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Mechanical characterization of dissimilar welded joint of SS202 and SS304 by tungsten inert gas welding

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Abstract

The dissimilar weld joint is considered as one of the most commonly used fabrication methods in now a day. The most popular welding for dissimilar alloy is tungsten inert gas welding (TIG) in which inert and active gases are used. In this work SS202 and SS304 are used for welding. SS 202 has almost similar mechanical properties as compared to SS304 grade, but its ability to resist corrosion is somewhat less as compared to SS304 grade in chloride environment. These materials and their welding is used in nuclear reactor and pressure vessel where high temperature is used.
The object of this paper is to investigate the mechanical properties and microstructure analysis of welded joint between SS202 and SS304 with two different filler metal SS308L and SS316L by tungsten inert gas welding. Higher tensile strength was achieved with filler rod SS308L. The analysis confirms the well mixing of stainless steel and mild steel with filler rods inside the weld pool. The mechanical properties in terms of ultimate tensile strength found to be high as 488.61N/mm^2 with filler rod SS308L and micro hardness value at the center of the welded zone was found maximum (272.2 HV) with filler material SS308L, the fracture of the tensile test specimen were obtained outside and at the weldment of the weld zone.

Keywords: Tensile Strength, Micro-hardness, Microstructure, stainless steel

1. Introduction

Gas tungsten arc welding (GTAW) or tungsten inert gas (TIG) is an arc welding process that creates an arc between a non-consumable tungsten electrode and a welded workpiece. TIG is commonly used in railway vehicle construction, automotive and chemical industries. Stainless steel is used as an important material in the industry due to its excellent corrosion resistance. TIG is one of the welding processes and is commonly used to weld uniform and different stainless steel joints. It has been observed that most of the work is done on stainless steel, which is the most commonly used stainless steel in the world. Key areas of research are weld characterization, dissimilar metal welding, parameter optimization, process modeling, fault analysis and automation of the TIG welding process. GTAW welding is an arc welding process in which fusion energy is generated by burning between a workpiece and a tungsten electrode by an electric arc. The electrode and the weld pool are protected from the harmful effects of the atmosphere by an inert protective gas during the welding process. The shield passes through the gas nozzle to the gas weld zone where it replaces the atmosphere. TIG welding differs from other arc welding processes in that the electrodes are not used like electrodes like other processes such as MIG / MAG and MM. Stainless steel is widely used in the manufacture of sheet metal, especially in automotive, chemical and railway passenger cars, mainly due to its corrosion resistance and weight ratio. Stainless steel is a generic name that covers a group of metal alloys with a chromium content of more than 10.5% and a maximum carbon content of 1.2% (according to European standard N10088). It is usually include other elements such as nickel and molybdenum.

Failure analysis and literature investigations of diffusion welded joints have shown that a large number of failures have occurred in the heat affected zone (HAZ) [1]. They studied dissimilar metal welds made of low alloy steel, Inconel 82/182, and stainless steel prepared using gas tungsten arc welding and shielded metal arc welding. The microstructure was observed using an optical and electron microscope. A specific dendritic structure was observed

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in the Inconel 82/182 weld. Tensile tests were performed using standard and small size samples and micro hardness tests were performed to measure the difference in weld thickness and weld cross strength [2]. In many high temperature applications of energy conversion systems, metal joints between stainless steel and low carbon carbon steel are being analyzed. In steam power plants, the components of the boiler are subjected to low temperatures for economic reasons because the primary boiler tubes and heat exchangers are made of trivalent steel [3-4]. Several studies have been conducted on the welding of carbon steel and stainless steel because they may fail in bimetallic joints before reaching their design life [5-6]. They analyzed that the interfacial region between the weld metal and carbon steel was the highest risk zone in this joint. All of the austentic ferritic dissimilar alloy weld failure that have occurred in service [7-10]. They found that, by increasing the coefficient of thermal expansion of the composite component, the service life of the joint can be increased by reducing the magnitude of the cyclic thermal stress [11-14]. The method in this direction is to use a filler material in which there is a coefficient of thermal expansion (CTE) between carbon steel and stainless steel. These studies show that these joints generate large thermal stresses during temperature fluctuations due to differences in thermal expansion coefficients [15-16]. They investigate that carbon migration takes place from high temperatures ranges to low. It is also responsible for the failure of carbon migration bimetal weld joints [17-18]. They use the filler material SS 308 L. Weld filler SS 308L has the same structure as SS 308, with the exception of reducing the possibility of carbide precipitation between particles, the carbon content is kept at a maximum of 0.30%. The SS 308L is ideal for welding 304, 321 and 347 stainless steel. It is a wire for low temperature applications [19].

