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Investigation on microstructure and tensile properties of dissimilar weld joints between AISI 316l and duplex 2205 stainless steel

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Abstract. The present study investigates the dissimilar weld joints between AISI 316L and Duplex 2205 stainless steel. The joints were fabricated with the Pulsed current gas tungsten arc welding with ER316L and ER309L filler wire. The weld joints were subjected to metallurgical and mechanical characterization. The macro examination and optical microstructure examination were carried out to see the defect in the weld joints and structural changes in the fusion zone. The results show that the defect free welding was achieved in the both the filler wire. The optical microstructure shows the ferritic structure in both filler wire. The strength of the weld joints was tested with the tensile test. The results indicate the fracture occurred in the base metal in both cases.

Key word: Duplex 2205, Dissimilar Welding, Pulsed Current Gas Tungsten Arc Welding.

1. Introduction

Dissimilar Metal Welding (DMW) plays a major role in the industry due to economic benefits and better performance. DMW involves the joining of two dissimilar materials which have a different chemical composition, the coefficient of thermal expansion and melting point [1-3]. The welding of dissimilar metal is possible by conventional arc welding techniques such as Gas Tungsten Arc Welding (GTAW) and Gas Metal Arc welding (GMAW) techniques. The major challenging task involving during DMW is proper selection of filler material. Lippold and Kotecki reported that the improper selection of filler material in DMW leads to the formation of unwanted secondary phases, cracking in fusion zone and HAZ [4].

Stainless steel AIS 316L is a highly corrosion resistance steel widely used in many industrial fields, such as nuclear industry, power plants, and ship buildings [5-7]. Duplex Steel 2205 also a highly corrosion resistant steels widely used in oil and gas industries, high chloride and marine environment, nuclear industries and power plants. Both austenitic stainless steel and duplex stainless have received major attention in the industries due to excellent mechanical properties and excellent resistance to corrosion in a wide range of environment.

The major problem associated with the welding of austenitic stainless steel is hot cracking due to segregation of chromium carbide precipitates in the grain boundary. The presence of delta ferrite 3-20% could avoid the hot cracking susceptibility [8]. The presence of higher amount of delta ferrite also susceptible to hot cracking in the high temperature in the presence of σ phase transformation. Many literatures reported that control of heat input avoids the formation of micro segregation during solidification. Based on the foregoing literature pulsed current gas tungsten arc welding technique provides the solution to the microsegregation. Manikandan et al.[9-10] reported that welding of alloy C-276 by pulsed current mode resulted in reduced microsegregation and improved metallurgical and mechanical properties of the weld joint. Manikandan et al. [11] also reported that welding of alloy C-276 by CCGTA and PCGTA with ER2553 filler wire. Authors indicated that PCGTAW shows improved metallurgical property and mechanical property compared to CCGTAW. Devendranath Ramkumar et al. investigated the dissimilar welding between AISI 316L and Inconel 718. The authors concluded that the pulsed current gas tungsten arc welding obtained superior welding quality in terms of the absence of secondary phase precipitates.
It is evident from the literature that there is scope to investigate the DSW between the austenitic stainless steel AISI 316L and Duplex stainless steel 2205. These two alloys have very good corrosion resistance in the wide range of industrial application. The present study is to investigate the metallurgical and mechanical properties of weld joints fabricated with 316L and 309L filler wires in the PCGTAW mode.

2. Experimental Procedure

AISI 316L and Duplex 2205 procured in the form of 10 mm thick plate in the present study. The chemical composition of the base metals is listed in table 1. The plates were cut in the dimension of 150×55×10 mm (length, breadth, and thickness) with the help of electrical discharge machining (EDM) process. The plates were cleaned with acetone to remove the dirt and other unwanted contamination on the plate surface and edges. The edges are prepared with 60^{o} included angle with 2 mm root gap and landing. The filler wire employed in the present study are SS 316L and 309L. The chemical composition of the filler wire is also listed in Table 1. The joints were fabricated with the help of KEMPPI DWE AC/DC manual TIG Welding machine. Argon was used as a shielding gas with a flow rate of 10 L/min. Clamping was done properly to avoid the distortion during welding. Welding was done in Pulsed current mode.

