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Metallurgical Behavior of Duplex Stainless Steel 2205 Joints Welded using GTAW And FCAW Process

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Abstract

Objectives: The aim of the present work was to investigate the influence of welding process variation as well as post weld thermal aging treatment on the metallurgical properties of Duplex Stainless Steel (DSS) 2205 welds. **Method**: Butt welded joints were fabricated using 10 mm thick plates of DSS 2205 by two different welding processes namely, Gas Tungsten Arc Welding (GTAW) process and Flux Cored Arc Welding (FCAW) process. These welded specimens were further subjected to thermal aging treatment at 800°C for 40 minutes to study the precipitation tendencies in the welds. **Findings**: Ferrite content was found to increase more in case of thermally aged FCAW joints as compared to the thermally aged GTAW joints. Also, GTAW weld metal showed a softening effect while FCAW weld metal underwent hardening after thermal aging treatment. Aging resulted into variation of ferrite content indicating that the process change can affect the important metallurgical ratio of austenite to ferrite in these welds. Ferrite phase was the predominating phase that showed dissolution which led to different inter-metallic phase formations like carbides, oxides as well as sigma phase formation. **Application/Improvements:** The present study is beneficial from the industrial view point, as the data generated through this piece of research can be directly used for DSS fabrications.

Keywords: DSS, FCAW Process, GTAW Process, Metallurgical Properties, Welded Point

1. Introduction

Duplex Stainless Steel (DSS) possesses balanced double phase structure of ferrite and austenite in fixed ratio of approximately 1:1, due to which these steels have excellent combination of corrosion resistance and mechanical properties[1]. Therefore duplex stainless steels found extensive use in petro-chemical, marine constructions, oil and gas transmission pipe lines, chemical processing plants pipe lines, nuclear power plants, and desalination services. At high temperature operating conditions (500^0C to 800^0C) these steels degrade in terms of mechanical properties and corrosion resistance due to thermal aging embrittlement[2,3]. Due to long exposure at this temperature range ferrite content decomposes into chromium enriched and molybdenum enriched compounds known as sigma and chi phases resulting in the hardening of ferrite[4,5]. Since welding is employed in most of the industries and after welding these fabricated welds is subjected to a wide range of operating temperatures, therefore understanding the effect of high temperature on duplex stainless steels is critical for the successful implementation of these steels. The unique behavior of duplex stainless steels towards the corrosion and mechanical properties is due to its ferrite/austenite phase balance. Generally base metals consist of appropriate ferrite/austenite ratio due to the combination

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of its composition and solution annealing. However, ferrite/austenite balance in case of welding of DSS cannot be maintained as in base metal. Welding thermal cycles may change the ferrite/austenite ratio. The desired 30-55% (typically about 45%) ferrite necessary for imparting combination of excellent corrosion resistance and mechanical properties can only be achieved by the selection of proper welding process, judicially designing the welding procedures and selecting the proper filler metal[6]. At fusion temperature DSS structure is completely ferrite which transforms partially to austenite on solidification. The optimum ferrite content (typically 45 %) or in the range of 30-55% can only be produced by slow cooling of the weld after welding. However, too slow cooling rate may lead to the formation of inter- metallic phases despite in the presence of optimum ferrite. Thus, microstructure of weld and heat affected zones depends upon the cooling rate, which can be controlled by selecting proper welding process. However, this research area has received little attention and thus needs to be explored for better understanding of the metallurgical aspects of DSS joints welded using conventional processes like GTAW and FCAW process.

2. Materials and Methods

The base and the filler materials combination comprised of rolled plates of AISI 2205 grade and the compatible grade fillers. Two pairs of plates of DSS bearing composition as given in Table 1 were cut into the sizes of 200mm×60mm×10mm each. Double V-groove with an included angle of 60° was provided on the edge of each plate. Groove design and specimens extraction plan is shown in Figure 1.

