Pipeline Research Council International, Inc.

Composite Repair of Transmission Pipelines Workshop

2020 PRCI Research Exchange

Presented by Dr. Chris Alexander, PE | ADV Integrity, Inc.

Tuesday, March 3, 2020 | 1:00 to 2:30 PM PST

Presentation Overview

- **Part 1:** The critical role of full-scale testing in evaluating composite repair technologies
- **Part 2:** Background on previous research and case studies
- **Part 3:** The future and advancing the state-of-the-art

High Level Composite Repair Concepts

- **Composite repairs systems include:**
  - E-glass or carbon fibers
  - Matrix (e.g., epoxy and urethane resins)
  - Filler (putty) materials
- **First use dates back to early 1990s**
- **Minimal debate regarding their use for corrosion and dent features**
- **Inspection of repairs is a gap**
- **Advanced applications include leak repairs and reinforcement of cracks**

Part 1: The critical role of full-scale testing in evaluating composite repair technologies

Why is testing important?

- Managing pipelines can be very difficult
- Integrity engineers are required to make complex decisions with limited information
- Numerical modeling can be effective in predicting behavior, but oftentimes has limitations due to unknowns with material properties and defect geometries
- In some regards, full-scale testing is “insurance” to help us better understand potential pipe behavior

Testing Program Key Elements

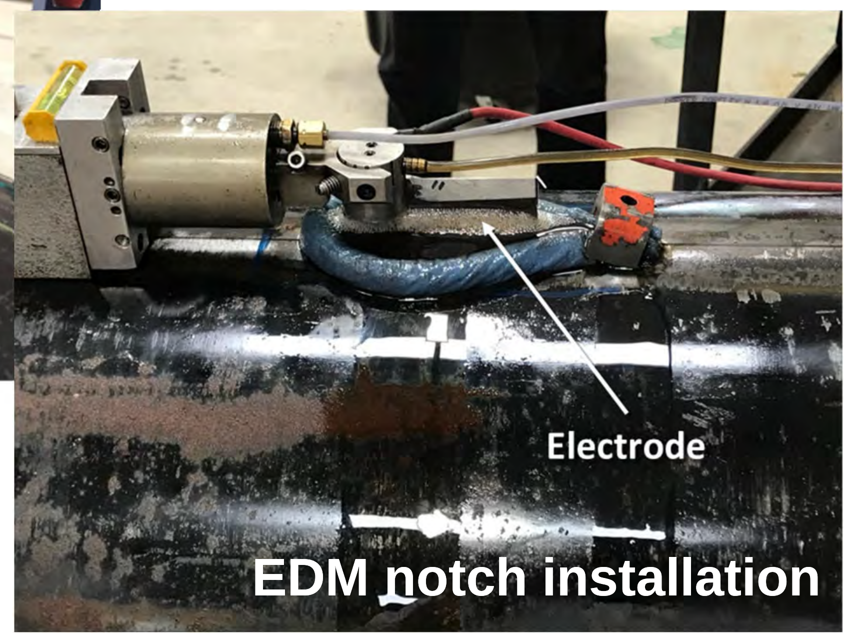
- Ronald Reagan's "Trust, but verify" concept is the essence of every testing program
- Full-scale testing allows us to simulate real-world pipeline conditions and establish a true limit state condition
- The ideal scenario is one that involves both full-scale testing and numerical modeling
- Testing can be extremely difficult and requires engineers and technicians with significant experience

Key Aspects (Equipment, 1/3)

Pressure test chamber

Key Aspects (Equipment, 2/3)

Dent installation test rig



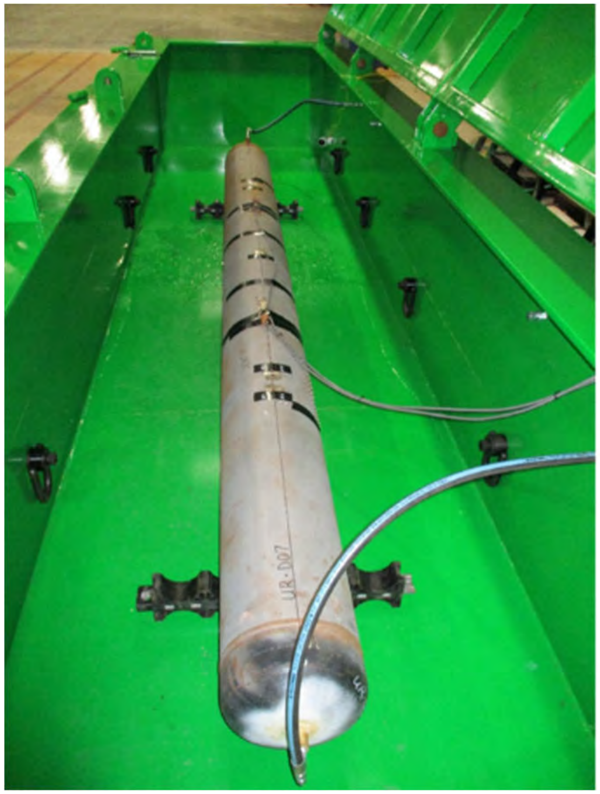
EDM notch installation

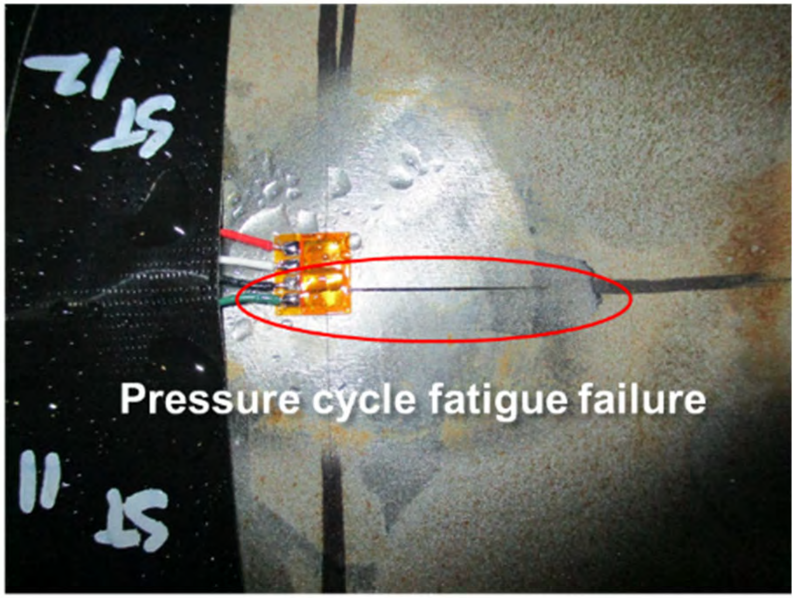
Key Aspects (Equipment, 3/3)

Cold Temperature Burst Box
(-51°F / -46°C)

Case Studies (1/3)

Pressure cycle fatigue testing dents





In the test lab, dents can be simulated to achieve any geometry and also include interactions with seam welds, girth welds, and corrosion (to name a few).

