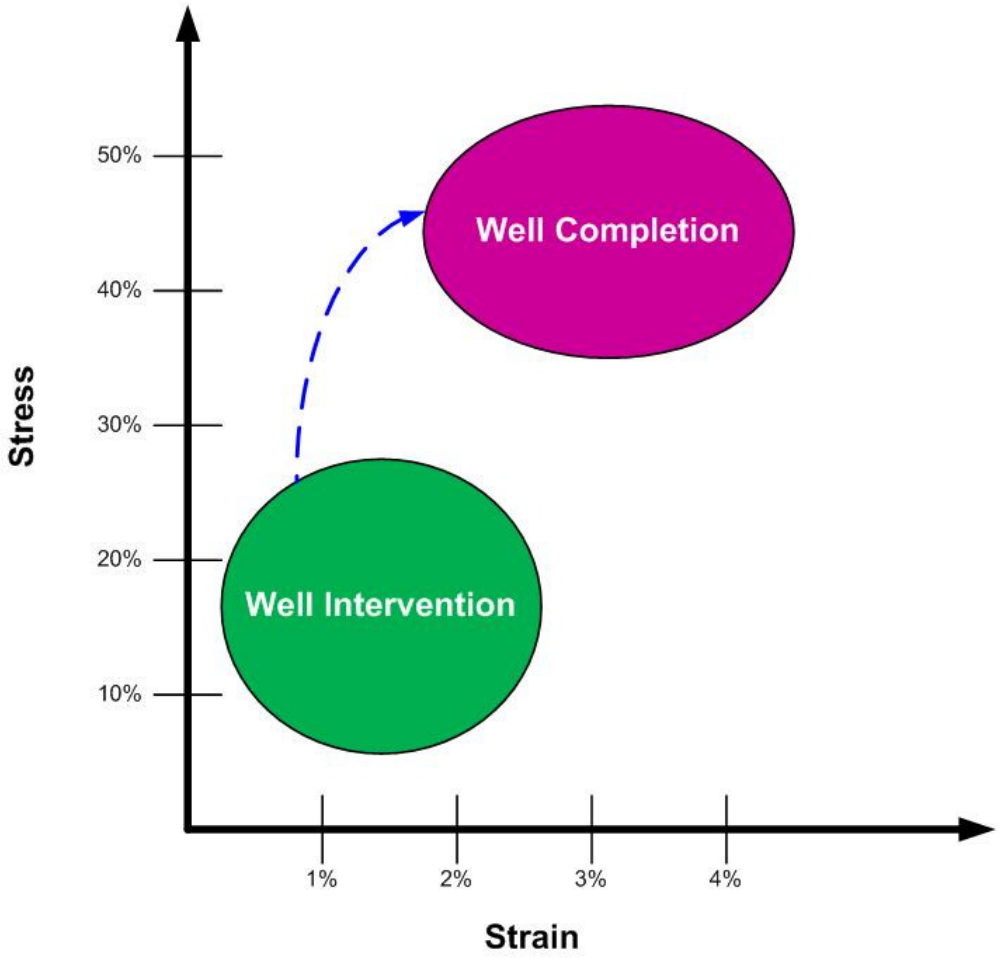
A Mechanical, Metallurgical and Operational Review of Bias Weld Performance

Martin Valdez, Radovan Rolovic, and Bruce Reichert, Tenaris Coiled Tubes

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)

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Other new factors (different fluids, re-use of water)

