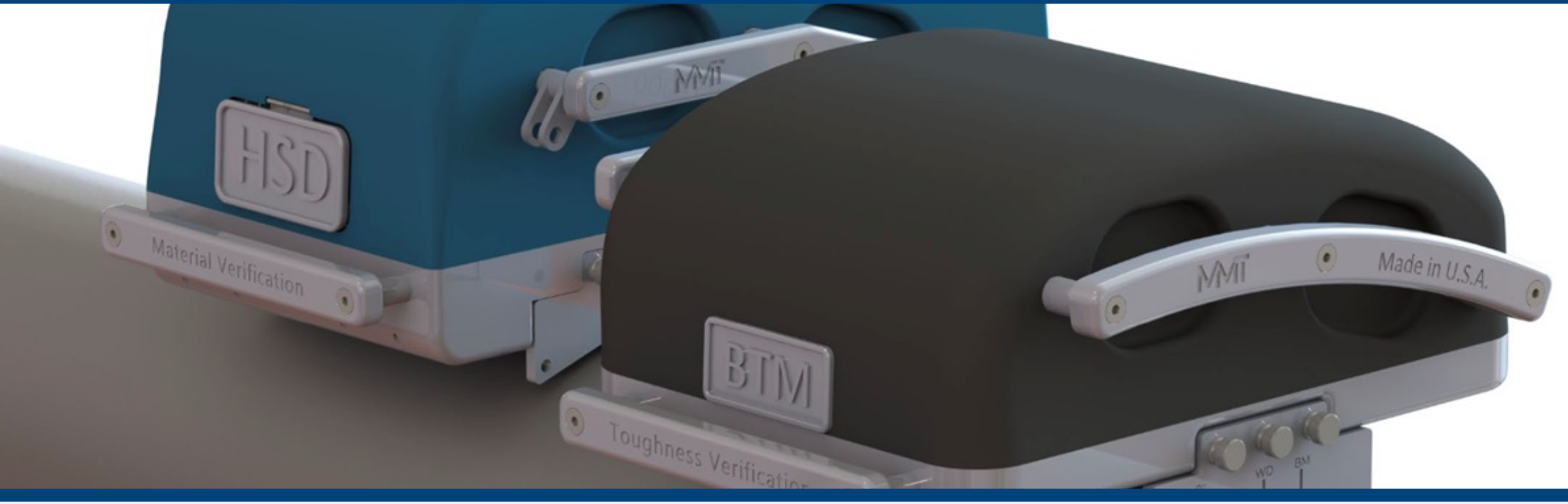
Impact of Cold Forming on Material Strength Verification for Storage Tanks and Other Vessels



January 23 - 25, 2024 | Henry B. Gonzales Center | San Antonio, TX

BIO SLIDE

- Victor Jablokov, VP of Innovation at MMT; MA, USA
- B.S./M.S. Metallurgy Penn State, MBA Wake Forest
- Previous roles at Siemens Energy, Allegheny Technologies, and several start-ups in AI and IoT.

MMT Overview

- Headquartered in Boston, MA with Houston, TX shop/office
- Founded in 2014 – First ever Frictional Sliding field instrument to more accurately measure material properties of pipelines, nondestructively.
- First tool (HSD) validated in 2018 through PRCI trial w/ PHMSA.

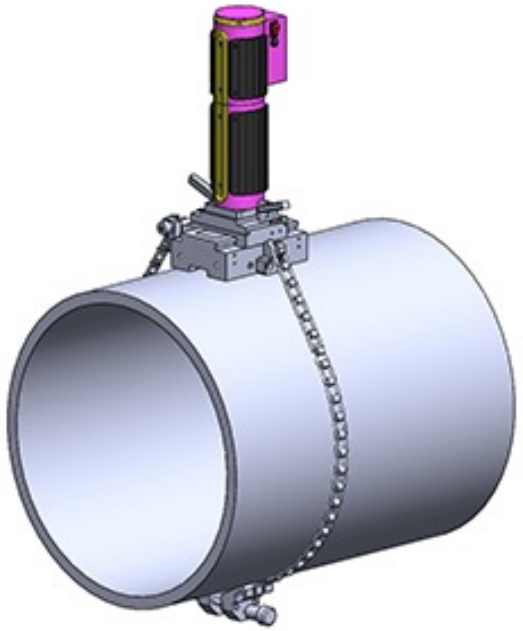
Current vs. New Methods for Material Testing Records

