



# New Insights in Repairing Damaged Pipes and Pipelines Using Composite Materials

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# Chris Alexander Background

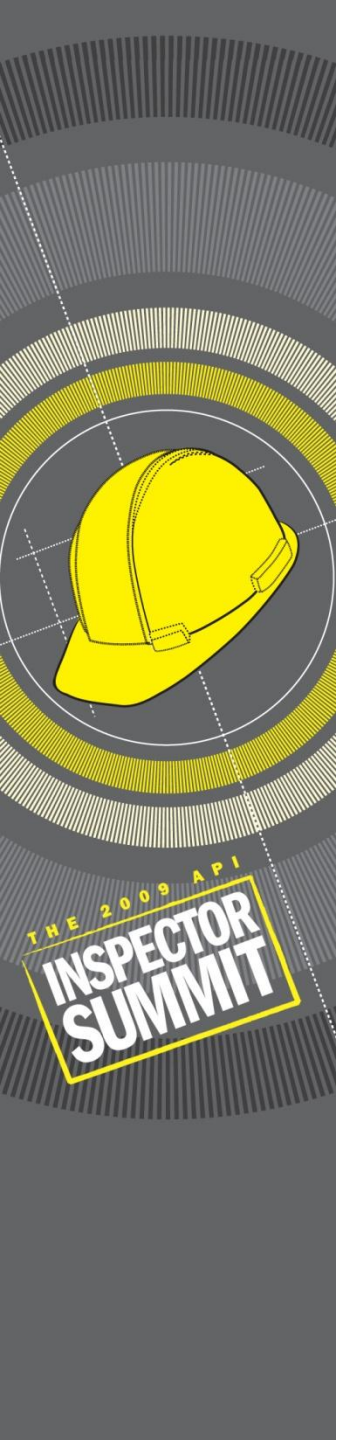
- Partner at Stress Engineering Services, Inc. (SES - Houston office)
- Member of the SES Fitness for Service Group with emphasis on pipeline practice area
- Actively involved in full-scale testing and analysis using finite element methods
- Areas of specialty include assessing pipeline damage and evaluating composite repairs
- B.S., M.S., and Ph.D. degrees from Texas A&M University in Mechanical Engineering



# Disclaimer

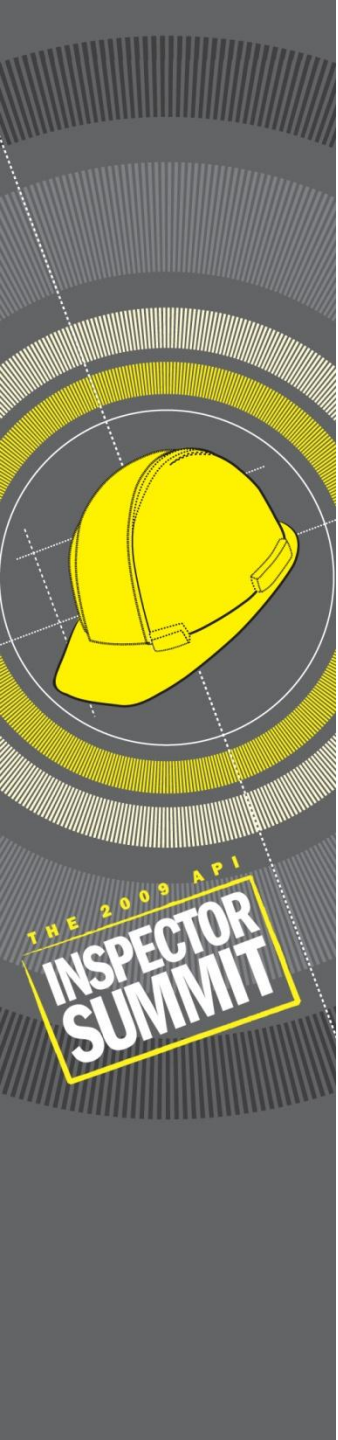
Although Stress Engineering Services (SES) will discuss specific composite repair systems and products today, SES does not endorse any particular composite repair system.

Users are encouraged to know and understand the capabilities and limitations of each composite repair system. SES has observed misrepresentation and incorrect distribution of technical data and information.



# Today's Presentation

- Background in pipeline evaluation and repairs
- Examples of when composites can be used to repair pipelines
- Background on the major pipeline repair systems using composite materials
- U.S. government regulations
- Guidelines for repair using composites and test program elements
- Repair of dents and gouges (mechanical damage)
- Long-term performance study
- Question & Answer Session



# 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

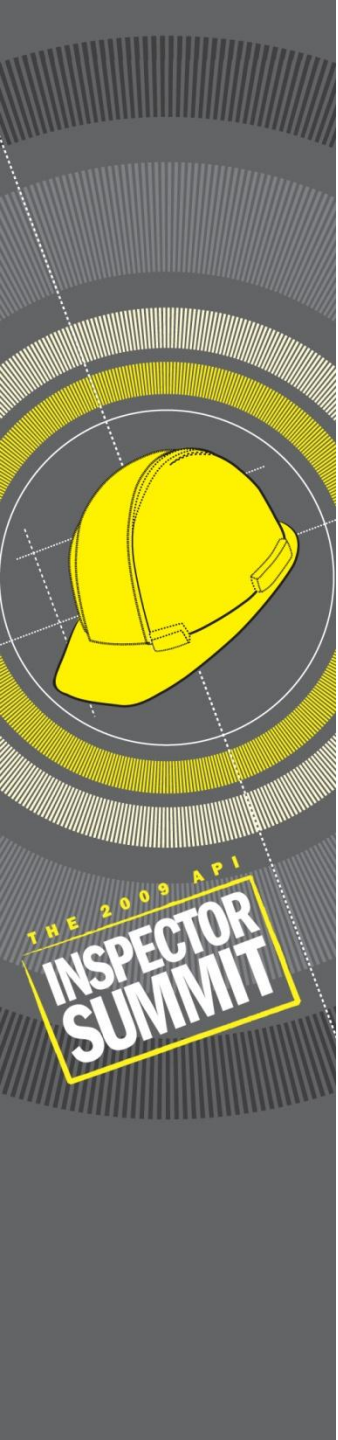
- Gas and Liquid Pipelines
- Water Pipelines
- Small Utility Lines
- Chemical Plants
- Gas Plants and Refineries