In steam power plants, the components of the boiler are subjected to low temperatures for economic reasons because the primary boiler tubes and heat exchangers are made of carbon steel. Other components, such as heaters, work on the final stage of the super heater and rework at high temperatures, where creep power and drag need to be increased, they are made of stainless steel [20].

The solidifications temperature for Al Alloy reduces and this is an important factor to consider which temperature the heat treatment not should exceed. When increase the silicon content then the melting point of aluminium alloy is decreases whereas fluidity was increases [21-22].

The Inconel-82 Buttering layer used in dissimilar welded joints can be used to reduce the residual stress in the HAZ of the trivalent steel. Therefore, reducing the butter will help to avoid/reduce the failure associated with the residual stress of one-twentieth of the welded joint [23]. They studied the mechanical properties of welded joints by friction stir welding, which depends to a large extent on the combined effects of the alloy and the processing parameters [24].

Stainless steel is an ideal material for explosion resistant structures because of its high strength, good energy absorption properties and high flexibility. The stress-stress curve in the plastic range ensures a high plastic resistance comparable to carbon steel. Compared with carbon steel, the strain sensitivity of stainless steel is more obvious, that is, compared with carbon steel, stainless steel can feel the same strength at a rapid tensile rate, especially 0.2% strain in the field in the past 20 years, The research program has sought guidance to develop these stretch rate effects in austenitic and duplex stainless steels as well as stainless steel designs in antiknock structures [25]. The ultimate tensile strength and hardness of steel increases by increasing the pre-stress, and ductility was decreases when thermal loading increases. For preventing brittle failure behavior of carbon steel the value of pre-stress and thermal stress should be low as possible [26]. Thermal cracking was observed in the BMW which was connected to the hot leg tube in the RPV nozzle. Hot leg tubes are large diameter, thick walled tubes. Typically, ferritic pressure vessel steel is joined to the stainless steel tube using a non-welded metal. Austenitic welds contain 4-10 volts of delta ferrite and fine dendrites, which can cause cracks, stresses and severe effects under the conditions of use [27]. The bimetallic joint stress could be reduced considerably by using a transition material Alloy 800H with an intermediate coefficient of thermal expansion between the 2-1/4 Cr-1Mo ferritic steel and the Type 316 austenitic stainless steel. Various filler metals corresponding to Types 309, 312, 347 and 16-8-2 were evaluated for joining alloy 800H to Type 316 stainless steel and their relative merits/demerits were highlighted. Weld ability studies showed that Type 16-8-2 weld metal was the least fissure sensitive while Type 347 was the most susceptible to hot cracking. Although Type 312 showed little cracking but it contained a relatively large amount of delta ferrite which could transform to sigma phases during high-temperature service [28]. The tensile strength of the joint is lower than that of the parent metal and it is directly proportional to the travel/ welding speed. Welding parameter such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints [29-33].

They proposed an improved tri-metallic transition metal configuration of austenitic stainless steel (SS 304)/ Alloy 800/ ferritic steel (2.25Cr-lMo). For the type 304 SS/Alloy 800 joint, a comparative evaluation of Inconel 182 and 16-8-2 welding consumables has been carried by the authors. 16-8-2 consumable was declared better over Inconel 182 for welding the joint between SS304 and Alloy 800 due to its various advantages which includes its lower tendency for micro fissuring along with the reduced mismatch in the coefficient of thermal expansion across the joint. Also the choice of 16-8-2 welding consumable, involve only a marginal penalty on the elevated temperature mechanical properties of the joint [34].

