MMT

Massachusetts Materials Technologies LLC

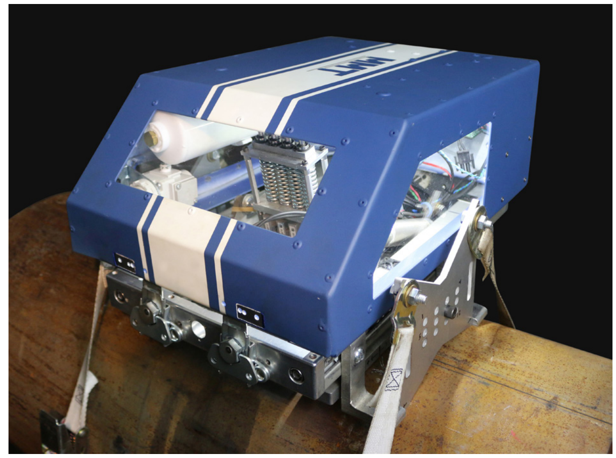
(617) 502 - 5636 | www.byMMT.com | 167 Prospect Street Waltham, MA

HSD Tester

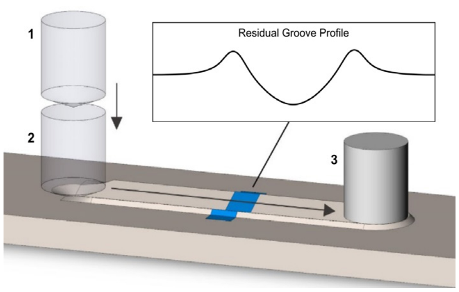
Nondestructive | Portable | In-Ditch Material Verification

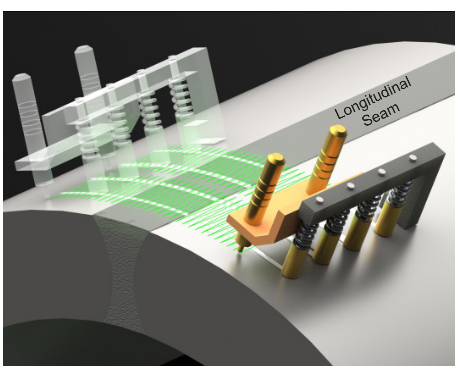
The Hardness, Strength, and Ductility (HSD) Tester is a portable and nondestructive instrument that is designed, developed, and used for in-ditch material verification by Massachusetts Materials Technologies (MMT) LLC. The HSD is capable of reliably identifying the longitudinal seam type and accurately measuring yield strength, ultimate tensile strength, and strain hardening behavior of in-service pipelines without the need for sample removal or service interruption.

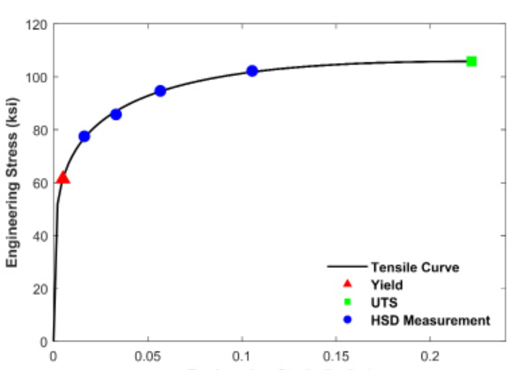
The HSD Tester will support the need to extend the life of aging pipelines and to perform quality control of new assets. Accurate and reliable data about the actual steel strength of specific pipe sections provides a cost-effective solution for prioritizing resources for integrity programs and reduces uncertainties in risk assessments.



Fundamentals of the HSD Tester







Contact Mechanics

MMT's technologies implement a contact mechanics method known as frictional sliding. This process consists of multiple hard styluses pressing into a softer material and then traveling across the surface of the sample. Each stylus creates a shallow groove that can be measured to assess the material response.

Hardness

A profiling tool measures the width and depth of each groove. This geometry, in addition to the force applied to each stylus, is used to calculate the hardness that indicates a material's resistance to permanent deformation.

Representative Stress & Strain

The material response for each stylus is used to calculate the representative stress and strain, relating the frictional sliding measurement to an equivalent tensile value.

Engineering Stress-Strain Curve

A complete stress-strain curve is fit to individual stylus measurement, allowing for determination of the tensile strength properties. This includes:

- 0.2% offset yield strength
- 0.5% elongation under load (EUL) yield strength
- Ultimate tensile strength (UTS)
- Strain hardening exponent (n)
- Power law strength coefficient (K)

HARDNESS, STRENGTH, AND DUCTILITY (HSD) TESTER

Third-Party Validation

The performance and capabilities of the HSD Tester have been demonstrated through testing on more than 100 integrity digs and an internal database of 124 steel pipe joints. Testing has been performed on pipes of varying vintage and fabrication, including seamless, electric resistance welded (ERW), submerged arc welded (SAW), and flash welded construction.

In Fall 2017, blind testing of 50 pipe joints was conducted by Pipeline Research Council International (PRCI NDE 4-8 Catalog No. PR-335-173816) to evaluate the performance of several proprietary testing methods for the nondestructive measurement of strength properties. When comparing these methods with the laboratory tensile tests on the same pipe joints, frictional sliding tests conducted with the HSD Tester by MMT was ***"the best performing technique with the lowest MAPE, highest correlation coefficients, and highest quantity of data within the specified error bands for both YS and UTS."*** A summary of the different statistical metrics applied to the 50 pipe samples is shown in the table below.