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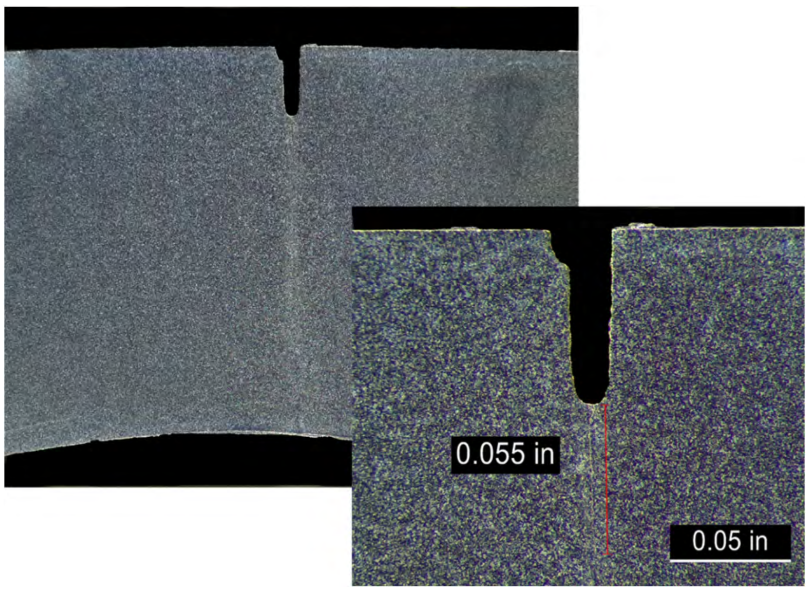
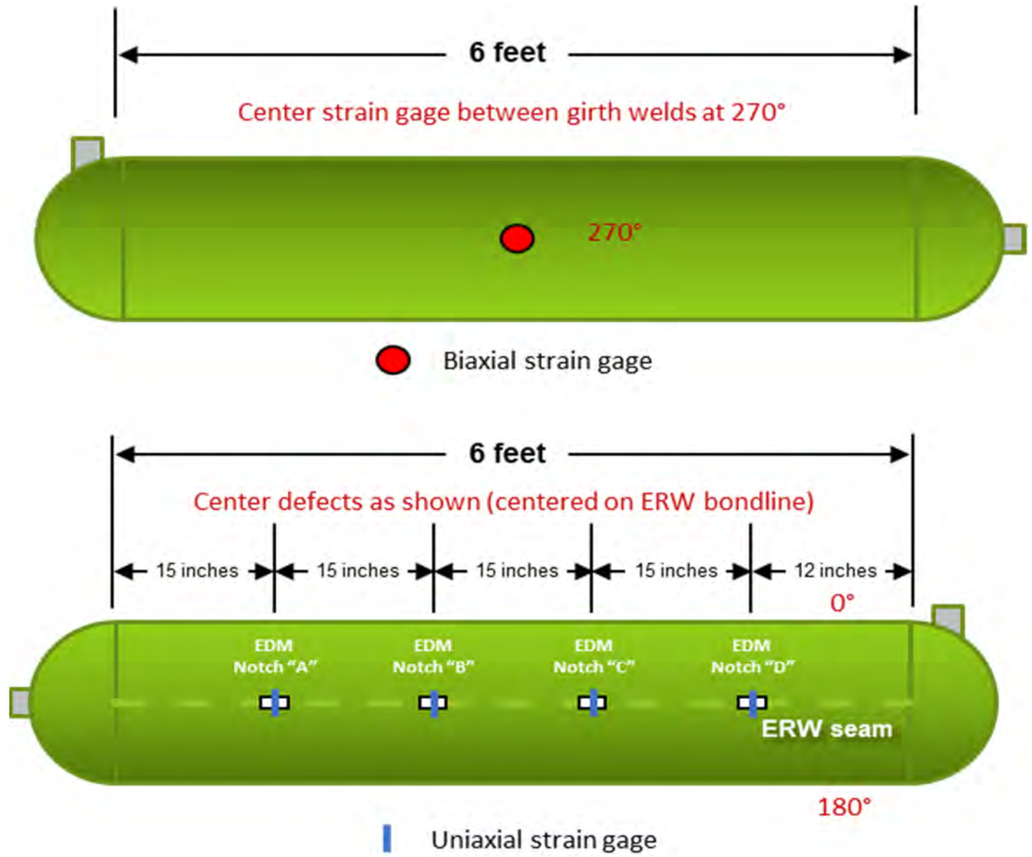
Case Studies (2/3)

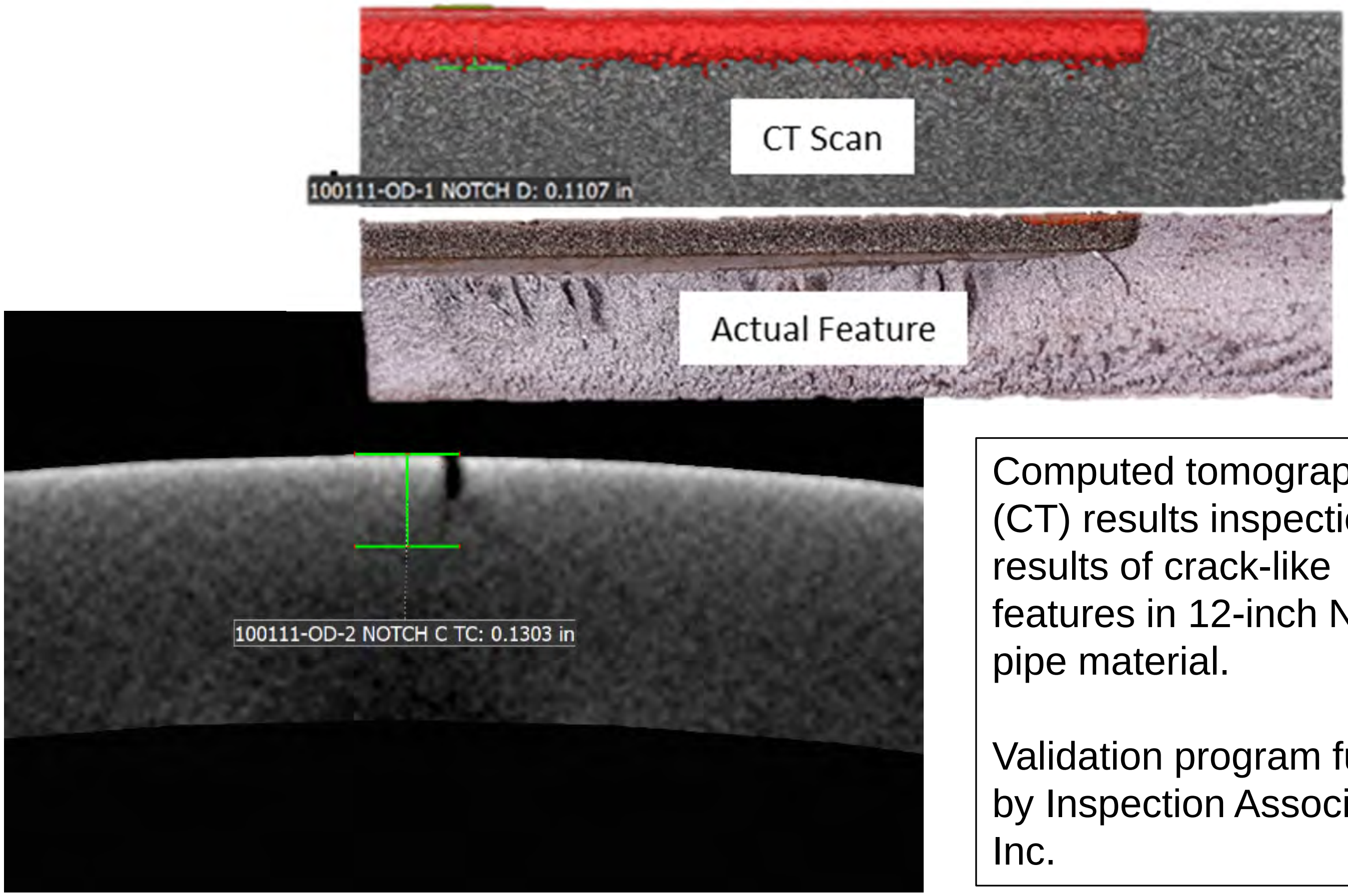
Seam weld cracking and technology validation





Case Studies (3/3)

