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Activated Tungsten Inert Gas Welding For Austenitic Stainless Steels

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ABSTRACT

Improvements in weld penetration have long been sought in austenitic stainless steel welds produced by TIG welding process.In the present work, a specific activating flux composition suitable for Autogenous TIG welds of stainless steel was developed and their angular distortion, micro hardness, tensile strength and depth of penetration are compared with conventional practices. Also, a mathematical modeling of Microhardness at the Welding Zone is developed and compared with the theoretical values. The results indicate that SiO2 flux is more desirable than ZnO, as it increases tensile strength, microhardness, and decreases angular distortion of the weld zone.

Keywords: Activated Tungsten Inert Gas Welding, Flux, EDAX, Microhardness.

1. Introduction

Fabrication of metal structures in space will require extensive use of various metal joining processes. The tungsten inert gas (TIG) welding process is one of several methods being considered for this purpose. The TIG welding technique is widely accepted for its ability to produce higher quality welds in a variety of materials. Advantages of this process include higher quality weld deposits, precise control of welding parameters, and relatively lower equipment costs. Consequently, the practical TIG welding technique is used in various industries to produce single pass full penetration welds and the root passes of multi-pass welds. The concept of using a flux with TIG welding is known as Activated Tungsten Inert Gas Welding (ATIG).This process involves applying a thin coating of the activated flux on the joint prior to welding. ATIG welding process leads to decrease in angular distortion and increase in weld penetration capability, as much as compared to conventional practices.

As reported by Shanping Lu et al. oxygen from the decomposition of the flux in the welding pool alters the surface tension gradients on the weld pool surface, and hence, changes the Marangoni convection direction and the weld pool penetration depth [1]. It was reported by Kuang-Hung Tseng et al. that the SiO_2 flux facilitated root pass joint penetration, but Al_2O_3 flux led to the deterioration in the weld depth and bead width compared with conventional TIG process. Activated TIG welding can increase the joint penetration and weld depth to-width ratio, thereby reducing angular distortion of the weldments [2]. Tsann-Shyichern et al suggested that the plasma column and the anode root are a mechanism for determining the morphology of activated TIG welds [3]. Microstructure evaluation and mechanical properties of 304 austenitic stainless steels (SS) jointed by tungsten gas (TIG) welding by using 308 stainless steel filler wire were examined byHalil Ibrahim Kurt et al . In weld metal chromium carbide precipitations was observed. The welding metal contained a dendrite structure (skeletal and lathy ferrite) [4].

2. Material selection and Fabrication

SS 304 plates measuring 6 mm thickness were cut into 100 x 50 mm strips. Then edge preparation was carried out as per the standards. The base metal strips are roughly polished with 400 grit silicon carbide paper to remove surface contamination and finally cleaned with acetone. The chemical composition of Austenitic type 304 stainless steel is tabulated in Table 1.

Table 1 SS 304 Chemical composition by weight %

Chemical	Carbon	Silicon	Manganese	Phosphorous	Sulphur	Chromium	Nickel
Weight %	0.07	0.51	1.30	0.026	0.013	18.7	8.16

Activating flux was prepared using two kinds of single component oxides namely SiO_2 and ZnO. They are packed in powdered form with about 30 – 60 µm particle size. These powders were mixed with acetone to produce a paint-like consistency. Before welding a thin layer of the flux was brushed onto the surface of the joint to be welded. The coating density of flux was about 6 mg/cm^2. TIG process was performed on the test specimen of size 100 x 50 x 6 mm using a manual welding machine to produce a bead-on plate joint. The welding process is carried in an inert gas atmosphere (argon). The flow rate of argon is 10 l/min. The gas flow rate is maintained in order to prevent the reaction between molten metal and atmospheric oxygen. The welding parameters during the process are tabulated in the Table 2. The welded samples are shown below

Fig.1 TIG weld

Fig.2 100% SiO_2 sample

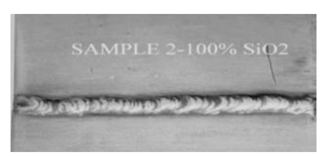


Fig. 3 100% ZnO sample

Table 2 Welding parameters

Parameter	Weld current	Travel speed	Diameter of electrode	Tip angle of electrode	Electrode gap	Shielding gas	Gas flow rate	Filler rod Material
Value	150 A	100 mm/min	3.2 mm	40^{o}	2 mm	Pure Argon	10 l/min	304 Stainless steel

3. Experimental work

3.1 Angular distortion

Distortion or deformation can occur during welding as a result of the non-uniform expansion and contraction of the weld and base metal during the heating and cooling cycle. In order to measure the angular distortion welded plate is kept on the Surface Table and one side is fixed as shown in Fig.4. Then the dial gauge moved from Welded zone (WZ) to Base metal zone (BM). By using the given formula angular distortion is calculated.

