



# ***Composite Repairs for Damaged Pipework***



# AGENDA

1. Introduction to composite repairs
2. Composite Repair Standards – Brief Overview
3. Industry Codes & Requirements
  - Defect Overview – Basic & Complex
  - Permanent V Temporary
4. Long-Term Performance





***INTRODUCTION  
TO COMPOSITE  
REPAIRS***



# WHERE DO WE USE THEM AS REPAIRS?

## Primarily Oil & Gas:

1. **Process Piping (upstream and downstream)**
2. **Transmission Pipeline (midstream)**
3. Risers / Caissons
4. Subsea pipelines
5. Storage tanks
6. Vessels
7. Structures



## Other Notable Industries:

1. Civil Infrastructure
2. Water plants



# WHAT IS A COMPOSITE REPAIR?

Specific focus on Oil & Gas variation....

A composite system consists of:

## 1. Thermoset Polymer Matrix (Resin)

- Protects the fibers
- Holds repair together

- Environmental resistance
- Chemical resistance
- Temperature limit
- Impact resistance
- Abrasion resistance

## 2. Fiber Reinforcement

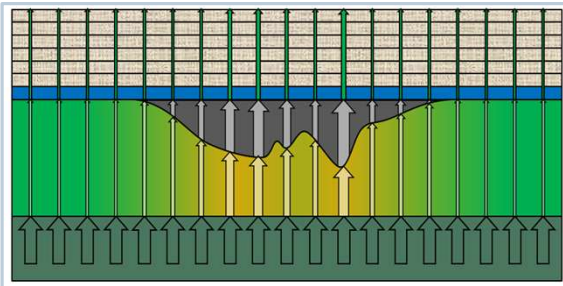
- Primary load carrying member
- Directionally dependent

- Directional strength
- Binding for resin
- Increased stiffness



# COMPONENTS IN A COMPOSITE REPAIR - PURPOSE

- **Filler:**
  - Fill defects/gaps/transitions
  - Transfers the "load" from the pipe
  - Removes voids in defect
- **Primer**
  - Bonds the composite wrap to the pipe
  - Acts as a moisture ingress prevention layer
  - Prevents corrosion from occurring under repair
- **Composite Wrap**
  - Restores strength / serviceability
  - Defect dependent
  - Minimizes further damage



# INSTALLATION STEPS

**Surface Preparation**



**Fill Defect**



**Apply Primer**



**Apply Composite Wrap**



**Constrict & Perforate**



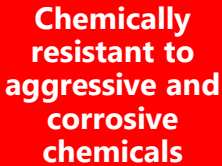
**Apply Top Coat**



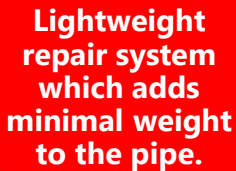
# BENEFITS OF A COMPOSITE REPAIR



Minimal disruption to operations as it can be applied during live operations



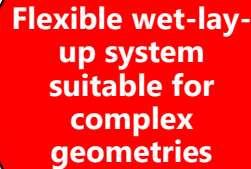
Chemically resistant to aggressive and corrosive chemicals



Lightweight repair system which adds minimal weight to the pipe.



Ease of transportation and installation



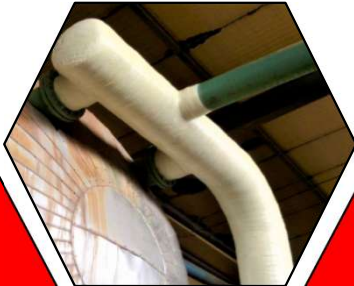
Flexible wet-lay-up system suitable for complex geometries



Can be utilised as a permanent repair option



Can be applied in wet conditions such as sweating and submerged pipe





***COMPOSITE  
REPAIR  
STANDARDS -  
OVERVIEW***



# STANDARDIZED GUIDANCE

- In 2002, ASME Post Construction Committee (PCC) in US and ESR Technology in UK identified the need for composite repairs to be governed
- First editions of ASME PCC-2 Article 4.1 & ISO24817 were published to do this in 2006, which were created simultaneously and in collaboration – updated regularly
- These standards were vital for improving acceptance and popularity
- ASME & ISO committees made up of manufacturers, operators, consultants, research organisations and specialists
- Similar standards (same principles) with minor differences



# STANDARDIZED GUIDANCE

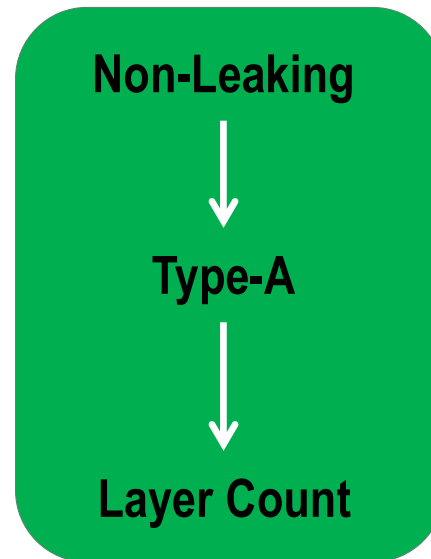
- ASME PCC-2 Article 401 & ISO 24817
- Two similar standards that provide:
  - **Qualification**
  - **Design**
  - **Installation**
  - **Inspection**
- Applicable to:
  - Metallic & GRP pipework, vessels (and storage tanks)
  - Thin-wall pipes, designed and installed to codes (mainly B31.3/4/8)
  - Wall Loss defects