Seam weld cracking and technology validation

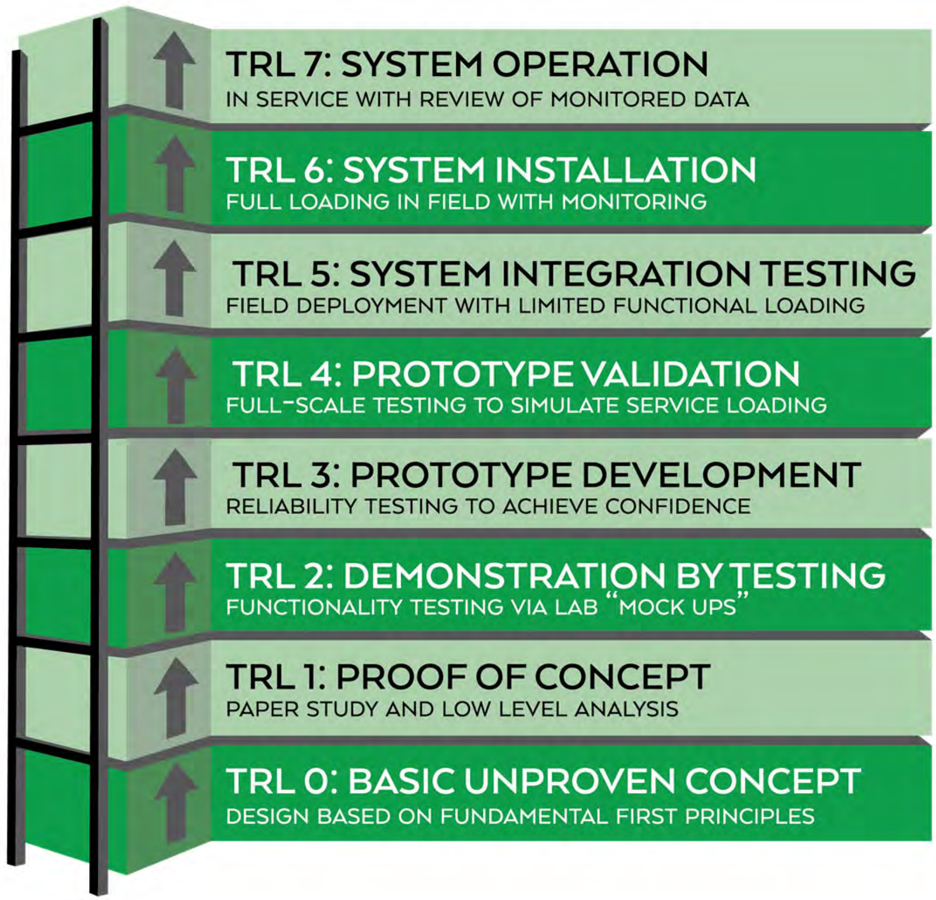


Inspection Technology

Computed tomography (CT) results inspection results of crack-like features in 12-inch NPS pipe material.

Validation program funded by Inspection Associates, Inc.

Technology Readiness Levels



Closing Comments on Testing

- A well-designed and executed testing program can help operators manage pipeline threats
- Testing takes much of the "guesswork" out of determining what impact defects have on pipeline performance
- There is no substitute in using full-scale testing to validate new and existing technologies
- Test results are usually clear and concise, allowing engineers to communicate to the public, upper management, and regulators what's important

Part 2: Background on previous PRCI research and case studies

Typical Aims of Pipeline Repair Methods

- Restore strength to damaged pipes
- Reduce strain in damaged areas of pipe
- Seal corroded area of pipe from further development of corrosion

Target Applications of Repairs

- Gas and Liquid Pipelines
- Water Pipelines
- Small Utility Lines
- Chemical Plants
- Gas Plants and Refineries
- Offshore Facilities


Clock Spring


Furmanite

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Uses of Composite Materials

(repair and structural reinforcement)

- Metal wall loss (due to corrosion)
- Plain dents
- Mechanical damage (dents with a gouge)
- Re-rating pipeline system to achieve higher operating pressures
- Reinforcing sections like branch connections, bends, and elbows

Types of Composite Repairs

(used to repair pipeline systems)

- **Wet lay-up systems**
  - Monolithic
  - Can be applied to non-straight geometries
  - Versatility in range of resin technologies (e.g. underwater, high temperature, slow cure, etc.)
- **Layered systems (e.g. Clock Spring and PermaWrap)**
  - First widely-used composite repair technology
  - Layered repair system
  - Limited to repair of straight pipes
- **Hybrid systems: Steel and adhesives (e.g. Western Specialties' ComposiSleeve)**

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Composite Repair Overview (1/2)

- Composites widely accepted and used in repairing non-leaking transmission pipelines
- Plants use composite materials, including the repair of leaks
- Since 1994, more than 35 different composite repair systems have been evaluated experimentally
- Much of the early funding provided by manufacturers, although more recently operators are providing much of the funding

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Composite Repair Overview (2/2)

- Manufacturer co-funding with PRCI has been an ideal means for comparing competing repair technologies
- The ASME PCC-2 Standard has provided a common basis for evaluating composite technology
- Composite repair systems can be designed for unique applications
- Since 2005, more than $20 million has been invested in composite repair research

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Government Regulations

(from U.S. Department of Transportation)

On January 13, 2000, ***Pipeline Safety: Gas and Hazardous Liquid Pipeline Repair***, was issued by the RSPA of the Department of Transportation, went into effect.

According to this document, the requirement for repairing corroded and dents in pipelines is as follows,

…repaired by a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe.

69664 **Federal Register** / Vol. 64, No. 239 / Tuesday, December 14, 1999 /Rules and Regulations

The final rules provide operators flexibility to choose the most cost-effective method of repairing pipe, while maintaining public safety. Thus, the rules will not add costs to industry, government, or the public. In fact, the rules should reduce operators' costs of transporting oil and gas, and perhaps the price consumers pay for these products. In comments on a proposed waiver to the Panhandle Eastern Corporation (58 FR 13823; March 15, 1993), the American Gas Association estimated that industry could save $6.5 million a year by using composite wrap to repair corroded or damaged pipe. Although part of the gas pipeline industry is already realizing these savings because of the Panhandle and other waivers, the final rules will create a similar opportunity for savings by the entire oil and gas pipeline industry. And still more savings could possibly result from the use of innovative technologies not covered by the waivers. In fact, this rulemaking fosters the use and development of new repair technologies without additional cost to the regulated industry. A Final Regulatory Evaluation document is available for review in the docket.

B. ***Regulatory Flexibility Act***

This rulemaking will not impose additional requirements on pipeline operators, including small entities that operate regulated pipelines. Rather, the rules offer operators the opportunity to use more economical methods of repairing corroded or damaged pipe. Thus, this rulemaking may reduce costs to operators, including small entities. Based on the facts available about the expected impact of this rulemaking, I certify, under section 605 of the Regulatory Flexibility Act (5 U.S.C. 605), that this rulemaking will not have a significant economic impact on a substantial number of small entities.

C. ***Executive Order*** *12612*

This rulemaking will not have substantial direct effects on states, on the relationship between the Federal Government and the states, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612 (52 FR 41685; October 30, 1987), RSPA has determined that the final rules do not have sufficient federalism implications to warrant preparation of a Federalism Assessment.

D. ***Executive Order*** *13084*

The final rules have been analyzed in accordance with the principles and criteria contained in Executive Order 13084, "Consultation and Coordination with Indian Tribal Governments." Because the rules will not significantly or uniquely affect Indian tribal governments, the funding and consultation requirements of Executive Order 13084 do not apply.

E. ***Paperwork Reduction Act of*** *1995*

This rulemaking contains no information collection that is subject to review by OMB under the Paperwork Reduction Act of 1995.

F. ***Unfunded Mandates Reform Act of*** *1995*

This rulemaking will not impose unfunded mandates under the Unfunded Mandates Reform Act of 1995. It will not result in costs of $100 million or more to either state, local, or tribal governments, in the aggregate, or to the private sector, and is the least burdensome alternative that achieves the objective of the rulemaking.

