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Research paper

Distortion control in multi pass dissimilar GTAW process using Taguchi ANOVA analysis

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Abstract

The present study is to observe the distortion development in the weldment of Inconel 625 to SS316L multipass weldments. In this work two-level factors such as welding process, filler wire and root gap were employed with L_4 orthogonal array. The welding has been carried out with continuous current and pulsed current gas tungsten arc welding process implementing ERNiCrMo-3 and ERNiCr-3 fillers rods respectively. The fractional factorial experimentation was analysis of variances (ANOVA), it was carried out to observe the critical parameter which influence distortion caused in the weldments. The quality of welds has been evaluated by X-Ray Radiography test. The results show that welding process and filler wire are contributing more in the distortion.

Keywords: *Dissimilar Materials; GTAW Multipass Welding; Vernier Height Gauge; Distortion.*

1. Introduction

Welding is one of the metal joining techniques used in the industries. Even though evaluation of several modern manufacturing techniques are existing, still welding plays a vital role on the shop floor. Industrial welding process control is essential to the customer as it is required for quality, cost efficiency, better performance which lead to safety and reliability. The GTAW has high efficiency and scatter free during the welding process and has wide applications for structural integrity. The SS316L and Inconel 625 materials used in nuclear, aerospace, power plant, and chemical industries. Many researchers and Akella et al, [1-2] have studied the thermal distributions and distortions development in the weldments with application of Taguchi method employing various welding process parameters.

Lung Kwang Pan [3] has studied the effect of various parameters used in Nd:YAG laser for welding of the thin plates of magnesium alloys using Taguchi optimization techniques. The factors -shielding gas, laser energy, convey speed of workpiece, the point at which the laser is focused, pulse frequency and pulse shape were used to optimize the Tensile strength. Anawa [4] used Taguchi approach in CO_2 continuous laser welding processes for optimizing the minimum fusion zone size of Dissimilar materials namely AISI 316 stainless steel and AISI 1009 low carbon steel plates. Laser power, welding speed, and defocusing distance combinations were selected as process parameters. Distortion and residual stresses for a 1mm thin plate is simulated and validated with experiments of Deng [5-7]. His studies include elastic-plastic deformation with temperature dependent parameters.

Moratis [8] employed numerical simulation method to study residual stress and distortions generated during Laser beam welding process in aluminium lap joints. It was observed that the laser beam gets embedded inside the molten metal, plume reflects within the dead end capillary keyhole and loses energy which is transmitted mostly by heat conduction and by absorption. Murali mohan et al. [9] stated that Influence of friction time and pressure which are evaluated in friction welding of 6082-T6 aluminium alloy to 1040 steel.

Harinadh et al. [10-11] have developed a weld model to study the distortion and residual stress for similar and dissimilar weldments using ANSYS software and observed the distortion and residual stress are effected by the thermal conductivity of the material. Saravanan et al [12] has investigated the influence tool rotational speed on joining AA2017-T6 and AA7075-T6 aluminium alloys using Friction stir welding (FSW). Phillip j Ross [13] has given Taguchi methods for industrial application that require optimized process parameters. Taguchi method is a powerful statistical tool [14] that yields optimized values of process parameters for the design response characteristics. Meticulous experimental design using Orthogonal array coupled with standard or S/N analysis of results using Taguchi techniques gives optimum levels of parameters with a minimum amount of experimentation.

In the present study multipass dissimilar welding of stainless steel 316L with Inconel 625 material which is used in nuclear fusion reactors is analysed for distortion. L_4 Taguchi experimentation was conducted with GTA welding processes. The distortion in the weldment is measured with Vernier height gauge. The two levels of three parameters, weld process, filler wire and root gap were optimised with ANOVA techniques.

2. Experimentation

In the present work, multipass dissimilar weld joints were prepared using SS316L and IN625 base materials. The experimentation process was carried out with continuous current and also with pulsed current gas tungsten arc welding processes. The base materials were joined with ERNiCrMo-3 and ERNiCr-3 filler wires respectively. The nominal composition of the base material and filler rods are given in Table

1. The process parameters were chosen based on the chemical composition, thermal and mechanical properties of the materials to be welded. The dimensions of the samples employed for the welding were 110mm x 60mm x 5mm. The standard single V-groove design configuration for butt joints, with an included angle of 60° has been used. The L_4 orthogonal array that was chosen for the present experimentation is as shown in Table 2. The processes parameters employed in multipass namely GTAW process, filler wire, and root gap of dissimilar welding (Inconel 625 to SS316L) are presented in Table 2.1. About 140 Amps of current was used for CCGTAW and for PCGTAW, 160 Amps of base current and background current of 80 Amps along with welding voltage of 13-15 volts were employed respectively. The flow rate of 10 LPM was maintained constantly for all the combination processes as shown in Table 3. The sequence of weld passes employed for the experimentation is shown in Fig. 1. The interpass temperature of 200^0C was maintained to avoid cracking of the weld sample. An NDT inspection method namely X-Ray radiography was used for detecting the flaws in the weldments as shown in Figure 2.

