

## DELTA FERRITE INFLUENCE IN AISI 321 STAINLESS STEEL WELDED TUBES

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**Abstract:** Usually a percentage over 2.5% of delta-ferrite is contained in AISI 321 stainless steel which leads to better workability (welding procedures). However a percentage like 10 % of delta ferrite or more can be harmful to the welded area due to the transformation of ferrite to sigma phase (which is a specific transformation of the steel alloyed with chromium). The best way to predict the content of delta ferrite in austenitic stainless steel is Schaeffler-DeLong diagram.

**Keywords:** delta ferrite, Schaeffler, DeLong, WRC Diagrams, stainless steel, welded tubes

### 1. INTRODUCTION

Austenitic stainless steels are widely spread in all industry branches because of excellent corrosion resistance and excellent mechanical properties. The austenitic type stainless steels have different compositions and different properties but in the same time many common characteristics such as hardening (which can be done only by cold rolling and not by heat treatment), nonmagnetic in annealed condition, at 25°C they retain austenitic structure.

The principal attribute of austenitic stainless steels is their corrosion resistance but also excellent properties in extreme temperature range. For that reason, austenitic stainless steels are considered to be the most weldable of the entire hi-alloy steel class. During the welding the temperature reached in the base metal produces microstructural transformations. The degree to which changes occur and the final effect upon corrosion resistance and mechanical properties depends of alloy contents, filler metal, thickness of the base metal, weld method etc.

All types of austenitic stainless steels are prone to hot-cracking during welding process. A percent over 2.5% of delta ferrite is intentionally introduced in all types of austenitic stainless because hot workability is dramatically improved. In the same time delta ferrite usually is controlled to prevent micro-cracks in stainless steel welds during welding. The best way to predict the content of delta ferrite is the Schaeffler-DeLong diagram. Delta ferrite has a body-centered cubic structure and remains in the metal structure at room temperature. By applying a heating treatment (1050 – 1100°C) the content of delta ferrite can be controlled reaching normal values (2,5 – 10%) which will not affect material properties. Delta ferrite content is controlled by the content of chromium, molybdenum, niobium, silicon, nickel, carbon, nitrogen, manganese and copper.

### 2. RESEARCH AND RESULTS

The study was started when a welded tubes manufacturer asked if it is possible that a big content of delta ferrite can produce enough magnetism which can affect arc welding process beside the intergranular or pitting corrosion. Generally the presence on delta ferrite in austenitic stainless steel can lead to some problems like:

a) In austenitic stainless steel with low nickel content (like AISI 301, AISI 316, AISI 304) cold rolling causes martensite transformation. A big content of delta ferrite lead to a big content of martensite. When the content of martensite increase, the workability decrease, and the risk of cracks occurrence increase.

b) In delta ferrite content drop under 2%, the workability of the material may develop micro cracks during welding process.

c) In acid environments, delta ferrite is preferentially dissolved. If the delta ferrite is present in big percent in the weld, it is possible that the weld to be dissolved.

The methods of ferrite measurement are several: magnetic measurement, x-ray diffraction, magnetic permeability, metallographic and calculation of ferrite from chemistry.

a) Ferrite determination from chemistry had been evaluated and was considered a statistically viable option for ferrite prediction through the application of some appropriate constitution diagrams. The Schaeffler and DeLong diagrams were the only applicable diagrams which incorporated alloy chemistry into ferrite content prediction.

b) Metallographic measurements, but the statistical accuracy (point counting) was highly influenced by the ferrite colony size, and the introduction of automated techniques had done little to improve upon operator variances. It was also observed that changes in ferrite content within the same substrate made quantification representative of the entire sample difficult.

c) The use of x-ray diffraction as a ferrite measurement technique was applicable. However, diffraction patterns were diffuse in nature and subject to interpretation. Sufficient accuracy was unattainable using this technique.  
 d) Magnetic permeability measurements required that a magnetic field be induced on a substrate and the resulting field strength be measured to establish the magnetic permeability. According this technique, the overall permeability of a two phase alloy containing one ferromagnetic and one non ferromagnetic phase, depends of the individual permeability, the content and demagnetization factor of the ferromagnetic phase at a given strength of the magnetizing field. In short words, this established that the strength of the induced field varied with the amount of ferromagnetic phase present.

Schaeffler-DeLong and WRC (Welding Research Council) constitution diagrams introduced a non-destructive method to relate alloy composition to the amount of ferrite present in an alloy. The development of such a non-destructive depends of accurate chemical analysis could be performed.

Schaeffler-DeLong and WRC diagrams are graphical methods easy to use as far as the numbers of calculation is not to high. The calculation method for FN (ferrite number) assumes parallel lines of constant ferrite numbers. FN Cr-equivalence includes other additional elements like Ti. Ni equivalence contain Cu and Co as additional elements.

