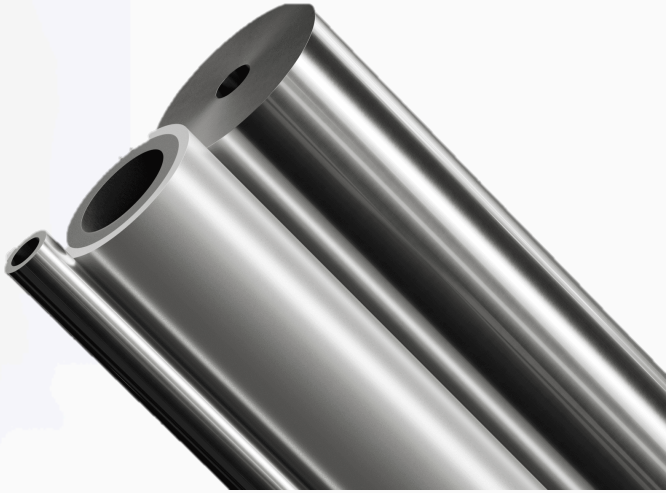
HEAT EXCHANGER WORLD CONFERENCE & EXPO AMERICAS

2022

Evaluation of Impact of Cold Deformation on Duplex, UNS S32205, Super Duplex, UNS S32750, and Super Austenitic UNS N08935 Grades for use in Chloride and Sour Environments

Luiza Esteves, P.h.D & Karen Picker

Alleima, Tube Americas



Heat Exchanger

Twisting, U-bending, and Finning

- Better heat transfer efficiency

Cold deformation

- Usually reduce corrosion properties
- Improper heat treatment operations are detrimental to U-bend design

- API technical report 938-C, 3rd ed.

> …testing has shown that the properties of the U-bends without heat treatment are acceptable for refinery services down to bend radiuses of 1.5 times the tube diameter for 25% Cr SDSS grades and at least 3.3 times the tube diameter for 22% Cr DSS.

- UNS S32750 has extensive data to chloride stress corrosion cracking and limited data to sulfide stress corrosion cracking (S-SCC)

Background

- Metallic materials in wet H_2S environment are governed by the international standard NACE MR0103:

Alloy	Hardness Max.	Hardness Conversion
DSS S32205	28 HRC	HRC = 0.091*HV - 2.4
SDSS S32750	32 HRC	HRC = 0.091*HV - 2.4
Highly alloyed austenitic SS	35 HRC (335 HV)	ASTM E140

- DSS tubing are typically produced to ASME 789
- Hardness values typically increase to a degree representative of the cold deformation induced during bending or twisting
- Higher hardness generally have an increased susceptibility to stress corrosion cracking presenting a challenge for the industry

Cold bending of heat exchanger tubing

UNS S32205 Seamless Tubes

- 0.750” OD x 0.083” AW (19.05 x 2.10 mm)

C	Mn	P	S	Ni	Cr	Mo	N	PRE
0.019	0.76	0.025	0.001	5.3	22.2	3.2	0.2	35

UNS S32750 Seamless Tubes

- 0.750” OD x 0.065” AW (19.05 x 1.65 mm)

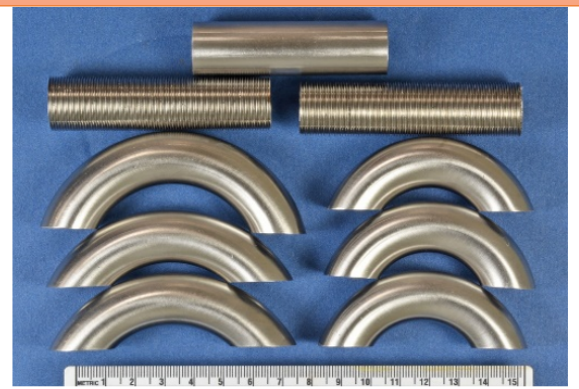
C	Mn	P	S	Ni	Cr	Mo	N	PRE
0.012	0.46	0.010	0.001	6.6	25.4	3.9	0.3	42.5

UNS N08935 Seamless Tubes

- 1.000” OD x 0.083” AW (25.4 x 2.10 mm)

C	Mn	P	S	Ni	Cr	Mo	N	PRE
≤0.03	0.8	≤0.03	≤0.02	35	27.0	6.5	0.3	52

PRE = %Cr + 3.3 x %Mo + 16 x %N



S32750 finned and u-bend samples bent to 1.5D and 2D shown on the right.

