Ohio Hydrogen Technology Forum

OFCHC THE OHIO FUEL CELL & HYDROGEN COALITION

THE OHIO STATE UNIVERSITY
INSTITUTE FOR MATERIALS AND MANUFACTURING RESEARCH

Composite Pipes for Hydrogen Transmission

Jeff Ellis, PhD

Senior Technology Leader – Polymers
jellis@ewi.org

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- Materials Engineering
- Structural Integrity
- Modeling
- Inspection
- Polymers
- Testing

Buffalo
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- Automation
- Data Science
- Metrology

90+
Technical Experts
14 PhD, 28 MS, 37 BS

$40M+
Capital Equipment

160,000
Total Square Feet

EWI performs applied R&D to bridge the gap between research and application.

H_2 Lab Capabilities Overview

Summary of Lab Infrastructure

H_2 Env. Testing Lab

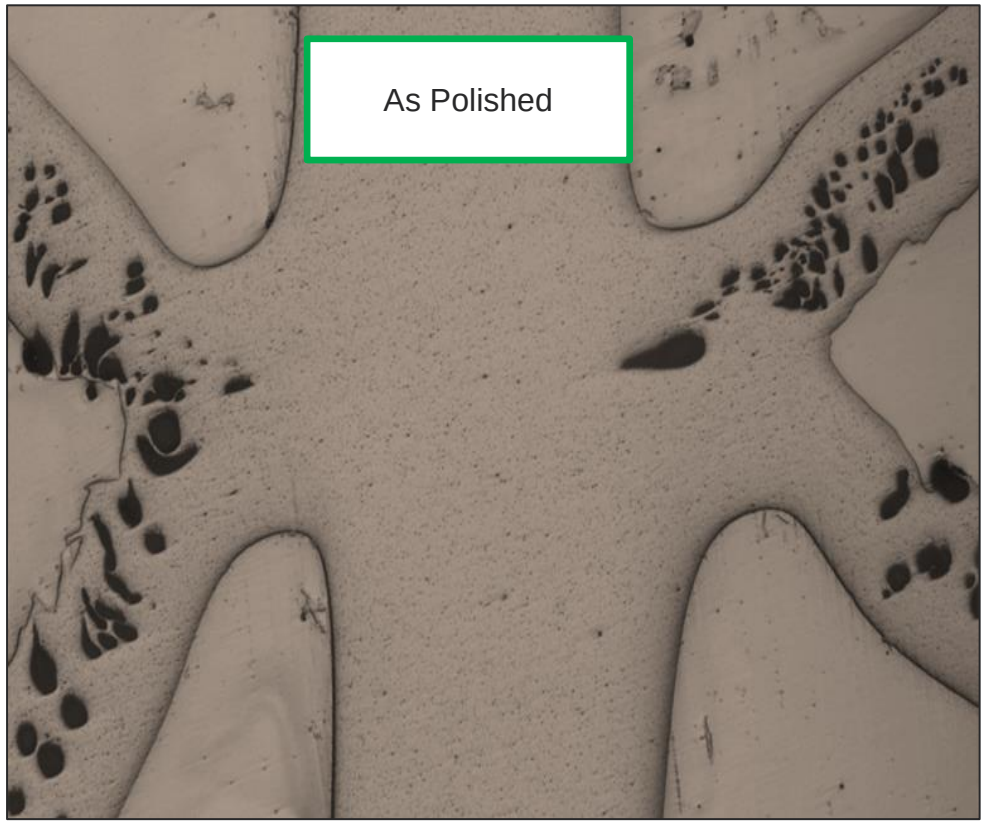
# of asset	Descriptor	Volume	Pressure/Load
1	Slow strain rate load frame	n/a	5 kip
2	Fatigue load frame	n/a	15 kip
2	Integrated Pressure Vessel	5L	5000 psi
8	Static Pressure Vessel	2L	2200 psi
4	Static Pressure Vessel	4L	2200 psi
1	Window Pressure Vessel	0.5L	2500 psi
1	Permeation Cell	N/A	2000 psi