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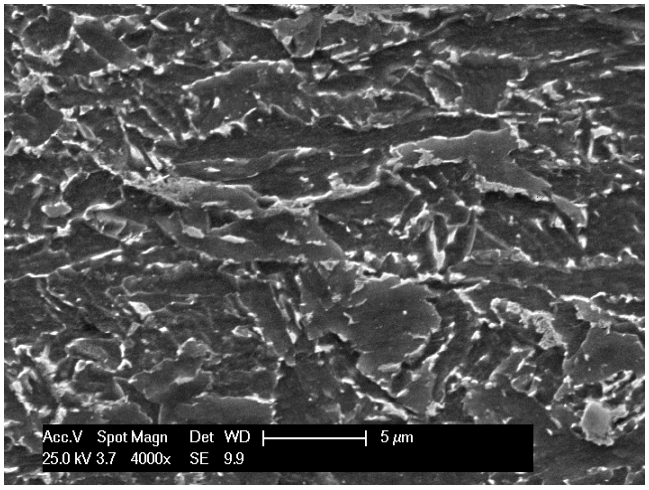
Frequency of bias weld issues have increased

Metallurgy of Current Coiled Tubing

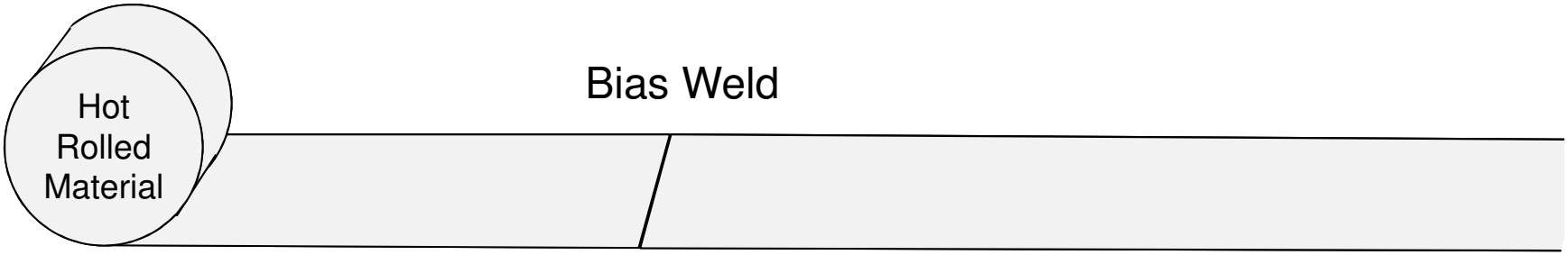


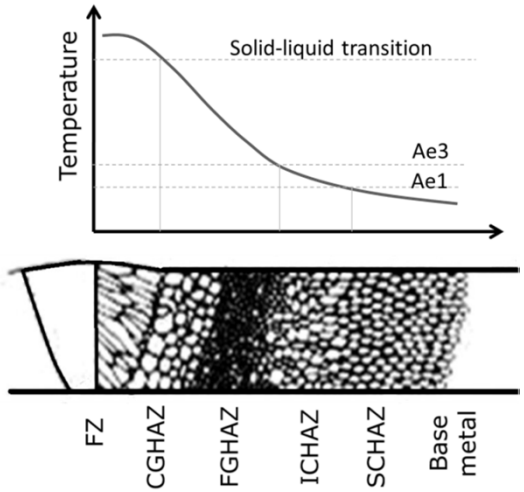
- Elongated Ferritic Grains with carbides in grain boundaries.
- Obtained by thermo-mechanically controlled rolling, accelerated cooling and low coiling temperature.
- Refine Microstructure Guarantees Mechanical Properties and Toughness

Mechanism to Produce High Strength Steel

CT Grade	Active Precipitates	Process Requirements	Resulting Microstructure	Hot Rolled Strip YS
70	Cementite + TiN	Thermomechanical Controlled Process (TMCP)	Ferrite and pearlite	≈ 60 ksi min
80				
90	Cementite + TiN + NbC	TMCP + Accelerated cooling (AC)	Ferrite and pearlite with carbides in grain boundaries	≈ 70 ksi min
110	Cementite + TiN + NbC	TMCP + AC + low coiling temperature	Ferrite matrix with carbides in grain boundaries.	≈ 90 ksi min
120+	Cementite + TiN + NbC	TMCP + AC + low coiling temperature	Ferrite matrix with carbides in grain boundaries + bainite	≈ 110 ksi min

