Tensile and Impact Properties of AISI 304L Stainless Steel Welded Joints Using Austenitic and Duplex Stainless Steel Filler Metal

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Abstract

The aim of this work is to study tensile and impact properties of AISI 304L stainless steel using GTA welding with austenitic and duplex stainless steel filler metal. Rolled plates of 3mm thickness are used as the base material for preparing single "V" butt welded joints. Yield strength, Ultimate tensile strength, percentage of elongation and toughness across the weld has been reported. The tensile and impact properties of the welded joints have been evaluated using Electro mechanical controlled Universal Testing Machine and Pendulum type Impact Testing Machine. The welding microstructures, tensile, impact and fracture surface test results are analyzed using an optical microscopy, stress–displacement, load–displacement curves and SEM. Joints fabricated by duplex stainless steel filler metal shows higher ductility and impact toughness compared with the joints fabricated by austenitic stainless steel filler metal.

1. Introduction

Austenitic stainless steel is an attractive engineering material because of its outstanding properties. It is widely used as structural steel parts in chemical, mechanical, automotive and nuclear applications. The joining of these parts is often achieved by welding, and consequently, the favorable welding characteristics of 304L SS play an important role in its selection as the material of choice. It is recognized that 304L SS can be successfully welded using a variety of techniques, including Shielded Metal Arc Welding (SMAW), Gas Tungsten Arc Welding (GTAW), Submerged Arc Welding (SAW) and Plasma Arc Welding (PAW) [1-4]. The austenitic stainless steels are generally considered the easy weldable of stainless steels [5]. Because of their physical properties, their welding behavior may be considerably different than those of the ferritic, martensitic and duplex stainless steels [6].

GTAW process suitable for the fabrication process involves the joining of stainless steel components. However, the thermal effects associated with the welding process cause a structure to fail at its welded joints, and consequently a number of researchers have investigated the relative influences of the welding structure, the welding parameters, the nitrogen content, the number of welding passes and the solidification morphology on the mechanical properties of welded austenitic stainless steel joints [7-11]

Duplex stainless steels are found increased application in the chemical, oil and gas industries, petrochemical process plants, pulp and paper industry, pollution control equipment, transportation and for general engineering to their outstanding corrosion resistance and mechanical properties [12]. The high corrosion resistance and the excellent mechanical properties combination of duplex stainless steels can be explained by their chemical composition and balanced duplex microstructure of approximately equivalent volume fractions of ferrite and austenitic [13].

Most of the reported literature focused on different types of welding methods, heat input and welds bead, etc., Hence the present investigation is carried out to study the effect of austenitic and duplex stainless steel filler metal on mechanical properties, microstructure, stress-displacement and load-displacement variation of GTA welded austenitic stainless steel joints.

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2. Experimental

The examinations were carried out on austenitic stainless steel 304L rolled plate of about 100x10x3mm and 55x10x3mm size for tensile and impact tests. The feasibility of these experiments was progressed by the fabrication of the single 'V' butt joints; using GTA welding method, with the two steels: austenitic stainless steel (ASS) and duplex stainless steel (DSS) filler metal.

The chemical composition of base metal and filler metals used was evaluated by spectrographic analysis and is given in Table 1. Welding joint preparation was done by machining on both edges to make 'V' shape having inclined angle of 90^0. By using tack welding the joint position was obtained by securing the plates in flat position. Applying clamping devices were made to avoid joint distortion. The welding parameters used to fabricate the joints are given in Table 2.

Table 1: Chemical composition of base metal and weld metals (wt %).

Type	C	Mn	P	S	Si	Cr	Ni	Ti	Mo	Cu	Fe
Base Metal(AISI304L)	.020	1.470	0.044	0.006	0.436	18.31	8.00	0.003	0.155	0.356	Bal
Filler Metal(AISI308L)	.035	0.82	0.018	0.015	0.67	19.00	11.00	-	0.01	0.1	Bal
Filler Metal(AISI2209)	.030	1.50	0.018	0.016	0.90	23.0	9.50	-	3.00	-	Bal

Table 2: Welding parameters for Gas Tungsten Arc Welding process

Current (A)	Voltage (V)	Welding Speed (mm/sec)	Heat input (j/mm)	Electrode diameter (mm)	Shielding gas (%)	Shielding gas flow rate (lt/min)
90	14	1.4	900	2.0	99.99	10

Using power hacksaw the welded joints were machined to the required dimensions for preparing tensile and impact specimens as shown in Fig.1 and photographs as authenticated in Fig.2. Mechanical properties of GTA welded joints were evaluated by tensile and impact tests. Tensile testing was performed at room temperature using an electro mechanical controlled universal testing machine and impact testing was performed by using pendulum type impact testing machine. ASTM E8M-01 and ASTM E23-56T specifications were followed for preparing and testing the specimens. Hence the plate thickness is small, sub sized specimens were prepared for tensile and impact tests.