# 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
- Corrosion repair and replacement
  - Under insulation coating (UIC)
  - Wear-resistant coatings (e.g. saddles)
  - Underwater coatings



# Types of Composite Repairs

(used to repair pipeline systems)

- Wet lay-up systems (e.g. Armor Plate Pipe Wrap, Diamond Wrap, Aquawrap, Pipe Wrap A+, Diamond Wrap HP, I-Wrap)
  - Monolithic
  - Can be applied to non-straight geometries
  - Versatility in range of epoxy products (e.g. underwater, high temperature, etc.)
- Layered systems (e.g. Clock Spring and PermaWrap)
  - First widely-used composite repair system
  - Layered repair system
  - Limited to repair of straight pipes



# General Composite Discussion

- Components in a composite material
  - Fiber
  - Matrix
- Types of fibers (common in pipe repair)
  - E-glass
  - Carbon
- Fiber orientations (common in pipe repair)
  - Uniaxial
  - Multi-axis (e.g. 0, 90, 45, etc.)
- Matrix types
  - Pre-cured
  - Pre-impregnated (e.g. water-activated urethane)
  - Wet applications using resins such as epoxy



Photos of carbon system



# Government Regulations (from the 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 and Other 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 16684; 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, 60105, 60108, 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 192.467(a) is revised to read as follows:

# Guidelines for Evaluation of Composite Repair Methods

The basic fundamental issues for evaluating composite repair methods are as follows:

- Strength of the composite material
- Environmental effects (e.g. cathodic disbondment, temperature, acids and alkalines)
- Effects of pressure (both static and cyclic)
- Mechanics of load transfer from pipe to wrap
- Long-term performance issues
- Consistency in application and quality control in manufacturing



# Elements of a Typical Testing & Analysis Program

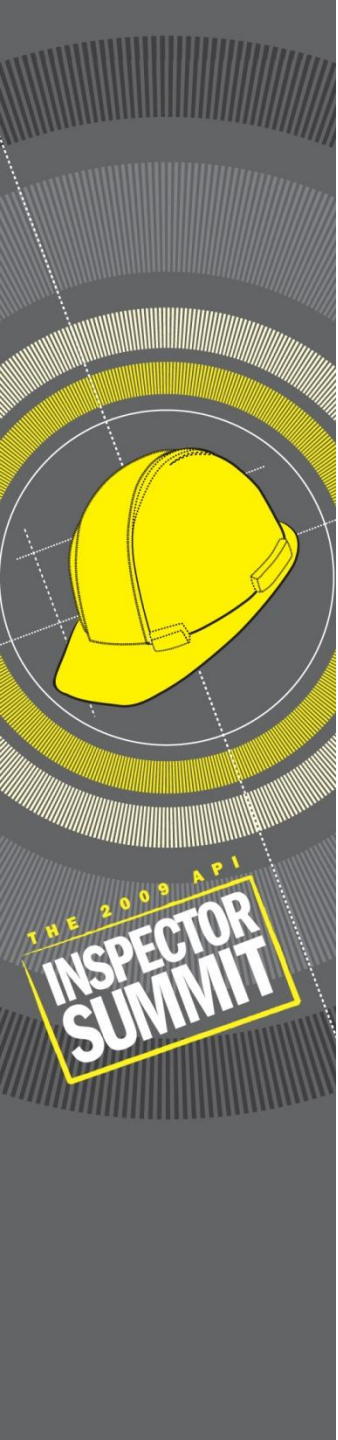
- Corrosion repair (burst testing)
- Cyclic pressure effects on burst strength
- Repair of mechanical damage (static and cyclic)
- Load transfer analysis using strain gages and Finite Element Analysis (FEA)
- Tensile testing of composite materials
- Adhesive lap shear testing
- Effects of pressure at time of installation
- Long-term testing



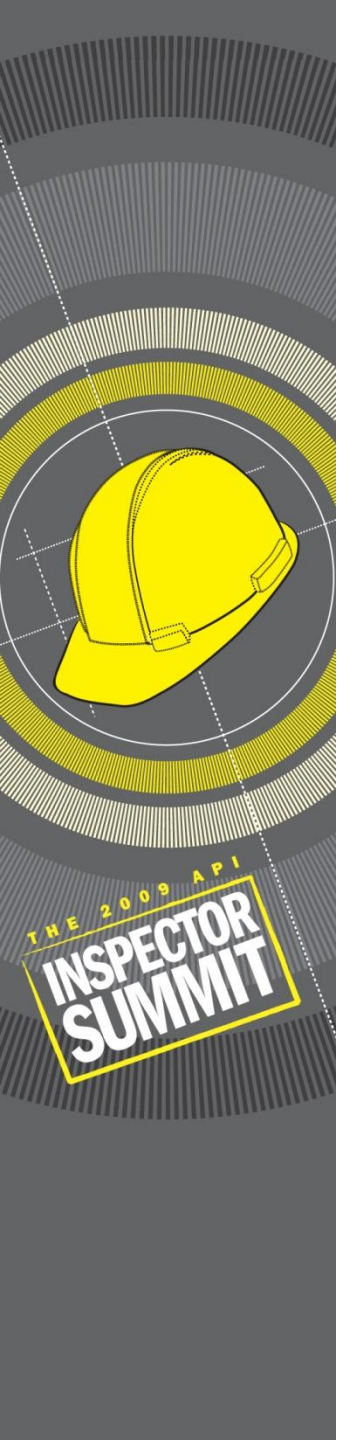
# Specific Technical Items

(discussed in today's presentation)

- Corrosion Repair and load transfer
- Repair of Mechanical Damage (dents with gouges)
- Repair of Pipe Fittings
- Installation Techniques using composites

