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Influence of post weld heat treatments on residual stress and mechanical properties of dissimilar welded joint of SS304 and SS202

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Abstract

A stainless steel SS304 and SS202 was welded by tungsten inert gas welding (TIG) with filler SS316L. The post weld heat treatments (PWHT) at 850^0, 900^0C and 950^0C for different periods of time were performed in order to improve the mechanical properties of the welded joint. The tensile strength was increased after post weld heat treatment, and maximum tensile strength i.e. 535.42 MPa was found in post heat treated welded joint at 9500C, and maximum percentage elongation i.e. 18.86% was found at 9000C. A decreasing profile of micro-hardness was found from the base metal (BM) to welded joint. This decrease profile may occur due to absence of martensite phase in heat affected zone (HAZ). The micro-hardness values were increased at the center of the welded joint, when post weld heat treatment (PWHT) applied. The maximum hardness values i.e. 260 HV was observed in heat treated welded joint at 950^0C. The compressive residual stresses was found at the center of the welded joint because of thermal expansion and heat conduction in the heat affected zone. The residual stress decreases when post weld heat treatment temperature increased. The minimum compressive residual stress i.e. 17 MPa was found in heat treated welded joint at 950^0C.

Keywords: Post weld heat treatment (PWHT), Tensile Strength, Microhardness, Residual Stress.

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 work-piece. 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. The residual stresses and brittle fracture can be minimize by the post weld heat treatment to the welded steel structures. The advantages of the post weld heat treatment is that reduction of tensile residual stress in the weldment and also improved the welded joint efficiency [1]. Residual stresses present in the weld joint are one of the main factors, which cause failures in dissimilar weld joints. A typical dissimilar weld joint, representing a joint used in an Indian Fast Breeder Test Reactor (FBTR) was fabricated between 2.25Cr–1Mo ferritic steel and AISI type316 stainless steel with and without Inconel-82 buttering on the ferritic steel side. Residual stress profiles across these weld joints were determined using the X-ray diffraction (XRD) technique. The Inconel-82 buttering layer employed in the dissimilar weld joint is useful in reducing the residual stresses in the HAZ of the ferritic steel and thus the buttering will be beneficial to avoid/minimize residual stress related failures of dissimilar weld joints [2]. There have been several studies on the welding of carbon steels and stainless steels because the failure in bimetallic joints can occur before the components reach their design life [3]. 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 [4]. The bimetallic investigations on transition metal joints between chromium-molybdenum (Cr-Mo) ferritic steel and austenitic stainless steel widely used in the steam generators of power plants. The failure causes in bimetallic welded joint were occurs