Table 1. Chemical composition of Base Metal and Filler Wire

		Chemical Composition (Wt %)								
Sample	Material	C	Mn	P	S	Si	Cr	Ni	Mo	N
Base metal	Duplex 2205	0.03	2.0	0.03	0.02	1	21 - 23	4.5 - 6.5	2.5 - 3.5	0.20 - 0.80
	Austenite 316L	0.03	2.0	0.045	0.03	0.75	16 - 18	10 - 14	2.0 - 3.0	0.10
Filler Wires	ER316L	0.038	2.5	0.033	0.038	0.65	20.33	13.09	-	-
	ER309L	0.035	1.58	0.024	0.021	0.53	23.45	12.6	-	-

The process parameters employed in the present study are listed in Table 2. Metallurgical and mechanical characterization was carried out in the transverse cross section of the weld joints. In order to reveal the microstructure the samples were polished from 220 to 2000 SiC paper followed by 0.5µm alumina powder and water polish was carried out to obtain the mirror finish. Etching was performed by two methods (i) electrolysis by using oxalic acid and (ii) using a mixture of glycerol, nitric acid, and hydrochloric acid. Optical and Scanning electron microscope analysis was carried out to evaluate the microstructure of the weld joints in fusion zone, HAZ and base metals. The tensile test was carried out to assess the strength of the weld joints. The specimen was prepared and confirmed to ASTM E8 standard.

Table 2. Welding parameter of PCGTAW

Welding Type	Filler Wire	Electrode Diameter (mm)	Peck Current (Amps)	Backward Current (Amps)	Voltage (V)	Frequency (HZ)
PCGTAW	309L	2.4	326	160	13.5-14	6
	316L		326	160	13.5-14	6

3. Results and Discussion

3.1. Macro Examination

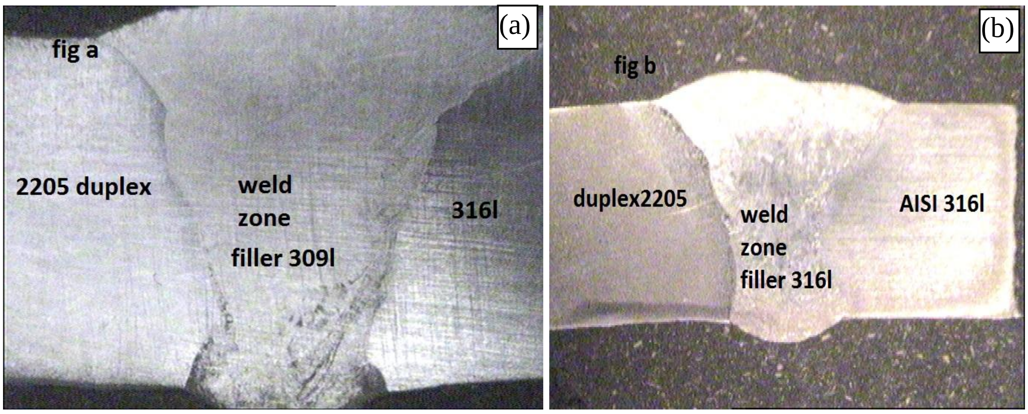

Figure 1. Marcograph of weld joints with (a) 316L filler wire (b) 309L filler wire

Figure 1 (a & b) shows the macrograph of DWM between AISI 316L and Duplex 2205 stainless steel with 316L and 309L filler wires. The micrographs show the steady fluid flow in the molten zone. There is no evidence for the weldment defects such as cracks, undercut and lack of penetration in the fusion zone. The macrograph confirmed that the process parameters employed in the present study to fabricate 4 mm thick plates of AISI 316L and Duplex 2205 are optimum.