Cut Outs

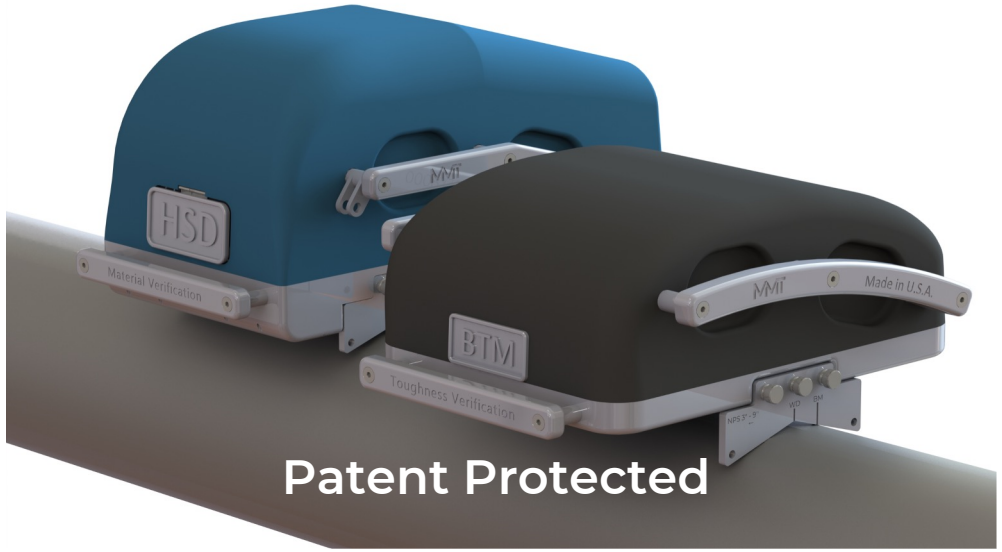
Non-Destructive Testing

Not cutting the pipe allows more data without service interruption and repairs

Non-Destructive Testing Solutions



Lab-Like Accuracy Reached (MMT)