Property	Test Methods	Test Type	Results
Per ply thickness	Determined from the tensile tests ASTM 3039	Mandatory	0.017"
Tensile Strength (Circumferential Direction)	ISO 527-1, ISO 527-2 or ASTM D 3039	Mandatory	166.72 ksi (1.15 GPa)
Tensile Modulus (Circumferential Direction)	ISO 527-1, ISO 527-2 or ASTM D 3039	Mandatory	9.81 Msi (67.6 GPa)
Tensile Strain to Failure (Circumferential Direction)	ISO 527-1, ISO 527-2 or ASTM D 3039	Mandatory	1.51%
Poisson's Ratio (Circumferential Direction)	ISO 527-1, ISO 527-2 or ASTM D 3039	Mandatory	0.17
Tensile Strength (Axial Direction)	ISO 527-1, ISO 527-2 or ASTM D 3039	Mandatory	19.90 ksi (137.2 MPa)
Tensile Modulus (Axial Direction)	ISO 527-1, ISO 527-2 or ASTM D 3039	Mandatory	2.95 Msi (20.3 GPa)
Tensile Strain to Failure (Axial Direction)	ISO 527-1, ISO 527-2 or ASTM D 3039	Mandatory	0.75%
Shear Modulus of Polymer	ASTM D 5379	Mandatory	167.7 ksi (1.16 GPa)
Shear Strength of Polymer	ASTM D 5379	Mandatory	7.6 ksi (52.4 MPa)
Target Value for Shore D Hardness / Barcol Hardness	ISO 868, ASTM D 2583 (ASTM D 2240-04)	Mandatory	85
Glass Transition Temperature saturant	ASTM D 6604	Mandatory	102 °C (216 °F)
Thermal Expansion Coefficient (Circumferential Direction)	ISO 11359-2, ASTM E 831	Mandatory	3.54 µm/(m °C) / 1.97 µin/(in °F)
Thermal Expansion Coefficient (Axial Direction)	ISO 11359-2, ASTM E 832	Mandatory	6.9 µm/(m °C) / 3.84 µin/(in °F)
Energy Release Rate	ASTM D 1599	Mandatory for Type B	2.16 in-lb/in <sup>2</sup> / (378 J/m <sup>2</sup> )
Impact Performance	ASTM G14 Modified, ASTM D 1599	Mandatory for Type B	3.49 in-lb/in <sup>2</sup> / (612 J/m <sup>2</sup> )
Short Term Spool Test	ASME-PCC 2	Mandatory	Passed @ 4,599psi
Lap Shear Strength (Lap Adhesion) 0.03" Bondline Thickness	EN 1465, ASTM D 3165 (ASTM D 5868)	Mandatory	1,333 psi (9.2 MPa)
Lap Shear Adhesion Strength 1000hr Soak @ 194°F (90°C) Water 1000hr Soak @ 194°F (90°C) Air	ASTM D 5868	Mandatory	1,370 psi (9.4 MPa) 1,259 psi (8.7 MPa)
Compressive Modulus (filler)	ASTM D695	Mandatory	0.55 Msi (3.8 GPa)
Compressive Strength (filler)	ASTM D695	Mandatory	14,379 psi (99.1 MPa)

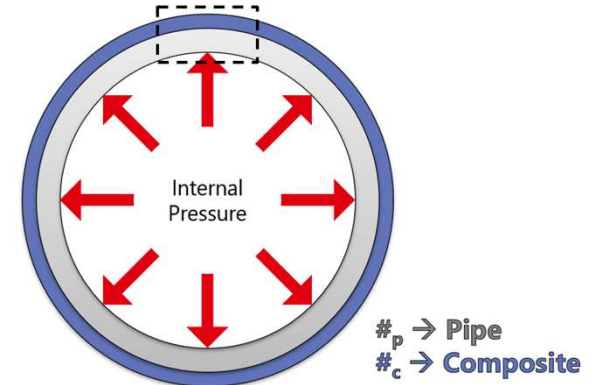
# DESIGN METHODOLOGY APPROACH

## Non-leaking Repairs

- Components not leaking or not projected to leak (during repair lifetime)
- Usually due to external corrosion:
  - o Structural reinforcement required (Type A)



## Type-A Analysis (Strength)



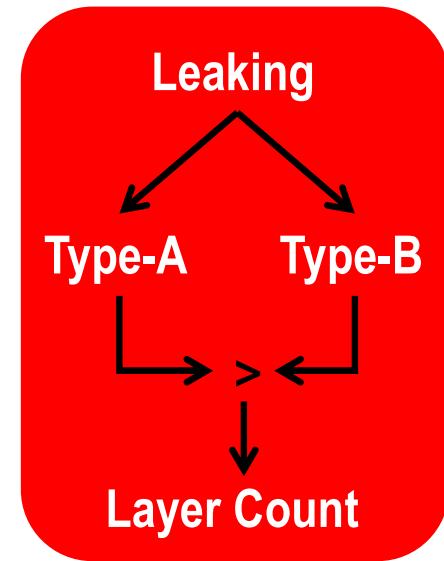
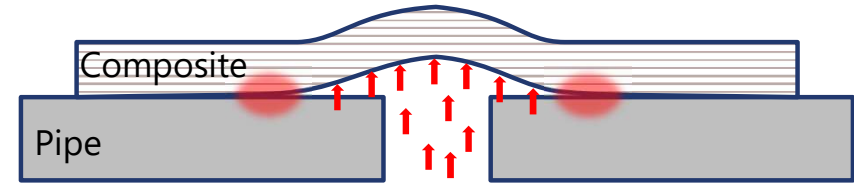
# DESIGN METHODOLOGY APPROACH

## Leaking Repairs

- Components leaking or projected to leak (during repair lifetime)
- Usually due to internal corrosion
- Components leaking requiring both:
  - o Structural reinforcement (Type A)
  - o Bond analysis – Leak containment via preventing interface separation (Type B)



