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Intermetallic Precipitation in Thermally Aged Duplex Stainless Steel Welds

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Abstract

The present work was carried out with an aim of studying the metallurgical aspects of duplex stainless steel (DSS) welds, when subjected to high temperature thermal aging treatment. DSS 2205 rolled plates of 10 mm thickness were butt welded using GTAW (gas tungsten arc welding) process. The welded specimens were subjected to thermal aging treatment at 850˚C/45 minutes followed by water quenching. Material characterization via SEM microscopy of thermally aged welded specimens showed different morphological changes indicating metallurgical imbalance in the ferrite-austenite ratio which was evidenced from the ferrite dissolution that occurred in these welds. Further, XRD examination of these thermally aged welded specimens confirmed the presence of different intermetallic phases like oxides, carbides and sigma phase formation.

Keywords: DSS 2205, GTAW process, ferrite-austenite ratio, thermal aging treatment, SEM, XRD, intermetallic phases.

INTRODUCTION

Duplex stainless steels (DSSs) simply have balanced double phase structure of ferrite and austenite in approximately equivalent volume fraction [1].Duplex stainless steels have been designed to provide a desired combination of strength and corrosion resistance. These steels possess approximately double strength as compared to conventional austenitic steels beside offering excellent weldability and ductility as compared to ferritic steels [2].Due to these advantages 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 [3,4]. It has typical composition of Fe-Cr-Ni-Mo-N .The optimum properties of duplex stainless steels can only be achieved when equivalent volume fraction of ferrite and austenite is present in the microstructure. During welding duplex stainless steel is subjected to non-uniform heating and cooling weld thermal cycles, due to which desired ferrite -austenite ratio get changed. Also, high temperature operating conditions (450^0C to 850^0C) may further lead to degradation of the fabricated welds in terms of mechanical properties and corrosion resistance due to thermal aging embrittlement [5, 6]. Longer exposures at this temperature range may lead to decomposition of ferrite content into chromium enriched and molybdenum enriched compounds known as sigma and chi phases, resulting in the reduction of volume fraction of ferrite [7,8]. 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 [9]. 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 zone depends upon the cooling rate, which can be controlled by selecting proper welding process [10].

Since welding is widely used in most of the fabrication industries, and after welding these fabricated welds are subjected to a wide range of operating temperatures, therefore understanding the effect of high temperature service exposures on duplex stainless steels is critical for the successful implementation of these steels. However, this research area has received little attention and needs to be explored further for getting better insight into various metallurgical aspects related to duplex stainless steel welds, In view of this important research gap the present work was carried out where duplex stainless steel welds were investigated for their metallurgical prospects, especially when subjected to high temperature thermal exposure.

METHODS

Two plates of DSS 2205 bearing composition given in table 1 were cut into the sizes of 200mm × 60mm ×10mm each and the edges of these plates were machined to a double V-groove with an included angle of 60^0. Fig. 1 shows the number as well as the sequence of weld passes that was used for welding.

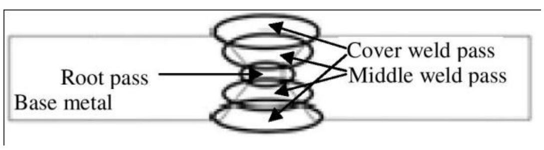

Figure 1: Schematic illustration showing the weld sequence and weld pass details

Root pass on the plates was made by GTAW process using 1.4mm diameter of ER2209 filler wire while the middle passes and cover passes on the plates were completed by the same process using ER2209 as the consumable filler wire of 2.4 mm in diameter. Thus welding on the plates was completed in total number of five passes (one root pass, two middle passes, and two cover passes). The welding parametric combination used for these welding is shown in Table 2. Two specimens from the welded plate were extracted. One was as-welded while the other was thermally aged at 850^0C for 45 minutes. These specimens were ground and polished with emery papers ranging in fineness from 100 up to 3000 equivalent meshes, and then polished with alumina suspension. Mean of three values of ferrite percentage on each specimen was determine at four different locations i.e. cover pass (CP), middle pass (MP), root pass (RP), and heat affected zone (HAZ). After determining their ferrite content, the specimens were 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 hot air.