Patent Protected

PIN Brinell (Hardness) — 1900

Ball Indentation (Strength) — 2000

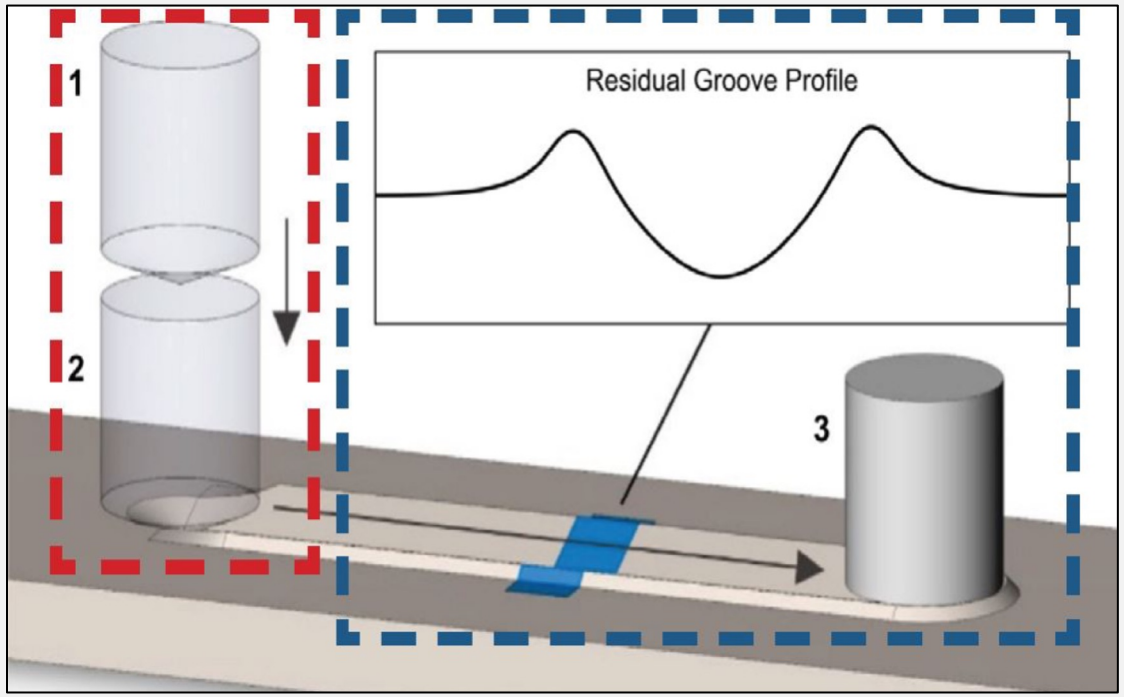
Frictional Sliding (Strength) — 2018

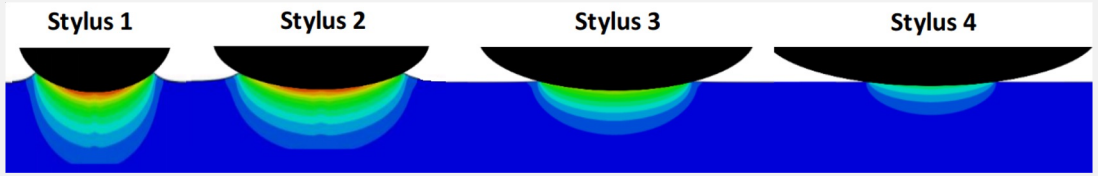
Planing-Induced Microfracture (Toughness) — 2024

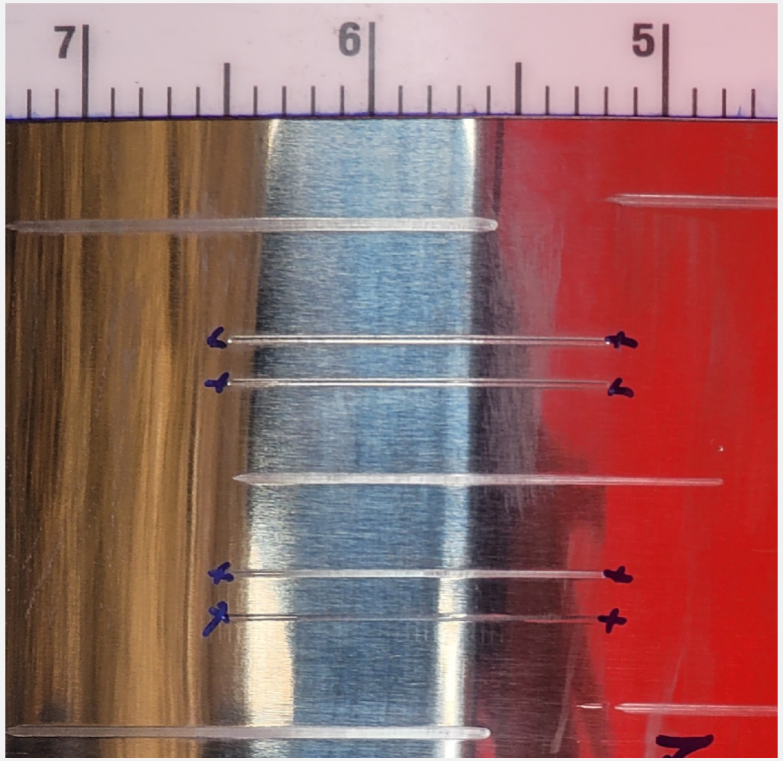
Frictional Sliding

Ball Indentation
(1 indenter)

MMT = Frictional Sliding
(4 styluses)