1) Delta Ferrite measurement using Schaeffler Diagram

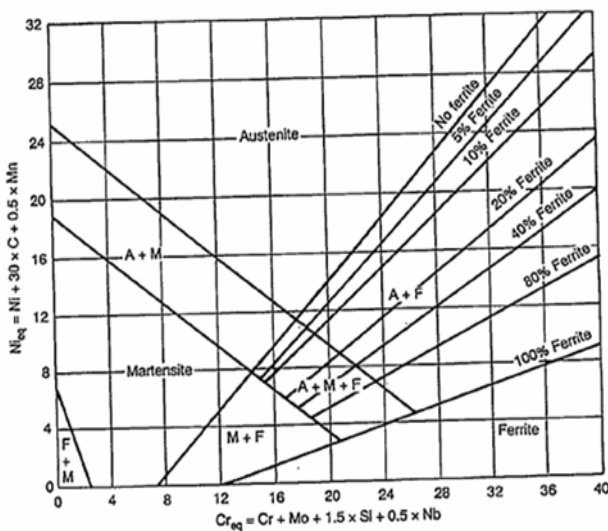


Figure 3: Schaeffler Diagram

We calculated Cr & Ni equivalences of the given steel composition then we determinate the intersection of the horizontal line (corresponding Ni – equivalence) and of the vertical line (corresponding to the calculated Cr equivalence). The intersection point is usually located between plotted lines of the constant ferrite numbers

(FN), thus we interpolated the approximated FN values or used the nearest FN line.

Table 1: Typical chemical composition for AISI 321

C	Mn	Si	P	S	Cr	Ni	Mo	Ti	N
0.025	1.030	0.570	0.026	0.001	17.130	9.050	0.190	0.240	0.016

$$Cr\ eq. = Cr + Mo + 1.5 \times Si + 0.5 \times Nb$$

$$Ni\ eq. = Ni + 30 \times C + 0.5 \times Mn$$

**Delta ferrite content : 6%**

1) Delta Ferrite measurement using De Long Diagram

The major advantage of the DeLong diagram was its introduction of nitrogen as a significant factor in ferrite formation. Nitrogen, an austenitizer, retards the formation of ferrite. DeLong postulated that variations in welding technique and atmospheric conditions could affect the nitrogen content in weld metal, thus affecting the amount of ferrite formed during solidification of the weld pool. His work increased the accuracy of the Schaeffler diagram and revealed that his estimations predicted increased ferrite over that of Schaeffler, for a given chemistry.

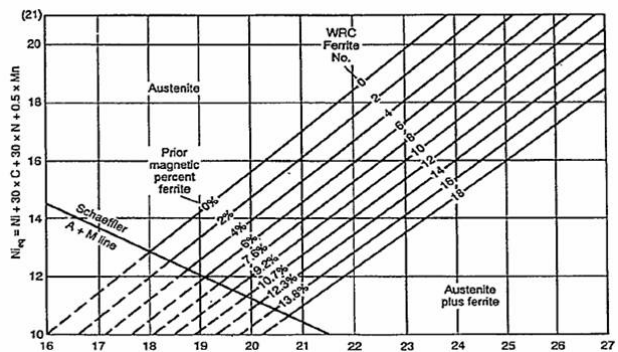


Figure 2: De Long Diagram From ASM Specialty Handbook on Stainless Steels,

The formulas for FN used in this case (fore same chemical composition) are:

$$Cr\ eq. = 1.5Si + Cr + Mo + 2Ti + 0.5Nb$$

$$Ni\ eq. = 30(C + N) + 0.5Mn + Ni + 0.5Cu + 0.5Co$$

$$FN = 3.34\ Cr\ eq. - 2.46\ Ni\ eq. - 28.6$$

**Delta ferrite content : 6.9 %**

3) Delta Ferrite measurement using WRC 1992 Diagram

In 1988, some members of Welding research Council (T. A. Siewert, C. N. McCowan and D. L. Olson) published a new diagram named WRC 1988. This diagram accounted for the following flaws in the Schaeffler and DeLong diagrams:

The DeLong diagram is essentially a finely tuned subset of the Schaeffer range, designed specifically for the 300-series stainless steel welds containing small amounts of ferrite. The refined nature of the DeLong diagram forced engineers to reference the Schaeffler diagrams for alloys containing more than 15% ferrite. As previously defined, the Schaeffler diagram did not have the improved degree of accuracy or accountability for nitrogen that the DeLong diagram developed.

The effect of manganese on ferrite formation had been incorrectly established. An improved database revealed that the original 0.5 weighting factor should have been changed to unity (1).

A study by WRC revealed that the effect of nitrogen on ferrite formation resulted in a decreased value of the nitrogen coefficient in the nickel equivalent. WRC suggested that the nitrogen coefficient be lowered from 30 to 20.

The effect of silicon on weld metal ferrite had been examined also by WRC. The results of this study revealed that the 1.5 silicon weighting factor used in both the Schaeffler and DeLong diagrams was inaccurate. WRC suggested that the weighting factor be reduced to 0.1. A similar study to investigate the effect of molybdenum and concluded that its coefficient be reduce from 1.0 to 0.7.



