Nondestructive Pipeline Material Strength Verification and Long Seam Identification

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Massachusetts Materials Technologies LLC
www.byMMT.com
Meeting Agenda

1. Company Overview and Value Provided
2. Technology Overview and Validation
3. Field Services
4. Joint Industry Program for NDE of Longitudinal Seams
5. Conclusions
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Massachusetts Materials Technologies

2014  MMT Founded

2  Nondestructive Testing (NDT) Technologies

1  Vision: To improve safety through cost-effective NDE

1. Offering pipeline material verification for strength and toughness.
2. Focused on delivery of accurate and reliable NDE data.
3. Driven to service existing and new customers.
Pipeline Material Verification

Vintage pipelines to operate under higher and higher safety expectations.

Zero major rupture goal!
How to Verify Materials

Old Methods

Hydrotest
Service interruption, potential damage and only partial information

Cut-outs & Lab Test
A very elaborate process

New | Affordable | Effective

In-Ditch NDE + In-Line Inspection
No service interruptions and recently validated
Identifies similar pipeline materials to map NDT data for pipe system

$$$$ $ $ $
## Partial 2018 Testing Summary for Gas Transmission Operator

<table>
<thead>
<tr>
<th>Line ID</th>
<th>Number of Joints Tested</th>
<th>Expected grade (year of install)</th>
<th>Seam Type</th>
<th>Yield Strength Range (ksi)</th>
<th>UTS Range (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>4</td>
<td>Grade B</td>
<td>Seamless</td>
<td>43.8 – 48.9</td>
<td>61.3 – 64.9</td>
</tr>
<tr>
<td>Line 2</td>
<td>3</td>
<td>Grade B (1952)</td>
<td>SAW</td>
<td>42.0 – 42.8</td>
<td>61.4 – 64.7</td>
</tr>
<tr>
<td>Line 3</td>
<td>3</td>
<td>Grade B (1950)</td>
<td>SAW</td>
<td>42.7 – 45.6</td>
<td>60.2 – 63.9</td>
</tr>
<tr>
<td>Line 4</td>
<td>3</td>
<td>Grade B (1950)</td>
<td>Seamless</td>
<td>38.1 – 43.8</td>
<td>61.5 – 65.1</td>
</tr>
<tr>
<td>Line 5</td>
<td>1</td>
<td>Grade B (1985)</td>
<td>Seamless</td>
<td>44.8</td>
<td>64.4</td>
</tr>
<tr>
<td>Line 6</td>
<td>1</td>
<td>X52</td>
<td>HFN-ERW</td>
<td>69.1</td>
<td>82.6</td>
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<tr>
<td>Line 7</td>
<td>1</td>
<td>X52 (1990)</td>
<td>HFN-ERW</td>
<td>62.7</td>
<td>75.8</td>
</tr>
<tr>
<td>Line 8</td>
<td>1</td>
<td>X52 (1990)</td>
<td>HFN-ERW*</td>
<td>56.1</td>
<td>67.4</td>
</tr>
<tr>
<td>Line 9</td>
<td>1</td>
<td>X42 (2001)</td>
<td>SAW</td>
<td>55.1</td>
<td>70.4</td>
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<tr>
<td>Line 10</td>
<td>2</td>
<td>X65 (1993)</td>
<td>HFN-ERW</td>
<td>67.3 – 71.5</td>
<td>85.7 – 87.1</td>
</tr>
</tbody>
</table>

*HSD weld test showed seam was partially normalized
Material Verification: MMT Vision

- **Corrosion Direct Assessment + MMT**
  - Low incremental cost (less than 5%)
  - Info for decisions on life extension as-is, make piggeable for ILI, or replace
  - Data provides justification for best use of budgets through prioritization

- **In-Line Inspection (ILI) + MMT**
  - Save on # of integrity digs
  - Save on overall repair cost

If toughness input is 40% greater then maximum acceptable flaw size is 100% greater

Added statistical confidence and/or mapping of system (anomaly & strength)
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MMT’s Patented Solutions

HSD Tester
Hardness, Strength, & Ductility

NDTT
Nondestructive Toughness Tester
Indentation technologies only do steps 1 and 2

Step 3 is unique to the HSD Tester allowing it to gather more data with a single test. Method is supported by journal articles, conference proceedings, and MIT PhD thesis.
Relating Frictional Sliding to Tensile Testing

1. Dissimilar styluses used to measure material response at different strains

2. Complete stress-strain curve obtained by fitting to independent stylus measurements

3. Determine yield and ultimate tensile strength (UTS) from stress-strain curve

FEA and dimensional analysis references:
Bellemare et al., *Int. J. Solids and Structures*, 2007;
Bellemare et al., *Journal of Applied Mechanics*, 2008;
Bellemare et al., *Acta Materialia*, 2010
Third-Party Validation of the HSD Tester

