Innovative Pipeline Technology,
Value-Focused Solutions

The Use of XHab™ for Reinforcement of Axially Aligned Notches in Pipelines

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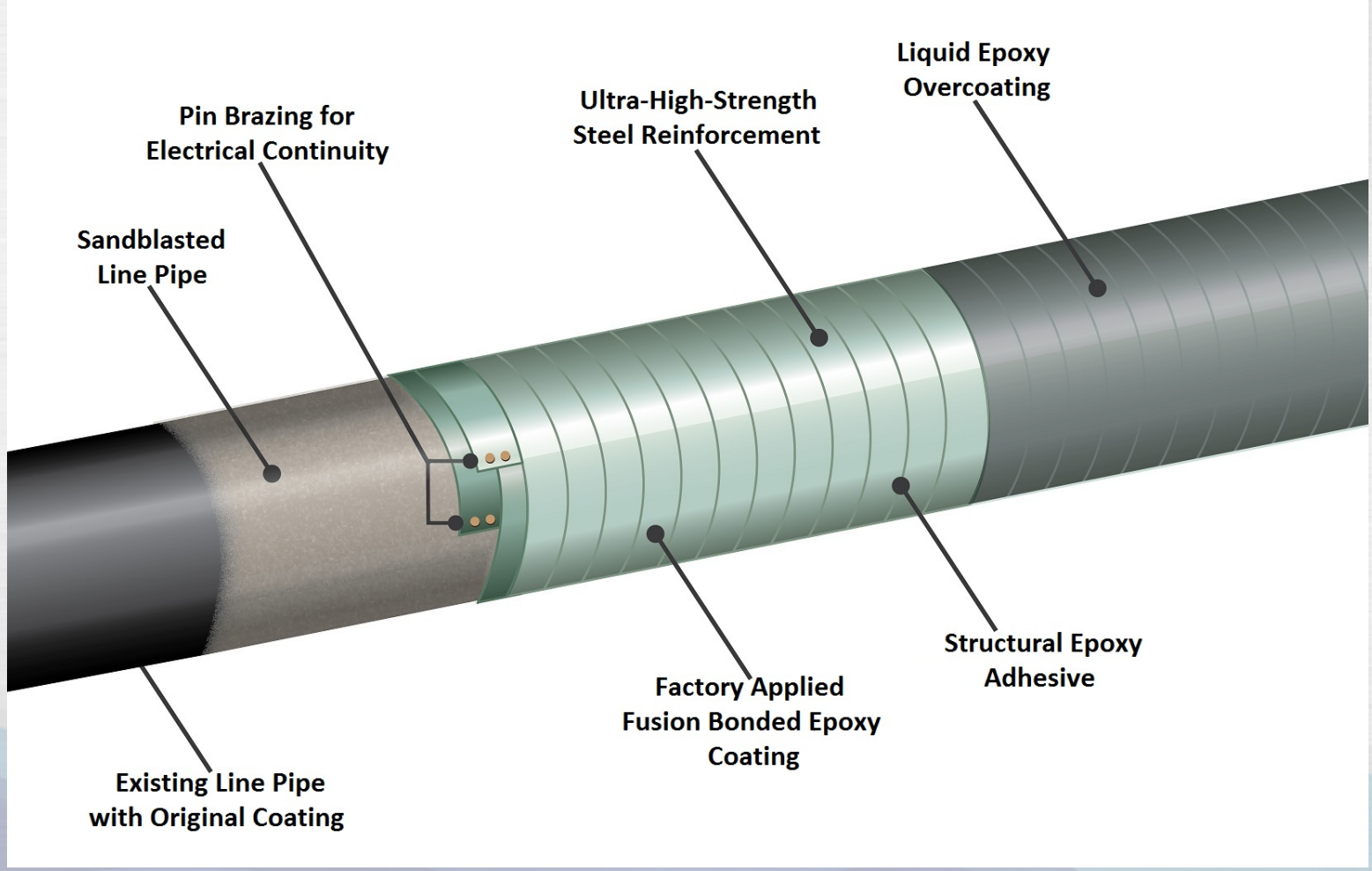
Brief Introduction to XHab

