REX2024
PRCI Research Exchange

Design and Practice of Gas Pipeline Composite Repair with reduced conservatism

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Outline

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  - Problem Statement
- **Historical TC Energy's Pioneering Research Initiatives**
  - Earlier Practices in TC Energy
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- **Enhancing Practices for Composite Repair Optimization**
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- **Conclusions & Overall Recommendations**
- **Q&A**

Introduction to Gas Pipeline Composite Repair Design

- **What it is:**
  - It is a method of reinforcing damaged pipelines by applying layers of composite materials.
  - Two types of repair systems:
    - Carbon fiber
    - Glass fiber
- **Intended Applications:**
  - Metal loss, deformations & structure reinforcement…

- **Advantages:**
  - More versatile for pipe shape/size
  - Can be used on bends
  - Simple, quick installation
  - Can be used when OD changes
- **Disadvantages:**
  - Limited shelf-life (usually 2 years)
  - Can degrade due to temperature changes
  - Due to the temperature constraints during storage, surplus composite materials cannot be returned to the warehouse
  - Limited research on long-term performance
  - Gap in current QA/QC process for the long term

Introduction to Gas Pipeline Composite Repair Design

- **Risk mitigation vs the financial burden**
  - TC Energy extensively utilizes composite repair or reinforcing of pipelines
  - Considerations on Cost and timeline Planning
- **Composite design vs material consumption**
  - ASME PCC-2-2022 on repair wrap layers and length
  - Conservatism vs the long-term performance
- **ASME PCC-2-2022 Design Calculations for Metal Loss**

NPS 42:

- 13 layers, 16kits/m
- 11 layers, 12kits/m

NPS 30:

- 13 layers, 12kits/m
- 11 layers, 8kits/m

Repair of 12.75-inch x 0.375-inch, Grade X42 pipe with 50% corrosion

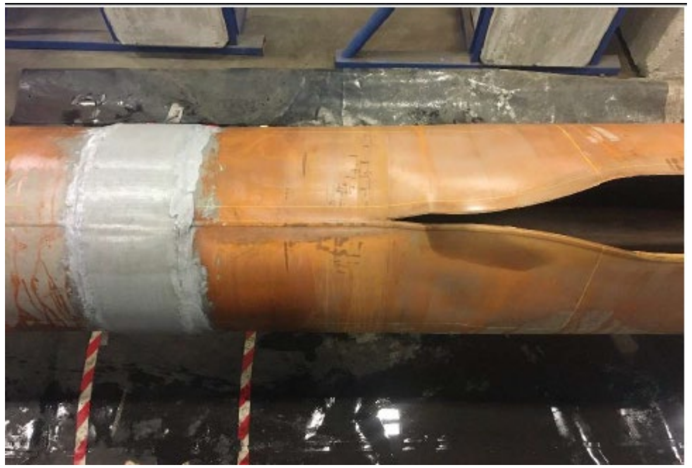
ASME PCC-2 Design Equation	Design Basis	Design Equation	Minimum Calculated Composite Thickness
(3)	Stress-based	$t_{min} = \frac{D}{2s} \cdot \left(\frac{E_s}{E_c}\right) \cdot (P - P_s)$	0.810 inches
(6)	Strain-based	$t_{min} = \frac{1}{\varepsilon_c E_c} \cdot \left(\frac{PD}{2} - st_s\right)$	0.307 inches
(12)	Performance-based	$t_{min} = \left(\frac{PD}{2} - t_s s\right)\left(\frac{1}{f s_{lt}}\right)$	0.138 inches

