REX2024
PRCI Research Exchange

In-Situ Measurement of Fracture Toughness using the Planing-Induced Microfracture Method

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San Diego, California

February 27, 2024

PRCI LEADING PIPELINE RESEARCH

Pipeline Research Council International

PRCI Led Innovation on NDE for Pipe Toughness

Including

PR-335-173816-R01 Validation of In-Situ Methods for Material Property Determination

Author(s)	Scott Riccardella, Jason Van Velsor, Aaron Dinovitzer, Bill Amend
Research Contractor	Structural Integrity Associates, Inc., BMT Fleet Technology Limited, DNV Inc. (research contractor)
Release Date:	09/14/2018
Number Of Pages	398
Catalog No:	PR-335-173816-R01
DOI No:	https://doi.org/10.55274/R0011521

PR-610-183867-R01 Fracture Toughness via In-ditch Non-destructive Testing - Validation

Author(s)	Steven Palkovic, Yasamin Salamat, Brendon Willey, Simon Bellemare
Research Contractor	Massachusetts Materials Technologies LLC - 610
Release Date:	09/08/2020
Number Of Pages	94
Catalog No:	PR-610-183867-R01
DOI No:	https://doi.org/10.55274/R0011802

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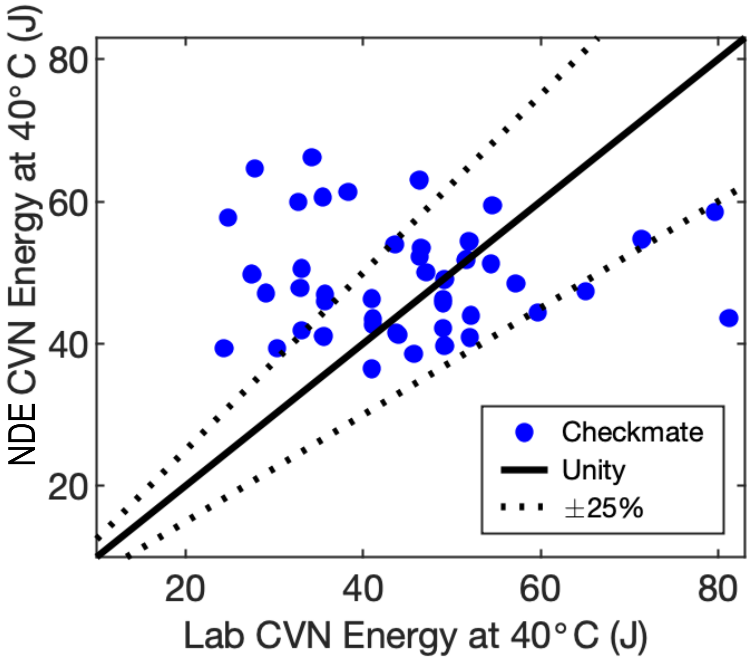
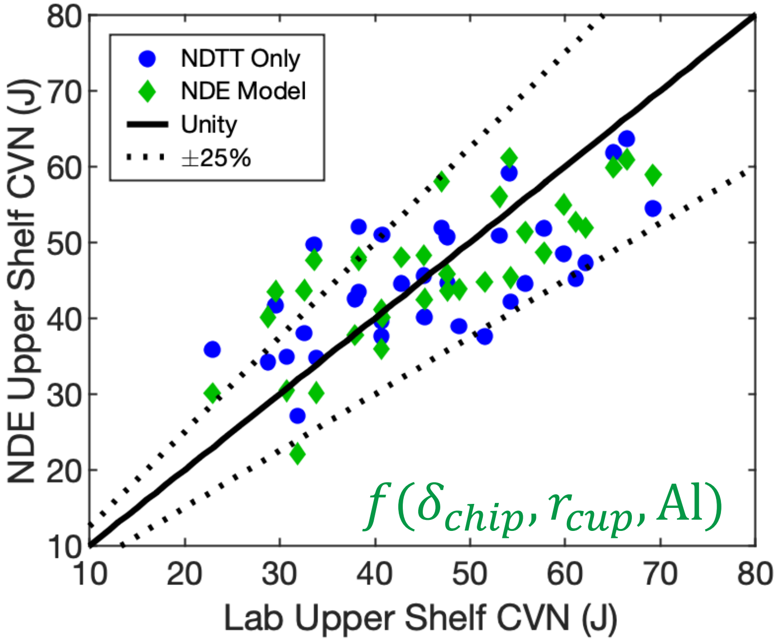
Published Pipe Toughness NDE Correlations

NDE 4-8
NDE-4C Model
(Hardness + micrographs + chemistry)



NDE 2-9
Regression Models
(NDTT $\delta_{chip} + r_{cup} + \mathrm{Al}$)



It has no Been Easy… (Low TRL)

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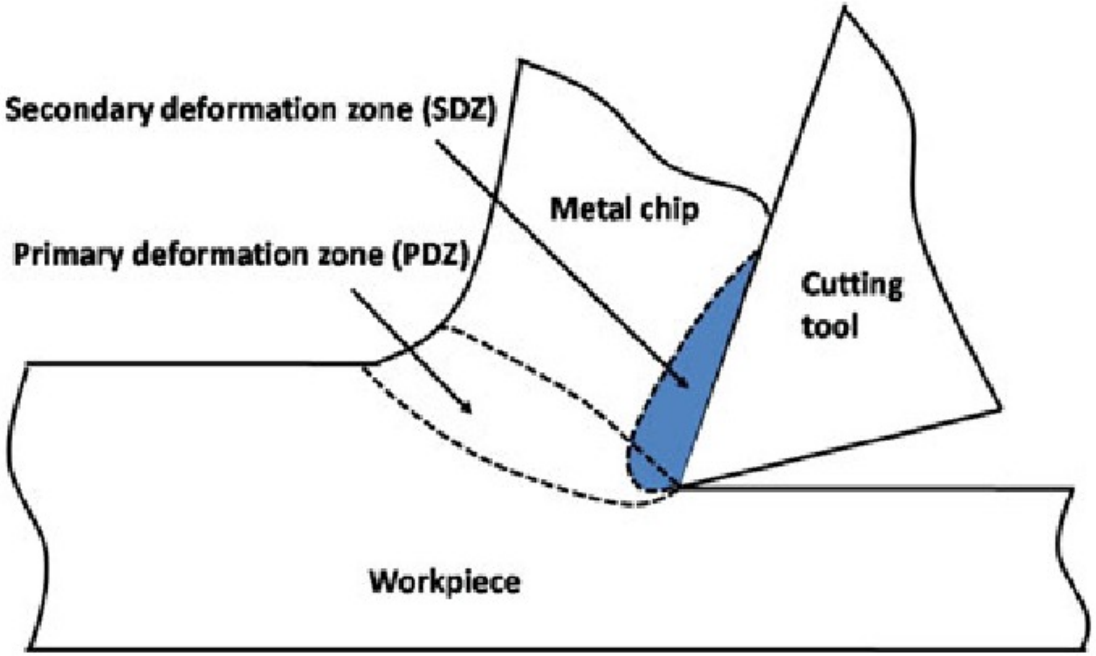
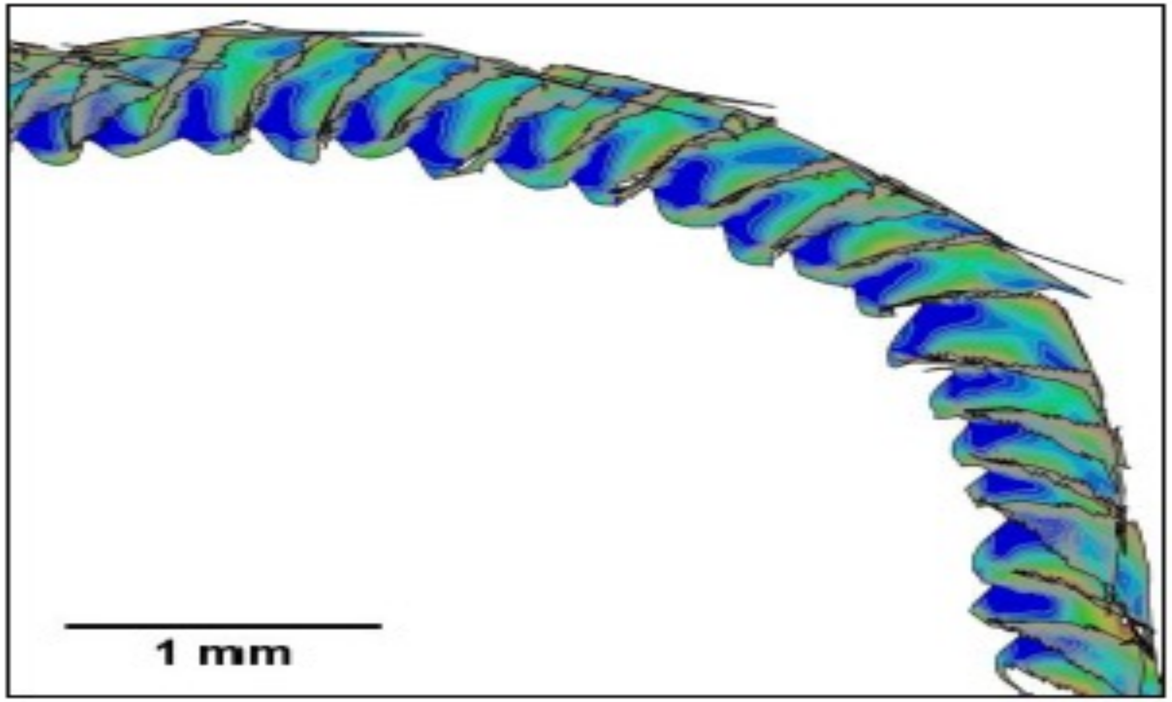
Unresolved Challenge with NDTT

Expected: Shear Zone



Recent Modeling Research on Cutting (U. of Central Florida, Texas A&M, etc.)



