

Girth Weld Strength Matching/ HAZ Softening

**API-AGA Joint Committee on Oil and Gas Pipeline Field Welding Practices
Bill Bruce (Part 1 – Introduction) and Yong-Yi Wang (Part 2)**

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Introduction

- Pipeline girth weld failures continue to occur on newly-constructed pipelines in North America
 - During pre-service hydrostatic proof testing
 - Soon after being placed in service
- Some from pipeline construction quality issues identified by PHMSA in ADB-10-03
 - High-low misalignment, unequal-wall-thickness transitions, high longitudinal stress/strain associated with lifting and lowering-in practices, inadequate tie-in and repair welding procedures, improper inspection and delay times, insufficient adherence to qualified welding procedures
- Others from undermatching strength and/or HAZ softening in otherwise “acceptable” girth welds
 - All in manual welds made using SMAW and cellulosic-coated electrodes
 - Most in large diameter X70 pipelines
 - None in mechanized GMAW welds



Girth Weld Strength Matching



- The rate of pipeline incidents (leaks and ruptures) attributed to defective girth welds has traditionally been low
 - Axial stresses (i.e., perpendicular to girth welds) from pressure loading are significantly lower in a completed pipeline than those in the circumferential (hoop stress) direction
- Axial stresses in completed girth welds
 - Occur during lifting and lowering-in →
 - Occur when the pipeline does not fit the ditch ↘
- Undermatching strength girth welds can be due to:
 - Pipe strength in axial direction is greater than weld metal strength
 - Softening in the heat-affected zone



Recent Industry Trends

- Two Recent PHMSA Advisory Bulletins
 - ADB-09-01 – Potential Low and Variable Yield and Tensile Strength and Chemical Composition Properties in High Strength Line Pipe
 - ADB-10-03 – Girth Weld Quality Issues Due to Improper Transitioning, Misalignment, and Welding Practices of Large Diameter Line Pipe
- Since ADB-09-01, trend for as-received line pipe strength levels has been toward the upper end of the acceptable range
 - Manufacturers aiming higher to account for variability in tensile testing practices by third-party labs (flattening procedure, Bauschinger effect, extensometer placement, etc.)
 - Anything a third-party lab does that is not ideal will tend to reduce the apparent strength
 - Strength in longitudinal direction is sometimes higher than that in the transverse direction
- Alloying strategy currently being used results in very lean chemical composition
 - e.g., %C < 0.05
 - High resistance to hydrogen-assisted cold cracking (HACC) in the HAZ – *but* –
 - Increased susceptibility to softening in the HAZ

Girth Weld Strength Requirements – 1 of 2

- There is no requirement in API 1104 for the actual strength of the weld to be greater than the actual strength of the pipe material
 - Cross weld tensile specimens are allowed break in the weld as long as they do so above the specified-minimum tensile strength of the pipe material
 - No requirement to qualify (or otherwise test) the welding procedure on “project pipe”
 - For many applications (e.g., pipelines in non-flat terrain), it is good practice to at least match the actual yield strength of the pipe
- When girth welds have undermatching strength – due to insufficient weld metal strength or HAZ softening – longitudinal strains can accumulate in the weld region
 - Evidence of necking in and adjacent to the weld 
 - Evidence of plastic strains in and adjacent to girth welds the form of cracks in epoxy field joint coating 

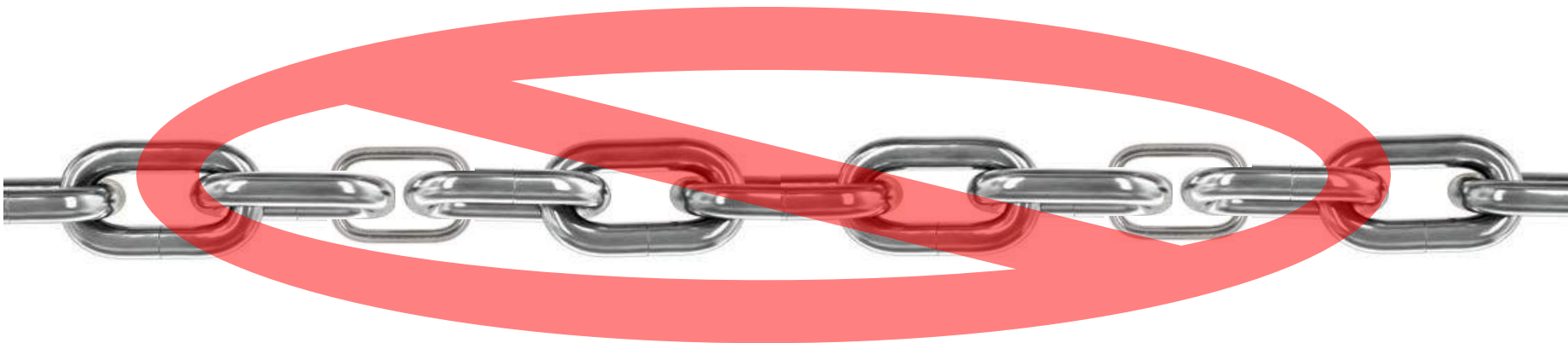


Girth Weld Strength Requirements – 2 of 2


- The use of matching strength girth welds prevents longitudinal strains from accumulating in the weld region, which is a natural stress concentration and is more likely to contain imperfections than the pipe material
 - Filler metal with yield strength that matches or overmatches the actual yield strength of the pipe material
 - No significant HAZ softening
- Inability of weld metal from cellulosic-coated electrodes to match the axial strength of modern X70
 - Can be made to be stronger, but hydrogen cracking in the weld metal becomes a significant concern