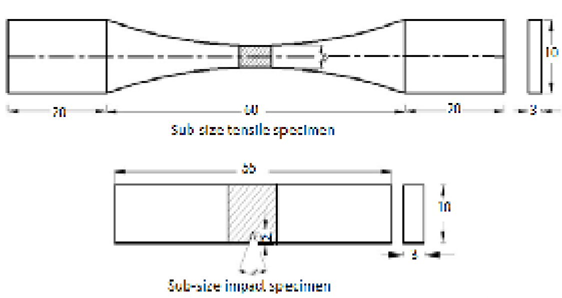


Fig.1: Dimensions of tensile test specimens

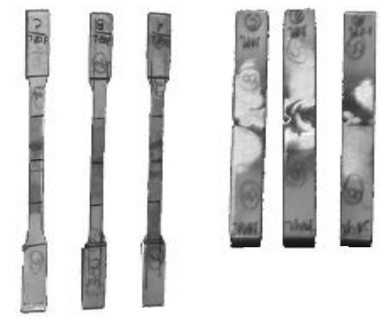


Fig 2: Photographs of tensile and impact test specimens

After mechanical deformation, the fractured specimens were prepared for metallographic observations. For the optical microscopy observations, the specimens were first mounted on metaserve DAP moulding powder and then ground with 400, 800 and 1200 series emery papers. Subsequently, the specimens were polished using a micro cloth with slurry of 0.3µm alumina and then etched in a solution of 33% HCL, 33% HNO_3 and 34% H_2O for one minute. Finally the specimens were observed by optical microscope.

3. Results and Discussion

3.1. Mechanical strength

The mechanical strength, including tensile strength, yield strength, percentage of elongation and toughness was measured from the test and the results are presented. From the above test three specimens were tested and the average of three results are presented in Table: 3. The findings prove that; Using electro mechanical controlled universal testing machine, gas tungsten arc welded joints using duplex stainless steel filler metal have higher strength values compared to gas tungsten arc welded joints using austenitic stainless steel filler metals. The strength value of GTADSS filler metal is approximately 9% compared to GTAASS filler metal.

Table 3: Tensile and Impact properties of base metal and welded joints.

Joint	Yield strength (Mpa)	Tensile strength (Mpa)	Peak Load (kN)	Elongation (%)	Max. displacement (mm)	Impact toughness (J)
BM	425	556	10.013	45.12	24.8	40
GTAASS	380	500	8.977	42.65	23.5	38
GTADSS	413	550	9.905	49.54	26.0	42

Figure 3.(a) plots both the stress and displacement curves from the tested specimens by

using GTAASS and GTADSS filler metals. From this graph it is observed that the GTADSS filler metal has higher strength value compared to GTAASS filler metal. Figure 3.(b) plots both load and displacement curves from the tested specimens by using GTASS and GTADSS filler metals. From this graph it is observed that the welded specimens GTADSS filler metal has higher strength compared to GTAASS filler metals.

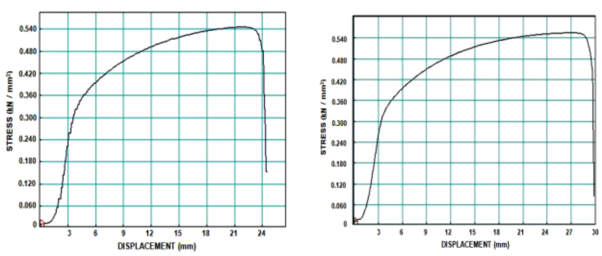


Fig.3.(a) Stress Vs Displacement Curves

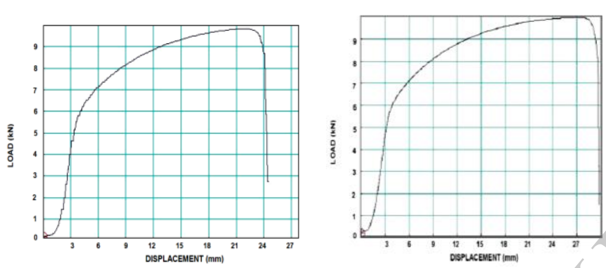
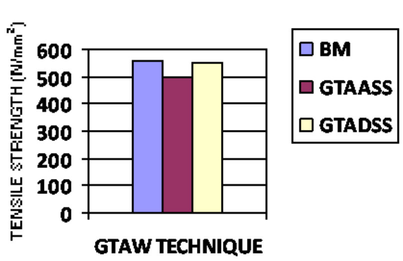
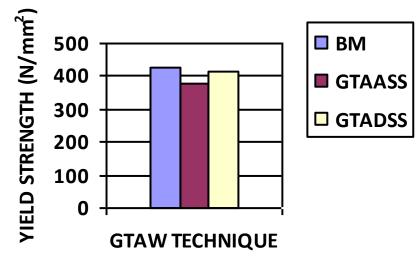
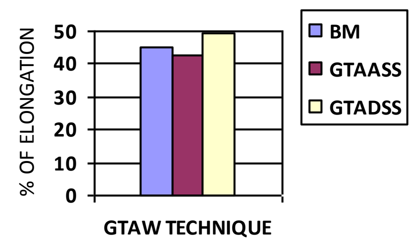