3.2. *Microstructure Examination*

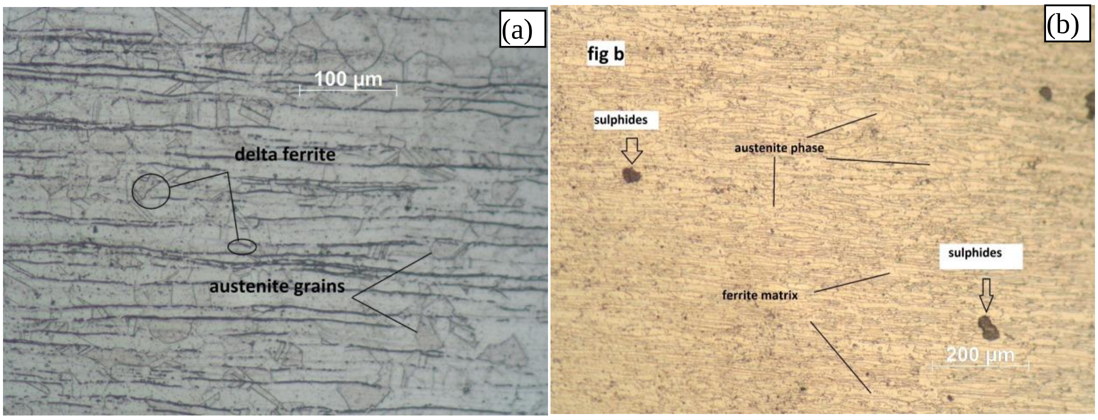

Figure 2. Base metal microstructure (a) AISI 316L and (b) Duplex 2205

Figure 2 (a & b) represents the base metal microstructures of AISI 316L and Duplex 2205 stainless steel. The base metal microstructure consists of austenite grain with the presence of delta ferrite (Fig. 1b). The microstructure of Duplex 2205 shows the presence of both ferrite and austenite phase.

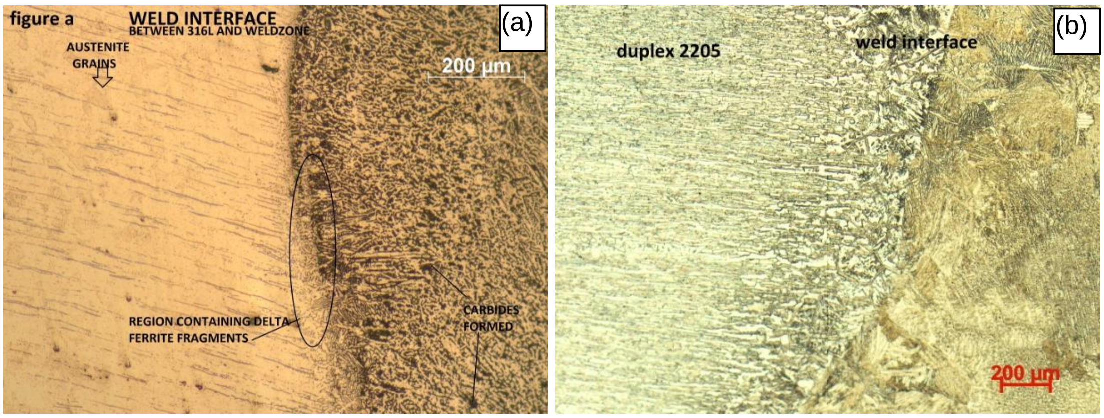

Figure 3. Weld interface region of joints fabricated with ER 316L (a) AISI 316 and (b) Duplex 2205