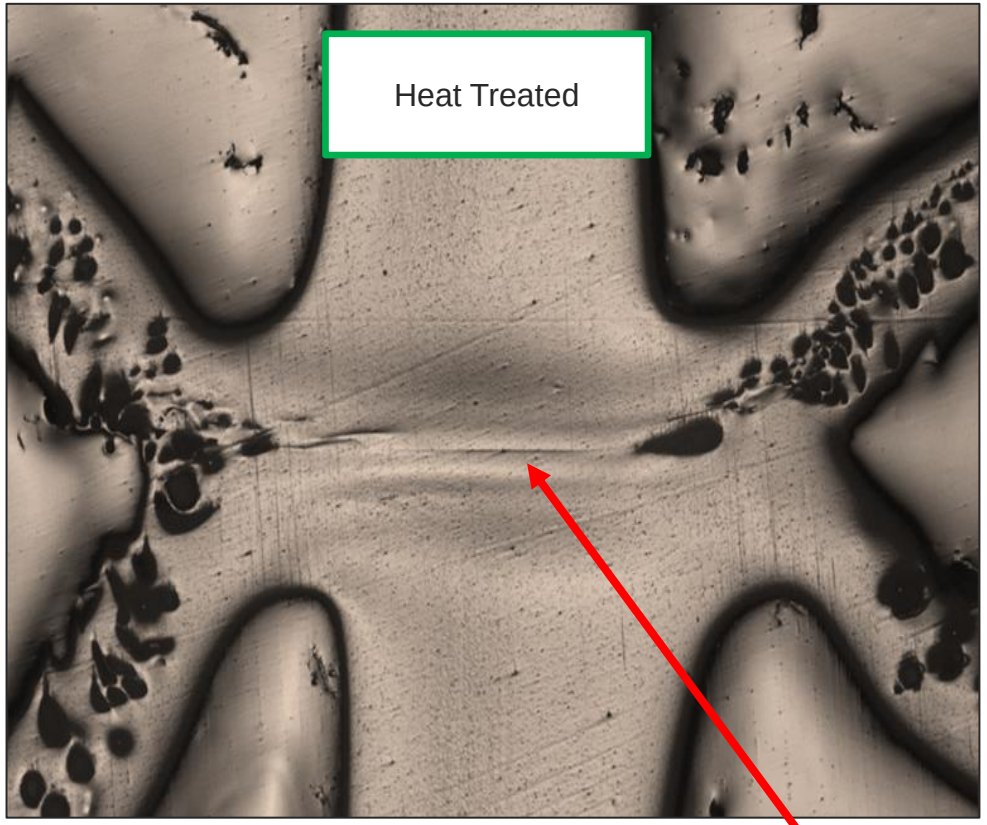
Supporting Capabilities

- In-house machining (custom fixtures or specimens)
- Polymer Thermal Lab (Aging, DSC, TGA, Rheology, FTIR)
- Mechanical Test Lab
- Microscopy Characterization (Optical, SEM, Keyence, HACS)
- Other aging environments
- Gas Chromatography, Energy Dispersive Spectroscopy

Polymer Joining Lab

Heated After Cross-Section (HACS) Examples





No intermolecular diffusion
(separation line across joint)

Composite Pipes for Hydrogen Transmission

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Project Description

- Objectives
  - Identify gaps and needs that impact the safety and integrity of alternative-steel and non-steel spoolable reinforced plastic line pipe (spoolable pipe) when used to transport pressurized hydrogen gas.
  - Develop guidance for pipe manufacturers and pipeline owner/operators to help ensure safe and economic manufacture and operation of future spoolable hydrogen gas pipelines.

Why Use Composite Pipes?

- Composite pipe is increasingly being used in conventional and low carbon O&G applications.
- It can be used as stand alone or as a liner in a steel pipe.
- Use drivers:
  - Manufactured and transported in long sections or manufactured onsite.
  - Lower material and installation costs.
  - Reduced corrosion concerns.