G. ***National Environmental Policy Act***

We have analyzed the final rules for purposes of the National Environmental Policy Act (42 U.S.C. 4321 *et seq.*). We prepared an Environmental Assessment (64 FR 16884; April 7, 1999) in which we concluded that the proposed action would not significantly affect the human environment because alternative repair methods would have to be as reliable as those the pipeline safety regulations currently allow. Thus any alternative method would provide the same level of pipe protection that the current repair methods provide. Based on this Environmental Assessment and no receipt of information showing otherwise, we have prepared a Finding of No Significant Impact (FONSI). This FONSI has been made part of the docket.

H. ***Impact on Business Processes and Computer Systems***

Many computers that use two digits to keep track of dates will, on January 1, 2000, recognize "double zero" not as 2000 but as 1900. This glitch, the Year 2000 Problem, could cause computers to stop running or to start generating erroneous data. The Year 2000 problem poses a threat to the global economy in which Americans live and work. With the help of the President's Council on Year 2000 Conversion, federal agencies are reaching out to increase awareness of the problem and to offer support. We do not want to impose new requirements that would mandate business process changes when the resources necessary to implement those requirements would otherwise be applied to the Year 2000 Problem.

This rulemaking does not require business process changes or require modifications to computer systems. Because this rulemaking does not affect the ability of organizations to respond to the Year 2000 problem, we have not delayed the effectiveness of the final rules.

List of Subjects

49 CFR Part 192

Natural gas, Pipeline safety, Reporting and recordkeeping requirements.

49 CFR Part 195

Ammonia, Carbon dioxide, Petroleum, Pipeline safety, Reporting and recordkeeping requirements.

In consideration of the foregoing, 49 CFR parts 192 and 195 are amended as follows:

PART 192—[AMENDED]

1. The authority citation for part 192 continues to read as follows:

Authority: 49 U.S.C. 5103, 60102, 60104, 60108, 60109, 60110, 60113, and 60118; and 49 CFR 1.53.

2. In § 192.309, paragraph (b) introductory text is revised to read as follows:

§ 192.309 Repair of steel pipe.

* * * * *

(b) Each of the following dents must be removed from steel pipe to be operated at a pressure that produces a hoop stress of 20 percent, or more, of SMYS, unless the dent is repaired by a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe:

* * * * *

3. Section 192.485(a) is revised to read as follows:

§ 192.485 Remedial measures: Transmission lines.

(a) *General corrosion.* Each segment of transmission line with general corrosion and with a remaining wall thickness less than that required for the MAOP of the pipeline must be replaced or the operating pressure reduced commensurate with the strength of the pipe based on actual remaining wall thickness. However, corroded pipe may be repaired by a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe. Corrosion pitting so closely grouped as to affect the overall strength of the pipe is considered general corrosion for the purpose of this paragraph.

* * * * *

4. Section 192.487(a) is revised to read as follows:

Page from the RSPA-98-4733 document

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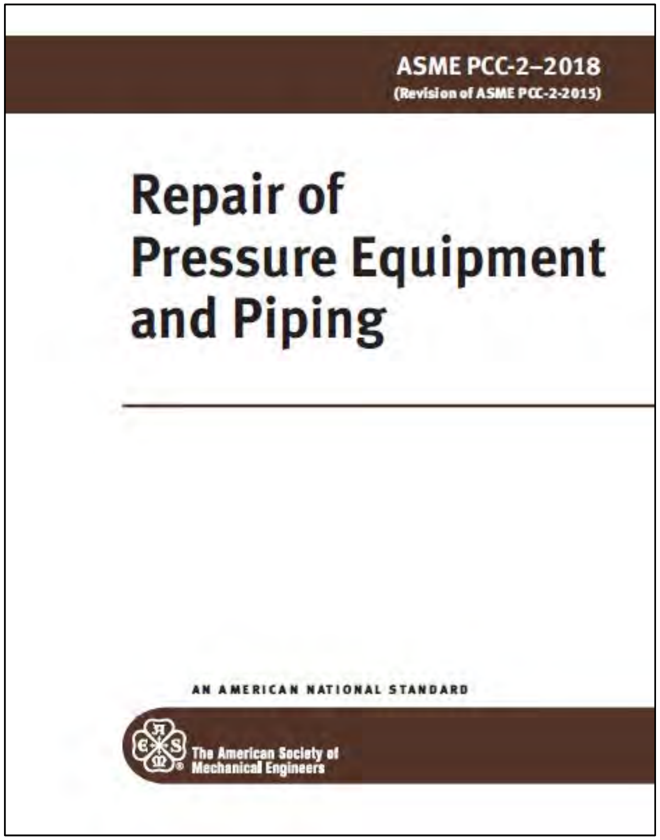
Industry Standards

- ASME PCC-2 (and ISO 24817)
- Part 4 – *Nonmetallic and Bonded Repairs*
- Committee is active and standard is developing to meet industries' needs
- Key benefit to industry is uniformity and establishing minimum design requirements



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PRCI Composite Project List

- MATR-3-3 *State of the Art* report
- MATR-3-4 Long-term buried pipe corrosion study
- MATR-3-5 Repair of dents (ERW and GW)
- MATR-3-6 Subsea study
- MATR-3-7 Girth weld study
- MATR-3-9 Re-rate study (est. MAOP)
- MATR-3-10 Composite Guideline Document
- MATR-3-11 Load transfer
- MATR-3-12 Delamination assessment
- MATR-3-13 Effects of pressure during installation
- MATV-1-2 Reinforcing wrinkle bends

MATR-3-4 Long-term Study

- **The original program objective was to validate composite materials for long-term service**
- **Thirteen (13) companies participating in study**
  - Five 10-year study participants (21 samples each)
  - Eight 3-year study participants (12 samples each)
- **Final burst testing completed**
- **In general, results have been good**