Metallurgy of Current Coiled Tubing



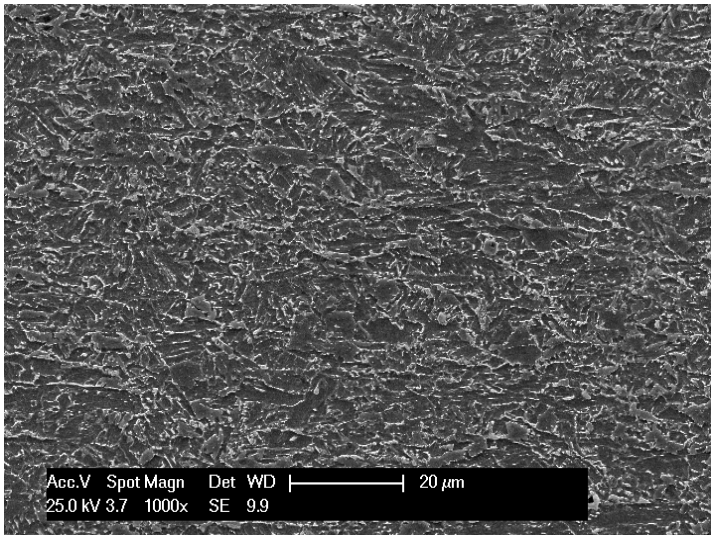


- Microstructure depends on thermal history during welding
- Fused Zone and near HAZ with substantial Grain Growth
- Variation of microstructure across the Fused Zone, Coarse and Fine Grain HAZ, Inter and Subcritical HAZ.
- Performance could not be guarantee in the as welded condition.

Metallurgy of Current Coiled Tubing

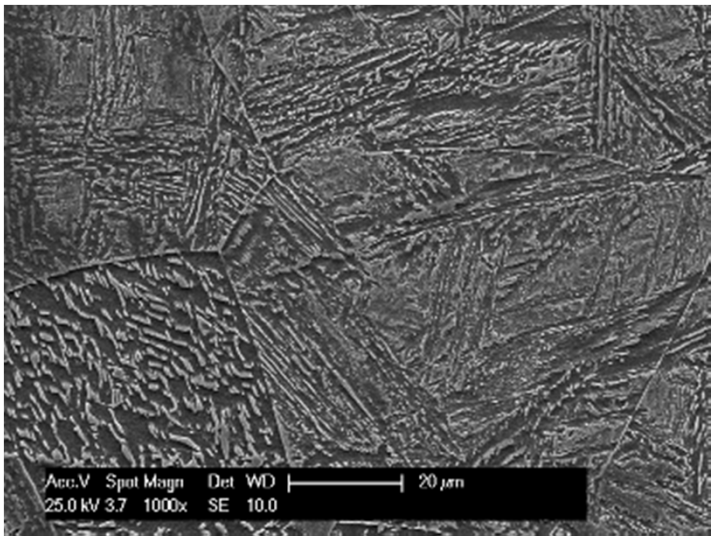
Typical microstructures (Grade HS-110)

Base tube



Carbides dispersed in a ferritic matrix

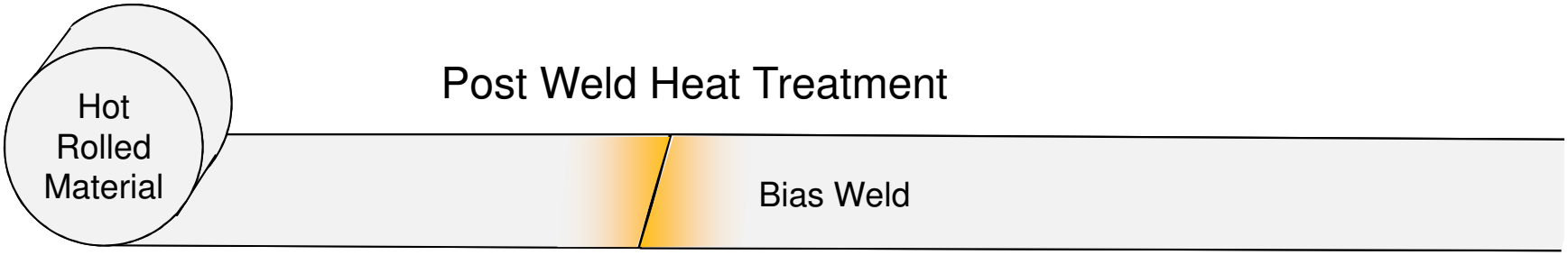
Bias weld (fusion zone)

