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Impact of Post Welding Heat Treatment Process on Microstructure and Mechanical Properties of TIG Welded SS-304 & SS316l Dissimilar Metals

K.L.N. Murthy[1] and A.C. Uma Maheshwar Rao[2]
[1]Asst. Prof., Sreyas Institute of Engineering and Technology/ Mechanical Engg. Department, Hyderabad, India.
murthy.kln@sreyas.ac.in
[2]Assoc. Prof., Sreyas Institute of Engineering and Technology/ Mechanical Engg. Department, Hyderabad, India
Umamaheswar.ac@sreyas.ac.in

Abstract: **The present work aims at improvising the mechanical properties of the weldments under different heating conditions. Two materials SS304 and 316L are joined under various parameters like current, gas flow rate, and root gap. The weldments are post heated to a temperature of 800^{0}C in a muffle furnace to improve the mechanical properties at fusion zone HAZ and parent materials. The microstructure of the specimens at different zones is studied under 500x magnification which revealed the formation of dendritic structure and austenitic grain boundaries with annealing twins showing elongated grains with ASTM No 7 and 8 at SS304 base material, Fusion zone, and SS316L parent material.**

***Index Terms*: hardness, microstructure, welding, weldments, base metal.**

I. Introduction

Just like preheating, Post welding heat treatment process is very important as a part of welding. As the name suggest Post welding heat treatment process is done after completion of the welding of a particular component. It helps to improve welding quality and stress relief [1,2], not only the quality of the weld metal but also increases the quality of the base metal. As said earlier it also releases the stresses which are internally developed during the welding process. It is impossible to see the temperature distribution inside the weldments with our naked eye and is possible only when observed under the thermal cameras.

This temperature distribution is different at various locations for example the central area is very hot when compared with the edges of the base metal. Because of this nonlinear temperature distribution several stresses are generated which are called as Residual Stresses. Which eventually effects the weld strength.

After completion of the welding of the metals there will be heat transfer between weld metal and base metal due to conduction heat transfer. This heat transfer will take place unevenly, sometimes the thickness of the base metal will also be the reason for uneven heat transfer. Depending up on the cooling rate weldment's mechanical and microstructure properties gets changed.

II . Literature

Effects of post-weld heat treatments on the microstructure, mechanical and corrosion properties of gas metal arc welded 304 stainless steel was studied by Taiwo Ebenezer et al [3]. It was observed that there is significant improvement of microstructure, mechanical and corrosion properties of the weldment after the post welding heat treatment process. Post tempering process increased the tensile strength to 10%. At the end of the experimentation, it was concluded that post tempering heat treatment process shows the better improvements than that of post annealing because more refined grains formed during tempering process.

In a study conducted by M. R. Dodo et al [4] on effect of post-weld heat treatment on the microstructure and mechanical properties of arc welded medium carbon steel. The study comprises of detail description of effect of the three different heat treatment processes i.e., annealing, normalizing and quenching on the weldment. It was concluded that normalizing heat treatment process is the best of the three processes. Tensile strength was increased after normalizing and quenching.

III. Experimentation

The experiments are performed on TIG welded SS-304 & SS-316L dissimilar metals with SS-316LER as filler metal. Table 1 shows the chemical composition of the metals used for the experiments. Fig.1 shows the sample weldment before and after heat treatment process.

TABLE I.
Chemical Composition of the Metals

S.no	Metal	C	N	Cr	Ni	Mo	Mn	Si
1	SS-304	0.05	0.05	18.3	8.1	0.3	1.8	0.45
2	SS-316L	0.02	-	16.4	10.5	2.1	1.8	0.50
3	SS-316LER	0.02	-	18.00	12	2.75	1.50	0.50

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TABLE II.

S.No	Test	Load (Kgf)	Indenter	Time (S)	Before Norm-alizing RHN	Avg	After Normal izing RHN	Avg
1	SS-304	150	Diamond	30	77		85	
2	SS-304	150	Diamond	30	58	**73.3**	98	**89**
3	SS-304	150	Diamond	30	85		98	
4	BEAD	150	Diamond	30	63		67	
5	BEAD	150	Diamond	30	90	**82.66**	99	**83.6**
6	BEAD	150	Diamond	30	95		85	
7	SS-316L	150	Diamond	30	92		91	
8	SS-316L	150	Diamond	30	87	**83.3**	91	**93.6**
9	SS-316L	150	Diamond	30	72		99	

HARDNESS VALUES OF TEST WORK PIECE 1

TABLE III.