Cold bending of heat exchanger tubing

BEND SCHEDULE

Bend Dies Radii	**1.125”**	**1.500”**	**2.250”**
Final Bend Radii	1.5D	2D	3D

No heat treatment after bending

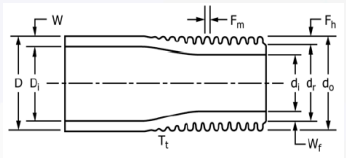
TUBE FINNING

Integrally finned tubes were manufactured according to ASTM A1012.

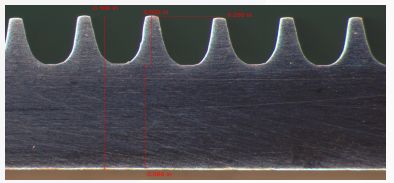
28 fins per inch (FPI):

S32205: 0.035” fin height (FH)
0.065” wall under fin thickness (WUF)

S32750: 0.035” fin height (FH)
0.045” wall under fin thickness (WUF)



Schematic of fin configuration showing the tube maintains original OD after finning operation.



Finning configuration dimensions demonstrating fin height, wall thickness under fin and tube OD for S32205 duplex tube sample.

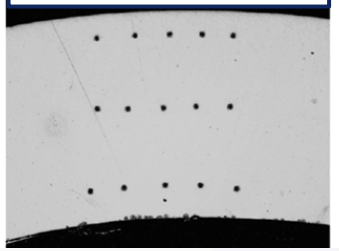
Hardness Testing

- Vickers scale with a load of 500 g

As Bent

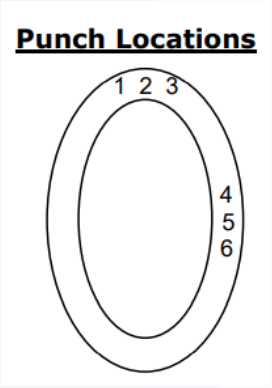
- sub-surface OD (Tension)
- Mid-wall (Neutral)
- sub-surface ID (Compression)