Figure 2: WRC Diagram

$$Cr\ eq = Cr + Mo + 0.7Nb$$

$$Ni\ eq = Ni + 35C + 20N$$

Delta ferrite content : 2.86 %

Next there are shown some microscopically analysis performed on a stainless steel welded tube made from AISI 321, 0.18 mm thickness, 2R (BA) surface finish.



Figure 4: Weld seam, stereomicroscope, magnification 10x.



Figure 5: Weld seam, magnification 100x, without metallographic attack.

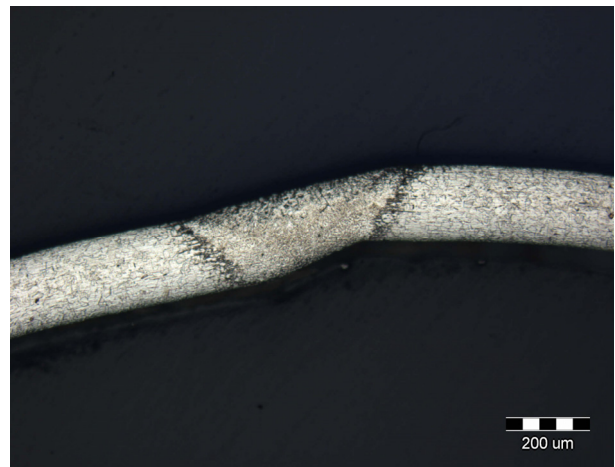


Figure 6: Weld seam, magnification 100x, with metallographic attack (oxalic acid 10%)

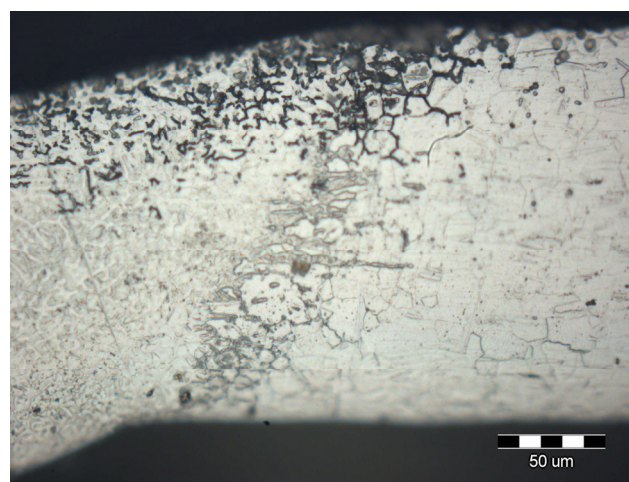


Figure 7: Weld seam, magnification 500x, with metallographic attack (oxalic acid 10%).

After analyzing 30 samples randomly chosen from a AISI 321, 0.18 mm welded tube and for a delta ferrite content

previously estimated from 2.86% (according to WRC diagram) to 6.9% (according to DeLong diagram) there are some conclusions:

- a) No cracks or discontinuities were observed on or next to seam area (Figures 4, 5, 6, 7);
- b) On all analyzed metallographic fields, we did not find nonmetallic inclusions.
- c) It was observed a non-uniformity of the width of seam and some scratches on the both sides of seam, probably formed during forming and welding operation.
- d) The microstructure of welded area is typical for austenitic welded steel.

### 3. CONCLUSIONS

1) Generally, austenitic stainless steel grades contain more or less a percent of delta ferrite (both in cast condition and in weld). The delta ferrite content decrease dramatically after hot rolling then by annealing of hot rolled materials. After cold rolling and annealing, the delta ferrite content decrease even more. The final welding method has a significant influence on the delta ferrite content of weld material.

2) There are a few tools used for predicting delta ferrite content, like Schaeffler- DeLong Diagram and WRC-1988 Diagram (beside others methods like metallographic point counting, magnetic indicators, attractive force, magnetic permeability, etc.).

3) All the literature indicates that a content of delta ferrite of max 8% in austenitic stainless steels weld is accepted without problems moreover decreases the cracking susceptibility of weld material and improve the cracking resistance.

4) In proportion greater than 10 %, delta ferrite is more can be harmful to the welded area due to the transformation of ferrite to sigma phase (which is a specific transformation of the steel alloyed with chromium).

5) Whichever method is used the proportion of delta ferrite can vary within a few percents. It is very important to known that the test made to measure ferrite delta of steel before welding is no so conclusive because some ferrite is transformed to austenitic during hot working.

6) Taking into account that the welding process is performed without filler metal, the weld metal has almost the same chemical composition as base metal but the microstructure of seam after solidification will contain predicted FN with mentioned diagrams.

7) Regarding the susceptibility to intergranular attack, it is known that 321 steel grade is a stabilized alloy with small addition of titanium which make it more resistant to corrosion than others austenitic steels.

8) After analyzing samples with delta ferrite content from 3% to 7%, no discontinuities or cracks were observed on or next to seam area.

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