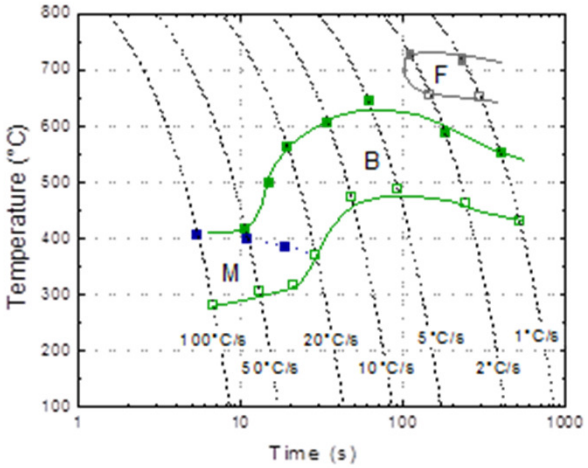


Coarse upper bainite

- 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

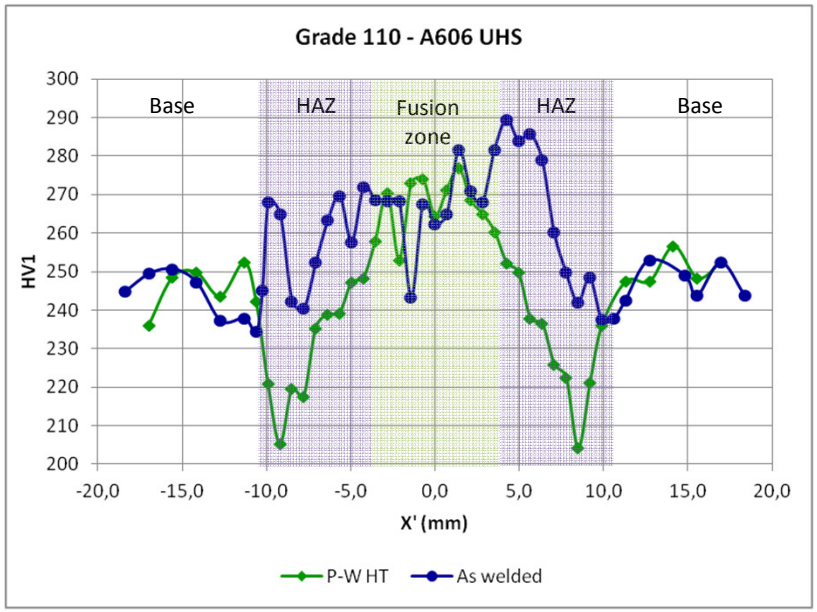


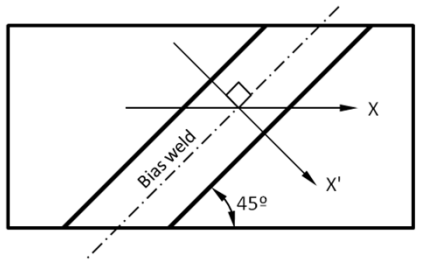


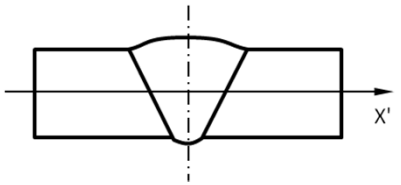
- Material is re-heated and subsequently cooled
- Compromise between satisfying strength requirements and avoiding the creation of brittle constituents that compromise fatigue
- Requires a clear understanding of material behavior.