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API 1104/5L Joint Work Group

- Originally established to address pipe-end dimensional tolerance issues as the result of “normalization” of API 5L
 - Conversion to metric measurements results in the potential for significant high-low misalignment
- Working group remains active and is ideally suited to address current issues between line pipe manufacturing and girth welding
 - API 5L side
 - Line pipe with strength levels toward the upper end of acceptable range
 - Line pipe chemical composition with increased susceptibility to HAZ softening
 - API 1104 side
 - Girth weld strength matching and requirements
- “Third leg” of the triangle is not represented here
 - High axial strains during and soon after construction
 - e.g., make sure the profile of the pipe string  matches the profile of the ditch
- Meets later this afternoon



Part 2 – Other Industry Activities (Yong-Yi Wang)

- Joint industry project (JIP)
- PRCI activities

Low Strain Tolerance in Some Newly Constructed Pipelines

Unexpected Incidents of Girth Welds

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API 1104 and 5L

01/23/2018

San Antonio, TX, USA

Acknowledgment

- ❑ Organizations contributed to the data/ideas shown in this presentation
 - ❖ PRCI
 - ❖ A JIP under way now, organized by ITI (more later)
 - ❖ Sponsors of a completed JIP on the management of ground movement hazards
 - ❖ Pipeline operators
 - ❖ DOT PHMSA
- ❑ Individuals contributed to this work
 - ❖ David Horsley
 - ❖ David Johnson
 - ❖ David Warman
 - ❖ Robin Gordon
 - ❖ Bill Bruce
 - ❖ Pat Vieth
- ❑ The opinions are those of presenters, not their organizations or API.

Overview

- ❑ Background
 - ❖ Relevance of this topic to pipeline service
- ❑ A few known incidents
 - ❖ Identifiers to specific incidents are left out for anonymity
- ❑ Contributors to the incidents
- ❑ Mechanism of failures
- ❑ Role of linepipe specifications and girth welding procedure qualification
- ❑ Possible directions for mitigation
- ❑ JIP and PRCI projects
- ❑ Concluding remarks

Why Do Pipelines Need Tolerance to Axial (Longitudinal) Strains?

- ❑ Conditions generating axial strains - most onshore pipelines
 - ❖ Differential settlement
 - ▶ Tie-in at crossings
 - ▶ Excavation/dig of pipelines that have been in service for a while
 - ❖ The profiles of trench and pipes don't completely match.
 - ❖ Pipe ends are forced together at tie-in locations.
 - ❖ Temperature change
- ❑ Conditions generating high axial strains - many onshore pipelines
 - ❖ Slow ground movement, e.g., landslide
 - ❖ Washout at water crossings
- ❑ Our practice
 - ❖ Internal pressure, thus hoop stress, is actively managed.
 - ❖ Longitudinal stress/strains in most cases are not actively managed
 - ▶ High strain locations exist more often than many expected.
 - ▶ These locations can be present unexpectedly.

Pipe moved laterally after excavation. There were axial strains in the pipe.



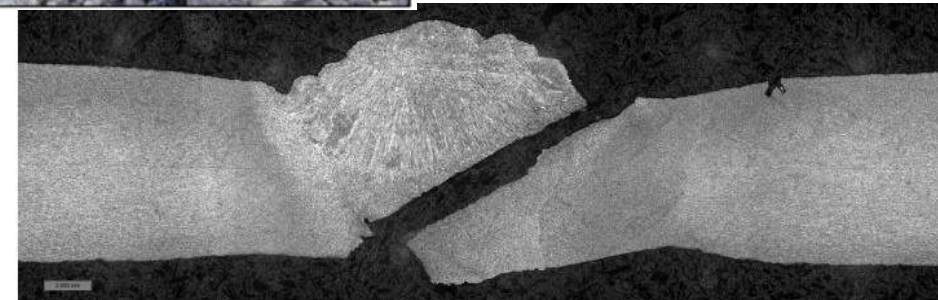
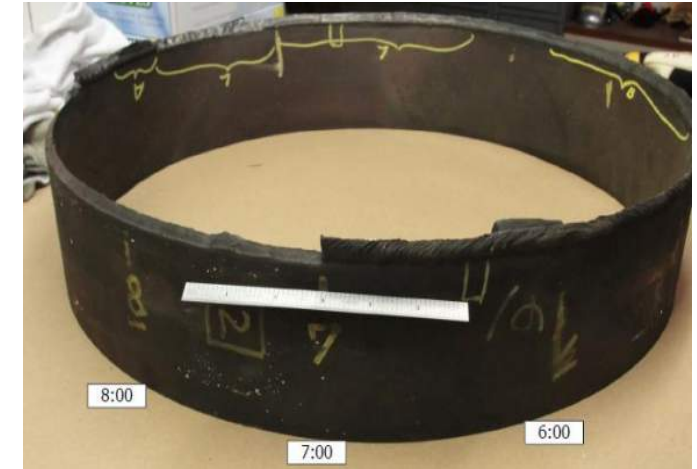
Overview of the Incidents

