Robust Girth Welds Suitable for Realistic Field Conditions

Yong-Yi Wang and Dan Jia

ywang@cres-Americas.com
djia@cres-Americas.com
614-376-0765

Steve Rapp

Stephen.Rapp@enbridge.com
281-773-1076

API 1104/5L Joint Task Group
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Overview

- Problem statement – girth weld incidents
- Why do we have this issue?
- Moving forward – linepipe
  - Interim supplemental linepipe specifications
  - Improvements in current practice
  - Future update in linepipe specifications and tools to support them
    ▶ Recommended test procedures
- Moving forward – girth welding
  - Selection of welding processes
  - Qualification requirements
  - Recommended test procedures
- Engaging stakeholders
Problem Statement – Girth Weld Failures

- Girth weld failures
  - Occurred in-service and during hydrostatic testing
  - About a dozen known in the US
    - Ten incidents with confirmed information, shown in the table
      - 6 in-service rupture
      - 1 in-service leak
      - 3 hydrostatic test leak
  - More incidents are suspected to have occurred, but might not have been reported or known to the outside.
  - At least a dozen incidents have occurred in Asian countries. (all manual or semi-automatic welds)

- Characteristics of failures in US
  - X52 to X80, most X70
  - Welding - all manual
    - SMAW: E6010 root, E8010 fill and cap passes
    - X70/X80: SMAW/E6010 root, FCAW fill and cap passes

<table>
<thead>
<tr>
<th>Incident No.</th>
<th>OD (inch)</th>
<th>Grade</th>
<th>Nature of Incident</th>
<th>Approximate Elapsed Time for Start of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20&quot;</td>
<td>X70</td>
<td>In-Service Rupture</td>
<td>1 Year</td>
</tr>
<tr>
<td>2</td>
<td>30&quot;+</td>
<td>X80/X70</td>
<td>In-Service Rupture</td>
<td>6 years</td>
</tr>
<tr>
<td>3</td>
<td>12.75&quot;</td>
<td>X52</td>
<td>In-Service Leak</td>
<td>14 years</td>
</tr>
<tr>
<td>4</td>
<td>30&quot;</td>
<td>X70M</td>
<td>Hydrostatic Leak</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>30&quot;</td>
<td>X70</td>
<td>Hydrostatic Leak</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>42&quot;</td>
<td>X70</td>
<td>In-Service Rupture</td>
<td>3 years</td>
</tr>
<tr>
<td>7</td>
<td>12.75&quot;</td>
<td>X52/X65</td>
<td>In-Service Rupture</td>
<td>4-5 years</td>
</tr>
<tr>
<td>8</td>
<td>24&quot;</td>
<td>X70</td>
<td>In-Service Rupture</td>
<td>3.5 years</td>
</tr>
<tr>
<td>9</td>
<td>36&quot;</td>
<td>X70</td>
<td>Hydrostatic Leak</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>Information can't be released</td>
<td>X70</td>
<td>In-Service Rupture</td>
<td>Less than 1 year</td>
</tr>
</tbody>
</table>
Impact to Industry

- Failures in brand new pipelines further enhances the negative opinion surrounding the dangers caused by pipelines. Further impacting the industries abilities to get permitting for future expansion projects or even key replacement efforts.
- Each incident of in-service failure typically costs in excess of $100M.
- These failures occur despite full compliance with the requirements in existing codes and standards.
Major Contributing Factor – Weld/HAZ Strength Undermatching

- Strain concentration in the weld/HAZ leading to rupture
  - Severe undermatch of weld relative to *actual* longitudinal pipe strength
  - Severe softening of HAZ

- Industry practice & codes have not kept pace with evolution in pipe materials

![Diagram showing weld and HAZ with strain concentration and hardness map.](image-url)
The weld strength from the E6010/E8010 consumables undermatches the strength of the X70 pipes.
Actual Pipe Strength Moved Up in Some Cases

- After excessive bulging during field hydrostatic testing was discovered, PHMSA issued advisory bulletin in 2009.
  - The issue was characterized as “low strength pipes.”
  - Some operators responded by adding extra 2-3 ksi in their minimum strength requirements.
  - Pipe mills and their suppliers added more “cushion” into the strength.
  - Some operators started to require mill hydrostatic testing at 100% SMYS

- PHMSA does not allow the counting of end loads for special permit pipelines.
- Test method systematically under-represents actual yield strength.
- Changes in steel making, test method, and definition of yield strength lead to large variations in reported yield strength of the same joint of pipe
  - Mills have to increase the averaged strength to meet the minimum strength requirements.
- Large range permitted in API 5L for the same grade
- The negative consequence of higher strength was not well recognized.