SEM examination of the welds was carried out to study the metallurgical changes in these welds due to thermal aging. Finally, the XRD examination of these welded specimens was also done to determine the intermetallic phases formed during ferrite transformation that showed a significant loss.

Table 2. Welding conditions used for GTAW process

S No.	Parameters	Parameters
1	OCV	30 V
2	Welding current	165 A
3	Welding speed	20 cm/min
4	Argon gas flow rate	20 L/min
5	Welding position	Flat

RESULTS AND DISCUSSION

Metallurgical imbalance in DSS 2205 welds

Ferrite studies of the welds showed a significant variation of austenite-to-ferrite ratio which could be attributed to non-uniform heating as well as cooling of the welds. Further, since multipass welding was involved here each and every weld pass exerted it influence on the previously deposited weld pass thus created a fresh HAZ in the previous passes.

Microstructural development in DSS 2205 welds

Fig. 2 to 5 shows the SEM micrograph of different zones of these welds. For instance, Fig. 2 shows the microstructure of the unaffected base metal which comprises of ferrite and austenite phase. Fig. 3 shows the microstructure of the base metal under aging condition whereas austenite and ferrite show breaking of their respective long bands. Fig. 4 shows the microstructure of the weld zone in the as welded condition where ferrite transforms into Widmansttaten austenite [11]. However, when subjected to aging treatment ferrite changes into sigma phase as indicted in the figure.