- ❑ Six incidents
 - ❖ Four in-service failures
 - ❖ Two hydrostatic failures (leak)
- ❑ Pipes
 - ❖ Two ERW pipes (12" and 20" OD)
 - ❖ Four SAWH (spiral pipes) 30+" OD
 - ❖ Grades
 - ▶ X52 12" OD
 - ▶ Four X70
 - ▶ One X70 and X80 (transition weld)
- ❑ Welding
 - ❖ Procedure for the 12" X52 is not known, but it's recent construction.
 - ❖ Four X70 welds: SMAW E6010 root, E8010 fill and cap passes
 - ❖ X70/X80: FCAW fill and cap passes

Known Incidents

□ Incident 1 – in-service

- ❖ In-service date: winter 2013/2014
- ❖ Time of incident: winter 2014/2015
- ❖ API 5L X70 20" OD 0.312" WT ERW pipe
- ❖ Pressure was at 82% of MOP at the time of failure.
- ❖ Pipe and weld met API 5L and API 1104.
- ❖ GW failure at ~0.44-0.50% overall strain in the pipe



Known Incidents (continued)

□ Incident 2 – in-service

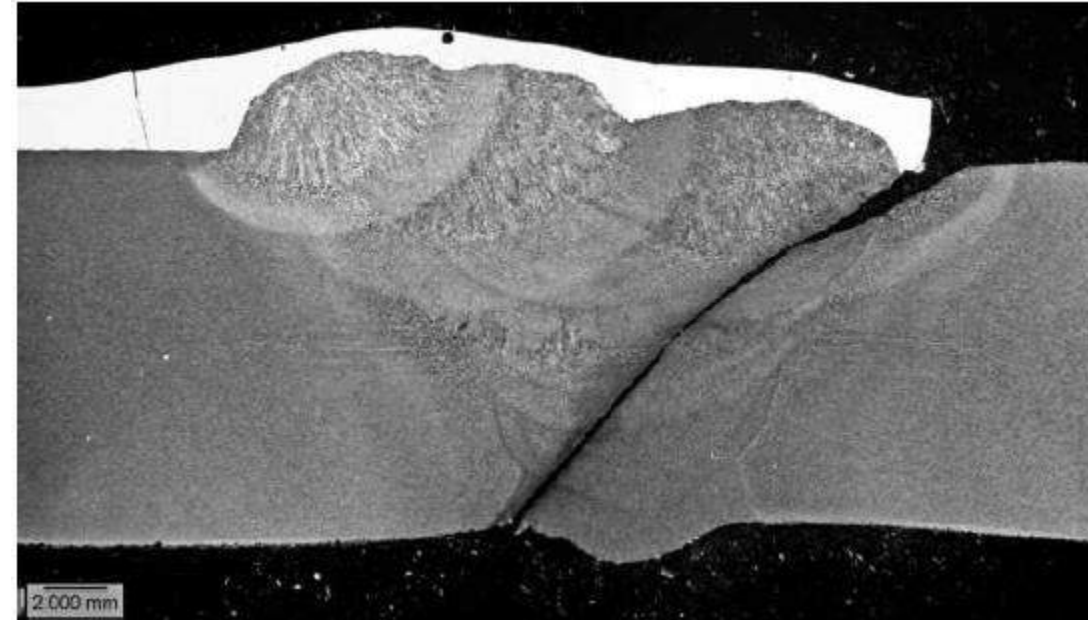
- ❖ In-service date: late 2000's
- ❖ Time of incident: 2014/2015
- ❖ Tie-in location, transition weld with wall thickness different
- ❖ Large diameter
- ❖ Failure initiated at the top of a girth weld, propagated around the circumference, had incomplete separate at the bottom of the weld
- ❖ Nominal tensile strain at failure was estimated at ~0.4-0.5%.

□ Welding and inspection

- ❖ Root: SMAW E6010
- ❖ Fill and cap passes: FCAW
- ❖ Inspected to API 1104

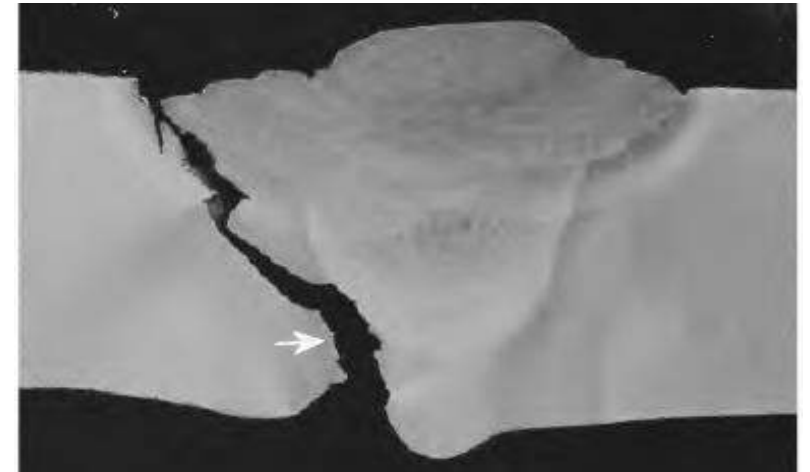
Known Incidents (continued)

