EVOLUTION OF LINEPIPE MANUFACTURING AND ITS IMPLICATIONS ON WELD PROPERTIES AND PIPELINE SERVICE

IPC2016-64633

Modified for
API 1104 and 5L Joint Task Group

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Outline

- Evolution of linepipe manufacturing
  - Chemical composition
  - Tensile properties
- Implications of high yield strength and low strain hardening
- Implications of lean chemistry
- Response to welding
  - HAZ softening
  - Sensitivity to changes to welding conditions
- Strain capacity: modern vs. vintage
- Recent experience and lessons learnt
- Implications on linepipe specifications and recommendations
- Implications on welding and procedure qualification and recommendations
- Acknowledgement
Linepipe Manufacturing

- Evolution of composition, rolling practice, and grade over time, as of ~2000

Linepipe Manufacturing

- Carbon content vs. pipe grade

Evolution of Tensile Properties

- X52 in early to late 1950’s
Evolution of Linepipe Manufacturing and its Implications

- **Line 3:** late 1960's, X60

- **Line 4:** late 1980's to early 1990, X65
Evolution of Tensile Properties

- **X80 2000’s**

- **X52 early 2010**

### Graphs

- Stress vs. Strain for different pipe types:
  - X80 Weld Metal No.1, +23C
  - X80 Base Pipe Longitudinal No.1, +23C
  - X80 Base Pipe Hoop No.1, +23C

### Table

<table>
<thead>
<tr>
<th>Pipe</th>
<th>Yield 0.2% MPa</th>
<th>Yield 0.5 % MPa</th>
<th>UTS MPa</th>
<th>0.2%Y/T</th>
<th>Uniform Strain</th>
<th>Elongation</th>
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<tbody>
<tr>
<td>Hoop-3:00</td>
<td>430</td>
<td>448</td>
<td>554</td>
<td>0.776</td>
<td>11.2</td>
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<td>559</td>
<td>0.971</td>
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*Variation with clock position - Note higher results for 6:00*
The UTS is kept to about 600 MPa from X52 to X65.

Yield strength increased over time, resulting in lower strain hardening.

Some of the new pipes have yield strength well exceeds the SMYS and very low strain hardening capacity.
Implications of Low Strain Hardening of Lean Chemistry

- Reduced tolerance to material property variation
- Reduced “implicit” safety factor

- Reduced tolerance to anomalies
  - Metal loss
  - Dents

- Reduced tolerance to accidental overloading
  - Pressure
  - Ground movement


Ken Lee: Pipeline Construction Challenges: Field Girth Welds, March 16, 2010
Lean chemistry leads to low HAZ hardness.
Permitted Strength Range – API 5L PSL 2 Pipes

- Range of yield strength = 20-30 ksi
- Range of UTS = 28-50 ksi
Pipe 1
YS = 86,000 psi

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

Pipe 2
YS = 91,500 psi

Pipe 1:
- X70, early 2010’s
- GW: Manual SMAW

Pipe 2:
- YS = 91,500 psi
- E6010 root bead
- YS ~ 66,000 psi
Girth weld failure due to strain concentration along the HAZ while the nominal strain in the pipe is low (0.4-0.5%)
Girth Weld Failure

- Failure in the HAZ at ~0.44-0.50% overall strain in the pipe
- Girth weld was in compliance with API 1104.
The difference in composition between two steels is quite small.

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>Grade</th>
<th>OD (mm)</th>
<th>WT (mm)</th>
<th>Chemical Composition (WT%)</th>
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<td>C</td>
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<tr>
<td>7</td>
<td>X80</td>
<td>1016</td>
<td>18.4</td>
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<td>ZDH</td>
<td>X80</td>
<td>1219</td>
<td>15.3</td>
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<td>Cr</td>
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</table>
Large shifts of transition temperature from BM to HAZ in one steel
- Much smaller shifts of transition temperature from BM to HAZ in another steel.