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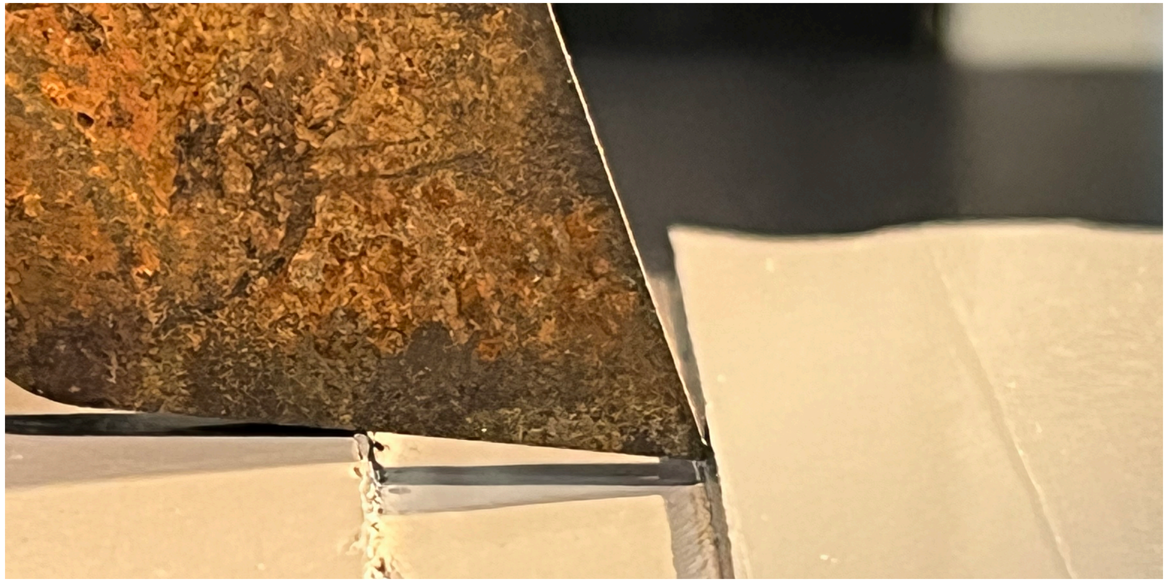
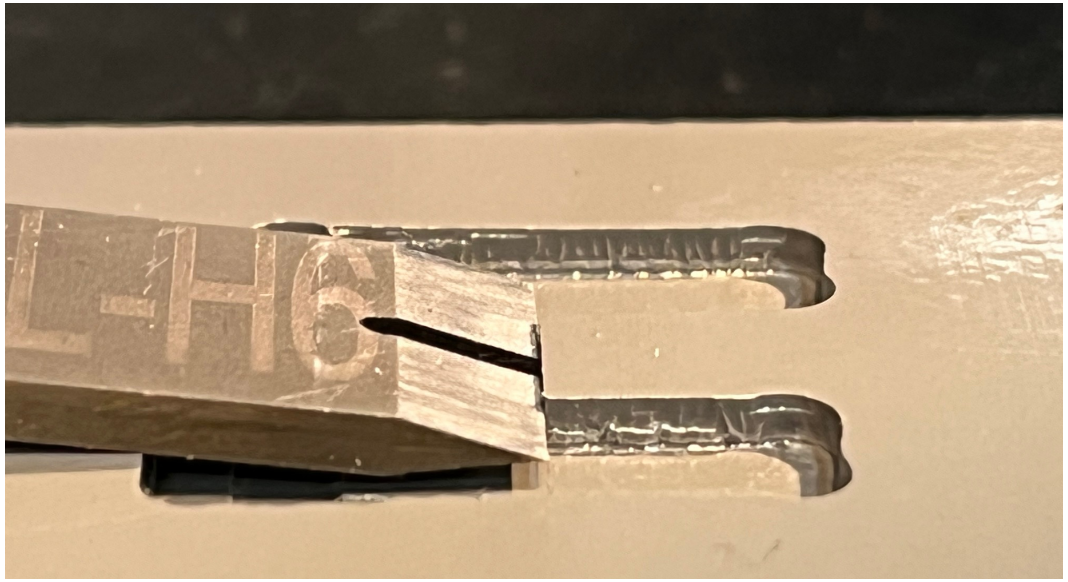
MMT Technology Pivot

2015: Micromachining



2022: Planing-Induced Microfracture



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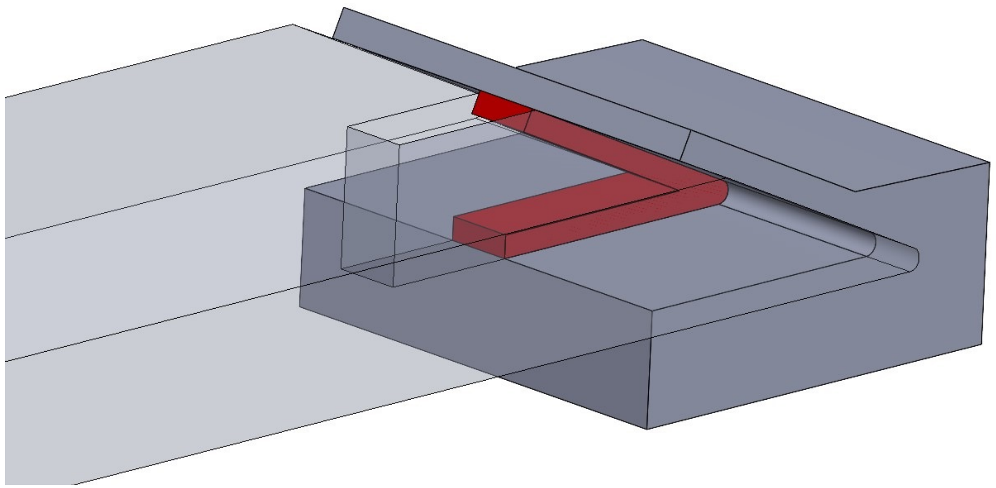
Planing-Induced Microfracture



- Material is stretched and then it fractures
- There is a fractured ligament on both sides that protrudes from the cutting plane