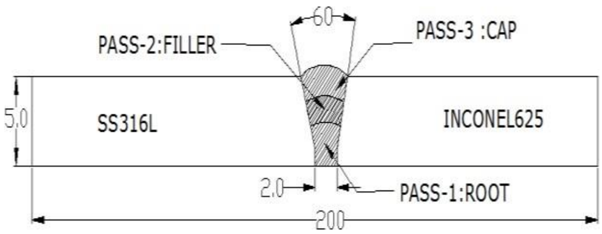

Fig. 1: GTA Welded Samples.

Fig. 2: GTA Welded Samples.

Table 2: Orthogonal Array

Trails	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Table 2.1: Welding Process Parameter

Trails	Welding Process, A	Filler rod, B	Root Gap, C
1	CC	Ernicrmo-3	1.8
2	CC	Ernicr-3	2
3	PC	Ernicrmo-3	2
4	PC	Ernicr-3	1.8

Table 2.2: Chemical Properties of the Materials

	Element (% by mass)								
	Ni	C	Mn		Cu	Si	Cr	P	Others
Inconel 625	Min 58	Max 0.1	Max 0.5	Max 0.015	Max 0.5	Max 0.5	20-23	Max 0.015	Fe Max 5, Al 0.40, Mo 8-10, Ti max 0.1
SS316L	App 12.00-18.00	Max 0.03	Max 2.00	Max 0.030	-	Max 1.00	16.00-18.00	Max 0.045	Mo 2-3,
Er-NiCrMo-3	Min 64	Max 0.1	Max 0.5	Max 0.015	Max 0.50	Max 0.50	22.0-23.0	Max 0.015	Fe Max 1.0, Al Max 0.40, Nb 3.6-4.5, Mo 0.015, Ti max 0.40
ERNiCr-3	Min 67	Max 0.05	2.5-3.5	Max 0.015	Max 0.50	Max 0.50	18.0-22.0	Max 0.015	Fe Max 3.0, Nb 2.0-3.0, Ti max 0.75

Table 3: Process Parameters and its Levels

S.No	Process	Root gap	Filler	Pulsed Current	Base current or welding current			Voltage	Avg Welding speed	Heat input
					P1	P2	P3			
		mm			Amps			Volts	mm/sec	kJ/mm
1	CC	1.8	ERNiCr-3	-	140	140	140	13	95.9	0.86
2	CC	2	ERNiCrMo-3	-	140	140	140	13	152.39	1.25
3	PC	1.8	ERNiCrMo-3	80	160	160	160	15	60.92	0.74
4	PC	2	ERNiCr-3	80	160	160	160	15	85.58	1.16

2.1. Distortion

Distortion is caused by the non-uniform expansion and contraction of the weld metal during the heating and cooling cycle of the welding process. Fig. 3. shows the distortion in transverse and longitudinal directions caused in weldments. Both the material properties and the welding process affect the extent of distortion. Some of the critical material properties like coefficient of thermal expansion, thermal conductivity, yield strength, modulus of elasticity was found to affect the distortion. Other than the physical properties of the material, the amount of welding distortion also depends upon the following factors like Welding processes, Amount of weld metal, Welding speed, Edge preparation and fit-up, welding procedure.

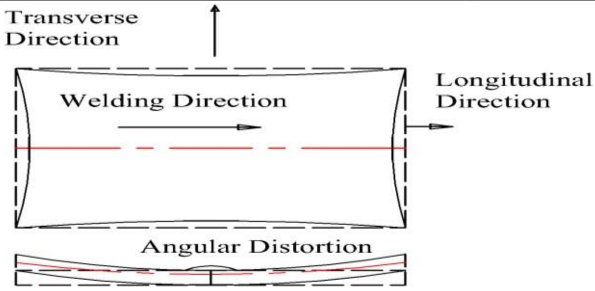

Fig. 3: Distortion Caused by Welding.

