Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com
RJEES

Original Research Article

OPTIMIZATION OF WELD BEAD UNDERCUTS IN TUNGSTEN INERT GAS MILD STEEL WELD USING RESPONSE SURFACE METHODOLOGY

***Ozigagun, A. and Achebo, J.I.**

Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Nigeria
*andrewzigs@yahoo.com; josephachebo@yahoo.co.uk

ARTICLE INFORMATION

Article history:
Received 15 December, 2017
Revised 20 December, 2017
Accepted 21 December, 2017
Available online 29 December, 2017

Keywords:
Welding
Undercut
Optimization
Weld bead
Mild steel pipe

ABSTRACT

Weld quality is adversely affected by the presence of undercuts, and this defect can reduce the strength and load bearing capability of welded joints. The aim of this study was to develop a model to optimize the undercut using response surface methodology. The experimental design yielded expert 30 run using central composite design (CCD). The tungsten inert gas welding equipment was used to produce 150 weld specimens from mild steel plates measuring10 mm x 60 mm x 40 mm for this study and the undercut was measured using the nondestructive wiki scanner. The second order polynomial model was adopted, taking current, voltage, gas flow rate and welding speed as input and undercut as response. To test for the model significance, adequacy and validity, the goodness of fit was determined via analysis of variance (ANOVA). The p values of the undercut models was 0.019 which is lower than 0.05, indicating the model was significant. The R^2 *value of 0.76 and a signal to noise ratio of 7.491 indicate that the undercut model is potent. The numerical optimal solution shows that a combination of current of 180.04 A, voltage of 18 V, welding speed of 3.01 mm/min and gas flow rate of 21.94 L/min will produce the least undercut of 0.0299 mm with a desirability value of 1.00. In this study an approach using the response surface method for optimizing weld undercut has been successfully introduced and its effectiveness and efficiency well demonstrated.*

1. INTRODUCTION

The automobile, aircraft, and oil and gas industries are sustained by the services rendered by the application of welding technology (Patel and Chaudhary, 2012). The deleterious effect of welding defects have constituted a major handicap affecting the integrity of virtually all types of welded joints and these defects often come in the form of undercuts and humps, with the consequent reduction in the service life of the welded products (Achebo and Salisu, 2015). An undercut occurs due to the application of excessive heat during the welding process, and the poor welding skill of the welder. Undercuts also reduce the cross-sectional thickness of the parent metal causing the edges of the joint to melt and drain into the weld, often leaving a drain-like impression along the length of the weld therefore reducing the strength of the welded joint (Achebo and Salisu, 2015). These defects can also occur due to the use of an incorrect filler metal, as this could create greater temperature gradients between the weld pool and the heat affected zones (HAZ) around the margins or edges of the weld (Gunaraj and Murugan, 1999).

The integrity of a weld is determined by the quality of the weld bead geometry. Undercut is a very important factor considered in assessing the integrity of welds (Yanget al., 1993). Research has shown that one of the practical ways to improve on weld qualities is to optimize the input process parameters, which can be achieved by employing various mathematical models (Chen et al., 2005). The optimization of weld bead undercuts in tungsten inert gas mild steel has not been established and this is the basis of this study. Janosch and Debiez (1998) reported that the intensive heat produced by the welding arc during welding, causes the heat affected zone on the base metal to melt and flow into a lower region, resulting in undercutting. Petershagen (1990) observed that undercuts has a strong effect on fatigue performance. He stated that the fatigue life of welds can be evaluated from the fracture mechanics equation. The type one and type two category of undercut can also be evaluated using the fracture mechanics equation. Petershagen (1990) further classified undercuts into three groups, which are wide, narrow and micro flaws and stated that undercuts are caused by the poor combination of the welding process parameters like current, voltage, arc distance, gas flow rate, electrode size, filler metal, travel speed, which can cause an irregular groove along the welded joint.