- Pipeline repair and reinforcement method for longer pipeline sections
  - Not directly competing with hand-applied repair systems
  - Providing an alternative to pipeline replacement
- Increases the operating pressure of a corroded or damaged pipeline back to its original MAOP.
- Modifies the hoop stress related to class location change (currently with special permit).
- Based on steel wrap, provides good response at low strain cycle levels which can be important in fatigue situations

Brief Introduction to XHab



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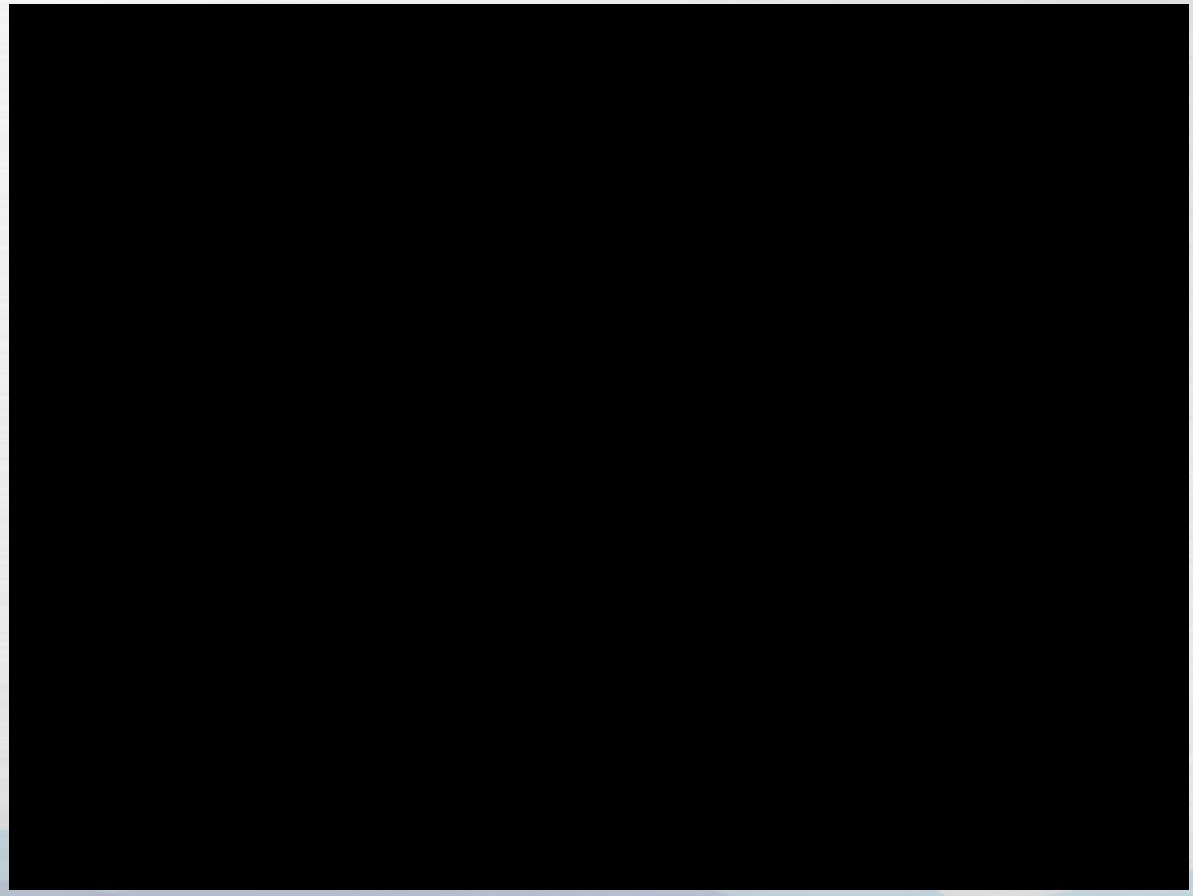


Prototype machine (XHab1) provided good experience…

Brief Introduction to XHab

…commercial machine (XHab2) much smaller and lighter!

