Study of Solid state Phase Transformation in Duplex Stainless Steel Weld Metal by using Induction End heating technique

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Abstract

Solid state phase transformation of duplex stainless steel weld metal was studied by induction heat source. Homogenous weld metal Duplex Stainless Steel 2209 was papered by physical simulation of weld metal and machined into cylindrical shape. One end of the specimen was fixed near induction coil resulting in highest heating from induction heat and decreasing toward another end. Different in temperature between both ends resulted in various solid state phase transformation as a function of temperature and distance. This methodology was conducted on physical simulation of weld metal in which it's more economical than conventional study on an actual weld.

***Keywords**: Phase transformation, Physical simulation, Induction heat, Duplex Stainless Steel*

1 Introduction

Duplex stainless steel is one of the best corrosion resistant materials used in engineering applications. Its microstructure consists of a mixture of austenite and ferrite phase. As a result, duplex stainless steel shows the properties of both austenitic and ferritic stainless steel. This combination of properties is the compromise of pure austenitic and ferritic grades. The microstructure of weld metal could affect the properties such as mechanical properties, and corrosion resistance, etc. There are many parameters that can affect the morphology of stainless steel weld metal microstructure such as welding heat input, chemical composition, dilution ratio, and cooling rate. Many researches had studied the solidification and morphology of stainless steel weld metal [1-3] which showed factors that could affect the weld metal microstructure in term of solidification mechanism as well as solid state transformation in which they are related with chemical composition, solidification mode, as well as thermal history. The microstructure of stainless steel weld metal could be predicted by Schaeffler Diagram which can be used for prediction of ferrite content formed in the microstructure of weld metal in term of Cr_{eq} and Ni_{eq}.

For solid state phase transformation of duplex stainless steel weld metal by using induction end heating technique, it could be done by using a special design small size copper mold [4-7]. Heating of weld metal could be controlled by using induction unit to heat the simulated weld metal. Then, the samples were placed for microstructure evaluation as well as determination of ferrite content.

2 Experimental Procedures

2.1 *Specimen Preparation*

Material used in this experiment was filler metal grade ER2209 (Duplex Stainless Steel) with diameter of 2.0 mm. The nominal chemical composition was shown according to Table 1. [8]

Table 1: Composition of duplex stainless steel welding filler metal AWSA5.9 ER2209. [8]

Composition (wt %)								
C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Cu**
0.02	0.5	1.6	0.02	0.025	22.5	8.0	3.0	0.14

2.2 *Weld Metal Melting*

Pieces of filler metal ER2209 were placed into a small capsule shape of copper mold affixed on a welding table. Gas Tungsten Arc Welding; GTAW was the welding heat source applied in order to melt the material and then allowed the material cool inside the copper mold as shown in Figure 1. With sufficient cooling rate resulting from the conductivity property of copper, the material solidified would have the microstructure morphology similar to what come from the actual welding process. Welding conditions and parameters for melt filler metal were summarized in Table 2.

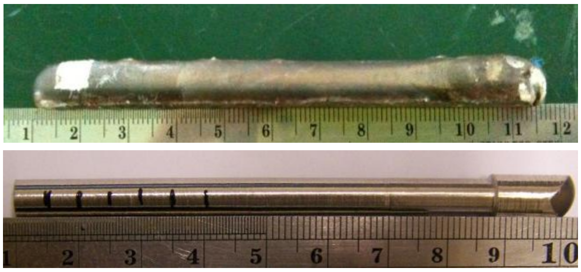

Figure 1: Weld metal specimens; (top) from simulated, (bottom) after prepare cylindrical shape.

2.3 *Induction end heating*

Homogenous weld metal Duplex Stainless Steel ER2209 was papered by physical simulation of weld metal and machined into a cylindrical shape. One end of the specimen was fixed near an induction coil resulting in highest heating from the induction heat source. A set of thermocouples type K were attached to the specimen at one end near the induction coil This process was repeated for total of 6 thermocouples with a distance among them of 5 mm as shown in Figure 2. A data logger was then used for recording temperature of the specimen picked up by those set of thermocouples.