- ❑ Incident 5 – hydrostatic test during construction
 - ❖ Time of incident: fall of 2015
 - ❖ API 5L X70 30” OD 0.515” WT
 - ❖ Test pressure was at 75% of the required test pressure.
 - ❖ Failure occurred a tie-in weld.
- ❑ Welding and inspection
 - ❖ SMAW, E6010 root, E8010 remaining passes
 - ❖ Inspected to API 1104, 24 hour delay
 - ❖ Films were audited prior to hydrotesting. No issues were found.
- ❑ A 4.5-degree bend was needed in the replacement spool, indicating bending stress was in the original segment.



Known Incidents (continued)

- ❑ Incident 6 – in-service
 - ❖ In-service date: fall 2012
 - ❖ Time of incident: summer of 2015
 - ❖ Failed weld: mainline weld, nominally equal WT on either side
- ❑ API 5L X70 42" OD 0.550" WT SAWH pipe
- ❑ There was some nominal settlement loading.



Non-Contributors to the Incidents

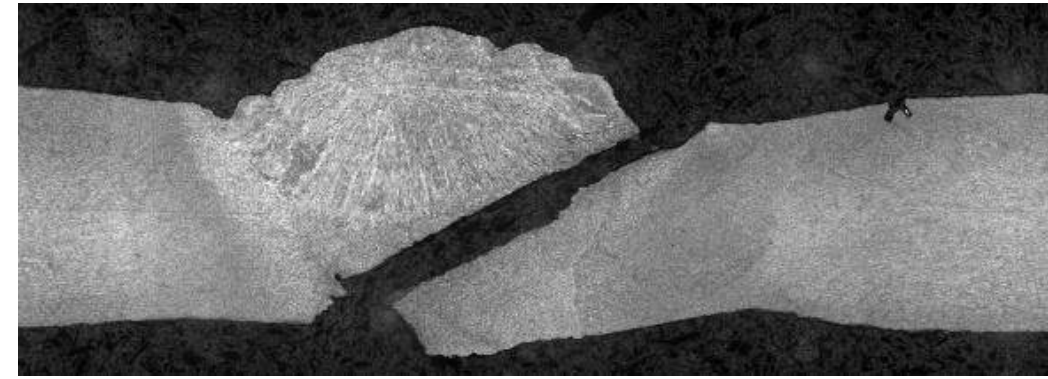
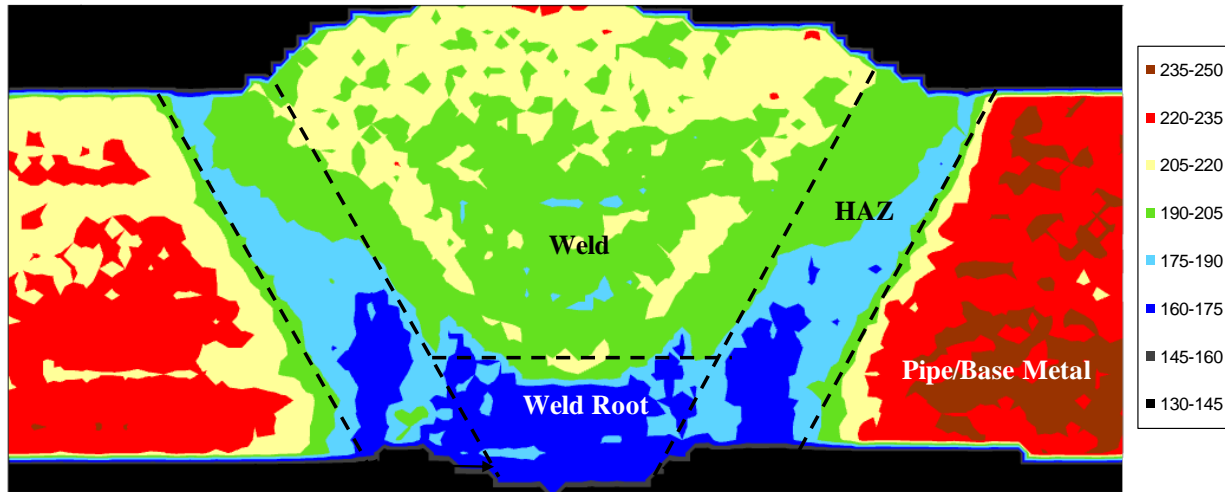
- ❑ There were little to no weld defects in the failed girth welds, except Incident 4.
- ❑ The pipe strength met API 5L requirements.
- ❑ The chemical composition of the pipes met API 5L requirements.
- ❑ The level of high-low misalignment is low in most cases. When moderate level of high-low existed, it was well within the recommended limit of API 1104.
- ❑ The cross-weld tensile tests met API 1104 requirements, despite welding strength being lower than the strength of the pipe by a wide margin in some cases.
- ❑ The toughness of the weld was adequate. The failures were strength-driven, not toughness-driven.
- ❑ Pipes and welds (including inspection) were code-compliant.

