WELDING FOR SOUR SERVICE

2017 Pipeline Materials Workshop

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Overview

• Weld metal & HAZ vs. base material
• Factors affecting weld & HAZ properties
• Mitigating Weld & HAZ susceptibility to sulfide stress cracking
• Codes, Standards, and Best Practices
• Sour Service Welding Challenges
• Additional Sour Service Welding Tools
Weld Metal & HAZ vs. Base Material

- Base material properties are due to chemistry and thermo-mechanical history.
  - Multiple cycles of deformation and heat treatment are possible

- Weld metal and HAZ properties are due to chemistry and thermal history only.
  - Mechanical deformation not possible as with rolled, forged, TMCP materials.
  - Weld metal is essentially cast material and cannot be “reworked,” only ground out and re-welded.
    - Partial heat treatment occurs in multi-pass welds
    - Post-weld heat treatment is an option, but not typically used in pipeline construction due to cost and schedule impact.
Weld Metal & HAZ

Figure 1: Mechanized GMAW weld cross-section
Critically & Inter-Critically Reheated HAZ

Figure 2: Fusion Line Microstructure Characteristics\textsuperscript{1}
Factors Affecting Weld & HAZ Properties

• Chemistry and Thermal History
  • Carbon equivalent
    • $\text{CE}_{\text{IIW}} = C + \frac{Mn}{6} + \frac{(Cu+Ni)}{15} + \frac{(Cr+Mo+V)}{5}$
    • $\text{P}_{\text{cm}} = C + \frac{Si}{30} + \frac{(Mn+Cu+Cr)}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B$
    • $\text{CEN} = C + [0.75 + 0.25 \tanh(20(C-0.12))] \frac{Si}{24} + \frac{Mn}{6} + \frac{Cu}{15} + \frac{Ni}{20} + \frac{(Cr+Mo+Nb+V)}{5}$
  • Preheating/Interpass Temperatures & Welding Heat Input
    • As these parameters increase cooling rate is reduced, affecting microstructure
    • Heat input range is inherent to welding process
  • Post-Weld Slow Cooling
  • Post-Weld Heat Treatment
    • Generally below AC$_1$. (1hr/in @ 1150°F, 1hr. min.)
    • Stress relief and hardness reduction due to transformation of non-equilibrium hard phases.
Mitigating Sulfide Stress Cracking (SSC)

- **Susceptible Microstructure**
  - Especially Martensite

- **Tensile Stress**
  - Applied or Residual

- **Hydrogen Charging**
  - Aqueous corrosion in the presence of H₂S

Mitigate by PWHT

Unavoidable in Wet Sour Service

Mitigate by 250 HV max hardness
Codes, Standards, Best Practices

- Welding codes generally do not address sour service welding requirements directly.
- Sour service welding requirements come from code of construction such as CSA Z662, ASME B31.4, ASME B31.8.
- Most construction codes point to NACE MR0175/ISO 15156 “Materials for use in $\text{H}_2\text{S}$-containing environments in oil and gas production.”
  - Material recommendations for carbon and low alloy steels as well as corrosion-resistant alloys.
  - Also includes recommendations for qualification of welding procedures.
- Most Pipeline Companies have supplementary welding requirements for sour service (hardness, CE, testing, etc.)
NACE MR0175/ISO 15156 Hardness Survey

Figure 3: NACE MR0175-2 Figure 2 – Butt-weld survey method for Vickers hardness measurement
NACE MR0175/ISO 15156 Hardness Survey With Supplementary Testing

Figure 4: Modified NACE MR0175-2 Figure 2

Not to Scale
Supplementary Weld Hardness Surveys

- NACE MR0175 Vickers hardness surveys may not identify all local hard zones.
- Lighter indenter loads may also be used (1kg, 500g)

Figure 5: Vickers Hardness Grid

Figure 6: Supplementary Vickers Hardness Testing
Sour Service Welding Challenges

- Joining high CE materials
  - CE is an essential welding variable in sour service per CSA Z662.
  - Existing pipeline materials may have much higher CE than currently produced pipe material, particularly Q&T fittings.
    - High CE tends toward higher hardness

- Affects of Preheat, Interpass & Heat Input
  - Increasing these parameters is common practice to reduce weld hardness, but can have detrimental effects to some materials, particularly higher strength TMCP pipeline materials that may exhibit softening and loss of notch toughness in the HAZ.
  - 2.5kJ/mm is a common rule of thumb to avoid detrimental affects in TMCP pipe, particularly when steel rolling practice includes accelerated cooling as final step
  - May need to qualify welding procedures on both TMCP pipe and wrought fittings to confirm acceptable properties
Sour Service Welding Challenges

- **In-Service Welding**
  - Accelerated cooling due to presence of fluid inside pipe can drastically affect properties including hardness.
  - Special procedure qualification under conservative cooling conditions is required.
  - Qualification of sour-service welding procedures for pipelines containing liquid or flowing gas is difficult.

Figure 7: In-Service WPS Qualification
Additional Tools – Weld Models

• Thermal-Microstructural Prediction Models for Weld & HAZ Hardness
  • Empirically-derived algorithms
  • Neural networks combining various models and data sets
• Algorithms typically based on chemistry (base metal and filler metal), and a thermodynamically determined time-temperature parameter, typically $t_{8.5}$
• Some models commonly used in industry include:
  • Yurioka
  • Lorens & Duren
  • Proprietary Neural Networks (Tenaris Tenweld, etc.)
• Good correlation but watch out for standard deviation!
Additional Tools – Weld Models

Figure 8: Tenaris Tenweld® Model Output – Mechanized GMAW Weld (J bevel)
Additional Tools – Sour Service Testing

- Testing of materials that don’t meet NACE MR0175 recommendations is permitted
  - Standard test solutions (severe conditions)
  - Environment-specific test solutions (less severe)
- Testing defined in NACE TM0177
  - Deaeratred, $\text{H}_2\text{S}$-saturated, Low-pH (buffered or un-buffered)
  - Various test methods, C-ring is most common for pipe
  - Applied stress of 80-90% AYS, depending on test solution
  - Minimum test duration of 720 hours (30 days)
  - Inspect a 10X magnification for cracks
  - Assessment can be pass/fail and/or time to failure
Additional Tools – Sour Service Testing

Figure 10: SSC Cracks, 10X Magnification

Figure 10: SSC Cracks, 10X Magnification²
Additional Tools – Sour Service Testing

- 10X magnification may not find small SCC cracks.
- Etching and 200X or higher magnification may be required to find cracks in local hard zones.

Figure 11: SSC Cracks, 200X Magnification²
References