2. Material and Methods

Bimetallic parts are used in manufacturing of equipment to satisfy different functional requirements of material. Functional requirement of material are strength, corrosion resistance or heat resistance.

The objective of the present work is to investigate mechanical properties and microstructural analysis of welded joint between

SS202 and SS304 with two different filler metal SS308L and SS316L by tungsten inert gas welding.

Bimetal welded joints are widely used in large stainless steel and carbon steel in many high temperature applications of energy conversion systems. In steam power plants, the components of the boiler are subjected to low temperatures for economic reasons because the primary boiler tubes and heat exchangers are made of carbon steel. Other parts, such as super heaters and creep strength and anti-oxidation work on it.

The material used in pressure vessel and primary boiler are SS 202 and SS304. These steels were received in the form of rectangular block. In this work, SS308L and SS316L filler rod is used to welding stainless steel SS202 and SS304 as shown in figure 1. It is highly alloyed austenitic steel used for its good oxidation resistance, creep resistance and high temperature strength. The lower nickel content of SS 308L improves resistance to Sulphur attach at high temperature. It is ductile and tough and can be readily fabricated and machined. It is a suitable wire for application at cryogenic temperatures.

Chemical composition of base material and filler material are given in table 1 and 2 respectively and the Mechanical and physical properties of base and filler material as shown in table 3.

Figure 1: Tungsten inert gas welding during process

Table 1: Chemical composition of base material [13]

Type of Stainless steel	C	Mn	Si	Cr	Ni	P	S
SS202 (base material)	0.03	2.0	1.0	18.0-20.0	8.0-12.0	0.045	0.03
SS 304 (base material)	0.08	2.0	0.75	20.0	10.5	0.045	0.03

Table 2:- Chemical composition of Filler material [13]

Type of Stainless steel	C	Mn	Si	Cr	Ni	P	S
SS308 L (filler material)	0.03	2.0	1.0	19.0-21.0	10.0-12.0	0.045	0.03
SS316 L (filler material)	0.03	2.0	1.0	22.0-24.0	12.0- 15.0	0.045	0.03

Table 3:- Mechanical and physical properties of base and filler materials [13]

Type of steel	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)	Thermal coeff. (10^{-6}m/m°C)	Density (Mg/m^3)
SS202	510	275	207	17.2-18.4	7.8-8.0
SS304	515	280	207	17.2-18.4	7.8-8.0
308L	618	448-460	190-210	17.2-18.4	7.7-8.03
316L	584	434	190-210	15.0-17.2	7.7-8.03

3. Results and Discussions

3.1 Tensile test

The tensile test specimens were prepared with the help of ASTM E8 standard to evaluate the tensile properties of test specimen by universal testing machine at room temperature. The welded test specimens were prepared by the TIG operation. The V groove at angle $45^0$was created on the base plate and the filler rod (SS308L and SS316L) of diameter 3.2 mm were used followed by the TIG operation. Three specimens were made for each case and average value was taken. Fig. 2, shows the stress strain diagram of base material (SS-202 and SS304) and weldment with different filler material (SS308L and SS316L). The numerical data are presented as shown in table 4. The average maximum tensile stress was found 488.61 MPa for weldment of SS202 and SS304 with filler rod SS308L. Some failure were found within the weld zone whereas some fracture were found away from the weldment. Because of presence of substantial voids, fracture may happened in heat affected zone (HAZ), the tensile strength value of weldment with filler 308L was found higher than the other specimen. It was found that steels containing allowing element i.e. Ti and Si increased number of precipitates such that they improve ductility and ultimate strength. It can also be suggested that the weldment was stronger than the base material with higher grade filler material [53-54].

Fig. 3 and table 4 shows the comparatively analysis of tensile strength of base material and their weldment with different filler material at room temperature. It was found that the ductility of welded joint is reduced as compared to base material, whereas the tensile strength of weldment was greater than the base material.

