#308 Validation of Planing-Induced Microfracture for Determining Pipe Body Toughness

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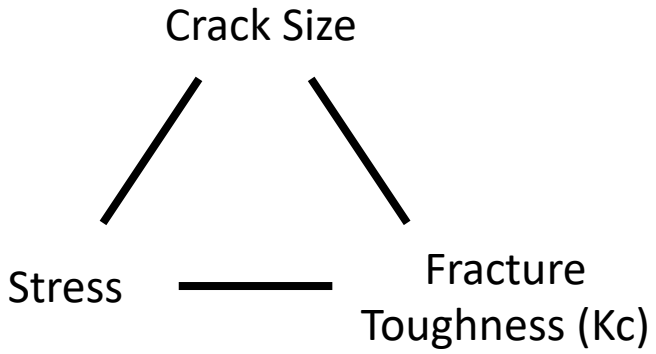
Flaw Assessment

- Flaws such as cracks, welding defects, and corrosion can develop in pipelines during manufacturing or operational life.
- It is important to know whether a flaw is 'critical' to ensure that maintenance and repair efforts are both effective and economical.
- Crack size (current or future), stress, fracture toughness are three key factors for assessment of crack-like flaws.



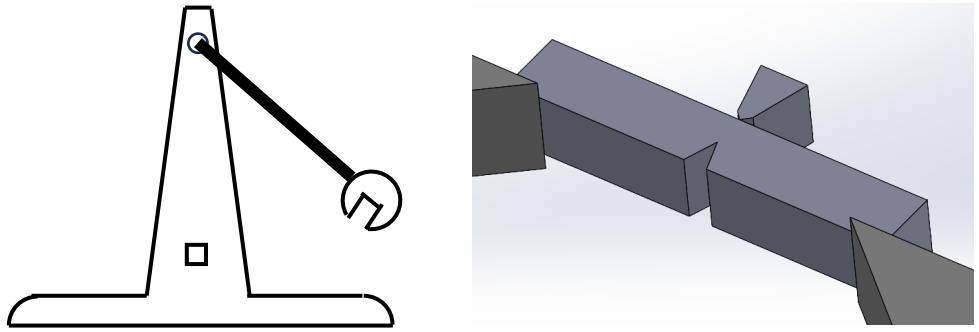
$$K(Crack\ Size, Stresses) < K_c$$

$$K(Crack\ Size, Stresses) > K_c$$

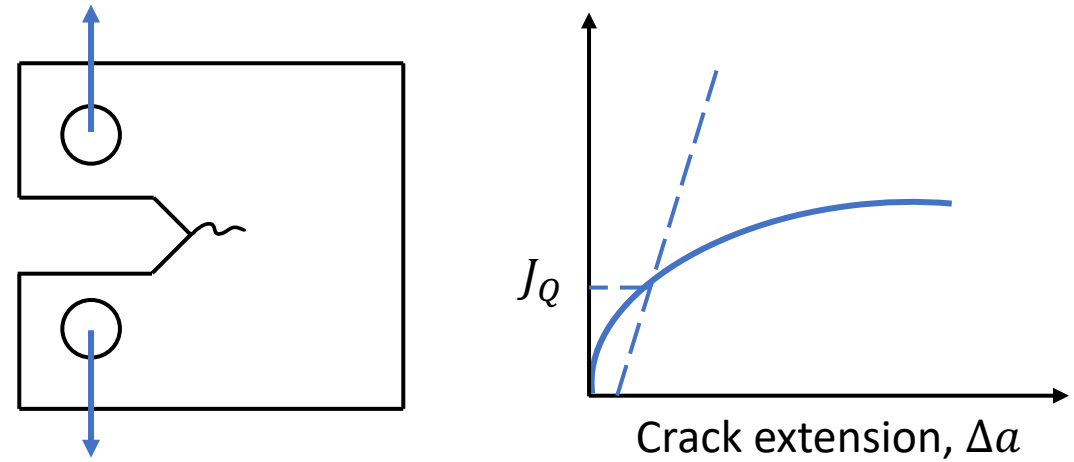
Fracture Toughness

- Unfortunately, many vintage pipelines do not have a record of fracture toughness.
- Fracture toughness can be evaluated using conventional lab testing (e.g., Charpy Impact Test, J-R curve)

  - Cut-out samples required, service intervention, time-consuming and expensive



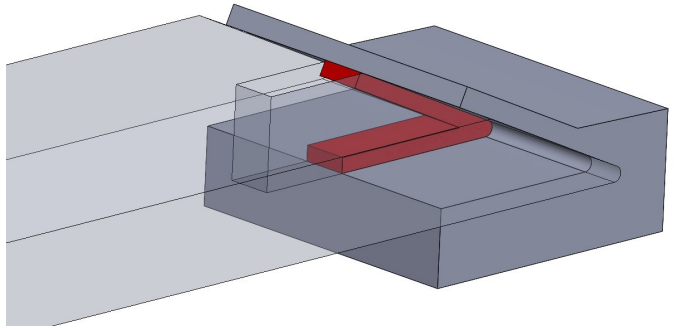
Charpy Impact Test



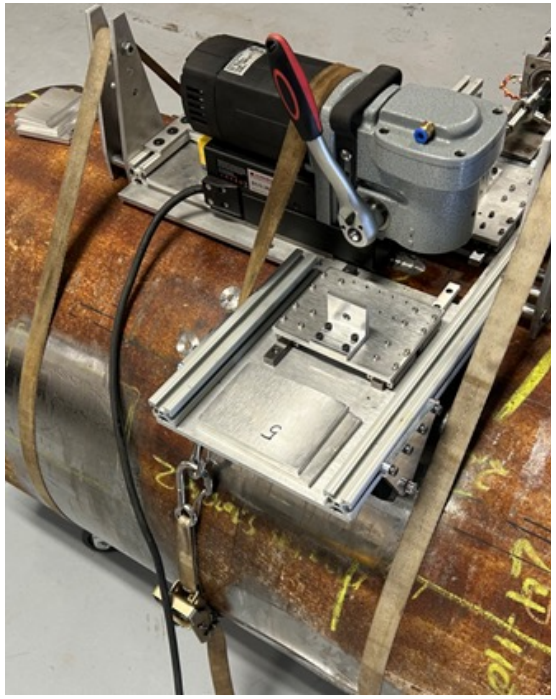
J-R Curve Method

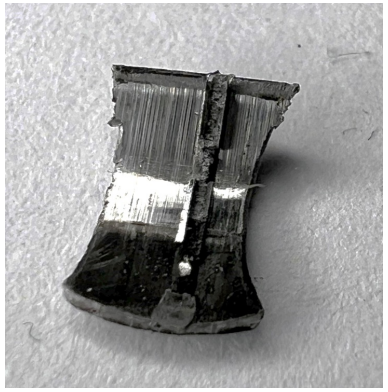
New Method: Planing-induced Microfracture