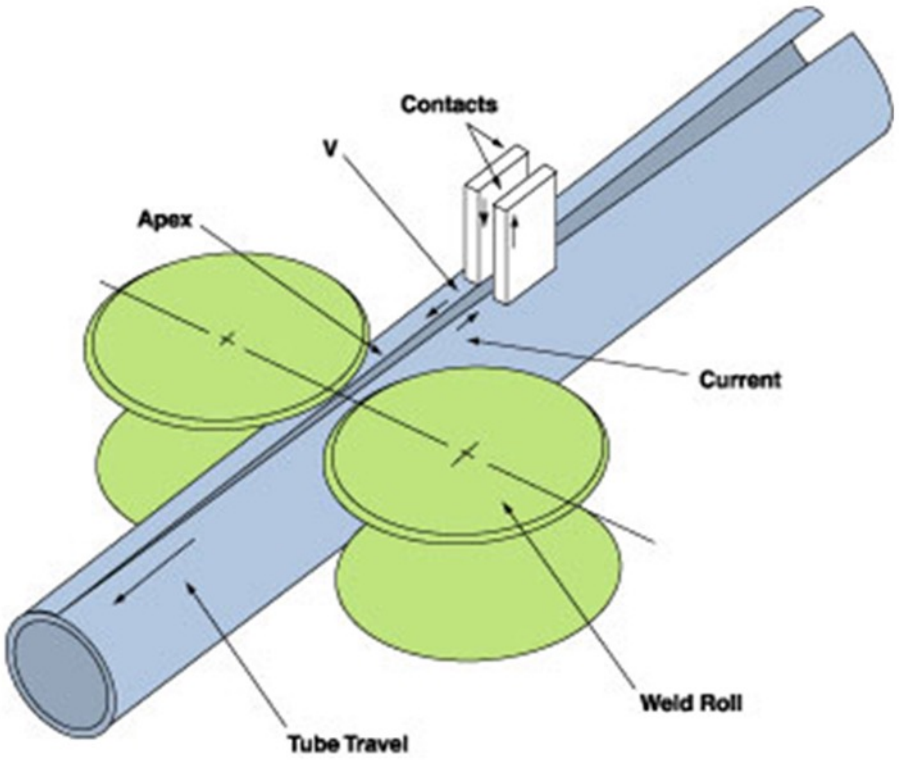


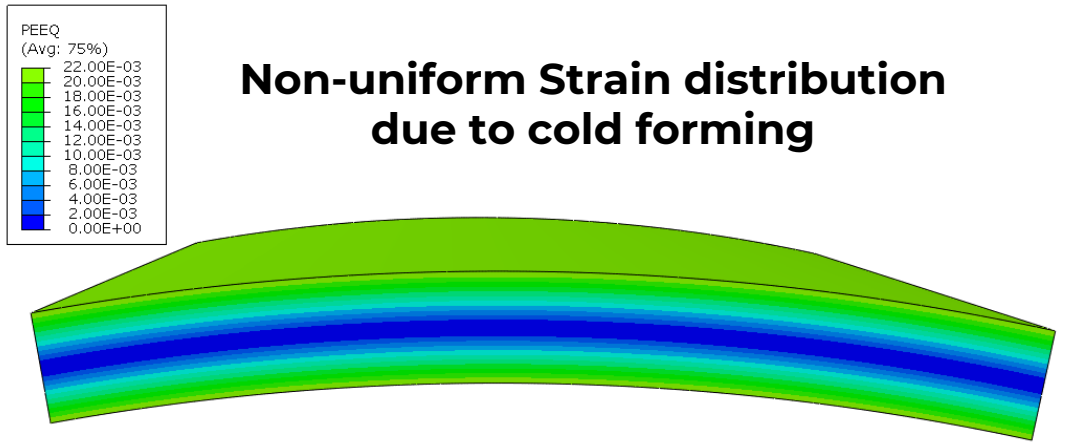




Single HSD test provides 200+ data points. HSD test is divided into 10 equal subsets along the length of the groove to provide 10 measurements per test.