PHMSA: Pipeline and Hazardous Materials Safety Administration
SMYS: Standard Minimum YIELD Stress
API: American Petroleum Institute
Relative hardness from different zones of girth welds involved in 8 of the 10 incidents

<table>
<thead>
<tr>
<th>Statistics on Weld Strength Mismatch and HAZ Softening</th>
<th>VHN_Avg_HAZ / VHN_Avg_Pipe</th>
<th>VHN_Min_HAZ / VHN_Avg_Pipe</th>
<th>VHN_Avg_FillCap / VHN_Avg_Pipe</th>
<th>VHN_Avg_ROOT / VHN_Avg_Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0.80</td>
<td>0.69</td>
<td>0.81</td>
<td>0.74</td>
</tr>
<tr>
<td>Max</td>
<td>0.99</td>
<td>0.92</td>
<td>1.06</td>
<td>0.98</td>
</tr>
<tr>
<td>Median</td>
<td>0.89</td>
<td>0.78</td>
<td>0.92</td>
<td>0.86</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td>0.06</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
</tr>
</tbody>
</table>
What Happened to GWs in a Land Movement Event - Sample

- Pipe deformed by lateral ground movement
  - 42” OD, 0.5” WT, nominally straight segment
  - Axial extent of movement: 200 ft
    - 5 joints, 6 girth welds
  - Maximum lateral displacement of the pipe: 3 ft

- Source of strain demands
  - Bending strain from the curvature of the deformed profile
  - Membrane strain from the axial extension

  **Nominal membrane strain = 0.054%**
  - Total extension of the affected segment is about 1.3”

- If the axial extension is concentrated at the GWs, each GW would see about 0.22” extension.

- If the axial extension is concentrated at one GW, that GW would see 1.3” extension.
Why Do We Have This Issue – Design vs. Field Condition

- Our practice - conventional stress-based design
  - Pipelines are “only required” to be able to tolerate strains up to 0.2%.

- Field conditions/practice
  - Longitudinal stress/strains in most cases are not actively managed.
  - High strain locations exist more frequently than many expect.
    - Tie-ins
      - Differential settlement
      - Pipe ends are forced together at tie-in locations
    - Changes in support conditions
      - “Over-excavation”
    - The profiles of trench and pipes don’t match.
    - Temperature changes
    - Land movement
  - Some IMU surveys show that there can be one high strain event in every one to two miles of pipeline in flat Texas field.
Why Do We Have This Issue – HAZ Softening

- X70 UOE pipe, ~2000
- X70 ERW pipes, ~2013

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Why Do We Have This Issue – GW Qualification Requirements

- API 1104 focuses on the prevention, detection, and repair of flaws exceeding certain limits.
- Weld strength can be significantly lower than the strength of the pipe, yet pass qualification.
- Welds can reach UTS before pipe reaches yield strength.
- In an event of settlement, strains are concentrated in the welds.
- The tensile strain capacity can be as low as 0.20%-0.25%.

### Factors Affecting Girth Weld Performance

<table>
<thead>
<tr>
<th>Factors Affecting Girth Weld Performance</th>
<th>Factors Addressed in API 1104</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe wall thickness</td>
<td>Mostly Yes</td>
</tr>
<tr>
<td>Pipe strain hardening capacity</td>
<td>No</td>
</tr>
<tr>
<td>Weld strength mismatch</td>
<td>YS mismatch</td>
</tr>
<tr>
<td></td>
<td>UTS mismatch</td>
</tr>
<tr>
<td>HAZ strength (Softening)</td>
<td>Cap reinforcement</td>
</tr>
<tr>
<td></td>
<td>Mostly No</td>
</tr>
<tr>
<td></td>
<td>Misalignment</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Bevel geometry</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Weld flaw</td>
<td>Flaw type</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Flaw dimensions</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Toughness</td>
<td>No</td>
</tr>
<tr>
<td>Applied stress/strain</td>
<td>No</td>
</tr>
</tbody>
</table>
Effective Approach in Managing Girth Weld Integrity

- Have strain-resistant girth welds
  - Girth welds of buried pipelines should be able to resist a minimum tensile strain of 0.5% under full pressure conditions.

- Why? Managing pipelines to a lower tolerance can be difficult.
  - Construction practice
  - Geohazards: land slips, land creep, landslides, karst, etc. on the ROW
    - E.g., Appalachian mountains and/or old mining sites
  - “Normal” changing pipe support conditions
    - Settlement
    - Excavation and uneven backfill
    - Temperature change
  - Tools are not available to detect low strain events.

- After achieving a minimal level of strain tolerance, limited number of sites facing high strains can be addressed in geohazards management programs.
Stop Bleeding - Supplemental Linepipe Specifications

- Specify maximum *longitudinal* pipe strength limits
  - SMYS + 17 ksi
  - SMTS + 17 ksi
  (Goal: *control pipe longitudinal tensile properties to facilitate girth weld overmatching*)

- Enhance HAZ hardenability
  - For example, through minimum composition limits on pipe chemistry
    - $P_{cm} \geq 0.140$
    - $C \geq 0.040$
  (Goal: *control / limit HAZ softening*)

- *These interim recommendations may be adopted by pipeline owners/operators for new pipelines. They are not intended for API 5L and equivalent standards yet.*
Stop Bleeding - Girth Welding Practice

- Eliminate E6010/E8010 cellulosic for X70 and X65 pipelines
- Use low hydrogen processes with increased weld metal strength
  (Goal: use welding procedures to produce girth weld overmatching)
Immediate Improvement in Pipe Tensile Testing