Contributors to the Incidents (Preliminary but Strong Indicators)¹

- ❑ Weld strength undermatching the actual strength of the pipe
 - ❖ Pipe strength being higher than the specified minimum
 - ▶ Pipe UTS could be as high as SMTS+20 ksi
- ❑ HAZ softening
- ❑ Soft root
- ❑ Weld bevel (manual SMAW/FCAW)
- ❑ Bending loads from normal ground settlement and other sources
 - ❖ Except for Incident 3, these loads are higher than loads experienced by most welds in onshore pipelines, but they are normal construction and settlement loads likely common in current industry practice.

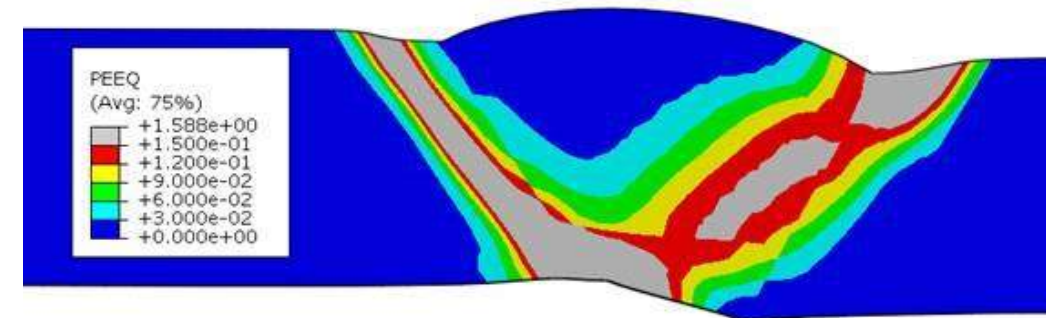
Note 1: The relative level of the contribution of these factors to the identified incidents vary from incident to incident. For instance, weld strength undermatching plays a greater role than HAZ softening in some cases. In other cases, HAZ softening may play a greater role. These factors interact and can't completely isolated.

Failure Path with HAZ Softening of a Manual Weld



□ Representative hardness values

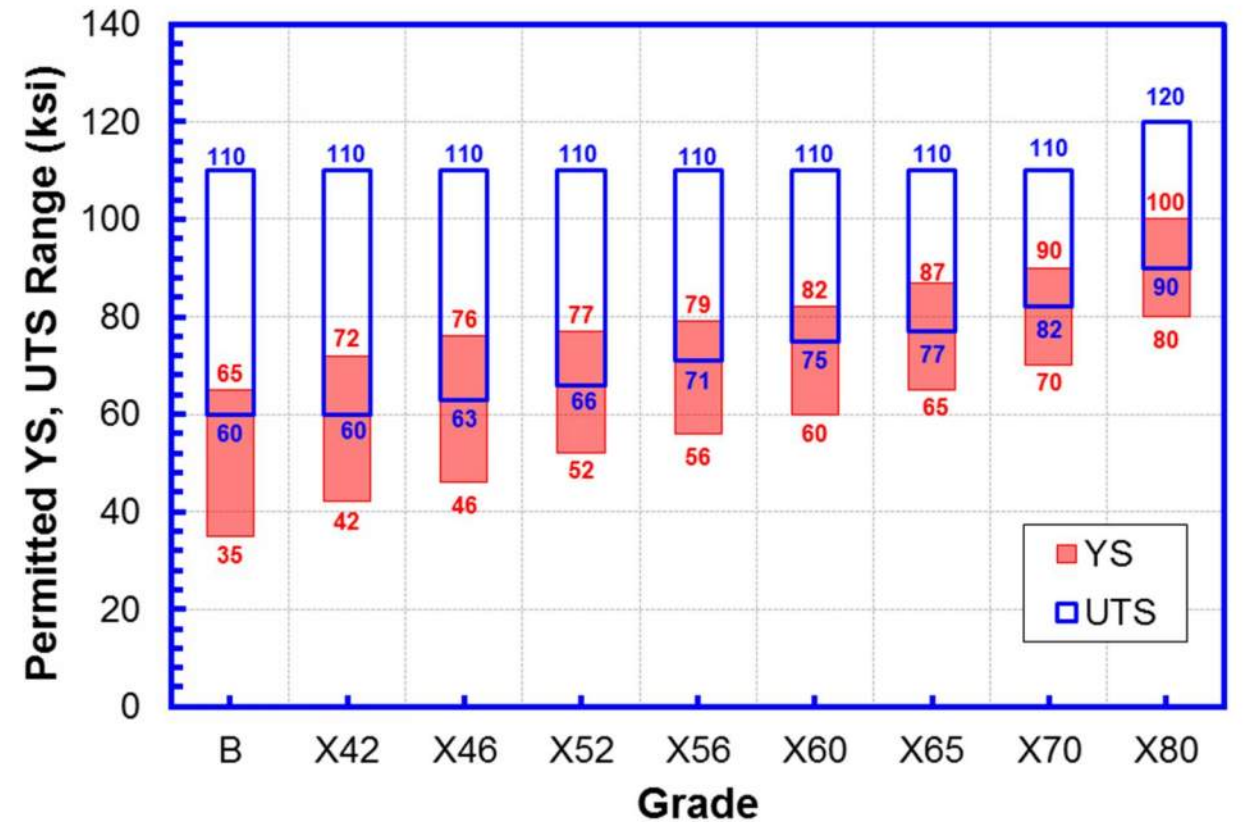
- ❖ Pipe: 235 Hv
- ❖ Root pass: 165 Hv (70% of pipe)
- ❖ Fill pass: 205 Hv (87% of pipe)
- ❖ HAZ: 185 Hv (79% of pipe)



