Girth Welding in the Age of Evolving Steel Manufacturing Processes and under Realistic Field Conditions

Current Practice and Gaps

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API 1104/5L Joint Task Group
1/22/2019
San Antonio, TX, USA
Overview

- Girth weld incidents and contributors
  - Contributors from technical perspectives
  - Contributors in our systems
- Gaps in our approaches
- Importance of taking holistic approaches to weld integrity rooted in fundamental understandings
Girth Weld Incidents

- Multiple incidents in the last few years
  - Most were in-service failures
  - Some were hydrostatic failures (leaks)

- Pipes
  - ERW pipes (12”, 20” and 24” OD)
  - SAWH (spiral pipes) 30+” OD
  - (One source indicated that there have been failures involving SAWL pipes, but CRES has no direct knowledge of such incidents.)
  - Grades
    - X52, X65 (small to medium diameter ERW)
    - Most were X70 (medium to large diameter, ERW and SAWH)
    - One X70 to X80 (transition weld)

- Welding – all manual
  - SMAW: E6010 root, E8010 fill and cap passes
  - X70/X80: SMAW/E6010 root, FCAW fill and cap passes
Features of Failure Path

A-A

A-B

B-A

B-B
Features of Failure Path
Hardness/Strength Distribution: a Good Indicator of Failure Path

Pipe 1
YS = 86,000 psi

E8010 hot pass, fill and cap YS ~ 78,000 psi

Pipe 2
YS = 91,500 psi

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

E6010 root bead
YS ~ 66,000 psi
Failure Path: in Softened HAZ without Weld Strength Undermatching
Contributors to the Incidents

- Weld strength undermatching the actual strength of the pipe
- HAZ softening
- Soft root
- Weld bevel (manual SMAW/FCAW)
- Bending loads
  - normal ground settlement
  - Mismatch between pipe and trench profiles
Non-Contributors to the Incidents

- Weld flaw
  - was a main contributor to a hydrostatic test leak.
  - Was not a factor in other incidents.
- The level of high-low misalignment is low in most cases. When a moderate level of high-low existed, it was well within the recommended limit of API 1104.
- The pipe strength met API 5L requirements.
- The chemical composition of the pipes met API 5L requirements.
- 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.
Factors Contr. to Weld Strength Undermatching

- Manual welding processes and consumables has not changed.
- Pipe strength progressively moved up.
  - Large range permitted in API 5L
  - 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.
  - Industry response to expanded pipes due to “understrength” pipes
    - PHMSA ADB
  - The negative consequence of higher strength was not well recognized.
Contributor to Pipe Having High Strength for a Grade

- EPRG tests show that flattened specimens could underrepresent the YS of full-size pipe specimens by
  - 12% on average, and
  - 18% at most.

- Observed actual high-end YS
  - X52: low 80s to low 90s ksi
  - X70: mid 80s to low 90s ksi

<table>
<thead>
<tr>
<th>Grade</th>
<th>API 5L PSL 2 YS (ksi)</th>
<th>Possible Actual YS Range after Considering 12% Under-Representation (ksi)</th>
<th>Actual Minimum YS Pipe Mills Would/Could Target Considering 18% Under-Representation (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>X52</td>
<td>52</td>
<td>77</td>
<td>59</td>
</tr>
<tr>
<td>X70</td>
<td>70</td>
<td>90</td>
<td>79</td>
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</tbody>
</table>

API 5L PSL 2 YS (ksi)
Possible Actual YS Range after Considering 12% Under-Representation (ksi)
Actual Minimum YS Pipe Mills Would/Could Target Considering 18% Under-Representation (ksi)
Changes in YS & Strain Hardening over Time

- In this case, newer steel has higher actual yield strength, lower strain hardening

- The 2010s X52 is more likely to have undermatching weld strength.
- Having strain hardening is important for the tolerance to mechanical damage.
  - Is 6% strain criterion for dent assessment good for linepipes with very low strain hardening and uniform strains less than 6%?
Failure Stress vs. Pipe & Weld Strength

- Failure stress taken from cross-weld tensile tests
- X70 pipes, E6010/E8010 consumables

Recent review of MTRs of X70 ERW pipes
- Mean of UTS: 100 ksi
- Range: 91-108 ksi

Weld strength is sufficient for some pipes in the distribution, but not so for many more.
Contributors to HAZ Softening - Steel Making Process

- Leaner chemistry: move towards lower carbon content and lower hardenability
- X70
  - Earlier days: C ~0.08%, Pcm: ~0.18-0.20
  - Present days: C: as low as 0.02%, Pcm: as low as 0.12
- Greater reliance on rolling and accelerated cooling to gain strength

From a paper by Malcolm Gray
Different Responses to Welding Thermal Cycles

- X70 UOE pipe, ~2000
- X70 ERW pipes, ~2013
HAZ Softening – Gaps in Linepipe Spec and WPQ

- HAZ softening is a result of pipe chemistry and girth welding thermal cycles.
- There is no qualification or testing of steel’s susceptibility to HAZ softening in
  - Linepipe spec, and
  - Girth weld procedure qualification
- In actual girth welds
  - Levels of HAZ softening vary greatly.
  - Softening level increases with repair welding
Gaps between Design and Field Conditions

❑ Our practice - conventional stress-based design
  ❖ Longitudinal stress is limited to 90% SMYS.
  ❖ Combined equivalent stress is limited to 90% SMYS.
  ❖ Implications: pipelines are “only required” to be able to tolerate strains up to 0.2%.