- Improve test procedures and data quality check in flattened strap tests
  - Define test specimen dimensions
  - Define instrumentation plan
  - Define and qualify flattening procedure
  - Post-test data processing, including data quality check
    - E.g., Young’s modulus
  - Ask for stress-strain curves up to at least 1.0% total strain

- These recommendations can be adopted by pipeline owners/operators and linepipe manufacturers to improve data quality.
Recommended Practice in Pipe Longitudinal Tensile Testing

- Full thickness
- Specimen dimensions
- Instrumentation plan
- Post-test data quality check
- Reporting requirements

- A stand-alone document with the recommended practice is available through PRCI project MATH-5-3B.
Alternatives to Pipe Hoop Tensile Tests

- Non-flattened “stubby” reduced-section tensile (OD > 12-18”)
  - Representative of near-full-thickness of pipe
  - No flattening needed

- Round bar (medium to large wall thickness and diameter)
  - Representative of partial thickness of pipe
  - No flattening needed

- Ring expansion (small to median wall thickness and diameter)
  - Produce most representative yield strength
  - Can’t generate UTS
  - No flattening needed
  - Specialized test equipment is needed.
  - One pipe producer was able to have test pace in line with production, but most producers don’t have the equipment or experience in production pace
Alternatives to Pipe Hoop Tensile Tests

- Minimal removal of pipe materials
- No flattening
- Design and practice of grips are needed
  - Hydraulic grips
  - Wedge grips

A stand-alone document with the test protocol is available through PRCI project MATH-5-3B.
Long-Term Changes in Linepipe Specifications

- Hoop tensile test
  - Move towards tests without using flattened specimens

- Test protocols
  - More rigorous test protocols for both hoop and longitudinal tests
  - New ways to define yield strength
  - Consequences
    - More accurate and consistent determination of yield strength
    - More representative yield strength
    - Allow using Y/T ratio as a proxy for strain hardening capacity of the material
Long-Term Changes in Linepipe Specifications

Requirements

- Longitudinal tests
- Lower upper limits of yield strength and UTS for a given grade
- Lower values of the upper limit of Y/T ratio
- Acceptance criteria for HAZ softening

Enhanced hardenability

- Performance-based qualification test to assess HAZ softening in multi-pass welds
  - Allow reasonable freedom in chemical composition and steel making process as long as HAZ softening is within an acceptable limit.

Implementation

- Technical basis
- Involve stakeholders to practice, gain experience, and provide feedback
- Standardization
## Selection of Welding Processes

### Parameters driving the selection
- tensile strength
- chemical composition

<table>
<thead>
<tr>
<th>Pipe conditions</th>
<th>≤ 94</th>
<th>&gt; 94</th>
<th>&gt; 94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe UTS (ksi)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipe Carbon (%)</td>
<td>≥ 0.050</td>
<td>≥ 0.040</td>
<td>&lt; 0.040</td>
</tr>
<tr>
<td>Pipe Pcm</td>
<td>≥ 0.160</td>
<td>≥ 0.140</td>
<td>&lt; 0.140</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Welding options, when any of the three pipe conditions applies</th>
<th>E6010</th>
<th>E6010</th>
<th>E8010</th>
<th>E8010</th>
<th>E6010</th>
<th>E8010</th>
<th>E8010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumable, root</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumable, remaining passes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weld cap reinforcement</td>
<td>Regular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass control</td>
<td>Regular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A stand-alone document with the recommended selection of welding processes and qualification requirements is available through PRCI project MATH-5-3B.
Selection of Welding Processes – Dimensions of Wide Cap

- Use cap to compensate the low-strength weld metal

A stand-alone document with the recommended selection of welding processes and qualification requirements is available through PRCI project MATH-5-3B.
Welding Procedure Qualifications

- Selecting pipes for qualification tests
  - Higher end of strength distribution (both yield and UTS)
  - Lower end of carbon and Pcm distribution

- Qualification criteria
  - No failure in the weld region (weld metal, fusion boundary, and HAZ)
  - Permitting failure in the weld region, provided a target strain capacity is achieved

A stand-alone document with the recommended selection of welding processes and qualification requirements is available through PRCI project MATH-5-3B.
Evaluate the performance of girth welds by examining the relative strain accumulation between the weld region and the base pipe.
Engagement of Other Stakeholders

- Stakeholders
  - Pipeline operators
  - Construction contractors
  - Pipe manufacturers, steel producers
  - Regulators

- Change in industry standards
  - Specifications governing different phases of a pipeline’s life cycle need to be coordinated
    - Design (ASME B31.4 and B31.8)
    - Linepipe specifications (API 5L and equivalent)
    - Field welding and inspection (API 1104 and equivalent)
  - Have a coordinated plan among relevant organizations
    - ASME, API, PRCI, INGAA, PHMSA
Acknowledgement

- PRCI
- JIP
- Pipeline operators
- Pipe and steel mills
- Staff at CRES
Thank You

- Q&A