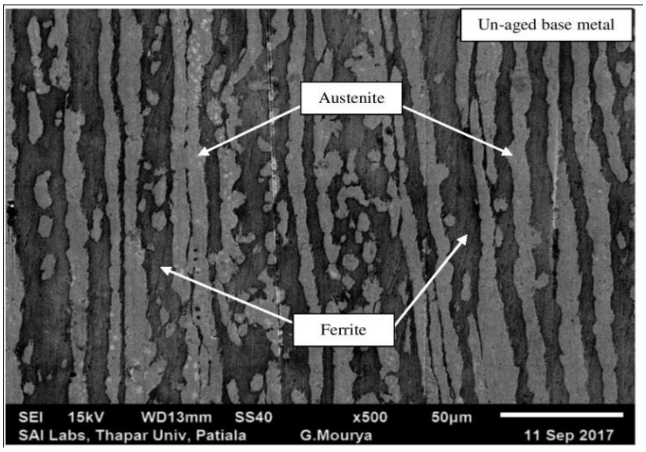

Figure 2: SEM micrograph of the base metal in the as received condition

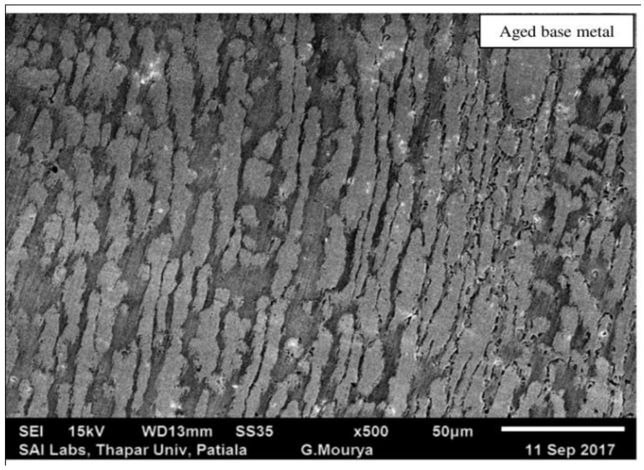

Figure 3: SEM micrograph of the base metal subjected to thermal aging

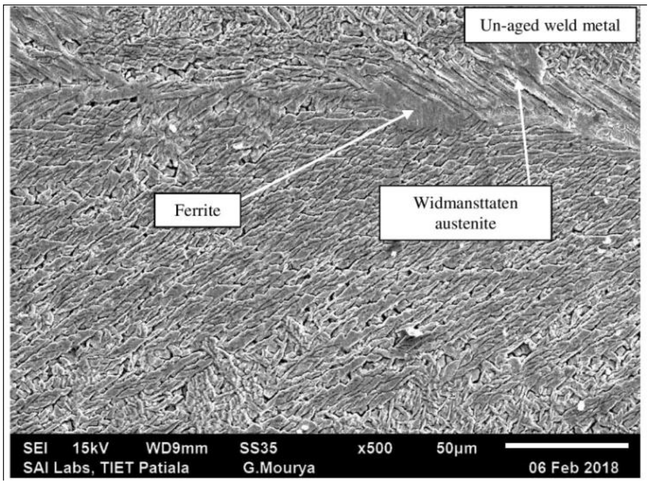

Figure 4: SEM micrograph of the weld metal in the as-welded condition

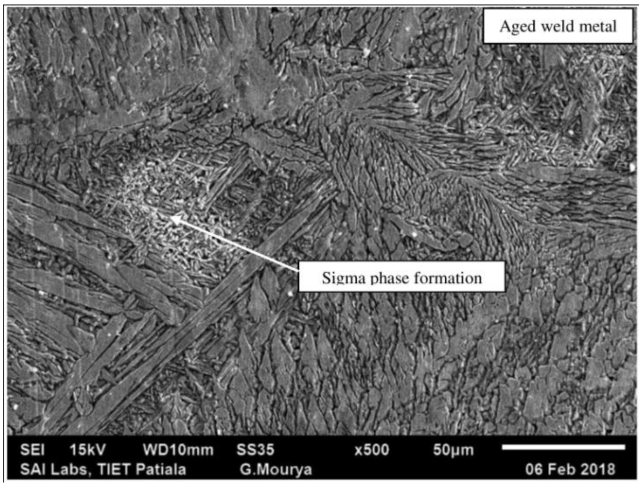

Figure 5: SEM micrograph of the weld metal subjected to thermal aging

Material Characterization of DSS 2205 welds using XRD examination

XRD results of these welds are shown in Fig.7 to 9 which show the presence of different peaks in the form of spectra. These peaks indicate the presence of different compounds. XRD result in Fig. 8 shows the compounds namely, of chromium and molybdenum ($Cr_{0.7}$ $Mo_{0.3}$) as well as nickel dioxide (NiO_2). Fig. 9 shows that due to aging carbides of the type Cr_7C_3, oxides of MnO and sulphides of Mn formed [12].