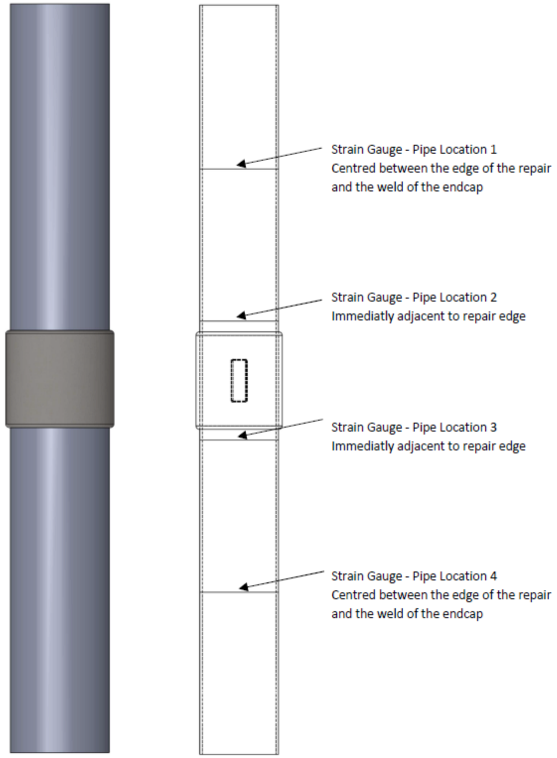
E_s	30 x 10^6 psi (steel pipe elastic modulus)
E_c	4.5 x 10^6 psi (composite laminate elastic modulus)
s	42,000 psi (pipe SMYS, or Specified Minimum Yield Strength)
P	1,778 psi (MAOP, design pressure of 72% SMYS)
P_s	980 psig (50% of failure pressure based on Modified B31G criteria)
t	0.375 inches (pipeline nominal wall thickness)
t_s	0.188 inches (50% corroded wall thickness)
ε_c	0.25% (allowable long-term composite strain from ASME PCC-2, Table 4)
f	0.5 (Service "design" factor from ASME PCC-2, Table 5)
s_{lt}	50,000 psi (long-term composite strength based on 1,000-hour testing, ASME PCC-2, Appendix V)

Historical TC Energy's Pioneering Research Initiatives

- **Earlier Practices in TC Energy**
  - Clock spring repair -1990's
  - Composite Reinforced Line Pipe (CRLP) – 2000's
- **Exploring New Horizons since 2018**
  - ASME B31G effective area Method for metal loss re-enforcement
    - Rather than using the conservative peak metal loss depth (Barlow's formula) design
    - The concept of using the effective area burst pressure with fewer layers
    - The composite repairs were installed at

Pipe	Pipe Diameter (NPS)	WT (mm)	Maximum Pressure (kPa)	Relative Failure Location	Comments
1	10	9.27	36,833	Pipe Body – End A	Repair Experienced Some Cracking and Tearing
2	20	6.35	12,957	Pipe Body – End B	Burst Along Seam Weld
3	20	9.53	22,421	Pipe Body – End A	Burst Along Seam Weld
4	36	9.53	14,182	Pipe Body – End A	Burst Along Seam Weld
5	36	12.70	19,142	Pipe Body – End B	Burst Along Seam Weld





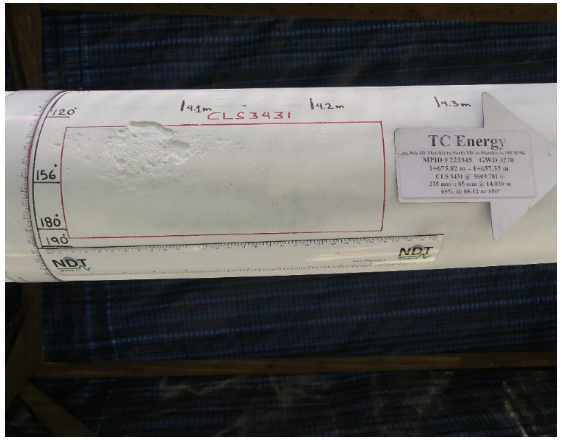
Historical TC Energy's Pioneering Research Initiatives

- **Exploring New Horizons since 2018**

• Composite Reinforcement of Severe Corrosion and Leaking Defects

- Improved design method for a full-scale test program on 85% deep corrosion leaking features
- The study showed that CSNRI Atlas could reinforce severe and through-wall corrosion metal loss features on small-sized (<NPS12) gas pipelines
- The field trial to repair significant corrosion features (>80%NWT) on an NPS6, NWT =3.18mm pipe
  - ✓ B sleeve or Cut out limitation
  - ✓As a four-year temporary repair while implementing a robust four-year monitoring program to confirm the suitability of the CSNRI Atlas repair system to be considered a permanent repair for severe metal loss defects in gas pipelines

GWD	ILI Feature ID	NDE Feature Details								
		AWT (mm)	As-Found ID	Axial Distance from GWD (m)	Orientation Start (°)	Axial Length (mm)	Field-Measured Depth (%)	Failure Pressure (Effective Area) (kPa)	SF at MOP	Remaining Wall Thickness Using Laser Scan and pit gauge (mm)
3270	CLS 3431	3.2	CLS-015	14.02	116.1	282.76	80.94	8154.4	0.97	0.61
3480	CLS 4500	3.1	CLS-005	4.2	146.35	44.24	85.16	10,610.8	1.27	0.46