Presentation Outline

- Pipeline design and materials suitable for hydrogen service.
- Hydrogen testing on the pipe materials (liner and reinforcement) and their responses.
- Gaps in the industry that need to be filled before large-scale commissioning of hydrogen transmission pipeline can commence.

Pipeline Design and Materials Suitable for Hydrogen Service

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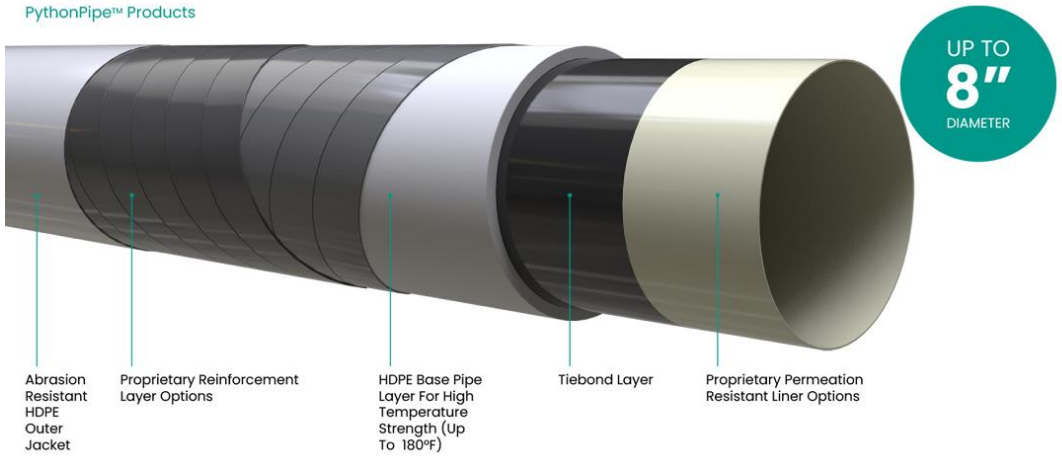
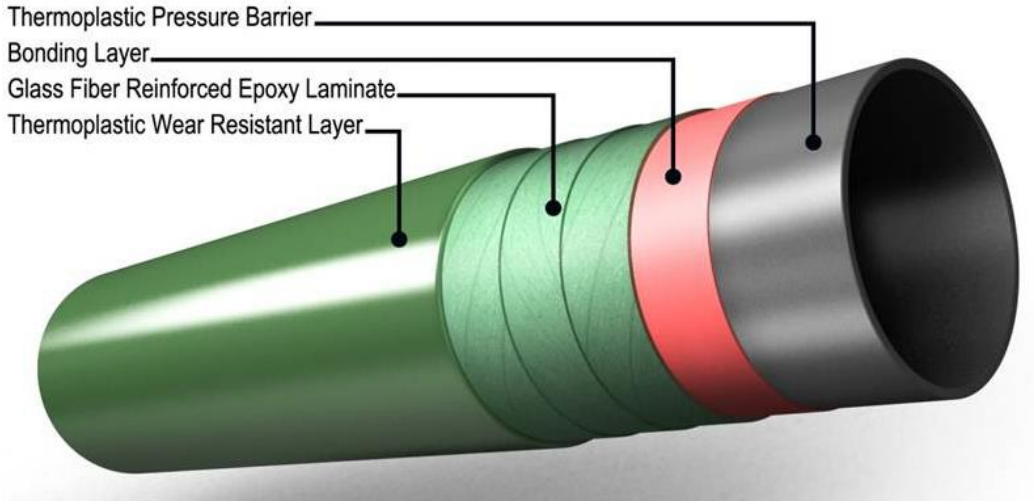
Composite Pipeline Design Examples