Surface vs. Bulk

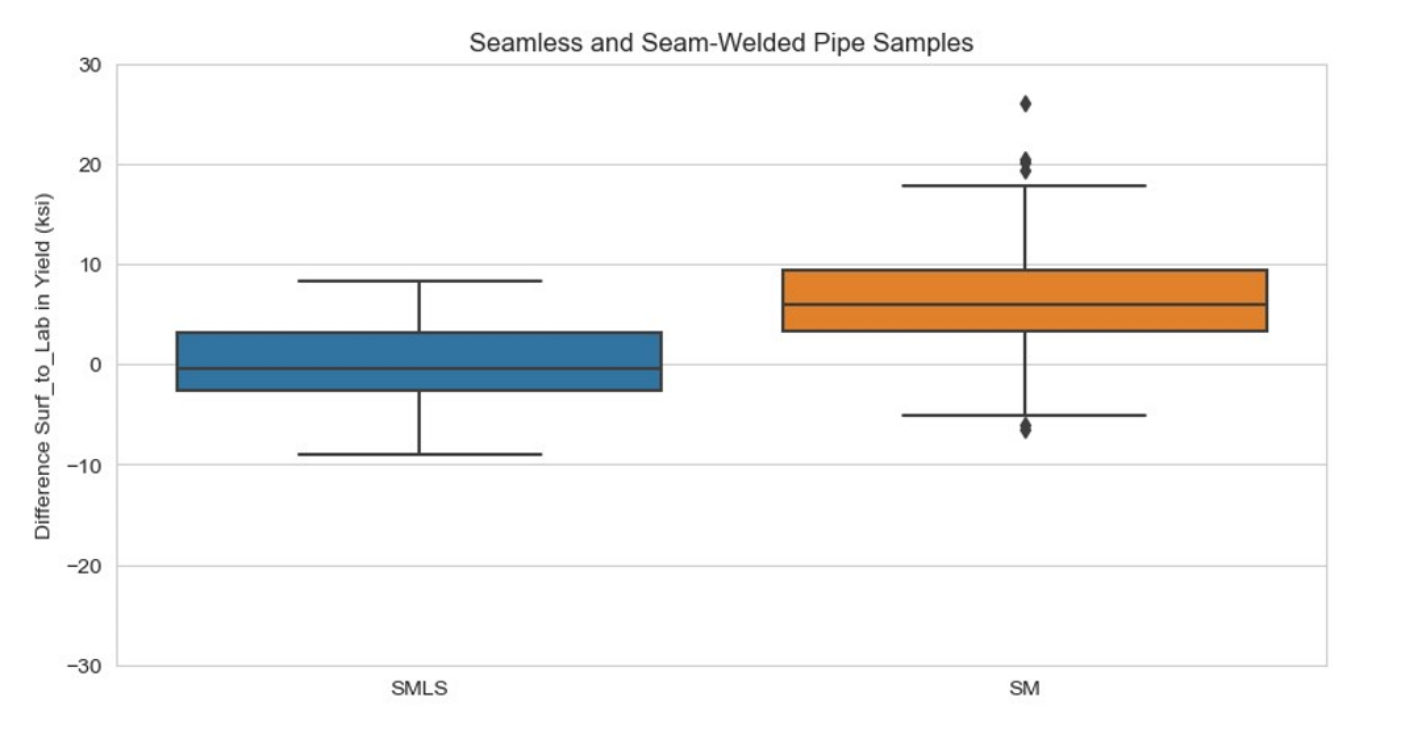




Non-uniform Strain distribution due to cold forming

- Surface measurements must be corrected to predict bulk properties.

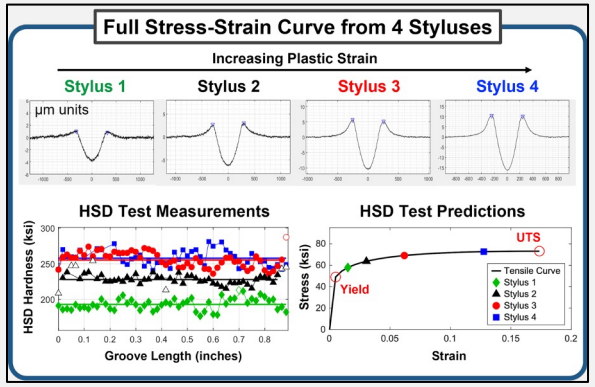
Case Study: Impact of Forming on Yield



- For seamless samples, the yield difference between surface and bulk is averaged at zero.
- For seam-welded samples, surface yield is ~5 ksi higher than bulk on average due to the bending strain from the forming process.