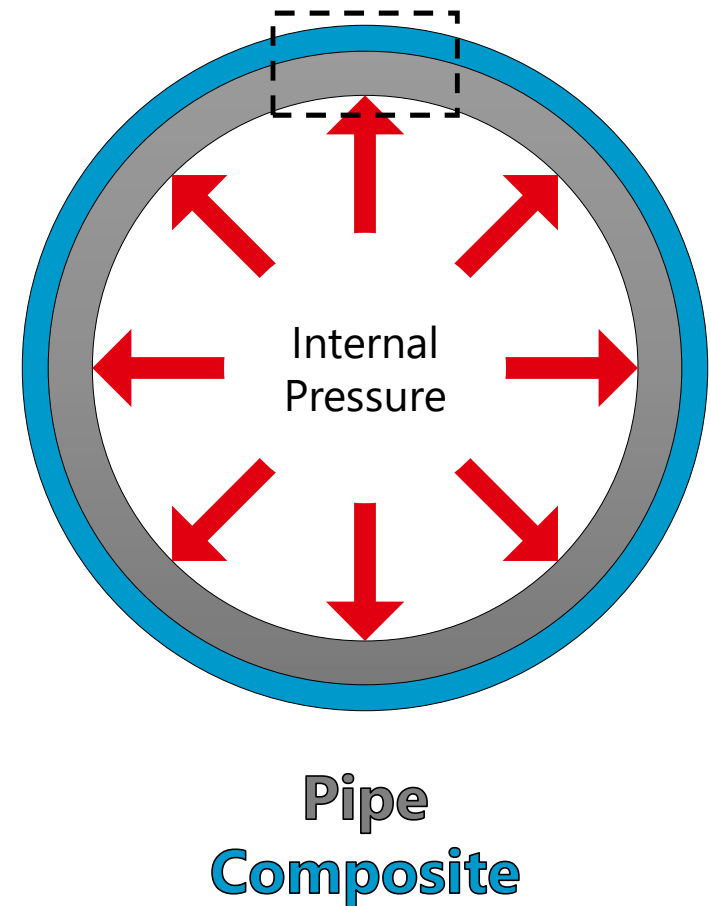
## Type-B Analysis (Bond)



## TYPE A - MULTI-LAYER BEHAVIOUR

### When flowing medium through a pipe + composite :

- Internal pressure pushes outward on the pipe wall
- For the pipe to expand, the composite must also expand
- To resist internal pressure, both materials must be stressed
- The result is load-sharing between the pipe and composite
  - Ultimately, the stress seen in the pipe is reduced



# TYPE A DESIGN – (OVERLY) SIMPLIFIED METHODOLOGY

1. Wall Loss in a Pipe

$$\sigma = \frac{PD}{2t}$$

as 't' reduces, pipe stress increases...  
reduced MAOP

2. Add in composite contribution...

$$\frac{PD}{2} = s_p t_p + s_c t_c$$

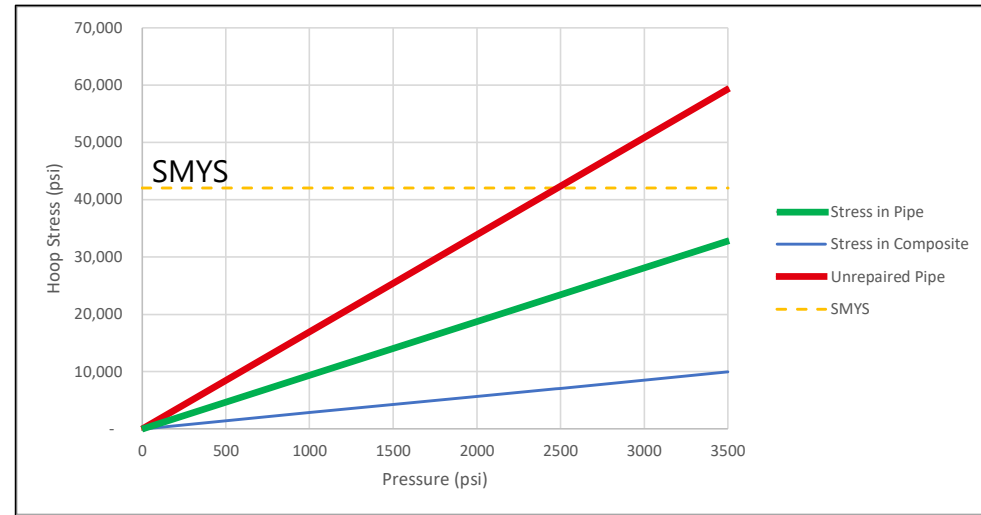
3. Utilize 2 key assumptions..

- a) Perfect Adhesion
- b) Both systems strain identically ( $\epsilon_p = \epsilon_c$ )



few derivations later...

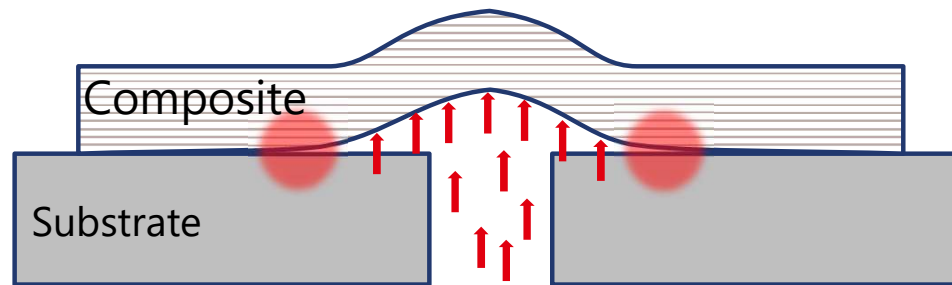
$$t_c = \frac{D}{2E_c \epsilon_c} (P - P_s)$$



# TYPE B DESIGN – BEHAVIOUR

Equations based on flat plate theory and fracture mechanics:

- Utilize through wall defect shape and size to determine pressure/load on repair
- Repair designed to preventing load-induced separation based on:
  - Adhesion (bond performance/properties)
  - Stiffness
  - Thickness