Portable, In-situ, and Minimally Invasive.



Initial Proof of Concept

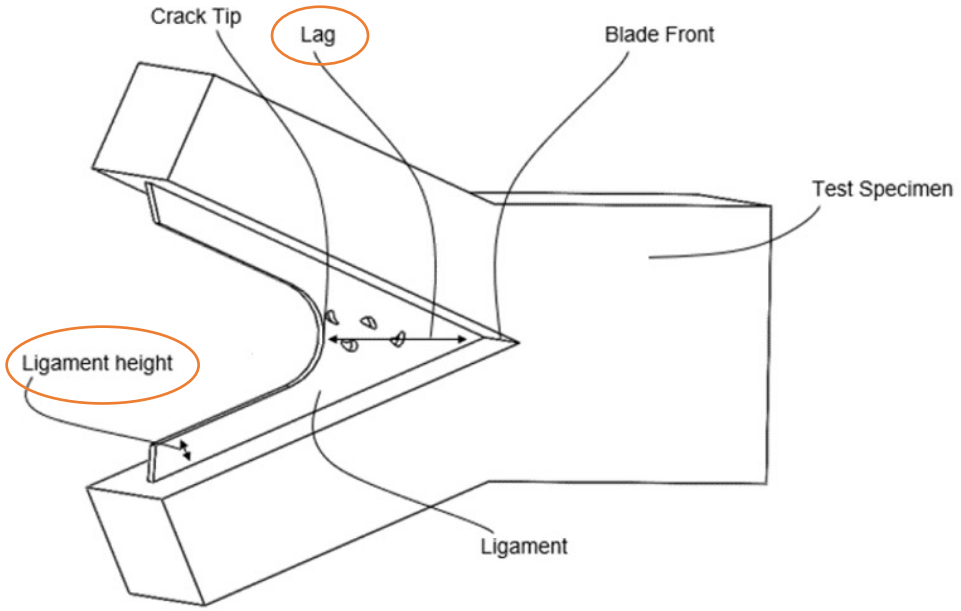


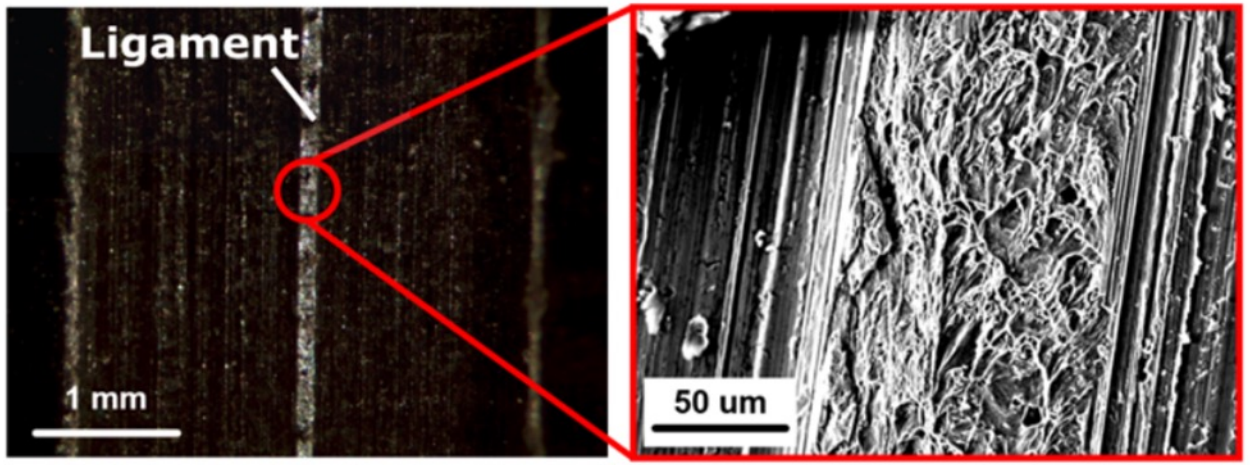


In-situ Pipeline Testing Configuration

New Method: Planing-induced Microfracture

- A true crack is introduced in the material utilizing a blade with central opening ("Stretch Passage").
- Crack propagates as the blade travel. Ductile fracture surface is confirmed.
- Correlation is established between the ligament features and the material fracture toughness.

