High strength coiled tubing (CT) can be successfully used in sour environments if properly managed

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ICoTA Canada Roundtable, October 21, 2015
Agenda

• Background
  – What is high strength CT?

• Sour Gas Issues
  – Environmental cracking mechanisms
  – Historical operating guidelines
  – Mitigation strategies

• Test Program Development
  – How to test
  – Specialized considerations for CT
  – Experiment design

• Results

• Conclusions
Background

• What is high strength CT?
  – CT with strength levels beyond CT100/110
  – In this case, CT130
    • 130 ksi SMYS (896 MPa)
    • 135 ksi SMUTS (931 MPa)
    • 39 HRC maximum hardness
Sour Gas Issues

• Environmental cracking in aqueous sour environments
  – Hydrogen induced cracking (HIC) generally affects lower strength steels with UTS up to 550 MPa (Metals Handbook).
    • HIC is caused by the absorption of hydrogen into the steel (NACE).
    • HIC is not the expected failure mechanism for CT.
  – Sulfide stress cracking (SSC) affects higher strength steels, such as 130 ksi yield strength especially if they are stressed.
    • Since CT is repeatedly bent past the point of plasticity, SSC is the expected failure mechanism for CT.
    • SSC is corrosion caused by cathodic polarization; cathodic protection of CT would worsen the problem.

NACE TM0284-2011 Foreword
Sour Gas Issues

Environmental cracking in aqueous sour environments (cont.)

- HIC
- Longitudinal

- SSC
- Transverse
Sour Gas Issues

- Historical operating guidelines
  - “A generally accepted rule for resistance of carbon and low-alloy steels to SSC is to maintain the hardness below HRC 22” (Craig).

<table>
<thead>
<tr>
<th>CT Grade</th>
<th>Minimum Yield Strength (psi [MPa])</th>
<th>Maximum Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT70</td>
<td>70,000 (483)</td>
<td>22 HRC</td>
</tr>
<tr>
<td>CT80</td>
<td>80,000 (551)</td>
<td>22 HRC</td>
</tr>
<tr>
<td>CT90</td>
<td>90,000 (620)</td>
<td>22 HRC</td>
</tr>
<tr>
<td>CT100</td>
<td>100,000 (689)</td>
<td>28 HRC</td>
</tr>
<tr>
<td>CT110</td>
<td>110,000 (758)</td>
<td>30 HRC</td>
</tr>
<tr>
<td>CT130</td>
<td>130,000 (896)</td>
<td>39 HRC</td>
</tr>
</tbody>
</table>

- Higher strength grades are above 22 HRC, so mitigation strategies must be employed to safeguard against SSC.

Sour Gas Issues

• Mitigation strategies: why CT can be used in sour environments without causing SSC

  – SSC is dependent on time and temperature
    • Time: decreasing exposure time decreases the likelihood of SSC for high-strength coiled tubing
    • Temperature: increasing temperature decreases the likelihood of SSC for high-strength coiled tubing

  – External mitigation – controlling the environment
    • Raise the pH
    • Scavengers
    • Operate overbalanced
    • Inhibitors
Test Program Development

• How to Test
  – Mitigation strategies alone do not provide assurances; best method is to test
  – Laboratory testing method NACE TM0177
    • Machined samples are stressed and placed in an aqueous acidic environment saturated with $\mathrm{H}_2\mathrm{S}$ for 30 days
    • Three primary sample types: tensile, C-ring, four point bent beam

NACE TM0177-2005
Photo Courtesy of Exova
There is no industry standard for testing CT in sour environments.


Specialized considerations for coiled tubing:
- CT is plastically deformed in operations
- CT contains both seam and bias welds
- Test program considerations:
  - Half of samples should not be fatigued
  - Half of samples should be fatigued to approximately ½ of fatigue life
  - Samples should include the parent tubing, seam weld, and bias weld
  - Samples should be tested in duplicate

Each environment should have 12 samples!

<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>QTY</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent Tubing</td>
<td>2</td>
<td>No Fatigue</td>
</tr>
<tr>
<td>Seam Weld</td>
<td>2</td>
<td>Pre-Fatigued</td>
</tr>
<tr>
<td>Bias Weld</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Parent Tubing</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Seam Weld</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Bias Weld</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Test Program Development

• Experiment design
  – Key variables
    • pH
    • \( H_2S \) partial pressure
    • With and without inhibition
  – Inhibitor
    • Identified as “CG”
    • 0.2% by volume in aqueous solution
  – The rules
    • Environment “passes” only if all 12 samples pass
    • If any sample fails, a 3-for-1 retest is undertaken
    • Test at room temperature for 30 days to be more conservative

<table>
<thead>
<tr>
<th>Pressure, MPa (ksi)</th>
<th>( H_2S ) Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.89 (1)</td>
<td>&gt;50</td>
</tr>
<tr>
<td>20.68 (3)</td>
<td>&gt;15</td>
</tr>
<tr>
<td>34.47 (5)</td>
<td>&gt;10</td>
</tr>
<tr>
<td>68.95 (10)</td>
<td>&gt;5</td>
</tr>
<tr>
<td>103.42 (15)</td>
<td>&gt;3</td>
</tr>
</tbody>
</table>

Sour Service Criteria (SPE 121294)
Results

- All sample sets failed when no inhibition was used.
  - It is possible that over-straining occurred.
Results

• All sample sets passed when inhibition was used, with the need for one 3-for-1 retest.
Conclusions

• A “safe operating zone” exists for CT130 (and all lower-strength coiled tubing grades) as low as 2.8 pH and 10 bar $H_2S$ partial pressure when inhibitor CG is used.

• CT130 can be treated the same as CT100 and CT110 when operating in sour and non-sour environments when inhibition is used.

• Lesson learned: Always make extra test samples.

• Additional testing in progress:
  • Testing up to 100 bar $H_2S$ partial pressure with inhibitor CG.
  • More testing is necessary to develop a no-inhibition “safe zone” for CT130.