capital Investment (16-in pipeline, $/mile)	$720k	$600k	$490k
Pipelines: Distribution			
Total Capital Investment (2-inch pipeline, $/mile)	$320k	$270k	$190k
Pipelines: Transmission and Distribution			
Reliability/Integrity (including 3rd-party damage issues)	Acceptable for current service		Acceptable for H_2 as a major energy carrier
H_2 Leakage *	Undefined	TBD	< 0.5%

* Leakage targets are being reviewed by the Delivery Tech Team

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Project Milestones

Date	Milestone or Go/No-Go Decision
Sep 2011	Milestone: Complete pressurization-depressurization cycle fatigue testing of fiber-reinforced polymer pipelines to determine the integrity of a pipeline material that will achieve the 2012 DOE H2 transmission target of <$0.90/gge H_2 (25% complete)

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Technical Highlights

- **Completed tests on aging of glass reinforcement fibers in high-pressure hydrogen**
  - **Tensile testing indicates that long-term exposures to high-pressure H_2 has negligible effect on tensile properties of fibers**
- **Began cyclic fatigue testing on FRP pipeline specimen using H_2 pressurizations to MAWP**
  - **Pressure-stress relationship and H_2 leakage rate will provide information on liner collapse resistance and crack propagation, reinforcement layer resistance to micro-cracking, crazing, crack propagation, fiber-resin interface failure, and integrity of joint sealing**
- **New diffusion and permeation system is providing faster measurements of D and P in pipeline polymers**

Technical Progress: Completed H_2 Compatibility Testing of Glass Fibers

- Designing a test to screen for hydrogen-induced failures is difficult because potential chemical incompatibilities are unknown
- Reinforced polymer pipelines contain many functional chemical groups organized in various ways (crystalline and amorphous polymers, glass and aramid fibers, etc.) and additives such as adhesives, plasticizers, colorants, processing aids and UV inhibitors. These constituent materials are generally regarded as immune to chemical attack by hydrogen.

Technical Progress: Completed H_2 Compatibility Testing of Glass Fibers

- Accelerated aging of glass fibers in hydrogen
  - To evaluate long-term effects of high-pressure hydrogen on strength of glass fibers used as composite reinforcement materials, we measurement fiber tensile strength before and after accelerated aging
  - Simplified protocol is based on Arrhenius model for activated process

    $$\text{reaction rate} = Ae^{-\lambda/kT}$$

    where A is a rate constant, λ is the activation energy, k is the Boltzmann constant, and T is the temperature
  - We use a temperature of 60°C, which is the rated maximum temperature of the FRP pipeline
  - No stressors other than hydrogen (i.e., no oxygen, water, chemicals, UV)
  - We assume elevated temperature itself does not degrade fibers (we include control specimens in test protocol to compare with specimens treated in hydrogen)

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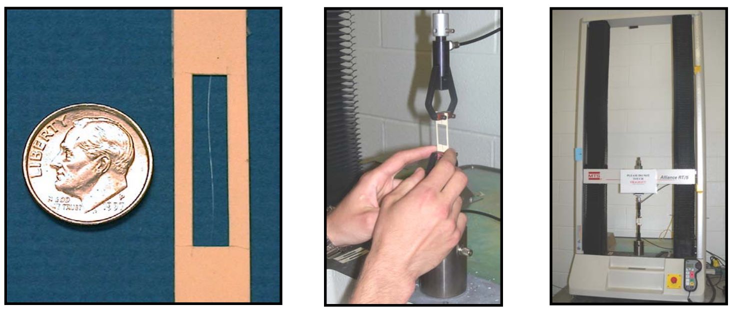
Technical Progress: Completed H_2 Compatibility Testing of Glass Fibers

Tensile strength, elongation and modulus measurements are performed on cohorts of individual filaments before and after hydrogen exposures



Single glass filaments used for strength, elongation and modulus measurements

Tube furnace containing high-pressure hydrogen reactor with glass filaments inside, in Polymer Matrix Composites laboratory

Technical Progress: Completed H_2 Compatibility Testing of Glass Fibers

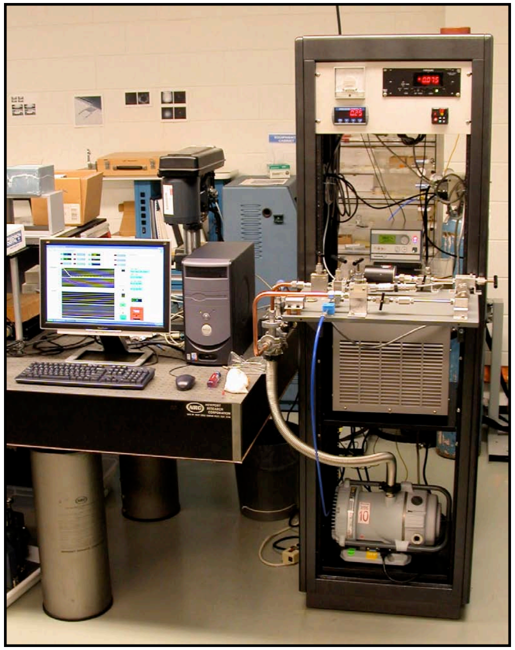
Results of tensile tests of glass filaments subjected to increasingly longer exposures to high-pressure hydrogen gas. There were no statistically significant changes in post-exposure measurements of applicable tensile properties, indicating that long-term exposures of high-pressure H_2 is likely to have a negligible effect on the integrity of glass reinforcements.