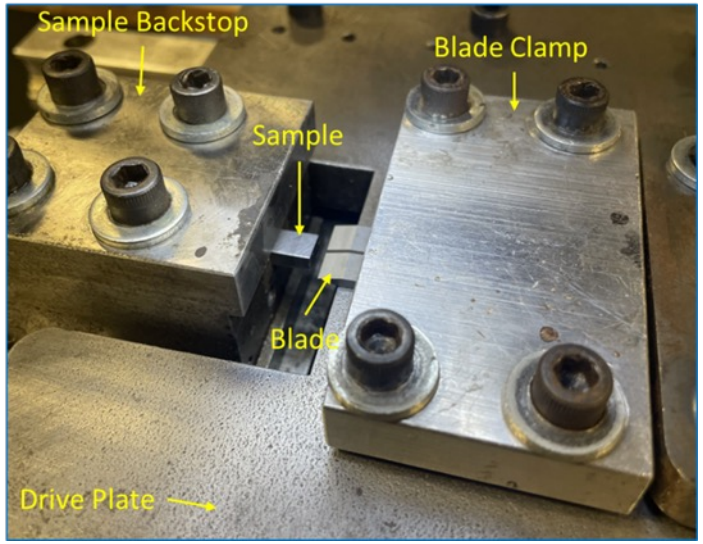




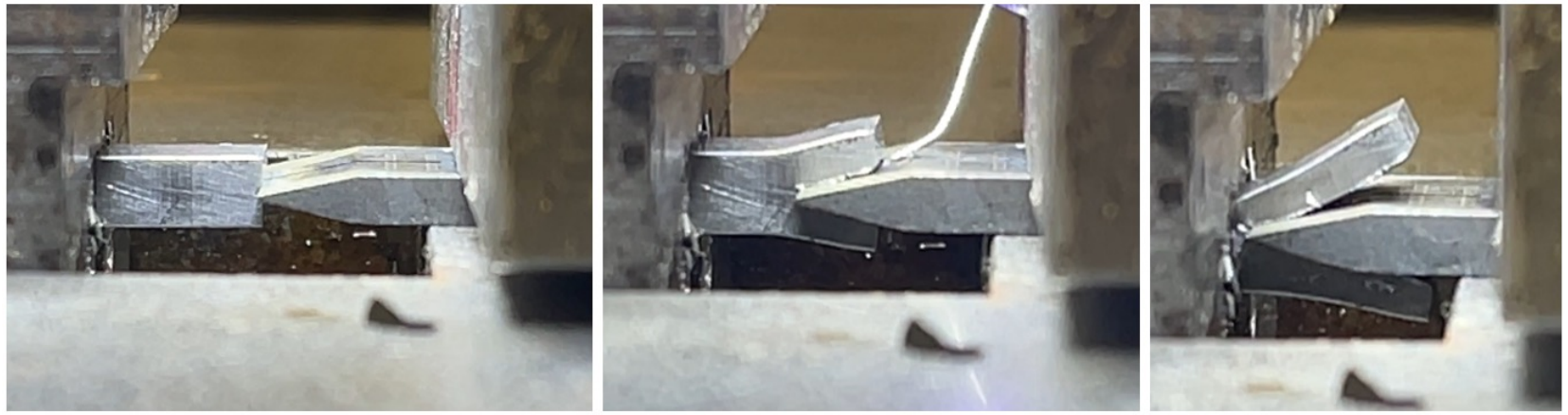
SEM Image of Ligament (Top View)

Proof of Concept Lab Testing

- Lab testing setup for proof of concept.

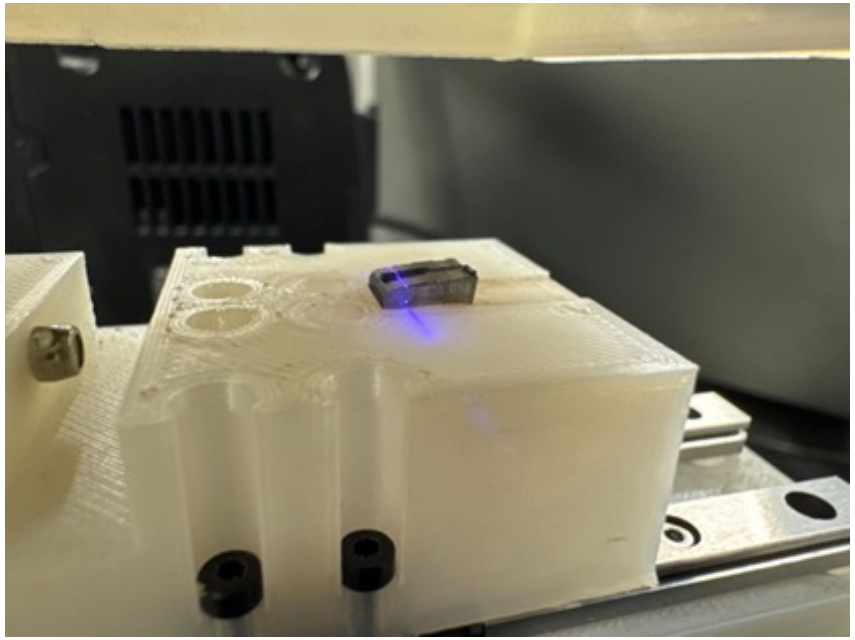


Step #1: Introduce microfracture

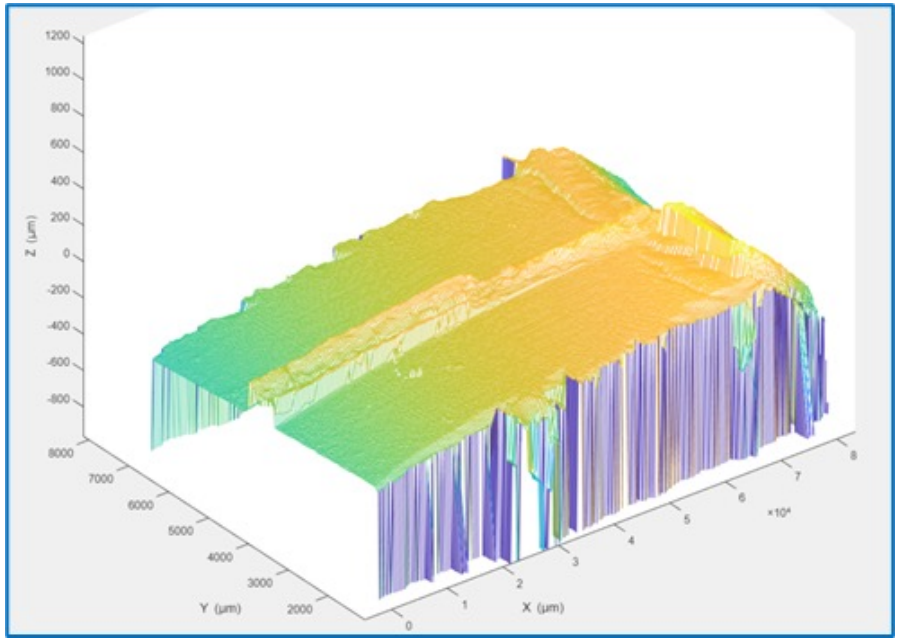


Step #2 Ligament Height Processing

- Ligament height is measured using a laser scanning system.