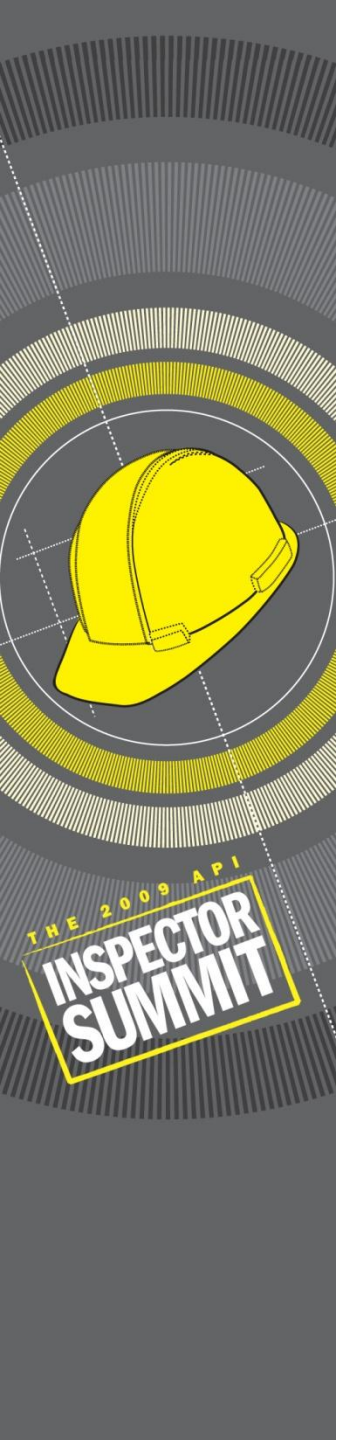


# CORROSION REPAIR

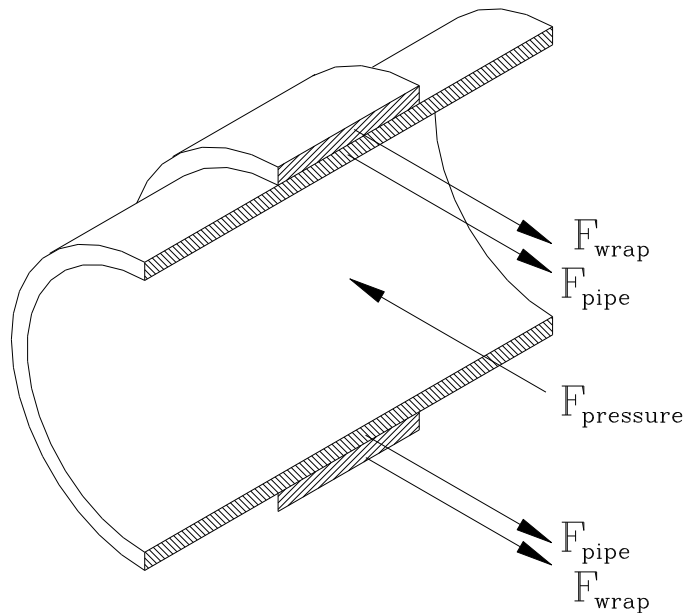


# Load Sequence of Composite Repairs during Pressurization

- Pipe and wrap stressed as internal pressure increased (load distribution dependant upon relative stiffness of two components)
- Once yielding in corroded region occurs, local stiffness of pipe reduced and load transferred to wrap
- Final burst pressure governed by ultimate strengths of pipe and composite materials



# Mechanics of Composite Repair Methods



Equation defining burst pressure

$$P_{burst} = \frac{\sigma_{ult_{pipe}} \cdot t_{pipe} + \sigma_{ult_{wrap}} \cdot t_{wrap}}{r_{inside}}$$

P = Internal pressure

$\sigma$  = Material failure stress

t = Thickness of material

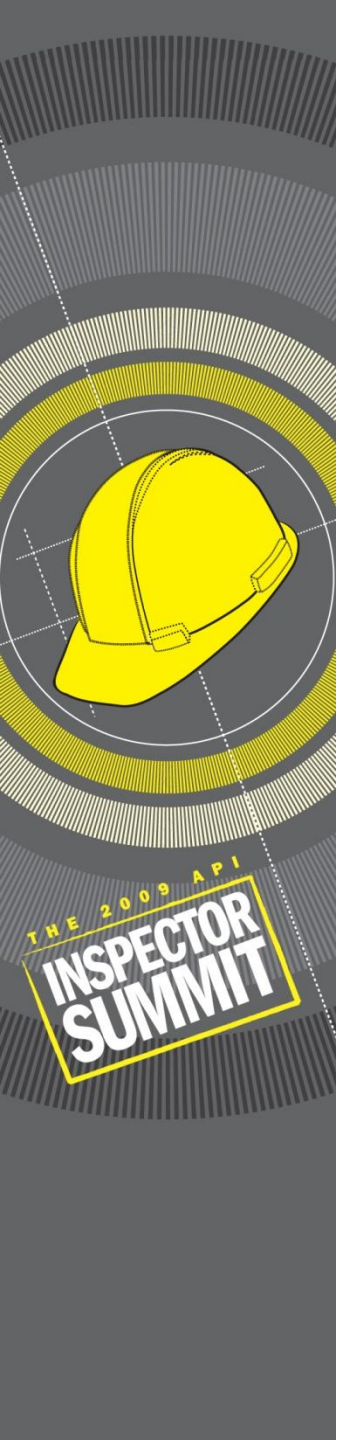
r = Radius of pipe

**Note:**

The above calculation is based on thin-wall shell theory and is not applicable for thick-walled pipes with diameter to wall thickness ratios less than 20.