Metallurgy of Current Coiled Tubing

Hardness profile across the bias weld



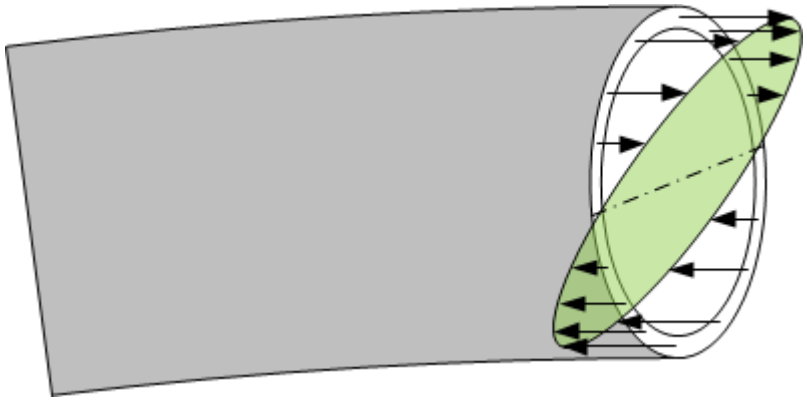




- Post-weld HT is useful (and necessary) to decompose brittle constituent such as retained austenite and martensite that are generated during welding.
- However, HAZ regions may be softened down to 40 HV below the base material hardness during the PWHT.

Tube stiffness

Elastic Bending (ρ/OD > 300)

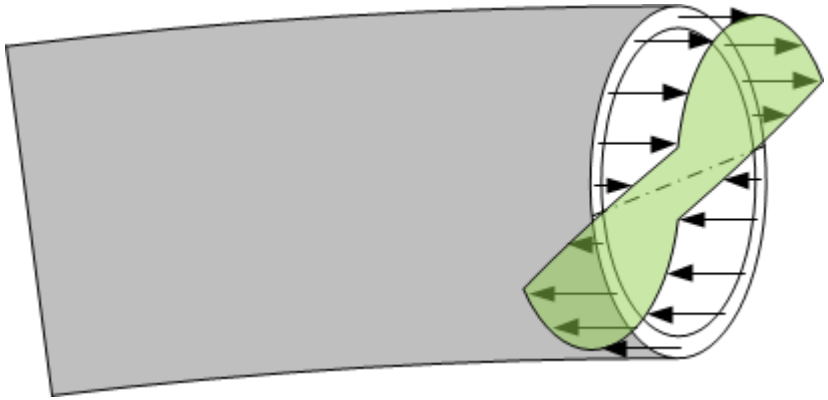


$$M = \frac{EI_2}{\rho}$$

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

$$E = Elastic\ Modulus$$

Plastic and Elastic Bending (ρ/OD < 300)