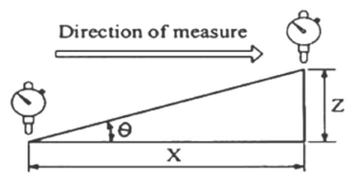


Fig.4 Measurement of angular distortion

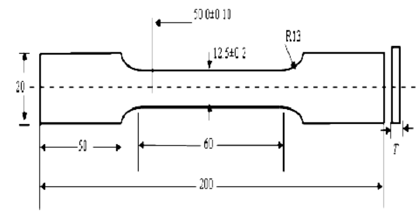


Fig.5 Test Specimen for the tensile test

$$\theta = tan^{-1}\left(\frac{z}{50}\right)$$

3.2 Microhardness test

The term micro hardness test usually refers to static indentations made with loads not exceeding 1 kgf. The indenter is either the Vickers diamond pyramid or the Knoop elongated diamond pyramid. Precision microscopes were used to measure the indentations which usually have a magnification of around x500 and measure to an accuracy of $\pm$0.5 micrometers. Also with the same observer differences of $\pm$0.2 micrometers can usually be resolved.

3.3 Tensile test

Tensile test is known as a basic and universal engineering test to achieve material parameters such as ultimate strength, yield strength, % elongation, % area of reduction and Young's modulus. The test was carried out in x – direction and with FUT 40 tensile testing machine. Load was applied at the rate of 0.5 mm/min. The specimens were prepared according to the ASTM E8-04 as shown in Fig.5.

3.4 Weld Bead geometry analysis

A longitudinal cross section of weld was cut out and polished from 300 grit to 1500 grit SiC paper. After fine polishing, the sample undergone wet polishing. The weld fusion zone was then revealed by etching the section with Ferric chloride solution for 10 minutes. The etched weld zone image was observed at 4x magnification using the Stereographic Microscope. Then the parameters of weld bead like depth of penetration and bead width are measured.

3.5 Microstructure analysis

Energy-dispersive x-ray spectroscopy [EDAX], is an analytical technique that uses characteristic x-ray radiation for compositional analysis which is used for the elemental analysis of a sample. EDAX (Make: Shimadzu, Model: XRD 6000, Japan) was used. It is used in this study in order to confirm the interactions between heats affected zones and welded zone. Also it can be applied for the identification of the nature of the superficial clusters presented in the matrix.

4. Results and Discussion

4.1 Microhardness test

The hardness value for all samples increases from base metal zone to welded zone. ATIG 100 % SiO_2 sample possess the maximum value of 232.4 VHN than ATIG 100 % ZnO sample of value 230.9 VHN AND TIG sample of value 230. The vicker's hardness values at various zones for all samples are represented in Fig.6.

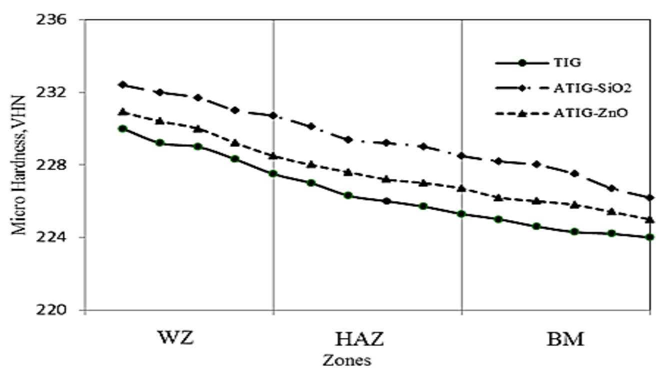


Fig.6 Micro hardness value for various samples

4.2 Angular Distortion

Fig.7 shows the effects of TIG welding on the angular distortion of the grade 304 stainless steel weldments with and without flux. Activated TIG welding increases both the joint penetration and the weld depth-to-width ratio. This is characteristic of a high degree of energy concentration during welding, and reduces the quantity of supplied heat. This in turn prevents overheating of the base material, and reduces the incidence of thermal strains and incompatible strain caused by shrinkage in thickness.

