

Evaluation Of The Suitability Of As Bent Super Duplex Stainless Steel UNS-S32750 Tubing For Refinery Sour Services

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ABSTRACT

The effect on corrosion performance of duplex stainless steels after cold bending with and without heat treatment have been widely studied and documented within the refining industry and material producers. Current recommendations exist regarding the minimum bend radii allowed for both regular duplex and super duplex stainless steels without the need to perform stress relieve heat treatment that could be detrimental to the material performance if not performed properly. While these recommendations are generalized for refinery services, they are based on conclusions drawn from strain calculations and possible resulting residual stresses found when bending 22% chrome duplex stainless steels or, in the case of 25% chrome duplex stainless steels, the recommendations are based on corrosion data for pitting resistance and chloride stress corrosion cracking testing. However, existing data does not address the suitability of either alloy for sour services in the refining industry in the as-bent condition.

This study evaluates the suitability of as-bent super duplex stainless steel UNS-S32750 tubing for refinery sour services by presenting data about the impact of work hardening by u-bending and evaluating these results against current hardness limits per NACE standard MR0103 for super duplex stainless steels. Several seamless .75" diameter super duplex tube samples with two different wall thickness were u-bent to bend radius of 1.5, 2, 3, 4, and 5 times the tube diameter. Hardness data as well as corrosion testing per ASTM G48 method A and NACE TM0177 were recorded and will be presented in order to demonstrate the material's performance despite residual stresses.

Key words: UNS-S32750, U-bending, duplex stainless steels, pitting, sulfide stress corrosion cracking, SCC

INTRODUCTION

One of the key aspects that have helped position the use of duplex stainless steels in the refining industry is its demonstrated high resistance to chloride stress corrosion cracking achieved by the right combination of chromium, nickel, molybdenum and nitrogen content and proper heat treatment operations. Nowadays, refiners have a great understanding of the mechanical and corrosion properties of this family of alloys and widely accepted practices have been developed for the use duplex stainless steels in shell and tube heat exchangers both in straight and u-bend designs.

When working with u-bend heat exchanger designs, refiners are faced with the decision of whether or not heat treatment of the u-bent tubes is required or necessary for their application. Practical as well as laboratory experience has demonstrated improper heat treatment operations are more detrimental than beneficial to the u-bend design and the higher alloyed the material is the more prone it is to the formation of detrimental σ -phase during improper heat treatment procedures¹. For this reason, the refining industry in general, does not specify the heat treatment of u-bends in heat exchanger tubing and instead it is widely accepted that for 22% Cr duplex stainless steel tubing, as bent tube are acceptable to be used in refinery services prone to chloride stress corrosion cracking as long as the resulting strain from the bend is not greater than 15% which limits the bend radii to 3.3 times the tube diameter.. While 25% Cr super duplex stainless steel tubing is resistant to chloride stress corrosion cracking with bend radii as low as 1.5 times the tube diameter².

While the performance of duplex stainless steels in the as bent condition is widely understood for chloride stress corrosion cracking, little is known about such behavior in Hydrogen Sulfide (H_2S) environments. In general, the suitability of metallic materials in wet H_2S environment is governed by the international standard NACE¹ MR0103 which limits duplex stainless steels base materials to 28HRC maximum hardness for materials with $PREN \leq 40$ and 32 HRC for $PREN > 40$ ³. Since, when cold bending highly alloyed duplex stainless steels, hardness values typically increase to a degree representative of the cold deformation induced during bending¹, this introduces a level of complexity in the evaluation of the suitability of as bent super duplex stainless steel UNS-S32750 tubing for refinery sour services.

In order to address this challenge, the effect of work hardening of S32750 super duplex stainless steel tubing by u-bending is evaluated as well as its effect in the stress corrosion cracking resistance of the material to sulfide stress corrosion cracking.

EXPERIMENTAL PROCEDURE

This study consisted of three stages, cold bending of heat exchanger tubing according to typical bend schedule, hardness measurement of as bent samples, and stress corrosion cracking in H_2S environment.

Cold Bending of Heat Exchanger Tubing

U-bend samples were produced using UNS S32750 seamless stainless steel tubing produced in 0.750" OD and two different wall thickness of 0.065" and 0.095" AW in the cold finished and bright annealed condition with chemical composition according to table 1.