XHab for Axial Cracks

- Other testing (dents, external defects, plain pressure cycling) has shown good response from the XHab reinforcement, even at very low strain levels.
- Axial cracks (e.g. fatigue cracks or from Stress Corrosion Cracking) may propagate under operational stress cycle ranges at low strains.
- XHab reduces both the average stress and stress cycle range and could substantially reduce crack growth rate, or potentially even bring below threshold level

XHab for Axial Cracks

- Testing program on axially-notched pipes just completed with Stress Engineering Services
- This is the first phase in a program to demonstrate ability to repair crack-like defects without grinding

- Other repair wrap and sleeve products have been tested in the past for repair of cracks, but only aimed at spot repairs rather than extended lengths

Notch Geometry

- EDM (electrical discharge machining) for control and repeatability of notch defects across a number of samples
- Preliminary assessments by Stress Engineering were simple estimates
  - Performed before pipe material data collected
  - Mostly based on nominal dimensions and properties
  - Quite conservative in their approach
  - Performed to size defects to ensure noticeable difference in results against experimental “scatter” but within reasonable timeframe
  - Not necessarily expected to be accurate predictions of actual tests

Notch Geometry

Dimension	Burst Tests	Fatigue Tests
Length	6 in.	6 in.
Width	0.02 in.	0.02 in.
Depth	0.094 in. (0.5 t)	0.062 in (0.33 t)
Location (ERW seam at 12 o'clock)	6 o'clock	3 o'clock 9 o'clock

Wrap Design

- Thickness of wrap was based around reinforcement required for re-rating nominally defect-free pipe
- Testing performed on 12.75” x 0.188” X52pipe (AYS=60000psi, ATS=70000psi)
- Design wrap thickness to reduce hoop stress from, say, 72% SMYS to <50% SMYS
- Total strip thickness of 0.10” applied to pipe in 3 layers
- Strip applied to pipe at zero pressure
- Theoretical reduction in hoop stress:
  - Hoop stress in wrapped section = **65%** of hoop stress in unwrapped section

Burst Test Arrangement

- Burst test specimens in pit with lid
- Maximum pressurization rate of 10psi per second
- 5 minute holds:
  - 766psi (50% SMYS)
  - 1104psi (72% SMYS)
  - 1240psi (estimated unrepaired failure)
  - 1533psi (100% SMYS)
- Increase pressure to failure