Converting Surface to Bulk Properties

Surface Hardness



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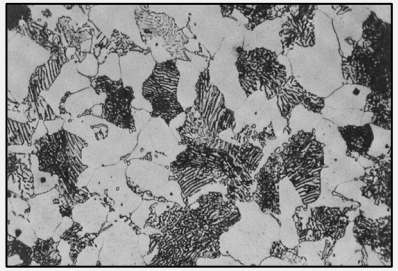
Grain Structure Image



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Material Chemical Composition

Element	Content (%)
Carbon, C	0.34
Iron, Fe	0.60
Manganese, Mn	0.44
Phosphorous, P	0.21
Sulfur, S	0.03
Chromium, Cr	4.78
Copper, Cu	0.08
Nickel, Ni	0.15
Molybdenum, Mo	1.61
Vanadium, V	0.51

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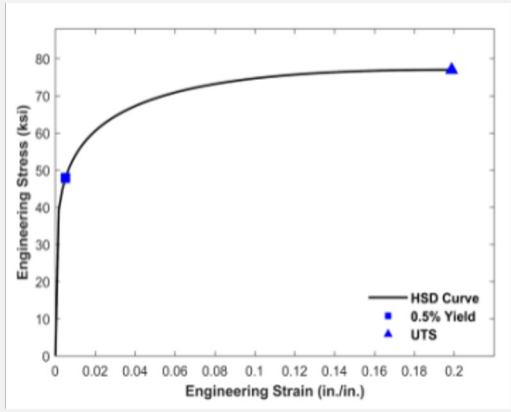
Bulk Prediction

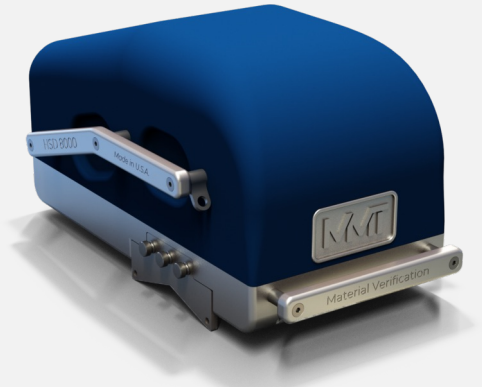


In-Field Test with HSD: Hardness data collected and converted to surface Yield and UTS data through use of equations developed using FEA modeling.

In-Field Grain Structure Image & Material Chemical Composition Collection: Microscopy image of grain structure and collection of burr samples followed by a lab test.

Bulk Material Strength Prediction: Surface YS, and UTS is then input into prediction model which utilizes machine learning.

Converting Surface to Bulk Properties



MMT Field Test Hardness Profiles

Physical FEA Simulation

Surface Strength

Additional Field Data: Chemistry & Microstructure

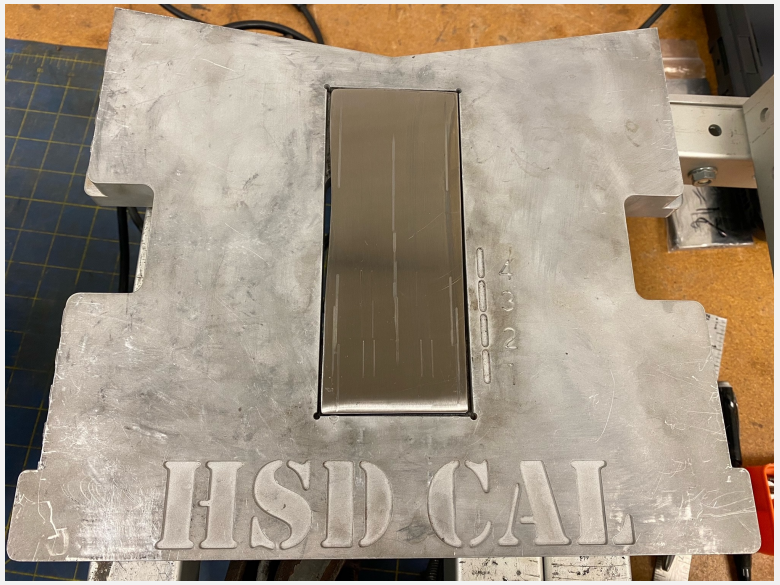
AI

Validation Database

Bulk Strength

Accuracy of 3.0 ksi (+/- 5% for 60 ksi yield strength) for Line Pipe

Frictional Sliding on Vessel Materials



- Testing Materials: A516 Carbon Steel / SS304 / Al 6061-T651 / 625 Nickel Alloy
- Samples were machined into plates and placed in a calibration plate holder.
- Tested with a lab HSD unit.