❑ Field conditions/practice
  ❖ Internal pressure, thus hoop stress, is actively managed.
  ❖ Longitudinal stress/strains in most cases are not actively managed.
    ►High strain locations exist more frequently than many expect.
Gaps between Design and Field Conditions

- Conditions generating axial strains - most onshore pipelines
  - Differential settlement
    - Tie-in at crossings
    - Excavation of pipelines that have been in service for a while
  - Pipe ends are forced together at tie-in locations
  - The profiles of trench and pipes don’t completely match
  - Temperature changes
In girth welding procedure qualifications

- Failure in the weld region is permitted if the failure stress is equal or above the minimum UTS of the pipe.
- For instance, for welds of X70 pipes
  - Pipe yield strength can be as high as 90 ksi.
  - Pipe UTS can be as high as 110 ksi.
  - Welds meet qualification requirements if they breaks at a stress level 82 ksi or higher.

Implications

- 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 Weld Performance vs. Qualification Requirements

- API 1104 focuses on the prevention, detection, and repair of flaws exceeding certain limits
- Effective integrity approach
  - No failure in nearly defect-free welds
  - Remove large flaws
- Requirements on welds, e.g., flaw acceptance criteria, should be tied to performance requirements
  - Loading conditions
    - Station welds vs. tie-in welds in hilly areas
    - Guard against overspecifying

<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>
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<tr>
<td>Weld strength mismatch</td>
<td>YS mismatch No</td>
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<td></td>
<td>UTS mismatch No</td>
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<tr>
<td>HAZ strength (Softening)</td>
<td>No</td>
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<tr>
<td>Weld profile</td>
<td>Cap reinforcement Mostly No</td>
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<td></td>
<td>Misalignment No</td>
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<tr>
<td></td>
<td>Bevel geometry Yes</td>
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<tr>
<td>Weld flaw</td>
<td>Flaw type Yes</td>
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<tr>
<td></td>
<td>Flaw dimensions Yes</td>
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<tr>
<td>Toughness</td>
<td>No</td>
</tr>
<tr>
<td>Applied stress/strain</td>
<td>No</td>
</tr>
</tbody>
</table>
Systematic Gaps

- Perception about standards
  - Standards committees
    - Standards are minimum requirements.
    - Additional requirements can be added by companies.
  - Purchasing and contract departments
    - Standards are sufficient.
    - May challenge any additional requirements
  - Contractors
    - Standards are the base and “everything”.
    - “If you ask more, you pay.”

- Purchasing department gets API 5L pipes with the lowest cost.
- Welding engineers don’t wish to get “punished” when they have to work with what they got.
  - Welding engineers may not have influence on pipe procurement and contracts.
- Construction crew wants to meet project deadlines.
Long-Term Mitigation Goals

- Having strain-resistant girth welds
  - Girth welds should be able to resist a minimum tensile strain of 0.5% at full pressure conditions

- Why? Managing pipelines to a low applied strain level is very difficult.
  - Construction practice
  - Terrain conditions
  - Changing pipe support conditions
    - Nearby third-party construction
    - Excavation and backfill in the future
    - Climate change, seasonable 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.
Concluding Remarks

- Welds have failed without the traditional contributors, such as
  - Flaws
  - Misalignment

- Welds have failed when
  - Applicable standards have been followed.
  - There is no large-scale external loading.
Concluding Remarks

❑ Gaps
  ❖ Design vs. field conditions
  ❖ Linepipe vs. welding
  ❖ Welding procedure qualification vs. field conditions

❑ There are gaps in
  ❖ Technology
  ❖ Transition and connection among multiple technical areas and disciplines
  ❖ Organizations
    ► Industry-wide: codes and standards
    ► Within a company: departments and teams
Concluding Remarks

- Our industry tends to define our practice by grades.
  - Grade could be a very loose indicator of strength.
  - Some fundamental material performance could have a very loose or even no connection with grades.
  - Our focus on grades could also prevent us from seeking fundamental understanding.

- The myth about grade
  - One knows the strength of a pipe by grade. *Maybe*
  - Grade can be used to rank the strength of pipes. *Maybe*
  - If a weld overmatches an X65 pipe in strength, it would overmatch X60 and X52. *Maybe*
  - If a weld is qualified for one grade for weld performance, it’s always good for this grade. *Maybe*
Concluding Remarks

- Our industry should take a holistic and coherent approach that examines all factors affecting the eventual performance of pipelines.
  - Steel making / linepipe specifications
  - Welding practice / requirements in welding procedure qualification
  - Field inspection and flaw acceptance criteria
  - Pipeline construction and service environment
  - Anomaly tolerance and assessment
  - ILI and in-ditch inspection
Concluding Remarks

❑ We could do a lot of busy work if we don’t understand the fundamentals.

❑ Our standards should move towards specifications based on engineering principles and understanding, augmented by historical experiences. Otherwise,
  ❖ We don’t know when we might “fall off a cliff”.
  ❖ We could be fixing “problems” that do not exist, e.g., removing good welds.
  ❖ We could be over-specifying requirements.
Thank You

- Q&A