S.No	Test	Load (Kgf)	Indenter	Time (S)	Before Norm-alizing RHN	Avg	After Normal izing RHN	Avg
1	SS-304	150	Diamond	30	68		75	
2	SS-304	150	Diamond	30	85	**78**	94	**87**
3	SS-304	150	Diamond	30	81		92	
4	BEAD	150	Diamond	30	51		71	
5	BEAD	150	Diamond	30	71	**57.6**	71	**71**
6	BEAD	150	Diamond	30	51		71	
7	SS-316L	150	Diamond	30	73		70	
8	SS-316L	150	Diamond	30	81	**73.3**	91	**78.33**
9	SS-316L	150	Diamond	30	66		74	

HARDNESS VALUES OF TEST WORKPIECE 2

TABLE IV.

S.No	Test	Load (Kgf)	Indenter	Time (S)	Before Norm-alizing RHN	Avg	After Normal izing RHN	Avg
1	SS-304	150	Diamond	30	77		100	
2	SS-304	150	Diamond	30	78	**76.6**	91	**95.5**
3	SS-304	150	Diamond	30	75		95	
4	BEAD	150	Diamond	30	74		95	
5	BEAD	150	Diamond	30	65	**70**	99	**97**
6	BEAD	150	Diamond	30	71		97	
7	SS-316L	150	Diamond	30	70		89	
8	SS-316L	150	Diamond	30	61	**73**	90	**89.3**
9	SS-316L	150	Diamond	30	88		89	

HARDNESS VALUES OF TEST WORKPIECE 3

TABLE V.

S.No	Test	Load (Kgf)	Indenter	Time (S)	Before Norm-alizing RHN	Avg	After Normal izing RHN	Avg
1	SS-304	150	Diamond	30	93		100	
2	SS-304	150	Diamond	30	97	**94.6**	91	**95.3**
3	SS-304	150	Diamond	30	94		95	
4	BEAD	150	Diamond	30	71		87	
5	BEAD	150	Diamond	30	59	**61.6**	96	**93.6**
6	BEAD	150	Diamond	30	55		98	
7	SS-316L	150	Diamond	30	83		98	
8	SS-316L	150	Diamond	30	77	**79**	92	**91**
9	SS-316L	150	Diamond	30	77		83	

HARDNESS VALUES OF TEST WORK PIECE 4

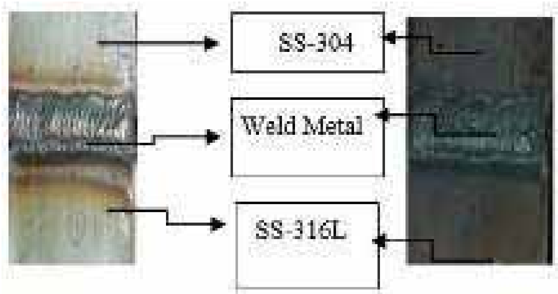


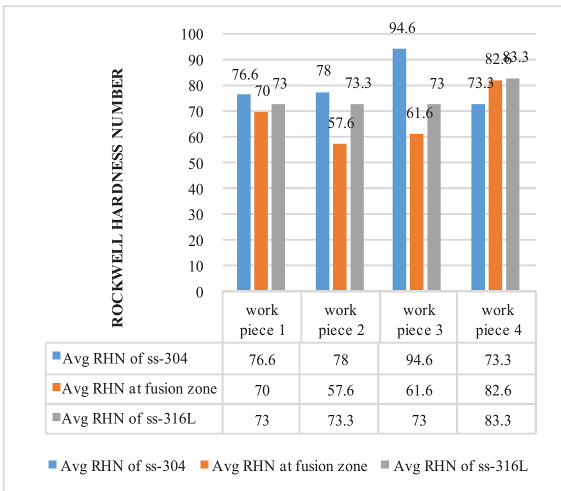
Figure.1 Weldment before and after heat treatment

Post Welding Heat Treatment (Normalizing) [6] is performed on the weldments in order to reduce the internal stress developed during the welding process. The weldments were kept inside Muffle furnace as shown in the Fig.2 and heated to 800^{0}C [7][8] such that recrystallization process takes place inside the weldment.

Figure 2. Heat Treatment Process

Hardness measurement was carried out on the SS-304 (HAZ), Weld zone and SS-316L (HAZ) of the weldment using Rockwell Hardness tester with Diamond indenter and with a load of 150 kg for a dwell time period of 30s. Hardness values were taken before and after Post Welding Heat Treatment Process (PWHT). The hardness values are tabulated in Tables 2, 3, 4 &5 and plotted in Graph.1&2 and compared with each other.