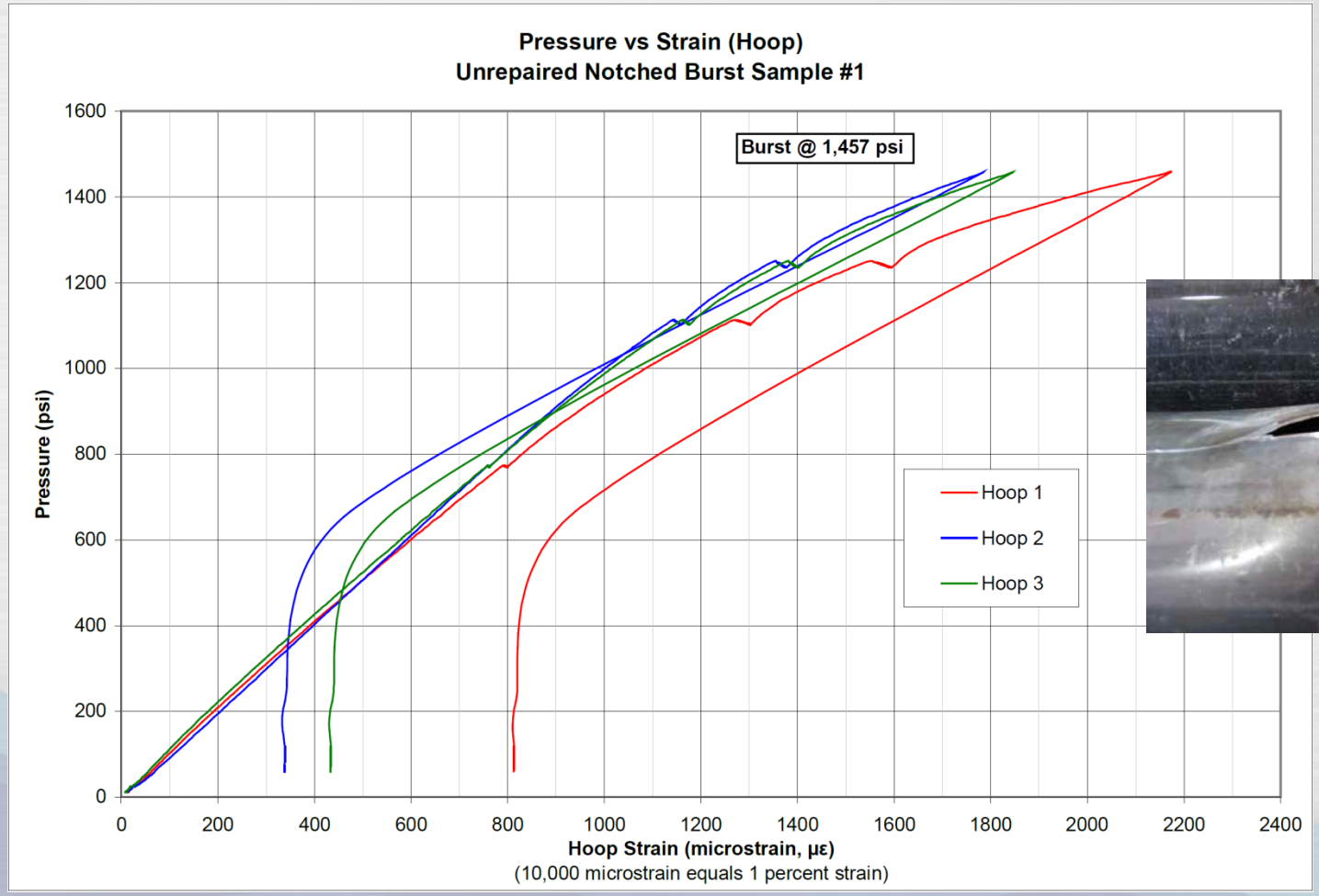
Burst Test Results

- Unrepaired pipes fractured at the notch location
- Simplified initial estimate 1240psi