Contour of plastic strain. Note that the plastic strain in the HAZ is much higher than that in the pipe and upper fill passes.

Role of Pipe Specifications and Weld Qualification Requirements

- ❑ Pipe strength can be significantly higher than the specified minimum strength
- ❑ Girth welds qualification requires welds meeting the minimum strength.
- ❑ For instance, for welds on X70 pipes
 - ❖ Pipe yield strength can be as high as 90 ksi
 - ❖ Welds can be qualified if it breaks at a stress level 82 ksi or higher.
 - ❖ Weld strength can be significantly lower than the strength of the pipe, yet pass qualification.
- ❑ In an event of settlement, strains are concentrated in the weld.

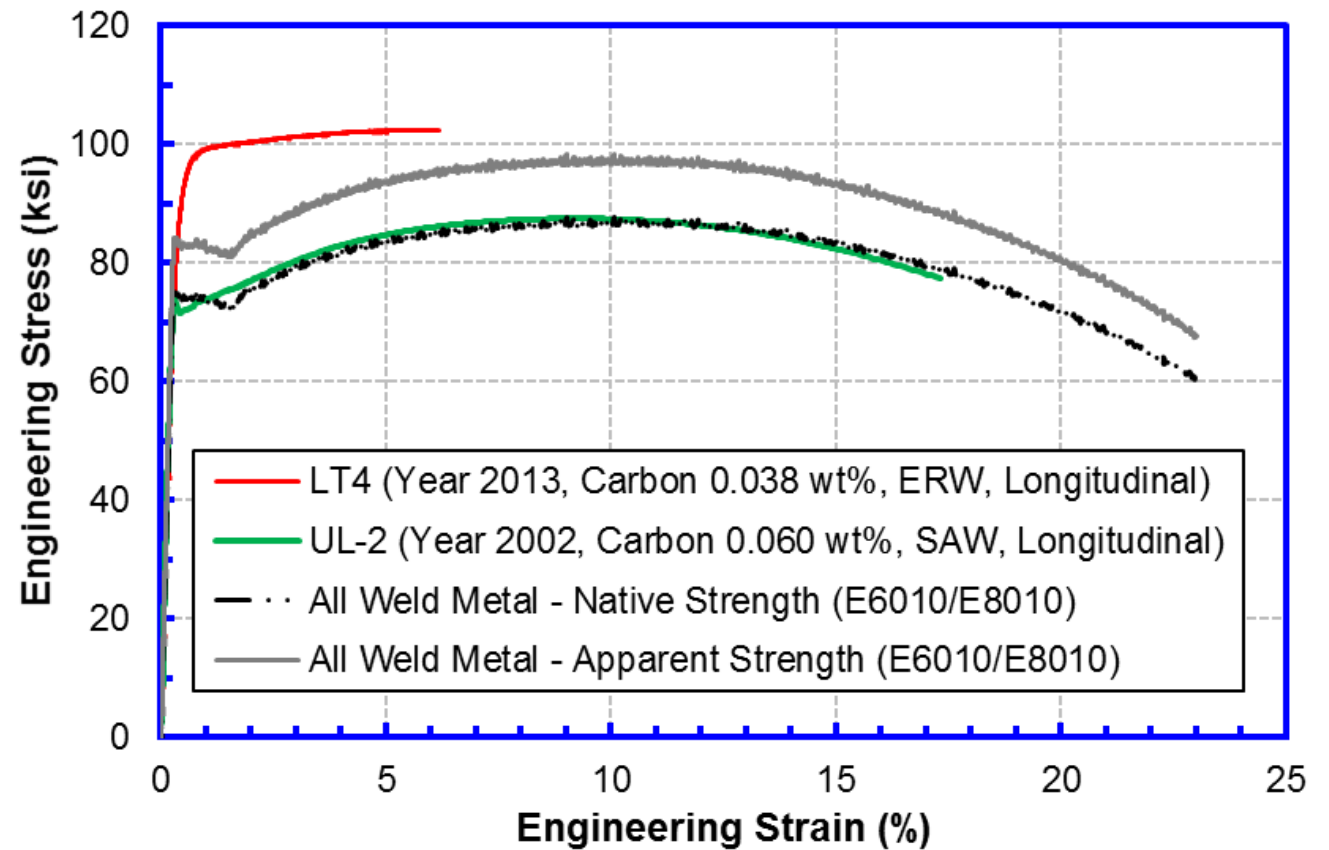


Why Is It Happening Now?