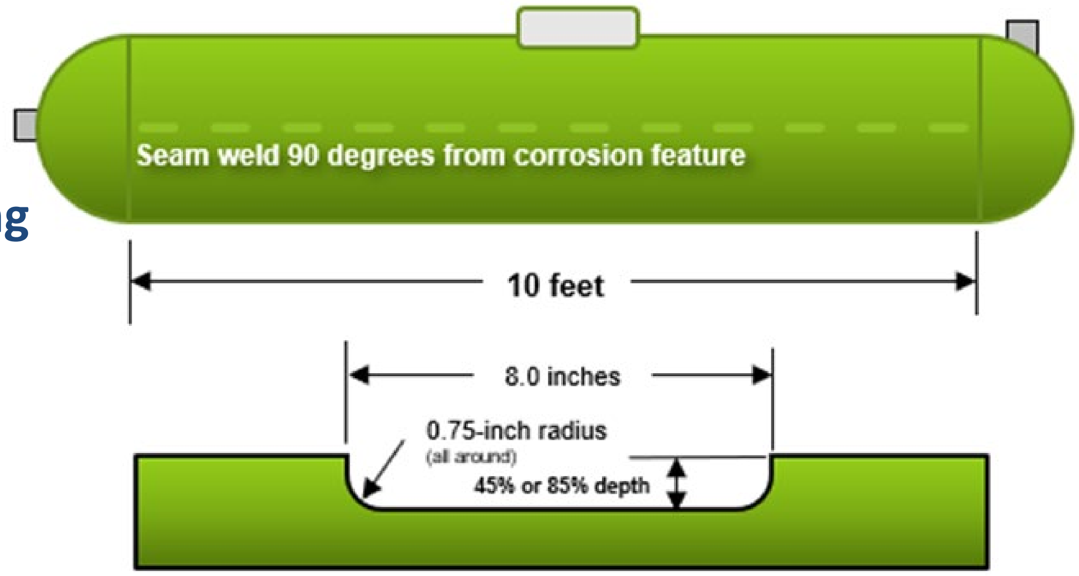


Enhancing Practices for Composite Repair Optimization

• Elevated Temperature Composite Repair Design & Testing

Key concepts

- **24-inch x 0.250-inch (6.4 mm), Grade X52 pipe.**
- **Testing CSNRI's Atlas™.**
- **Metal loss depths range from 45% to 85 %nwt, including**
  - a larger general corrosion feature
  - a narrow longitudinal groove corrosion feature.
- **Cyclic pressure testing**
  - with a maximum pressure of 80% SMYS at 60°C (140°F),
  - with a pressure range of 40% SMYS (ΔP = 40% to 80% SMYS).
  - One test will be conducted at room temperature.



Machined Feature Details

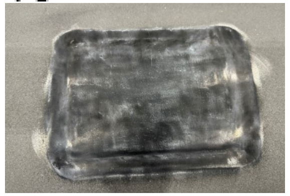
Enhancing Practices for Composite Repair Optimization

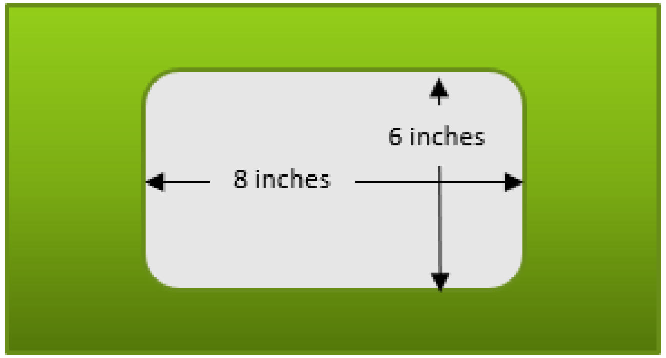
- **Elevated Temperature Composite Repair Design & Testing**

Sample Matrix and Associated Details

Sample No.	Design Equation and Resulting Layer Count	Test Temp.	Defect Geometry	Corrosion Depth	Est. Minutes Cycles to Failure
CS-GRV-45HT-1	ASME PCC-2 Eq. 12 | 12 layers	60°C (140°F)	8-inch x 1-inch	45%	348,347
CS-GRV-45RT-2	ASME PCC-2 Eq. 12 | 12 layers	25°C (77°F)	8-inch x 1-inch	45%	348,347
CS-GRV-85HT-3	ASME PCC-2 Eq. 12 | 20 layers	60°C (140°F)	8-inch x 1-inch	85%	76,638
CS-GRV-85HT-4	ASME PCC-2 Eq. 16 | 42 layers	60°C (140°F)	8-inch x 1-inch	85%	1,568,811
CS-GEN-45HT-5	Custom Modified B31G | 4 layers	60°C (140°F)	8-inch x 6-inch	45%	98,795
CS-GEN-45HT-6	ASME PCC-2 Eq. 12 | 12 layers	60°C (140°F)	8-inch x 6-inch	45%	348,347
CS-GEN-85HT-7	Custom Modified B31G | 12 layers	60°C (140°F)	8-inch x 6-inch	85%	12,713
CS-GEN-85HT-8	ASME PCC-2 Eq. 12 | 20 layers	60°C (140°F)	8-inch x 6-inch	85%	76,638