P_{b_1} = 1457psi
P_{b_2} = 1473psi
P_{b_3} = 1467psi

P_{b_av} = 1466psi
CoV = 0.6%

Burst Test Results



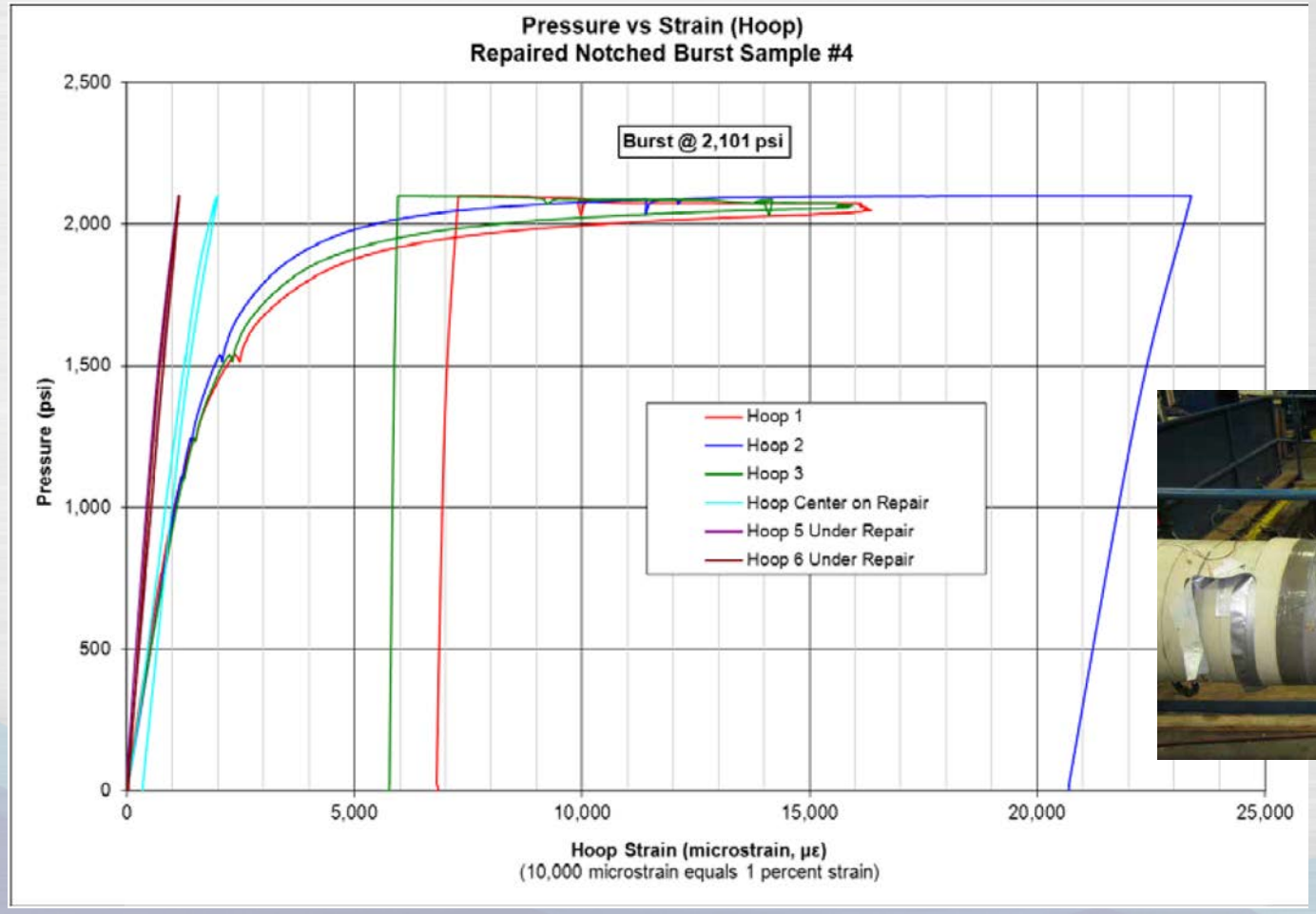
Burst Test Results

- Repaired pipes fractured in base pipe away from repair
- Simplified initial estimate 2064psi (Barlow formula using AYS)

