ISSN 2229-5518

Assessment of Delta ferrite for SA 240 Type 304L Austenitic Weld Metal using Different Filler Materials

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Abstract— A minimum of ferrite number FN 4 and a maximum of ferrite number FN 21 are essential to prevent hot cracking in austenitic stainless steel. It's essential to restrict the amount of delta-ferrite as material becomes magnetic. Above ferrite number more than FN 21 delta ferrite can be harmful to the welded area due to the transformation of ferrite to sigma phase. To restate, steel with ferrite numbers between 4 and 21 solidify as primary ferrite with austenite. Delta ferrite content is limited by the content of chromium, nickel, carbon, manganese, molybdenum, silicon, copper, nitrogen, and niobium. Therefore to formulate effect of ferrite on microstructure the MIG welding process is performed with different filler wires, to predict suitability of filler materials with respect to weld metal on the basis of ferrite number and composition. To determine the suitable composition and the corresponding ferrite numbers for type SA 240 Type 304L Schaeffler Diagram, WRC 1992 Diagram and magnetic induction method is used.

Index Terms— Austenitic stainless steel, Delta ferrite, Feritoscope, Hot cracking, MIG welding, Schaeffler Diagram, WRC 1992 Diagram

1 Introduction

PRESENCEof delta ferrite is necessary to avoid microcracks in austenitic stainless steel during welding. Amount of delta ferrite is controlled by the carbon, chromium, manganese, molybdenum, nickel silicon, niobium, nitrogen, and copper. Higher value of delta ferrite results the more martensite transformation, decreases ductility and increases hardness in the weld [1]. The lathy ferrite microstructure also develops due to greater ferrite contents as dependent of weld microstructure stainless steel is more sensitive to hot cracking and intermetallic precipitations compared to mild steels [2, 3]. However the incidence of center cavities and undercuts is not noticeably influenced by the solidification mode [4]. Hence, a minimum FN is essential to avoid hot cracking tendency in steel whereas maximum FN determines the susceptibility to embrittlement due to second phase precipitation [5].

The Ferrite Number approach was built up in order to minimize the huge variation in ferrite levels determined on welds when measured using different techniques [6]. Principally, if FN is less than 30, stress corrosion cracking resistance and strength reduced in austenitic stainless steel. When the FN is above 70, ductility and toughness reduces correspondingly [7]. As shown in figure 1, weld solidification cracks in a fully austenitic weld metal having FN=0 and weld metal with FA solidification mode with FN = 6 [18].

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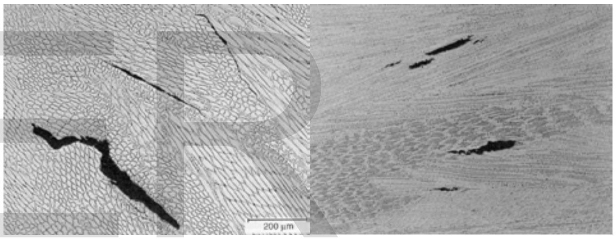

Fig. 1: Weld solidification cracks in a) fully austenitic weld metal (FN= 0) b) weld metal with FA solidification mode (FN= 6) [18]

The susceptibility of 304L to Hot Cracking, stress corrosion cracking, embrittlement and segregation, with respect to FN, three distinct weld characteristics related to composition of base metal is reviewed. This article presents a general framework for selection of optimum filler material by predicting delta ferrite for SA 240 Type 304 L stainless steel welds in MIG welding. It includes both predictive and measurement methods as well as merits and drawbacks of the presently used methods are also considered.

2 Experimental Details

To determine the delta ferrite content the 48 samples from plates with 60^{o} V groove with dimensions of 80mm×35mm×6 mm, had been obtained from austenitic stainless steel SA 240 Type 304L as shown in figure 2. Experiments were carried on the INMIG-250I welding set-up manufactured by Warrp Engineers Pvt. LTD. Steel wires as per AWS/ A 5.9 specifications with diameters of 2 mm has been used as the welding consumables.