Table 4: Mechanical properties of base materials and their weldment

Material	Specimen No	Stress (N/mm^2)	Mean Stress (N/mm^2)	Strain	Mean Strain
SS 202	1	438.96	443.51	0.407	0.402
	2	448.21		0.395	
	3	443.36		0.404	
SS 304	1	474.89	465.58	0.381	0.381
	2	458.52		0.369	
	3	463.34		0.394	
Weldment (Filler SS308 L)	1	484.89	488.61	0.391	0.396
	2	491.45		0.409	
	3	489.51		0.389	
Weldment (Filler SS316 L)	1	473.35	475.98	0.39	0.384
	2	478.9		0.398	
	3	475.7		0.364	

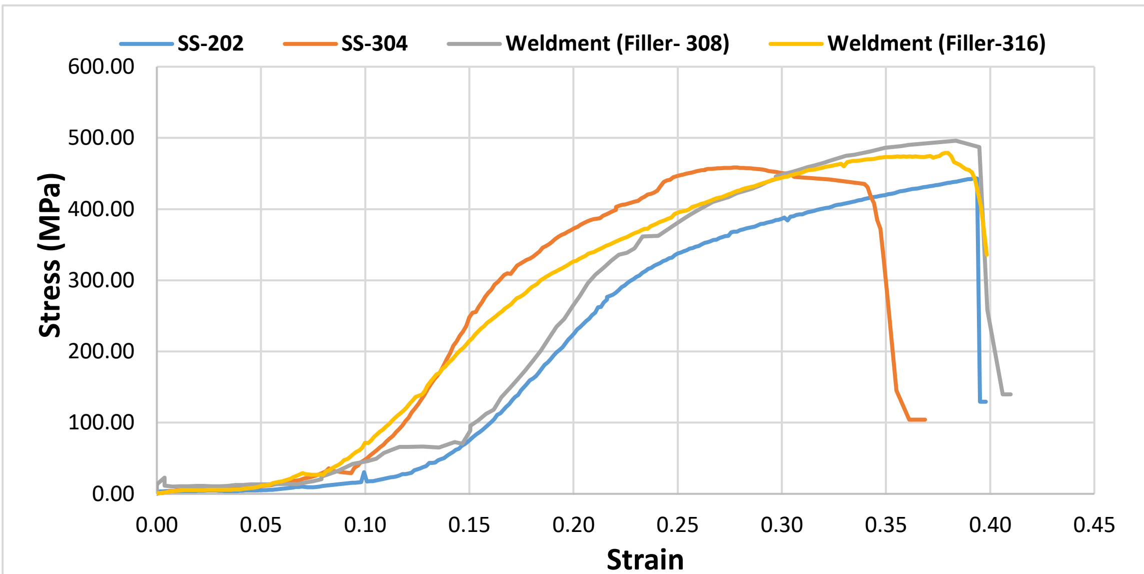


Figure 2: Comparison of Stress strain curve for base material and welded material

