Composite Use Overview

- **Composite Materials in Pipeline Applications (+25 years)**
  - Corrosion
  - Mechanical Damage (Dents plus Gouge, Dent + Metal Loss)
  - Wrinkle Bends
  - Fittings
  - Girth Welds
  - Pipeline re-rate
  - Cracks
  - Development of Standards (ASME PCC-2; ISO 24817)

- **Past, Current and Future Work**
  - **Dent repair (Past)**
  - **Vintage Girth Weld Reinforcement (Past)**
  - Repair of pipe fittings (Past)
  - Long-term study (Current)
  - Subsea Repair (Current)
  - **Pipeline Re-rate (Current)**
  - **Crack Mitigation (Current)**
  - NDE of composites (Future)
  - Certification programs (Future)
  - Integration of different technologies (Future)
Variables to Consider When Using Composites

- Environment of pipeline
- Operating conditions
  - Loading, temperature,
  - Failure modes (static overload, fatigue, material degradation)
- Geometry of anomaly
- Geometry of repair
  - Stiffness of repair
- Total Disruption Time
- Reliability
- Ease of installation
- Inspectability
- Traceability
- Industry recognition, regulating entities
PRCI Research Programs

- MATR-3-4 Long-term performance (10-year study)
- **MATR-3-5** Repair of dents
- MATR-3-6 Repair of subsea pipelines/risers
- **MATR-3-7** Girth weld reinforcement
- MATV-1-2 Wrinkle bend reinforcement
- **MATR-3-9** Re-rating to establish MAOP
- NDE 2-3 NDE & Inspection Techniques
- MATR-3-10 Composite Repair Guideline Document
- Composite Roadmap
- Future (potential) programs
  - Crack repair and reinforcement
  - Effects of pressure during installation
  - Elevated temperature testing
Case Study: Repair of Dents

- PRCI-sponsored program (25%) along with co-funding from manufacturers (75%)
- Ten (10) repair systems participating in study
  - 2 rigid coil system (one E-glass & one steel)
  - 3 carbon systems
  - 4 E-glass systems
  - 1 Steel Sleeve
- One unrepaired test sample served as baseline
- 68 total dents in study
- Intent was to validate composite materials for repairing dents subject to cyclic service
Dented Pipeline Samples – Strain Gage Locations

Samples fabricated using 12.75-inch x 0.188-inch, Grade X42 pipe material, $\Delta P = 72\%$SMYS

28-ft (two 4-ft sections plus one 20-ft section)

4-ft (typ)

Girth welds (2)

Plain Dents (2)

Dent in Girth Weld (2)

ERW pipe seam

Dent center

Top View of Pipe Sample

(notice position of dents relative to welds)

Dent in Seam Weld (2)

Gage #1 (24 inches from end)

Gage #2

Gage #3

Gage #4

Gage #5

Gage #6

Gage #7

Notice orientation of bossets

Close-up View of Dented Region

(approximate region having minimum radius of curvature)

Dent center

2-in

4-ft (typ)

Dent in Girth Weld (2)

Plain Dents (2)

ERW pipe seam

Gage #1 (24 inches from end)
Cycles to Failure – Not all Systems Created Equal!

Cycles to Failure for Composite Repaired Dents
Dents initially 15% of OD installed on a 12.75-inch x 0.188-inch, Grade X42 pipe using a 4-inch end cap. Dents installed with 72%SMYS pressure in pipe and cycled to failure at $\Delta \sigma = 72\%$ SMYS.

<table>
<thead>
<tr>
<th>Dent Type</th>
<th>Cycles to Failure</th>
<th>Unrepaired</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERW-1</td>
<td>250,000 cycles</td>
<td>run-out</td>
</tr>
<tr>
<td>ERW-2</td>
<td>250,000 cycles</td>
<td>run-out</td>
</tr>
<tr>
<td>GW-1</td>
<td>250,000 cycles</td>
<td>run-out</td>
</tr>
<tr>
<td>GW-2</td>
<td>250,000 cycles</td>
<td>run-out</td>
</tr>
<tr>
<td>PD-1</td>
<td>250,000 cycles</td>
<td>run-out</td>
</tr>
<tr>
<td>PD-2</td>
<td>250,000 cycles</td>
<td>run-out</td>
</tr>
</tbody>
</table>

(ERW: dent in ERW seam | PD: plain dent | GW: dent in girth weld)
Case Study – Girth Weld Reinforcement

• Focus is to evaluate the ability of composite materials to reinforce girth welds subject to axial and bending loads

• Full scale test program involving:
  ▪ Vintage welds (intentional defects)
  ▪ Repair using composite materials (PCC-2 as guide)
  ▪ Test loads: Pressure (36% SMYS, constant), axial tension and bending.

• Five (5) composite systems participated
MATR-3-7 Test Plan

1. Purchase pipe material (12.75-inch x 0.188-inch, Gr. X42)
2. Perform material characterization (Chemistry, tensile, and Charpy including properties in exemplar weld)
3. Weld samples with intentional girth weld deficiencies (weld cap only) and threaded end caps
4. Sandblast
5. Install strain gages at select locations
6. Install composite repairs
7. Set-up test fixtures
8. Conduct test and record data
   1. Pressure cycles from 8% to 80% SMYS, 18,000 cycles.
   2. Pressurize sample to 36% SMYS
   3. Apply tension (or bending) loading with holds at specific load levels
   4. Apply tension (or bending) loads to failure
9. Inspect failures including photo documentation region of failure
Reduced Bonding Area Sample

Sample with Mylar packing tape shown (to cover \( \frac{1}{2} \) of the pipe’s outer surface)
**Configuration for 8-ft Tension Samples**

**Key Points**
1. Surface preparation
2. Length of reinforcement
3. Consistent girth weld fabrication
4. Instrumentation: strain gages beneath and on top of the composite
5. Generate load deflection curves for each manufacturer

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**Measure wall thickness at each strain gage location**

ACME Threaded End Caps

Girth weld

Strain gage locations on pipe

Strain gage locations on repair

SG: ½", 2", & 6" from toe of GW

Composite repair location zone
Tension to Failure

Tension vs. Axial Strain for 12.75-inch OD x 0.188-inch , Grade X42 Pipe, With a "Cap Only" Girth Weld With 36% SMYS Internal Pressure

Axial Microstrain (10,000 Microstrain = 1% Strain)

Load (kips)

Hybrid Carbon/E-Glass
Carbon Fiber
E-Glass
Bending to Failure
Case Study: Pipeline Re-Rating

• Objective was to determine how effective are composite materials at re-rating a pipeline
  ▪ What does re-rate mean anyway?
  ▪ How does one establish re-rate criteria?
    – Lower strain values?
    – Higher burst pressure?
    – Increased margin on safety?
  ▪ Installed strain gauges on sample, reinforced and unreinforced, initial pressure cycles (current life), strain measurements, burst

• Conclusions:
  ▪ Significant strain reduction was observed on the Xhab repaired system during normal operations
  ▪ Burst pressure significantly increased
Case Study: Crack Arresting

- Objective was to repair cracks
- Challenges
  - Initial defect
  - Grow a crack (not through wall) through operating conditions
    - Monitor the growth
  - Stop the growth
  - Repair the crack
  - Continue operations
- Conclusions
  - XHab system was able to effectively extend the life of the samples; including no failure
Closing Comments

• Design standards are necessary to designate minimum performance requirements
• Products that cannot meet minimum standard requirements should not be used to repair high pressure pipelines
• Composite repair systems should be designed to restore integrity to damaged pipelines based on actual service conditions
• Don’t extrapolate – verify by testing and analysis
Questions?

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