Performance Criterion	NDE-4C Technique	Proprietary Technique 1	Proprietary Technique 3	MMT (2017)	MMT (2019)
MAPE	8.4%	7.6%	12.9%	7.0%	5.2%
Maximum Error	21.8%	34.6%	53.9%	13.4%	15.1%
R-Squared	0.58	0.63	0.16	0.70	0.83

Formulas and Nomenclature

PE = percent error

$\mathbf{PE} = \frac{\text{NDE}-\text{tensile}}{\text{tensile}}$ (%)

$\mathbf{R^2}$ = correlation coefficient

$\mathbf{R^2} = 1 - \frac{\sum_{i=1}^{N}(x_i - f_i)^2}{\sum_{i=1}^{N}(x_i - \bar{x})^2}$

where x_i = strength measurement

$\bar{x}$ = mean strength measurement

f_i = linear model prediction

MAPE = mean absolute PE

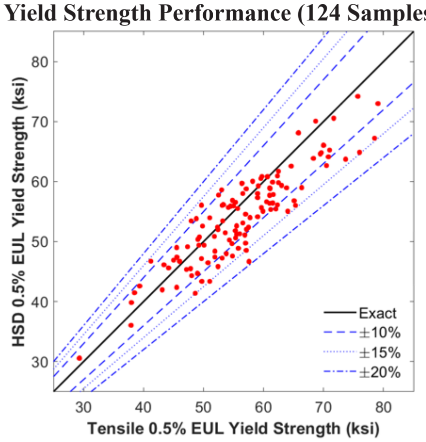
$\mathbf{MAPE} = \frac{\sum_{i=1}^{N}\text{abs}(\text{PE}_i)}{\text{N}}$

where N is number of samples

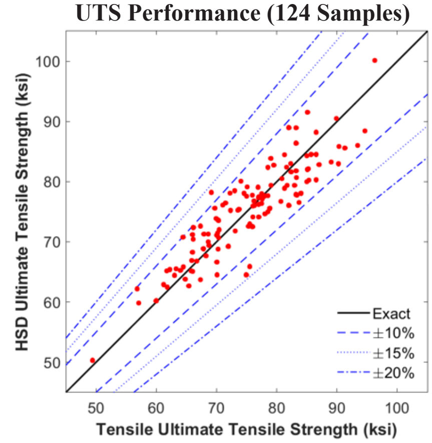
MMT continuously improves our prediction method as more samples are added to the validation database.

Comparing the accuracy of tensile strength prediction of the HSD Tester with laboratory tensile testing for 124 pipe samples, the yield strength is within +10% to -15% for over **90%** of the pipes, and the ultimate tensile strength is within +10% and -10% for over **95%** of the samples.

Yield Strength Performance (124 Samples)

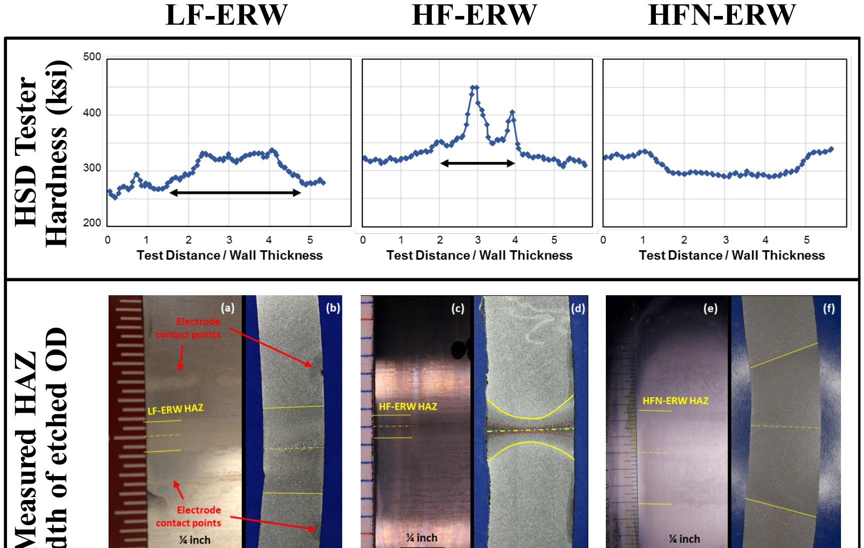


UTS Performance (124 Samples)



Nondestructive Longitudinal Seam Determination

LF-ERW | **HF-ERW** | **HFN-ERW**



$L_{HAZ}/t = 121\% \pm 28\%$ (10 samples) | $L_{HAZ}/t = 46\% \pm 8\%$ (7 samples) | $L_{HAZ}/t = 253\% \pm 56\%$ (15 samples)

L_{HAZ} = width of etched HAZ *t = pipe wall thickness*

MMT has developed a nondestructive method to classify low frequency (LF), high frequency (HF), and high frequency normalized (HFN) ERW seams. This approach uses multiple NDE techniques that can be combined in an automated classification model (shown below) based on comparisons with an in-house database.