8-inch (l) x 1-inch (w), 45% or 85% deep groove corrosion feature



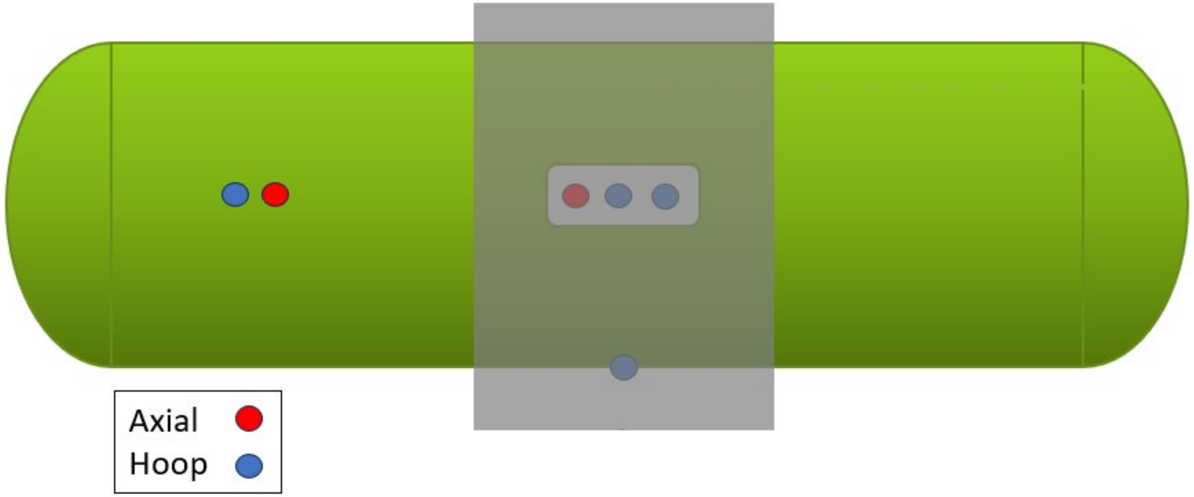


8-inch (l) x 6-inch (w), 45% or 85% deep corrosion feature

Enhancing Practices for Composite Repair Optimization

- **Elevated Temperature Composite Repair Design & Testing**

Sample Strain Gauge



Sample in Cycle Test Setup Before Testing

Enhancing Practices for Composite Repair Optimization

- **Elevated Temperature Composite Repair Design & Testing**

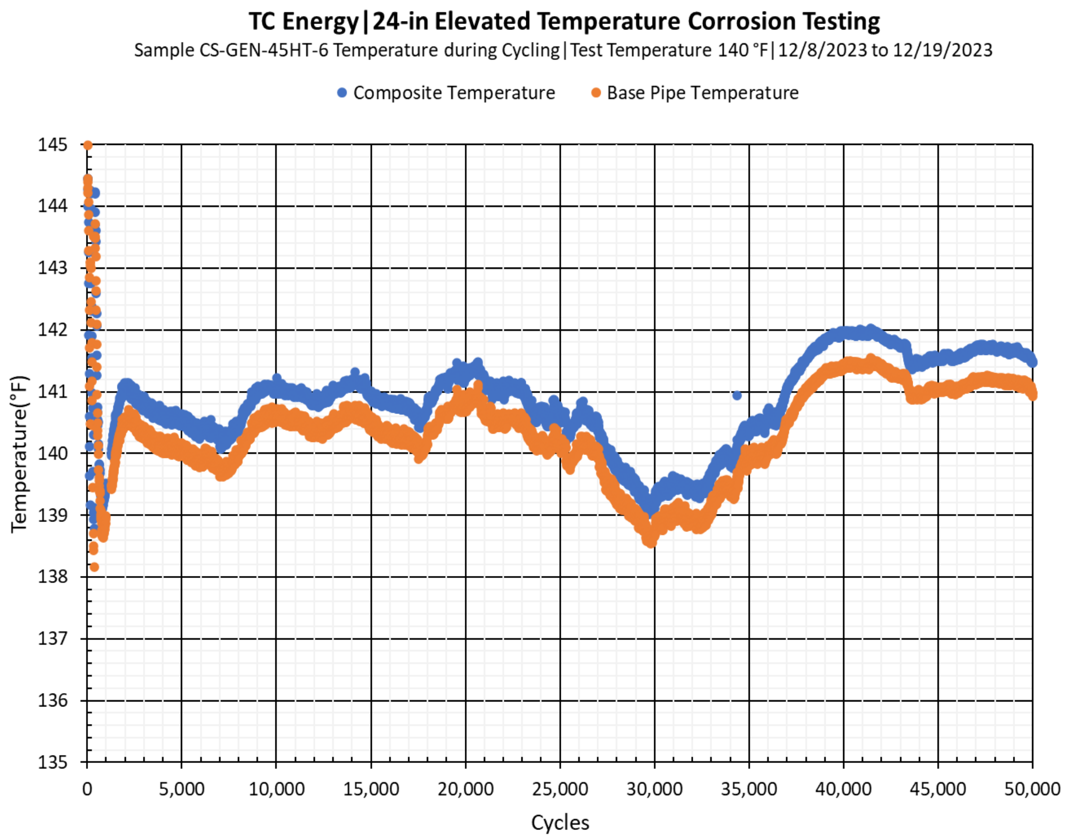
Summary of Results

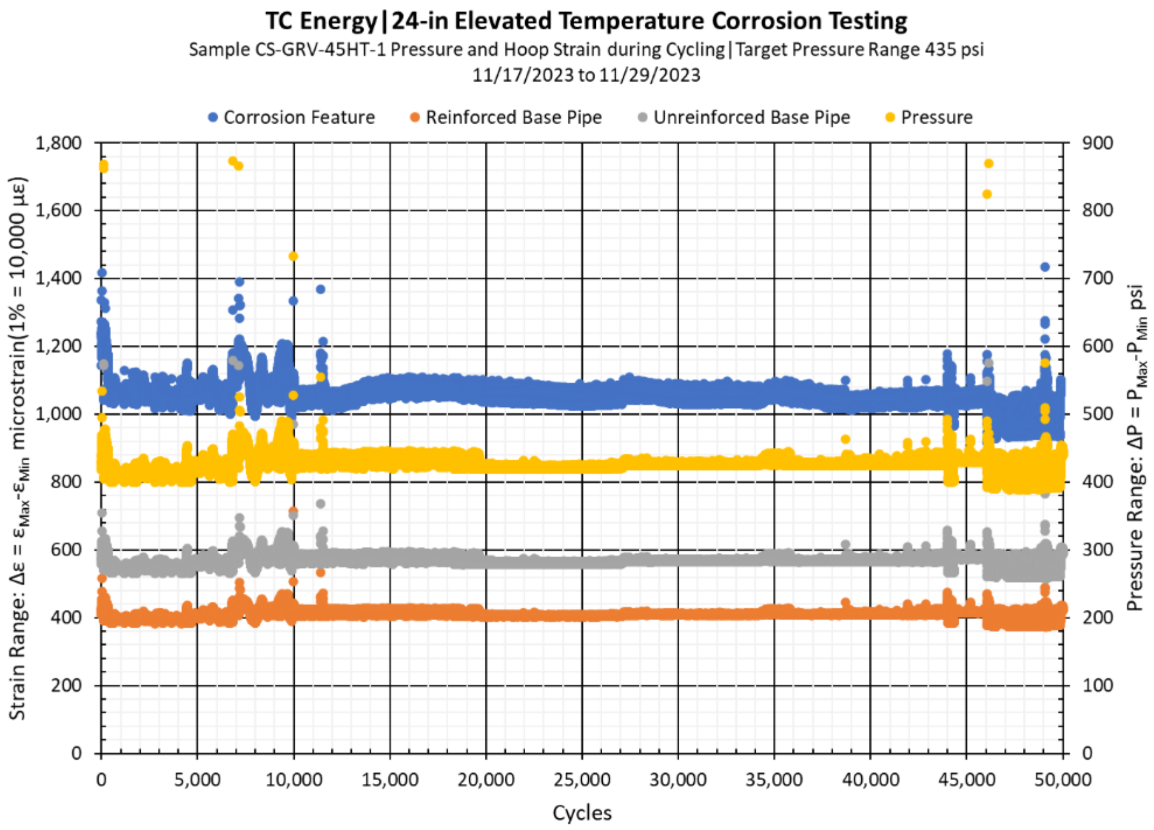
Sample No.	Design Equation and Resulting Layer Count	Estimated Cycles to Failure	Actual Cycles to Failure	Burst Pressure (Psi)	Failure
CS-GRV-45HT-1	ASME PCC-2 Eq. 12 | 12 layers	348,347	50,000*	1,490	Outside wrap
CS-GRV-45RT-2	ASME PCC-2 Eq. 12 | 12 layers	348,347	50,000*	1,609	Outside wrap
CS-GRV-85HT-3	ASME PCC-2 Eq. 12 | 20 layers	76,638	176**	N/A	Inside wrap
CS-GRV-85HT-4	ASME PCC-2 Eq. 16 | 42 layers	1,568,811	1,250	N/A	Inside wrap
CS-GEN-45HT-5	Custom Modified B31G | 4 layers	98,795	38,431*	1,497	Outside wrap
CS-GEN-45HT-6	ASME PCC-2 Eq. 12 | 12 layers	348,347	50,000*	1,499	Outside wrap
CS-GEN-85HT-7	Custom Modified B31G | 12 layers	12,713	106	N/A	Inside wrap
CS-GEN-85HT-8	ASME PCC-2 Eq. 12 | 20 layers	76,638	50,000*	1,499	Outside wrap