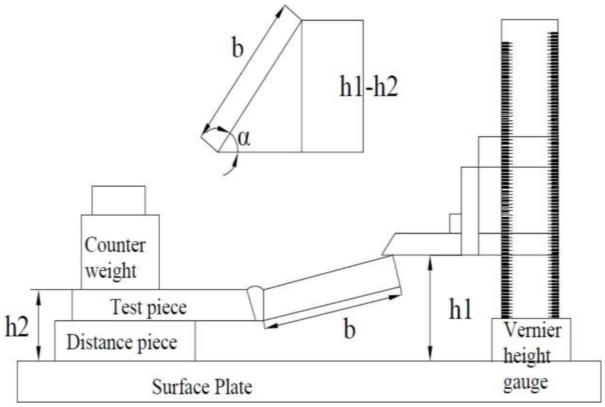

Fig. 4: Schematic Representation of Measurement of Distortion Using Vernier Height Gauge.

Fig. 5: Actual Measurement of Distortion in Weldments.

The schematic of distortion measurement of the weldment in the transverse direction shown in Fig. 4. The Vernier height gauge [15] used for measuring of distortion of weldments is as shown in Fig. 5. The equation (1) used for calculating the distortion in the weldments is as given below.

$$\alpha = \sin^{-1}\left[\frac{h_1 - h_2}{b}\right] \quad (1)$$

Where h_1= total height at Vernier height.
h_2= total height of the work piece from surface.
b= distance of the work piece.

3. Results and discussions

Tests of the hypothesis (null hypothesis) method deals with testing equality of at most two means. If one is interested in testing equality of several methods at a time, technique of analysis of variance is used. Based on F-ratios computed in ANOVA the significance of each factor and interaction can be decided. Taguchi Technique provides a simple, efficient and systematic approach to optimize designs for performance, quality and cost. The methodology is valuable when process parameters are qualitative and discrete. The parameter design based on the Taguchi method can optimize the quality characteristics through a set of process parameters and reduce the sensitivity of the system performance to the sources of variation. In recent years, many applications of Taguchi method have been available in an extensive range of industries and nationalities [10]. The quality characteristics of the Distortion is Lower the better. The responses of the distortion in the weldments are shown in Table 4.

Table 4: L_4 Inconel-SS Distortion

	Factor			Response
Trial#	A=Process	B=Filler	C=Root gap	Distortion
1	CC	B1	c1	1.55
2	CC	B2	c2	0.69
3	PC	B1	c2	0.69
4	PC	B2	c1	0.17

3.1. Anova

Total Number of Experiments, N were 4 and the variation of distortion from mean data for each experiment is shown in Fig. 6. It was observed that the distortion responses were varying around zero. The values of Sum of Squares of mean, SS_m, Total Sum of Squares, SS_T are shown in Table 5. From these two values, Sum of Squares of Error, SS_e was calculated using $SS_e=SS_T-SS_m$. Sum of squares can be used to calculate the variance. The criticality of the parameters was calculated by using the No-Way Anova and was found to be about 90% in the experiments and is given in the Table.6.

Table 5: Calculation of Sum of Squares (SS)

$SS_T=\sum Yi^2$	3.3836
Sum, S=∑Yi	3.1
Avg T = Sum/Expts. =S/N	0.775
$SS_m=S^2/N=N*(T*T)$	2.4025
$SS_e=SS_T-SS_m$, Error sum of Squares	0.9811

Table 6: No Way Anova Summery

Source	SS	DoF	Variance	F, table	F.1,1,3	F...05,1,3	F.01,1,3
Mean	2.4025	1	2.4025	7.346346	5.54	10.1	34.1
Error	0.9811	3	0.327033				
Total	3.3836	4					

Table 7: ANOVA Summary

	SS	DoF,ν	Variance, V	F-Table	F.1,1,5	F..05,1,5	F.01,1,5	Confidence	P, % Contribution
A, Process	0.4761	1	0.4761	16.4741	4.06	6.61	16.8	++	47.14
B, Filler wire	0.4761	1	0.4761	16.4741				++	47.14
C, Root Gap	0.0289	1	0.0289	1					2.86
Error	0.0289	1	0.0289						2.86
SS_T	1.01	4							100.00