P_{b_4} = 2101psi
P_{b_5} = 2101psi
P_{b_6} = 2059psi

P_{b_av} = 2087psi
CoV=1.1%

Burst Test Results

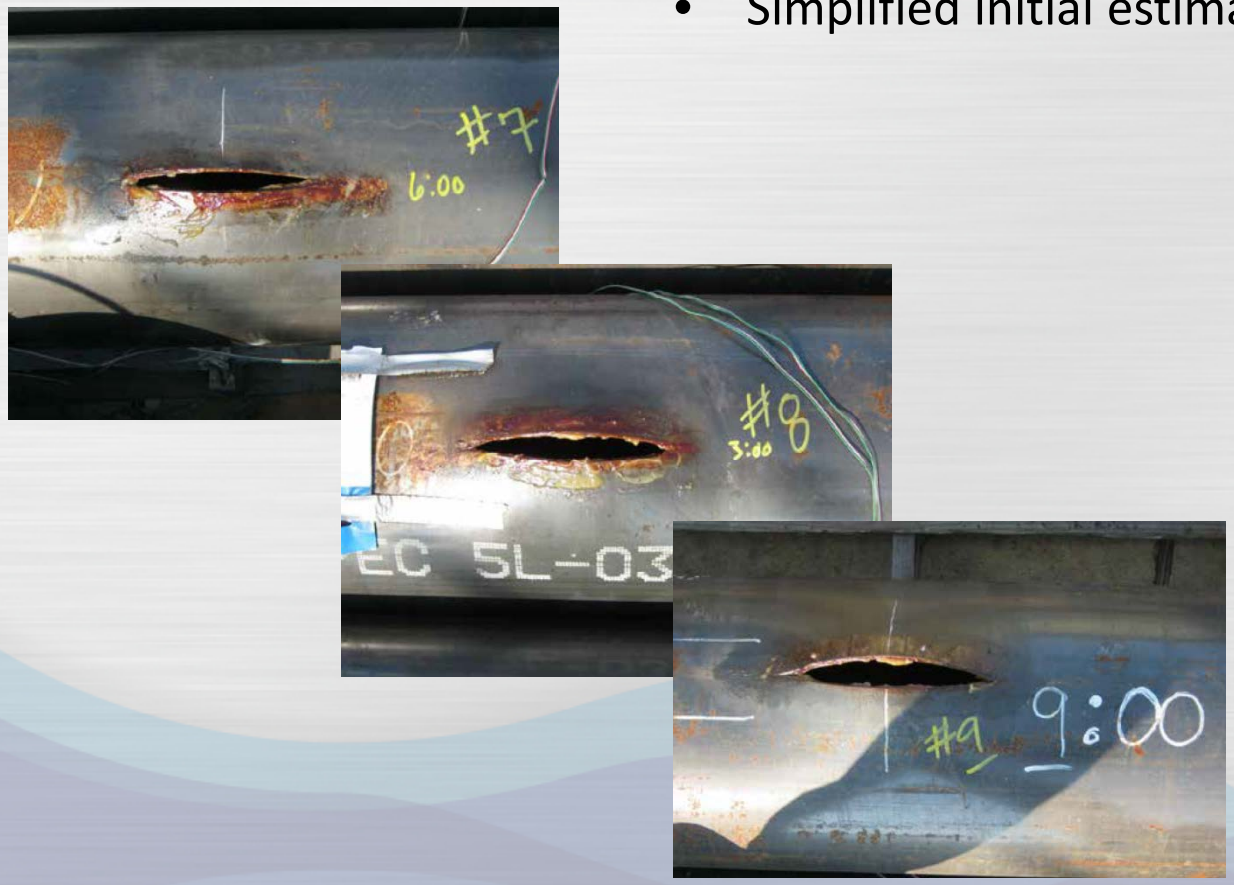


Fatigue Test Arrangement

- Fatigue test specimens in shield structure
- Pipes connected in parallel for pressurization from single pump
- Cycle between 100psi (6.5% SMYS) and 1204psi (78.5% SMYS)
- ΔP = 1104psi (72% SMYS)
- 1 cycle every 7 seconds (approx.)
- Record 5 cycles of data at various intervals during test

Fatigue Test Results

- Unrepaired pipes fatigue / fracture at the notch location
  - Simplified initial estimate 2670 cycles



N_{cf_7} = 4,085 cycles
N_{cf_8} = 4,097 cycles
N_{cf_9} = 4,117 cycles

N_{f_av} = 4,100 cycles
CoV = 0.4%

Fatigue Test Results

- Repaired pipes reached run-out or failure of base pipe remote from repair
- Simplified initial estimate 15650 cycles

N_{c_10} = 60,649 cycles
(2nd end cap failure)

N_{c_11} = 41,409 cycles
(2nd end cap failure)