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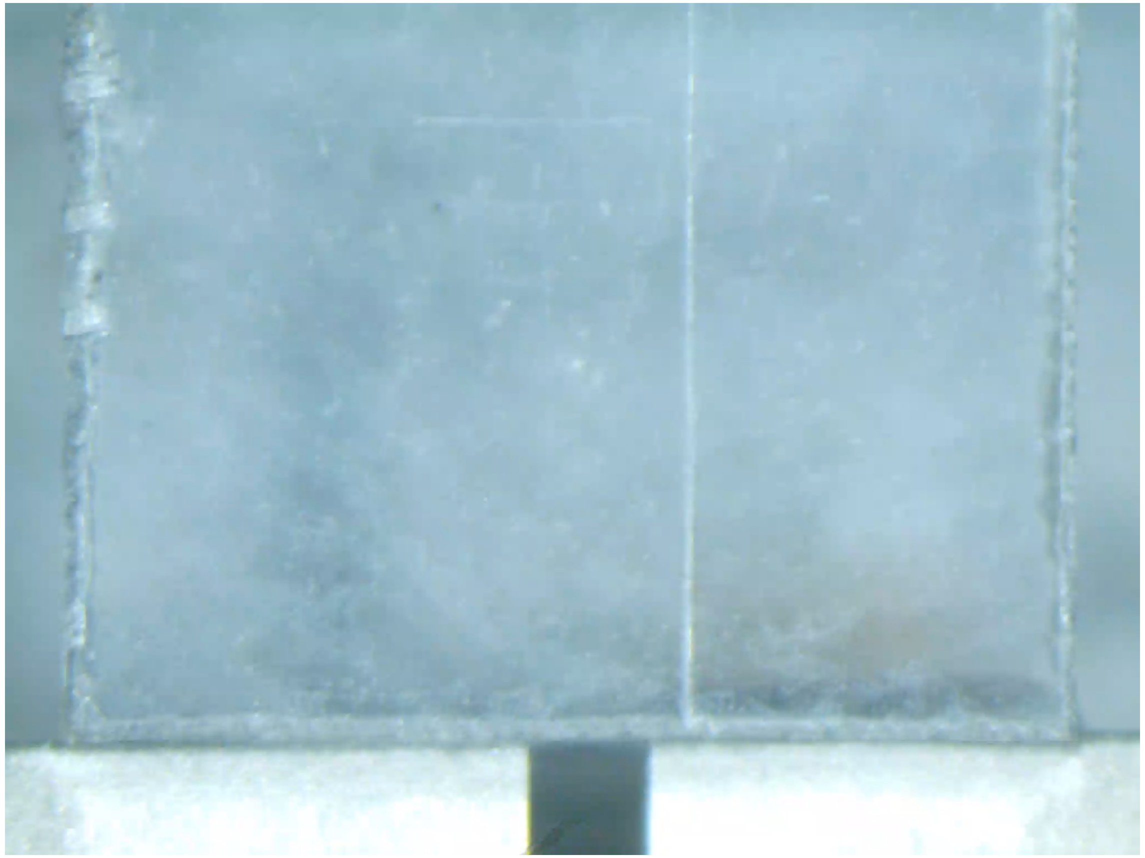
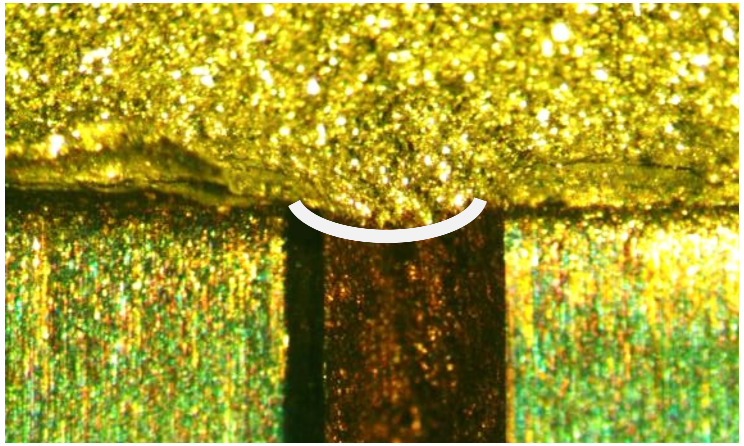
Planing-Induced Microfracture in Action

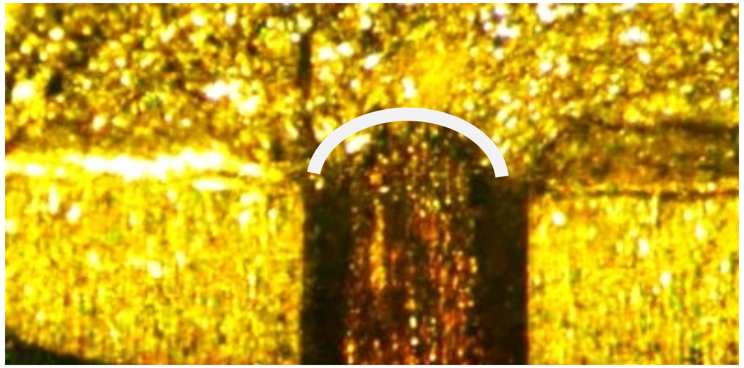


Blade Movement

High Pipe Toughness



Lower Pipe Toughness



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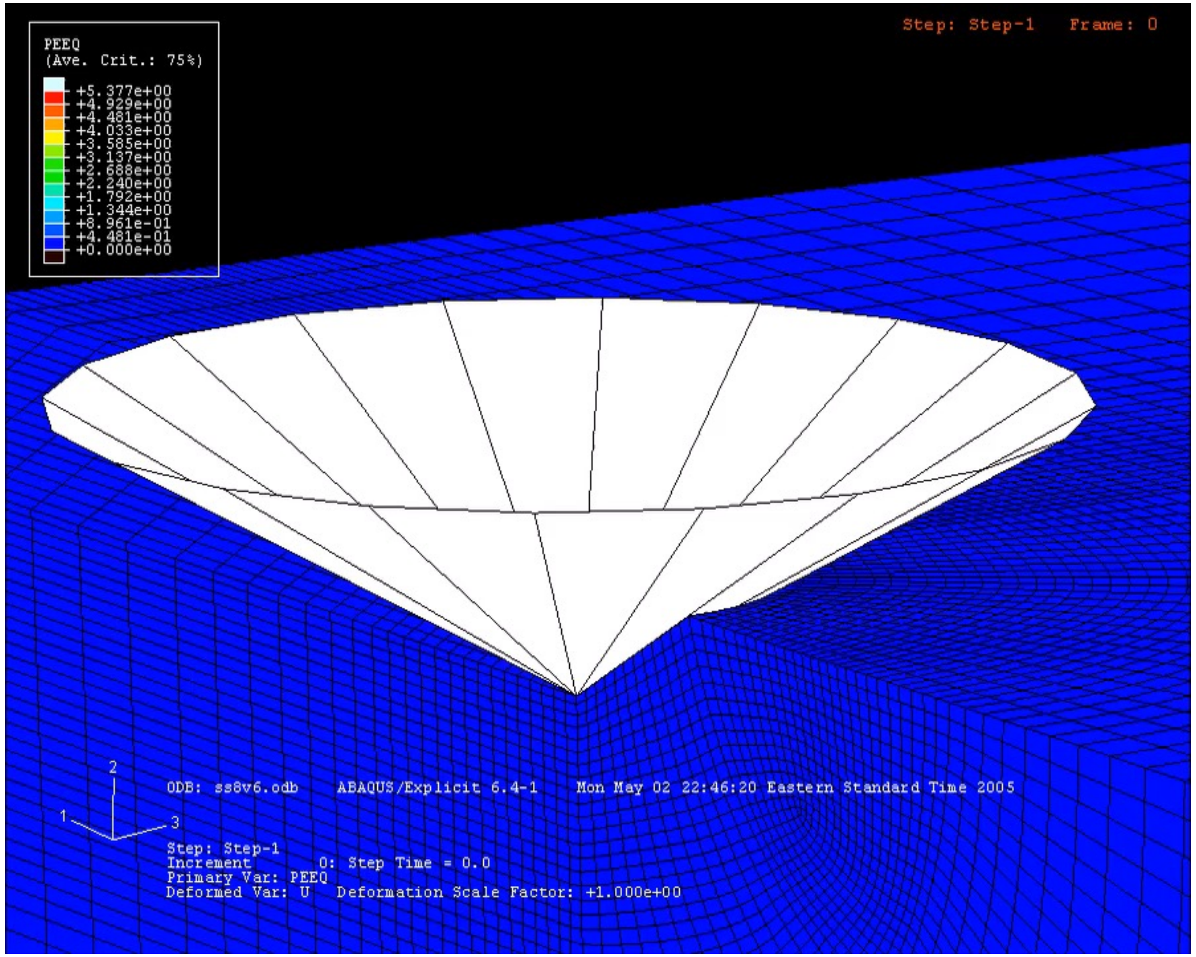
General Learning Moment 1

In Elasto-Plastic Contact Mechanics,

What Does Steady State Means?

No Longer Path Dependent



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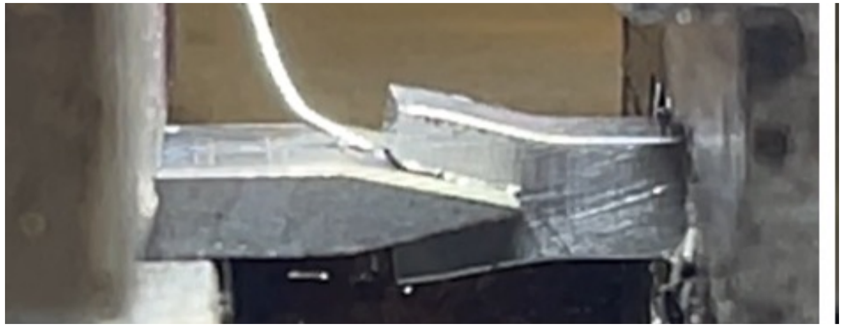
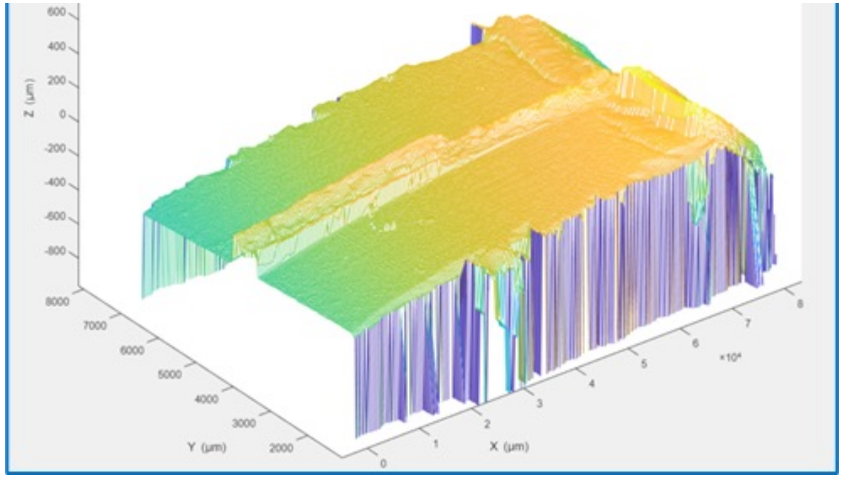
Proof of Concept for the Method