Welding was accomplished using root passes on each set of plates that were made by GTAW process with

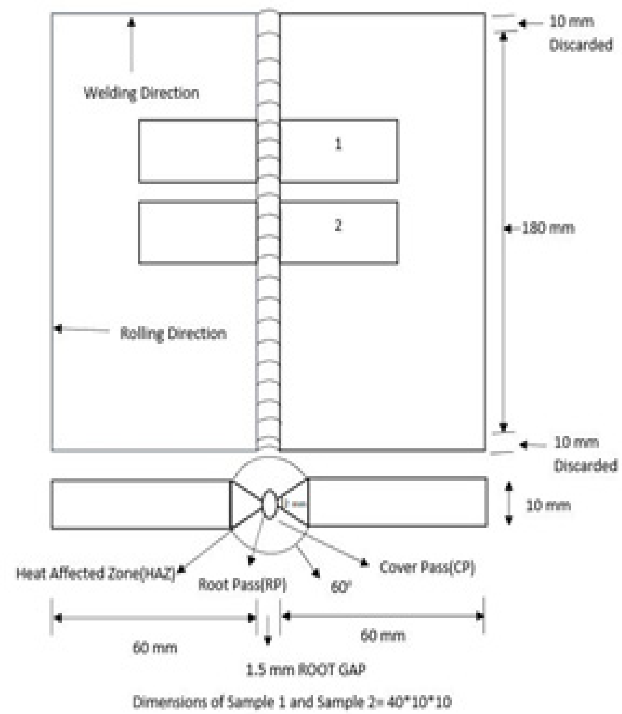

Figure 1. The sample extraction from the butt welded joints using double-V groove design.

Table 1. Chemical composition of the base material DSS 2205 and the filler wires used

Materials	C	Si	Mn	P	S	Ni	N	Cr	Mo	Cu	Fe
Base material (AISI 2205)	0.018	0.54	0.92	0.011	0.003	5.3	0.17	22.9	3.0	0.042	Bal.
Filler wire for GTAW(ER2209)	0.008	0.48	1.54	0.017	0.0006	8.63	0.15	22.94	3.07	0.14	Bal.
Filler wire for FCAW(E2209)	0.04	0.46	1.08	0.017	0.011	8.73	0.146	23.02	3.57	0.10	Bal.

Table 2. Welding conditions used for GTAW process

S No.	Parameters	Specifications
1	OCV	25 V
2	Welding current	160 A
3	Welding speed	13 cm/min
4	Argon gas flow rate	15 L/min
5	Welding position	Flat

Table 3. Welding conditions used for FCAW process

S No.	Parameters	Specifications
1	Wire feed rate	5 m/min
2	OCV	32 V
3	Welding current	170 A
4	Welding speed	20 cm/min
5	Nozzle to plate distance	12 mm
6	Argon gas flow rate	20 L/min
7	Welding position	Flat

1.4mm diameter of ER2209 grade filler wire. Cover passes on first and second set of plates was completed by GTAW and FCAW processes respectively. Cover passes by GTAW process were provided with the help of tungsten electrode of 2mm diameter using ER2209 filler wire of 2.4 mm in diameter. For FCAW process cover passes were provided by E2209 of 1.2 mm diameter. Thus welding on each set of plates was completed using the root pass as well as the middle and the cover pass. Welding parameters for GTAW process and FCAW process is given in Table 2,3 respectively.

Two specimens from each welded plate were extracted. One is as-welded while the other is thermally aged at 800˚C for 40 minutes. These specimens were ground with emery papers ranging in fineness from 100 up to 3000 equivalent mesh, and then polished with alumina suspension. Mean of three values of micro-hardness and ferrite percentage each was determine at three different locations i.e. Cover Pass (CP), Root Pass (RP), and Heat Affected Zone (HAZ). After determining the micro-hardness the specimens were again polished and finally etched in a solution of (1 gm $K_2S_2O_5$, 15 ml HCL and 85 ml H_2O) then rinsed with water and dried by forced air.

Optical microscopic examination for CP, RP, and HAZ was done at 100X magnification to determine the effects of two welding processes as well as thermal aging on the microstructure at different weld zones and some of these are presented in figure.

