Taking on your toughest technical challenges.

Technology Transfer Forum
Sponsored by BSEE and PHMSA

Meeting Date: October 28, 2015

Prepared for: BSEE, PHMSA, Operators, Composite Manufacturers, and Service Companies

Prepared by: Chris Alexander

Taking on your toughest technical challenges.
Meeting Agenda

• Today’s Meeting Schedule
• Presentations from BSEE and PHMSA
• Elements of the study
  ▪ Technology assessment and gap analysis
  ▪ Full-scale testing
• Path Forward
• Questions
## Today’s Meeting Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 – 9:15</td>
<td>Arrival of guests, sign-in, breakfast</td>
</tr>
<tr>
<td>9:30 – 9:50</td>
<td>Background on current efforts and motivation for research program (Mick Else, BSEE)</td>
</tr>
<tr>
<td>9:50 – 10:10</td>
<td>BSEE perspectives on composite repairs (Angie Gobert, BSEE)</td>
</tr>
<tr>
<td>10:10 – 10:30</td>
<td>PHMSA perspectives on composite repairs (Max Kieba, PHMSA)</td>
</tr>
<tr>
<td>10:30 – 11:30</td>
<td>Program overview, including BSEE / PHMSA project phases of work (Chris)</td>
</tr>
<tr>
<td>11:30 – 12:30</td>
<td>Lunch Break</td>
</tr>
<tr>
<td>12:30 – 1:15</td>
<td>Q&amp;A with Panel (Mick, Angie, and Max with Chris moderating)</td>
</tr>
<tr>
<td>1:15 – 1:30</td>
<td>Wrap-up and dismissal (Chris)</td>
</tr>
</tbody>
</table>
Presentations from BSEE & PHMSA

Background and motivation for program (Mick Else, BSEE)
BSEE perspectives on composite repairs (Angie Gobert, BSEE)
PHMSA perspectives on composite repairs (Max Kieba, PHMSA)
Program Overview (Phases of Work)

Phase 0  Host “Kick-off” meeting and preparation
Phase 1  Perform a gap analysis to evaluate composite repair state-of-the-art
Phase 2  Evaluate and analyze plastic pipe insert technology.
Phase 3  Baseline Inter-layer Strain (ILS) Test (corrosion: burst and fatigue)
Phase 4  Baseline Inter-layer Strain (ILS) Test (12-inch pipe, dent, fatigue)
Phase 5  Long-term 10,000-hr Test (subsea, 75% corrosion, 3 samples)
Phase 6  Pressure during installation (50% corrosion and dent samples)
Phase 7  Inspection of samples (before and after testing)
Phase 8  Simulated field trial testing (SES's Waller Testing Facility)
Phase 9  Final Report with and Composite Repair Guideline Document
Phase 10  Host Final “Wrap-up” Workshop and preparation

Testing phases of work
Gap Analysis Process

• Evaluate **what we know** relative to what we **want to know**

• The basis of the assessment involved:
  - Prior research
  - Prior and ongoing installations
  - Guidance from composite repair codes

• The current program will improve knowledge on the following subjects:
  - Effects of pressure during installation
  - Long-term design stress based on extreme loads
  - Subsea installation and exposure
  - Inspection methods
PRCI Composite Repair Programs

- MATR-3-3  State-of-the-art assessment
- MATR-3-4  Long-term repair of corrosion performance study
- MATR-3-5  Repair of dents using composite materials
- MATR-3-6  Repair of corroded underwater pipelines / risers
- MATR-3-7  Repair of vintage girth welds
- MATR-3-9  Composite reinforcement re-rate study
- NDE-2-3  NDE applied to composite wrap repairs

The above programs have been completed, three (3) programs are ongoing.
## Gap Analysis Chart