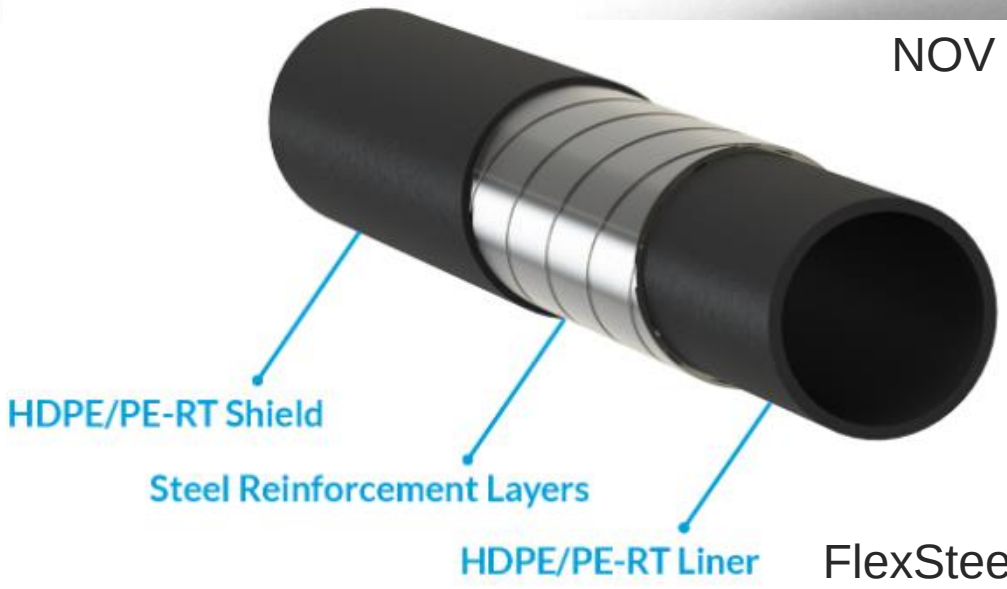


Baker Hughes



NOV Fiberglass Systems

- Many are 8-inch diameter
- Typically, up to 180°F
- Typically, up to 3,000 psi



FlexSteel

Composite Pipe Materials

- Inner Liner – HDPE, PE-RT, TPU, PA11, PA12, PVDF, PPS
- Reinforcement
  - Fiberglass tape, fiberglass reinforced epoxy,
  - Aramid fiber, aramid fabric,
  - Steel wire/cord, steel strips,
  - Liquid crystal polymer fiber,
  - Carbon fiber
- Permeation resistant layers – aluminum, other proprietary materials
- Outer Shield – UV stabilized HDPE

Aramid

Glass

Composite Pipeline Categorization

Spoolable Reinforced Plastic Pipe – API 15S

- Spoolable composite pipe (SCP)
- Flexible Composite Pipe (FCP)
- Spoolable Glass-Fiber Reinforced Epoxy (S-GRE)
- Reinforced Thermoplastic Pipe (RTP) – Unbonded or Bonded

Thermoplastic Composite Pipe (TPC) – DNV ST F119

- Offshore only
- Flexible Composite Pipe (FCP)

Reinforced Thermosetting Resin (RTR) – API 15HR

- Glass Reinforced Plastics (GRP)
- Glass-Fiber Reinforced Polyester (GRP)
- Glass-Fiber Reinforced Vinyl Ester (GRV)
- Glass-Fiber Reinforced Epoxy (GRE)
- Fiber-Reinforced Plastics (FRP) Pipe – Spoolable and Stick
- Fiberglass Pipe