ISSN 2229-5518

Type	C	Mn	P	S	Si
308L	0.03	1.0-2.5	0.03	0.03	0.3-0.65
	Cr	**Ni**	**Mo**	**Cu**	**Fe**
	19.5 -22.0	9.0-11.0	0.75	0.75 max	Bal-ance

Fig. 2 a): SA 240 plates

Figure 2 b): INMIG-250I welding set-up

Commercial Argon + 2 % CO_2 are utilized as the shielding gas in all the experiments. A butt welding is performed by adopting a single pass bead on plate technique. Direct current electrode positive (DCEP) polarity is used to carry out the MIG welding. The chemical composition of the investigated steel plate is given in Table 1.

Type	C	Mn	P	S	Si
SA 240 (plate)	0.03	2.0	0.045	0.03	1.0
	Cr	**Ni**	**Mo**	**N**	**Fe**
	18.0-20.0	8.0-12.0	-	0.10	Balance

Table 1: Typical chemical composition for AISI 304L (SA 240) Plate

The weld with a different chemical composition was tested. The chemical composition of filler materials are presented in Table 2.

Table 2: Composition of Austenitic Stainless Steel AWS Filler Metals Composition (wt %)

308H	**C**	**Mn**	**P**	**S**	**Si**
	0.04-0.08	1.0-2.5	0.03	0.03	0.3-0.65
	Cr	**Ni**	**Mo**	**Cu**	**Fe**
	19.5-22.0	9.0-11.0	0.75	0.75 max	Bal-ance
308LSi	**C**	**Mn**	**P**	**S**	**Si**
	0.03	1.0-2.5	0.03	0.03	0.65-1.0
	Cr	**Ni**	**Mo**	**Cu**	**Fe**
	19.5-22.0	9.0-11.0	0.75	0.75 max	Bal-ance

3 Chronology of Predictive and Measurement Methods

Presented below is a chronological review of techniques that researchers have offered including predictive and measurement methods. The delta ferrite content was determined using three methods: Schaeffler's diagram and WRC 1992 Diagram and feritscope.

3.1 Determination of ferrite number by Schaeffler's diagram

Schaeffler diagram was declared to give a universal precision of ± 4% volume ferrite, or ± 3 FN for 78% of cases, and it has been extensively used for ferrite prediction in welded stainless steels as well as for prediction of microstructure in dissimilar welds once the characteristic percentage dilution due to the welding process is recognized [9].

Table 3: Rules for determining Ferrite % w.r.t. % of compositional elements [10]

Element	Rule
Silicon	Mostly the maximum composition % is given otherwise calculate with minimum 0.3 % if the maximum is 1.0 % and minimum 0.6 % if the maximum is 1.5 or 2.0 %.
Manganese	Take a minimum of 0.6 % if only a maximum value is given.
Nickel and Molybdenum	Minimum is 0 % if only a maximum is given.
Carbon	If only a maximum is given: minimum 0.01 % if the maximum is 0.04 % or lower and minimum 0.04 % if the maximum is higher as 0.04 %.

During the calculation of delta ferrite, if the real chemical composition is not known, two calculations will be made: one with the minimum and one with the maximum values. Doing this, we obtain an area , in which the real composition will be present. An austenitic stainless steel needs a minimum of 12 %

of chromium in the matrix. Due to this condition, the part of the graph below a chromium-equivalent of 12 % is not applicable [10].

Table 4: Schaeffler Diagram: Solidification phases w.r.t. to coordinates (Cr_{eq}-Ni_{eq}) and structures (ferrite %) [10]

Phase	Location of Structures by the coordinates (Cr_{eq}-Ni_{eq})	Structures
Austenite	Above the lines (0-25) till (16-12) till (36-36)	Austenite + 0 –5 - 10 % Ferrite
Ferrite	Under the line (11-0) till (36-9)	Ferrite + Carbides (chromium-carbides, TiC, NbC...)
Duplex	Within the lines (36-36) till (16-12) till (22-4) till (36-9)	40 - 60 % Austenite, 60 - 40 % ferrite
Martensite	Within the lines (0-7) till (3-0) till (7-0) till (12-8) till (0-19)	Martensite + Austenite + (Ferrite) + Intermetallic components

The formulas for nickel and chromium equivalent used in Schaeffler Diagram are [11]:

$$Cr_{eq}.= Cr+ Mo+1.5\ Si+0.5\ Nb$$
$$Ni_{eq}. = Ni + 30C +0.5\ Mn \qquad (1)$$

The intersection point is usually located between plotted lines of the constant ferrite numbers (FN), thus we interpolated the approximated Ferrite % values.