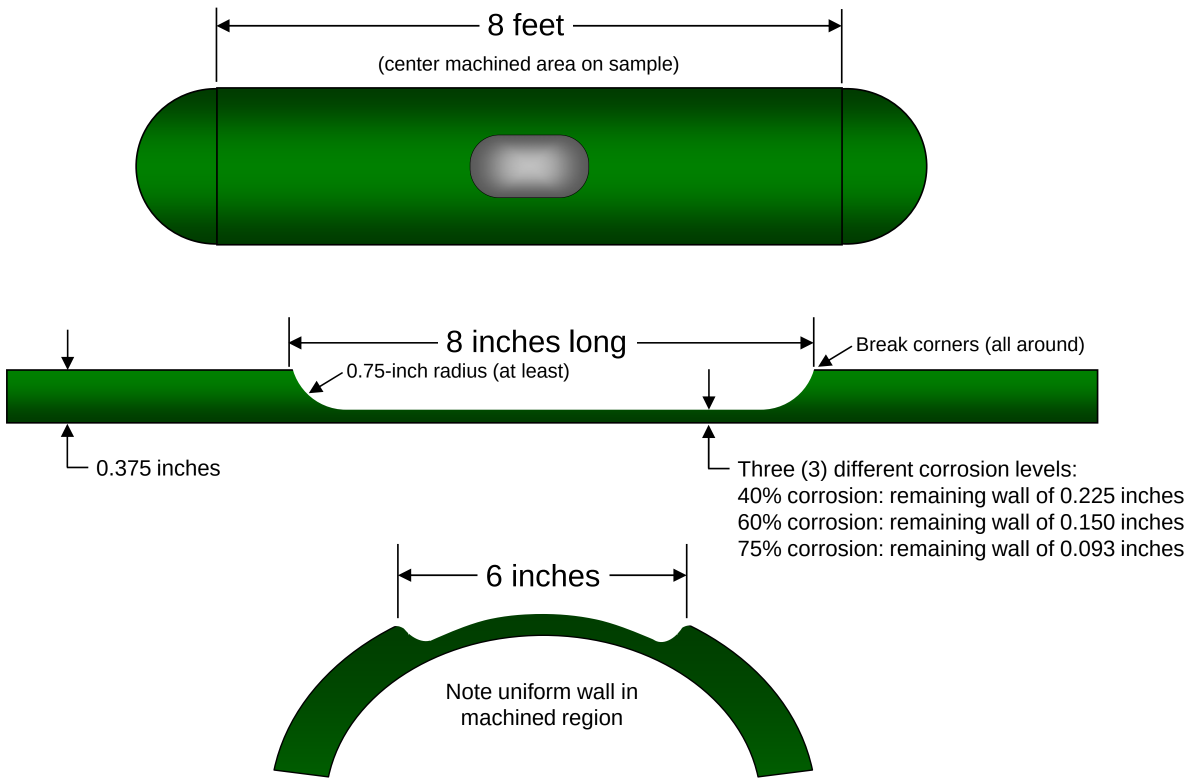
Original Participants

- Armor Plate, Inc. (10 years)
- Air Logistics Corporation (3 years)
- Clock Spring Company, LLC (3 years) *
- Citadel Technologies (10 years) *
- EMS Group (10 years) **
- Furmanite (3 years)
- Neptune (3 years) *
- Pipe Wrap, LLC (3 years) *
- Pipestream (10 years) **
- T.D. Williamson, Inc. (10 years)
- Walker Technical Resources Ltd. (3 years)
- Wrap Master (3 years)
- 3X Engineering (3 years)

* Currently operating as CS-NRI
** No longer in the composite repair business

Pipe Test Samples

12.75-inch x 0.375-inch, Grade X42 pipe (8-feet long)



Details on machining
(machined area is 8 inches long by 6 inches wide)

Courtesy of Stress Engineering Services, Inc.

Test Field Layout



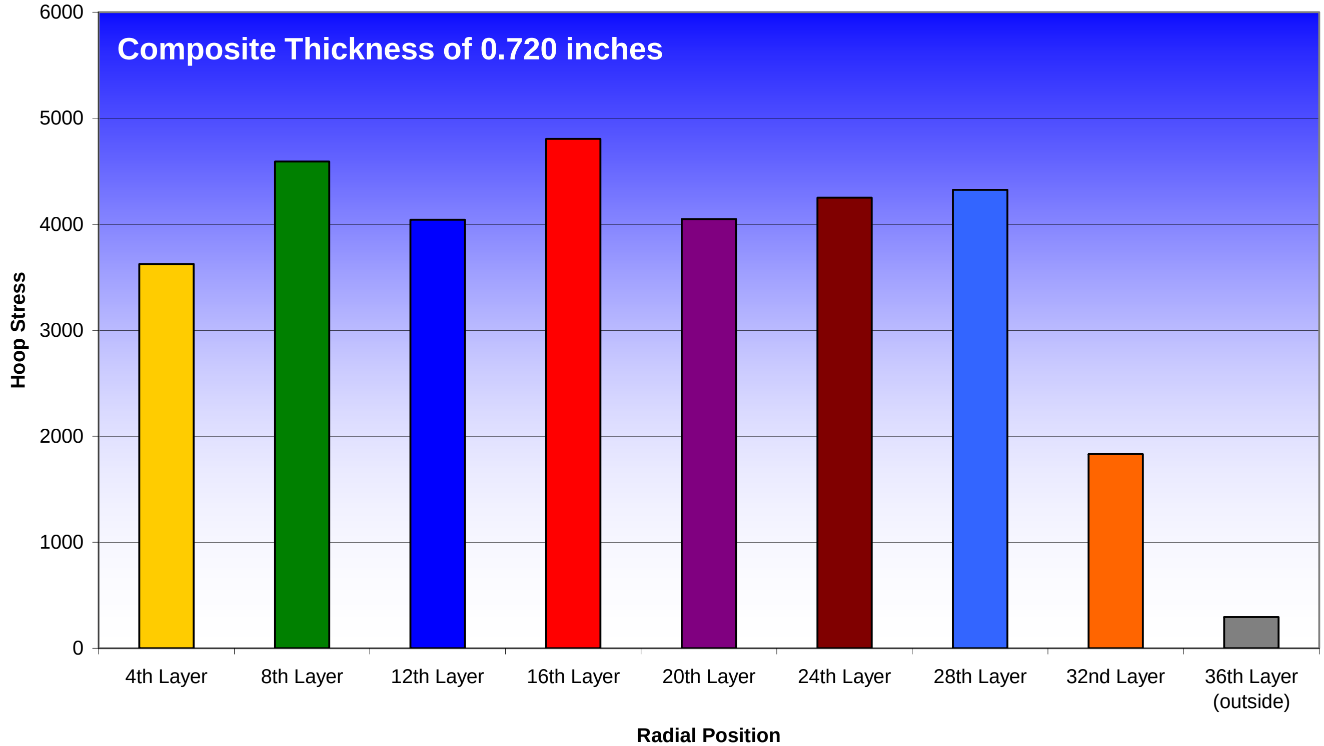

Courtesy of Stress Engineering Services, Inc.

Burst Test Effort

Courtesy of Stress Engineering Services, Inc.

Inter-Layer Stresses

Hoop Stress at 72% SMYS as a Function of Radial Position



Key for Long-term Performance

Safety Factor of <u>10.8</u> on short-term tensile strength

Courtesy of Stress Engineering Services, Inc.

Pressure Cycle Test Results

- **12.75-inch x 0.375-inch, Grade X42 pipe samples with ΔP = 36% to 72% SMYS (75% corrosion)**
- **Results for different repair systems:**
  - E-glass system: 19,411 cycles to failure
  - 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: 212,888 cycles to failure
  - Carbon system: 256,344 cycles to failure
  - Carbon system: 202,903 cycles to failure
  - E-glass system: 259,537 cycles to failure
  - Carbon system: 532,776 cycles (run out, no failure)
  - Hybrid steel/Epoxy system: 655,749 cycles to failure
  - Hybrid steel/E-glass system: 767,816 cycles to failure