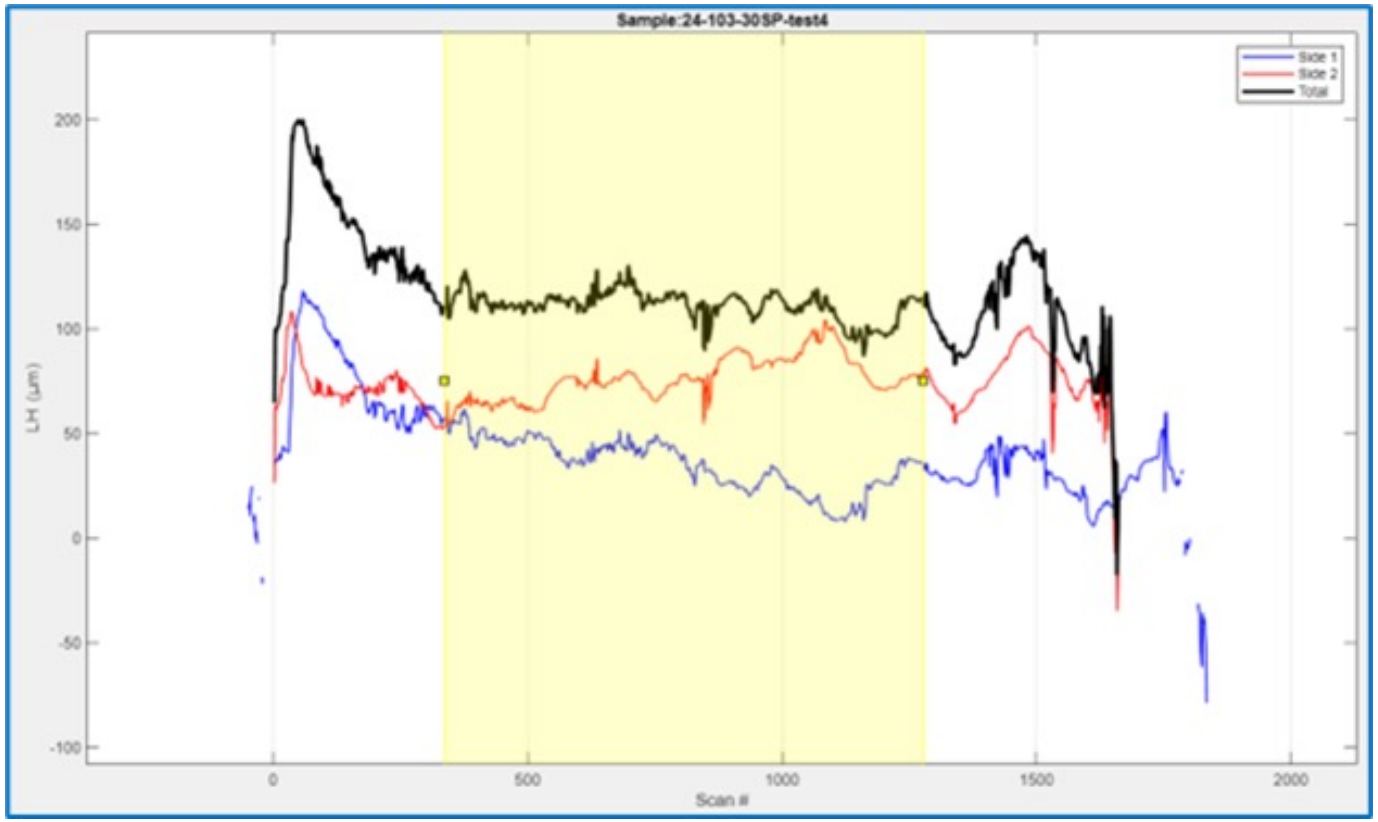


Laser Scan Platform



Reconstructed Ligament Profile

Step #2 Ligament Height Processing



Ligament Height Processing

- Ligament height on two sides are aligned and combined.
- Region with stable combined ligament height is selected (highlighted in yellow). Average of ligament height within the region is calculated.

Step #3 Physical Model

- According to Oh [1], there is a correlation between the fracture toughness (K_{Ic}) and the toughness measured using the area under the tensile stress-strain curve up to the elongation at break (K_f):

$$\left(K_{Ic}/\sigma_y\right)^2 = \alpha \left(K_f/\sigma_y\right)^2$$

- K_f can be estimated using the yield strength, ultimate tensile strength (σ_u), and elongation at break (ε_f):

$$K_f \approx \varepsilon_f \left[k\sigma_y + (1-k)\sigma_u\right], \qquad 0 < k < 1$$

- Hypothesis: the ligament height (LH) is linearly proportional to the elongation at break considering the material within the stretch passage is subjected to predominantly tensile stress and stretched to failure:

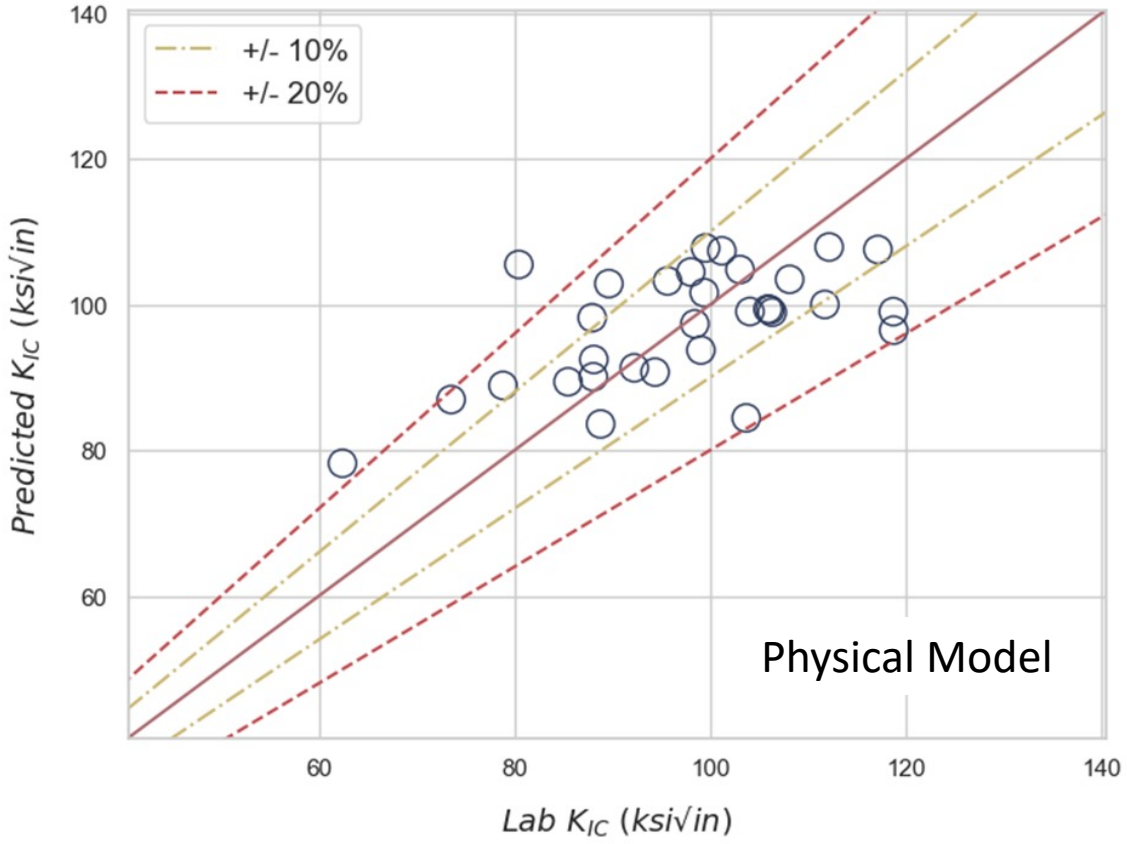
$$\varepsilon_f = a * LH + b$$

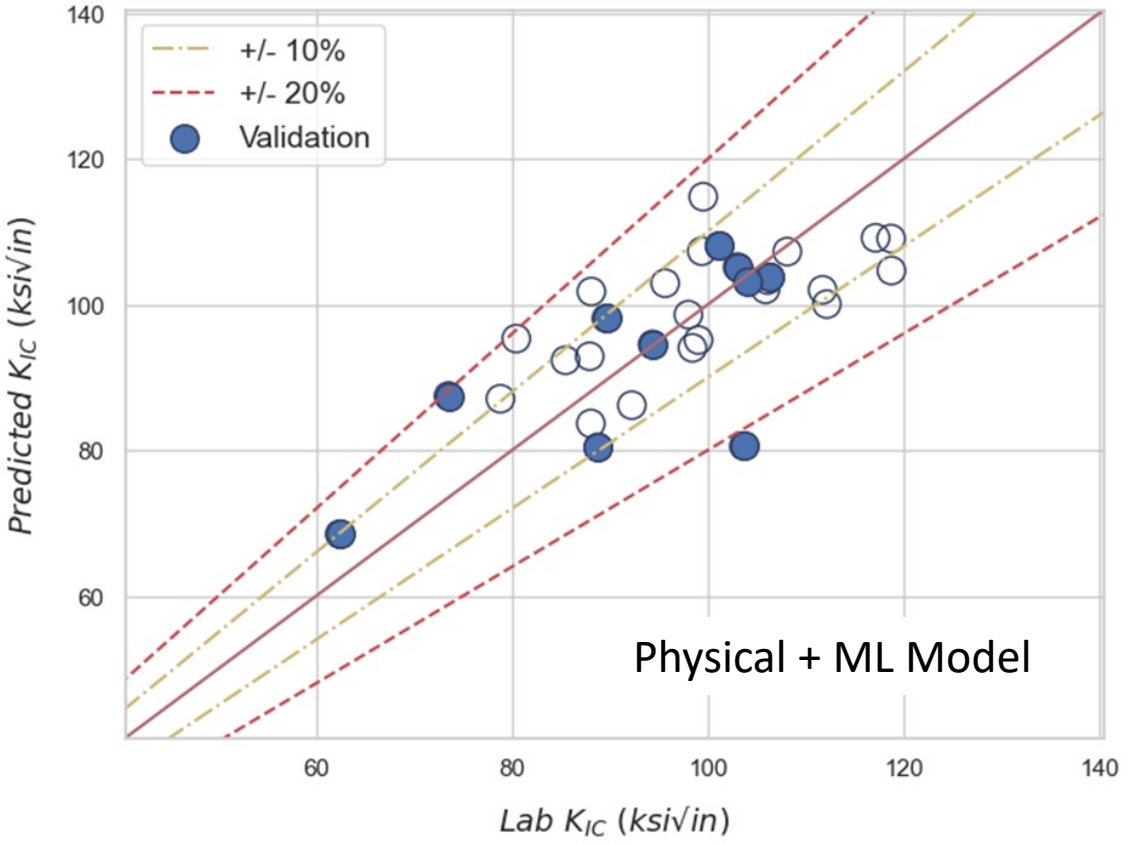
- Proposed correlation between K_{Ic} and ligament height:

$$K_{Ic}/\sigma_y = C_1 * \left[k + (1-k)\sigma_u/\sigma_y\right] * LH + C_2/\sigma_y + C_3$$