U-bend



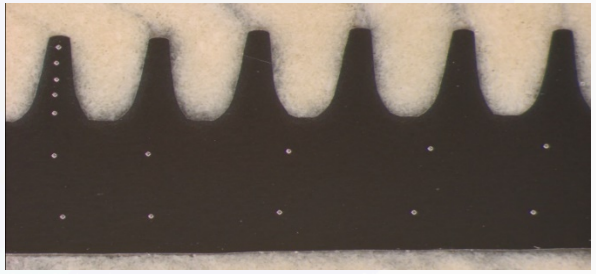
Micro-hardness indentation

Twisted



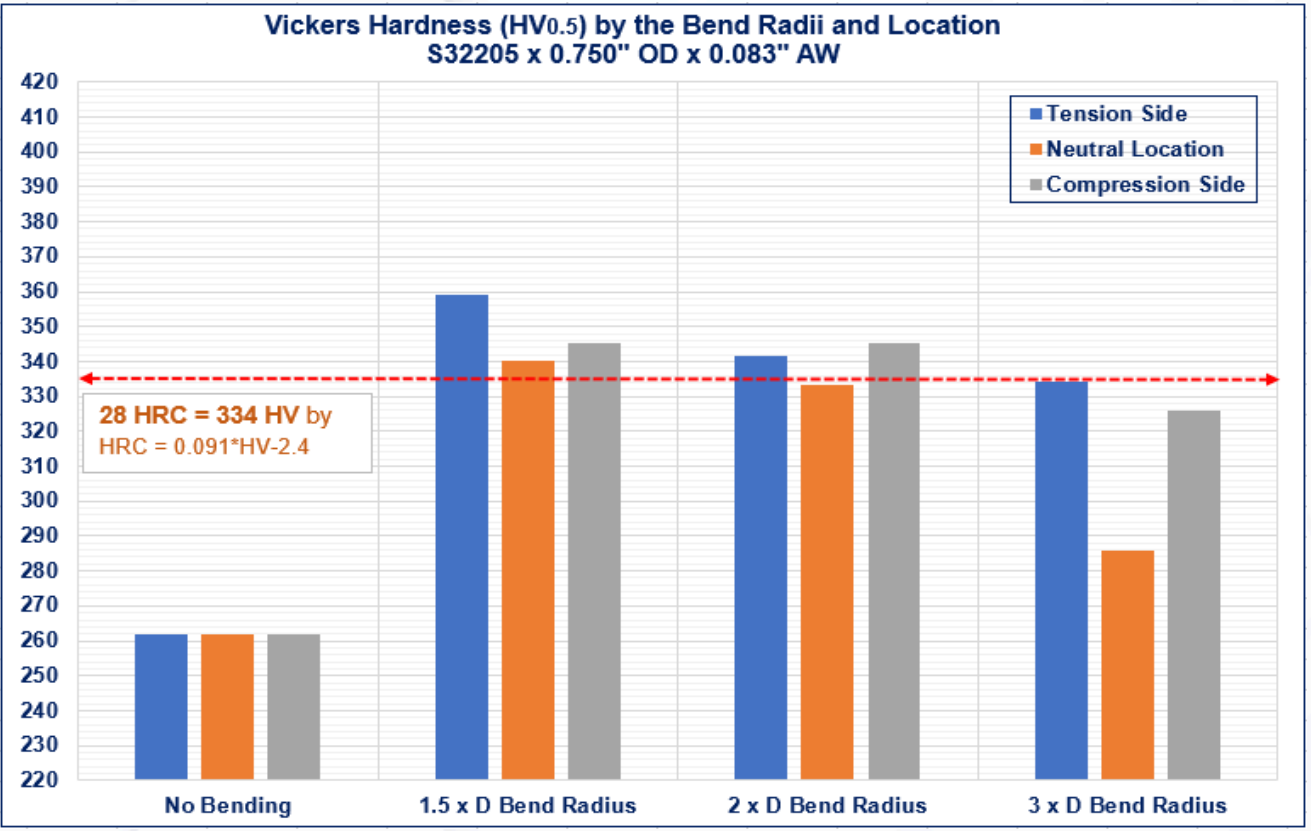
As Finned

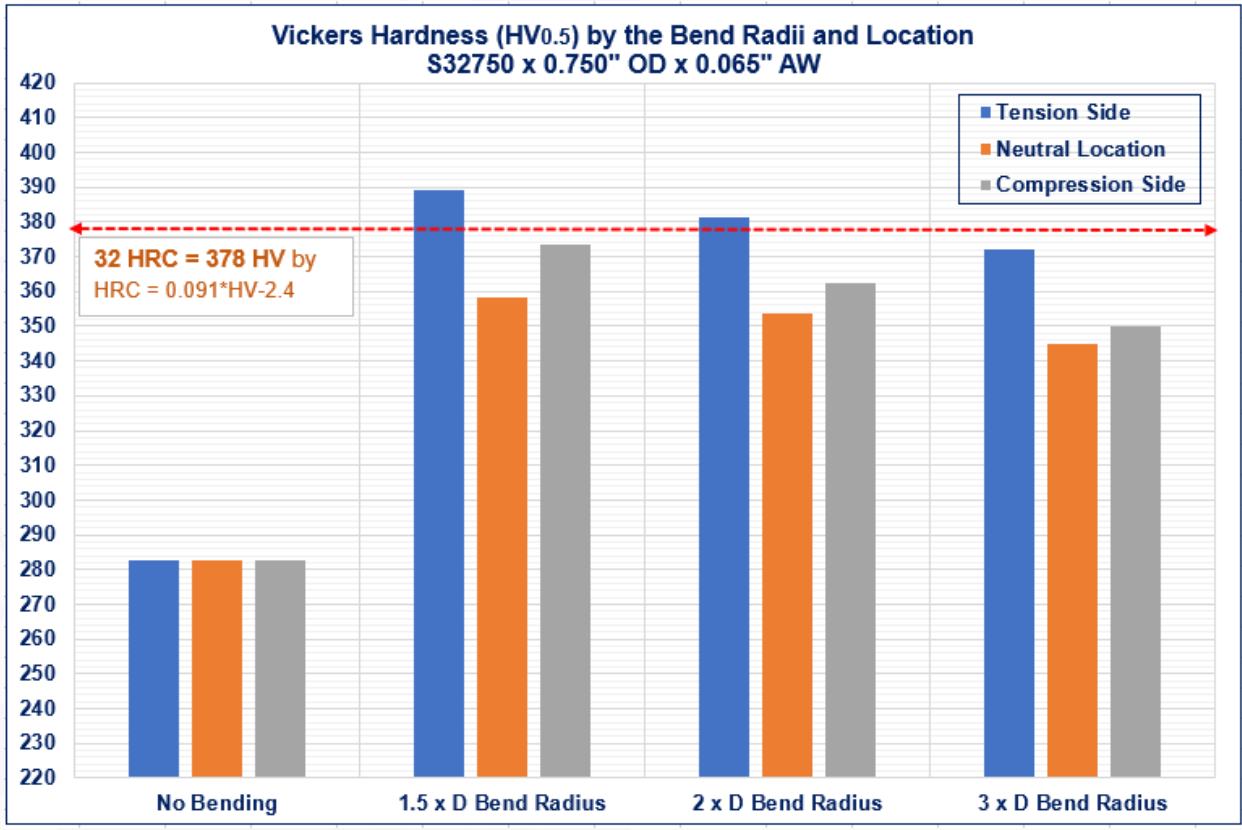
- S32205 and S32750 tube were cut longitudinally
- Fin tip, mid-section of the base tube, and ID of the base tube



Microhardness indentation of the as finned tube samples.