# TYPE B DESIGN – SIMPLIFIED METHODOLOGY

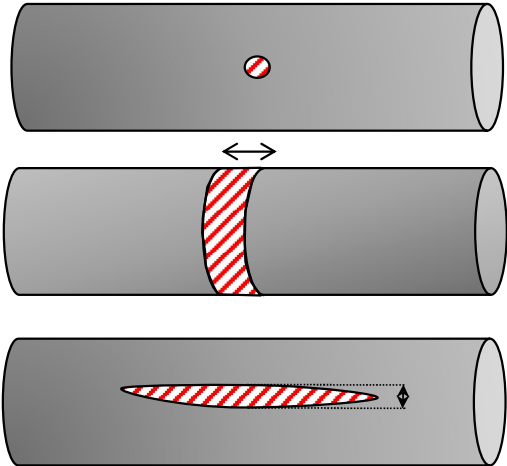
- The bond performance usually controls repair thickness and repair capability/limitations
- i.e. Energy Release Rate of the composite repair system (unique material property)
  - $\gamma$  = Energy release rate  $\rightarrow$  the maximum energy the system can take prior to the onset of failure (crack growth)

Safety Factor Energy release rate

$$P = f_T f \sqrt{\frac{\gamma_{LCL}}{\frac{(1 - \nu^2)}{E} \left( \frac{3}{512 t_{min}^3} d^4 + \frac{1}{\pi} d \right) + \frac{3}{64 G t_{min}} d^2}}$$

Design Pressure Shape factor (H)

$$P = \sqrt{\frac{\gamma}{H}} \rightarrow \gamma = H * P^2$$





***INDUSTRY  
CODES &  
REQUIREMENTS  
- PERMANENCY V DEFECT TYPE***



# PROCESS PIPING – UPSTREAM & DOWNSTREAM

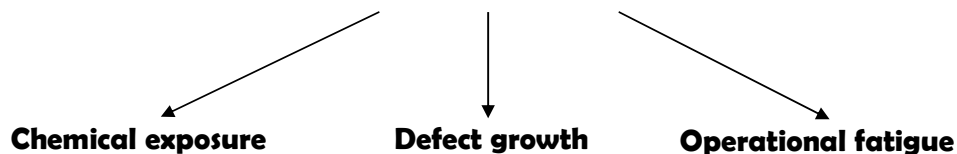
- **ASME B31.3** – if a defect is found in-service, defer to ASME PCC-2 for the specific engineering of a composite wrap, (found specifically in **ASME PCC-2 Part 4**)

**Through-wall defects the main concern** due to:

- More corrosive mediums/atmosphere
- Higher temperatures
- Pipe material selection

**Type B dominated design:**

- Bond weakens/degrades over time



- **Repair Lifetime not governed by design codes:**

- ISO/ASME assessment

- Engineers Assessment

- Rule of thumb:

- <10 bar – up to 20 years

- 10 to 20 bar – up to 10 years

- 20-35 bar - < 2-5 years

- 35 - 50 bar - < 2 years

- 50+ bar – NR (< 1 year)

*Permanent*

*Temporary*

# TRANSMISSION PIPELINE - MIDSTREAM

- Liquids Pipelines
  - **ASME B31.4**
  - ISO 13623
- Natural Gas Pipelines
  - **ASME B31.8**
  - ISO 13623



\*Local codes, regulations, and standards are regionally dependent and may differ than those discussed here.

# GENERALIZED PRODUCT PERMANENCY GUIDE

Metal Loss					Deformation*					Crack-Like*									
External	Internal	Gouge	Girth Weld	Corrosion Near Seam Weld	Plain Dent	Dented Girth Weld	Dented Weld Seam	Dent w/ Interacting Metal Loss/Gouge	Buckle	Wrinkle, Ripple	Ovality	Seam Anomalies (LOF, Planar, Hook)	SSWC	SSWC	Laminations	Arc Burns	Hard Spot	C-SCC	Girth Weld

\*permanency is dependent on defect size and cyclic profile

ISO 24817  
ASME PCC-2

● Permanent (50+ years)   ◁ Temporary   ◂ Permanent only if defect is mitigated

**NOTE: ISO24817 & ASME PCC-2 does not cover complex defect design**

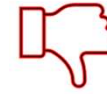
Table 451.6.2.9-1 Acceptable Pipeline Repair Methods (Nonindented, Nonwrinkled, and Nonbuckled Pipe)

Type of Defect	Repair Methods								
	1 Replace as Cylinder	2 Removal by Grinding	3 Deposition of Weld Metal	4a Reinforcing Full-Encirclement Sleeve (Type A)	4b Pressure-Containing Full-Encirclement Sleeve (Type B)	5 Composite Sleeve	6 Mechanical Bolt-On Clamps	7 Hot Tap	8 Fittings
External corrosion $\leq 80\% t$ (excluding grooving, selective, or preferential corrosion of ERW, EFW seams)	Yes [Note (1)]	No	Limited [Note (2)]	Limited [Note (3)]	Yes	Yes [Note (3)]	Yes	Limited [Note (4)]	Limited [Note (5)]
External corrosion $> 80\% t$	Yes [Note (1)]	No	No	No	Yes	No	Yes	Limited [Note (4)]	Limited [Note (5)]
Internal corrosion $\leq 80\% t$	Yes [Note (1)]	No	No	Limited [Note (6)]	Yes	Limited [Note (6)]	Yes	Limited [Note (4)]	No
Internal corrosion $> 80\% t$	Yes [Note (1)]	No	No	No	Yes	No	Yes	Limited [Note (4)]	No
Grooving, selective or preferential corrosion of ERW, EFW seam	Yes [Note (1)]	No	No	No	Yes	No	Yes	Limited [Note (4)]	No
Gouge, groove, or arc burn	Yes [Note (1)]	Limited [Note (7)]	Limited [Notes (2), (7)]	Limited [Notes (3), (8)]	Yes	Limited [Notes (3), (8)]	Yes	Limited [Note (4)]	Limited [Notes (5), (8)]
Crack	Yes [Note (1)]	Limited [Note (7)]	No	Limited [Note (7)]	Yes	Limited [Note (7)]	Yes	Limited [Note (4)]	No
Hard spot	Yes [Note (1)]	No	No	Limited [Note (3)]	Yes	No	Yes	Limited [Note (4)]	No
Blisters	Yes [Note (1)]	No	No	No	Yes	No	Yes	Limited [Note (4)]	No
Defective girth weld	Yes [Note (1)]	No	Limited [Note (2)]	No	Yes	No	Yes	No	No
Lamination	Yes [Note (1)]	No	No	No	Yes	No	Yes	No	No



# WHAT DO THEY SPECIFY ? – COMPLEX DEFECTS

- ASME B31.8 851.4.2 (2016) (e) “Permanent Repairs...”
  - Dents / Mechanical Damage - “Nonmetallic composite wrap repairs are not acceptable for repair of injurious dents or mechanical damage, unless **proven through reliable engineering tests and analysis.**”
- ASME B31.4 (2016) 451.6.2.9 “Permanent Repairs”
  - “Nonleaking corroded areas and certain other types of defects may be repaired by the installation of a composite sleeve provided that **design and installation methods are proven** for the intended service prior to the application.”