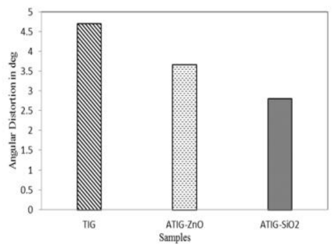


Fig.7 Angular Distortion

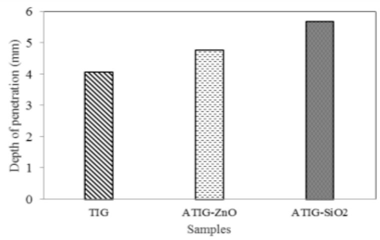


Fig.8 Depth of Penetration

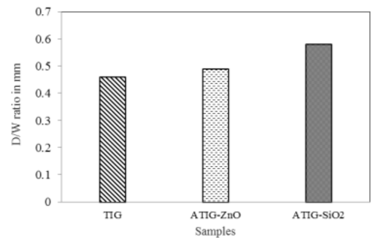


Fig. 9 Effect of D/W ratio

Therefore, this approach reduces the angular distortion of the grade 304 stainless steel activated TIG weldment. In this study, the grade 304 stainless steel TIG welding with SiO_2 flux produced a significant increase in the joint penetration and the weld depth-to-width ratio. Consequently, the angular distortion in the weldment was reduced.

4.3 Weld Bead geometry

The dimensions and depth/width ratio of the fusion zone were calculated for all the samples. The depth of penetration and depth to width ratio are compared against the TIG sample and graphs are plotted as shown in Fig.8 and Fig.9 respectively.

4.4 Microstructre analysis

In order to confirm the results related to the interactions between the welded zone and heat affected zone, EDAX was used. The results of EDAX analysis are shown in Figures 10, 11 and 12 respectively. EDAX spectra indicate the clusters consisting base metal and flux powder.

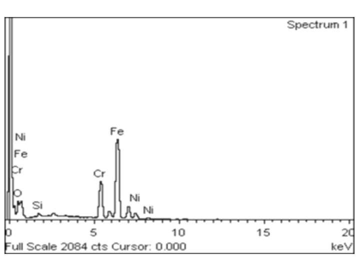


Fig.10 EDAX for TIG sample

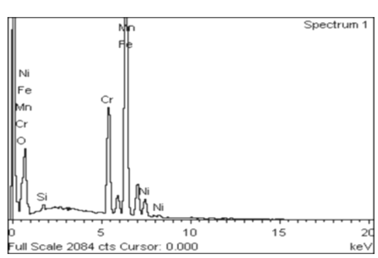


Fig.11 EDAX for ATIG 100% ZnO

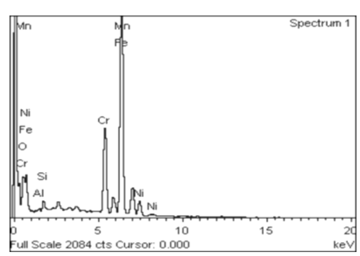


Fig.12 EDAX for ATIG 100% SiO_2

4.5 Tensile test

The tensile test specimens are tested as per the ASTM standards and the results are shown in Fig 13. The ATIG 100% SiO_2sample possess the ultimate tensile stress of 561.1 N/mm^2. The ATIG 100% ZnO sample and TIG sample possess the ultimate tensile stress of 548.4 $N/mm^2$and 519.4 N/mm^2respectively. All the specimens are fractured at welded joint.

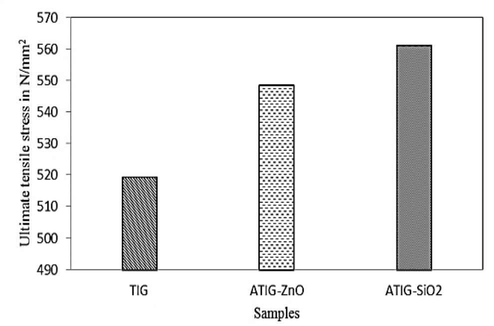


Fig.13 Ultimate tensile stress for all samples

5. Mathematical modelling of microhardness

Table 3 shows the microhardness and their levels used in modeling and the Box-Behnken design matrix shown in Table 4 consisting of 9 sets of coded conditions was selected to conduct the experiments. It has no extended axial points, so it uses only two level factors.The microhardness of the SS samples is a function of different zones, which can be expressed as

H=f (Z, F)…………….. (1)

The second order polynomial regression equation used to represent the response surface 'Y' for k factors is given by

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum_{i=1}^{k} b_{ij} X_i X_j \quad ……………(2)$$

Where b_0 is the average of responses, and b_i, b_{ii} and b_{ij} are the coefficients which depend on the respective main and interaction effects of the parameters.Flux combination 1 represents conventional TIG welding,flux combination 2 represents 100% ZnO flux coated TIG welding and flux combination 3 represents 100% SiO_2 coated TIG welding.