Microhardness Results – U bends

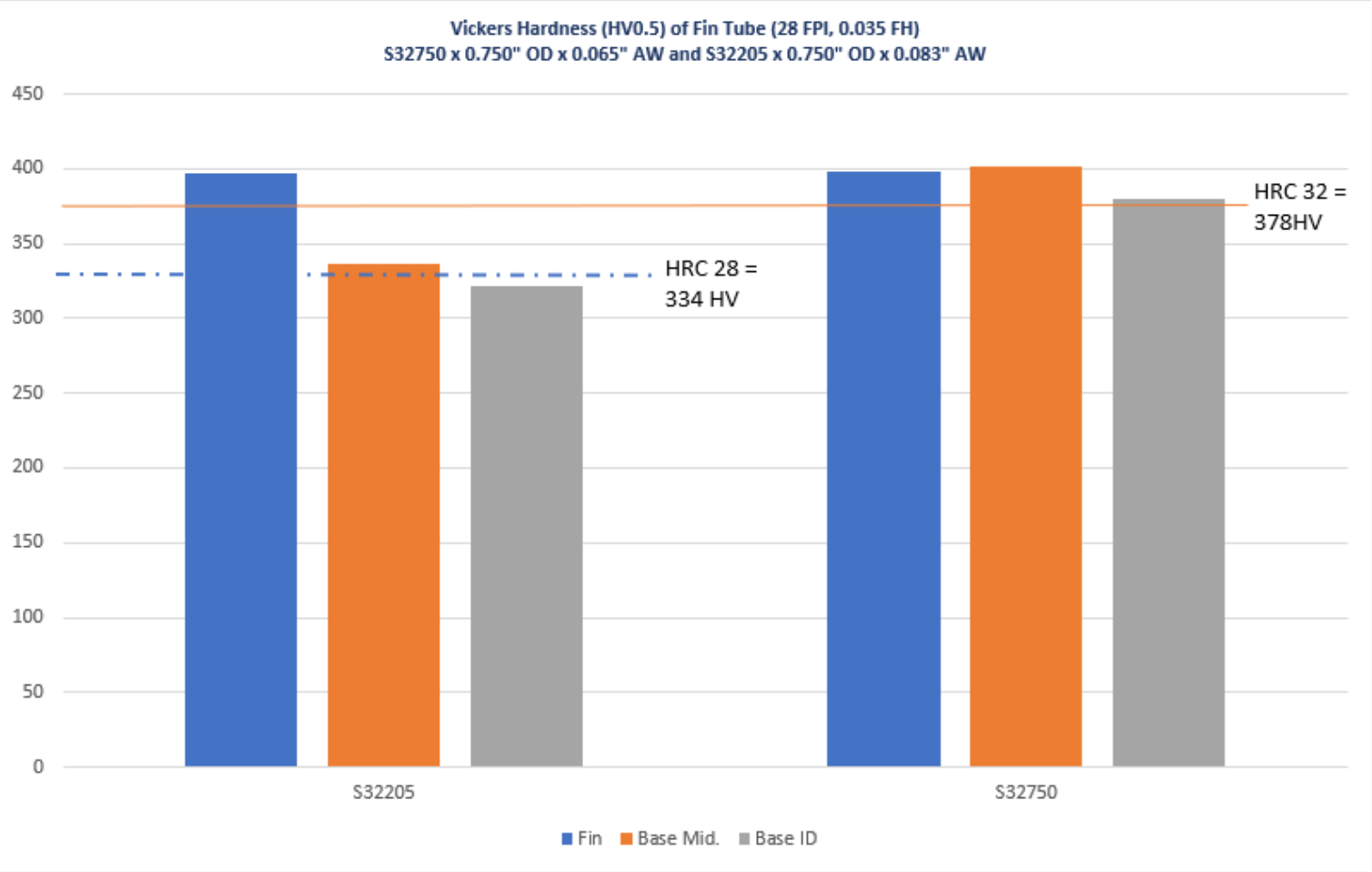




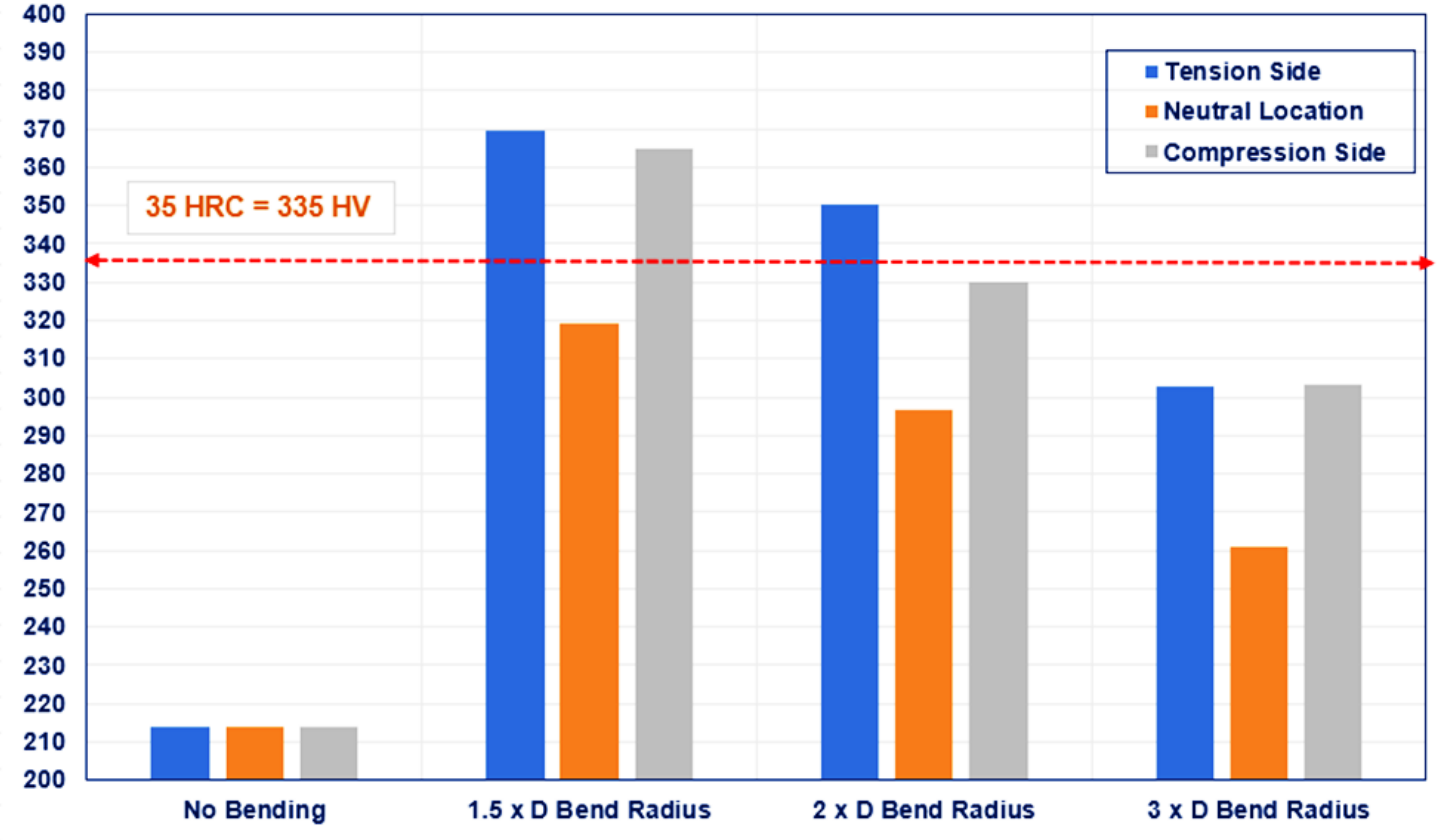
Dashed red line indicates 28HRC reference line for sour services per NACE MR0103 and CSCC per ASME 789

Dashed red line indicates 32HRC reference line for sour services per NACE MR0103 and CSCC per ASME 789

Microhardness results - Finned



MICRO-HARDNESS OF N308935, 1.000” X 0.083" AW BY BEND RADII.