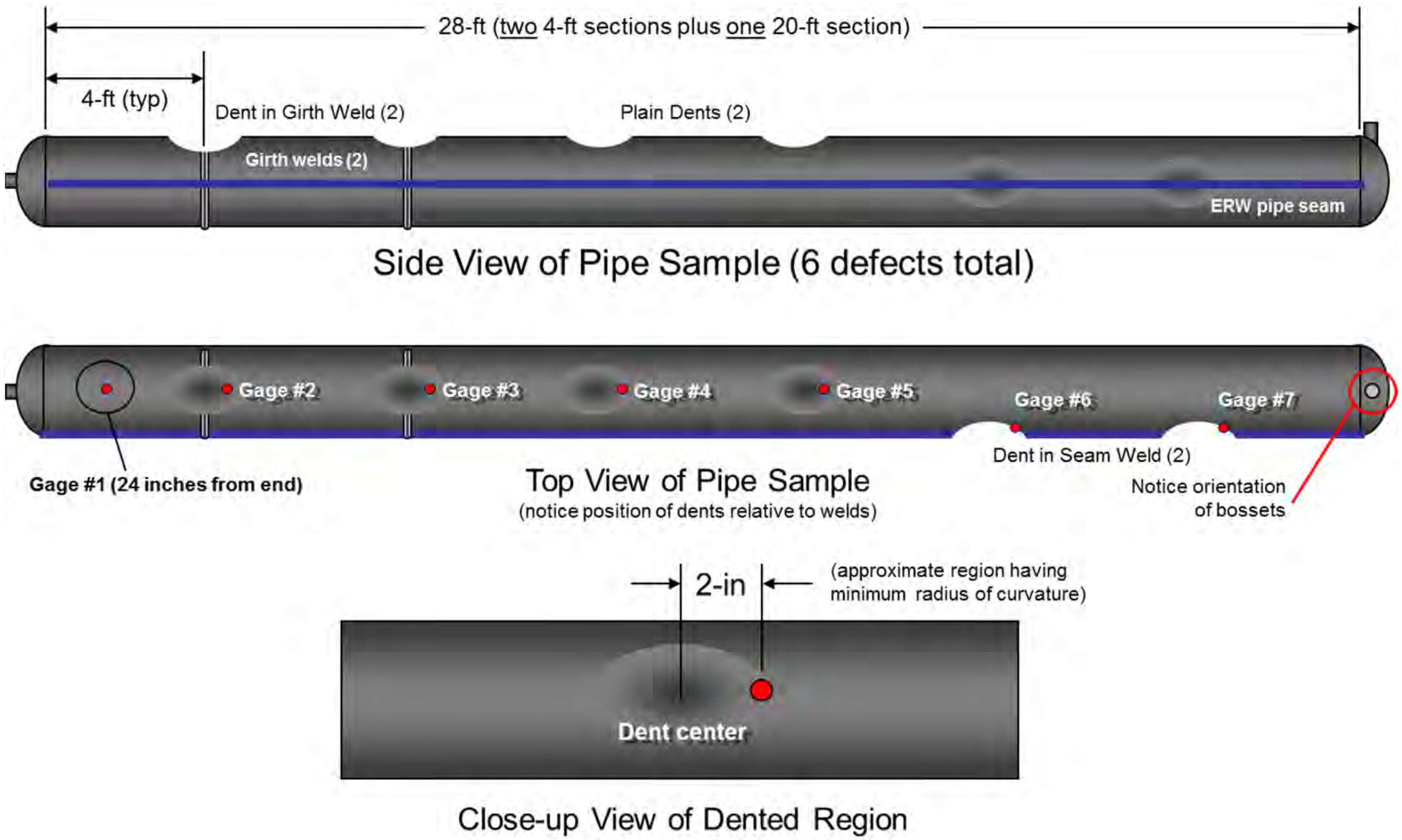
Courtesy of Stress Engineering Services, Inc.

MATR-3-5 Dent Study Overview

- **Program objective is to validate composite materials for repairing dents; comparison with existing technology**
- **Eleven (11) repair systems participating in study**
  - 2 rigid coil Systems (one E-glass & one steel)
  - 4 carbon Systems
  - 4 E-glass Systems
  - 1 Steel Sleeve System
- **One <u>unrepaired</u> test sample to serve as baseline**
- **Pipe: 12.75-inch x 0.188-inch, Grade X42 (ΔP=72% SMYS)**
- **Measured strain using strain gages beneath repairs**
- **Samples cycled to failure with 68 total dents in study**
  - 62 completed evaluating composite materials
  - 6 dents repaired using Dresser steel sleeves

Strain Gage Locations

Samples fabricated using 12.75-inch x 0.188-inch, Grade X42 pipe material



Courtesy of Stress Engineering Services, Inc.0

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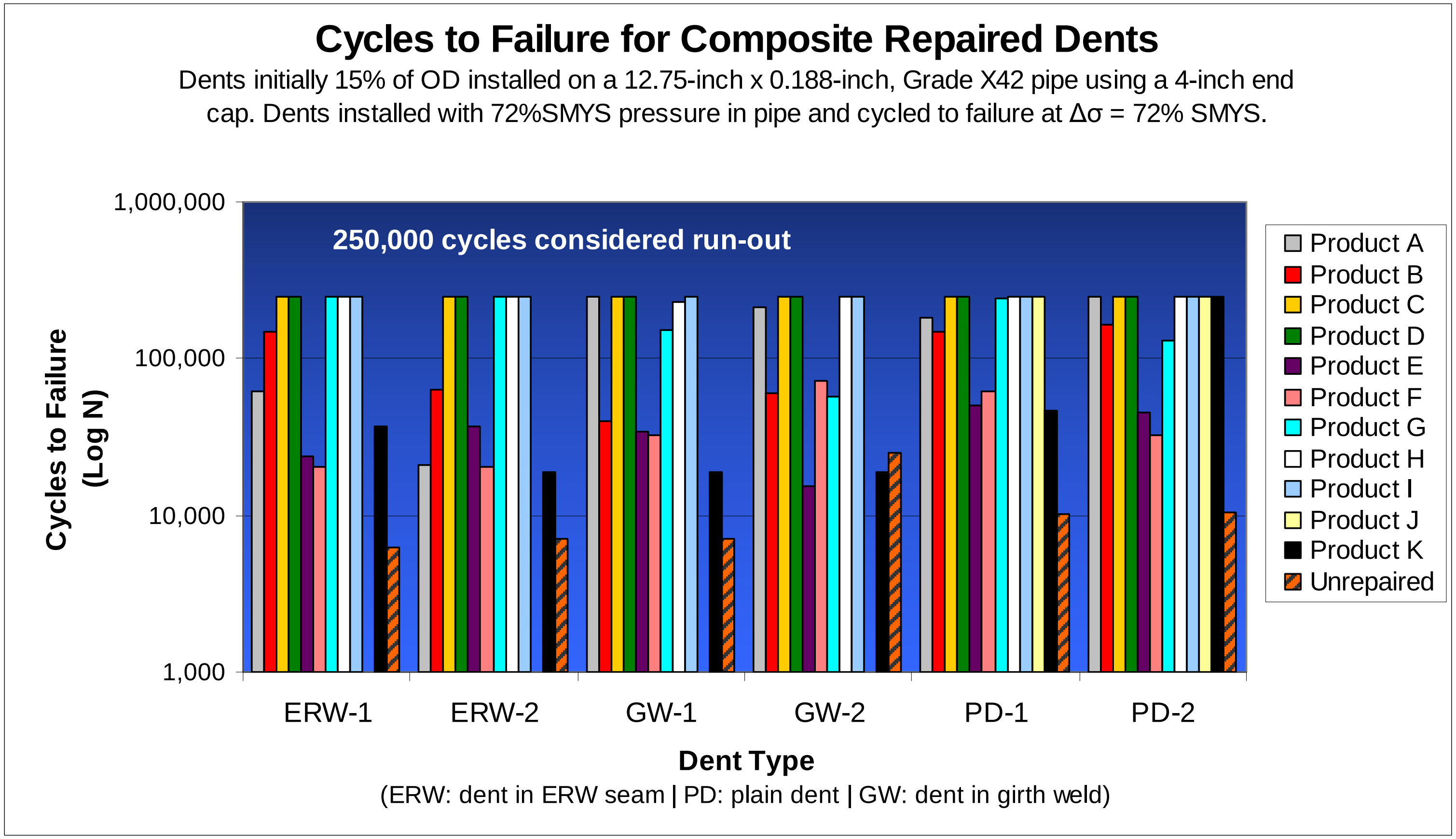
Pressure Cycle Fatigue Data



Courtesy of Stress Engineering Services, Inc.

MATR-3-6 Subsea Study Overview

- **Test sample repair configurations (5 repair systems)**
  - Burst sample
  - Pressure cycle fatigue sample
  - Tension-pressure sample (pre-blast / underwater blast)
  - Bending-tension-pressure sample
- **Test period of 10,000 hours**
- **All installation and testing work done underwater (simulated seawater conditions)**

MATR-3-6 Photos (1/4)

Courtesy of Stress Engineering Services, Inc.

MATR-3-6 Photos (2/4)

Courtesy of Stress Engineering Services, Inc.

MATR-3-6 Photos (3/4)

Courtesy of Stress Engineering Services, Inc.