Table 2: Welding conditions for melt filler metal

ID	**No. of Layer**	**Welding Parameter**			
		Current (A)	**Volt (V)**	**Speed (mm/sec)**	**Heat input (kJ/mm)**
1	2	170	13.4	0.78	2.939
2	2	170	13.4	0.78	2.939

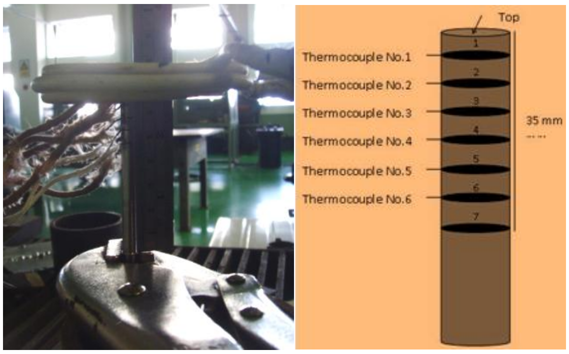

Figure 2: Weld metal cylindrical shapes; (left) in the induction coil, (right) thermocouple location and distances for one point to other point about 5 mm.

2.4 *Metallographic examination*

Specimens heated by induction heat were then cut cross section into 7 pieces at the points where the thermocouples attached and then mounted for microstructural evaluation. Those samples were grinded and polished followed by etching using etchant called Beraha’s tint etch with the composition as 25 mL HCl, 3 g ammonium bifluoride, 125 mL wate and 0.2 g potassium metabisulfite. This procedure was prepared according to ASTM E407 [9]. An optical microscope was employed for evaluation and photographing.

2.5 *Percent Area of Ferrite Measurement*

Duplex stainless steel filler metal ER2209 used in this study was heated by induction heat with various distances away from the heating end resulting in variation of heat and cooling from one end to the other. This would result in the variation in the amount of ferrite content formed inside weld metal microstructures. The amount of ferrite could be derived from the micrographs taken by the optical microscope and then analyzed by computer software called “Scientis”. The amount of ferrite was measured based on the area of ferrite phase shown on the micrographs according to ASTM E1245 [10].

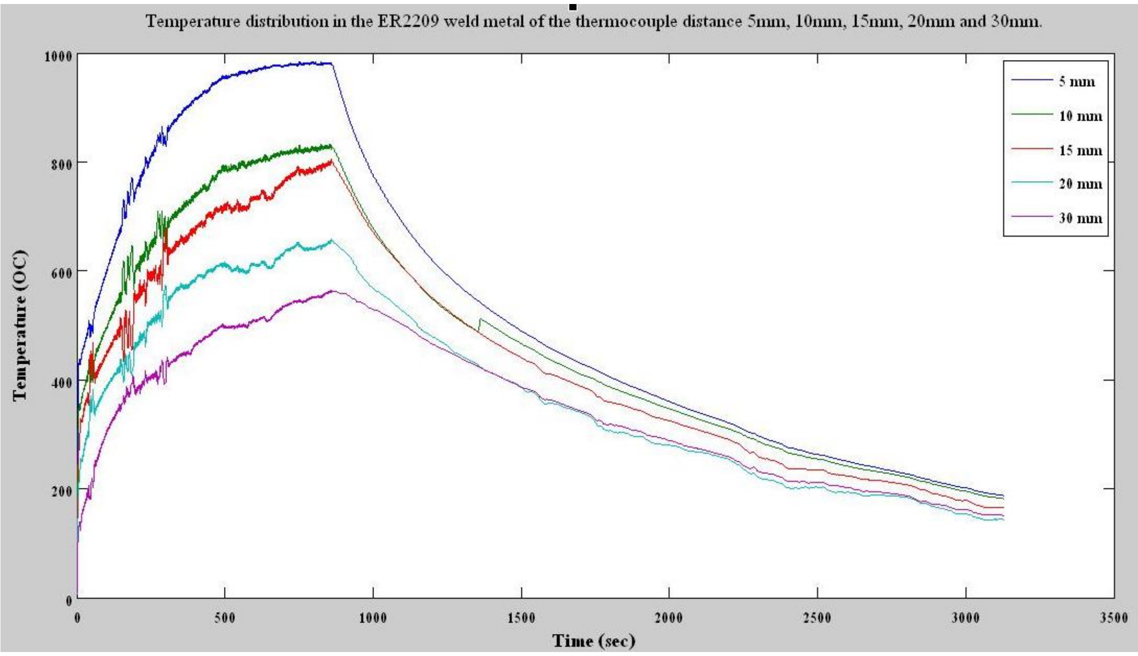

Figure 3: Temperature distribution in the ER2209 weld metal.