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in Ni base metals instead of stainless steel. 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 [5]. 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 [6]. The bimetallic investigations on transition metal joints between chromium-molybdenum (Cr-Mo) ferritic steel and austenitic stainless steel widely used in the steam generators of power plants. The investigators highlighted the various failure causes of bimetallic joints using Ni-base weld metals and instead of austenitic SS weld metals. 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. Ultrasonic technique of evaluating residual stresses for any particular material is based on the measurement of changes in the velocity of ultrasonic waves due to stress after establishing the acousto-elastic constant (AEC) for that material. A-TIG weld joints have been reported to exhibit lower residual stresses compared to weld joints made by conventional TIG welding process [7-8]. The grain size measurements were made at the heat affected zone (HAZ) of the weld joints. The HAZ of the A-TIG weld joint exhibited a coarse grain size of 59µm whereas the HAZ of the TIG weld joint exhibited a grain size of 38µm. Therefore, A-TIG weld joint exhibited a coarser grain size by 1.5 times compared to that of the TIG weld joint due to higher peak temperature during welding caused by intense heat source [9]. Coarser grain size and lower ferrite content enhance the creep rupture life of the 316 LN stainless steel and so best suited for high temperature applications [10]. Distortion in a welded structure is the result of the non-uniform expansion and contraction of the weld and surrounding base material, caused by the heating and cooling cycle during welding process. Welding distortion has negative effects on the accuracy assembly, external appearance, and various strengths of the welded structures. In many cases, additional costs and schedule delays are incurred from straightening welding distortion. On the other hand, increasingly, the design of engineering components and structures relies on the achievement of small tolerance. For these reasons, measurement and control of welding deformation have become of critical importance. A-TIG welding process has been reported to produce stainless steel weld joints with reduced distortion [11]. The mechanical properties of reheated, quenched and tempered (RQT) HSS plate manufactured to grade S690 at elevated temperatures as well as its residual strength after heating and cooling down. It is found out that while RQT-S690 HSS showed good resistance to low temperature (below 400°C) heating, serious deterioration in strength would occur at higher temperatures and its post-fire mechanical properties are different from those of traditional hot-rolled normal strength steels [12]. The ultimate tensile strength of the welded joint is higher than the parent material and it is directly proportional to the welding speed, welding parameter such as tool rotation, transverse speed and axial force is also effect the welded joint in friction stir welding, fine grains structure could be achieved by the variation/ controlling of processing parameter [13-17]. Different regions of weldment like base metal, HAZ and weld metal to compare and analyze the results obtained in as-welded and different heat treatments from transverse Tensile testing of weldment and base metal, Charpy-V-Notch Impact toughness test. From this mechanical properties investigations it was concluded that there was a significant improvement in the mechanical and Microstructural properties with the PWHT and the best suitable heat treatment time was proposed to get the desired properties in the structures for the industrial applications. Microstructural changes were observed during different post weld heat treatments and their effect on mechanical properties were observed [18]. A reduced temperature with longer holding time may lead to the same heat treatment result of a higher temperature with shorter holding time. Note that even the reduced 600^0C holding temperature is not a safe limit for heat treating for weldment since it is proven that maintaining at 600^0C for just 10 min would be enough to introduce noticeable changes to the mechanical properties of base metal [19]. 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 [20]. The effect of post-weld heat treatment (PWHT) on the reheated, quenched and tempered (RQT) grade S690 high strength steel welded connections. Firstly, the effect of PWHT on the mechanical properties after welding is investigated. It is found that the loss of both strength and ductility after welding could be serious but PWHT could be able to improve the ductility of the affected specimens at the expense of strength. The hole drilling tests employed to study the residual stress reveal that PWHT is able to decrease the residual stress level near the weld toe significantly. The tensile test results show that proper PWHT could improve both the ductility and the maximum resistance while the reduction of plastic resistance can be kept in a negligible level. However, it is found that if the specimens are overheated, although the ductility could still be increased, the reduction of load carrying capacity was severe [21]. The bimetallic 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 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 [22]. The hardness and ultimate tensile strength of bimetallic weld joint was increases by increasing the pre-stresses, and by increasing the thermal loading ductility was decreases. To avoid the brittle failure of carbon steel, the value of thermal stress and pre stress should take low as possible. At plastic range, the shape of stress strain curve of stainless steel is higher than the carbon steel [23-25].

2. Materials and Methods

Both SS304 and SS202 stainless steel plates of 22 mm thickness was available in the market. A single v groove of an angle 45 degree was made between these two plates. The stainless steel SS202 and SS304 plates were fully machined then after applying welding with filler rod it is again machined to obtain the required geometry. The schematic diagram of welded joint is shown in fig.1.

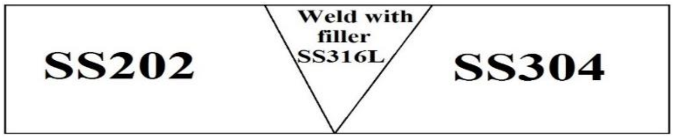


Figure 1: Schematic representation of weldment

Table 1: Welding parameters

Type	Current (A)	Voltage (V)	Wire feed (mm/mint)
Welding	175	21	42

The shielding gas was used commercially available argon 99.97 and a gas flow rate of 10 liters/min was selected after the test plate was taken, the processing parameter of TIG welding as shown in table 1. This particular price was chosen because good weld properties were obtained at this gas flow rate. The rate of feeding into the weld was 4 cm/min. The tensile testing was performed on ASTM E8 standard samples to evaluate the mechanical properties of different welds as shown in fig.2. In all cases, the failure occurred in the welded joint. Before the fracture, Welds produced a large amount of plastic deformation in the ductile failure mode.

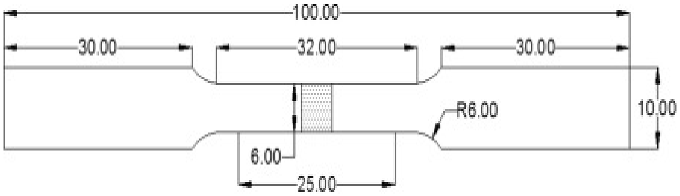


Figure 2: ASTM E8 standard test specimen

The tensile test specimens were placed in baffle furnace for 1 hour for post weld heat treated at temperature 850^0, 900^{0}C and 950^{0}C and then found mechanical properties of PWHT specimens as shown in fig.3. The Chemical composition of base metal and filler rod are given in table 2. Mechanical and physical properties of various stainless steels are given in table 3.