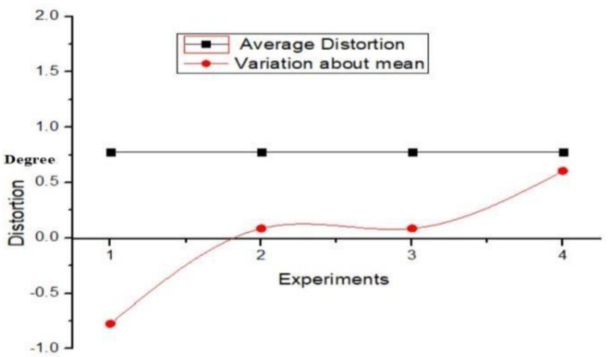

Fig. 6: Variation of Mean & Data about Zero.

Table 6 shows the ANOVA of the weldments to find the criticality from the experiment. Mean and Error (Variance) are two different parameters which evaluate the critical parameter that defines distortion data. For lower the better, the average is expected to be near to zero and comparing mean as a parameter need to be properly looked at. It was observed that the F-table is greater than F.1,1,7 with 90% confidence and variance of Mean, Variance of Error belong to different estimates. The variation of mean, from zero level, is observed to be a significant parameter. Experiments would give significant results up to 90% confidence.

The influence of each parameter on distortion by parametric levels shown in Fig. 7, Fig. 8 and Fig .9. The analysis of parameters and the variance explained in Table.7. As Ftable is greater than F.01,1,5, hence the Filler Wire selection is essential to control the distortion. With 95% Confidence level it has been observed that the Process and Filler wire are crucial Parameters for distortion with Lower the better. Further, Root gap of 2.0 mm is observed to be better but not a significant parameter can be set as per design. Welding Process of Pulsed current is better and has a significant parameter. Filler wire with ERNiCr-3, was resulted in better and is a significant parameter.

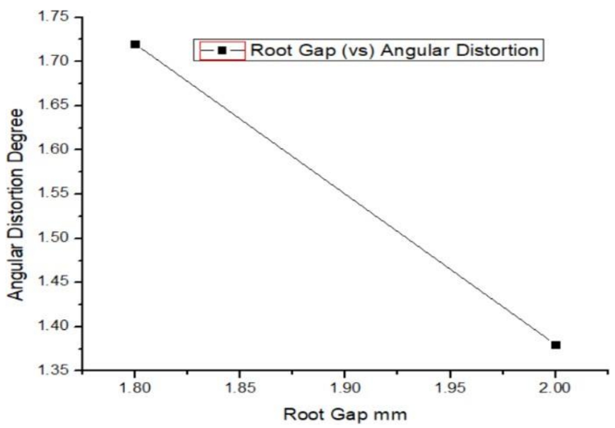

Fig. 7: Effect of Root Gap on Distortion.

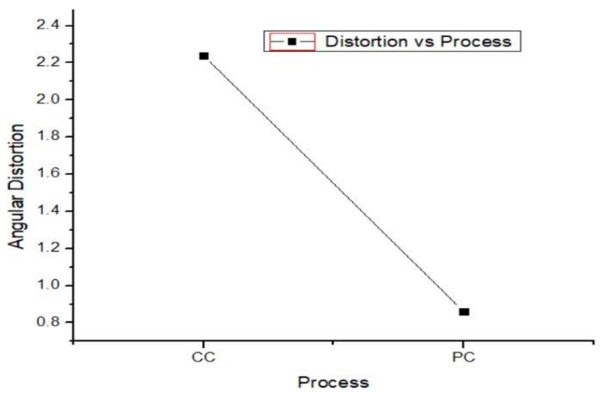

Fig. 8: Effect of Weld Process Distortion.

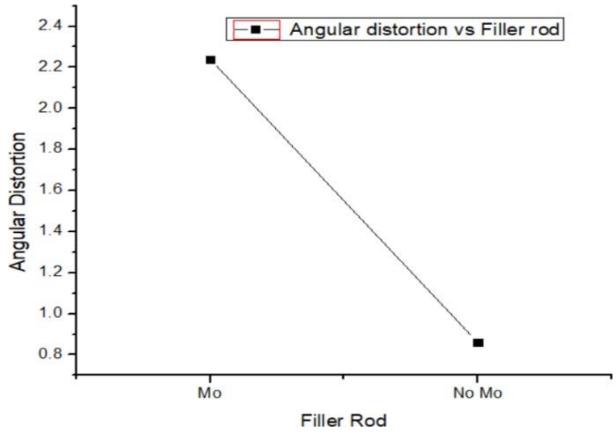

Fig. 9: Effect of Filler Wire on Distortion.