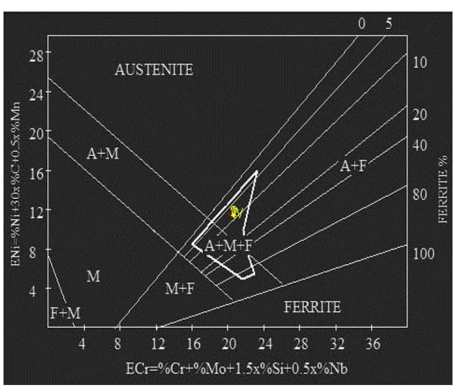

Fig. 3 a) : Schaeffler's diagram for AWS 5.4 308L

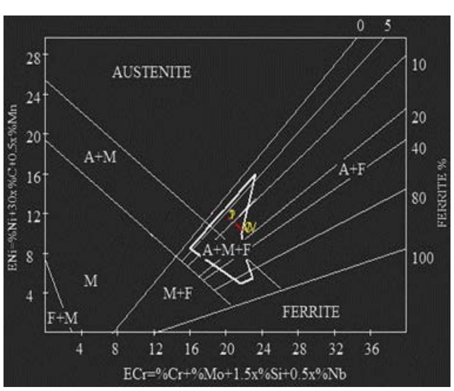

Fig. 3 b): Schaeffler's diagram for AWS 5.4 308 H

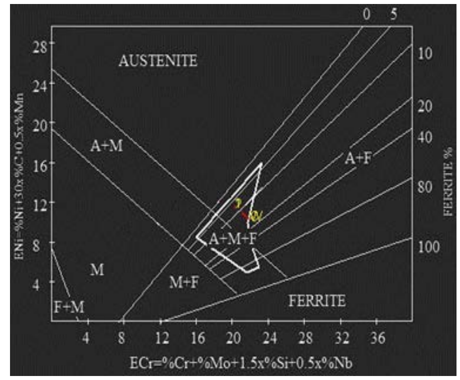

Fig. 3 c): Schaeffler's diagram for AWS 5.4 308LSi

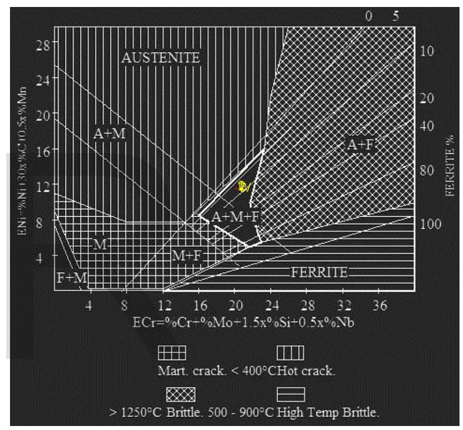

Fig. 4 a): Schaeffler's diagram for AWS 5.4 308L demonstrating warning zones

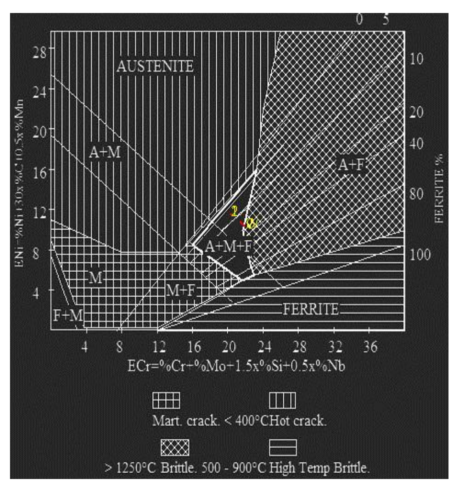

Fig. 4 b): Schaeffler's diagram for (a) AWS 5.4 308L demonstrating warning zones

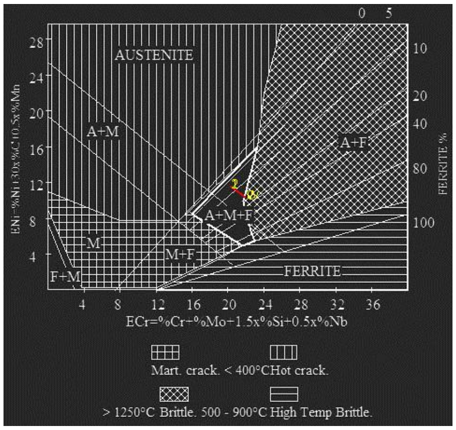

Fig. 4 c): Schaeffler's diagram for AWS 5.4 308LSi demonstrating warning zones

3.2 Determination of ferrite number by WRC-1992 Diagram

The WRC-1992 diagram calculated for all three filler wires is presented in Figure 5. Whereas the extended axes of the diagram allow a wide range of base and filler metal to be plotted, the FN prediction is valid only when the weld metal composition falls within the iso-FN lines of the diagram [12]. At the present time, the WRC-1992 diagram