Frictional Sliding on Vessel Materials

Material	Lab Yield[1] (ksi)	FS Yield[2] (ksi)	Error (%)	Lab Tensile[1] (ksi)	FS Tensile[2] (ksi)	Error (%)
A516 CS	53.8	64.3	19.5	78.5	78.4	-0.1
304 SS	44.2	43.9	-0.7	91.8	93.8	2.2
6061-T651 Al	35.8	46.9	31.0	45.6	51.1	12.1
625 Ni Alloy	72.8	59.6	18.1	129.5	154.2	19.1

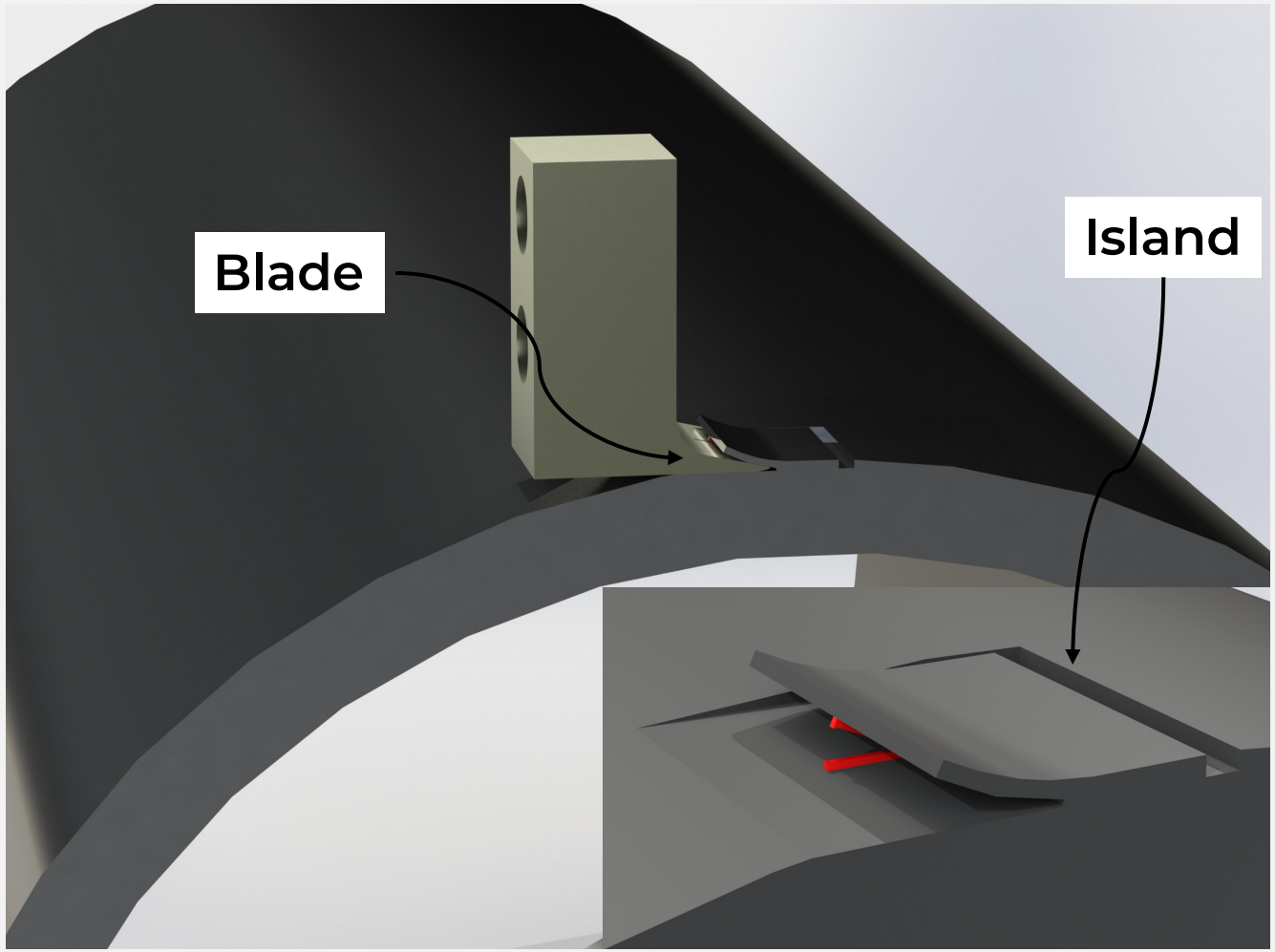
[1] Lab test results. Averaged from two tensile tests.