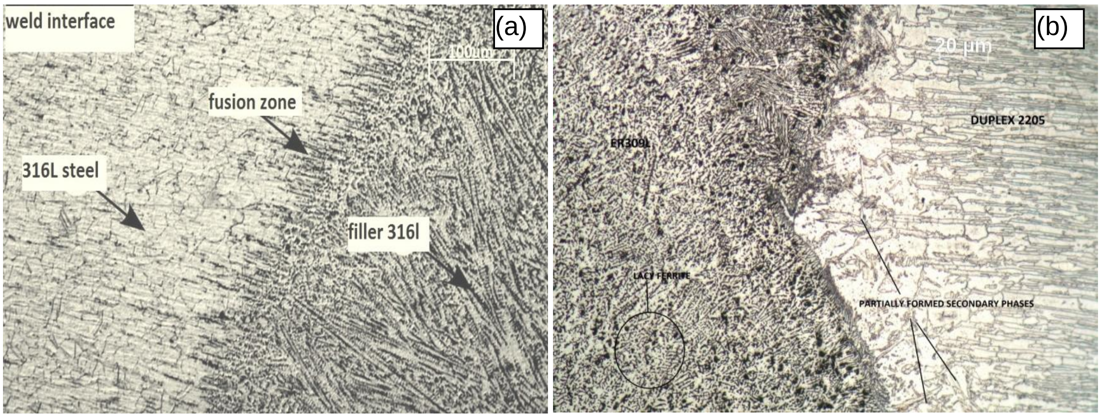

Figure 4. Weld interface region of joints fabricated with ER 309L (a) AISI 316 and (b) Duplex 2205

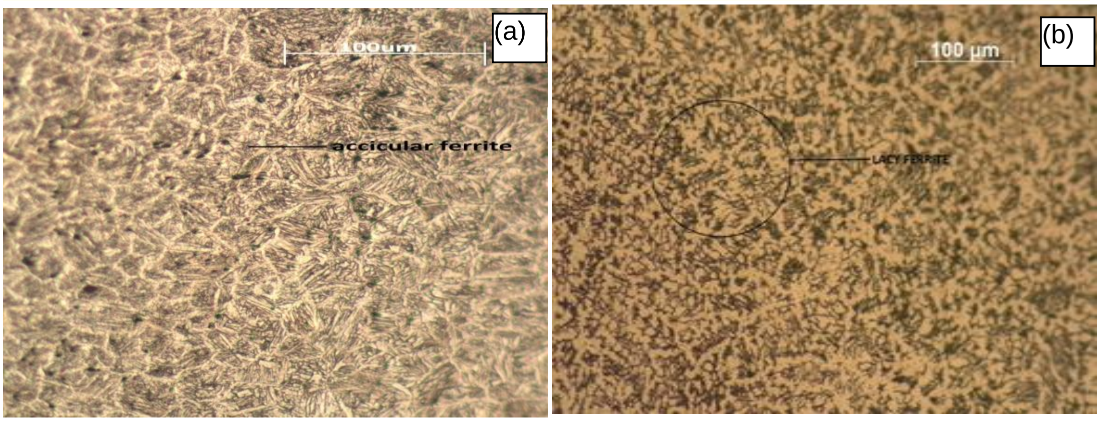

Figure 5. Fusion zone microstructure (a) ER 316L and (b) ER 309L

Figure 3 and 4 represent the microstructure of weld interface regions of ER 316L and ER 309L filler wires. It is observed from the weld interface regions, formation of delta ferrite is revealed. This could be due to phase transformation of austenite to ferrite due to slower cooling in the multi-pass welding. The presence of ferrite suppresses the hot cracking tendency in the HAZ regions of both filler wire. It is observed from the weld interface region that there no evident for the unmixed zone. It confirmed that the filler wire employed for the dissimilar combination is optimum.
Figure 5 represents the fusion zone microstructure of DWJ between AISI 316L and Duplex 2205. Figure 5a shows the microstructure of joint fabricated with ER316L and fig. 5b illustrates the filler wire ER309L. It is observed from the microstructure acicular and lacy ferrite occurred in the ER316L and ER309L filler wires. The formation of these phases is due to the cooling rate during solidification.

4. Mechanical property

Table 3 list the cumulative mechanical properties of the DWJ between AISI 316L and Duplex 2205 stainless steel. It is observed from the table ER316L shows the average tensile strength of 548 MPa and ER309L filler wire shows the 544 MPa. The base metal strength also gave the table for the comparison.

Table 3. Tensile property of the dissimilar weld joints

Material	Welding type	Filler material	Tensile strength (MPa)	Elongation (%)	Fracture zone
AISI 316L	-	-	515	55	-
Duplex 2205	-	-	621	25	-
Weldment	PCGTAW	316L	546	42.852	AISI 316L Parent metal
		316L	549	42.024	AISI 316L Parent metal
		309L	552	40.837	AISI 316L Parent metal
		309L	536	41.136	AISI 316L Parent metal