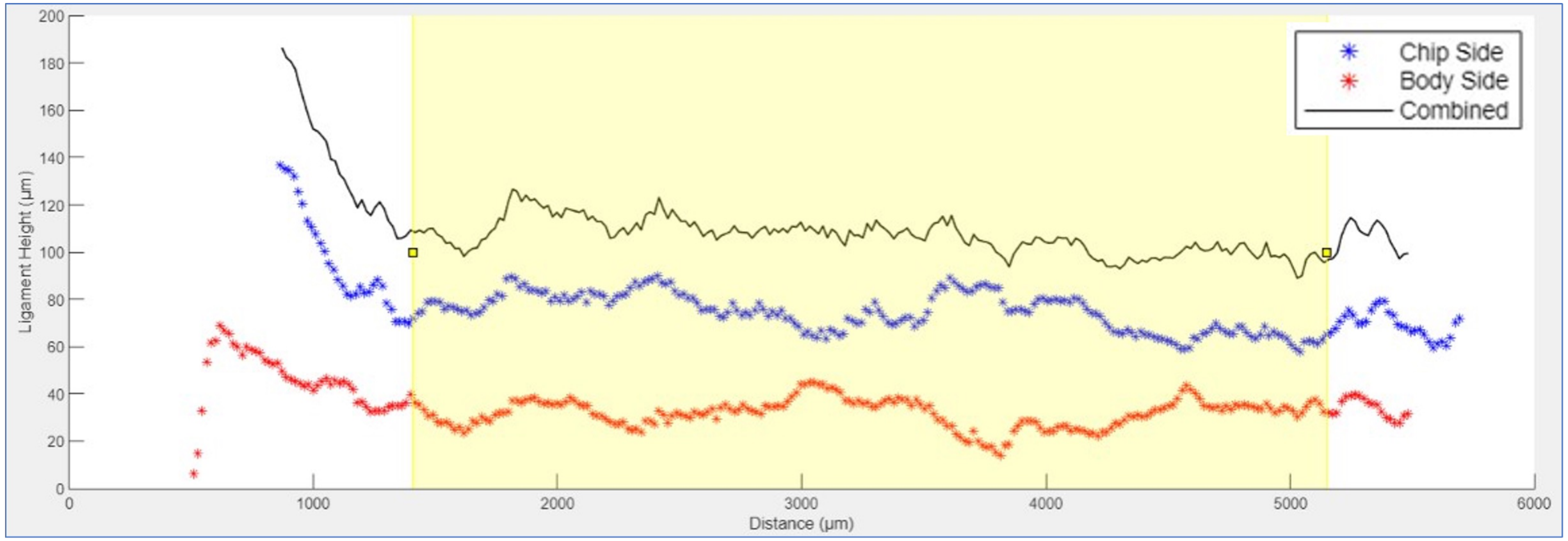
Step #1: Introduce microfracture



Step #2 Scan Ligaments



Step #3 Assemble



Blade Travel Distance

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Step #4: 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):**

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

- **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.

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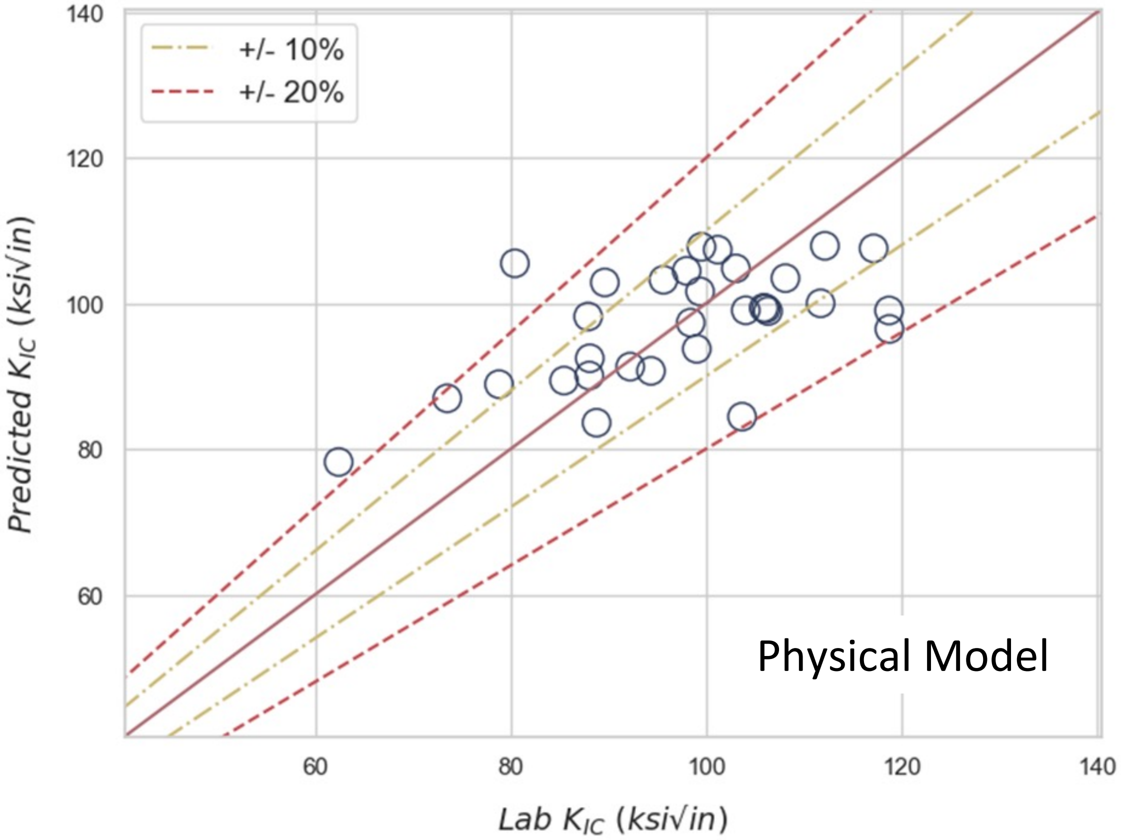
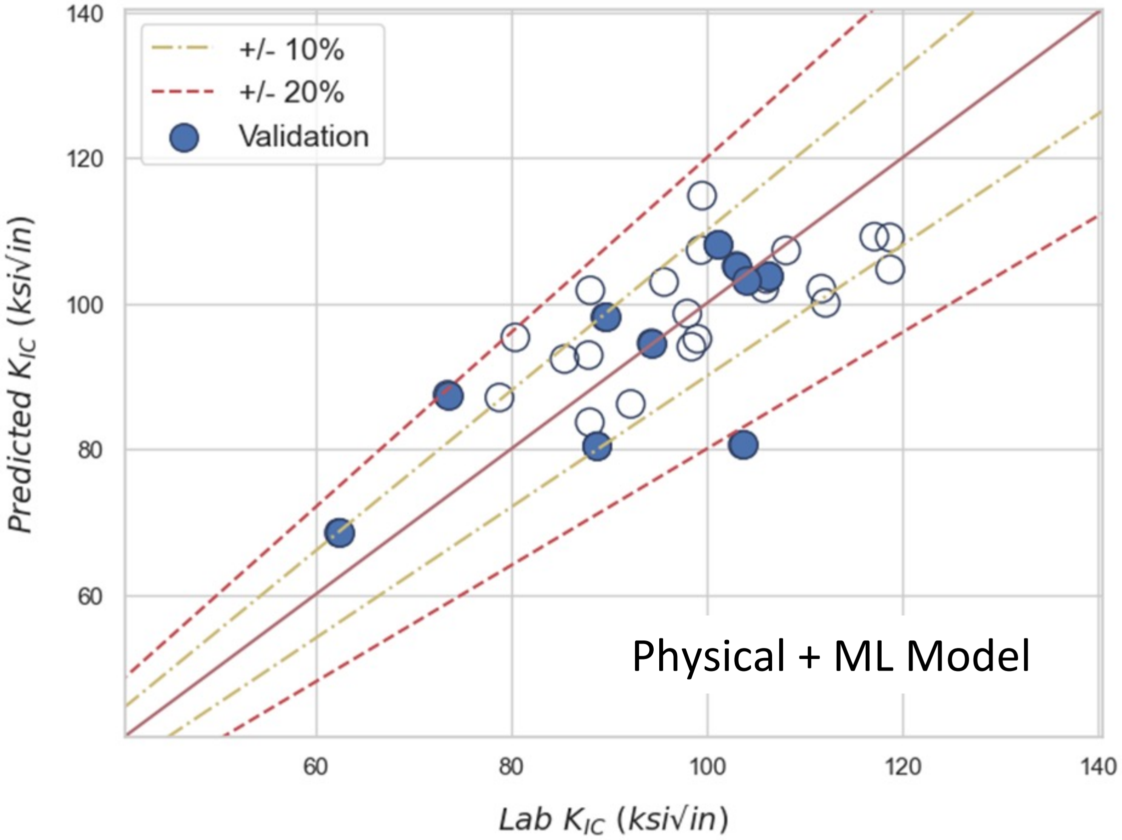
Validation Results