# Experimental Efforts

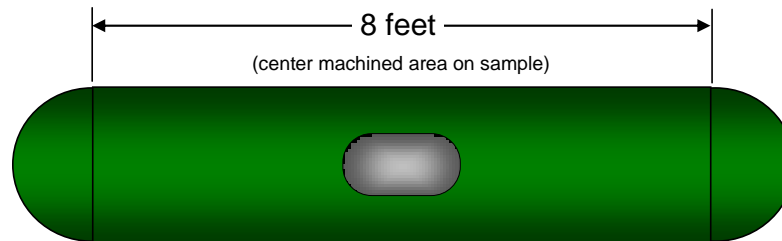
- SES fabricated two test samples with a machined corrosion region in each
  - 12.75-inch x 0.375-inch, Grade X42
  - 75% deep corrosion with 8-inch x 6-inch dimensions
  - Refer to figure on following page for details
- Strain gages installed on test samples and used to measure strains in the corroded section beneath the reinforced region during pressurization
- One sample pressurized to failure, while a second sample pressure cycled to failure ( $\Delta P=50\%$  MAOP)



# Geometry for Test Samples

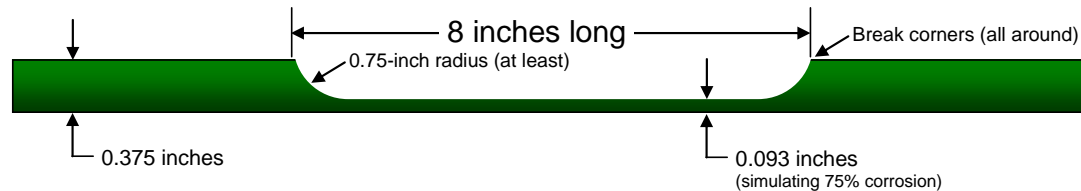
## 75% corrosion sample

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

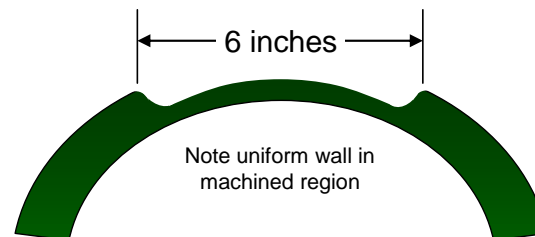


8 feet  
(center machined area on sample)

- Steps for machining**
1. Measure nominal wall and mark on pipe
  2. Machine material to reach target wall thickness
  3. Verify wall thickness using a UT meter (average 9 points) and mark on pipe



**NOTE:** Perform all machining 180 degrees from longitudinal ERW seam.

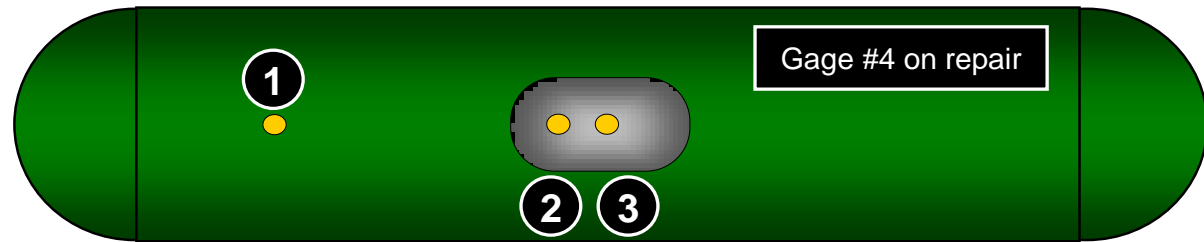


Note uniform wall in machined region

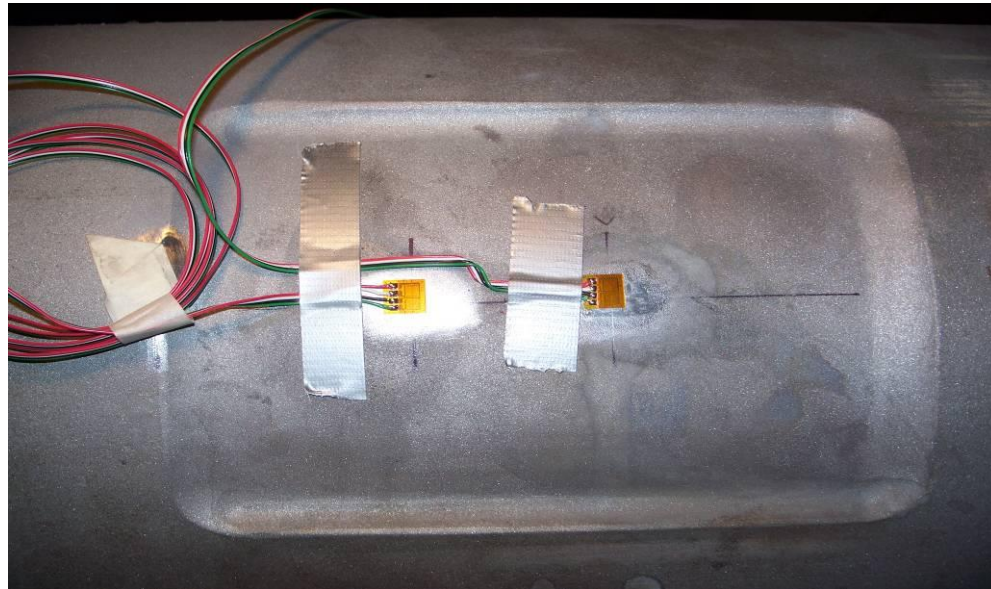
**Details on machining**  
(assume machined area is 8 inches long by 6 inches wide)