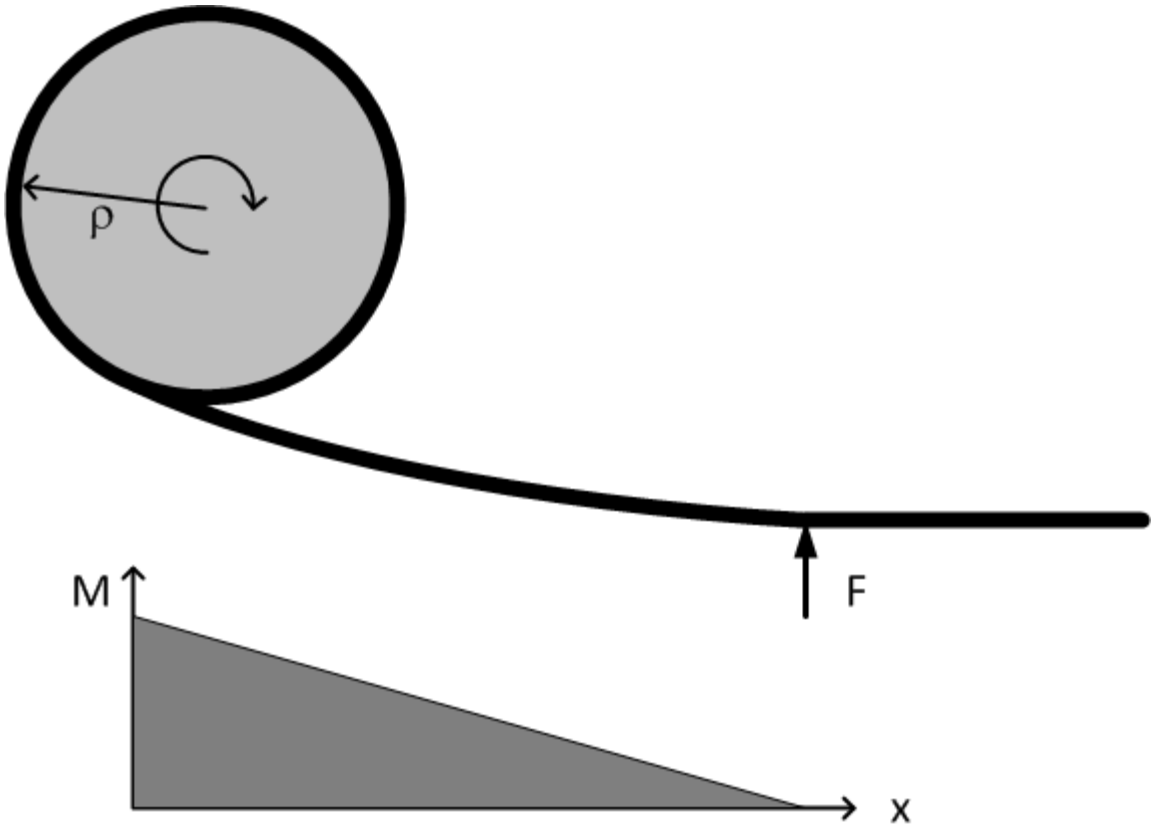


$$M = \sigma_{ys} I_1$$

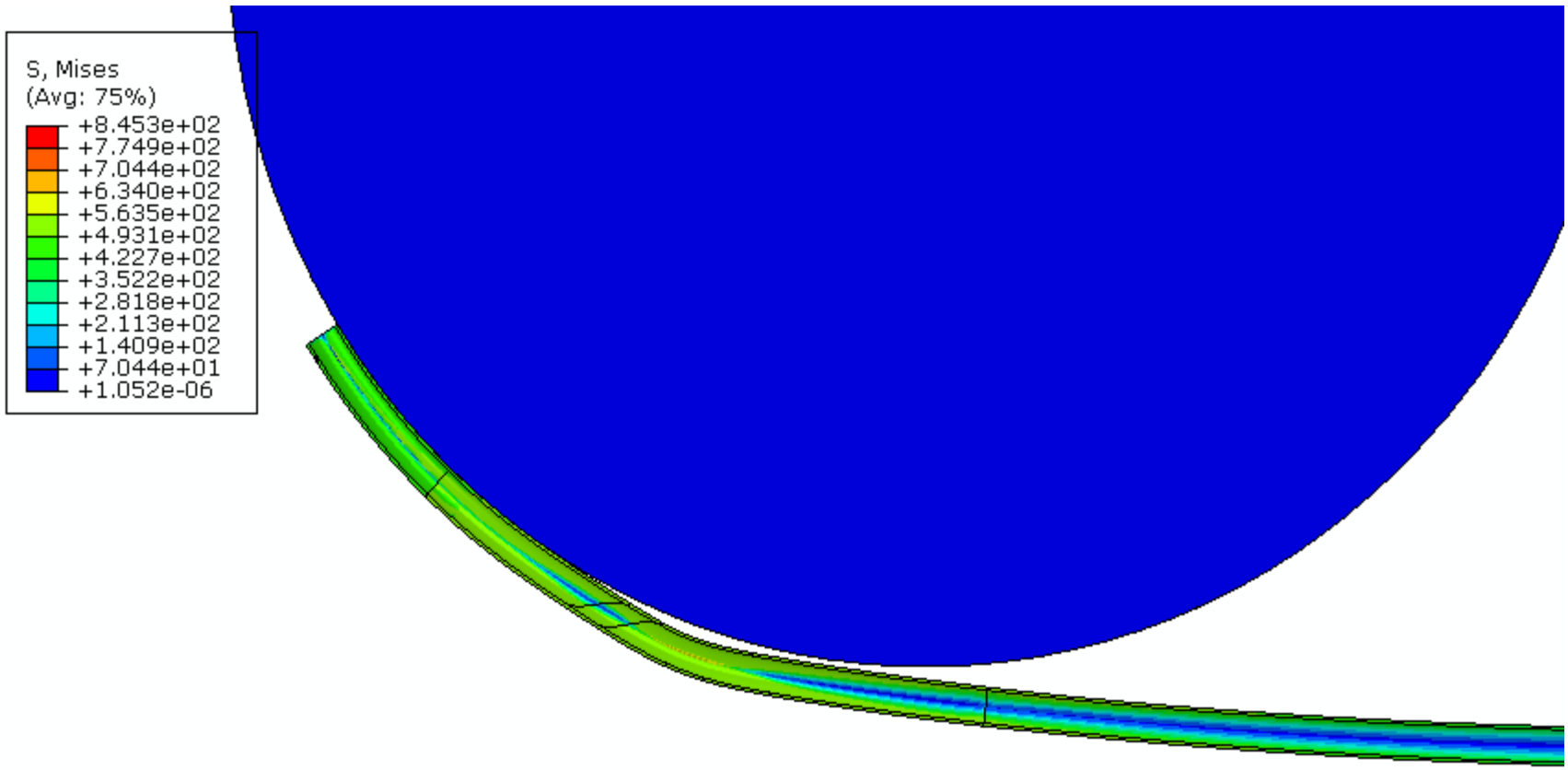
$$I_1 = \frac{1}{6}(OD^3 - ID^3)$$

$$\sigma_{ys} = Yield\ Strength$$