Hydrogen Testing on the Pipe Materials and their Responses

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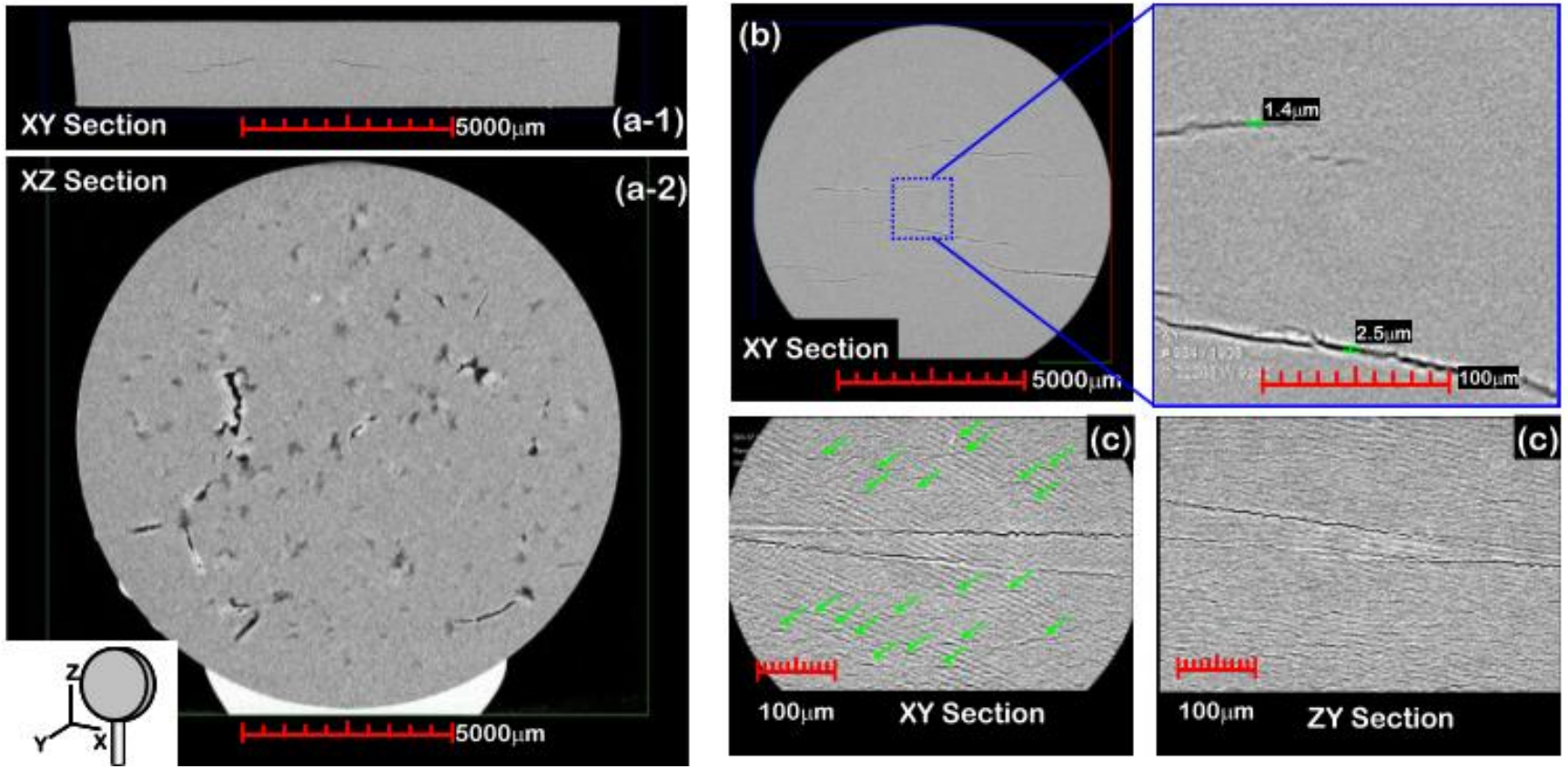
Findings on Polymer Properties after H_2 Exposure

- Rapid Gas Decompression (RGD)
  - Dissolved hydrogen reaches saturation, causes bubbles, voids, blisters if the decompression rate is high.
- Hydrogen Induced Property Changes
  - Increased volume due to hydrogenation, decreased modulus.
- Hydrogen Permeation
  - Permeation rates are higher than natural gas due to small size.
- Hydrogen Embrittlement
  - Hydrogen diffused into material causes cracks to initiate, not a typical concern for polymers.

Lab Testing Versus Pipeline Operating Conditions for RGD

- RGD has been shown to induce voids to polymers when pressure is above 10,000 psi.
- No data has been found for RGD in HDPE for pressures less than 3,000 psi.