# Strain Gage Installation



Location of strain gages installed on the test sample



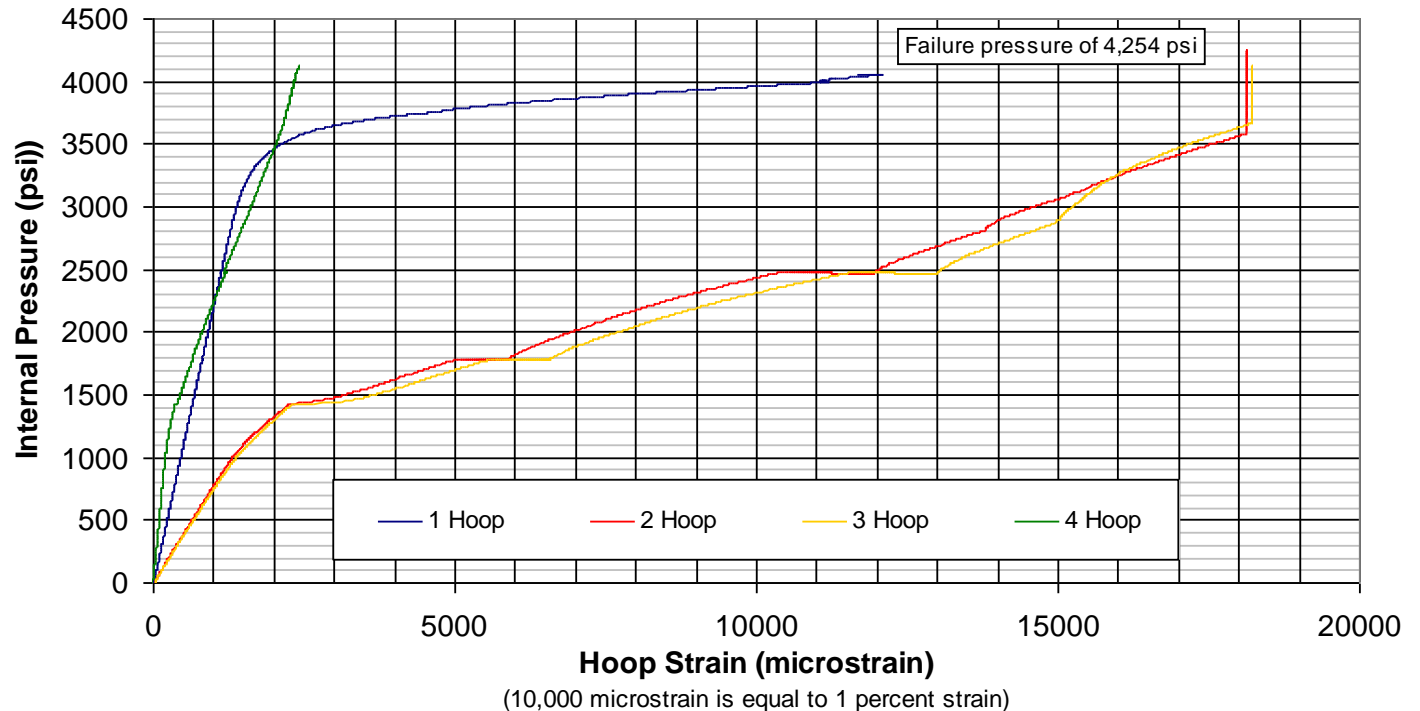
Photograph of strain gages installed in the machined corrosion region



# Burst Test Results (1/2)

## Hoop Strain Versus Pressure for Neptune Repair System

Burst test of 12.75-inch x 0.375-inch, Grade X42 pipe with with 75 % Corrosion with Gages #2 and #3 beneath repair on steel. Failure pressure at 4,254 psi (1.72 times SMYS pressure of 2,470 psi).

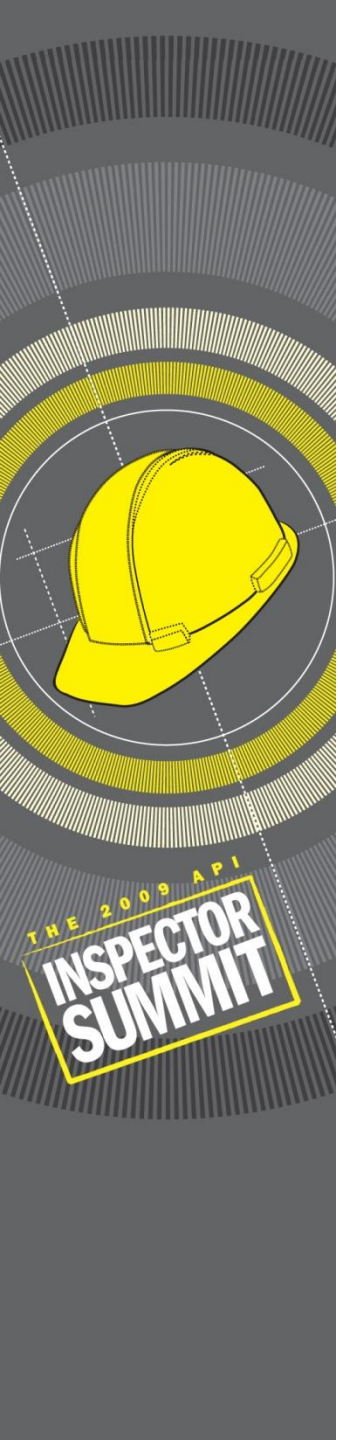


# Burst Test Results (2/2)



Cross-section of burst test sample ( $P_{burst} = 4,254$  psi)

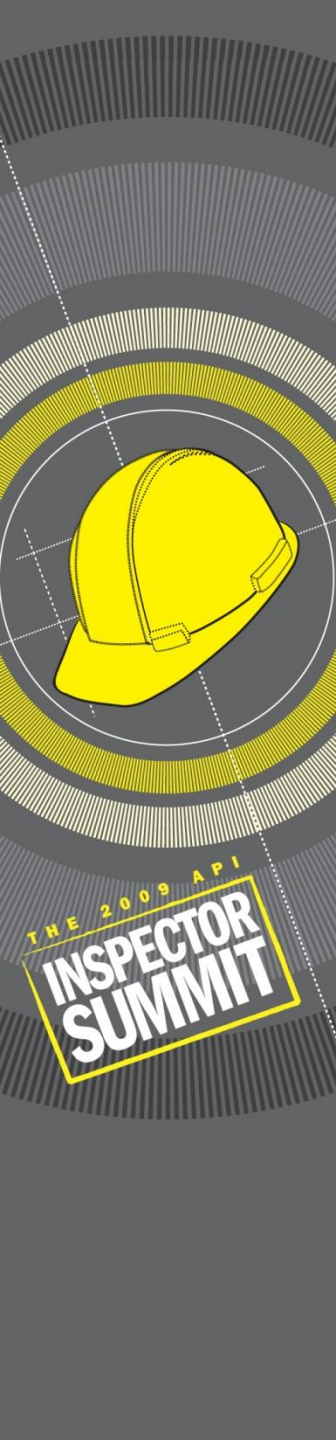




# **MECHANICAL DAMAGE (Dents with gouges)**

# Defect Classification (and associated failure modes)

- Plain dents
- Gouges (no denting present)
- Mechanical damage (dents with gouges)
- Rock dents (constrained)
- Failure modes/methods
  - Static overload or leak before break condition ( $K_{IC}$ ,  $\sigma$ ,  $a$ )
  - Fatigue failure (S-N relation)