Figure 1: Specimen after heat treatment

Table 2: Chemical composition of Stainless steel [1]

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
SS304 (base material)	0.08	2.0	0.75	18-20	8-10.5	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 SS 202, 304 and filler rod [1]

Type of steel	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)	Thermal coeff. (10^{-6}m/m°C)	Density (Mg/m^3)
SS202	515	205	207	17.2-18.4	7.8-8.0
304	575	295	190-210	17.2-18.4	7.7-8.03
316L	644	489	190-210	15.0-17.2	7.7-8.03

3. Results and Discussion

3.1 Tensile strength

The tensile strength was evaluated with the help of computer operated universal testing machine (UTM) at room temperature. This test were conducted on three sample for each case as per ASTM E8 standard. To minimize the machining error, three specimens were fabricated for each case. The dimension and drawing of tensile sub test specimen as per ASTM standard E8 is shown in fig.2. The fabricated tensile test specimen were subjected to test and ultimate tensile strength and percentage elongation were evaluated. After welding, the heat treatment process have been done. The tensile test specimens were placed in baffle furnace for 1 hour for post weld heat treated at temperature 850^0, 900^{0}C and 950^{0}C and then found mechanical properties of PWHT specimens. During tensile test, the load was increased till specimen fractured. The yield point was also observed during testing and both stress and strain were read off from the computer which is attached to the universal testing machine. The results of the tensile test for different samples are shown in table 6 and fig.4. In this figure, the highest tensile strength i.e. 535.42 MPa was found in the heat treated sample at 950^0C whereas highest percentage strain i.e. 18.86 was found in the heat treated sample at 900^0C. The tensile test results shows that dissolving precipitates and decreasing the ferrite matrix grains leading to increase the tensile strength of the welded joint.

Table 2: Mechanical properties of SS 202-SS304 weldment and heat treated weldment

Material	Mean tensile Stress (N/mm^2)	Mean Strain (%)	Residual Stress at weld center (N/mm^2)	Micro-hardness at weld center
SS 202-SS304 with filler SS316L	467.88	15.52	41	202
Heat treated with 850^0C temperature	513.14	17.44	39	230
Heat treated with 900^0C temperature	527.82	18.86	25	256
Heat treated with 950^0C temperature	535.42	16.95	17	260

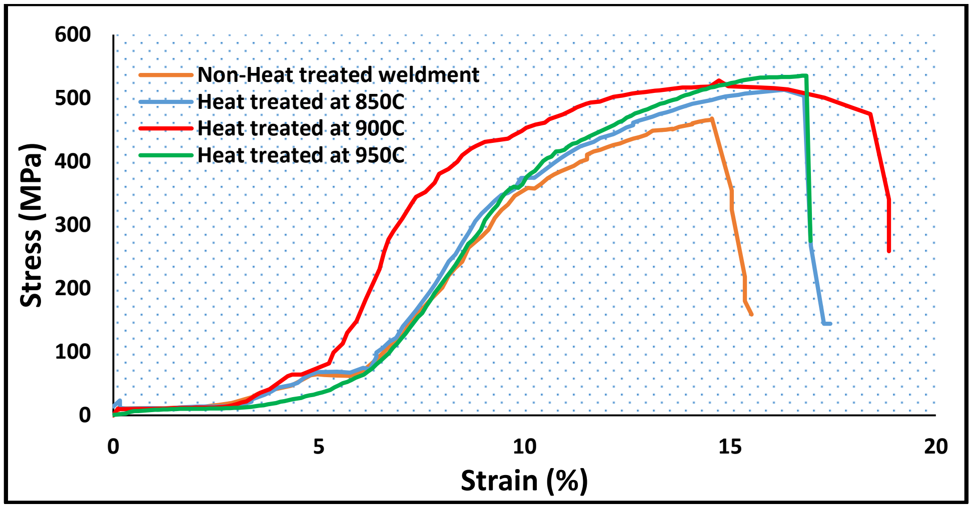


Figure 4: Comparison of stress strain diagram of non-heat treated and heat treated weldment

Due to improvement of size distribution of martensitic zone with decreasing the ferrite grain size, the mechanical properties of weldment increases [26-27]. The fraction percentage elongation after heat treatment increased from 17.44 % to 18.86% whereas the tensile strength values after heat treatment increased from 513.14 MPa to 535.42 MPa.After heat treatment, the tensile strength of fusion zone was increased because of carbides precipitating along the grain boundaries. Considering the weld metal (WM), the orientation of grains give the higher tensile strength in the traverse direction of the welded joint [28].