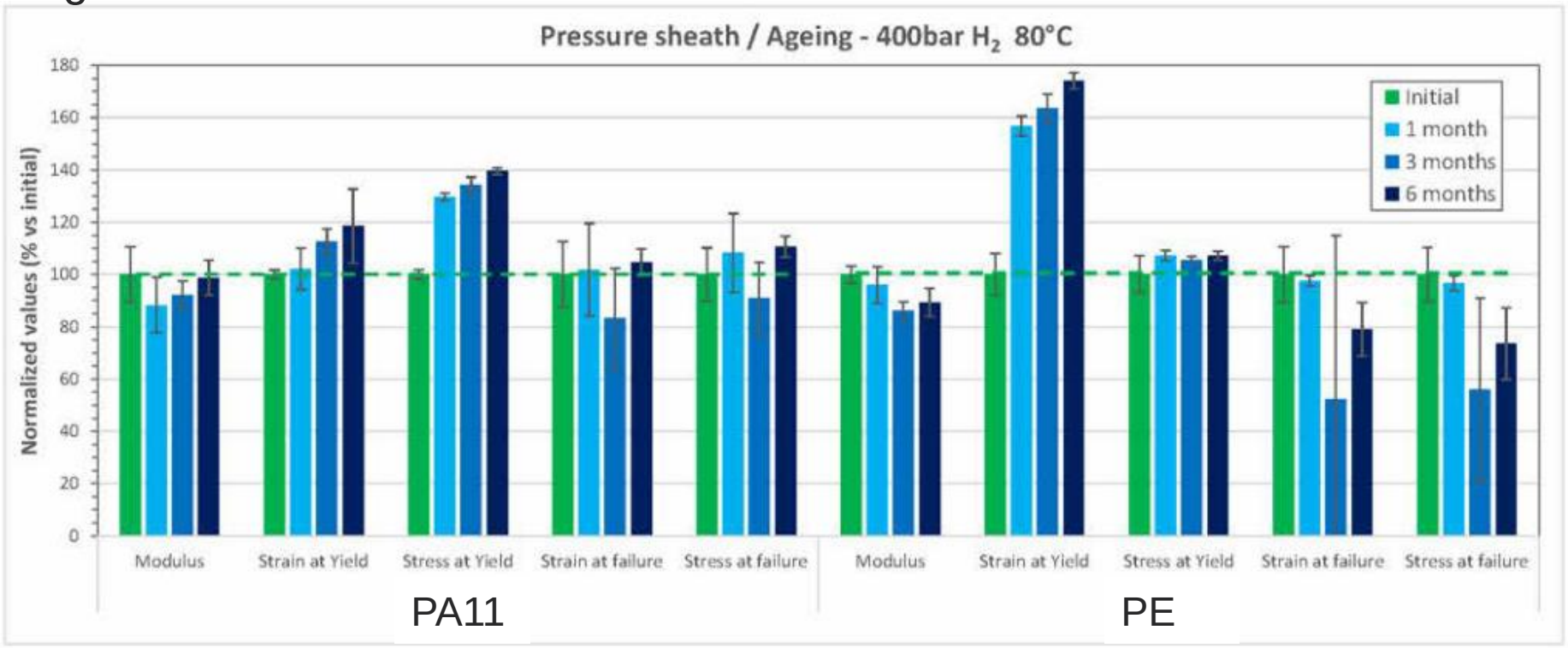


Damage in LDPE after rapid decompression from 13,000 psi

Fujiwara et al., International Journal of Hydrogen Energy 2021

Hydrogen Induced Property Changes

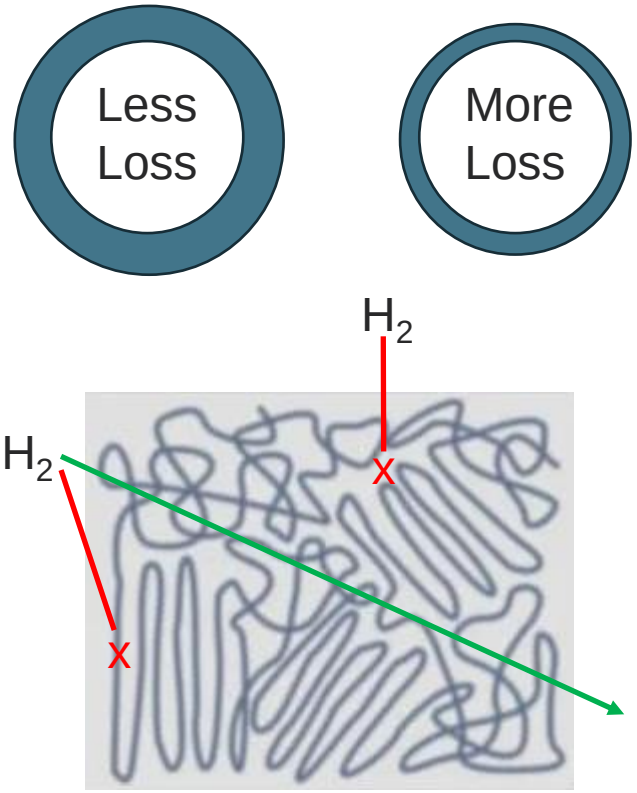
- Property changes have been recorded at 5,800 psi after up to 6 months aging.
- Only less significant changes have been shown for less than 3,000 psi.
  - In a composite pipe, these materials are reinforced so the pipe strength is independent of polymer strength alone.