- Vickers hardness (HV 0.5V)

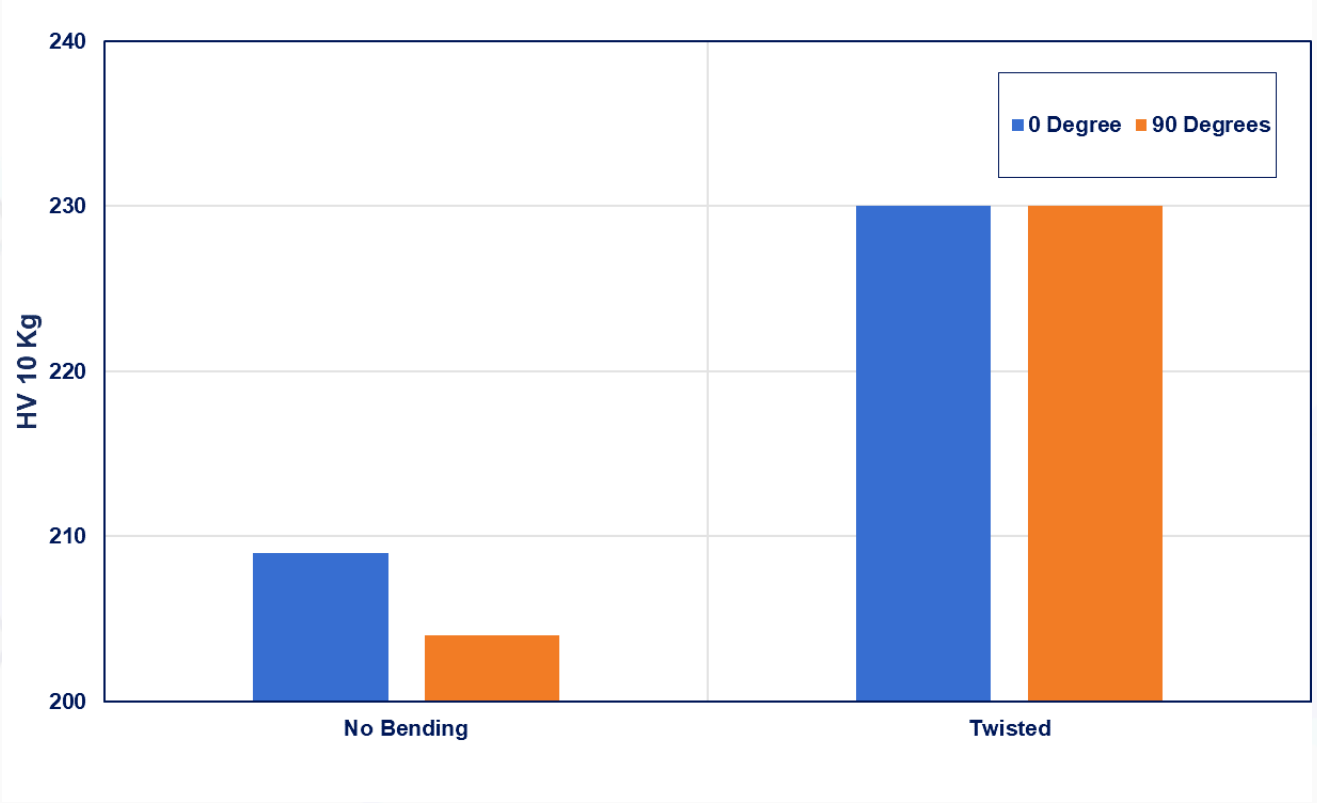
Hardness increase with cold bending

1.5xOD > 2.0xOD > 3.0xOD

Dashed red line indicates 35 HRC reference line for sour services per NACEMR103

Microhardness results

UNS N08935, 1.000” X 0.083" AW TWISTED TUBES



- Vickers hardness (HV 10 kg)
- Average hardness value was lower than U-bends hardness
- Slightly increase compared to straight tubes of Alloy 35Mo
- Hardness values were lower than the limit required per NACE MR0103 for sour services (335 HV)

Pitting Corrosion results

S32205 and S32750 u-bend specimens

Grade	ASTM G48 Method ($FeCl_3$ + HCl)	Bend 1 1.5 x OD (1.125 in)	Bend 2 2.0 x OD (1.500 in)	Bend 3 3.0 x OD (2.250 in)
S32205	25°C (77°F), for 24 h	No Pitting	No Pitting	No Pitting
S32750	50°C (104°F), for 24 h	No Pitting	No Pitting	No Pitting