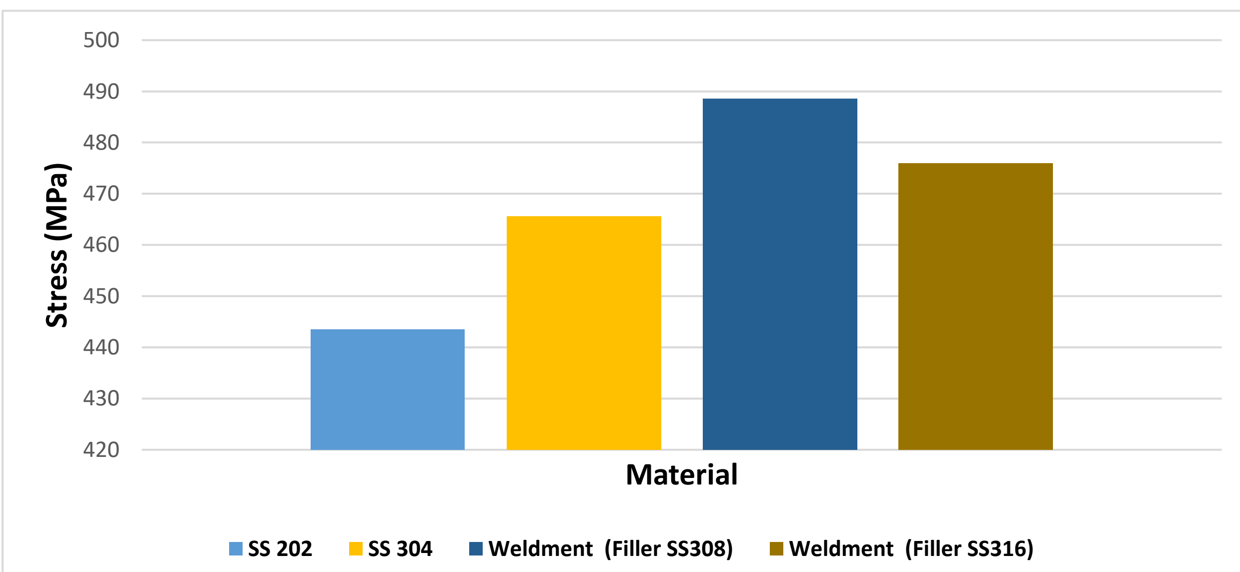


Figure 3: Comparison of Stresses of base material and welded joint by bar graph

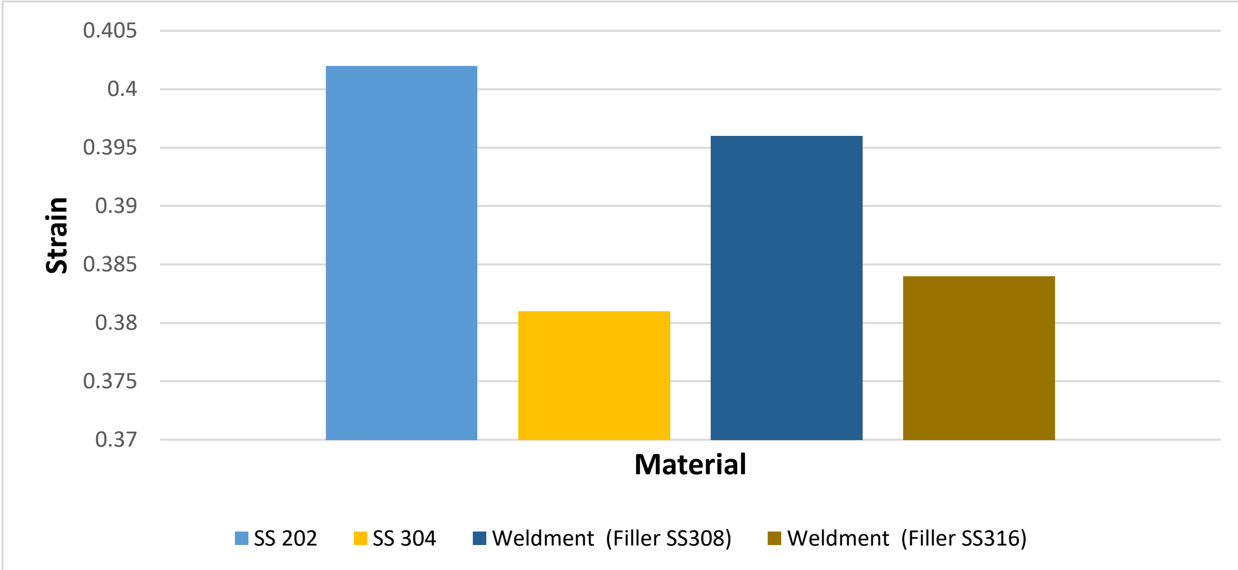
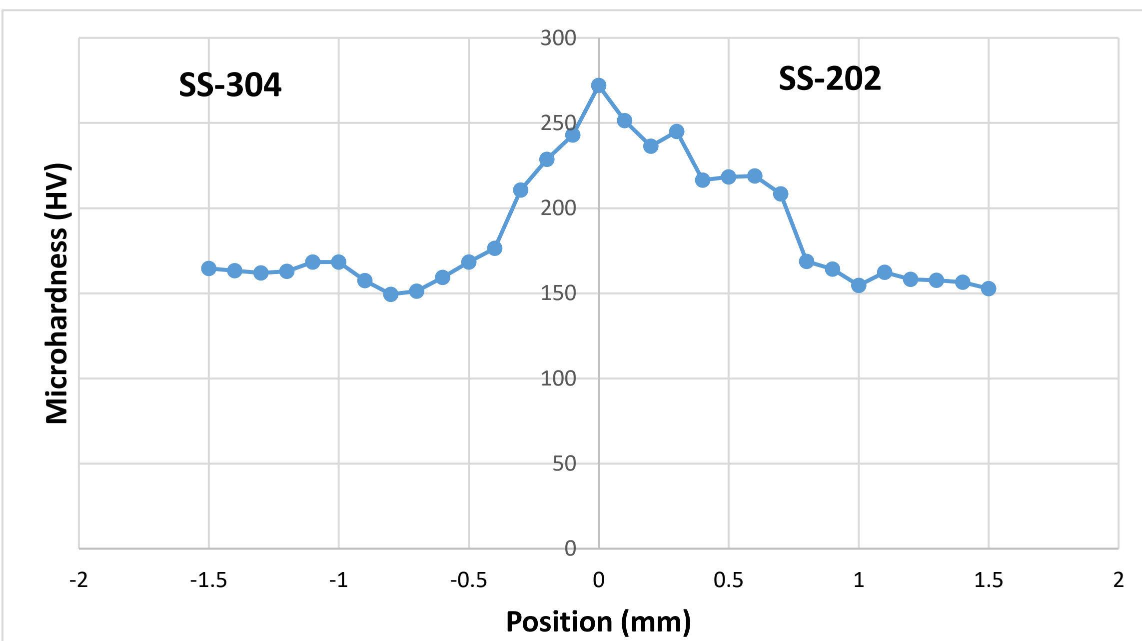