4. Conclusion

It is concluded that the multipass dissimilar welding of SS316L to IN625 with GTAW process with different filler wire was employed successfully. The weldments are free from defects and verified using X-Radiography. From No Way ANOVA it is understood that factors chosen to have contributed to variation with 90% confidence level. From the ANOVA, it was found that with pulsed current weld process and filler with ERNiCr-3 were contributing to lower angular distortion of 0.17^{O} with 95% confidence level.

References

[1] Mackwood, A.P. and Crafer, R.C., 2005. Thermal modelling of laser welding and related processes: a literature review. Optics and Laser Technology, 37(2), pp.99–115. https://doi.org/10.1016/j.optlastec.2004.02.017.

[2] Pan LK, Wang CC, Hsiao YC, Ho KC.2005. Optimization of Nd:YAG laser welding onto magnesium alloy via Taguchi analysis. Optics & Laser Technology, 37(1), pp.33–42. https://doi.org/10.1016/j.optlastec.2004.02.007.

[3] Akella, S., Kumar, B.R. and Krishnaiah, Y., 2013. Optimisation of welding process parameters for distortion control with Taguchi approach. International Journal of Precision Technology, 3(2), p.206. https://doi.org/10.1504/IJPTECH.2013.053305.

[4] Anawa, E.M. and Olabi, A.G., 2008. Using Taguchi method to optimize welding pool of dissimilar laser-welded components. Optics & Laser Technology, 40(2), pp.379–388. https://doi.org/10.1016/j.optlastec.2007.07.001.

[5] Deng, D., 2009. FEM prediction of welding residual stress and distortion in carbon steel considering phase transformation effects. Materials & Design, 30(2), pp.359–366. https://doi.org/10.1016/j.matdes.2008.04.052.

[6] Deng, D. and Murakawa, H., 2008. FEM prediction of buckling distortion induced by welding in thin plate panel structures. Computational Materials Science, 43(4), pp.591–607. https://doi.org/10.1016/j.commatsci.2008.01.003.

[7] Deng, D., Murakawa, H. and Shibahara, M., 2010. Investigations on welding distortion in an asymmetrical curved block by means of numerical simulation technology and experimental method. Computational Materials Science, 48(1), pp.187–194. https://doi.org/10.1016/j.commatsci.2009.12.027.

[8] Moraitis, G.A. and Labeas, G.N., 2008. Residual stress and distortion calculation of laser beam welding for aluminum lap joints. Journal of Materials Processing Technology, 198(1-3), pp.260–269. https://doi.org/10.1016/j.jmatprotec.2007.07.013.

[9] Muralimohan, C.H., Haribabu, S., Hariprasada Reddy, Y., Muthupandi, V. and Sivaprasad, K., Joining of AISI 1040 Steel to 6082-T6 Aluminium alloy by friction welding. Journal of Advances in Mechanical Engineering and Science, 1(1), pp.57–64.

[10] Vemanaboina, H., Akella, S. and Buddu, R.K., 2014. Welding Process Simulation Model for Temperature and Residual Stress Analysis. Procedia Materials Science, 6, pp.1539–1546. https://doi.org/10.1016/j.mspro.2014.07.135.

[11] Akella, S., Vemanaboina, H. and Kumar Buddu R., 2016. Heat Flux for Welding Processes: Model for Laser Weld. Sreyas International Journal of Scientists and Technocrats, 1(1), pp.10–15. https://doi.org/10.24951/sreyasijst.org/2016011002.
[12] Saravanan, V., Rajakumar, S. and Muruganandam, A., 2016. Influence of tool rotation speed on macrostructure, microstructure and mechanical behavior of dissimilar friction stir welded AA2014-T6 and AA7075-T6 Aluminium alloys. Journal of Advances in Mechanical Engineering and Science, 2(4), pp.19–24. https://doi.org/10.18831/james.in/2016041003.
[13] Phillip J Ross, Taguchi Techniques for Quality Engineering, Tata McGraw Hill, 2008.
[14] Ranjith Roy, "A Primer An Taguchi Methods", Van Nostrand Reinhold, Newyork,(1990).
[15] Welding Engineering and Technology by R. S. Parmar, Edition-2, Khanna Publishers, 2010.