GRAPH I.
ROCKWELL HARDNESS NUMBER VS WORK PIECES BEFORE POST WELDING HEAT TREATMENT PROCESS



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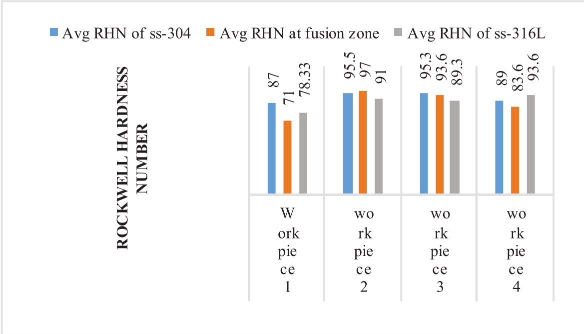
GRAPH II.
2 ROCKWELL HARDNESS NUMBER VS WORK PIECES AFTER POST WELDING HEAT TREATMENT PROCESS.



It can be observed from the above Tables and Graphs that the hardness values of the work pieces are increased after post welding heat treatment process (normalizing).

Microstructure analysis is performed under optical microscope at 500X magnifications at different location's i.e., at HAZ of 304, HAZ of 316L and fusion zone of workpiece 2 as it had performed very well when compared it with other workpieces. It is very difficult task to reveal the microstructure of the welded bimetallic joint due to the existence of the different chemical composition across the weldment. Composite region of the work piece is polished using emery sheet, which was then followed by disk polishing machine with aluminum oxide. Etchant used was modified Fry's reagent consisting of 25ml of hydrochloric acid (HCL), 1g of Cupric Chloride ($CuCl_2$), 150ml of water (H_2O) and 25ml of Nitric acid (HNO_3) [9]. The microstructure of the workpiece is shown in the fig.4. Table 6 shows the microstructure at different locations. To get the grain size according to ASTM standards Jeffries' formula (1) is used. Fig 3 shows the Jeffries' multiplier (f) values [10].

TABLE 5 Relationship Between Magnification Used and Jeffries' Multiplier, *f*, for an Area of 5000 mm² (a Circle of 79.8-mm Diameter) (*f* = 0.0002 *M*²)

Magnification Used, *M*	Jeffries' Multiplier, *f*, to Obtain Grains/mm²
1	0.0002
10	0.02
25	0.125
50	0.5
75^A	1.125
100	2.0
150	4.5
200	8.0
250	12.5
300	18.0
500	50.0
750	112.5
1000	200.0

^A At 75 diameters magnification, Jeffries' multiplier, *f*, becomes unity if the area used is 5625 mm² (a circle of 84.5-mm diameter).

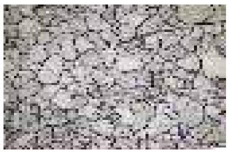
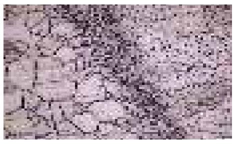
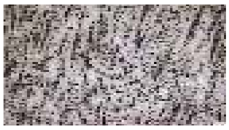
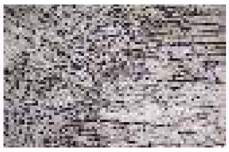
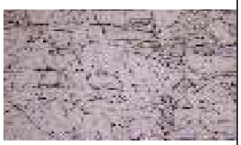
Figure 3. Values of Jeffries' multiplier

$$N_A = f\left(N\ inside + \frac{N\ intercept}{2}\right) \quad \text{--------------------(1)}$$

N_A = number of grains per square millimeter.
N_{inside} = number of grains inside the circle.
$N_{intercept}$ = number of grains on the circumference of the circle.

Figure 4. Cross Section zoomed in image of the workpiece-2

TABLE VI.
MICROSTRUCTURE AT DIFFERENT LOCATIONS WITH DESCRIPTIONS

Microstructures	Description
 SS-304	SS-304 base material consisting of the austenitic grain boundaries with annealing twins showing elongated grains since the material7 is rolled. The grain size is ASTM No = 8.
 SS-304 HAZ	SS-304 HAZ consisting of austenitic grain boundaries with annealing twins showing Equiaxed grains since the material affected by the heat so the grains are recrystallized.
 Fusion Zone	The Fusion zone is showing the dendritic structure (Epitaxial Grain Growth).
 SS-316L HAZ	SS-316L HAZ structure consisting of austenitic grain boundaries with annealing twins.
 SS-316L	SS-316L base material structure consisting of austenitic grain boundaries with annealing twins having the grain size ASTM No = 7.

IV. RESULTS

- 22.435% increase in average hardness of SS-304.
- 68.402 % increase in average hardness of fusion zone.
- 24.657 % increase in average hardness of SS-316L.
- It can be clearly said that Post Welding Heat Treatment process (Normalizing) increases the hardness of the SS-304 and SS-316L TIG welded dissimilar metals.

V. Conclusions

In this study Post Welding Heat Treatment process (PWHT) is carried out on all the four work pieces. A change can be observed on comparing the hardness values of the weldments before and after the heat treatment process. There is a significant increase in the hardness values of workpiece-2.

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