ISO24817 // ASME PCC-2



## In Summary:

- Good defect specific testing
- Good defect specific analysis
- Good engineering design methods
- Justified long-term safety factors
- Good product installation method
- Show reliability in all the above... the composite repair may be deemed “permanent”



CSNRI Custom Repair



# DENT - EXAMPLE

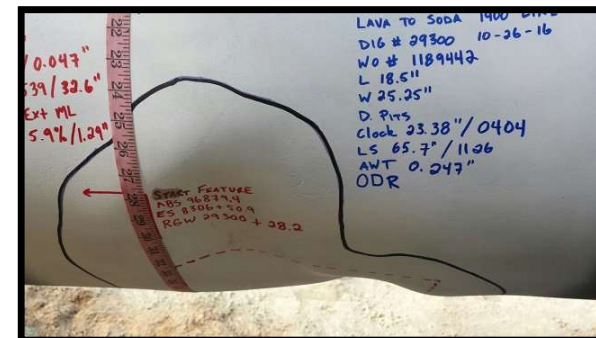
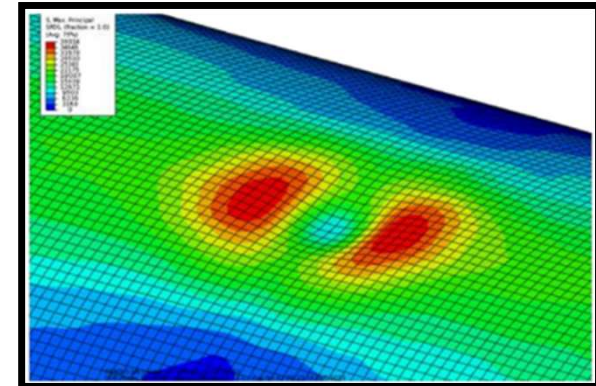
Two primary concerns with dents:

## 1. Short term burst failure

- Increased SCF's at dent
- High stress at dent combined with wall thinning / gouges may cause failure at high pressures

## 2. Long term fatigue

- Increased fatigue damage due to dent may cause early failure in aggressive cyclic conditions



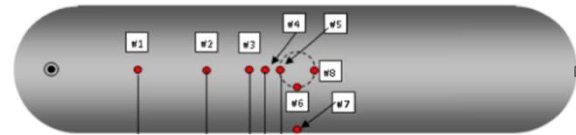
# DENT TESTING PROGRAMS

## Sample Preparation:

- Simulate dent defects on various spools
- Fit strain gauges in dent zone, good steel, composite
- Overwrap with composite repair

## Test Procedure:

- Cycles:
  - from 10% SMYS (7 bar) to 72% SMYS (60 bar)
  - Cycled to failure or until run-out (~100,000 cycles)
  - Increased pressure to burst/failure
- Measuring – SCF, burst pressure, cyclic fatigue ( $\Delta\sigma$ )



# DENTS – DESIGN METHODOLOGY

1. Custom Design Methodology developed based on substrate-composite and defect behaviours:

- Reinstatement the strength of pipe to prevent premature failure (reduce SCF)
- Increase the fatigue lifetime of the pipe (reduce SCF and Stress range ( $\Delta\sigma$ ))

$$t_{min} = \frac{1}{E_c \epsilon_c} \left( \frac{(P_d - P_s) D}{2} \right)$$

**$t_{min}$  = Req'd Repair Thickness**  
 **$P_d$  = Design Pressure**  
 **$P_s$  = Safe Operating Pressure**

$$P_s = \left( \frac{2st_s}{D} \right) / SCF$$

2. Test results utilized to validate custom design methodology to:

- Reduced SCF's
- Stress range ( $\Delta\sigma$ ) at dent location

$$N = \frac{C}{\Delta\sigma^m}$$

<u>Unrepaired</u>	<u>Repaired</u>
$\sigma_p = SCF * \frac{PD}{2t_{rem}}$	$\sigma_p = SCF * E_p \left( \frac{\frac{PD}{2} + E_c t_c \epsilon_{live}}{E_p t_{rem} + E_c t_c} \right)$

Meets the requirements of pipe codes (B31.4/8) and builds on ISO24817/ASME PCC-2



# DEFECT TYPE ASSESSMENTS

## Wall Loss

Design fundamentals:

- Stress distribution

Resulting assessments:

- Burst pressure
- Generalized fatigue

Comments

- Bases for most repair standards and easiest repair scenario

$$t_c = \frac{D}{2E_c \epsilon_c} (P - P_s)$$

## Deformation

Design fundamentals:

- Stress distribution
- Stress Intensification

Resulting assessments:

- Burst pressure with SCF
- SCF induced fatigue

Comments

- Relies on models that estimate SCF for various defect types

$$K_d = 1 + C_s \sqrt{\frac{t}{D} d_d^{1.5} C_{ul}^{1.5}}$$

## Crack / Crack Like

Design fundamentals:

- Stress distribution
- Fracture mechanics

Resulting assessments:

- Burst pressure
- Cyclic crack growth

Comments

- Highly depended on crack type, length, orientation, and depth

$$K_{IC} = F \frac{PR}{2t} \sqrt{\pi a}$$

## Axially Dominated

Design fundamentals:

- Stress distribution
- Beam bending

Resulting assessments:

- Axial strain to failure
- Adhesion

Comments

- End-user specified design objectives and loading are critical for success

$$\sigma_{xx} = \frac{F}{A} + \frac{My}{I}$$

# WHY ARE WE CONFIDENT? TESTING. LOTS OF IT.

- PRCI:
  - MATR-3-4: Long-term Performance (10-year)
  - MATR-3-5: Dented Weld Seam
  - MATR-3-7: Vintage Girth Weld Reinforcement
  - MATR-3-11: Load Transfer Study
  - MATR-3-13: Repair of Dents Installing at Pressure
- Joint Industry Programs (JIP's):
  - GRI – 10-year Clock Spring study
  - GTI – long term adhesive and cathodic disbondment testing
  - Wrinkle Bend Reinforcement
  - The Reinforcement of Non-Leaking Crack-Like Defects using Composite Repair Materials
  - 10,000hr Offshore Test
  - Dent Validation (DVCIP)
  - Selective Seam Weld Corrosion (SSWC)
  - Stress Corrosion Cracking (SCC)
  - Girth Weld Geohazard Reinforcement JIP
- Countless internal or customer specific testing





***LONG-TERM  
PERFORMANCE***



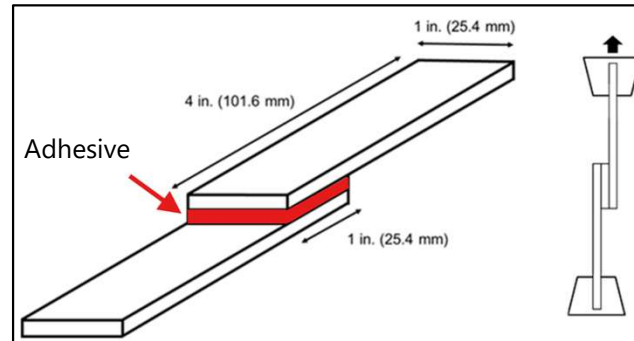
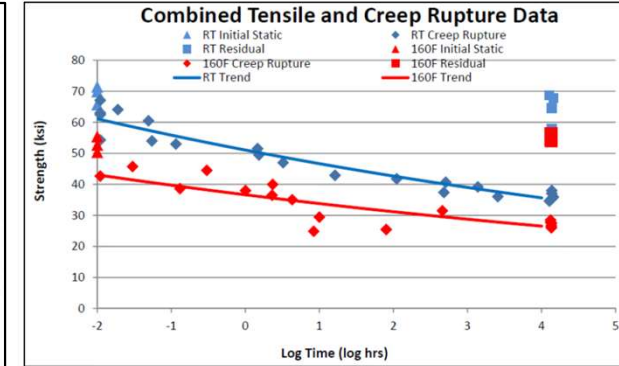
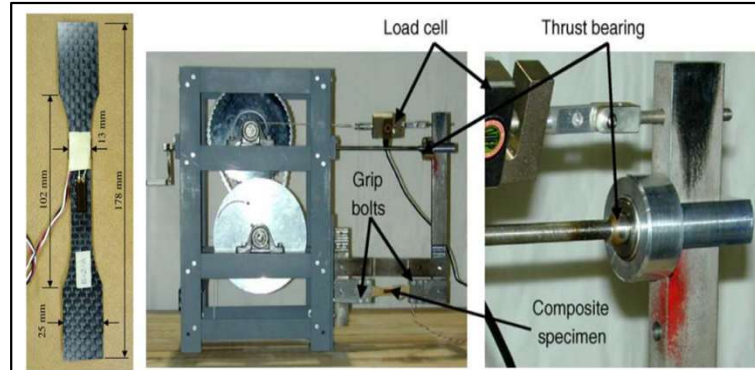
# LONG-TERM TESTING – DESIGN PROPERTIES

- **Creep Testing (lifetime)**

- Deformation & Failure
- Reduction (material properties)

- **Long-Term Bond (& Chemical)**

- Lap Shear Strength
  - Chemical exposure (10,000hrs)
  - Max. Temperature limits
- Static loading



# LONG-TERM TESTING – IN-FIELD PERFORMANCE

- **Full Scale Testing**

- Long-term Strength Performance
- Evidence of:
  - long-term performance
  - Design validation
  - In-field evidence



# 25-YEAR CLOCK SPRING TEST

- A ClockSpring repair was removed from service after 25-years from initial install date and tested.
- 24" (610mm) diameter Natural Gas pipeline
- Operating pressure 52 bar) – including various cycles deviations during lifetime
- Installed in 1995
- Total of 9 repairs made to cover multiple corrosion defects