¹ NACE International, 15835 Park Ten Place, Houston, Texas 77084, USA

Table 1: Chemical Composition of the tubes used for bending and samples for testing. All values are wt. %

Sample	C	Mn	P	Cr	S	Si	Ni	Cr	Mo	N	Cu
UNS S32750	0.012 %	0.46	0.022	27.0	0.0005	0.29	6.49	25.53	3.83	0.299	0.13

Test tubes were bent using bend dies with radii of 1.125", 1.500", 2.250", 3.000", and 3.750". Each representing bend radii of 1.5D, 2D, 3D, 4D, and 5D times the tube diameter of 0.750". After bending, sample tubes were not stress relieved. Samples were prepared from each bend radius for hardness measurement. Each sample was cut from each bend radius tube at the center of bent section and clearly marked the position of (1) inner section of the bend (compression side), (2) outer section of bend (tension side), and (3) circumferentially between inner & outer section (neutral side).

Hardness Measurement of Straight and As Bent Samples

Straight Samples

Before the bending operations, the as-produced mechanical properties were recorded from Material Test Report (MTR) as seen in table 2. Hardness testing of the straight samples was conducted using Vickers 0.5 HV scale at three different locations; sub-surface of tube OD, mid-wall, and sub-surface of tube ID. The hardness values obtained are being reported in table 3 and the corresponding conversion to HRC scale was done for reference purposes using formula 1 below.

$$HRC = 0.091 * HV - 2.4 \quad (1)$$

Table 2: Mechanical Properties of as produced straight tube samples.

Sample	Yield Strength	Tensile Strength	Elongation	Hardness
0.750 x 0.065" AW (19.05 x 1.65 mm)	751.7 MPa (109,000 psi)	958.3 MPa (139,000 psi)	30%	25/26 HRC
0.750 x 0.095" AW (19.05 x 2.41 mm)	737.9 MPa (107,000 psi)	944.8 MPa (137,000 psi)	36%	26 HRC

Table 3: Micro-hardness measurement of straight tube samples and corresponding HRC conversion.

Tube Size (OD x W)	Location of Measurement	Micro- hardness HV0.5	Conversion to HRC
0.750" OD x 0.065" AW (19.05 x 1.65 mm)	OD sub- surface	290	24.0
	Mid-Wall	287	23.7
	ID sub-surface	294	24.3
0.750" OD x 0.095" AW (19.05 x 2.41 mm)	OD sub- surface	283	23.4
	Mid-Wall	278	22.9
	ID sub-surface	282	23.2

As Bent Samples

Samples were prepared from the as bent tubes by cutting a whole tube cross sectional area, mounting and polishing it as shown in figure 1 below. Each cross section was measured at the tension point (outside of the bend with maximum tension stress), compression point (inside of the bend with maximum compression stress), and neutral point (theoretical neutral location of the bend). Additionally, each of these hardness testing location (tension, compression and neutral) was divided into three sections: sub-surface OD, mid-wall, and sub-surface ID, as seen in figure 2, and five hardness measurements were taken at each section using Vickers scale with a load of 500 g.

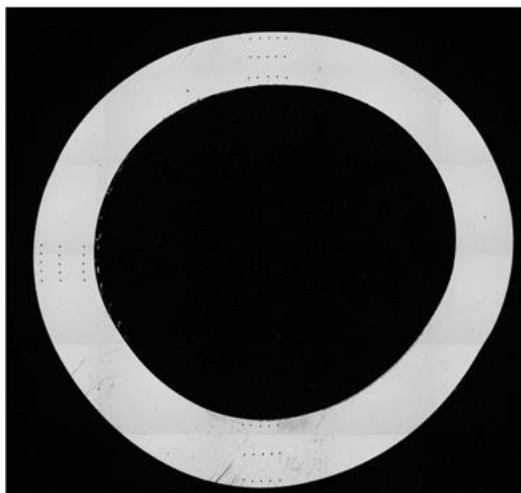


Figure 1: Example of Cross Sectional Area of tube mounted and polished showing the three testing locations: tension, compression and neutral points of the bends.

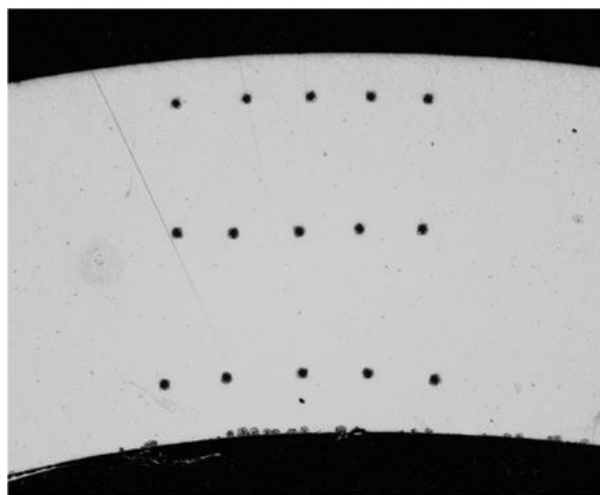


Figure 2: Example of micro-hardness indentation showing three sections and five measurement points per section.