3.2 X-ray diffraction (XRD)

The X-ray diffraction (XRD) of welded joint of SS202 and SS304 with filler wire SS316L as shown in fig.5. In this XRD pattern the sharp peak of austenite was found in the welded joint. There are two other peaks Cr_7C_3 and Cr_3Si that indicate the presence of secondary phases in the welded joint. A small amount of δ ferrite is required to avoid the problem of hot cracking during weld solidification [29].

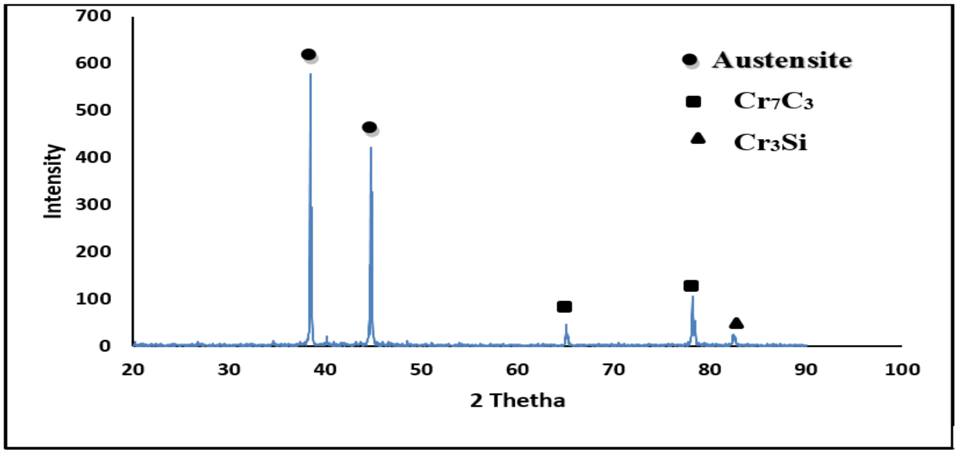


Figure 5: X-ray diffraction of welded joint

3.3 Microhardness

After the welding operation of SS202 and SS304 with filler rod SS316L, and normalizing heat treatment of butt welded joint with various temperature (850^0, 900^0, and 950^0C) the micro-hardness values were evaluated for each case. Thirty one hardness values were taken from each specimen to investigate the micro-hardness changes from the welded joint to base metal. The micro-hardness variation for each case as shown in fig.6. The micro-hardness values are less significant in affecting the mechanical properties of the material, because processing parameter and feed rate have more influencing factor over the hardness values [30]. The micro-hardness value near the top surface shows a comparatively smoother transition. All the major effect was detected in the middle and bottom of the weldment. Because of changing in solidification sequence and cooling rate of weldment, the grain size and micro-hardness number were changes. The micro-hardness number also play a very important role to recognizing the metallurgical phase [31]. Decrease in micro-hardness was observed from the base metal (BM) to weldment, due to absence of martensite phase in heat affected zone (HAZ), the micro-hardness profile shows the decrement from the base metal to weldment. After the normalizing heat treatment the micro-hardness values increases from 202 HV to 260 HV. And the maximum hardness value i.e. 260HV found in heat treated sample at 950^0C as shown in fig.7.