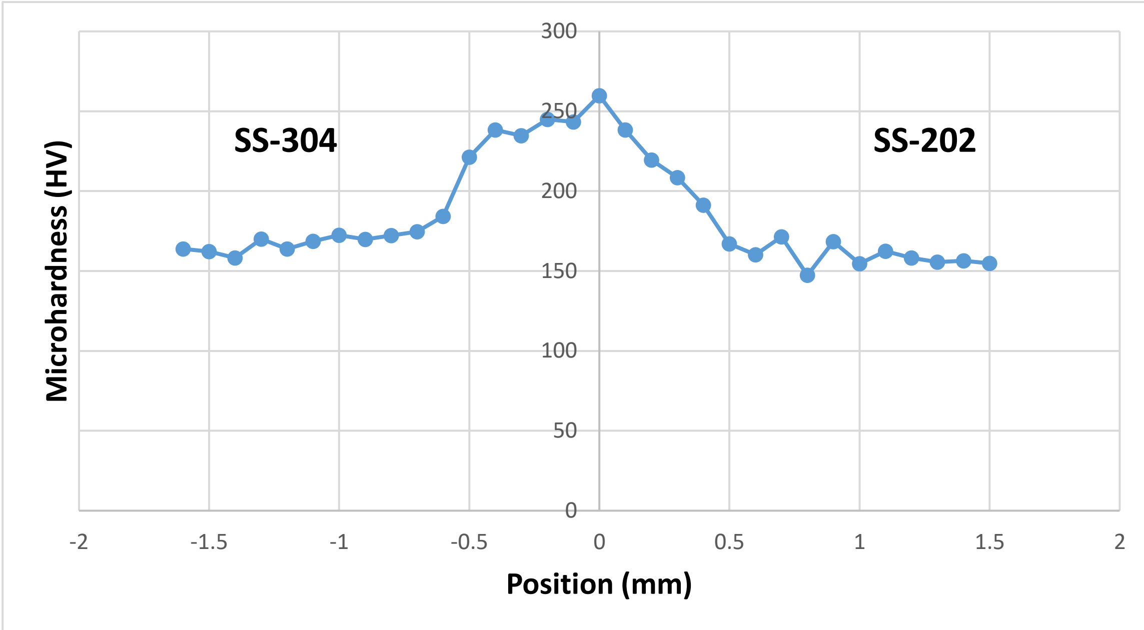
Figure 4: Comparison of Strain of base material and welded joint by bar graph

