A Mechanical, Metallurgical and Operational Review of Bias Weld Performance

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Outline

• Changes in CT operations have introduced new challenges for CT performance
• Understanding the metallurgy of CT is key to improving performance (fatigue, corrosion, etc)
• CT property changes can introduce local deformation
• Complementary continuous HT process can address most issues
Coiled Tubing Operations Have Changed

- Increase in both stress (pressure) and strain (larger OD tubing)
- Other new factors (different fluids, re-use of water)
- Frequency of bias weld issues have increased
Metallurgy of Current Coiled Tubing

- Elongated Ferritic Grains with carbides in grain boundaries.
- Obtained by thermo-mechanically controlled rolling, accelerated cooling and low coiling temperature.
- Refine Microstructure Guarantees Mechanical Properties and Toughness
## Mechanism to Produce High Strength Steel

<table>
<thead>
<tr>
<th>CT Grade</th>
<th>Active Precipitates</th>
<th>Process Requirements</th>
<th>Resulting Microstructure</th>
<th>Hot Rolled Strip YS</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>Cementite + TiN</td>
<td>Thermomechanical Controlled Process (TMCP)</td>
<td>Ferrite and pearlite</td>
<td>≈ 60 ksi min</td>
</tr>
<tr>
<td>80</td>
<td>Cementite + TiN + NbC</td>
<td>TMCP + Accelerated cooling (AC)</td>
<td>Ferrite and pearlite with carbides in grain boundaries</td>
<td>≈ 70 ksi min</td>
</tr>
<tr>
<td>90</td>
<td>Cementite + TiN + NbC</td>
<td>TMCP + AC + low coiling temperature</td>
<td>Ferrite matrix with carbides in grain boundaries.</td>
<td>≈ 90 ksi min</td>
</tr>
<tr>
<td>110</td>
<td>Cementite + TiN + NbC</td>
<td>TMCP + AC + low coiling temperature</td>
<td>Ferrite matrix with carbides in grain boundaries + bainite</td>
<td>≈ 110 ksi min</td>
</tr>
<tr>
<td>120+</td>
<td>Cementite + TiN + NbC</td>
<td>TMCP + AC + low coiling temperature</td>
<td>Ferrite matrix with carbides in grain boundaries + bainite</td>
<td></td>
</tr>
</tbody>
</table>
Metallurgy of Current Coiled Tubing

- Microstructure depends on thermal history during welding
- Fused Zone and near HAZ with substantial Grain Growth
- Variation of microstructure across the Fused Zone, Coarse and Fine Grain HAZ, Inter and Subcritical HAZ.
- Performance could not be guarantee in the as welded condition.
Metallurgy of Current Coiled Tubing

Typical microstructures (Grade HS-110)

- As a result of the controlled rolling process in the steel mill, a fine dispersion of carbides in a ferritic matrix is found in the base tube.
- However, a coarse grained microstructure composed of upper bainite, with large laths of cementite, is found in the bias welds.
- This micro constituent has poorer fatigue resistance since cracks can propagate along the large laths of cementite.
Metallurgy of Current Coiled Tubing

• Material is re-heated and subsequently cooled
• Compromise between satisfying strength requirements and avoiding the creation of brittle constituents that compromise fatigue
• Requires a clear understanding of material behavior.
Post-weld HT is useful (and necessary) to decompose brittle constituent such as retained austenite and martensite that are generated during welding.

However, HAZ regions may be softened down to 40 HV below the base material hardness during the PWHT.
Tube stiffness

Elastic Bending ($\rho/OD > 300$)

Plastic and Elastic Bending ($\rho/OD < 300$)

\[ M = \frac{EI_2}{\rho} \]

\[ I_2 = \frac{\pi}{64}(OD^4 - ID^4) \]

\[ E = \text{Elastic Modulus} \]

\[ M = \sigma_{ys}I_1 \]

\[ I_1 = \frac{1}{6}(OD^3 - ID^3) \]

\[ \sigma_{ys} = \text{Yield Strength} \]
Spooling Coiled Tubing
Effect of Tubing Tension
BlueCoil™ Microstructures

Microstructures

- An homogeneous microstructure was obtained in both the base metal and the bias welds.
- Fatigue resistance in the bias welds is similar than it is in the base tube.
- Mechanical property variation is reduced along the entire length of the tube.
Summary

• The frequency of bias weld field issues have increased

• Most bias weld performance issues are based in the metallurgy that results from the current manufacturing process

• Complementary continuous HT process shows significant performance improvement