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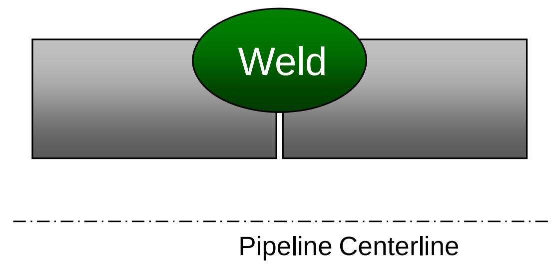
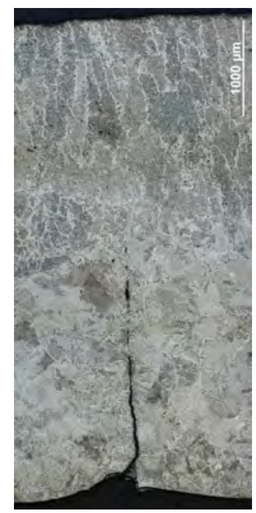
MATR-3-6 Photos (4/4)

Courtesy of Stress Engineering Services, Inc.

MATR-3-7 GW Study Overview

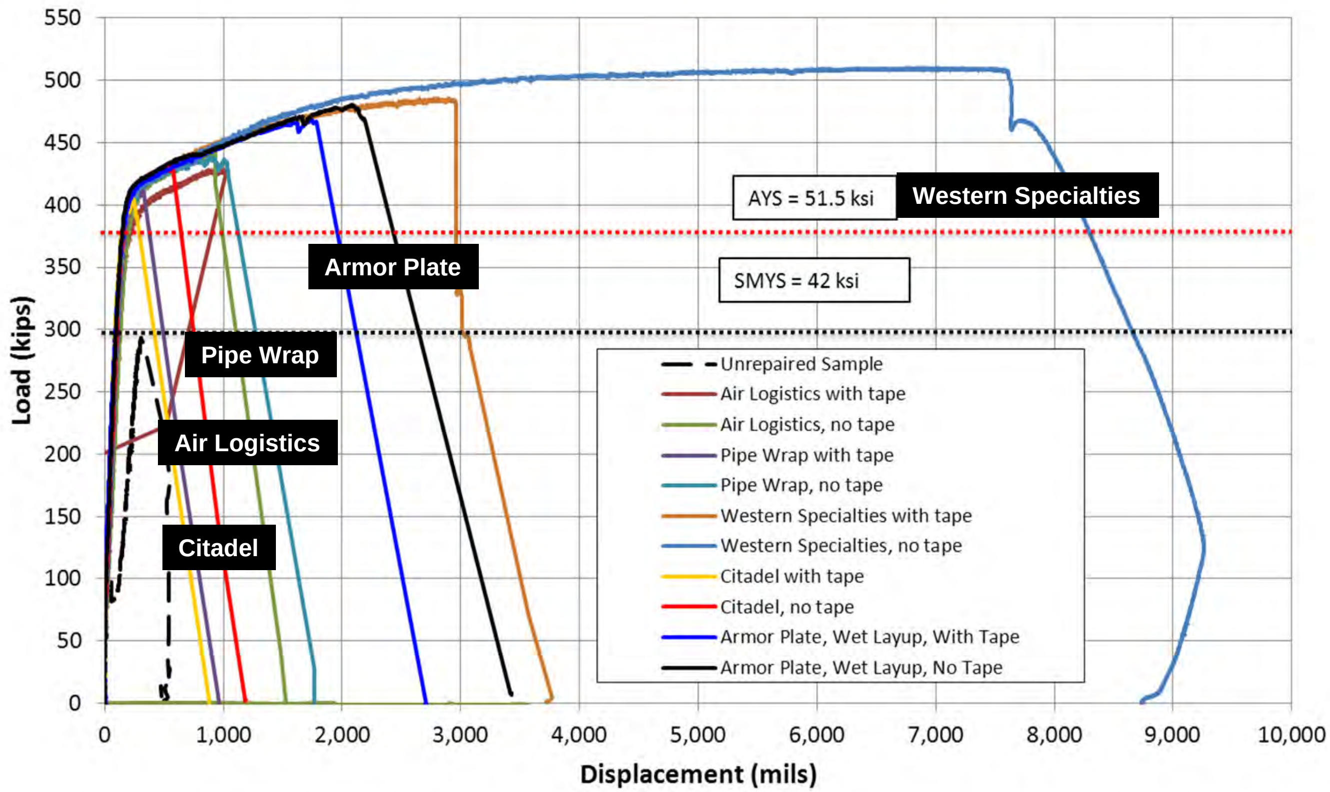
- **12.75-inch x 0.188-inch, Gr. X42**
- **Sample preparation**
  - Deflective girth welds fabricated (lack of penetration)
  - Material testing
  - Surface sandblast (NACE 2)
  - Strain gages installed
- **Five (5) repair systems tested**
- **Tension and bending tests**





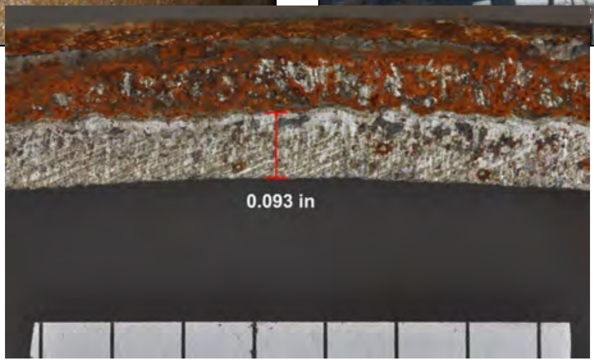
Courtesy of Stress Engineering Services, Inc.

Tension to Failure Results



Courtesy of Stress Engineering Services, Inc.

Unrepaired Test Failures



Courtesy of Stress Engineering Services, Inc.

Repaired Test Failures

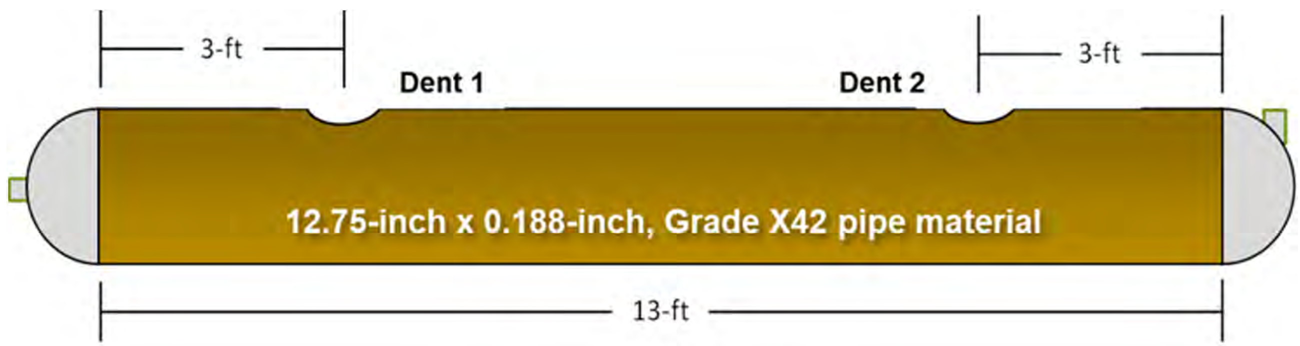

Sample prior to testing in tension


Failure in tension sample

Courtesy of Stress Engineering Services, Inc.