- ❑ There could be multiple causes.
- ❑ General facts
 - ❖ Manual girth welding of X70 pipes has largely unchanged since the use of X70.
 - ❖ More spiral pipes are being used in cross-country pipelines in last two decades.
 - ❖ All incidents so far are on spiral or ERW pipes.
 - ❖ Steelmaking continues to evolve.
 - ▶ Lean chemistry, contributing to (1) reduced propensity of HAZ hydrogen cracking and (2) higher levels of HAZ softening
 - ▶ Increase in pipe strength, at least evident from pipes involved in the incidents
 - ▶ Very large increase, in some cases, in pipe yield strength, although the increase in UTS is less.

Weld Strength Mismatch - Impact of Changing Pipe Strength

- ❑ Two girth welds
 - ❖ Same weld metal strength
 - ❖ 2002 SAWL pipe
 - ▶ low strength, weld strength overmatching
 - ❖ 2013 ERW pipe
 - ▶ high strength, weld strength undermatching
- ❑ The strength of pipes and welds has distributions, not a single value.
- ❑ The example may or may not represent a broad industry trend.

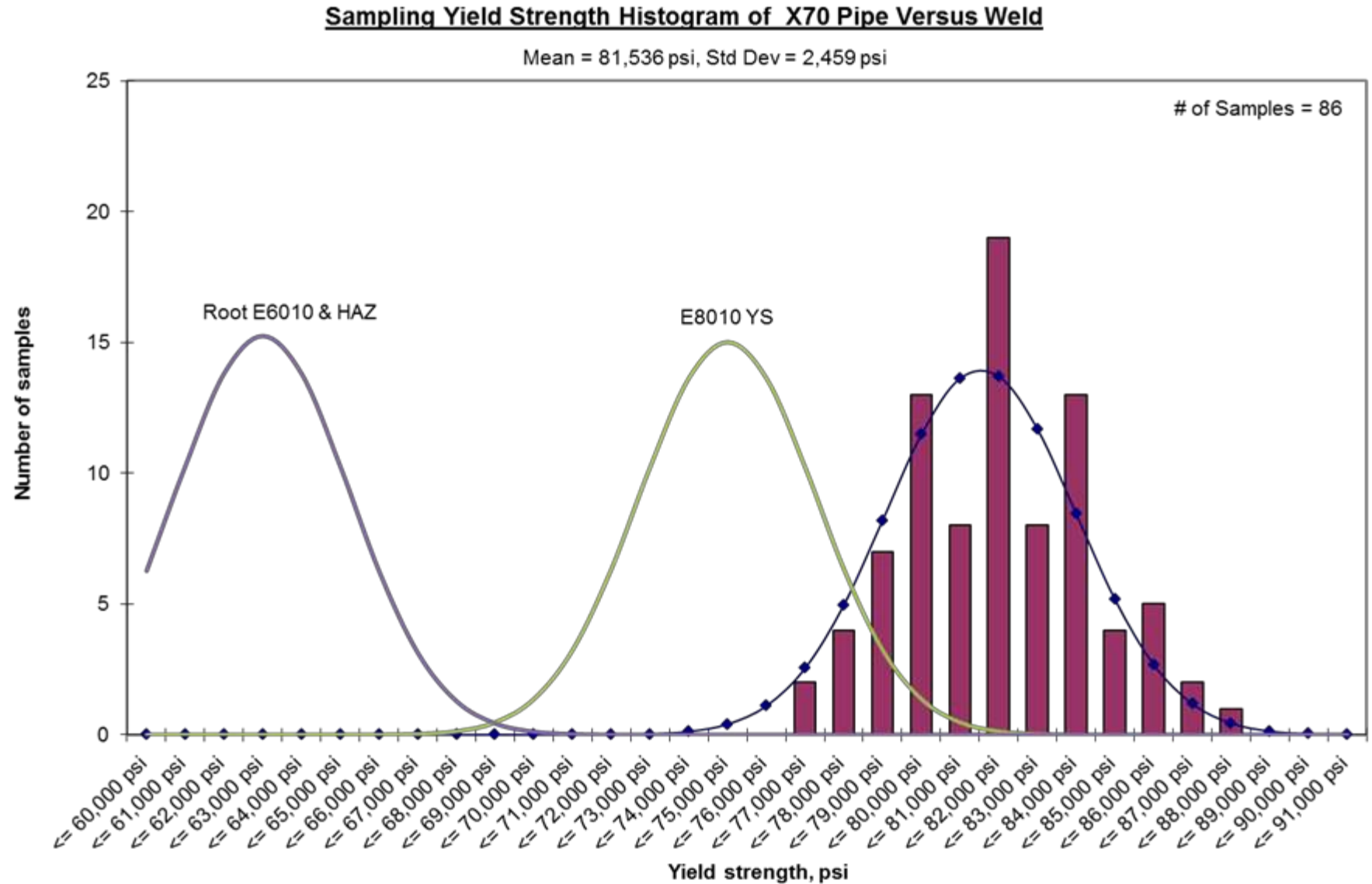


All Weld Metal – Native Strength: strength as measured by all weld metal tensile test