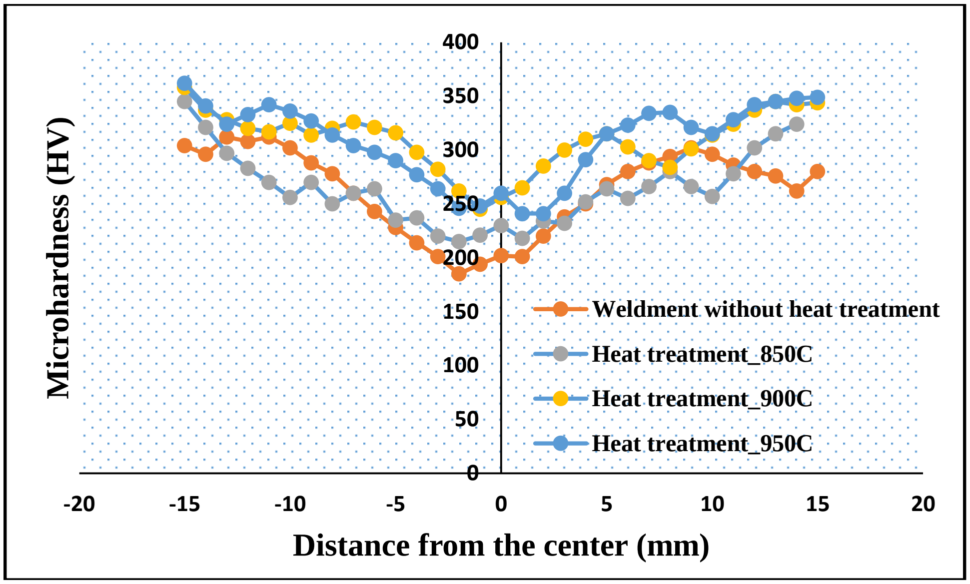


Figure 6: Comparison of micro-hardness of non-heat treated and heat treated weldment

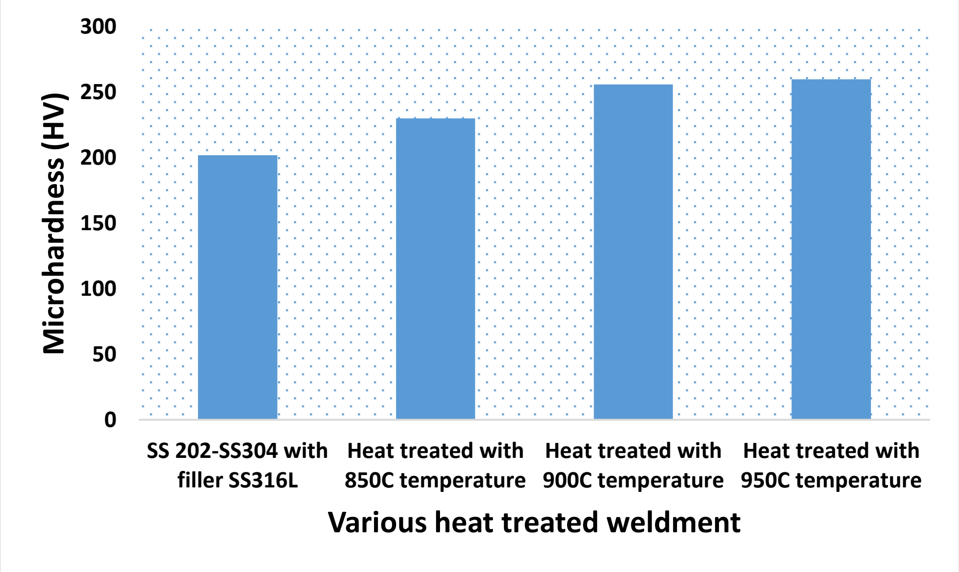
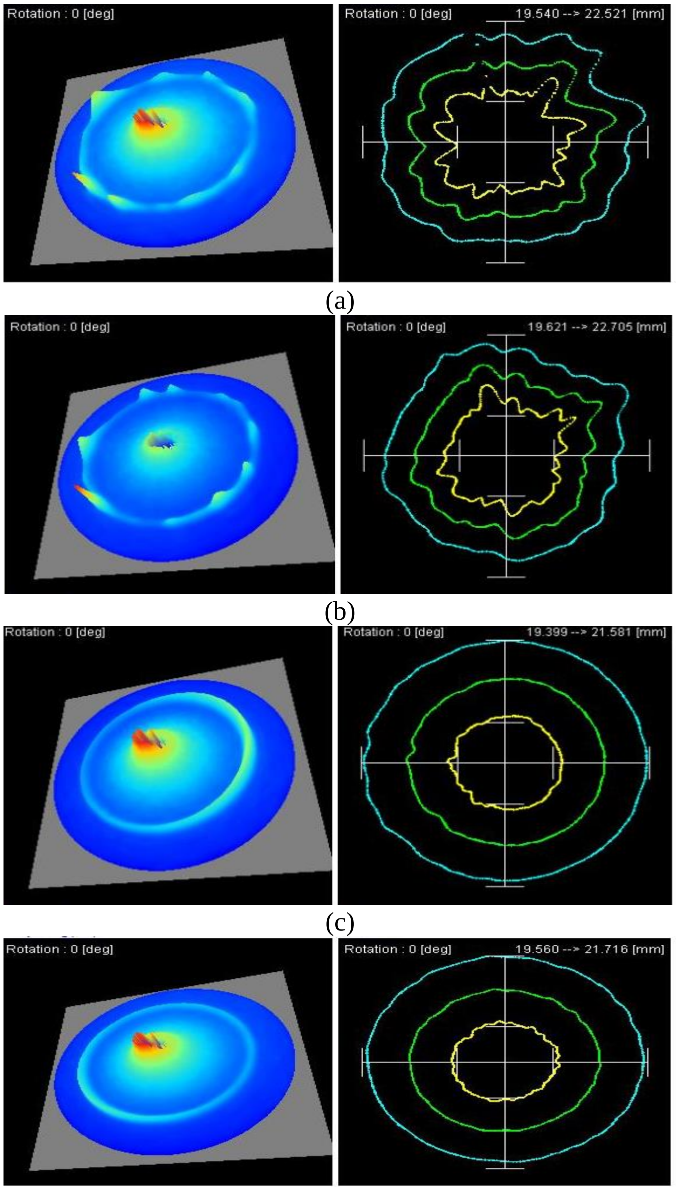