### Pipeline Anomaly, Technical Issue, or Feature

<table>
<thead>
<tr>
<th>Major Gaps</th>
<th>PRCI Research</th>
<th>Actual Field Installations</th>
<th>Guidance from Standards (ASME &amp; ISO)</th>
<th>Independent Research</th>
<th>Acceptability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion &gt; 80%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>Internal corrosion (non-leaking)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>External stress corrosion cracking (SCC)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Repair of leaks for high pressure applications</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
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<tr>
<td>NDE Techniques as a basis for acceptance criteria</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
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<tr>
<td>Deepwater repairs including ROV-installed systems</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.25</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Moderate Gaps</th>
<th>PRCI Research</th>
<th>Actual Field Installations</th>
<th>Guidance from Standards (ASME &amp; ISO)</th>
<th>Independent Research</th>
<th>Acceptability Score</th>
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</thead>
<tbody>
<tr>
<td>Uprating (re-rating) pressure</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td>Establishing/Maintaining MAOP</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td>Dents with metal loss</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Seam weld defects</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Forged Tees</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Subsea and shallow water installations</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Performance at elevated temperatures (140F&lt;T&lt;250F)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Use of Composites as Crack Arrestor</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimal Gaps</th>
<th>PRCI Research</th>
<th>Actual Field Installations</th>
<th>Guidance from Standards (ASME &amp; ISO)</th>
<th>Independent Research</th>
<th>Acceptability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dents in welds (seam and girth) subjected to cyclic pressure</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td>Vintage girth welds (pressure, tension, bending)</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td>Reinforced branch connections</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td>Reinforcing elbows and bends</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td>Effects of cyclic pressure &amp; hydrotest on corrosion (fatigue design)</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td>Plain dents subjected to cyclic pressure</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Wrinkle bends</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>External corrosion</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Gap Analysis Chart (2/2)

• Areas of competence including reinforcement of:
  ▪ Corrosion (onshore)
  ▪ Plain dents (onshore)

• Moderate gaps
  ▪ Reinforcement of planar defects and cracks
  ▪ Dents with interacting threats
  ▪ Establishing MAOP using composites

• Major gaps:
  ▪ Leak repair for high pressure oil and gas
  ▪ NDE Techniques as a basis for acceptance criteria
  ▪ Deepwater repairs including ROV-installed systems
Plastic Pipe Insert Technology

![Diagram of plastic pipe insert technology]

- **Outer Layer**: Abrasion-resistant BASF thermoplastic polyurethane
- **Kevlar Fabric**: Seamless, woven aramid fibers from DuPont
- **Inner Layer**: Media specific: Hydrocarbon media at high temperatures, Solvay Solexis PVDF from Solvay Chemicals

Key Components:
- Protective Outer Cover
- Retention Windings
- High Strength Fiber Wrap
- Fiber Optic Monitoring and Communication Cable
- High Strength Pulling Tapes
Part 2: Testing Program Overview (1/2)

- Load transfer study to evaluate the effects of internal pressure during installation
- Onshore repair study including the measurements of stresses in the composite material used to reinforce corrosion and dents
- Offshore repair study with 10,000-hour exposure in a simulated seawater environment including internal pressure, axial tension, and bending loads
Part 2: Testing Program Overview (2/2)

- SES held a dinner meeting on May 12 in Houston for all composite repair companies to discuss this and other programs.

- Participating composite repair companies:
  - Air Logistics
  - Citadel
  - Furmanite
  - Milliken
  - NRI
  - Western Specialties
Load Transfer Study
Load Transfer Study

- To be conducted in conjunction with PRCI MATR-3-11
- Samples having simulated corrosion 50% deep; repaired at varying pressures and then tested
- Six samples will be tested per participating system
- The repaired test matrix for this program includes the following (color coded based on installation pressures – 0% SMYS is RED | 32% SMYS is BLUE | 64% SMYS is GREEN):
  - Burst test; repaired at 0 psi;
  - Cyclic pressure fatigue test ($\Delta P = 40\%$ to $80\%$ SMYS); repaired at 0 psi
  - Burst test; repaired at $40\%$ of $80\%$ SMYS ($32\%$ SMYS)
  - Cyclic pressure fatigue test ($\Delta P = 40\%$ to $80\%$ SMYS); repaired at $32\%$ SMYS
  - Burst test; repaired at $80\%$ of $80\%$ SMYS ($64\%$ SMYS)
  - Cyclic pressure fatigue test ($\Delta P = 40\%$ to $80\%$ SMYS); repaired at $64\%$ SMYS