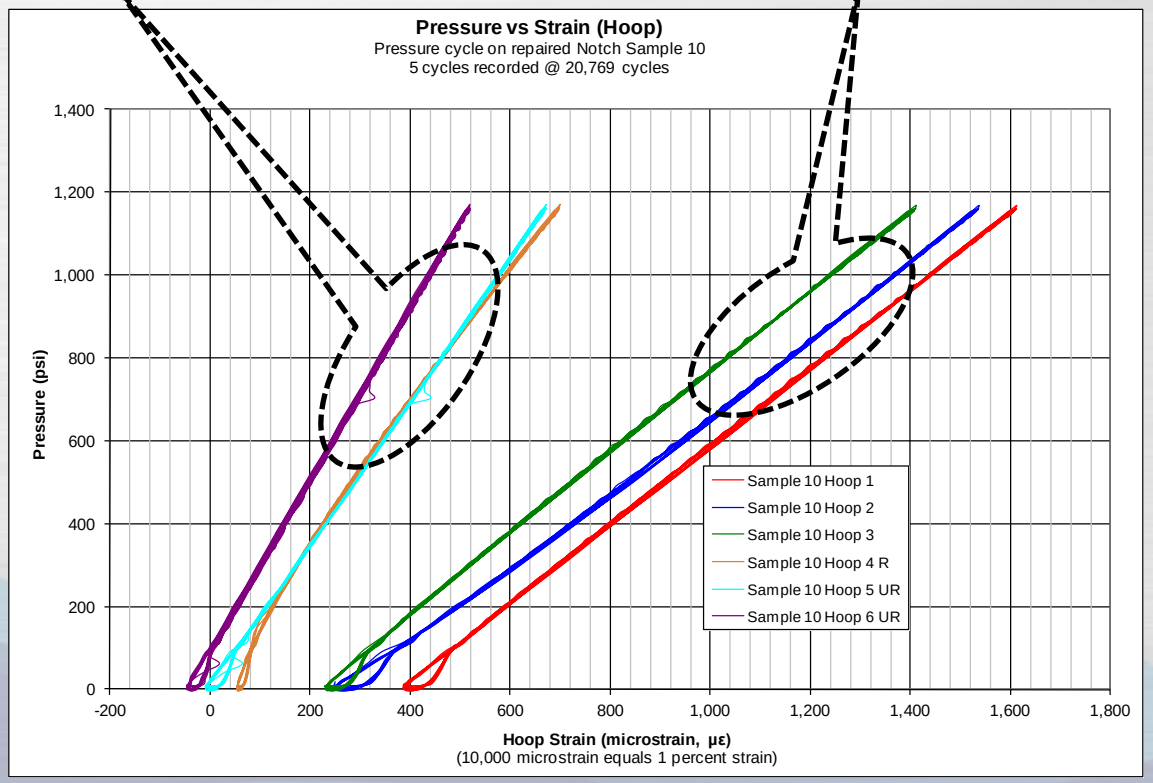
N_{c_12} = 60,671 cycles
(ERW pin hole leak outside repair)

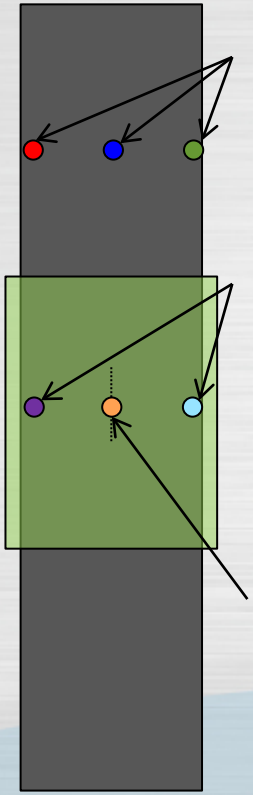
Fatigue Test Results

This particular XHab repair design reduced strain range in pipe by factor of ~2

~0.53 με/psi

~1.05 με/psi





Fatigue Test Results

- A reduction in stress range reduces initial stress intensity factor range (ΔK) by same amount
- Large effect on rate of crack growth rate (da/dN)
  - Factor of 2 on ΔK
  - → Factor of 8 on da/dN
- Reducing $\Delta K_{initial}$ (by reducing stress range) has two beneficial effects:
  - reduced da/dN initially
  - slower increase in ΔK since a increases much more slowly