Figure 7: Comparison of micro-hardness of non-heat treated and heat treated weldment

3.4 Residual Stress

For evaluating the residual stress in the welded joint, pulstec µ-x360n (from Delhi Technological University, New Delhi) apparatus is used which is work on cosα method. The cosα method is most widely used for residual stress measurement. If there is no residual stress in the welded joint then there will be no strain in the weldment. The Debye ring is the cycle ring, in which the radius at any angle α is same. If some residual stress was found in the material then the lattice distances of the crystals with different orientation will be unequal. This will lead to the distortion of Debye ring, in which the radius at different angle is not same as shown in fig.8. So, the Debye ring can be used to evaluate the residual stress in the existing specimen.



(a)

(b)

(c)

(d)

Figure 8: 3D & 2D Debye ring and distortion ring at the center of the welded joint, (a) Non-heat treated, (b) heat treated at 850^{0}C, (c) heat treated at 900^{0}C (d) heat treated at 950^{0}C

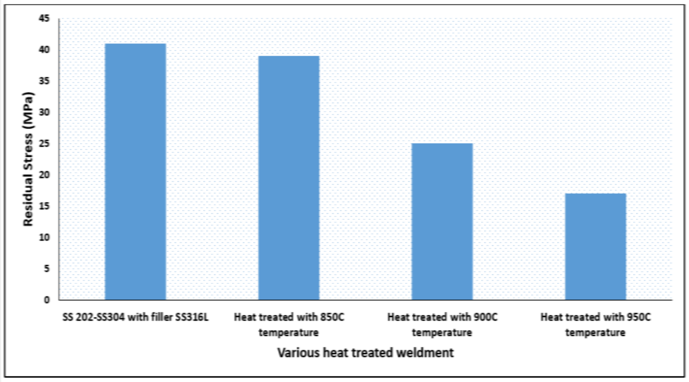


Figure 9: Comparison of residual stress of non-heat treated and heat treated weldment

Residual stress investigation of TIG welded joint of SS202 and SS304 with filler SS316L on the weld center with or without heat treatment as shown in fig.9. The variation of residual stress lies between 17 MPa to 41 MPa at with or without heat treated weldment. The maximum residual stress i.e. 41 MPa was found in the non-heat treated weldment, whereas minimum residual stress i.e. 17 MPa was found in the heat treated weldment at 950^{0}C as shown in fig. 9.

4. Conclusions

The fundamental objective of this work is to investigate the mechanical properties of dissimilar welded joint of SS202 and SS304 with filler SS316L by tungsten arc welding (TIG) and effect of post weld heat treatment (PWHT) on the welded joint. There are following conclusions are made from this experimental work which are as follow.

- The tensile strength was increased after post weld heat treatment, and maximum tensile strength i.e. 535.42 MPa was found in post heat treated welded joint at 950^{0}C, and maximum percentage elongation i.e. 18.86% was found at 900^{0}C.
- A decreasing profile of micro-hardness was found from the base metal (BM) to welded joint. This decrease profile may occur due to absence of martensite phase in heat affected zone (HAZ).
- The micro-hardness values were increased at the center of the welded joint, when post weld heat treatment (PWHT) applied. The maximum hardness values i.e. 260 HV was observed in heat treated welded joint at 950^{0}C.
- The compressive residual stresses was found at the center of the welded joint because of thermal expansion and heat conduction in the heat affected zone. The residual stress decreases when post weld heat treatment temperature increased. The minimum compressive residual stress i.e. 17 MPa was found in heat treated welded joint at 950^{0}C.

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