Note: The pressure of $32\%$ SMYS corresponds to $40\%$ of $80\%$ SMYS.
The pressure of $64\%$ SMYS corresponds to $80\%$ of $80\%$ SMYS.
Sample Configuration

6.5 feet (center corroded area on sample)

8 inches long

0.75-inch radius (at least)

Break corners (all around)

0.375 inches

0.188 inches (simulating 50% corrosion)

6 inches

Note uniform wall in machined region

Strain gage locations
# Installation Pressures

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Installation Pressure (psi)</th>
<th>Pressure Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample #1 (Unrepaired Base Case)</td>
<td>0</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #2</td>
<td>0</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #3 (20% MAOP)</td>
<td>356</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #4 (40% MAOP)</td>
<td>712</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #5 (80% MAOP)</td>
<td>1,424</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #6 (80% MAOP)</td>
<td>1,424</td>
<td>Cycling</td>
</tr>
</tbody>
</table>

Pressures could change based on available pipe material.
Onshore Study
Onshore Repair Study

• Inter-Layer Strain (ILS) Tests of samples with 75% simulated corrosion and dents

• Strain gages will be installed in between layers to measure strains at given points through the thickness of the repair (ILS measurements have never been made on dents)

• Types of anomalies
  - Corrosion samples (cycled and burst tested)
  - Dent samples will be pressure cycled ($\Delta P=63\%$ SMYS)
Hoop Stress in Composite as a Function of Radial Position
Measurements taken at 1,779 psi (72% SMYS) for 12.75-in x 0.375-in, Grade X42 pipe with 75% corrosion repaired with 0.76 inches of Pipe Wrap A+

Composite design strength ~ 12,000 psi
Composite tensile strength ~ 55,000 psi

This is why ASME PCC-2 systems work
Pressure Cycle Test Results

- 12.75-inch x 0.375-inch, Grade X42 pipe pressure cycled at 36% SMYS with 75% deep corrosion
- Results for 8 different systems
  - E-glass system: 19,411 cycles to failure (MIN)
  - E-glass system: 32,848 cycles to failure
  - E-glass system: 129,406 cycles to failure
  - E-glass system: 140,164 cycles to failure
  - E-glass system: 165,127 cycles to failure
  - Carbon system (Pipe #1): 212,888 cycles to failure
  - Carbon system (Pipe #2): 256,344 cycles to failure
  - Carbon system (Pipe #3): 202,903 cycles to failure
  - E-glass system: 259,537 cycles to failure
  - Carbon system (Pipe #4): 532,776 cycles (run out, no failure)
  - Hybrid steel/E-glass system: 767,816 cycles to failure (MAX)
Corrosion Testing Overview

• Pipe: 12.75-inch x 0.375-inch, Grade X42
• Corrosion depth of 75% installed by machining
• Strain gages installed in corrosion region, on base pipe, and outside of repair
• Thickness of repair based on material properties and expected mechanics of repair
• Test sample types (proposed items):
  ▪ Burst test
  ▪ Inter-layer strain measurements
  ▪ Pressure cycle to failure (or runout) test
Pipe Sample Layout (1/2)

- 6.5 feet (center corroded area on sample)
- 8 inches long
- 0.75-inch radius (at least)
- 0.188 inches (simulating 50% corrosion)
- 6 inches

Note uniform wall in machined region
Pipe Sample Layout (2/2)

ASME PCC-2 Calculated Composite Thicknesses for $P_{live}$

<table>
<thead>
<tr>
<th>Installation Pressure</th>
<th>Using PCC-2 Equation 5</th>
<th>Using PCC-2 Equation 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{live} = 0$</td>
<td>1.45 inches</td>
<td>N/A 0.620 inches</td>
</tr>
<tr>
<td>$P_{live} = 32%$ SMYS</td>
<td>1.8 inches</td>
<td>124% 0.770 inches</td>
</tr>
<tr>
<td>$P_{live} = 64%$ SMYS</td>
<td>2.2 inches</td>
<td>152% 1.168 inches</td>
</tr>
</tbody>
</table>

For repaired samples, Gage #6 is located on OD of the repair.