# 25-YEAR CLOCK SPRING TEST

## Test 1 – Hydrostatic Pressure Testing

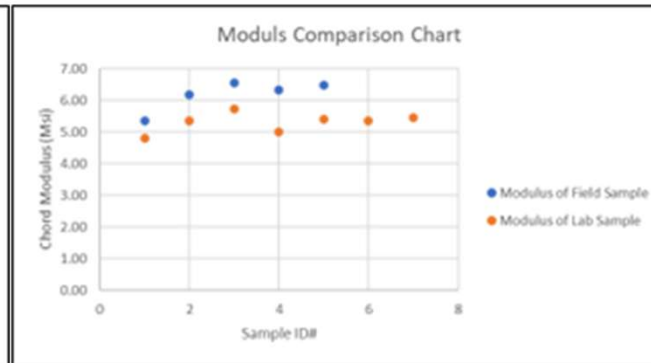
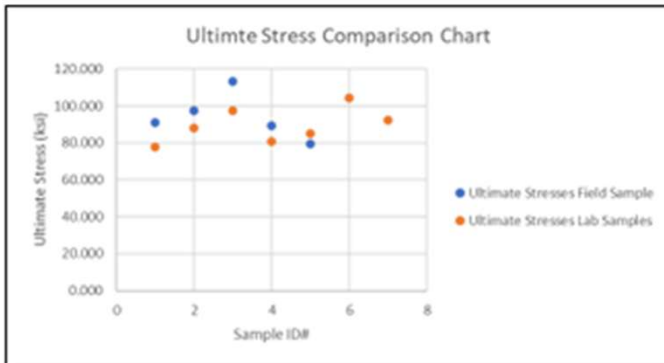
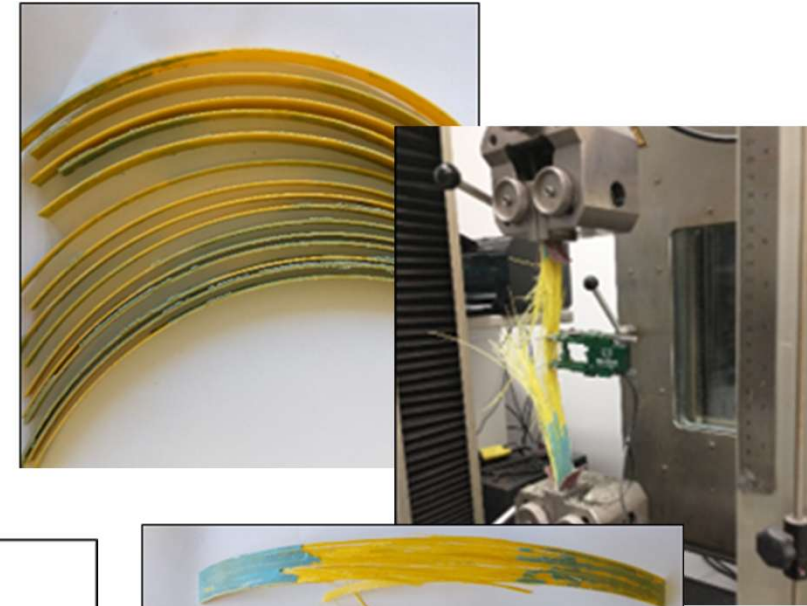
- Pressurized and held at 1.5 MAOP
  - 100 bar
- Released, and then re-pressurized until failure
  - Burst outside of repaired area at 152 bar
- Failure ripped along pipe, until encountering the repair edge, where it turned circumferential



# 25-YEAR CLOCK SPRING TEST

## Test 2 – Tensile Testing

- Measurement of stress, strain and modulus compared to newly created ClockSpring sample (Year 0 v Year 25 comparison)
- Strips were cut for from 25-year sample
- Results show great consistency & performance
- No noticeable degradation of concern after 25 years



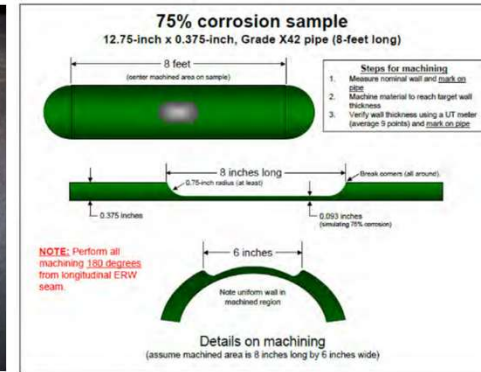
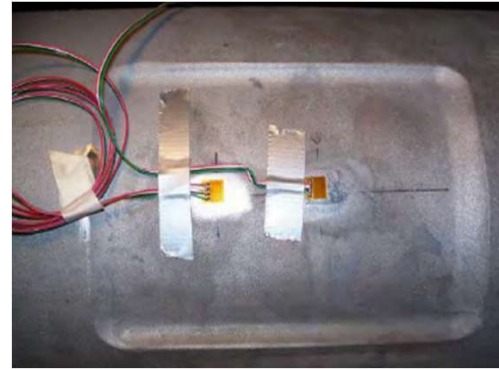
# 10-YEAR LONG-TERM BURIED STUDY

- Pipeline Research Council International (PRCI) – study of long-term performance of composite repairs for external corrosion
- Gas and liquid transmission lines being the key focus area
- Stress Engineering Services (SES) chaired JIP which included 13 composite repair suppliers
- Duration: 2008 to 2018 – SES Waller facility in Texas, USA
- This testing was endorsed by ASME and other bodies for code utilization/updates

# 10-YEAR LONG-TERM BURIED STUDY

## Testing Overview:

- 12" spool samples with machined defects to simulate wall loss of 40%, 60% & 75%
- Strain gauges fitted in defect region and on 'good area' (reduced SCF etc.)
- Composite repairs applied to the defect zones as calculated
- Benchmark/Baseline tests carried out at '0' years for benchmark performance values
- Spools buried @ 1m, subject to pressure and cyclic loading for required duration
- Spool removed at 1, 2, 3, 5, 7.5 & 10 years for burst testing and analysis of results and performance
- Comparison of results carried out to conclude findings on long-term performance
- 201 samples in total (39 Year '0' burst tests and 162 buried samples)