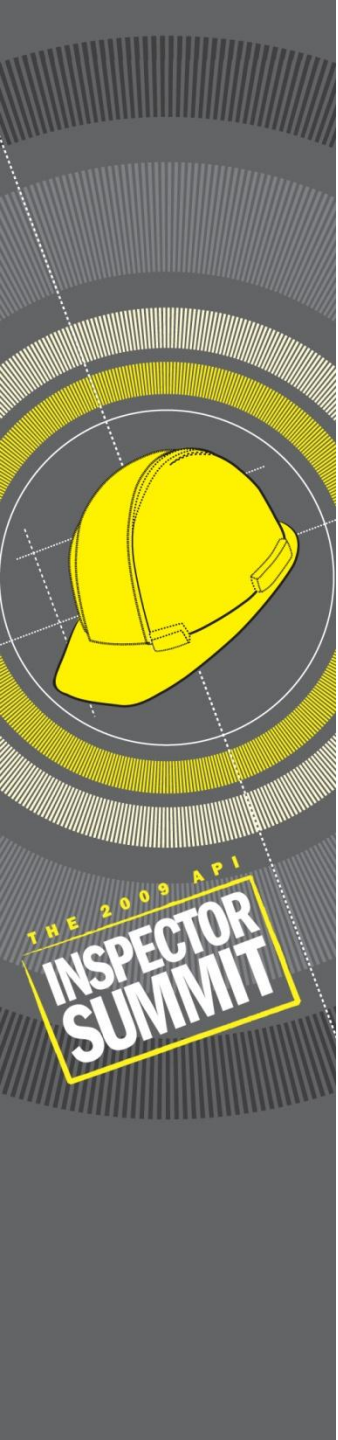


# Zone of Initiation/Propagation



# Verification of Crack Propagation

An initial gouge depth of 20% (a/t) propagated to a final crack depth that was 50% of the wall thickness when pressurized a single cycle to MAOP.



# Repair by Grinding Limitations

- Gouge depth limitations
  - Up to 40% of the wall thickness (use equation below that is from CSA Z662 for length limitation) – also in current edition of ASME B31.8 in ¶ 851.42(c)(3)

$$L \leq 1.12 \sqrt{Dt} \sqrt{\left( \frac{a/t}{1.1 a/t - 0.11} \right)^2 - 1}$$

**L** – Gouge length (limitation) | **D** – Pipe diameter | **t** – pipe thickness | **a** – crack depth

- Ductile material



# Repair of Mechanical Damage

Based upon reportable incident data, third-party mechanical damage is a leading cause of pipeline failures in the United States. Mechanical damage normally involves a dent with some type of gouge with cracks.

## Process for repairing mechanical damage with composites

- Inspect dent for presence of gouges and cracking
- Remove metal in cracked area by grinding
- Insure removal of cracks by Magnetic Particle or Dye Penetrant
- Fill in dented region with epoxy putty
- Repair damaged region using the appropriate number of wraps



# Applicable Codes and Standards

- CFR 48 Parts 186 to 199 (October 1, 2004)  
192.309 (b)(3)(ii)
  - In pipes with 12-inch NPS and above operating at a hoop stress more than 20% SMYS, dents greater than 2 percent of the nominal pipe diameter must be repaired using a method that permanently restores the serviceability of the pipe OR
  - the dent must be removed from the steel pipe
- Reference to ASME B31.8 (2007 edition)
  - 851.41(d) - Plain dents are considered injurious if they exceed a depth of 6% of the nominal pipe diameter
  - Plain dents of any depth are acceptable provided strain levels associated with deformation do not exceed 6 percent
  - 851.42(e) – Nonmetallic composite wrap repairs are not acceptable for repair of injurious dents or mechanical damage, unless proven through reliable engineering tests and analysis