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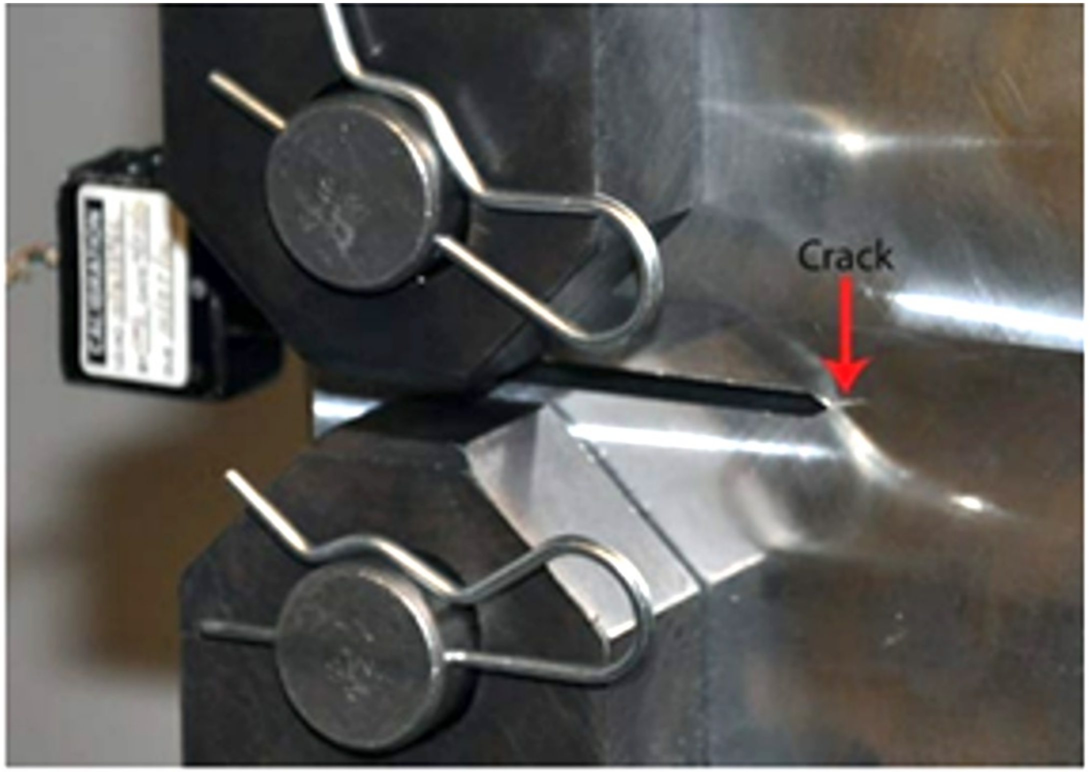
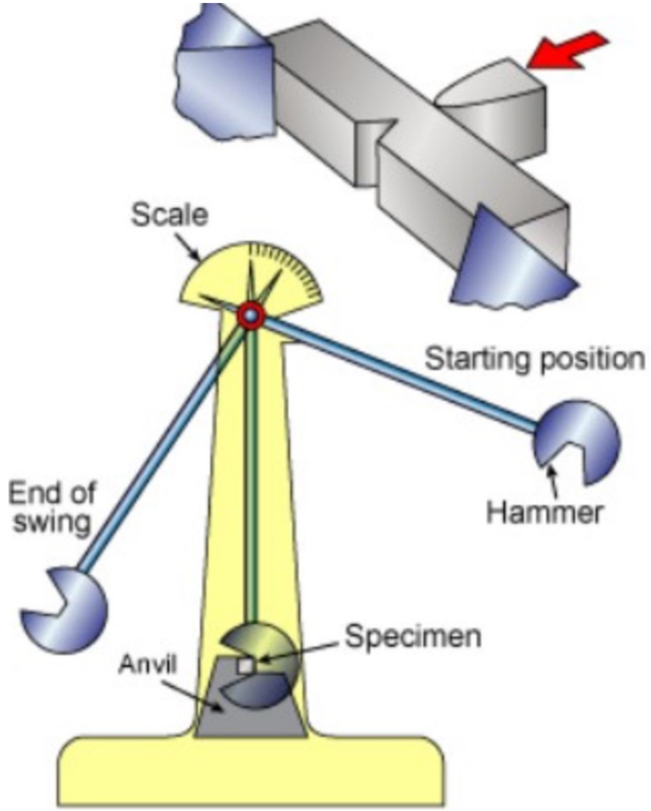
General Learning Moment 2

The direct measurement:
Fatigue pre-cracked



Indirect measurement:
Impact Energy



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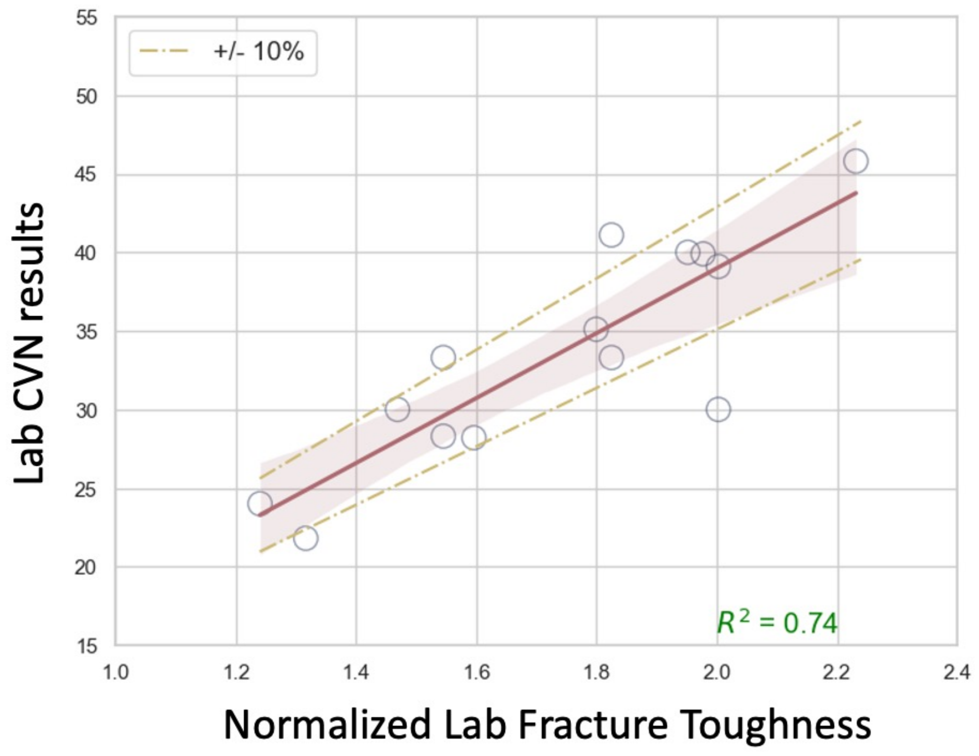
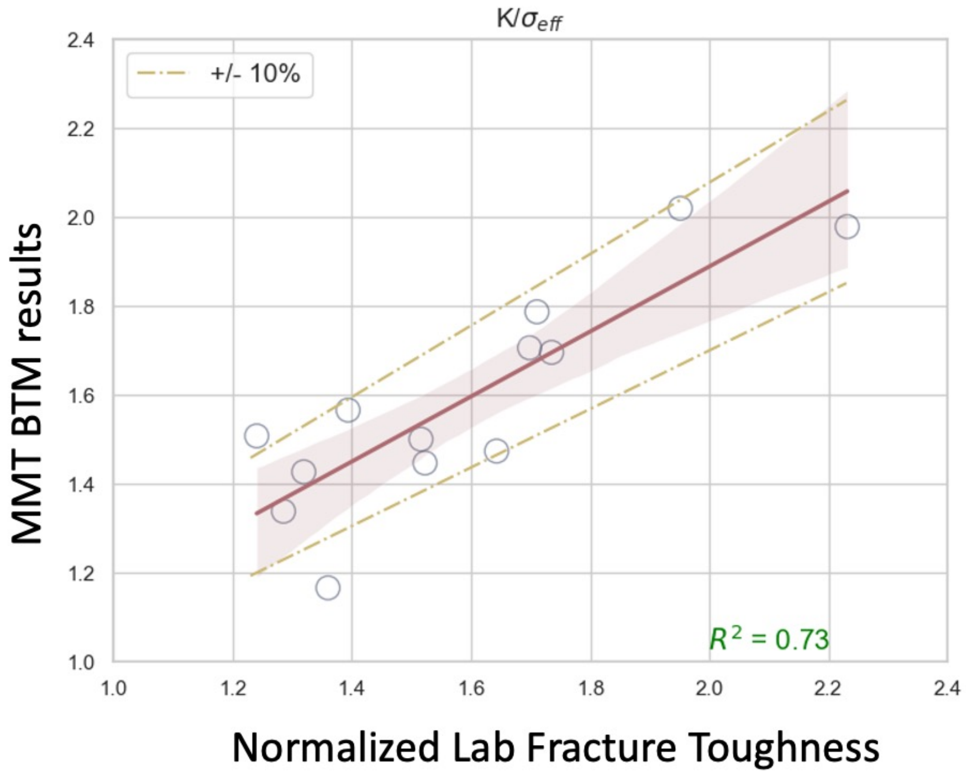
Benchmark Comparison