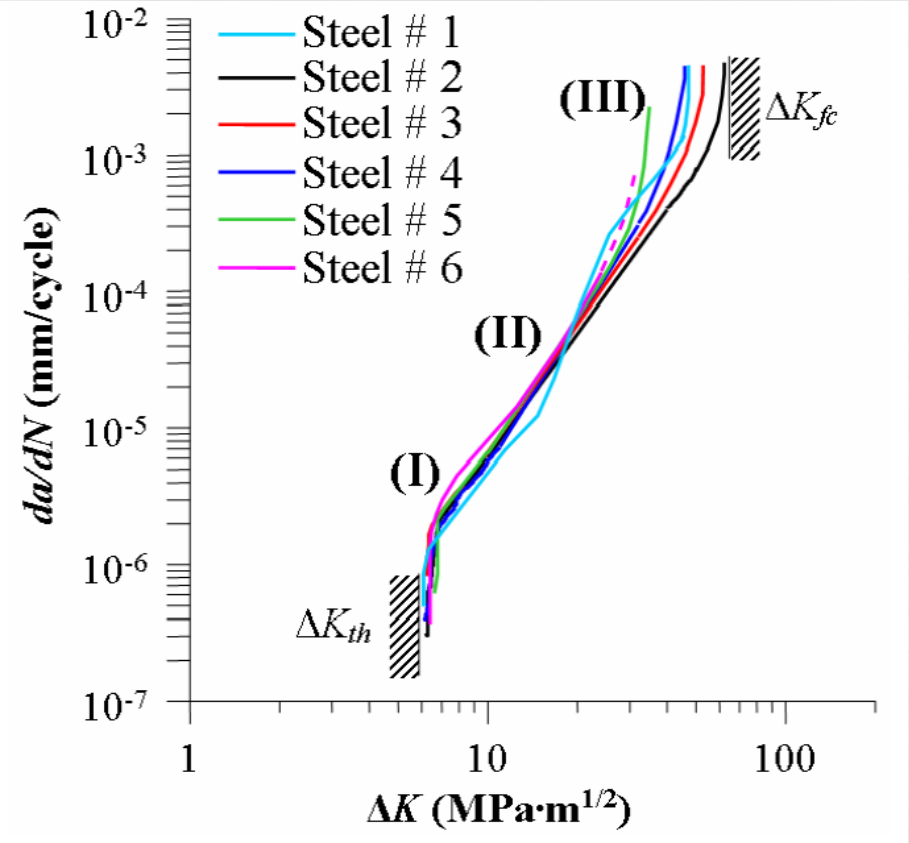


Figure from "Fatigue crack growth rates in six pipeline steels" by A Bussiba et al., IPC2006-10320.

Fatigue Test Results

- SES considered what these results might mean for a real gas transmission pipeline
  - 'Aggressive' operating history gives 58 equivalent full MAOP (72%) cycles per year
  - Include a factor of 10 on the fatigue design life (typical value)
    - Unreinforced pipe : 6.9 years
    - Reinforced pipe : 103.4 years
  - Values reduced (but maintaining x15 factor between them) for liquid pipelines, where pressure cycle tends to be more aggressive

Next Steps

1. Re-analyze results based on measure pipe fracture toughness properties
   - Identify differences between initial (simplified) predictions and actual results
   - Any other effects e.g. restricting crack mouth opening due to adhesive?
2. Additional testing on notched + pre-cracked pipe specimens
   - To account for differences between flat-bottom notch and sharp crack at the time of repair
3. Test effectiveness of repair on pipe with cracks (SCC) removed from service
   - Seeking support from operator(s) to identify and supply appropriate pipe
4. Refine design criterion for repair thickness / application pressure
   - Use of finite element analysis to cover sensitivities

Closing Thoughts

- Bonded wrap repairs or sleeves have been considered for non-ground crack repairs previously, but not over extended length
- Technologies move forward:
  - Materials
  - Assessment tools and methods
- We shouldn't discount the potential for alternative methods simply because "something similar" was not taken up previously
  - "Similar" can prove very different in key areas
- As engineers, we should always be exploring the boundaries of our knowledge (safely, of course…)

"Don't tell me to improve my diet. I ate a carrot once and nothing happened!"