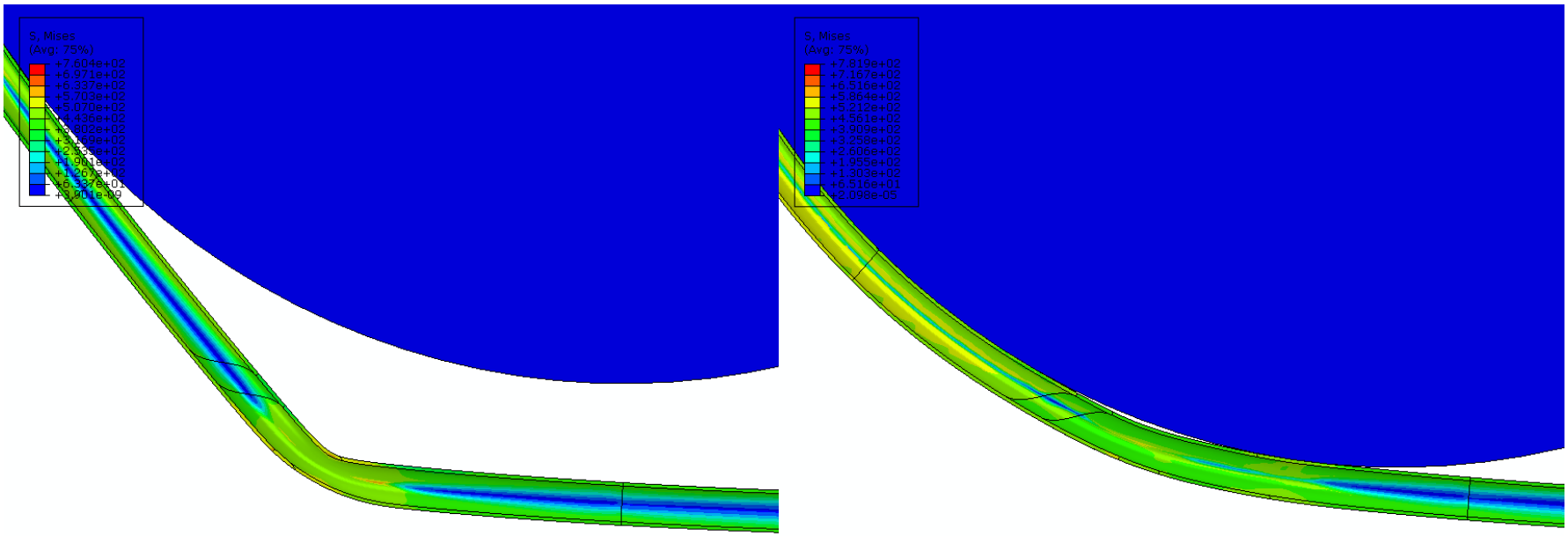
Spooling Coiled Tubing



Change in Stiffness During Spooling



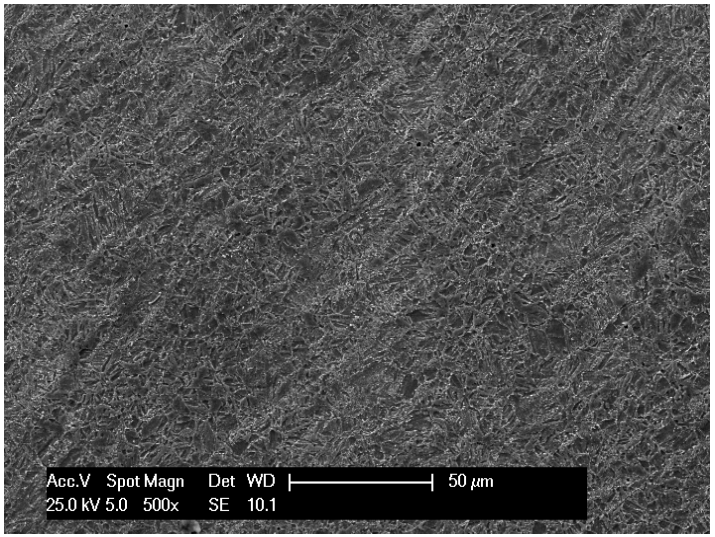
Effect of Tubing Tension



BlueCoil™ Microstructures