X-Axis = Direct Measurement

Using same pipe samples





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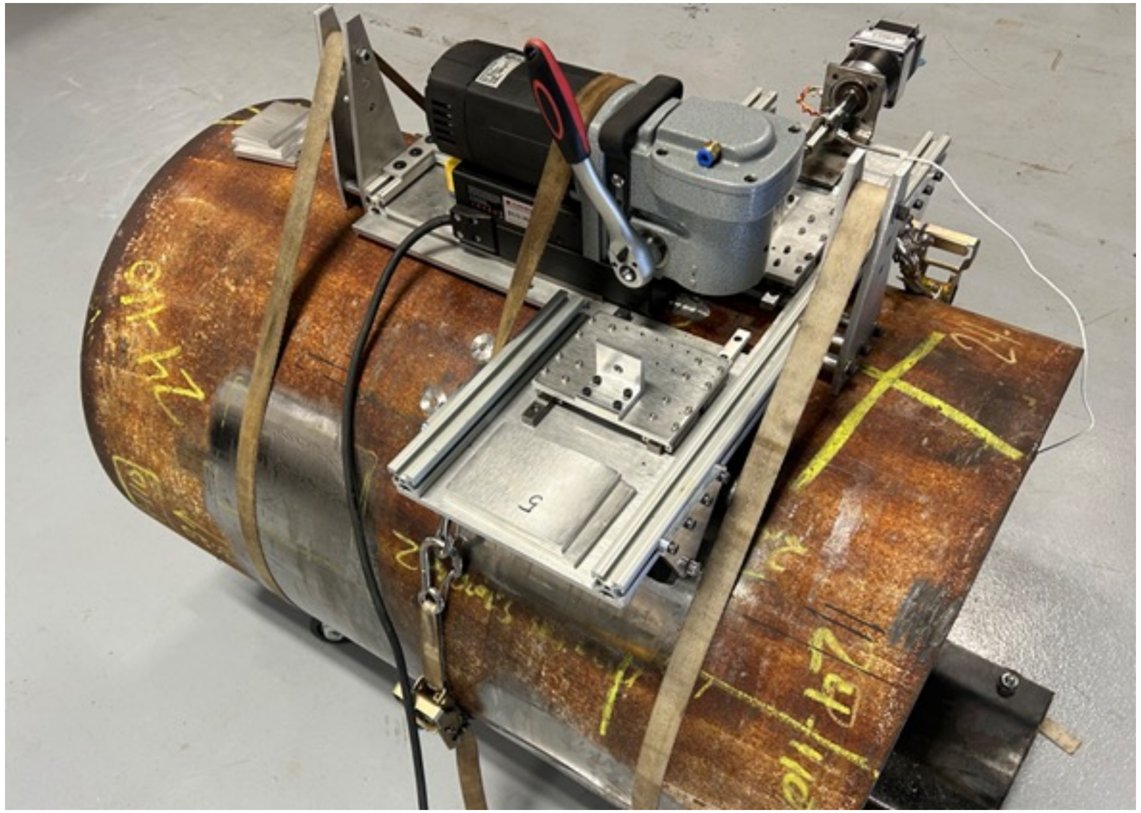
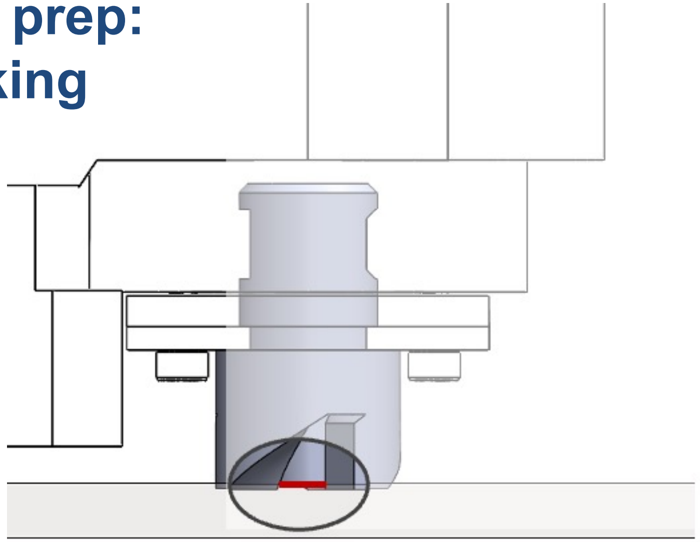
The Blade Toughness Meter (BTM) Prototype



Field Prototype 2024 Q2

A. Surface prep:
island making



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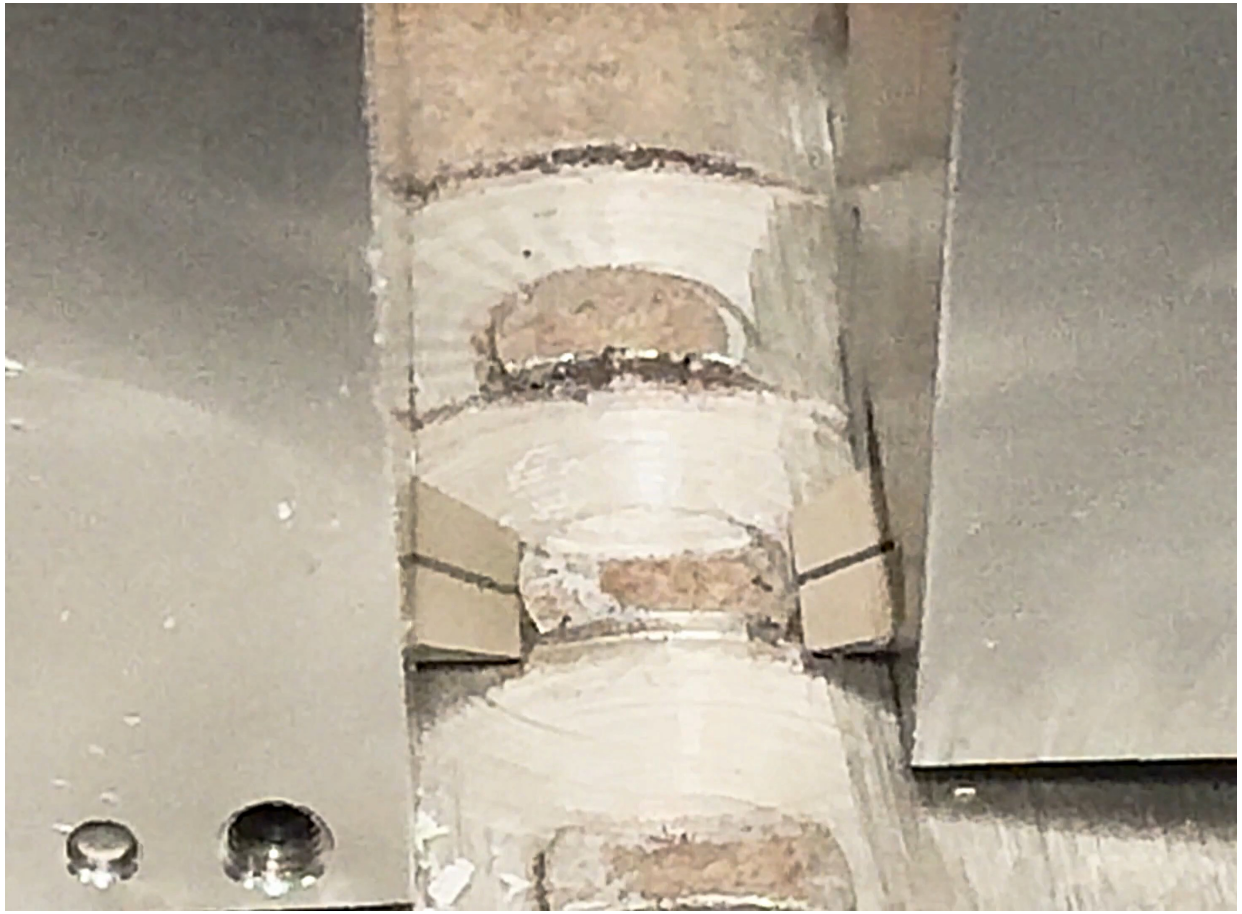
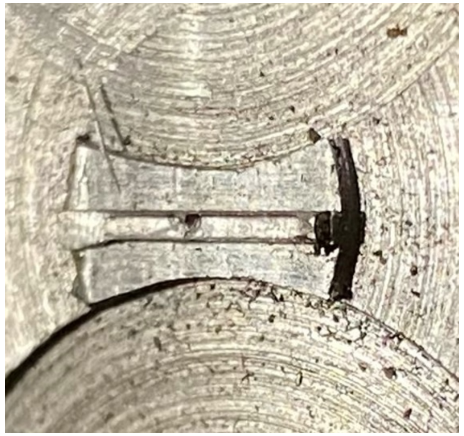
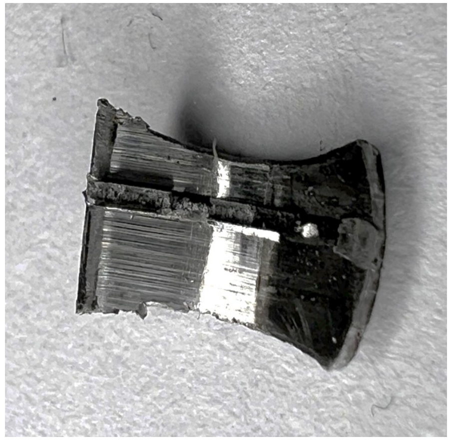
Test in Action