# 10-YEAR LONG-TERM BURIED STUDY

## Loading Procedure:

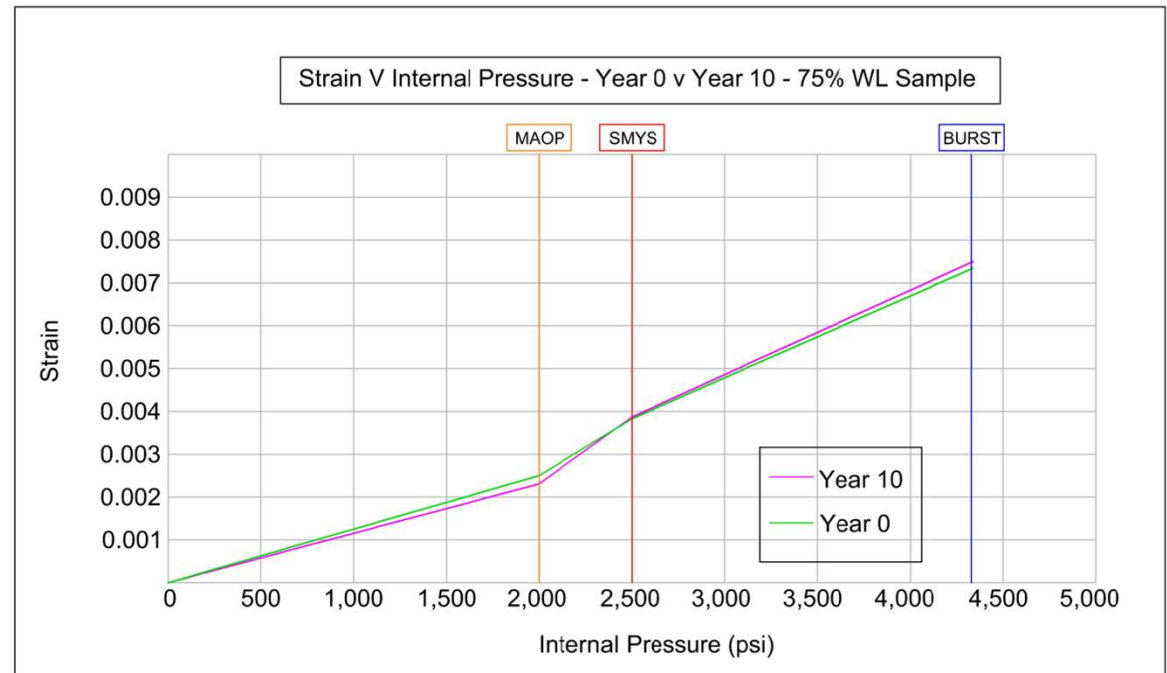
- Continuous pressure @ 36% SMYS (62 bar)
- Cycled:
  - 75 times per month from 36% SMYS to 72% SMYS (124 bar)
  - 1 time per month from 0% SMYS to 72% SMYS
- Once removed after 'X' years, pressurized to failure



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**Results:** Comparison of Year '10' strain results v Year '0' (sample size only)

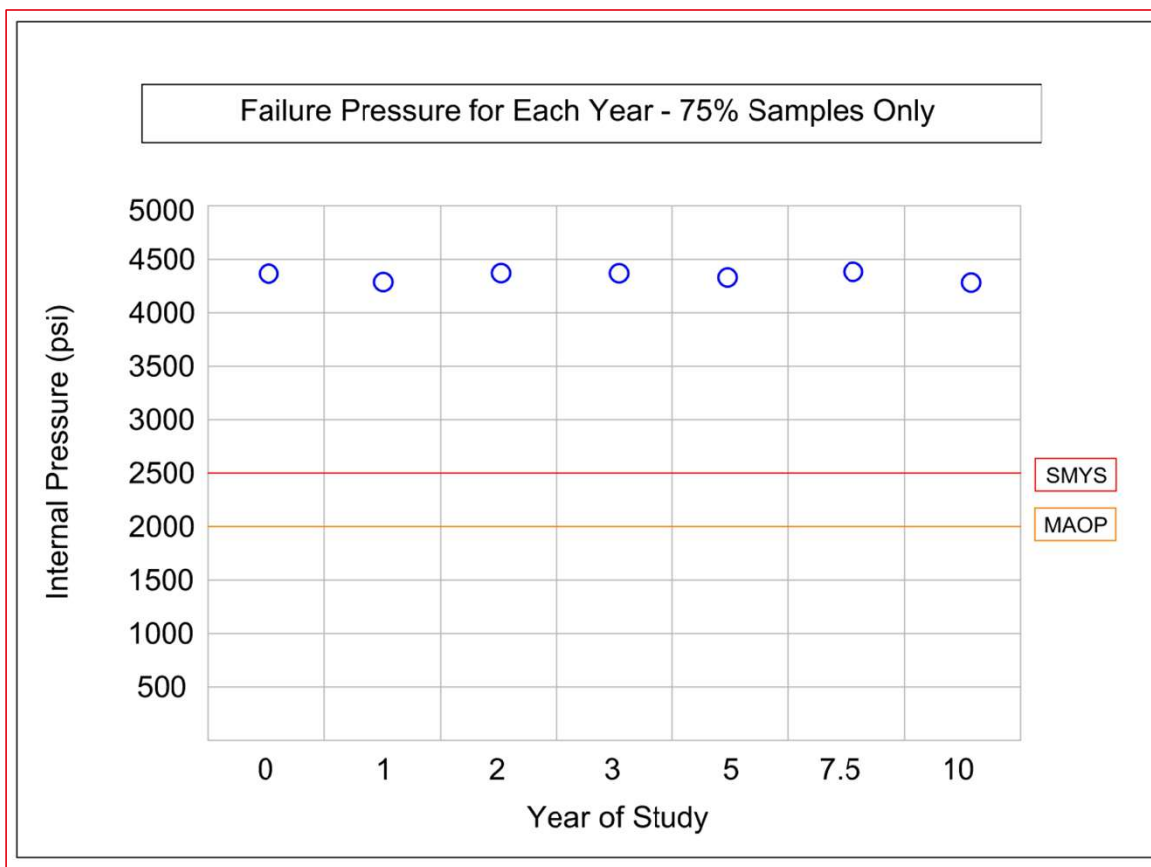
Year	Corrosion Depth (%)	Pressure Level	Hoop Strain Under Repair (centre)
10	75	MAOP	2,321
		SMYS	3,852
0	75	MAOP	2,513
		SMYS	3,841



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## Results:

- Year '10' burst pressure for 75% wall loss (sample size only) shown on graph
- All Year 10 specimen results summary:
  - 40% corrosion – failed at the defect repair at 172% of SMYS
  - 60% corrosion – failed outside the defect area at 167% of SMYS
  - 75% corrosion – failed outside of the defect area at 175% of SMYS





***THANK YOU !!***

***QUESTIONS ?***