All Weld Metal – Apparent Strength: estimated weld strength in a girth weld, incorporating the apparent strength increase due to weld cap reinforcement and the constraint of the weld bevel

Weld Strength Mismatch – Distribution of Strength

- ❑ The native strength of root pass, fill and cap passes, and the HAZ is lower than the strength of the pipe.
- ❑ Even incorporating the effects of weld cap reinforcement and weld bevel constraint, the apparent strength of the weld can be lower than the strength of the pipe.
- ❑ Weld strength undermatching is more likely than overmatching, after considering the distributions.



Mitigation – Possible Directions, NOT Final Recommendations

- ❑ Welding
 - ❖ Stronger root pass
 - ❖ Stronger fill and cap passes
 - ▶ Low hydrogen processes
 - ▶ FCAW-G or FCAW-S
 - ❖ Wider weld cap, i.e., cap reinforcement
- ❑ Pipe
 - ❖ Test in longitudinal direction
 - ❖ Lower upper limits of the permissible strength range
 - ❖ Lowering yield strength more than lowering UTS
 - ▶ Having strength overmatching at yield level at a minimum, if overmatching at UTS can't be achieved.
 - ❖ Reduction in the level of HAZ softening
- ❑ Axial (longitudinal) strain
 - ❖ Make sure the profile of the pipe string fits the profile of the ditch
 - ❖ Don't force pipe ends together at tie-in locations, etc.
 - ❖ Backfill procedures

JIP on X70 Girth Welds – Project Research Team

- ❑ Robin Gordon, PI, Microalloying International
- ❑ Yong-Yi Wang, Technical Investigator, CRES
- ❑ Malcolm Gray, Technical Investigator, MSI
- ❑ Phil Kirkwood, Technical Investigator, Micro-Met International
- ❑ Daniel Guzman, Project Manager, ITI International
- ❑ Patrick Vieth, Project Support, Dynamic Risk
- ❑ Bill Bruce, Project Consultant, DNV GL

JIP Structure - Sponsors

□ Operators

- ❖ Enbridge, Steve Rapp, Chair
- ❖ Williams
- ❖ Cheniere
- ❖ Enterprise Products
- ❖ Energy Transfer
- ❖ PG&E
- ❖ Kinder Morgan
- ❖ Boardwalk Pipelines
- ❖ TCPL

□ Non-operators

- ❖ STUPP
- ❖ JSW Steel USA
- ❖ SSAB
- ❖ Berg Pipe
- ❖ American Steel Pipe
- ❖ Dura-Bond Pipe
- ❖ Arcelor Mittal
- ❖ Jindal Tubular
- ❖ Welspun Tubular
- ❖ Evraz R&D

JIP and PRCI Project

□ JIP – Overall goals

- ❖ Focus on future construction projects
- ❖ Linepipe specifications
- ❖ Welding practice

□ Status

- ❖ Phase I complete
- ❖ Phase II is about to be launched

□ PRCI – Overall goals

- ❖ Proper use of modern linepipes and application of welding processes to minimize the risk of girth weld failures, and
- ❖ Anomaly assessment of pipelines constructed of modern linepipes

□ Year 2018

- ❖ Risk ranking and mitigation options for pipelines already in service
- ❖ Recommendations for pipe replacement projects

□ Year 2019

- ❖ New tensile test methods,
- ❖ New yield strength definitions, and
- ❖ Anomaly assessment procedures

□ Year 2020

- ❖ Overall summary and recommendations

Concluding Remarks

- ❑ Unexpected girth weld failures have occurred.
- ❑ Linepipe specifications and girth weld qualification requirements are not sufficient to guarantee girth welds to have adequate strain capacity under conditions frequently encountered in service.
- ❑ Together, between linepipe properties and welding practice, there can be integrity risks of girth welds.
- ❑ One might be tempted to think this as a linepipe vs. girth welding issue, but this is not a wise approach.
 - ❖ The weld performance is affected by pipes and welding processes/procedures.

Concluding Remarks

- ❑ Our industry should take a coherent approach that would examine factors affecting the eventual performance of pipelines.
 - ❖ Steel making
 - ❖ Linepipe specifications
 - ❖ Welding practice
 - ❖ Requirements for welding procedure qualification
 - ❖ Pipeline construction and service environment
- ❑ Let's look at the most effective approaches, incorporating real-world conditions, i.e., conditions that we can control vs. those we can't control.
- ❑ Ultimately girth welds of new pipelines should be safe against normal construction and service loads.

How Can Everyone Here Contribute?

- ❑ Check if there were girth weld failures that seem “out of ordinary”
 - ❖ No significant flaws
 - ❖ Welding and inspection were done per general industry practice.
 - ❖ Pay special attention to incidents identified as “overload failures”
- ❑ Determine if you wish to share the information
- ❑ If yes, contact the presenters

Thank You

- Discussion and comments