Fig.3.(b) Load Vs Displacement Curves

The impact properties by using pendulum type impact testing machine the charpy 'V'- notch impact test was carried out for weld metal. Gas tungsten arc welded joints using duplex stainless steel filler metal has higher charpy impact toughness values compared with the gas tungsten arc welded joints using austenitic stainless steel filler metals. The toughness value of DSS filler metal is approximately 11% compared to ASS filler metal.







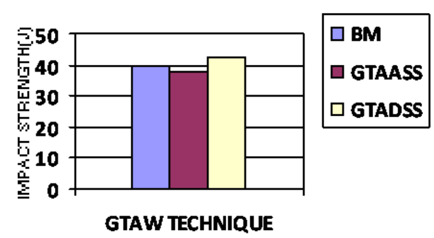


Fig 4 Bar diagram for Tensile Strength, Yield Strength, Percentage of Elongation and Impact Strength Using GTAW Technique

Figure 4 shows the bar diagram for tensile strength, yield strength, percentage of elongation and impact using GTAW technique for base metal, GTAASS and GTADSS filler metals. From the entire four bar diagrams the GTADSS (fabricated by duplex stainless steel filler metal) shows superior compared to GTAASS (fabricated by austenitic stainless steel filler metal).

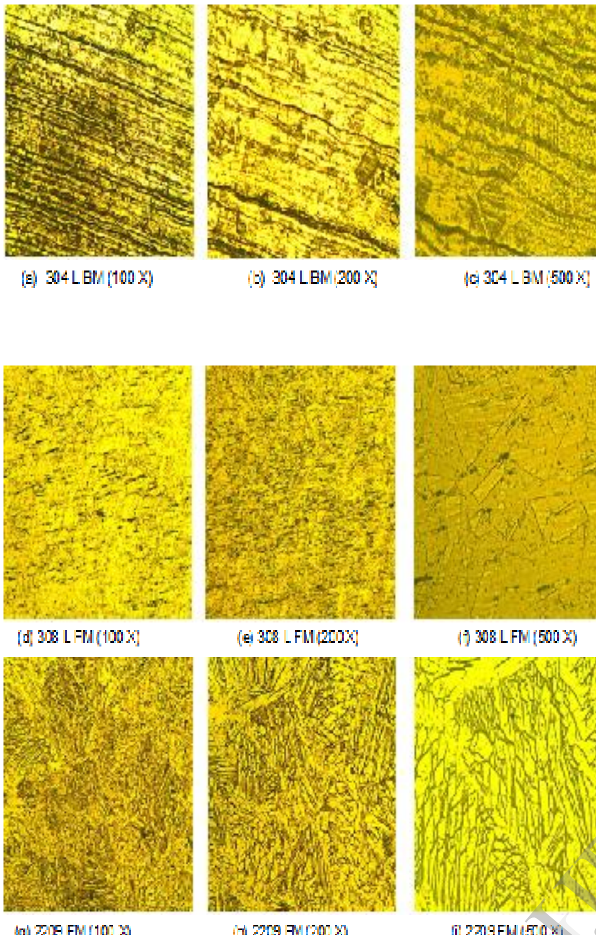


Fig. 5 Microstructure of the Investigated Materials.

From the above experimental results, it was understood that the tensile and impact properties (yield strength, tensile strength, percentage of elongation and toughness) are very much influenced by the filler metals used. From the two joints GTADSS joints are superior compared to GTAASS. The variation in tensile and impact properties of austenitic stainless steel joints is caused by the two important characteristics of weld metal. They are (a) chemical composition of the weld metal and (b) microstructure of the weld metal.