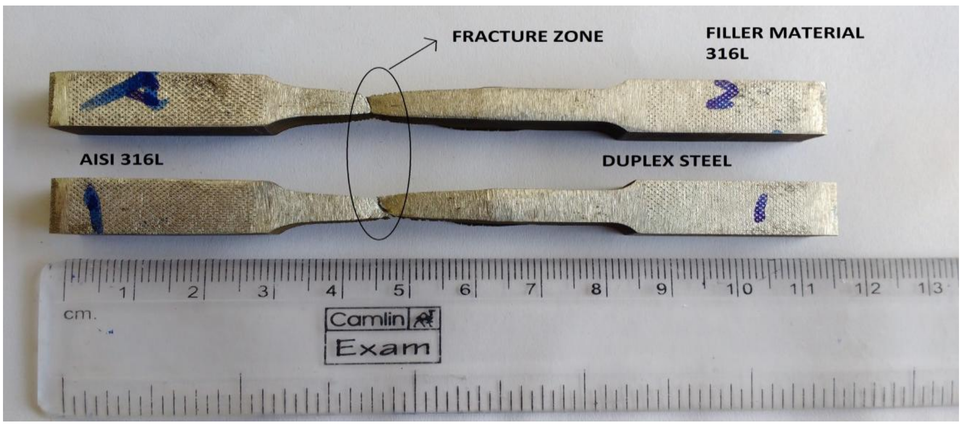

Figure 6. Tensile failure of weld joint fabricated with ER 316L filler wire

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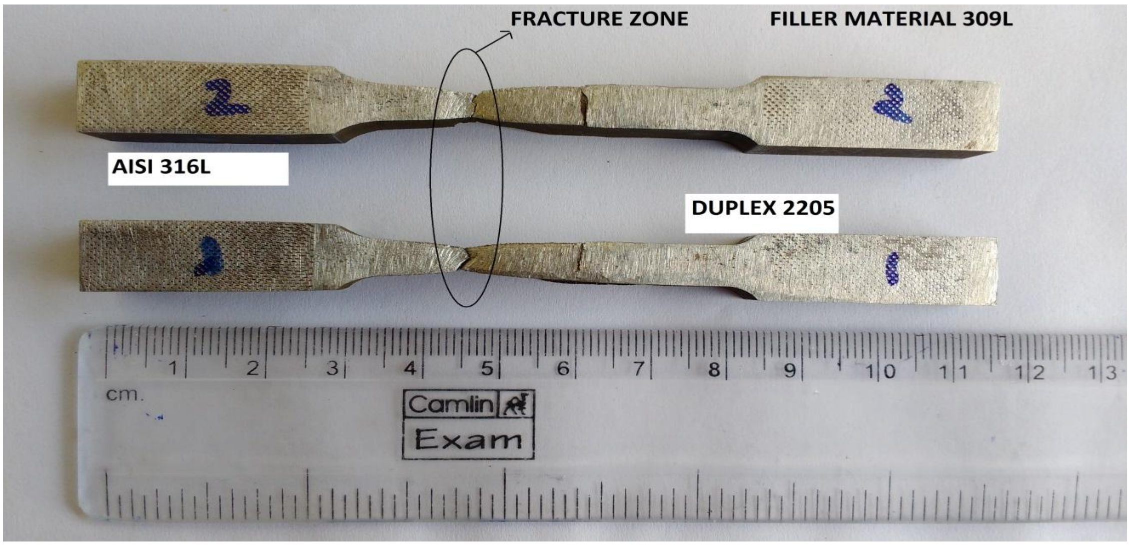

Figure 7. Tensile failure of weld joint fabricated with ER 309L filler wire

Figure 6 and 7 shows the tensile failure of DWJ fabricated with ER 316L and ER309L filler wire. It is observed from the both condition that the failure occurred in the base metal 316L. The present study confirmed that the filler wire employed in the present study is optimal to fabricate the dissimilar weld joint between AISI 316L and Duplex 2205 stainless steel.

5. Conclusion

1. Macro examination revealed that the defect free weld joints were fabricated with the ER316L and ER309L filler wire.
2. The macro examination also confirmed that the process parameters employed in the present study are optimum
3. The optical microstructure reveal the presence of ferrite phases in the both filler wires
4. Test confirmed the fracture occurred in the base metal in both filler wire.

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