![Graph showing the impact energy vs test temperature for different samples.](image)
Hardness of Vintage Welds

- Welds fabricated in 1950’s
- Weld metal strength is lower than the strength of the pipe.
- However, the big weld cap effectively serve as the reinforcement to the weld metal.
- There would be no strain concentration in the weld region due to the large weld volume.
- This weld can tolerate high stress/strain in the pipe’s longitudinal direction.
Welds fabricated in mid-1950’s, X52

- Weld failed at
  - Cross weld strain of 3.5%
  - Averaged strain in base pipe of 2.0%

- Strain capacity with Class 1 pressure = 1.0%
Strain Capacity – Vintage vs. Modern

- Vintage - SMAW
  - Weld flaw not acceptable by API 1104 workmanship criteria
  - Strain capacity = 1.0% (internal pressure to Class 1 gas pipelines)

- Modern - SMAW
  - No flaws
  - Strain capacity = 0.4-0.5% (internal pressure to Class 1 gas pipelines)

- If the same modern pipe is welded using mechanized GMAW process, the weld strength would higher and the HAZ softening would be less, leading to higher strain capacity.
Girth welds in newly constructed pipelines have experienced failures in hydrostatic tests and in-service.

These failures occurred despite
- Pipes were procured by and in compliance with API 5L,
- Girth welds were fabricated, inspected, and in compliance with API 1104.

Loads on these failed welds were high, but no greater than the level historically experienced by pipeline girth welds.
- These loads are NOT associated with ground movement.
- These loads could be associated with nominal ground settlement, elevated stresses at tie-in locations, and other construction stresses from generally accepted practice.

Welds in compliance with API 5L and 1104 are generally expected to maintain integrity against nominal construction stresses.

Current standards failed to meet this expectation in some cases.
- There is no provision against having highly undermatching weld strength.
- There is no provision against high level of HAZ softening.
Experience and Lessons Learnt

- Onshore pipelines can have longitudinal (axial) stress greater than design stress (90% SMYS)
  - Tie-in
  - Pipes forced to match trench profile
    - IMU runs in flat farm lands confirm there could be locations of high strain in the absence of ground movement.

- Longitudinal stresses are generally not managed, regardless how the pipelines are designed.

- Hydrogen cracks have been a rare issue in vintage pipelines.

- There could be more instances of unintentional undermatching and HAZ softening in modern pipelines than hydrogen cracks in vintage pipelines.

- Failure can occur when linepipe and girth welding are completely compliant with standards.
Current specifications place emphasis on strength, but neglect the evolution of chemical composition and steel making process.

Weld (including HAZ) properties are driven by steel’s chemical composition and welding thermal cycles, not by grade or strength.

The industry has gone too far in relying on controlled rolling to achieve strength target in some cases.

- Low carbon and lean chemistry were used to reduce the propensity of hydrogen assisted cracks (HAC) in HAZ and increase toughness.
- HAC is no longer an issue when carbon is reduced to a certain level.
- Recent failure events indicate that there is no benefit of having high toughness (beyond certain level) when the welds would failure due to under-strength and HAZ softening.
Implications on Linepipe Specifications

- The large range in strength permitted in the linepipe specifications poses uncertainties and difficulties (for high strength pipes) in producing reliably overmatching strength welds.

- Reduction in the strain hardening capacity of the linepipes leads to lower safety factor, compared to historical pipeline norms, in non-perfect conditions (anomalies and unexpected overloading).

- Recommended path forward
  - Set low-bound limits on carbon and other hardenability parameters, e.g., $P_{cm}$. Both carbon and hardenability parameters have to be above certain minimum values.
  - Reduce the strength range for a given grade
  - Set requirements on strain hardening
Implications on Welding and Procedure Qualification

- Principal drivers to weld (HAZ and deposited weld metal) properties
  - Chemical composition
  - Thermal cycles the materials are subjected to.

- Response to welding thermal cycles (e.g., HAZ properties) can be very different for the pipe of the same grade, but different vintage and chemical composition.

- Weld qualification by grade is fundamentally insufficient.
  - It works if the basic material response to thermal cycles remains similar or self-consistent. This is not the case from vintage to modern linepipes.
Recommended path forward

- Provide clear message, stating that weld qualification should consider:
  - Linepipe chemical composition,
  - Steel manufacturing process, and
  - Actual strength of the linepipes as delivered.

- Allow for alternative weld quality assurance, such as effective weld cap reinforcement.

- Encourage the use of low hydrogen processes that can produce high strength welds at low heat input (reduce the propensity of HAZ softening).
Acknowledgment

- David Warman, Enterprise
- Bo Wang, CRES
- Kunal Kotian, CRES
- Dan Jia, CRES
- Jim Gianetto, CANMET
- Steve Nanney, US DOT PHMSA

The views and opinions expressed here are those of the authors and do not necessarily reflect the official position of the sponsoring organizations.
Thank You and Questions