The formation of ferritic structure will enhance the tensile strength and subsequently increases the yield strength values. However, the formation of austenitic structure will enhance the percentage of elongation and subsequently increases the impact toughness values [14]. The formation of carbides such as chromium carbide and molybdenum carbide will also be beneficial to enhance the strength of stainless steels to some extent. But higher volume fraction of these carbides will lead to reduction in tensile strength and impact toughness values [15]. In GTAASS joints, due to the presence of less percentage of chromium, molybdenum and higher percentage of nickel content led to the reduction in strength and impact toughness properties. However, the formation of combined ferritic and austenitic structure in the weld metal region of GTADSS joint due to the presence of balanced percentage of chromium, molybdenum and nickel content led to the higher strength and impact properties.

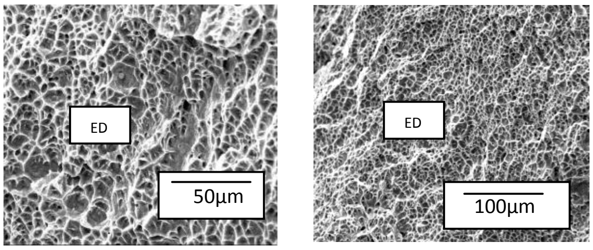
3.2 Microstructure

Fig.5 shows the microstructure of the investigated materials. Fig.5 (a), 5(b) and 5(c) presents the microstructure of the 304L base metal as received and treated condition. As can be seen the microstructure contains uniform grain distribution containing two micro constituents, namely ferrite (dark) and austenitic (light) with about 100X, 200X and 500X magnifications. The 304L GTA weld metals are shown in Fig.5(d), 5(e) and 5(f) using 308L filler metal they display dis- continuous network of vermicular ferrite structure. Figure 5(g), 5(h) and 5(i) presents the microstructure of the duplex stainless steel filler metal (2209) as received and treated condition. The microstructure contains a mixture of elongated and equiaxed grains with about 100X, 200X and 500X magnifications respectively. The duplex GTA weld metals display acicular ferritic structure. The main observation is that the joint fabricated by ASS filler metal contains solidified dendrite structure of austenitic, but the joint fabricated by DSS filler metal contains solidified austenitic structure in the ferritic matrix. Hence, the austenitic and ferritic fine grains shows the yield strength, tensile strength and impact toughness are more in GTADSS compared with GTAASS joints. This is also one of the reasons for superior higher strength of the GTADSS joints.

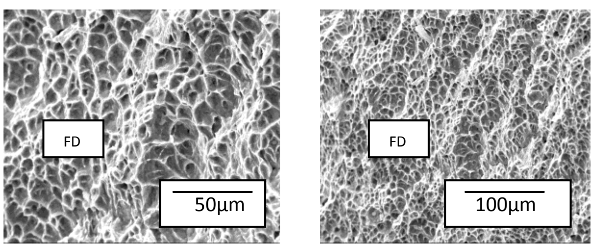
3.3 Fracture surface

The fractured surface of impact specimens of welded joints was analyzed by scanning electron microscope (SEM) to reveal the fracture surface morphology. Figure 6 displays the fractographs of impact specimens. The impact fracture surfaces of GTAASS joints (304L base metal with 308L filler metal) with about 50µm and 100µm respectively shows ductile fracture. The impact surfaces of GTADSS joints (304L base metal with 2209 filler metal) with about 50µm and 100µm respectively shows ductile fracture. The main difference exists in the size of the dimples between GTAASS and GTADSS joints. Elongated dimples are seen in GTAASS joints, whereas fine dimples are seen in GTADSS joints. Large numbers of fine dimples are seen in GTADSS joints compared to GTAASS joints.

Since fine dimples are a characteristics feature of ductile fracture, the GTADSS joints have shown higher ductility compared to GTAASS joints.



(a) GTAASS (304LBM-308FM)



(b) GTADSS (304LBM-2209FM)

Fig. 6 SEM fractographs of impact specimens.
(a) GTAASS (b) GTADSS.
FD-Fine dimples ; ED-Elongated dimples

4. Conclusions

From this investigation, the following important conclusions are derived:

- The yield strength, tensile strength, percentage of elongation, maximum displacement and impact toughness of austenitic stainless steel joints fabricated using duplex stainless steel filler metal are superior compared to the joints fabricated using austenitic stainless steel.
- Comparatively GTADSS endured 9% higher tensile strength and 11% higher toughness compared to GTAASS joints.

Acknowledgement

The authors are grateful to the Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar, Tamil Nadu, India for extending the facilities of Metal Joining Laboratory and Materials Testing Laboratory to carry out this investigation. The authors are indebted to Mr. S.Sisodia, DGM (Quality), Mr. T.Kalayana Sundaram, AGM (PAD) and Mr. P.Selvamani, Asst. Manager (SMS), Steel Authority of India limited, Salem, India for providing stainless steel plates for conducting the experiments successfully.

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