is the most reliable and most accurate for the prediction of Ferrite Number in the austenitic and duplex stainless steel welds. The formulas for nickel and chromium equivalent used in WRC-1992 Diagram are:

Ni_{eq}=Ni+35C+20N+0.25Cu

Cr_{eq} = Cr + Mo + 0.7Nb (2)

FN = –48.53 – 13.85 C + 12.73 Si + 1.16 Mn + 3.89Cr – 3.14 Ni + 4.60 Mo + 10.10 Cu – 20.36 N (3)

For SA 240 type 316L, approximately one third of the possible compositions will solidify as austenite, one fourth as

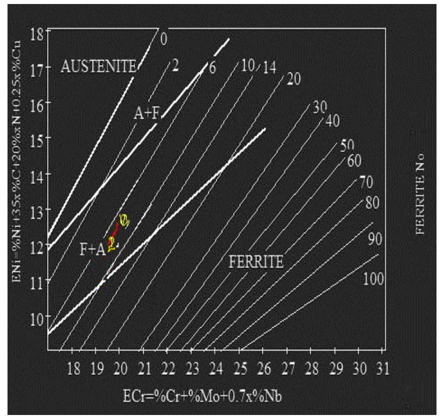

Fig. 5 a): WRC 1992 diagram for AWS 5.4 308L

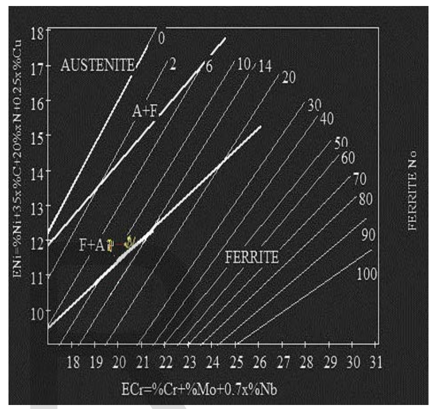

Fig. 5 b): WRC 1992 diagram for AWS 5.4 308H

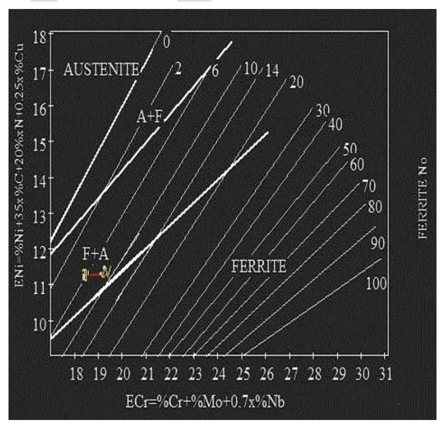

Fig. 5 c): WRC 1992 diagram for AWS 5.4 308LSi

primary austenite, one third as primary ferrite and the balance as ferrite. It should be noted that the maximum carbon content permitted by the SA 240 was used for the calculations [8]. In addition, due to the absence of specification limits for nitrogen, a typical amount of 500 ppm was assumed.