3. Results and Discussion

3.1 Ferrite Studies of the Joints

Ferrite evaluations carried for GTAW and FCAW joints reveal that ferrite percentage did not vary much for the joints in the as welded condition. Ferrite content values for GTAW welded joint at CP, RP and HAZ were found to be 37.9%, 41.2% and 43.7% respectively, while for FCAW welded joint the corresponding values were 37.5%, 42.8% and 41.3% which have been graphically represented in Figure 2. However, it was observed that the ferrite content in the weld metal was less than the HAZ for both GTAW and FCAW joints. The RP weld zone showed a higher value of ferrite than the CP zone which could be attributed to the fact that the welding heat input that was used for giving the root pass was lower as compared to

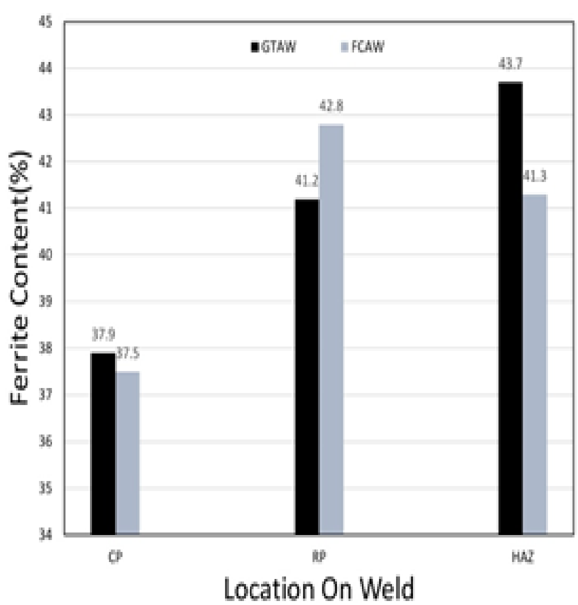

Figure 2. Ferrite content at different locations in the weld for as-welded condition.

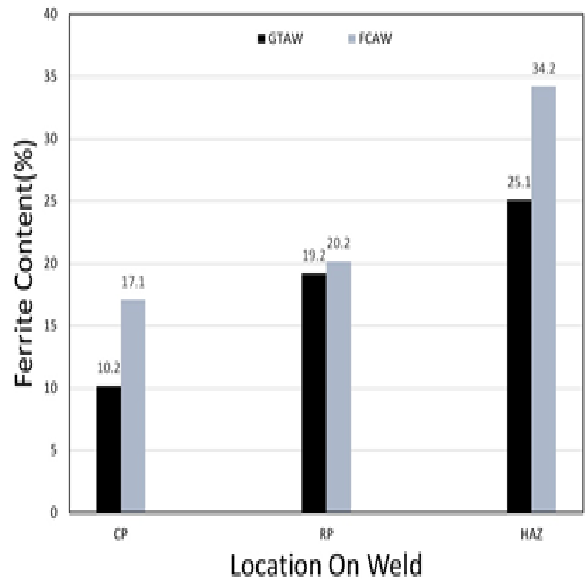

Figure 3. Ferrite content at different locations in the welds aged at 800°C/40min.

the one used for CP, which resulted into higher cooling rate and thus the time required for the transformation of ferrite into austenite was less. But when these joints were subjected to thermal aging treatment at 800°C for 40 minutes, it was observed that the ferrite content showed an appreciable loss in the weld zone as well as the HAZ of these joints which could be attributed to ferrite dissolution which occurred at high temperature during thermal aging treatment[7,8]. Ferrite content in the thermally aged GTAW welded joints at CP, RP and HAZ was found to be 10.2%, 19.2% and 25.1% respectively, while for thermally aged FCAW welded joints the corresponding values were 17.1%, 20.2% and 34.2% which have been shown graphically in Figure 3. GTAW CP weld pass showed relatively higher loss of ferrite than the FCAW weld metal indicating that a higher extent of precipitation in it.