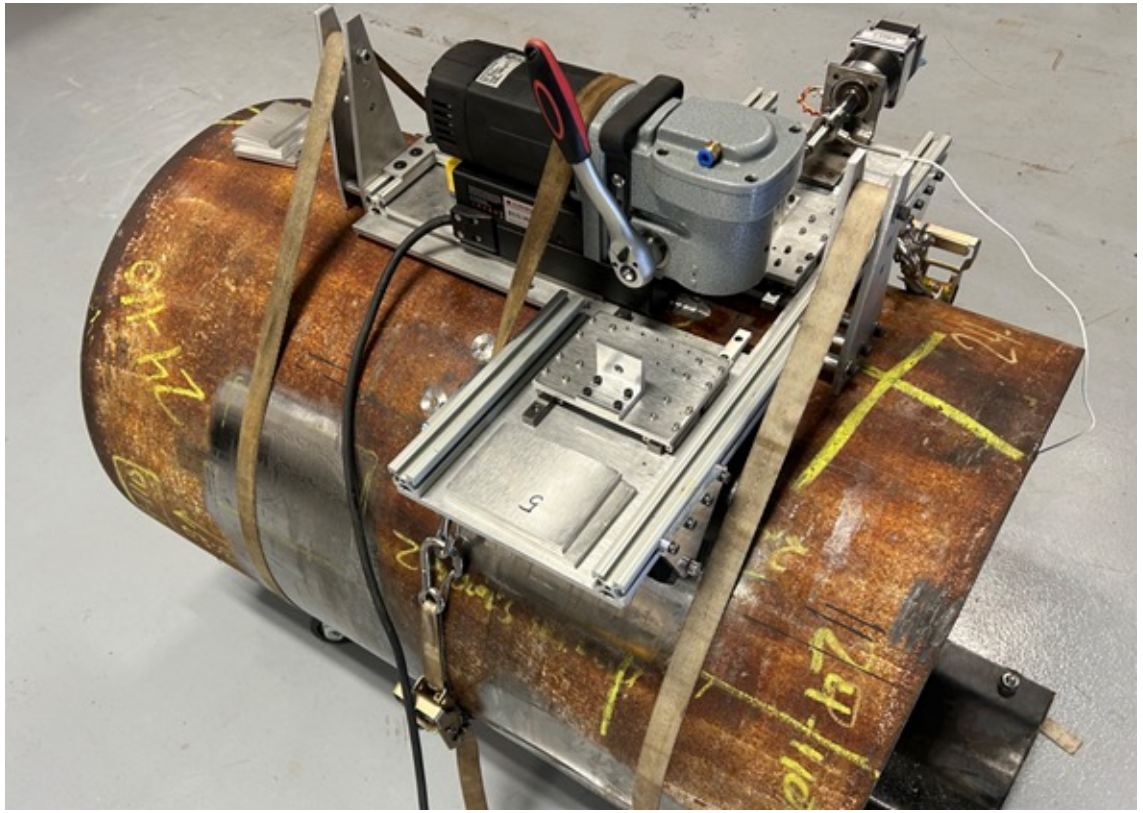
[1] Oh, Gyoko. "A simplified toughness estimation method based on standard tensile data." International Journal of Pressure Vessels and Piping 199 (2022): 104733.