Notes:
*Sample completed runout condition without failure in repair or pipe.
**Failed at 25 cycles.

Enhancing Practices for Composite Repair Optimization

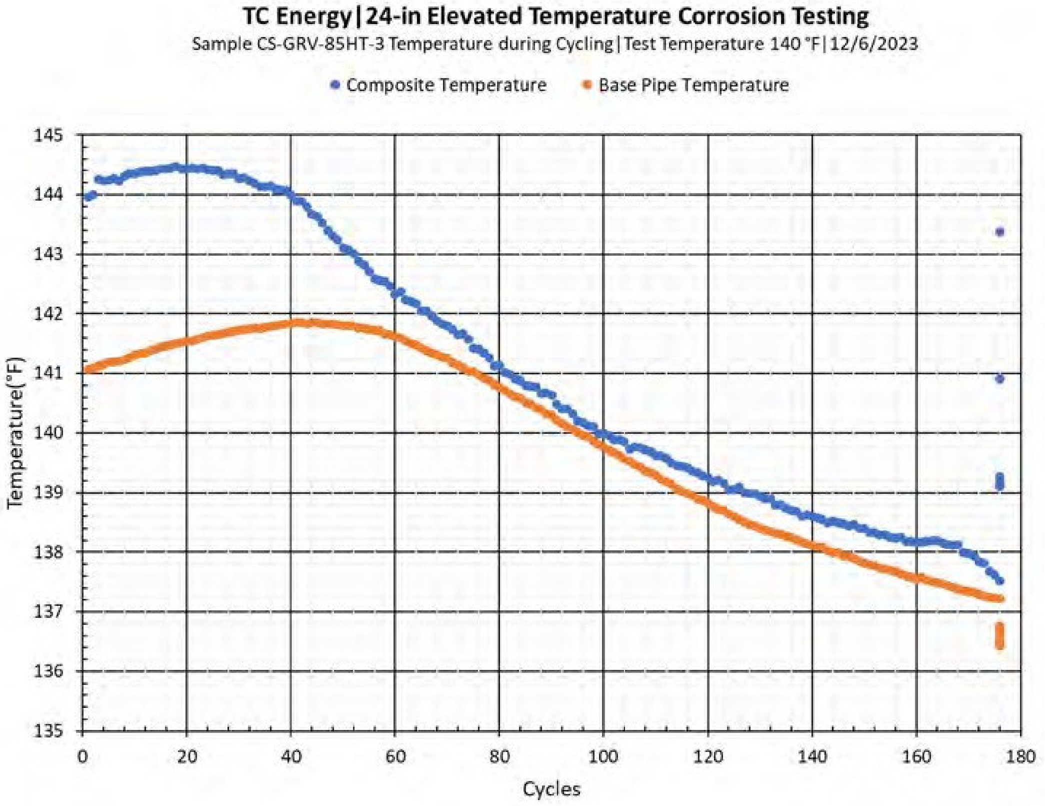
- **Elevated Temperature Composite Repair Design & Testing**