B. Island Removal



C. Ligament Analysis





>>> BTM Report (~Strain to Failure)

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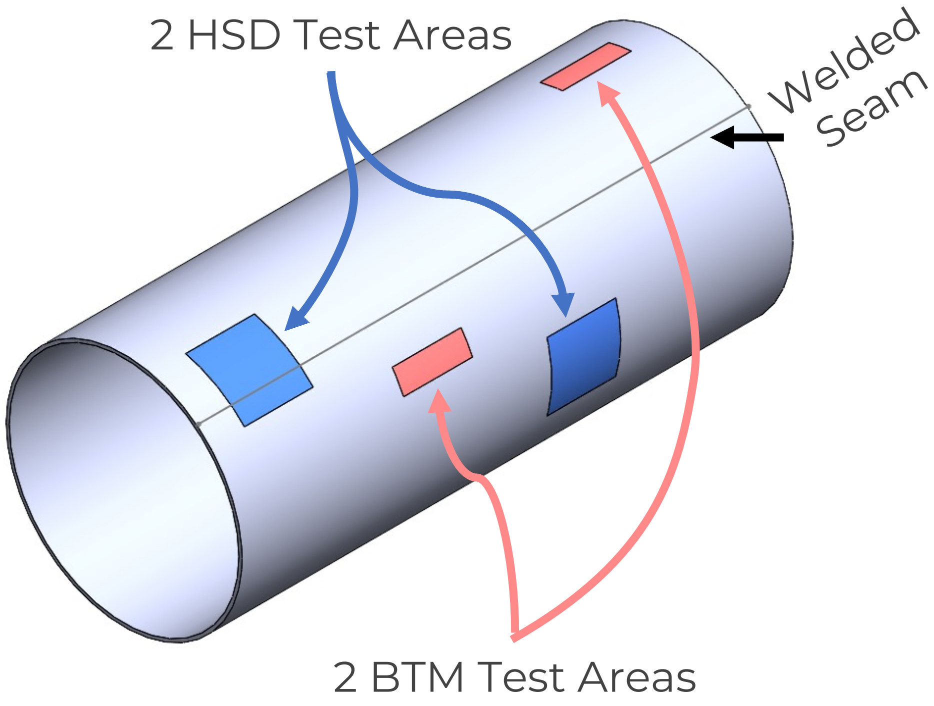
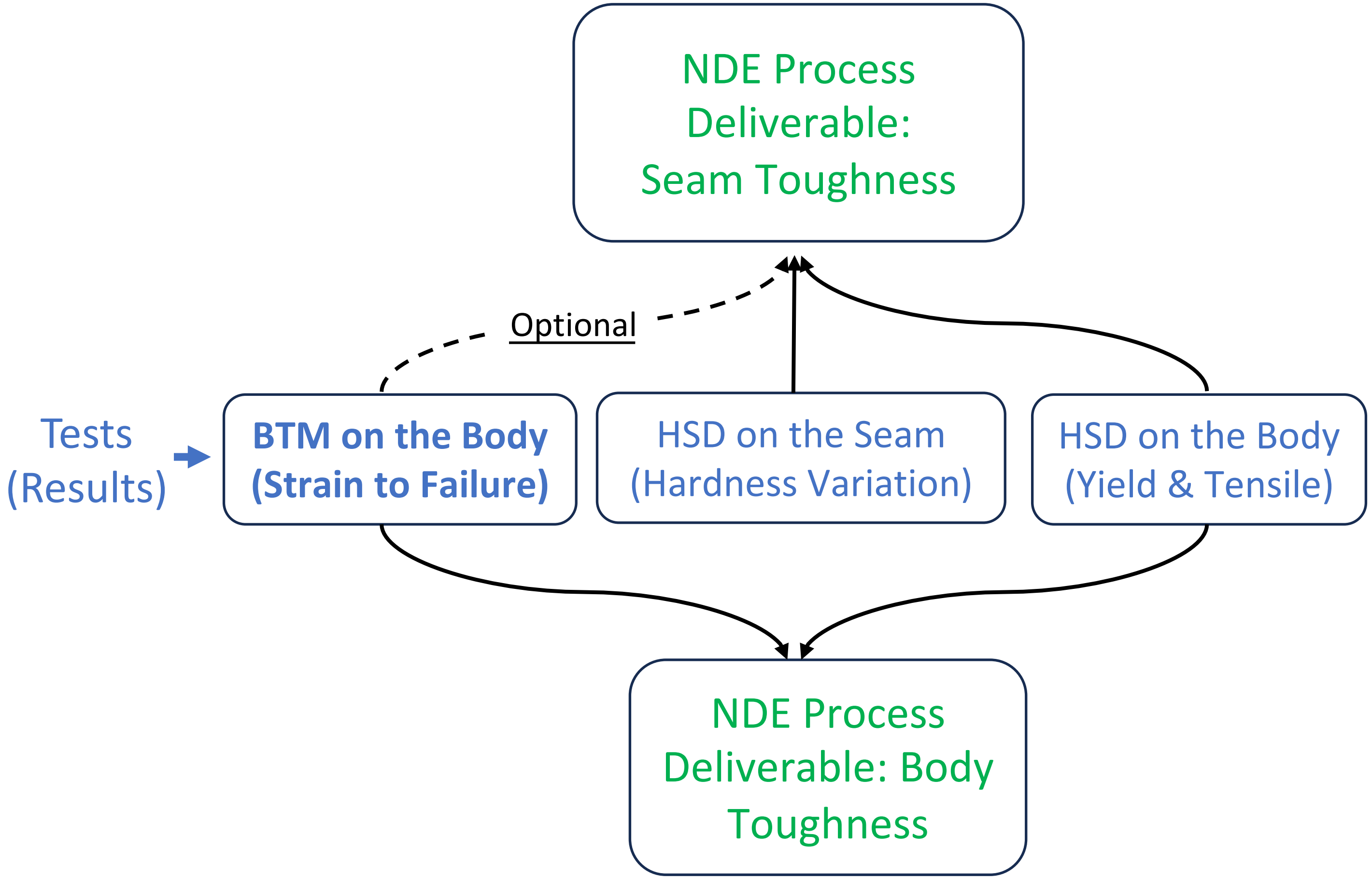
Field Implementation: Two Complementary Tools