# Photos from Test Program (1)

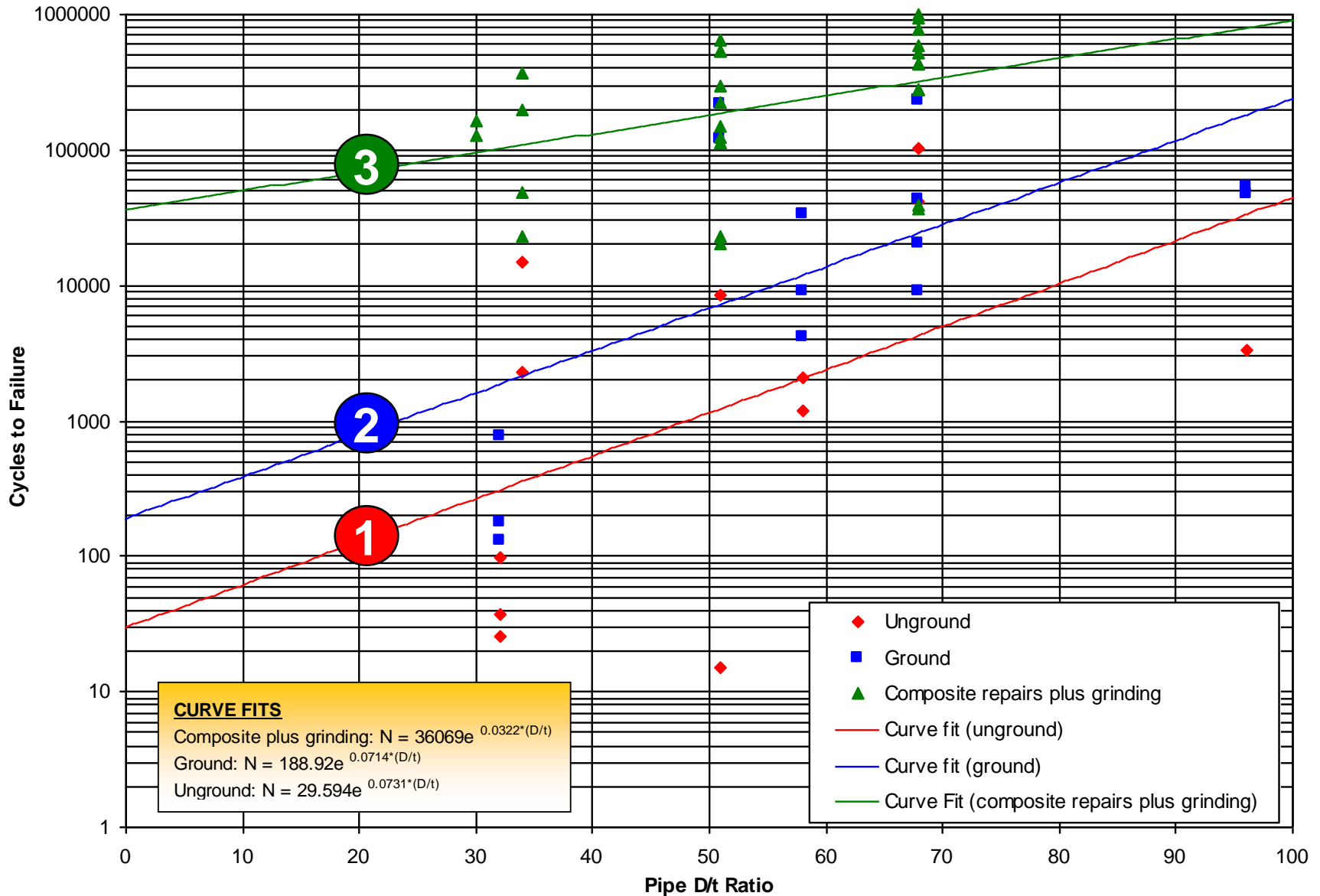


# Photos from Test Program (2)



# Cycles to Failure as a Function of D/t Ratio

Test results from pressure cycle fatigue tests performed on a range of pipe D/t ratios with a pressure range of 50% MAOP and initial dent depths of 15% and initial gouge depths of 15%.



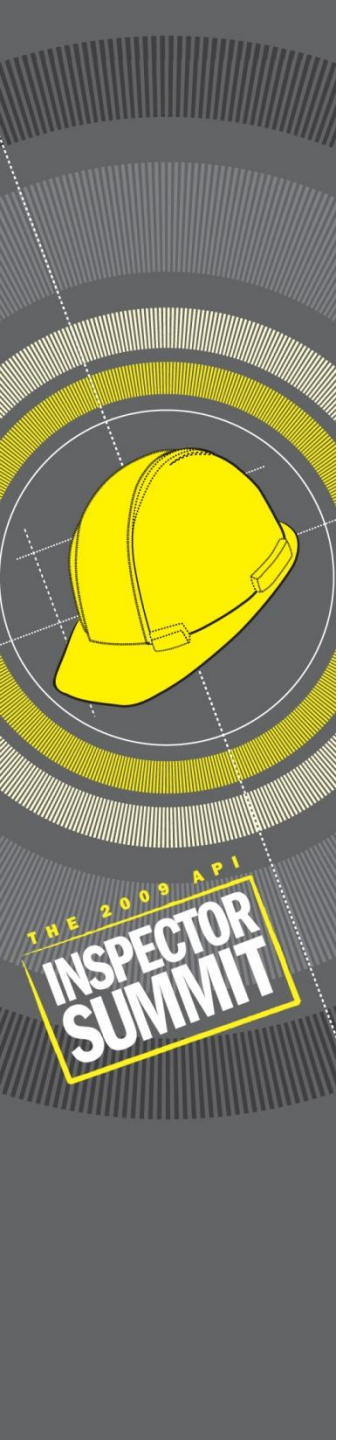
# MECHANICAL DAMAGE (Conclusions)

- Samples repaired by grinding had fatigue lives that were approximately 10 times those of *unrepaired dents and gouges*.
- Those defects that were repaired by grinding and composite\* had fatigue lives that were approximately 1,000 times those of *unrepaired dents and gouges*.

\* - composite testing based on Armor Plate Pipe Wrap, Pipe Wrap A+, Aquawrap, Citadel Diamond Wrap HP, and Clock Spring



# REPAIR OF PIPE FITTINGS



# Repair of Pipe Fittings (1/2)

(Test results from Armor Plate Pipe Wrap test program involving 12.75-inch x 0.375-inch, Y52 elbow and tee pipe fittings having machined 50% corrosion) – typical operating pressure is 1,778 psi

## 12-in STD Tee (50% corrosion)

Unrepaired: 3,059 psi

Repaired: 4,617 psi



Failures in repaired fittings occurred outside repairs in base pipe.



# Repair of Pipe Fittings (2/2)

(Test results from Armor Plate Pipe Wrap test program involving 12.75-inch x 0.375-inch, Y52 elbow and tee pipe fittings with machined 50% corrosion) – typical operating pressure is 1,778 psi

## 12-in STD Elbow (50% corrosion)

Unrepaired: 2,610 psi

Repaired: 4,625 psi



Failures in repaired fittings occurred outside repairs in base pipe.