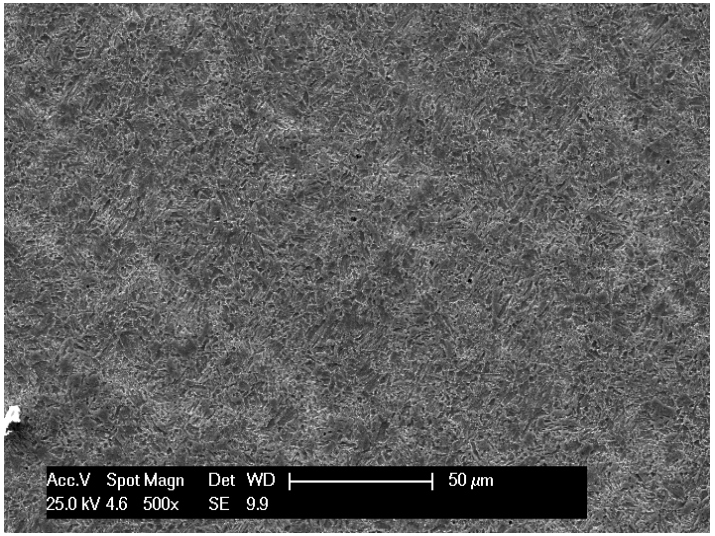
Microstructures

Base tube



Tempered material

Bias weld (fusion zone)



Tempered material

- 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