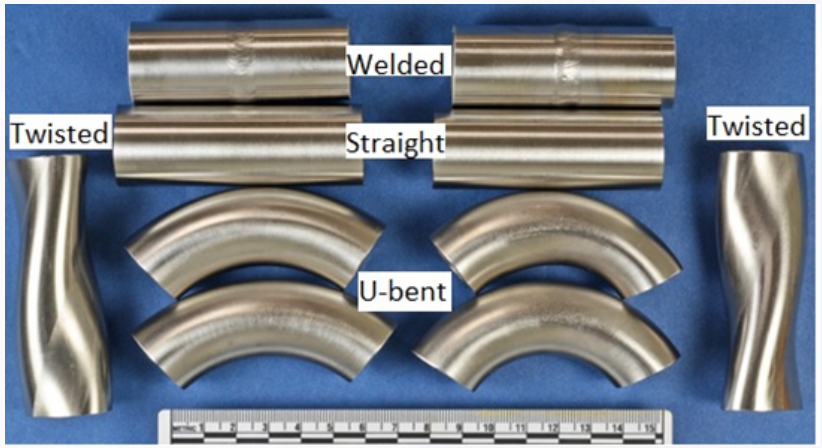
Pitting corrosion testing for S32205 and S32750 as finned tubes

Grade	ASTM G48 Method ($FeCl_3$ + HCl)	As Finned sample 1	As Finned sample 2
S32205	25°C (77°F), for 24 h	No Pitting	No Pitting
S32750	50°C (104°F), for 24 h	No Pitting	No Pitting

Pitting Corrosion Results

ASTM G48 Method C

- Acidified 6% $FeCl_3$
- High pitting corrosion resistance



Grade	ASTM G48 Method C	Results
Twisted N08935	>85°C (185°F), for 24 h	No Pitting
U-bend N08935 1.5xOD	>85°C (185°F), for 24 h	No Pitting
U-bend N08935 2.0xOD	>85°C (185°F), for 24 h	No Pitting
U-bend N08935 3.0xOD	>85°C (185°F), for 24 h	No Pitting

Chloride Stress Corrosion Cracking (CSCC)

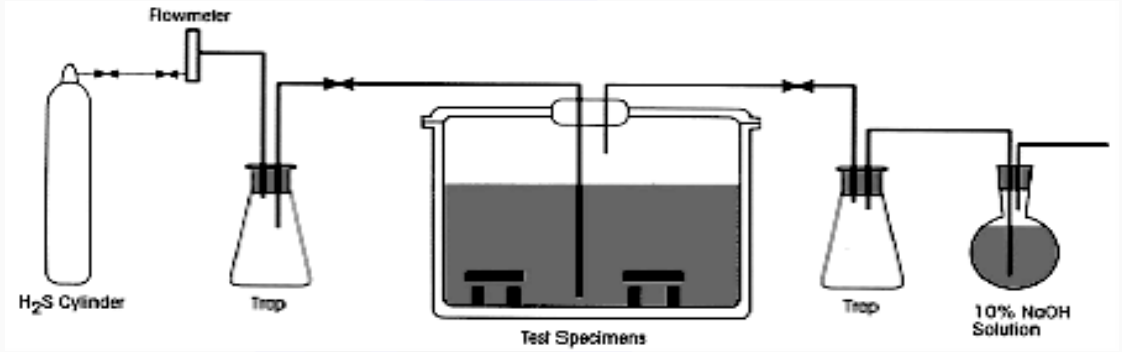
TWISTED UNS N08935 SHOWED GOOD RESISTANCE TO CSCC

CSCC Method	Time to failure (h)	Results
ASTM G123 (25%NaCl, pH 1.5 at 106-110°C Boiling)	1000 h	No cracking
40% $CaCl_2$, pH 6.5 at 100 ℃	1000 h	No cracking

Sulfide Stress corrosion cracking testing

NACE TM0177 Method C

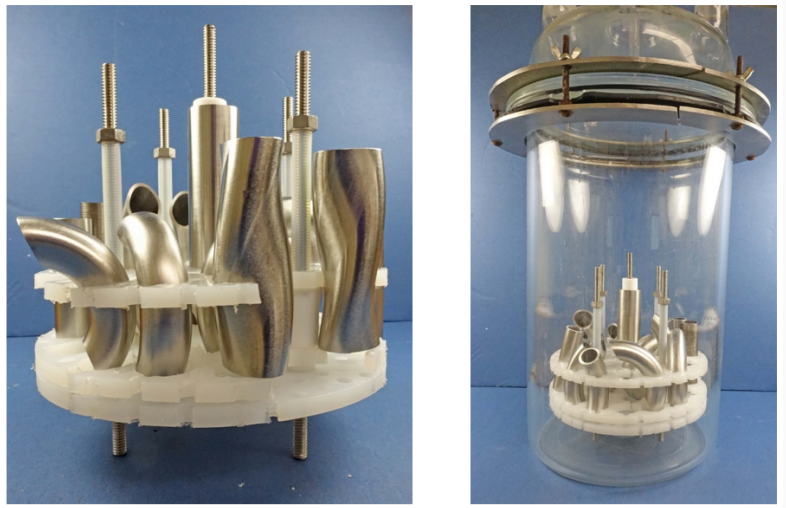
- NACE TM0177 Solution A, acidified NaCl
- 60,000 ppm H_2S in Nitrogen at 90°C (194 °F)
- Pressure: Ambient pressure
- Final pH = 3.1