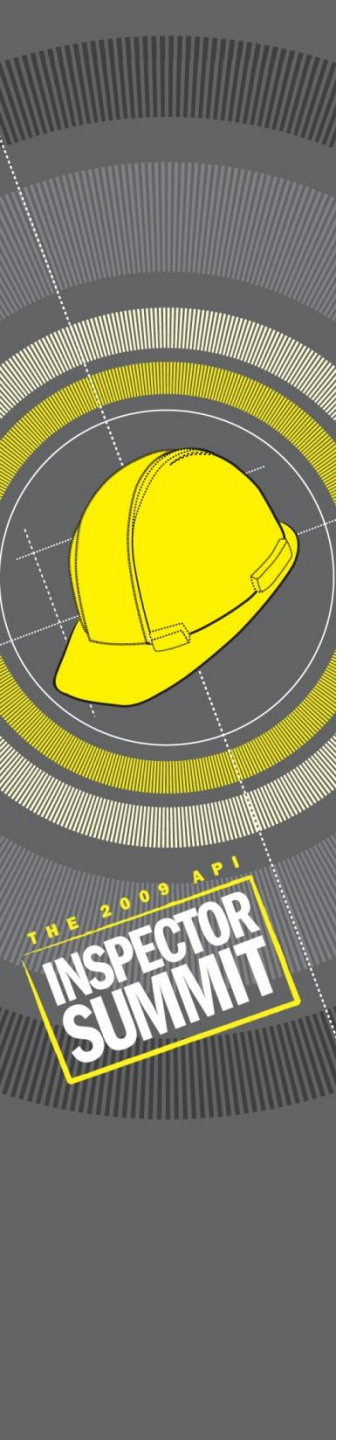


# INSTALLATION AND APPLICATION TECHNIQUES



# Steps in Pipeline Repair

- Locate damaged section(s)
- Assess severity of damage (e.g. corrosion, mechanical damage, etc.) and determine if repair is possible
- Calculate required number of wraps (if appropriate for respective repair type)
- Clean and prepare pipe (surface preparation critical)
- Install composite repair
- Allow repair to cure per manufacturer's recommendations
- Restore pipeline environment (e.g. backfill and re-pressurize)



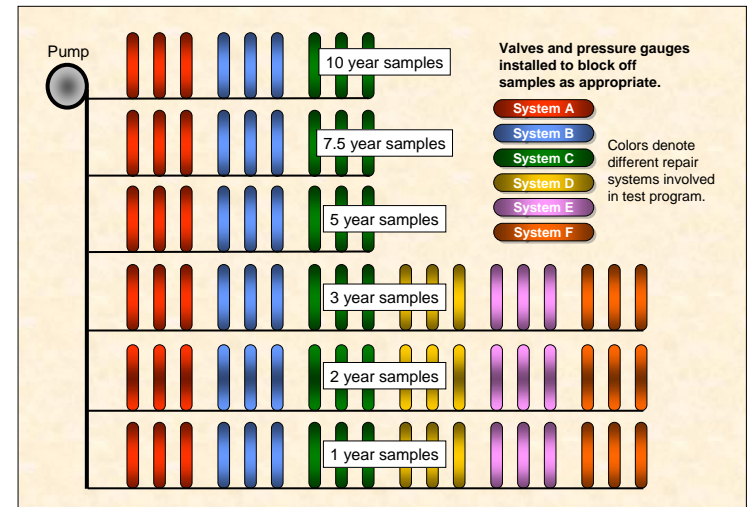
# Observations on Composite Repair Methods

- For more than 10 years, the pipeline industry has been making repairs using composite materials
- A significant body of research exists addressing a variety of repair types
- It is the presenter's observation that the missing link in most of the composite repair systems is long-term test data (especially in terms of the adhesive systems)
- For the above reason, pipeline companies should be hesitant to define composite repairs as permanent repairs



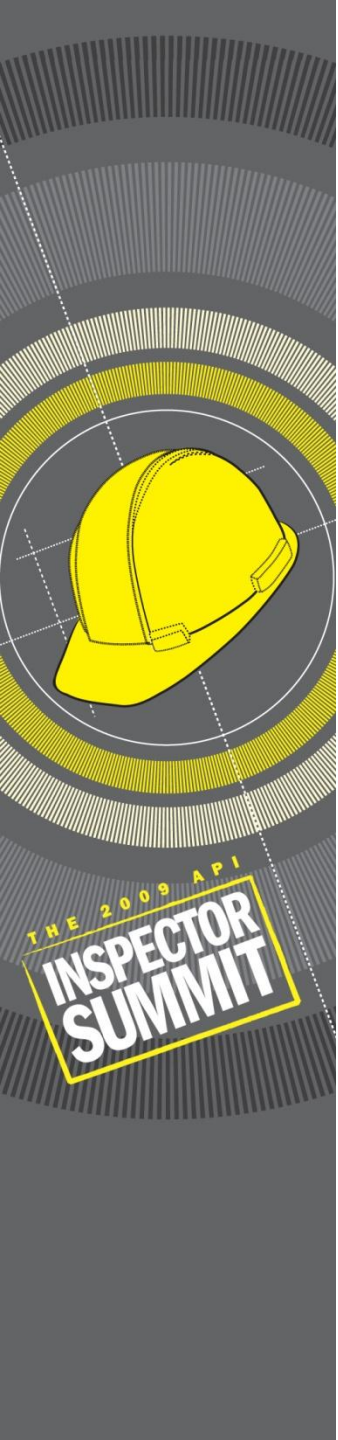
# Long-term Composite Program

- Study to evaluate long-term performance of composite materials
- Sample details
  - 12.75-inch x 0.375-inch, Grade X42 pipe
  - Corrosion depths of 40, 60, and 75%
- Participation in 10-year study involves pipes to be removed and burst at 1, 2, 3, 5, 7.5, and 10 years
- 12 companies currently participating



# Inspectors – What to look for

- Surface preparation critical to prevent future corrosion development
- Thickness of composite material should be sufficient for required reinforcement
- The resin system must be able to withstand all chemicals to which it will be exposed
- The repair must have been tested previously at the required operating conditions (i.e. pressure and temperature)
- Documentation is important to ensure that no mistakes have been made during the installation process



# QUESTION & ANSWER SESSION

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