MATR-3-13 Study

- **Dented pipe samples 12.75-inch OD x 0.188-inch WT, Grade X42**
- **Pressure cycled until first failure**
  - Failed dent is cutout, endcap re-welded, surviving dent is cycled to failure
- **One (1) Unreinforced sample**
- **Six (6) Repair installations made <u>under pressure</u> (64% SMYS)**



12.75-inch x 0.188-inch, Grade X42 pipe

NRI Steel Wrap

NRI-D02-64|Dent 2 leaked after 30,814 cycles

WrapMaster

WM-D03-64|Dent 2 Leaked after 24,721 cycles

Western Specialties ComposiSleeve

WSCS-D04-64|Dent 1 leaked after 59,927 cycles

Recent Advances

- Optimized technologies, including the ability to weave specific fabrics for particular applications
- “Smart” sleeves involving the embedding of sensors and fiber optic technologies
- Remote monitoring with the ability to assess repairs and pipelines
- Deepwater composite repairs, including ROV-assisted installations (work with NRI)

“Smart” Sleeve Technology
Used with permission - Western Specialties

Subsea Deepwater Curing Simulation (10,000-ft depth at 40°F)
Used with permission - NRI

Overall Observations

- For more than 25 years, the pipeline industry has been using composite repair systems
- A significant body of research exists addressing a variety of repair types
- We continue to learn more, which improves our confidence with composites
- Validating long-term performance is a critical effort in ongoing and future efforts
- Installation and quality control are probably today's hottest topic in composite repairs

Part 3: The Future and Advancing the State-of-the-art

Where do we go from here?

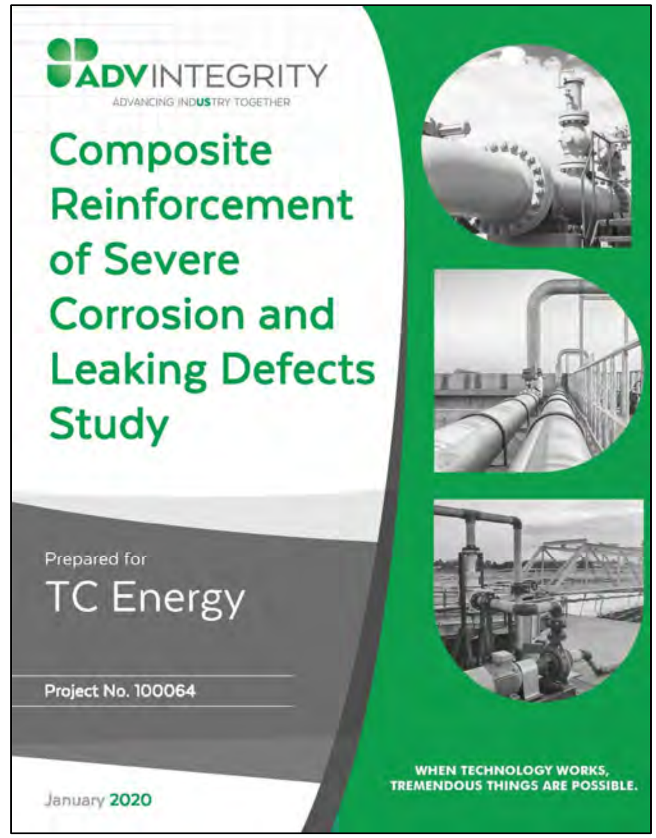
- **Number of repairs will likely increase as ILI tools are improving their "sizing" capabilities**
- **Knowledge gaps exist in terms of:**
  - Elevated temperature performance
  - Reinforcement of cracks
  - Repair of leaking defects
  - Inspection technologies and assessment criteria
- **Current Research Ideas (TC Energy and ADV):**
  - *Composite Technology Leak Repair Research Idea* (June 13, 2019)
  - *Reinforcement of Crack-like Features Using Composite Materials* (July 7, 2019)

Recent TC Energy Work

A two-year study was conducted to evaluate the ability of composite repair systems to repair leaking corrosion features (Upcoming Paper No. IPC2020-9757)

Recent Leak Repair Study (1/3)

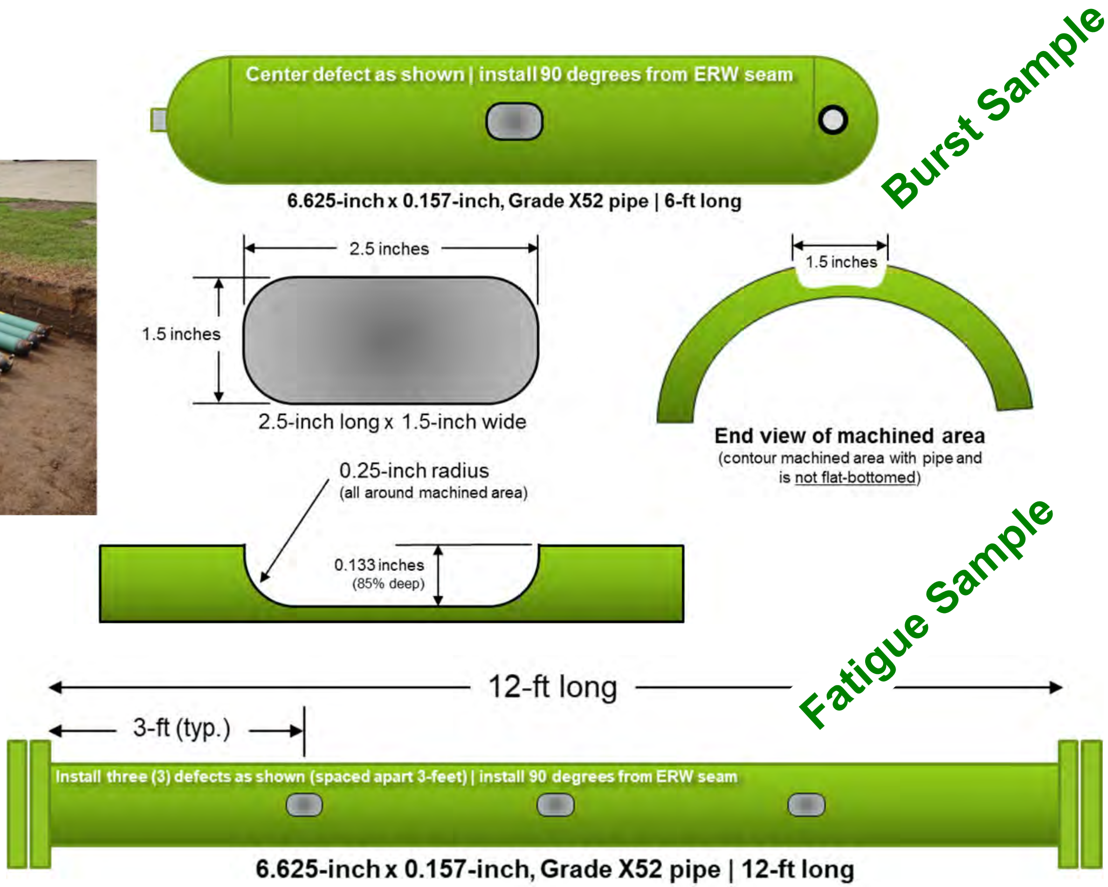
- Stage I testing started in February 2018 and originally involved four (4) companies
- Stage II started in 2019 and involving Milliken and Western Specialties



Recent Leak Repair Study (2/3)

- **Major testing categories / elements:**
  - Severe corrosion (85%) with thru-wall defects in extremely thin-wall 6-inch x 0.157-inch pipe
  - Buried pipe samples with nitrogen gas (90 days)
  - Elevated temperature up to 60°C (140°F)
  - Cyclic pressure up to 80% SMYS, including elevated temperatures
  - Reduced surface preparation (flash rust)
  - Some repairs made with shop air
- **Qualification based on burst and cyclic pressure results**

Recent Leak Repair Study (3/3)



Wrapping it all up…

Points of Discussion

- **New "applications" of composite repairs require careful consideration**
- **It's important to understand the anomalies' behavior and response to loading**
- **The** required level of reinforcement **dictates design of the composite**
- **Once designed, the composite repair should be validated via full-scale testing**
- **PHMSA advocates** design by performance **and supports validation using full-scale testing**

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Presentation Closing Comments

- Thank you for not falling asleep!
- There is a wealth of research completed to date involving more than 1,000 tests over the past 20 years
- We keep learning more about reinforcing defects, but there is <u>more work to be done</u>
- Quality control in relation to installation methods and design optimization are the two biggest factors facing us in the pipeline industry

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