	5-week exposure		11-week exposure		20-week exposure		39-week exposure	
Test Result	1,000 psi Hydrogen @ 60°C	Ambient air @ ~25°C (control)	1,000 psi Hydrogen @ 60°C	Ambient air @ ~25°C (control)	1,000 psi Hydrogen @ 60°C	Ambient air @ ~25°C (control)	1,000 psi Hydrogen @ 60°C	Ambient air @ ~25°C (control)
Strength (ksi)	268.6 (26.6)	320.9 (26.1)	305.1 (23.4)	275.6 (23.8)	343.1 (23.1)	268.6 (33.8)	298.4 (22.6)	292.8 (24.0)
Modulus (Msi)	9.8 (14.3)	11.2 (17.7)	9.3 (18.3)	8.6 (16.3)	11.3 (18.4)	10.8 (19.6)	10.4 (13.2)	10.3 (14.1)
Elongation (%)	2.8 (28.8)	2.9 (23.8)	3.0 (19.6)	3.3 (19.6)	3.3 (17.0)	2.7 (31.4)	3.1 (19.4)	3.3 (21.2)

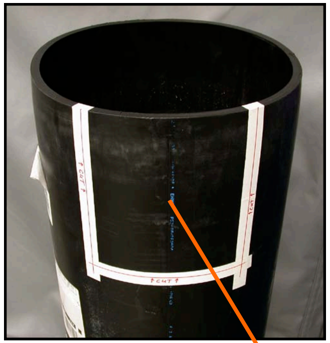
Numbers in parentheses are coefficients of variation (in %) for the particular data set.

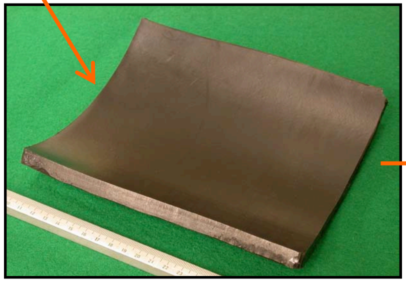
Technical Progress: New apparatus for measuring H_2 permeation rates

A new automated system is providing faster, more reliable diffusion and permeation measurements in polymer specimens



Test specimens are sectioned from commercial extruded pipelines and carefully machined to 50-mm diameter by 1-mm thick disks to ensure accurate and reproducible measurements





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Technical Progress: Began cyclic fatigue tests in H2 environment

- Next step in determining H_2 compatibility of FRP pipelines is to test for strain-induced H_2 deterioration
- High-pressure cyclic fatigue tests are basis for verifying that combination of H_2 environment and pressure-induced stress does not adversely affect composite pipeline integrity and service life
- High-pressure cyclic fatigue tests provide information on pipeline integrity after repeated H_2 gas pressurization-depressurization cycles.
- Fatigue testing provides information that can't be derived from constant pressure testing, including
  - Liner collapse resistance (similar to blowdown testing)
  - Resistance to micro-cracking, crazing, crack propagation, fiber-resin interface failure, etc. of composite reinforcement layer
  - Resistance to environmental stress-corrosion phenomena
  - Integrity of joint attachment/joint sealing under cyclic loading

Future Work

- **FY 2011**
  - Report results of pressurization-depressurization cycle fatigue testing of fiber-reinforced polymer pipelines with an assessment of the pipeline integrity
  - Report final measurements of *P* and *D* in liner materials, including measurements of surface fluorination samples and bi-modal PE
- **FY 2012**
  - ORNL and collaborators will work to demonstrate a composite H_2 pipeline
    - Collaboration will be springboard for a commercial demonstration project of the pipeline technology
    - Consideration for resistance to third-party damage will be included in the prototype design
    - Milestones:
      - First prototype of composite H_2 pipeline produced
      - Tests for resistance to third-party damage completed
      - Joint industry pipeline demonstration project initiated

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Project Summary

Relevance: Need viable alternative to metallic pipelines to achieve cost and performance targets for hydrogen transmission and distribution

Approach: Investigate applicability of composite pipelines in use in oil & gas gathering operations and develop path forward for hydrogen delivery

Progress: Cost scenario shows composite pipelines can meet DOE 2012 goals and are close to 2017 goals; hydrogen compatibility of pipeline materials is acceptable; pipeline leakage rates are lower than predicted

Collaborations: Pipeline and polymer industries, National Lab

Future: Codes & standards; prototype FRP pipeline system for H_2 delivery; demonstration project

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