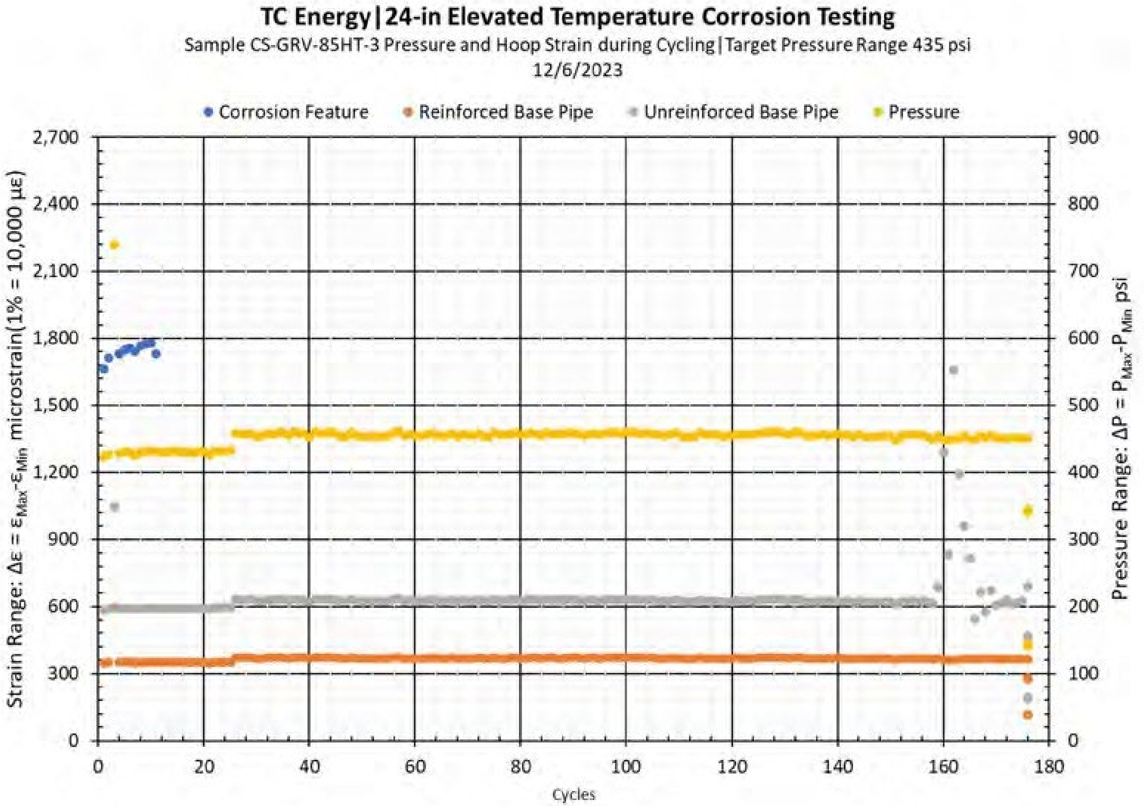




Enhancing Practices for Composite Repair Optimization

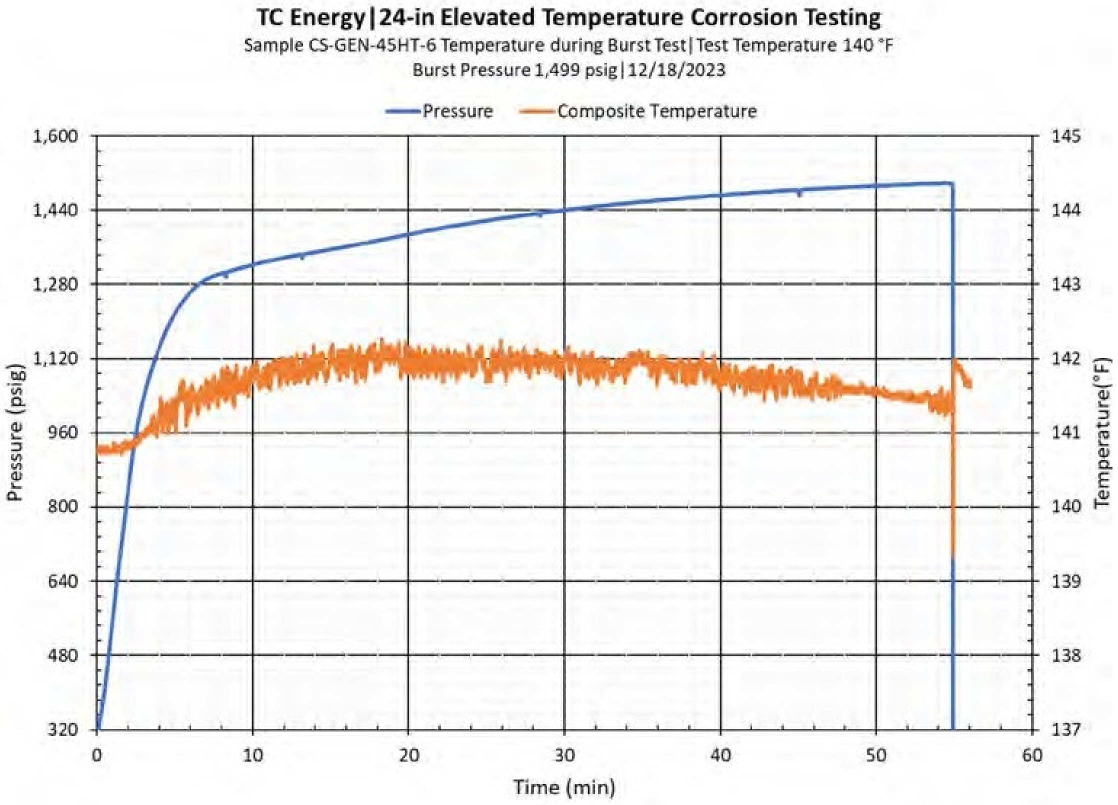
- **Elevated Temperature Composite Repair Design & Testing**