Strain gage locations on pipe / on composite
Dent Testing Overview: Sample Details

Side View of Pipe Sample (2 dent defects total)

Base pipe (18 inches from end cap)

Notice orientation of bossets

2-in (this length might change based on profile of first dent)

Close-up View of Dented Region

Bi-axial strain gage locations (1 per dent AND 1 on base pipe)
Offshore Study
Offshore Repair Study

• Simulated corrosion samples (75% wall loss) to be repaired in simulated seawater

• Repaired samples will be “soaked” in simulated seawater for 10,000 hours

• After 10,000-hour exposure samples will be tested to evaluate:
  o Cyclic pressure (50,000 cycles at $\Delta P = 36\%$ to $72\%$ SMYS)
  o Cyclic thermal loading (12 cycles at $\Delta T = 70^\circ F$ to $120^\circ F$)
  o Axial tension and bending loads (pressure to $72\%$ SMYS, apply failure tension and bending loads)
  o Long-term effects of UV exposure (90 day exposure)
  o Evaluating the effects of improper installation techniques
Offshore Repair Study Overview

- Build on prior MMS 2006 / PRCI MATR-3-6 composite repair studies
- Test sample repair configurations:
  - Burst sample
  - Pressure cycle fatigue sample
  - Tension-pressure sample
  - Bending-tension-pressure sample
- Corrosion sample with 75% deep region
- Test period of 10,000 hours
- All installation and testing work done underwater
Simulated Field Trial

- Cyclic pressure (50,000 cycles at $\Delta P = 36\%$ to $72\%$ SMYS)
- Cyclic thermal loading (12 cycles at $\Delta T = 70^\circ F$ to $120^\circ F$)
- Axial tension and bending loads (pressure to $72\%$ SMYS, apply failure tension and bending loads)
- Long-term effects of UV exposure (90 day exposure)
- NDE inspection before submersion, after removal, and after testing.
- Evaluating the effects of improper installation techniques.
Waller Test Facility Photos (1/4)
Waller Test Facility Photos (2/4)
Waller Test Facility Photos (3/4)
Waller Test Facility Photos (4/4)
Previous Testing Work (1/2)

Pressure Cycle and Burst Test

Axial Tension Test
Previous Testing Work (1/2)

Four-point Bending Test
## Program Schedule

<table>
<thead>
<tr>
<th>Phases</th>
<th>Phase of Work</th>
<th>Allotted Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Host “Kick-off” Meeting</td>
<td>0.5 months</td>
</tr>
<tr>
<td>1</td>
<td>Composite Repair Gap Analysis and State-of-the-art Report</td>
<td>1.5 months</td>
</tr>
<tr>
<td>2</td>
<td>Evaluate and Analyze Plastic Pipe Insert Technology</td>
<td>2 months</td>
</tr>
<tr>
<td>3</td>
<td>Inter-layer strain corrosion burst and cycle test</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Inter-layer strain dent pressure cycle fatigue test</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Effects of pressure during installation</td>
<td>18 months</td>
</tr>
<tr>
<td>6</td>
<td>10,000-hr testing effort</td>
<td></td>
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<tr>
<td>7</td>
<td>Inspection of samples (before and after testing)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Simulated field trial testing</td>
<td></td>
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<tr>
<td>9</td>
<td>Final Report</td>
<td>1.5 months</td>
</tr>
<tr>
<td>10</td>
<td>Host Final “Wrap-up” Workshop</td>
<td>0.5 months</td>
</tr>
</tbody>
</table>

**TOTAL TIME ESTIMATE** 24 months
Significance of this Work

• There is a need to have guidelines for qualifying, designing, installing, and monitoring/inspecting composite repairs, especially offshore.

• This seems to be a good model for industry working together to safely repair pipelines.

• It is envisioned that ASME standards, such as PCC-2, will be influenced by the results of this study.

• The continued investment in evaluating composite repair technology, including resin and fiber selections, improves our understanding / confidence.
Path Forward

• Reports to complete in next month
  ▪ Gap analysis
  ▪ Plastic pipe insert technology

• Testing to be completed by end of the year
  ▪ Load transfer study
  ▪ Onshore study

• Offshore study will be started by end of the year with sample fabrication and inspection work
Thank You!

Questions & Answers

Chris Alexander
chris.alexander@stress.com
(281) 450-6642 (cell)