3.2 Microhardness

The micro-hardness of different weldment zone was evaluated by using a digital Vickers micro-hardness machine. Basically the range of micro-hardness of steel varies from 195-315HV. The micro-hardness are less momentous in affecting the mechanical properties of the material. The micro-hardness is indirect indication of tensile properties of the material. So its measurement and influences the strength values are conceded across the weldment of different zone. The processing parameter i.e. feed rate, current etc have more influencing factor over the hardness values [51]. The higher micro-hardness 272 HV was found at the center of weldment (SS-202 and SS304) with filler SS308 and lower micro-hardness 152 HV was found at the base material SS202.



(a)



(b)

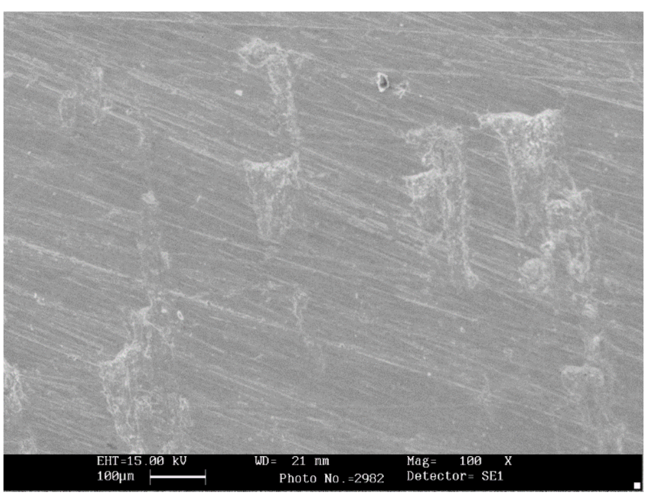
Figure 5: Variation of micro hardness across the cross section of the weldment, (a) Filler rod SS 308L, (b) Filler rod SS316L

The micro-hardness play an important role to recognize the metallurgical phase. All the major effects were identified in the bottom and middle of the weld zone. The failure point of the weldment is consisting with hardness distribution profile. The failure ensued in all joints along the lowest distribution region. Because of cooling rate and solidification of welded joint, the grain size and hardness were changes [52].

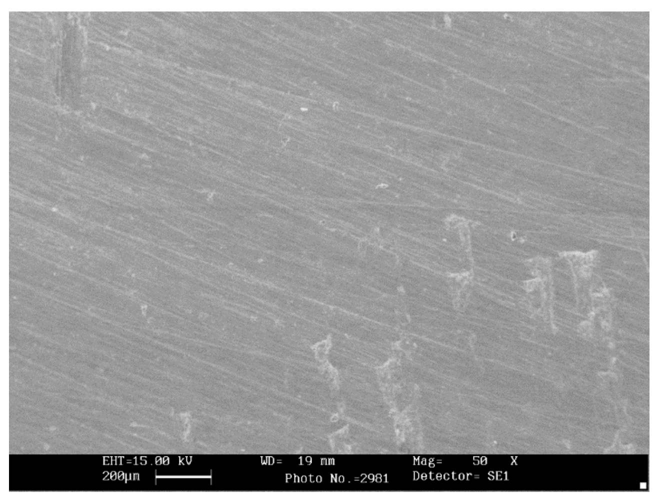
Hardness was found to be very high in heat affected zone (HAZ) of SS202 and SS304 weldment with filler material SS 308L i.e. 272 HV, whereas 259.8 HV micro-hardness was found with filler material SS 316L as shown in fig 4-5. The failure occurred in all joints along the lower hardness distribution region of SS202.