[2] Average from three tests.

Conceptual Design for in-situ Vessel Testing

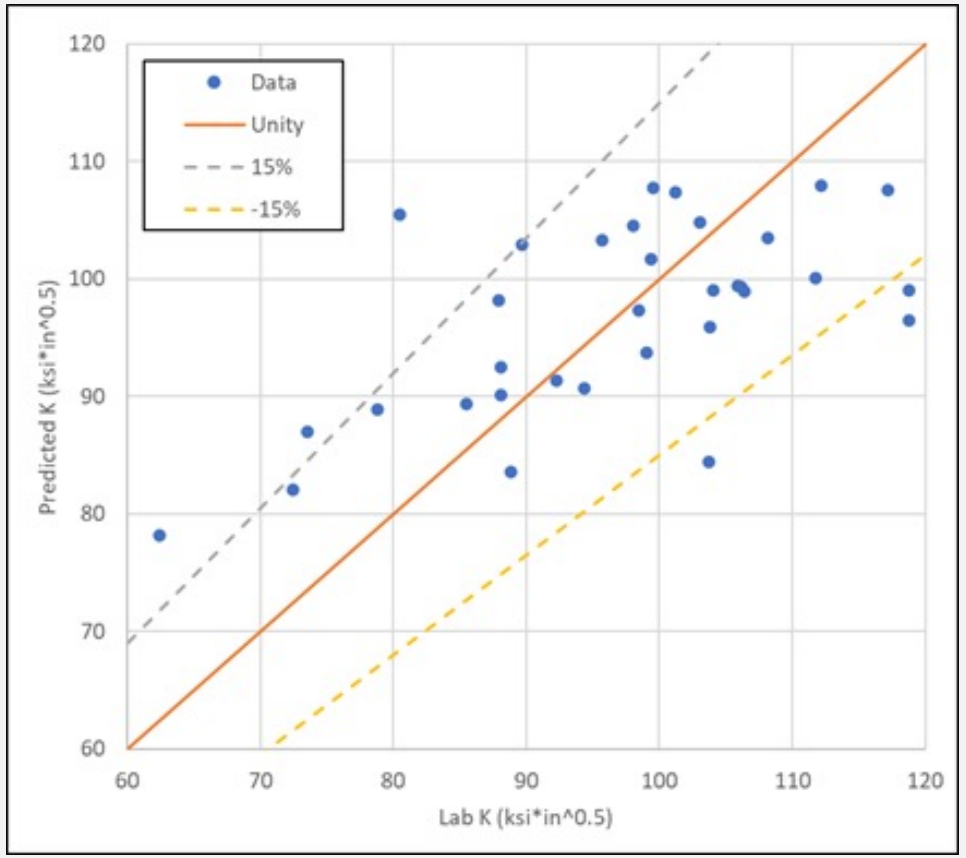
- Preliminary results show that the frictional sliding method can be applied to various vessel materials and obtain reasonable results.
- For higher tensile materials, like Nickel alloy, the current stylus geometry needs to be modified and/or higher load need to be applied to generate a measurable groove on surface.

Fracture Toughness via Planing-Induced Microfracture



Sample

Validation Test Results



A validation test was performed with 33 pipe steel samples.

Preliminary results show that the predicted K_{Ic} values are within ±15% of the lab-tested values.

Conclusion

- Surface and bulk properties can be different due to forming processes.
- Surface strengths can be measured using a frictional sliding method.
- Correcting surface measurements to bulk properties can be achieved using machine-learning models for pipeline steels.