- **Solution**: Predictions based on database of combined HSD measurement + chemistry + grain size
- **Database**: 124 pipe joints (74 in-house, 50 PRCI)

**PRCI Validation Results on 50 Blind Samples for Yield Strength**

<table>
<thead>
<tr>
<th>Performance Criterion</th>
<th>NDE-4C Technique</th>
<th>Proprietary Technique 1</th>
<th>Proprietary Technique 3</th>
<th>MMT (2017)</th>
<th>MMT (2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAPPE</td>
<td>8.4%</td>
<td>7.6%</td>
<td>12.9%</td>
<td>7.0%</td>
<td>5.2%</td>
</tr>
<tr>
<td>Maximum Error</td>
<td>21.8%</td>
<td>34.6%</td>
<td>53.9%</td>
<td>13.4%</td>
<td>15.1%</td>
</tr>
<tr>
<td>R-Squared</td>
<td>0.58</td>
<td>0.63</td>
<td>0.16</td>
<td>0.70</td>
<td>0.83</td>
</tr>
</tbody>
</table>

**Performance improves as more data collected**

PE = percent error
PE = \( \frac{\text{NDE—tensile}}{\text{tensile}} \) (%)

MAPE = mean absolute PE
MAPE = \( \frac{\sum_{i=1}^{N} \text{abs}(PE_i)}{N} \)

where N is number of samples

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

where \( x_i \) = strength measurement
\( \bar{x} \) = mean strength measurement
\( f_i \) = linear model prediction

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Nondestructive Toughness Tester (NDTT)

**Concept:** Select stylus geometry to induce tensile (Mode I) fracture response in ductile metals

**Microscopic Images of Ligament Surface**

![Microscopic Images](image)

(a) Aluminum Alloy  (b) Steel Alloy

**Implementation:** Fracture response is measured on ligament preserved within stretch passage
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Field Testing Services Overview

- We have current working relationships with over 15 different pipeline operators
- Each Field Crews consisting of 2 Techs each
  - 1 Senior and 1 Junior Tech, both are fully versed with all our in-house procedures
- Every field technician is OSHA 10hr certified, has a TWIC card, and is DOT PHMSA Drug and alcohol tested
- We are listed on both ISNetworld and NCMS Compliance sites
- OQ Plan in place for all employees to meet operators requirements, thru NCCER, MEA and Veriforce
- Field team tests 2 to 3 joints per day based on location
- A team can be mobilized as quickly as 24 hour notice
Field Testing Services Overview

Prepare pipe surface
Surface prepped to a defect free 2000 grit finish

Attach HSD Tester
Tests 3 – 60 inch diameter pipes, flat plate, elbows

Perform HSD test
10 minute duration for HSD, more time for chemistry & grain size

Analyze Data
Immediate surface result Final report within 2 weeks

We test 2 quadrants of the pipe joint to be in compliance with pending rules for material documentation with nondestructive methods. These quadrants will be at different locations around the circumference of the pipe joint, and typically at least 90 degrees apart. For ERW pipes, 1 quadrant will be centered on the seam where we will perform 1 base metal test and 1 seam test, and for the other quadrant we will perform 2 base metal tests. For SAW, flash-welded, and seamless pipes, we perform 2 base metal tests in each quadrant (4 tests total).
We want to provide our services to other industry service providers

**2014 – Present:** MMT is sole provider of HSD Tester
- 50 digs in 2017, 150 digs in 2018, 400 planned for 2019

**2019:** Collaboration with NDE service providers
(1 MMT staff + 1 ASNT staff)

**2020:** Independent NDE service providers, with MMT continuing to provide QA/QC
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Motivation

Longitudinal seam weld quality is critical for integrity management

Comments on NPRM §192.624 for MAOP verification through ECA

• Seam CVN = 4 ft-lb if no toughness data is available

Reference: Comments on Pipeline Safety: Safety of gas transmission pipelines, MAOP reconfirmation, expansion of assessment requirements and other related amendments, Produced jointly by AGA, API, APGA and INGAA on May 1, 2018.
JIP Objective

To develop a nondestructive methodology for classifying seam types and predicting an index of seam toughness through in-ditch direct assessments.
Existing MMT Work – Seam Classification