3.3 Microstructural Analysis

Stainless steel are commonly used in pressurized water reactor and boiling reactor designs, In order to check the microstructure of welded joint which is one of the most important mechanical properties as shown in fig 6-7.

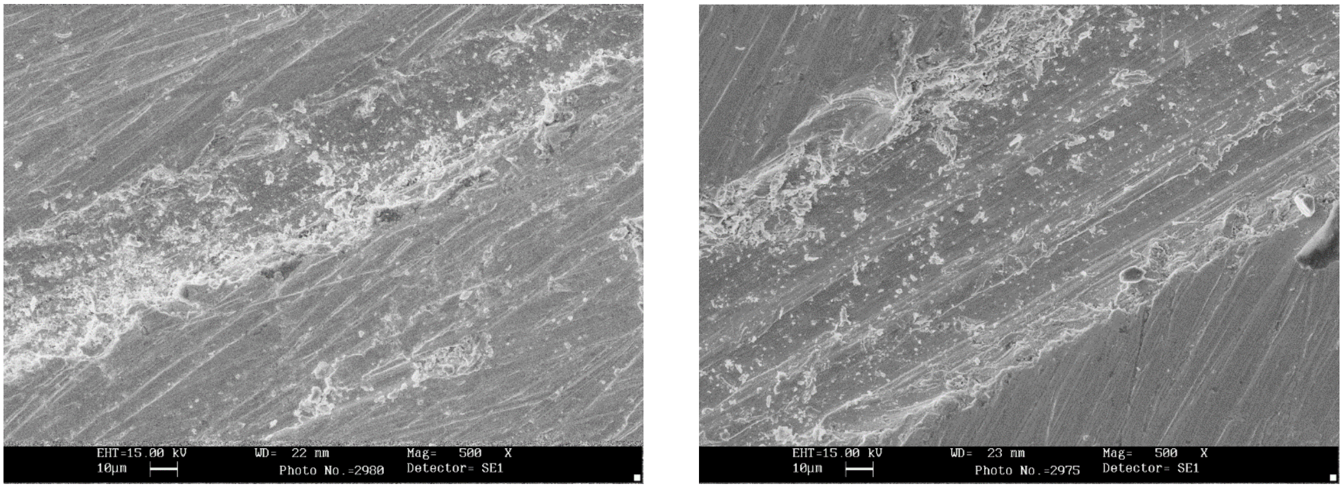


(a)



(b)

Figure 6: SEM images of base material (a) SS-202, (b) SS-304



(a) *(b)*

Figure 7: SEM images of welded joint with filler (a) SS308, (b) SS316

Variation of filler material (SS 308L and SS316L) and parent metal chemical composition lead to the thermal variation in weldment as well as solidification of weld metal. Slow cooling rate may reduce the interfacial energy between the austenite and ferrite, which result in formation of acicular ferrite [35-38]. Filler rod also play an important role in weldment of the metal and it is not possible to produce homogenous weld in fusion welding processes. The microstructure of weldment is influenced by the heat input, processing parameter and chemical composition of filler material. Generally, coarse grain in welded metal is obtained by higher heat input leads to slower cooling rate, whereas fine microstructure was obtained by the lower heat input leads to fast cooling rate [34].

4. Conclusions

Influences of the different filler rod on the mechanical properties of welded joint of stainless steel SS202 and SS304 by tungsten inert gas welding has been done, and the following conclusions can be made.

- Due to grain refinement and unique metal composition of welded joint fabricated by TIG process with filler SS308L exhibited higher strength value 488.61 MPa, whereas lower ultimate stress was found in base metal (SS202) i.e. 443.51 MPa.
- Due to proper fusion of filler metal with base micro-hardness value at the center of the welded zone was found maximum (272.2 HV) with filler material SS308L.
- At high welding speed, there is chance of welding defects and improper penetration of weld metal tales place. Welding defect like porosity can drastically affect the properties of welded joint
- Welding Strength or ultimate tensile strength of the welded joints of SS202 depends upon processing parameter and filler material.

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