$$H=b_0+b_1Z+b_2F+b_{11}$$

$$Z^2+b_{22}F^2+b_{12}ZF \quad …………………..(3)$$

The coefficients were calculated using the software SYSTAT 13. The mathematical model was developed after determining the coefficients. All the coefficients were tested for their significance at 95% confidence level. The in significant coefficients were eliminated without affecting the accuracy of the mathematical model using t-test. The developed final mathematical model is

$$H = 227.244 - 2.917Z + 1.117F + 0.683Z^2 + 0.383F^2 - 0.2ZF \quad \ldots\ldots\ldots\ldots\ldots(4)$$

Table 3 Microhardness and their levels

Parameters	Notations	Levels		
		-1	*0*	*1*
Zones	Z	WZ	HAZ	BM
Flux combination	F	1	2	3

Table 4 Design Matrix

Trail Run	Microhardness Parameters				
	Z	F	Actual Value	Predicted Value	Error %
T01	1	1	226.2	226.313	-0.0486
T02	1	-1	224.6	224.476	0.0552
T03	-1	1	232.4	232.544	-0.0619
T04	1	0	225	225.013	-0.0044
T05	0	1	229	228.744	0.1119
T06	-1	0	230.9	230.844	0.0243
T07	0	-1	226.3	226.512	-0.0927
T08	0	0	227.2	227.244	-0.0194
T09	-1	-1	230	229.911	0.0391

Table 5 ANOVA results of developed mathematical model

Source	Degrees of	Type I SS	Mean Squares	F-Ratio	P-Value
Regression	5	59.911	11.982	210.078	0.001
Linear	2	58.523	29.262	513.029	0.000
Quadratic	2	1.228	0.614	10.763	0.043
Interaction	1	0.160	0.160	2.805	0.193
Residual	3	0.171	0.057	-	-
Total error	8	60.082	-		-

The adequacy of the developed mathematical model was tested using the analysis of variance (ANOVA) technique which is presented in Table 5.The calculated values of F-ratio are greater than the tabulated values at 96% confidence level, which means the developed mathematical model is considered to be adequate. The model has a higher r^2 value of 0.995.

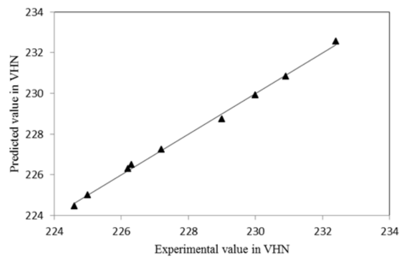


Fig. 14 Scatter diagram for Micro hardness

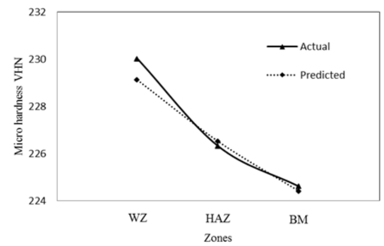
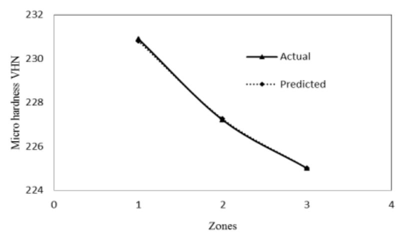


Fig.15 TIG sample



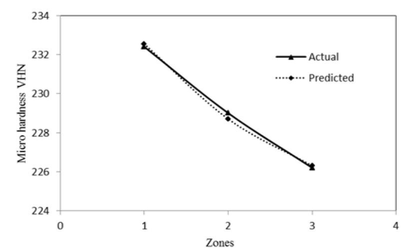


Fig.16 100 % ZnO ATIG Sample

Fig.17 100 % SiO_2 ATIG Sample

Fig.14 shows the scatter diagram of the developed mathematical model. The experimental values and predicted values from the mathematical model are scattered both sides and close to 45^o line, which further proves the adequacy of the model.The effect of flux on micro hardness is shown in Fig.15, 16 and 17 respectively

6. Conclusion

In this study, the SS304 plates were successfully TIG welded with SiO_2 and ZnO flux materials. The SiO_2 flux increased the hardness value (232.2 VHN) at WZ, causes minimum angular distortion (2.80), provides greater depth of penetration and depth-to-width ratio, and increases the ultimate tensile strength than ZnO flux. This is similar to the results submitted by Kuo et al [5]. Further, a mathematical model was developed for micro-hardness The modeling values are in accordance with theoretical values with a tolerance of ± 9%. This shows the correctness of modeling.

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