- Visual Inspection
  - Weld Reinforcement
    - Square Cap
      - Flash-Welded
    - Rounded Cap
      - Submerged-Arc-Welded (SAW)
  - No Observable Surface Characteristics
    - Electric-Resistance-Welded (ERW)
      - Low Frequency (LF)
      - High Frequency (HF)
      - HF Normalized (HFN)
HSD Provides Unique Information Across the Seam

HSD measures changes as it slides across the surface

Hardness Response for Different Seam-Types

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

**Flash**

- **SAW**

- **HAZ**
  - Stylus-1
  - Stylus-2
  - Stylus-3
  - Stylus-4
Examination of Etched Seam for ERW Joints

Macro-etch reveals apparent HAZ at the seam on pipe outer surface

\[ \frac{L_{HAZ}}{t} = 121\% \pm 28\% \] (10 samples)

\[ \frac{L_{HAZ}}{t} = 46\% \pm 8\% \] (7 samples)

\[ \frac{L_{HAZ}}{t} = 253\% \pm 56\% \] (15 samples)

\( L_{HAZ} \) = Width of etched HAZ

\( t \) = pipe wall thickness
ERW Classification using HSD + Seam Macro-etch

Comparison of nondestructive measurements for 32 ERW pipes in MMT database

Measured Data

Classification Tree
Seam Type Classification Methodology

JIP Milestones:

(1) Add samples to seam database to update and compare classification models

(2) Validate the most promising classification models through testing on blind samples
Motivation to Extend Beyond Classification

Toughness data compiled by Kiefner and Associates, reference:
JIP Scope-of-Work for Predicting Index of Toughness

Classified Seam Type (LF, HF or HFN-ERW)

- HSD Weld Test
- Examination of Etched HAZ
- Chemistry
- Vintage, grade, Installation Year
- Seam Microscopy

Regression Model for Index of Toughness (CVN)
JIP Scope-of-Work for Predicting Index of Toughness

- Classified Seam Type (LF, HF or HFN-ERW)
- HSD Weld Test
- Examination of Etched HAZ
- Chemistry
- Vintage, grade, Installation Year
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Regression Model for Index of Toughness (CVN)
JIP Scope-of-Work for Predicting Index of Toughness

Classified Seam Type
(LF, HF or HFN-ERW)

HSD Weld Test
Examination of Etched HAZ
Chemistry
Vintage, grade, Installation Year
Seam Microscopy

Regression Model for Index of Toughness (CVN)

Temperature (°C)

CVN (J)

Increasing Carbon

JIP Scope-of-Work for Predicting Index of Toughness

Classified Seam Type (LF, HF or HFN-ERW)

HSD Weld Test  
Examination of Etched HAZ  
Chemistry  
Vintage, grade, Installation Year  
Seam Microscopy

Regression Model for Index of Toughness (CVN)

API Grade

JIP Scope-of-Work for Predicting Index of Toughness

**Classified Seam Type** (LF, HF or HFN-ERW)

- HSD Weld Test
- Examination of Etched HAZ
- Chemistry
- Vintage, grade, Installation Year

**Regression Model for Index of Toughness (CVN)**

**Grain size, morphology, and phases**

- Bond Line
- Heat Affected Zone
- Base Metal

- Not Normalized
- Normalized

**Diagram:**
- Bond Line
- HAZ start
- HAZ end - Base Metal
- Grain Size vs. Distance
JIP Scope-of-Work for Predicting Index of Toughness

JIP Milestones:

(1) Develop regression models to correlate multiple nondestructive measurements to measured CVN seam toughness values

(2) Validate models through testing on blind samples
**Proposed Schedule and Fees**

**Basic Program:** 8 participants who each contribute $50,000

<table>
<thead>
<tr>
<th>Date</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 6, 2018</td>
<td>JIP Presentation at IDT Expo</td>
</tr>
<tr>
<td>December 20, 2018</td>
<td>Commitments confirmed for interested participants</td>
</tr>
<tr>
<td>January 2019</td>
<td>Finalize test plan and samples with JIP participants</td>
</tr>
<tr>
<td>May 2019</td>
<td>Charpy and NDE completed for calibration pipe samples</td>
</tr>
<tr>
<td>July 2019</td>
<td>Classification and regression models developed</td>
</tr>
<tr>
<td>September 2019</td>
<td>Blind samples tested for model validation</td>
</tr>
<tr>
<td>November 2019</td>
<td>Summary Report and Presentation, discussions for future work</td>
</tr>
</tbody>
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Conclusions

- HSD Tester is validated solution for material strength properties
  - More than 200 in-ditch inspections and thousands of HSD tests completed
- NDTT is developing solution for fracture toughness of pipe body
- JIP will extend and validate NDE of longitudinal welded seam type and quality
Questions?

Massachusetts Materials Technologies LLC

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