In-Field Test Matrix





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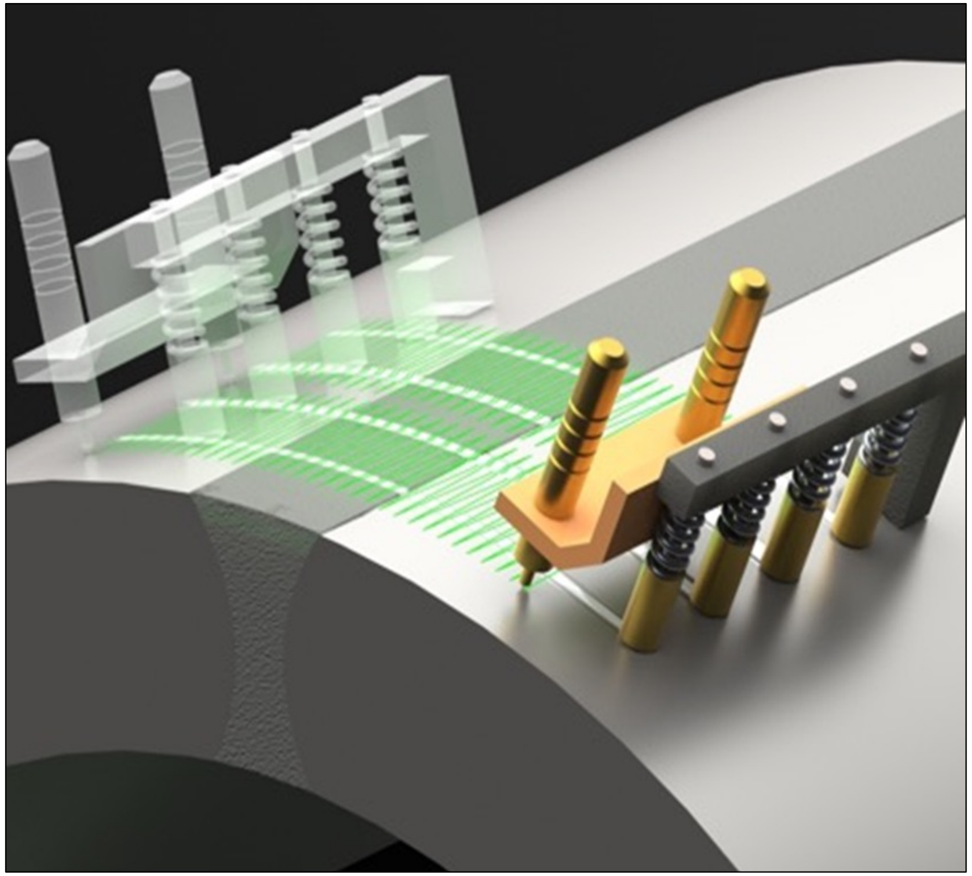
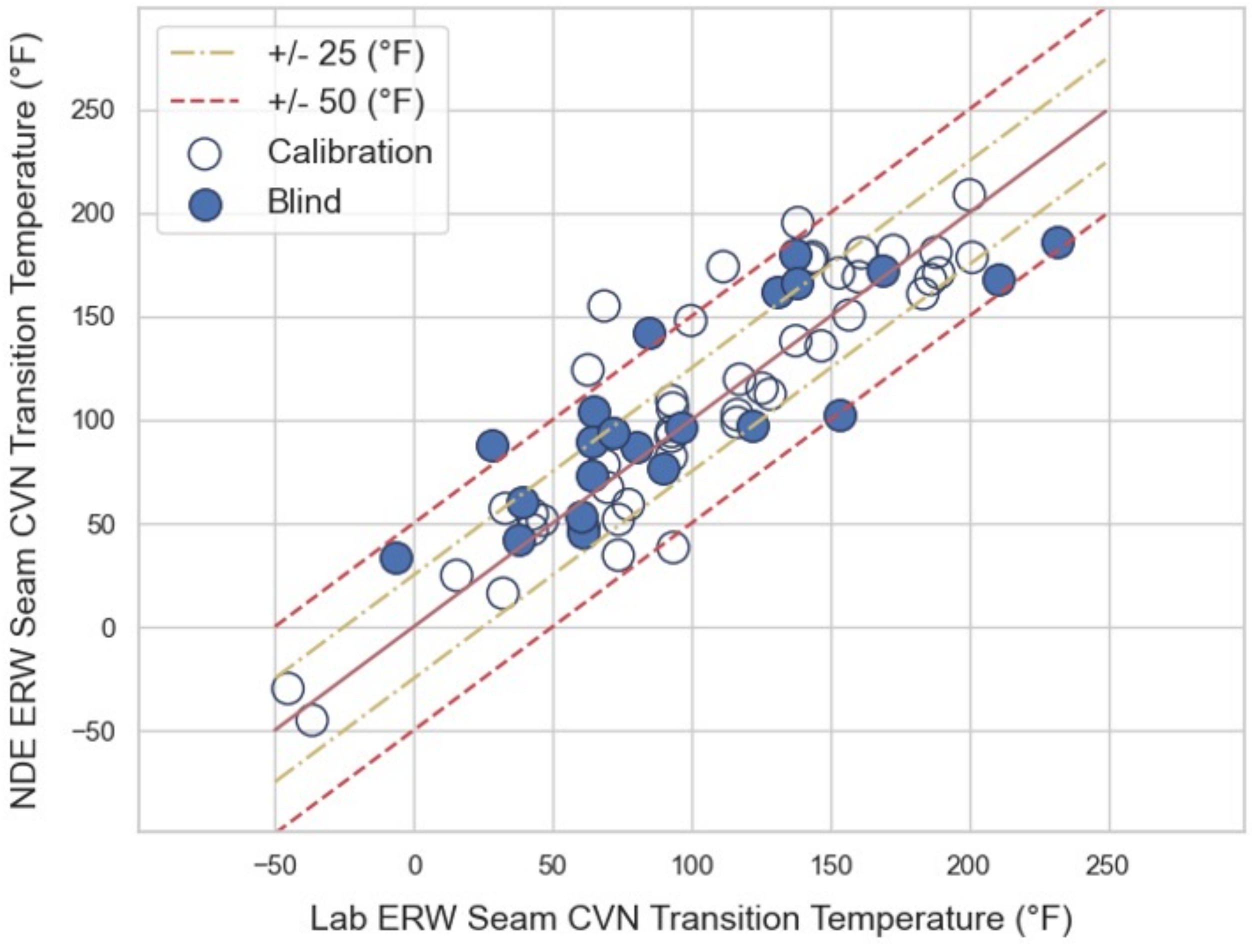
ERW Seam Testing with the Current HSD





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Technology Status

- BTM is approximated twice as accurate as NDTT.
- Preliminary result from a validation test of 30 vintage pipe samples shows an average predicted K value within ±20% of the average tested value.
    - Typical practice of taking lowest value of 3 measurements to be discussed.
- A prototype unit is developed and will be used in upcoming additional validation work and field trials.
- HSD and BTM are complementary tools for a complete solution.
- The HSD today (field procedures) includes the ability to receive a report for the 85% shear transition temperature & conservative upper shelf.

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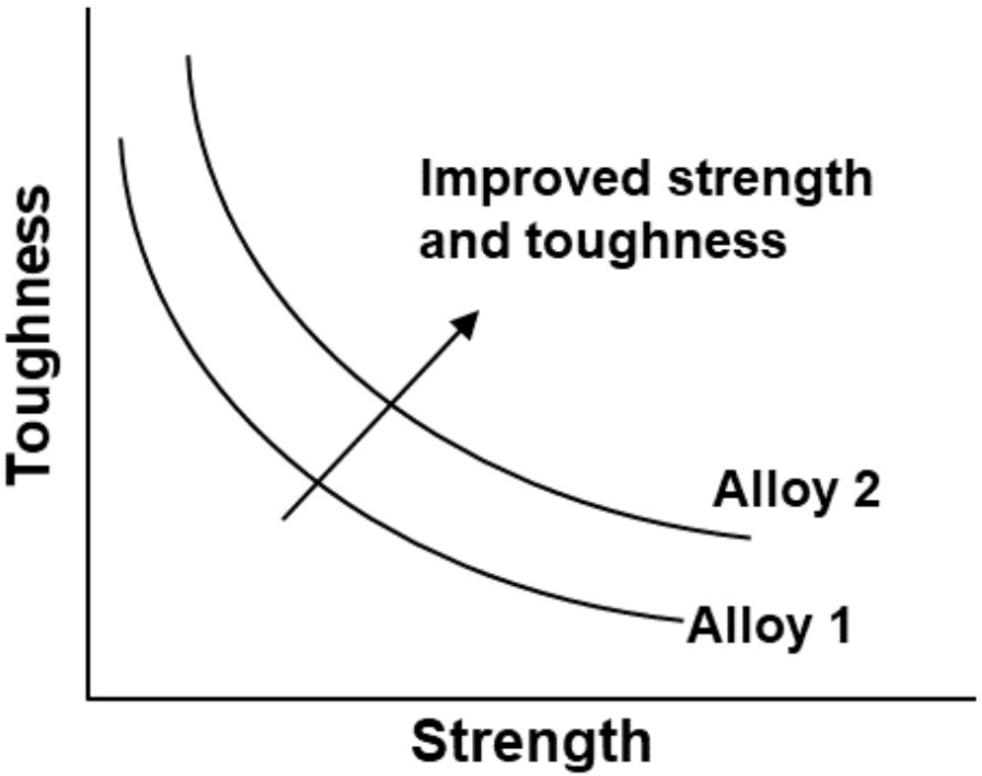
Concluding Remarks

- General Learning Moment 3: fracture toughness and material strength are two different properties
- In-situ minimally invasive tests to determine pipe toughness is becoming available.
- It is a considerable and collaborative effort.
- Many opportunities to engage in 2024: Industry validation programs, PHMSA BAA, field pilot projects.



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thank you

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