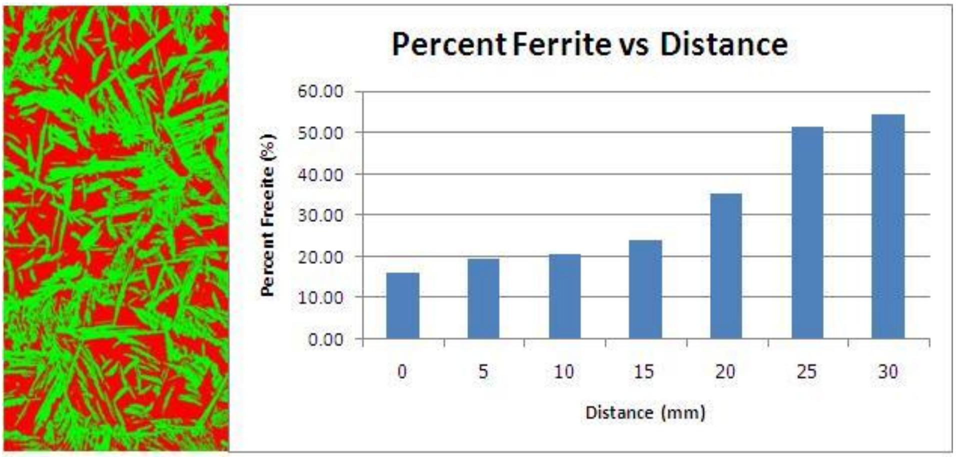

Figure 4: Percent ferrite vs Distance; (left) microstructure, (right) percent ferrite.