3.2 Micro Hardness Evaluation of the Joints

In the as welded condition, micro hardness values across the weld metal zones as well as HAZ zones were found to be in close range to each other for both GTAW as well as FCAW joints which has been graphically represented in Figure 4. HAZ of both the weld showed lower levels of

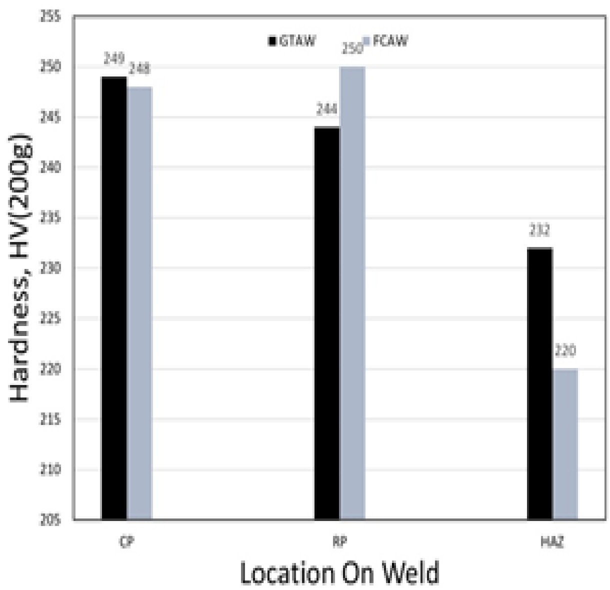

Figure 4. Micro hardness at different locations of the weld for as-welded condition.

hardness owing to the tendency of these joints to undergo grain coarsening effect which is a typical characteristic of stainless steel welds.

However, when these joints were subjected to thermal aging treatment micro hardness value of the weld metal of both the joints showed a variation in it which could again be attributed to precipitation that occurred in the weld metal involving microstructural changes. The precipitation products such as carbides, nitrides, oxides and sigma have been reported to occur under such conditions of high temperature thermal aging the weld joints[9-11]. Graphical representation of micro hardness variations across different zones of these weldments are shown in Figure 5.

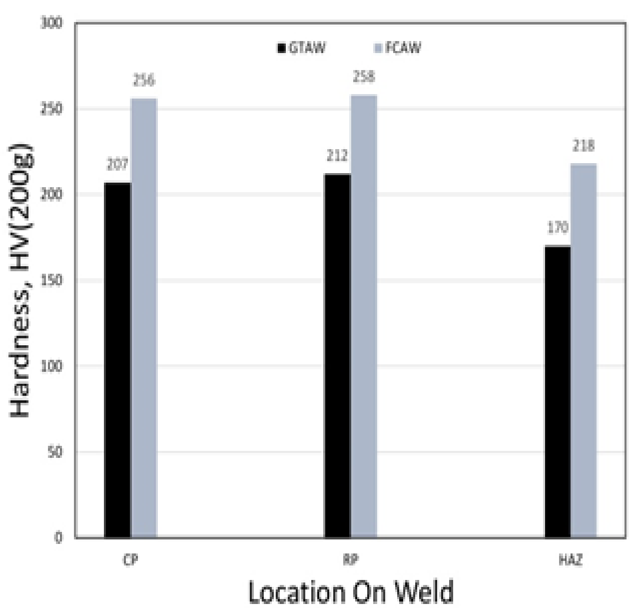

Figure 5. Micro hardness at different locations of the welds aged at 800°C/40min.

3.3 Micro Structural Studies of the Joints

Optical micrographs of the different zones of the welded joints fabricated by using GTAW and FCAW were captured in order to reveal various microstructural transformation products. Formation of precipitates can be observed in case of the aged welds. These precipitates comprise of carbides, oxides beside the formation of sigma phase. This sought of intermetallic phase formation, as reported above, results into change in the hardness and ferrite variation, that can exert a significant influence on the mechanical and corrosion properties of these joints[12-14]. Microstructures at CP, RP and HAZ of both GTAW and FCAW welded joints are shown in Figure 6.

4. Conclusions

Although ferrite variation in both the weld was in a close range in the as welded condition, but aging resulted into variation of ferrite content indicating that the process change can affect the important metallurgical ratio of austenite to ferrite in these welds.