Gabet et al., Offshore Technology Conference, 2023

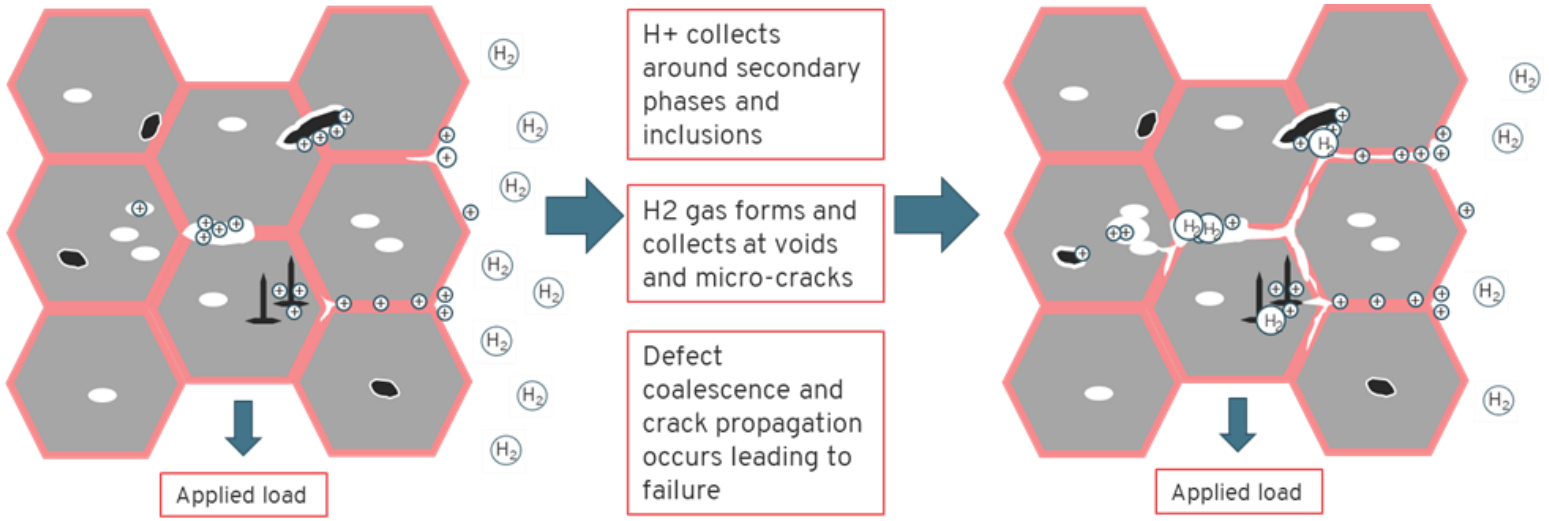
Permeation of Hydrogen Through Polymers

- The diffusion of hydrogen through polyethylene pipe walls is up to 5x higher than that of natural gas.(Haeseldonckx & D'haeseleer, 2007)
- Polymer thickness does not influence the permeability, diffusion, or solubility coefficients; however, it does directly affect the permeation flux.(Kane, 2008)
- Hydrogen permeation has been shown to only take place in the amorphous regions.(Voyiatzis & Stroeks, 2022) The crystalline regions act as a barrier and restrict permeation completely.(Kane, 2008)
- Other factors that affect permeation:
  - free volume, side chain complexity, density, chain orientation, crosslinking, Tg, plasticizers, humidity, and fillers.



Hydrogen Embrittlement

- Rigid polymers are largely not affected by hydrogen embrittlement,
- Metallic reinforcement (strips, fiber, cords) and field connectors could be affected by hydrogen induced cracking (HIC).
- The published data on this subject is currently lacking, however propriety data is showing that when the proper steel is chosen, the maximum effect of the saturated H^+ ion causes a non-significant change in their strength and elongation properties after 6 months aging.



Pipe Stability after Hydrogen Exposure

- A Danish distribution plastic pipe network has been studied for 10 years, and they found no degradation associated with long-term exposure to hydrogen.
- A 2008 assessment by Savannah River National Laboratory states that here is no plausible mechanism for the degradation of polymeric materials (some installed in composite pipes) in the presence of pure hydrogen, unless some other reaction catalyst, such as heat, humidity, or radiation source is present. (Kane, 2008)
- Netherlands-based project (Groningen Seaport) will install 4 km of 150 mm pipe to operate with 40 bar hydrogen.
  - We are all interested in hearing the results of this project.

https://forcetechnology.com/en/cases/hydrogen-transport-danish-gas-pipelines-ideal, Ditte Bilgrav Bangsgaard and Trine Nybo Lomholt, Danish gas pipelines are ideal for transporting hydrogen

Gaps in the Industry

Initial Thoughts on Gaps in Standards (Hazard Analysis)

- ASME B31.12 Case 200 is the most complete document for Hydrogen Piping and Pipelines using composites.