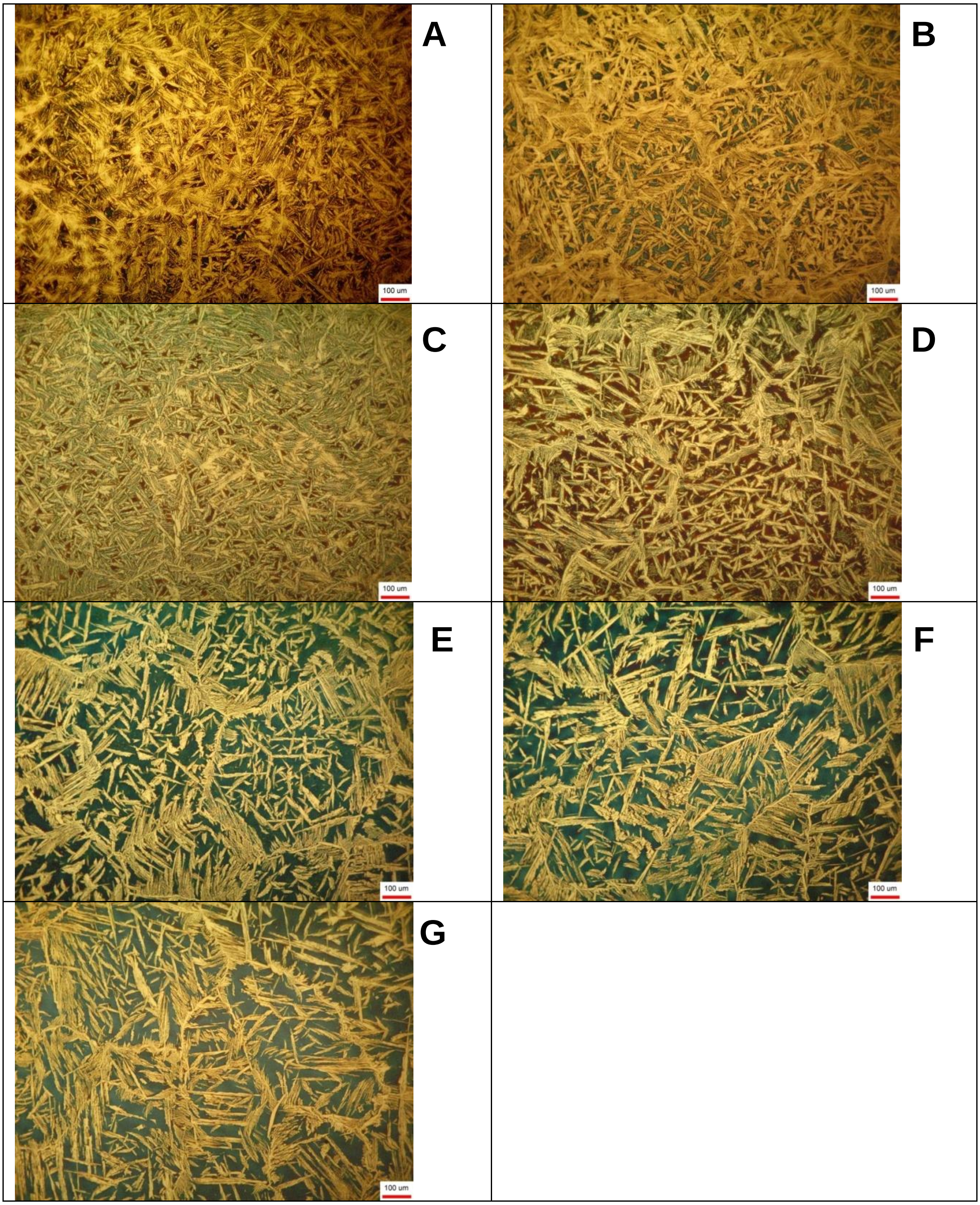

Figure 5: Weld metal microstructure. A; On the top of specimen, B; Distance 5 mm from the top, C; Distance 10 mm from the top, D; Distance 15 mm from the top, E; Distance 20 mm from the top, F; Distance 25 mm from the top, G; Distance 30 mm from the top.

3 Results and discussion

3.1 *Temperature distribution and δ-ferrite Content*

Temperature distribution of weld metal that heated by induction coil shown in Figure 3 could be plotted on temperature and time for study about temperature distribution along a long of specimen. This temperature profile vs time was varied from the highest temperature at the heating end and decreased as the distance away from the heating end to the other end.

From the microstructure of simulated weld metal, the amount of ferrite was determined as shown in Figure 4. According to distance from the top of specimen at the heating end, the ferrite content was low and increased as distance forward to the other end. When distance increate. At the top of specimen, the heat from induction coil was highest giving time to promote more austenite while the other end had lower temperature then ferrite was remained [2].

3.2 *Ferrite-Austenite Morphology Evaluation.*

The morphology of δ-ferrite and γ-austenite were depending on composition and cooling rate. As can be seen in Figure 5 from (a) to (g), microstructure of the simulated weld metal was a mixture of ferrite and austenite at different ratio.

Weld metal ferrite content is controlled though a combination of composition and thermal conditions. The rapid cooling rate can promote ferrite content [2]. In this case of simulated weld metal, it was solidified as FA or F mode in which ferrite formed at the beginning of solidification followed by solid state phase transformation. However, since fast cooling is associated with welding, therefore it was not enough time for ferrite weld metal to transform into austenite as with equilibrium state. As a result, more ferrite phase could be expected in the microstructure of weld metal as shown in Figure 5 (g) at the far end from induction heating.

Upon heating by induction heat source at one end, this would act as post weld heat treatment asserted on the weld metal. This would promote more solid state transformation as secondary austenite would form resulting in less ferrite content. The higher heating and longer time were, the closer to equilibrium state. As a result less ferrite content in this area would be expected.

As can be seen in Figure 4, the amount of ferrite was increased as further distance from the heating end. This was the effect of less heating in the area further away and secondary austenite was promoted lesser.

4 Conclusions

The study of solid state phase transformation in duplex stainless steel weld metal by using induction end heating technique could be concluded as the following:

- The temperature of simulated weld metal was highest at the heating end.
- Solidification mode of simulated weld metal was FA or F in which more ferrite would be expected in the microstructure
- More austenite would be expected in the area close to the heating end as it acted as post weld heat treatment that would promote secondary austenite.
- As the area further away from the heating end, temperature was lower, and fewer secondary austenite formed.
- This technique could be applied for controlling the balance of ferrite and austenite content in weld metal

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