Aging reduced ferrite content both in the weld metals as well as in the HAZ of both GTAW and FCAW welded joints, thus indicating that ferrite was the predominating phase that showed dissolution due to ageing. Microhardness for the as welded condition was found to be in a close range for both weld metal as well as HAZ. However, thermal aging treatment results into weld metal softening of the GTAW joints and weld metal hardening of the FCAW joints which largely resulted because of micro alloying additions made via different filler electrodes. Microstructural studies showed that thermal aging treat-

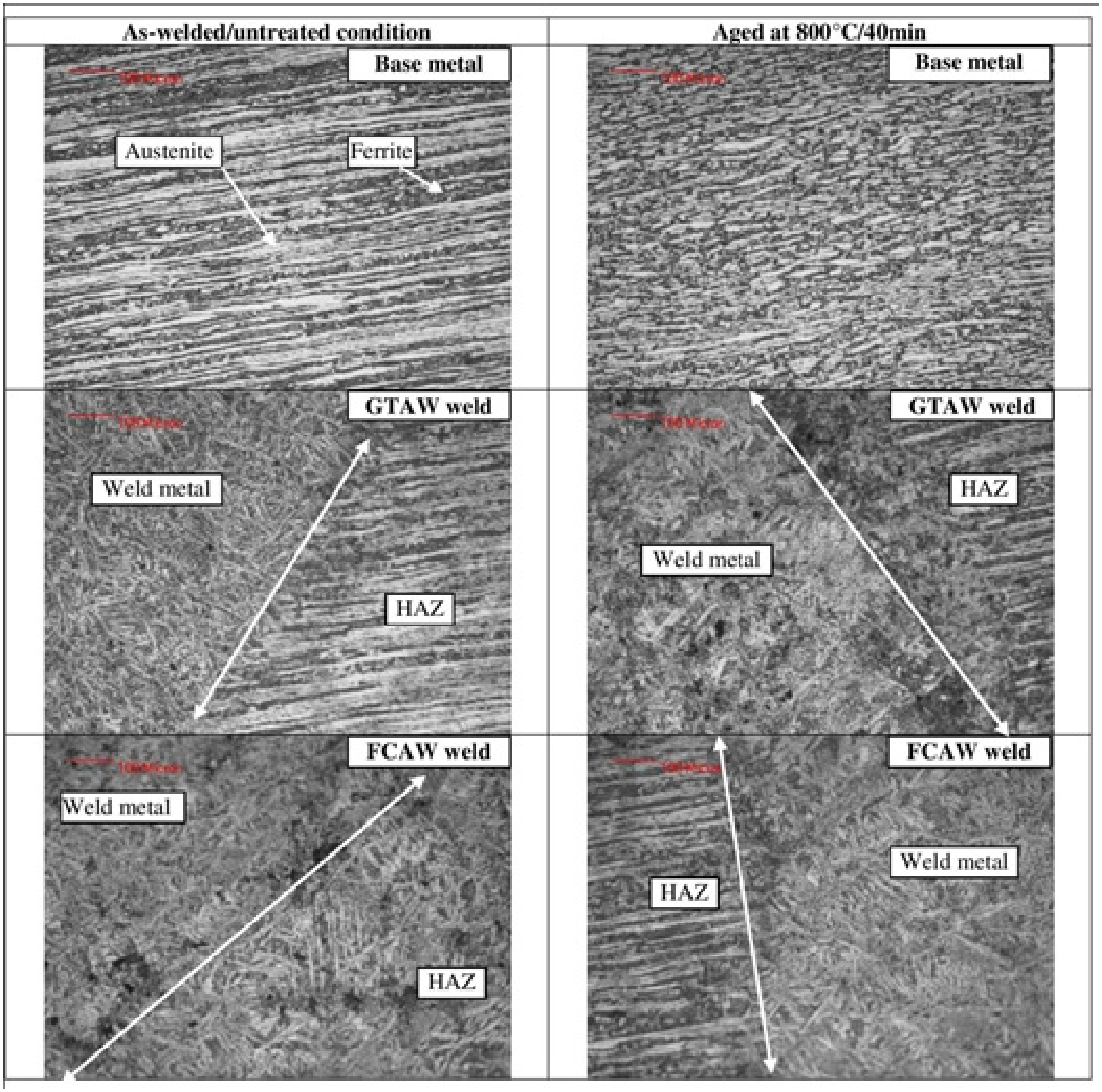

Figure 6. Base metal as well as welds under different conditions.

ment resulted into formation of different inter-metallic phases like carbides, oxides as well as sigma phase formation, which had a consequential effect on the ferrite content as well as on micro-hardness of both GTAW and FCAW welds. The present study is beneficial from the industrial view point, as the data generated through this piece of research can be directly used for DSS fabrications.

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