Test apparatus for NACE TM 0177

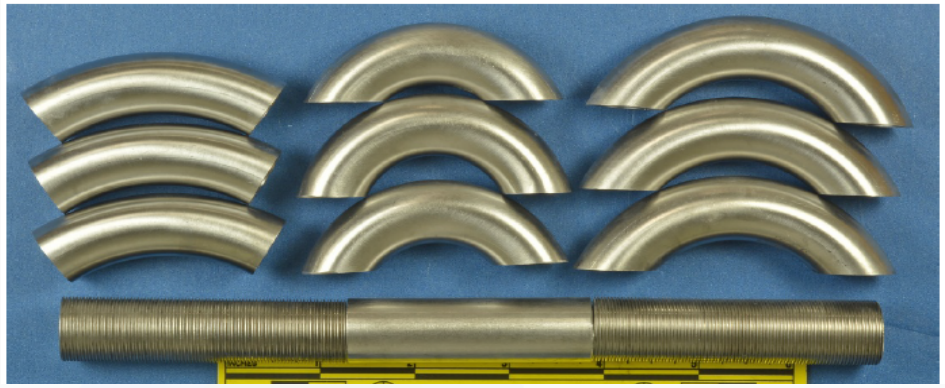
Alloy UNS N08935

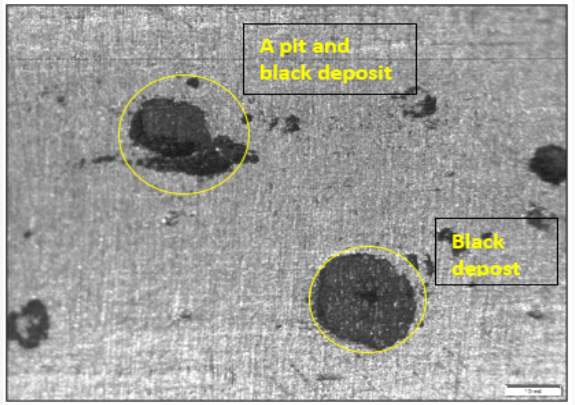
No cracks were detected in any straight, u-bend, twisted and welded specimens


Specimens in test vessel

S-SCC – TM0177 – 60,000 ppm H_2S

- No cracks were observed by dye penetrant
- No cracks on the mid-wall and inside surface of 1.5D samples by microscopic analysis
- One SDSS S32750 sample from vessel A and three duplex S32205 samples from the vessel B show signs of OD pitting with shallow depth
  - OD pitting appear to be from under deposit corrosion and not related to stress corrosion cracking.
- No tube ID surface pitting was identified.





Luiza Esteves - Alleima

Conclusions

1. Hardness values increased with cold forming of u-bends, twisting, and integral finned tubes.
2. DSS and SDSS: Bend radius below 3D tube diameter and integral finning of tubes results in hardness values above the acceptable level recommended by industry standard NACE MR0-103, making the materials, in theory, not suitable for wet H_2S applications.
3. Super austenitic stainless steel: Bend radius 2D tube and below diameter brings hardness values above the acceptable level recommended by industry standard NACE MR0103 which in theory would not be suitable for wet H_2S applications.
4. Solution annealing is not necessary as the as cold work twisting finning and bending do not have any negative impact on the corrosion resistance of the alloy.

HEAT EXCHANGER WORLD CONFERENCE & EXPO AMERICA

2022

Thank you!

Luiza Esteves, PhD
luiza.esteves@alleima.com

Sponsored by: Brask, Inc. The Heat Exchanger People; CUST-O-FAB; DUNN HEAT EXCHANGERS; ELLIOTT TOOL TECHNOLOGIES; Flexitallic; Ohmstede Industrial Services Inc.; SUPERIOR PLANT RENTALS; TEADIT Sealing for a Safer and Greener Tomorrow; VAHTERUS; WARD VESSEL & EXCHANGER