- API 15S (onshore) and DNV-ST-F119 (offshore) are the most complete documents but have yet to mention use for hydrogen.
- Inspection and real-time monitoring technologies could be better defined to assess the long-term structural health of the composite pipes.
  - Testing and development is currently being worked on by ADV Integrity CLASPS JIP and PHMSA study led by GTI
- More testing on mixed or contaminated hydrogen gas streams to better understand the rate of polymer degradation under different chemical, heat, and pressure conditions.

Initial Thoughts on Gaps in Standards (Hazard Analysis)

- Special attention given to purging and venting requirements and protocols due to potential void formation in polymeric materials, hydrogen heating during depressurization, and the related explosion hazards when mixed with air. (Voyiatzis & Stroeks, 2022)
- Ensure that there are standards addressing permeated hydrogen accumulation (e.g., in the annulus when composite pipe is pulled-through another pipe) so that explosion hazards are mitigated.
- Standards for hydrogen permeation exist for structures other than polymer transmission pipes, such as Type IV tank, but it needs to be better defined for pipe.

Conclusions

- Composite pipes are increasingly being used in conventional and low carbon O&G applications, including trials for hydrogen transmission.
- Multiple types of composite pipes are best suited to different applications.
- If hydrogen pressures, temperatures, contamination, and depressurization are all controlled, it is unlikely composite pipes will have significant property changes.
- More supplier and pipe manufacturer technical data must be published or shared to better inform regulators.
- Permeated hydrogen must be monitored so that explosion hazards outside pipes can be mitigated.

Acknowledgment of Funding

- US Department of Transportation Pipeline and Hazardous Materials Safety Administration (DOT PHMSA)
  - Research Announcement #693JK323RA0001 | Research Topic: Materials – 19, Knowledge Development – Investigating the Integrity Impacts of Hydrogen Gas on Composite/Multi-Layered Pipe

Thank you for your time.

Jeff Ellis, PhD, *Senior Technology Leader*

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