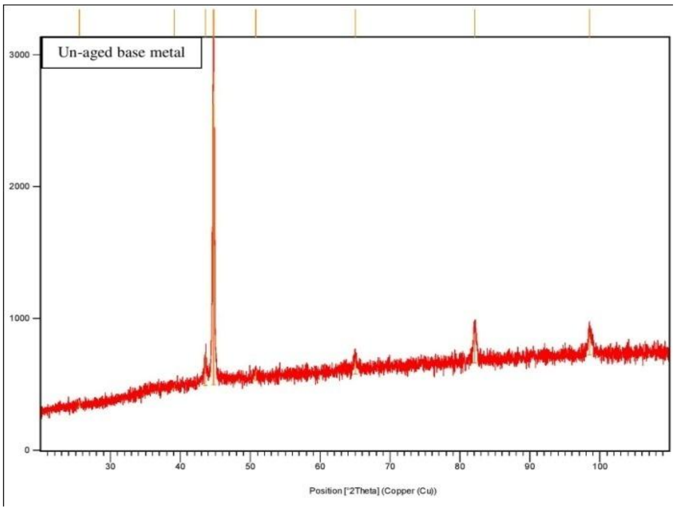

Figure 6: SEM micrograph of the base metal in the as received condition

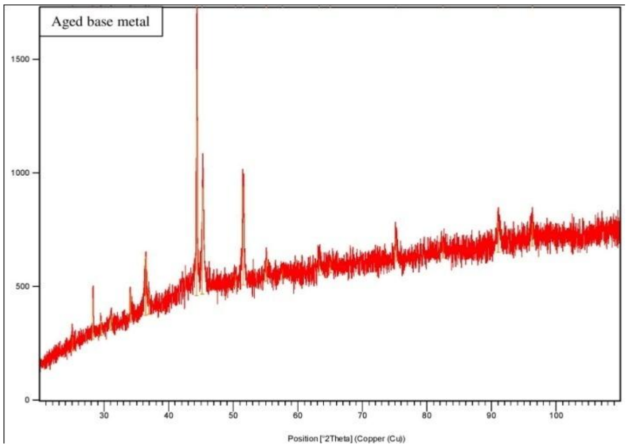

Figure 7: SEM micrograph of the base metal in the aging condition

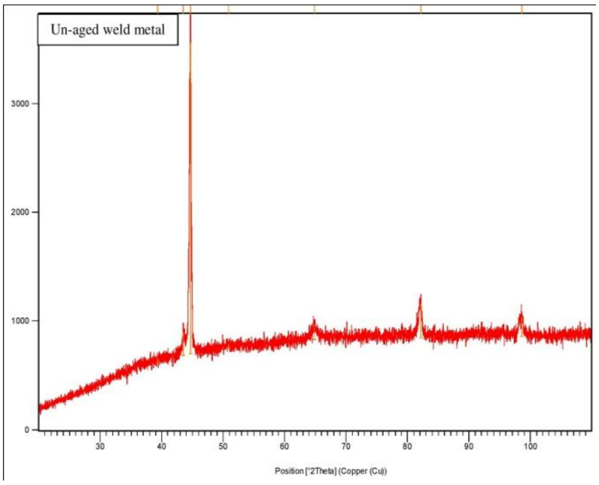

Figure 8: SEM micrograph of the weld metal in the as-welded condition

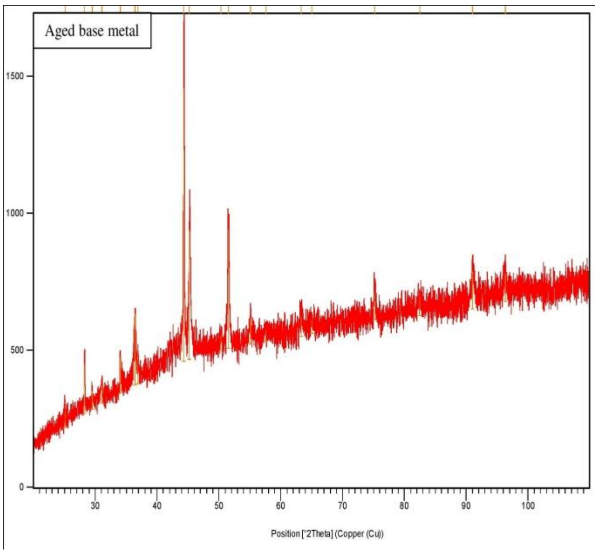

Figure 9: SEM micrograph of the weld metal subjected to thermal condition

CONCLUSIONS

1. Non-uniform heating and cooling in DSS 2205 welds resulted into a metallurgical imbalance of ferrite-austenite ratio which consequently affected its microstructural phases.
2. Post weld thermal aging treatment resulted into a significant ferrite dissolution which led to formation of intermetallic phases like oxide, carbides and sigma phase.
3. Sigma phase formation being rich in chromium and molybdenum can led to serious degradation of corrosion properties of these welds.
4. XRD results show that significant intermetallic precipitation occurs in these welds due to thermal aging which comprise of different carbides, oxides and sulphides.
5. The data generated through this research can be directly used by the welding and fabrication industries involved in the duplex stainless steel fabrication works.

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