3.3 Determination of ferrite number by Feritcope

Feritscope or Ferrite content meters are very convenient in use, durable and portable device. It offers full nondestructive measurement of many kinds of metal. Feritscope Test is based on the detail that the delta ferrite is magnetic and the austenite is nonmagnetic [12]. The eight tests was carried out at each weld sample and taken the mean value.

4 Results and Discussions

On the base of the results for obtained values of Cr_{eq} and Ni_{eq} and using a Schaeffler's diagram can be approximated that the content of delta ferrite is in the range from 4-16%. Here delta ferrite content depends on the chemical composition of the weld using different filler materials. The disadvantage of Schaeffler Diagram is that it can only estimate the interval of the delta ferrite content. Also, in practice for steels for which the Schaeffler diagram predicts delta ferrite content of 0-15%, the actual measured content is usually lower than predicted content [6].

WRC 1992 analysis confirmed delta ferrite content ranging from 6.0 to13.0%. WRC diagram analysis revealed that the effect of nitrogen on ferrite formation resulted in a decreased value of the nitrogen coefficient in the Ni_{eq}. WRC proposed that the nitrogen coefficient be decreased from 30 to 20. WRC analysis explained that the 1.5 silicon weighting factor used in both the Schaeffler and DeLong diagrams was inexact and it should be reduced to 0.1. It also explained emphasis of molybdenum and concluded that its coefficient be lowered from 1.0 to 0.7 [11].

The magnetic induction technique (MIT) for delta ferrite measurement can be a method for measuring the absolute content of delta ferrite, whereas Schaeffler's Diagram and WRC analysis provide only approximate contents of the ferrite. Comparing the results with other methods as shown in Table 5, we find a lower value of delta ferrite by MIT ranging from 0.9 to 7.32. Average mean of all eight weld sample joined by filler wire 308 L, 308 H and 308L Si has been taken respectively. The result presented here reveals delta ferrite for weld produced by AWS 304L (F % = 3.23) is found least and maximum for AWS 308H (F % = 6.22) filler material.

Table 5: Delta ferrite content for SA 240 Type 304L weld

Filler Wire AWS 5.4	Cr_{eq}	Ni_{eq}	Cr_{eq}/ Ni_{eq}	Ferrite %		
				Schaeffler	WRC 1992	Feritscope
308L	19.35	12.24	1.58	7	6-7	3.23
308H	21.40	12.11	1.76	8-15	8-13	6.22
08LSi	22.75	13.99	1.63	4-16	6-10	5.87

5. Conclusions

1. The delta ferrite content was quantified for 24 welds joined by MIG welding opting three different filler materials 308L, 308 H, 308 L Si respectively. Three methods were used for testing: Schaeffler's diagram, WRC 1992 Diagram and Feritscope Test. The analysis of results revealed that the delta ferrite content was from 0 to 15% depending on the filler wire composition and test methods.
2. It is also recognized that for the same combination of base material and consumable, differences in the experimental values can also be found related to the specific welding procedure and parameters used [13]. Hence, whatever ferrite % is assigned to a weld metal should be quantified from mean of several measurements.
3. To control primary mode of solidification and to prevent hot cracking a calculated Cr_{eq}/Ni_{eq} of 1.52 to 1.9 is recommended for type 304L austenitic stainless steel. It has been validated that Cr_{eq} to Ni_{eq} ratio lies between permissible limit hence weld can be produced by any of three filler wires.
4. Whichever analysis is used the fraction of delta ferrite can differ within a few percents. The test made to measure ferrite delta of steel before welding is no so decisive because some ferrite is transformed to austenitic during hot working.
5. Literature Data 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 [15].
6. Despite their practical limitations, wherever it is possible, experimental measurements based on Feritscope are better than predictive methods, whose accuracy is mainly dependant on the reliability of chemical composition.
7. However, in the early stage of projects where the weld deposit is not available such as where alternative welding consumables are being considered, then predictive methods have their scope [12].

Acknowledgment

The author is grateful to her Guide Dr K. M. Moeed. Author also wants to thanks Dr. Inderjeet Singh for his continuous support and motivation. Authors show their gratitude to Mr. Ameel who had given permission to conduct our experiment in Era Engg. Workshop.

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