Validation Results





The Blade Toughness Meter (BTM) Prototype

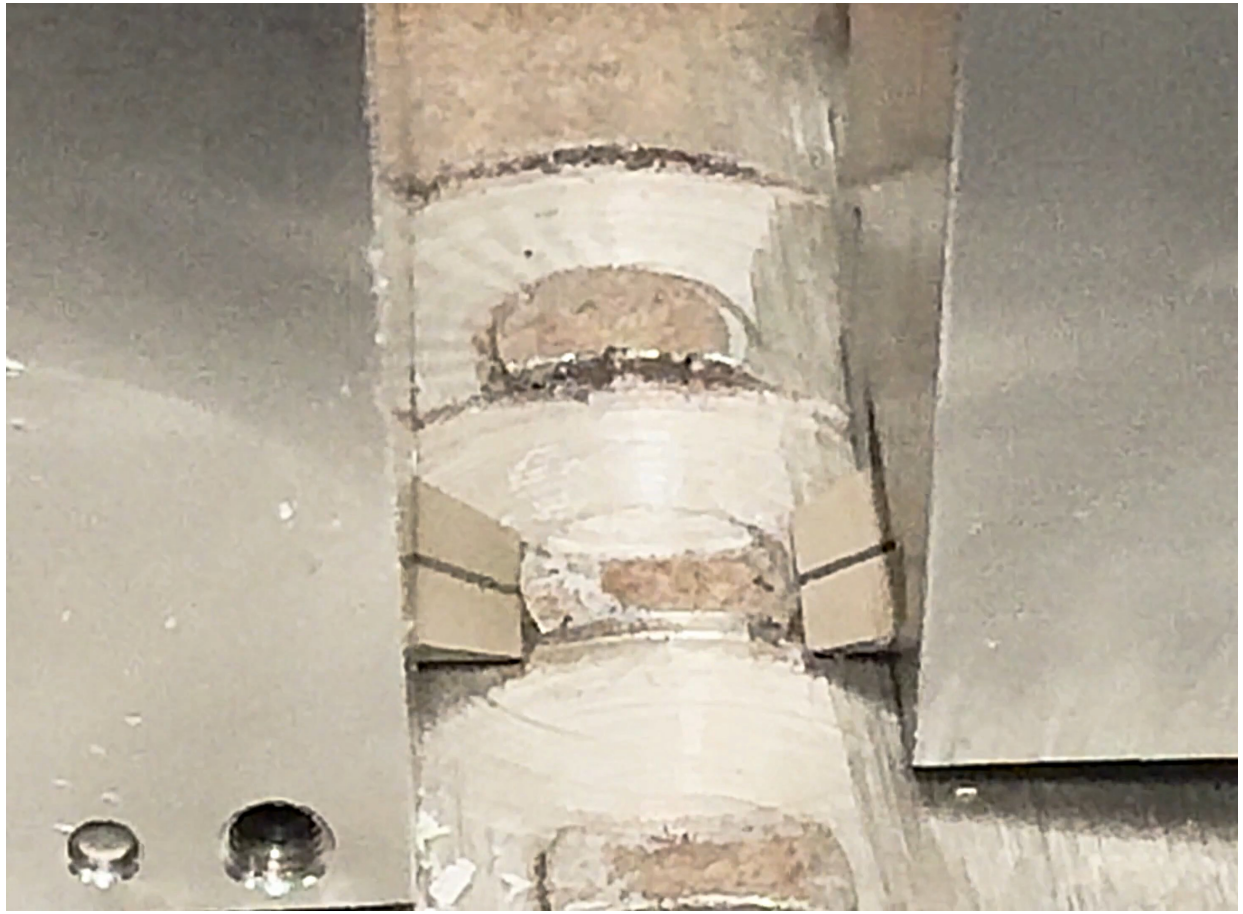


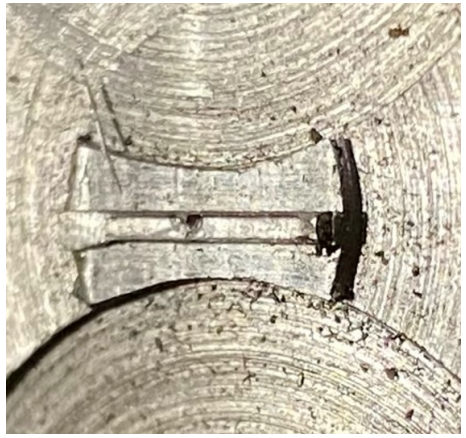
Field Prototype of Blade Toughness Meter (BTM)