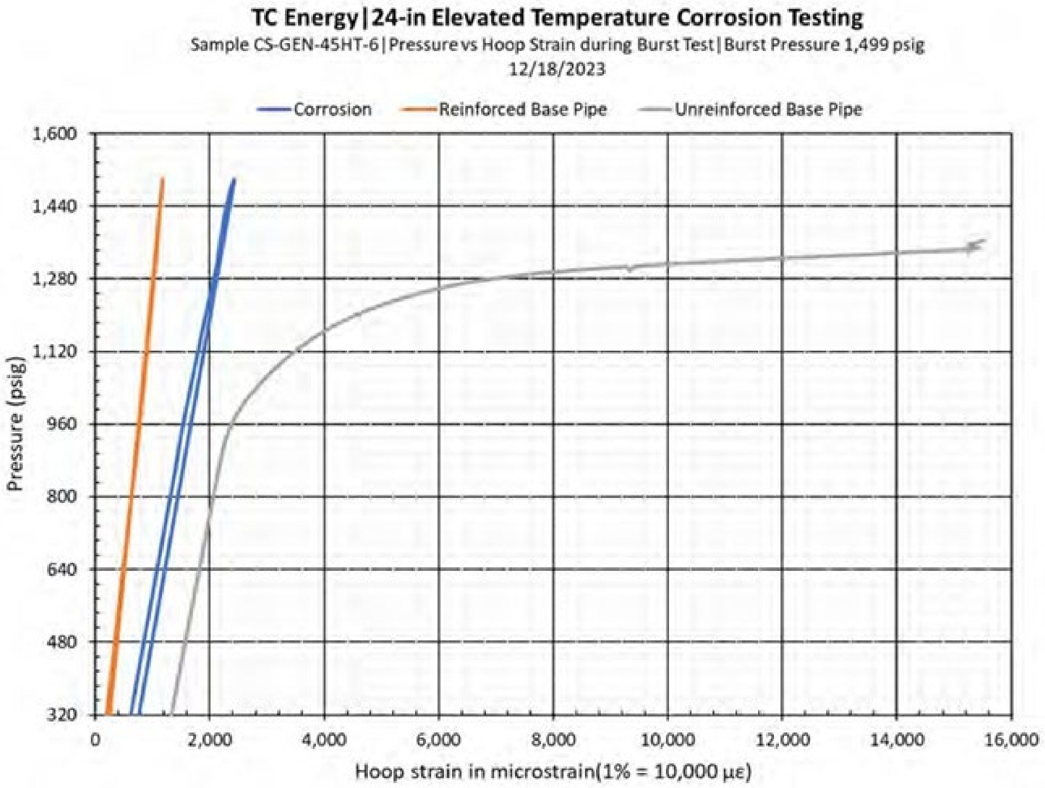




Enhancing Practices for Composite Repair Optimization

- **Elevated Temperature Composite Repair Design & Testing**





Conclusions & Overall Recommendations

- Neither ASME B31G nor ASME PCC-2 consider the effects of corrosion width, and certainly neither considers the effects of cyclic pressure loading.
- Failure mechanism for the severe groove corrosion features (i.e., depth of 85%) is predominantly high strain
- Geometric limitation needs to be established for accepting when composite materials can be used to reinforce groove corrosion features, likely based on a combination of corrosion depth and width.
- Effects of temperature cannot be discounted when considering composite repairs.

thank you

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