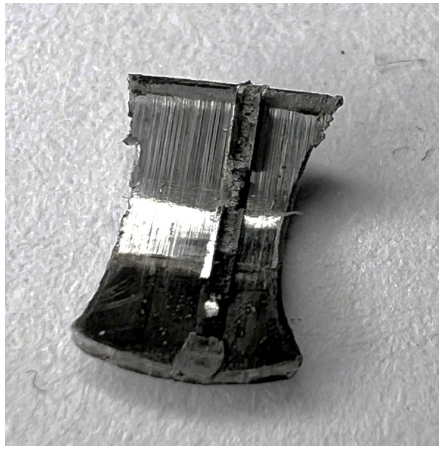
1. Surface prep: island making

2. BTM testing

Tester in Action

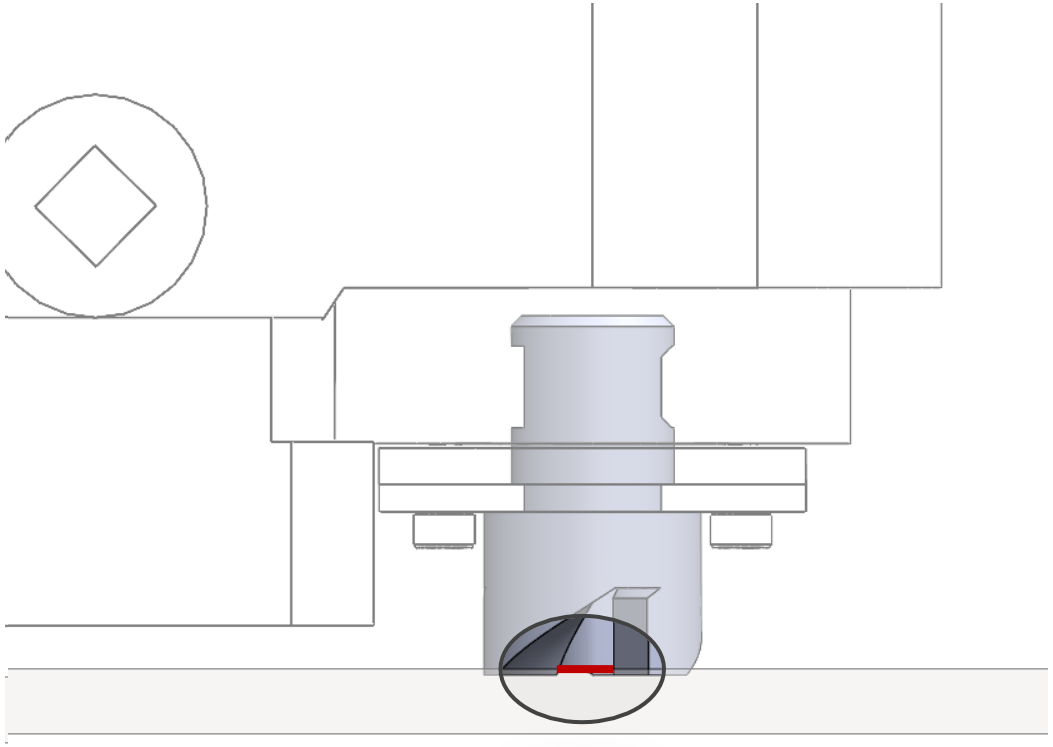




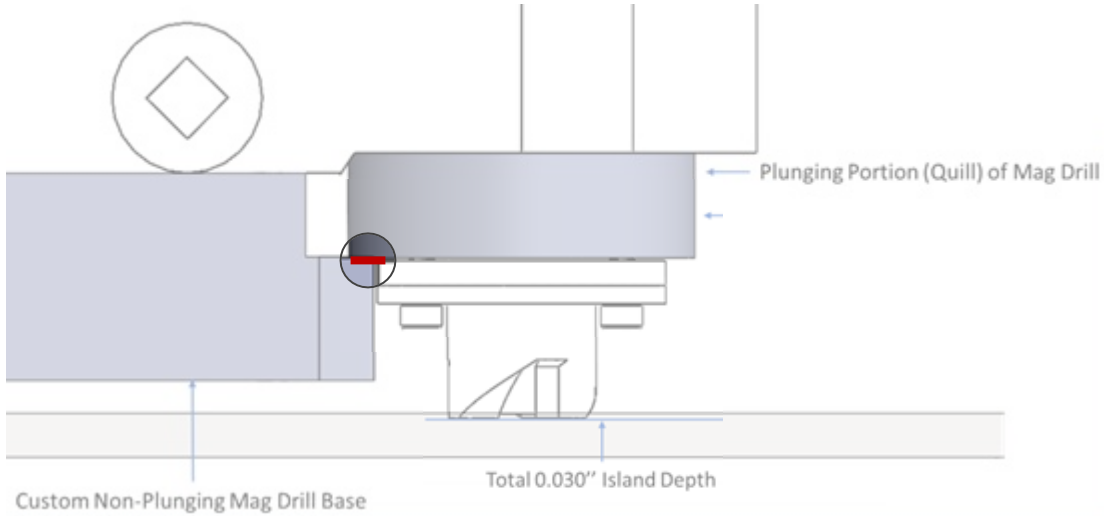


Field Prototype Safety Features

Non-Plunging End Mill

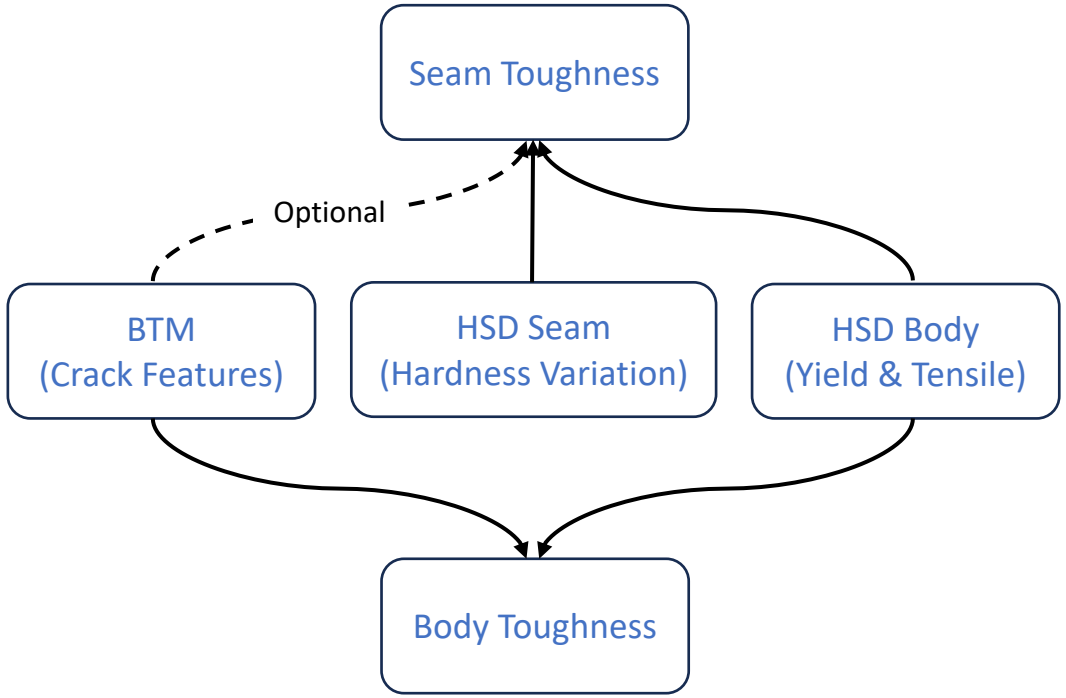


Physical Limit Stop

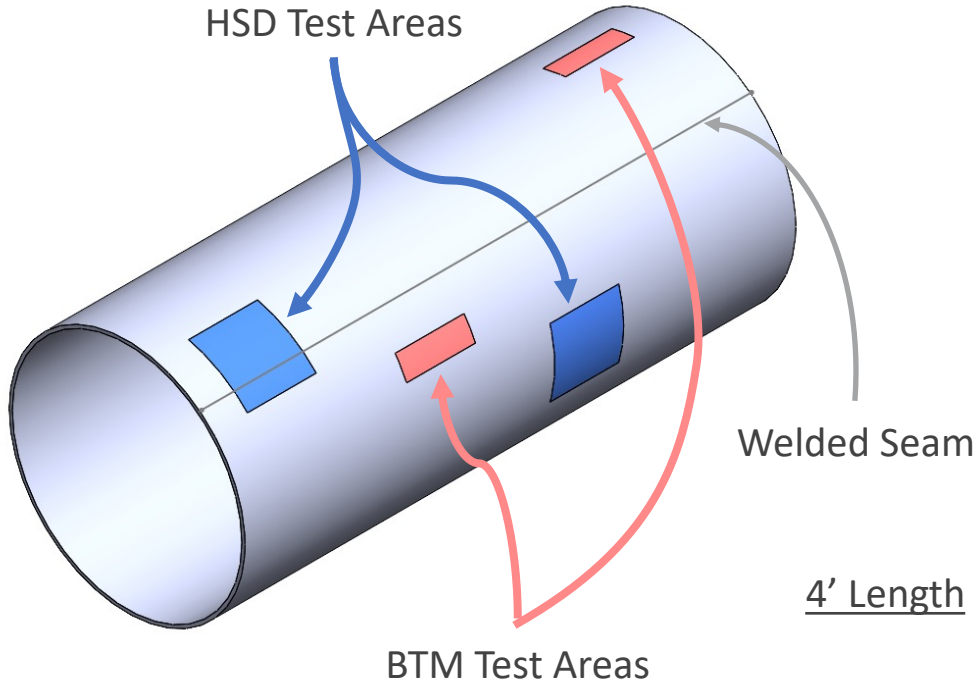


Field Implementation

Data Integration



In-Field Testing



Conclusions and Future Work

- A microcrack is introduced into the test sample using a special blade with a stretch passage.
- Features of the microcrack such as ligament height are extracted and correlate to the fracture toughness of the material.
- Preliminary result from a validation test of 33 vintage pipe samples shows predicted K value within ±20% of lab tested value.
- A prototype unit is developed and will be used in a coming JIP. Plan to test ~250 pipe samples. This will provide more data to the ML model and improve model accuracy.
- An in-situ, minimally invasive test to determine fracture toughness will help operators make better decisions on pipe repair, enhancing safety while reducing unnecessary costs.

Thank You

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