Response surface methodology (RSM) is used to obtain optimum model to predict the output quality of the weld. This is important because it explores the relationships between several explanatory variables and one or more response variables (Box and Wilson 1951). The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Tarng et al. (2000) used the modified Taguchi method to determine the process parameters for optimum weld bead geometry in tungsten inert gas (TIG) welding of stainless steel that allowed the simultaneous consideration of all the weld bead geometry quality characteristics for optimization. Arya et al. (2013) optimized five process parameters, wire diameter, welding current, arc voltage, welding speed and gas flow rate for metal inert gas (MIG) welding based on bead geometry of welding joint in relation to parameters of MIG welding bead geometry, tensile strength, bead width, bead height, penetration and heat affected zone (HAZ) for quality target. Elangovan et al. (2012) developed a methodology to determine the optimum welding conditions that maximize the strength of joints produced by ultrasonic welding by coupling response surface method (RSM) with genetic algorithm (GA). Murugan et al. (1993) used response surface methodology (RSM) to establish quadratic relations between the welding process parameters and bead geometry for depositing 316L stainless steel onto structural steel, using automated submerged arc welding (SAW).

This work seeks to apply response surface methodology to optimize weld bead undercuts in Tungsten Inert gas mild steel weld.

2. MATERIALS AND METHODS

2.1. Material Preparation

Mild steel plates measuring 60 mm x 40 mm x 10 mm were used for this study. For each run, five specimens were used.

2.2. Welding Process

The tungsten inert gas welding equipment was used to weld the plates after the edges have been beveled and machined. Figures 1 and show the TIG machine set up and shielding gas cylinder.

Figure1: Tungsten inert gas welding machine

Figure 2: Shielding gas vessel and regulator

2.3. Experimental Design

The central composite design (CCD) was developed for this study using the Design Expert software version 7.1. This design is for any input parameters considered within the range of 3-5 levels. The input variables considered in this work were welding current (A), gas flow rate (B), welding voltage (C) and welding speed (D) and the output variable was the weld undercut. The range of values of the process parameters was obtained from the open literature accessed, and each parameter has two levels which comprise the high and low. This is expressed in Table 1.

Table 1: Welding parameters and their levels

Parameters	Unit	Symbol	Coded value	
			Low(-1)	High(+1)
Current	A	A	180	240
Gas flow rate	L/min	B	16	22
Voltage	V	C	18	24
Welding speed	cm/min	D	3	4.5

2.4. Experimental Procedure

Mild steel plate of thickness 10 mm was selected as material used for the experiment. The mild steel plate was cut with dimension of 60 mm x 40 mm with the help of power hacksaw and grinded at the edge to smoothen the surfaces to be joined. The surfaces of the coupon were polished with emery paper; thereafter the mild steel plates were fixed on the work table with flexible clamp to weld the joints of the specimen. A tungsten inert gas (TIG) welding process was used with alternate current (AC) to perform the experiments while 100% argon gas was used as the shielding gas. The specimens were cut at the cross section for undercut to be measured for each sample. For each experimental runs five specimens were used, and the average of the five experimental readings was recorded for the 30 runs as shown in Table 2.

Table 2: Central composite design (CCD) matrix

Run	Current (A)	Voltage (V)	Welding Speed (cm/min)	Gas Flow Rate (lit/min)
1	210	21	3.75	19
2	210	21	3.75	19
3	210	21	3.75	19
4	210	21	3.75	19
5	210	21	3.75	19
6	210	21	3.75	19
7	150	21	3.75	19
8	270	21	3.75	19
9	210	15	3.75	19
10	210	27	3.75	19
11	210	21	2.25	19
12	210	21	5.25	19
13	210	21	3.75	13
14	210	21	3.75	25
15	180	18	3	16
16	240	18	3	16
17	180	24	3	16
18	240	24	3	16
19	180	18	4.5	16
20	240	18	4.5	16
21	180	24	4.5	16
22	240	24	4.5	16
23	180	18	3	22
24	240	18	3	22
25	180	24	3	22
26	240	24	3	22
27	180	18	4.5	22
28	240	18	4.5	22
29	180	24	4.5	22
30	240	24	4.5	22

3. RESULTS AND DISCUSSION

3.1. Statistical Analysis

Analysis of variance (ANOVA) helps us to determine the significance of the model developed. The result of Table 3 shows that the model is significant and possess a very good fit. A p-value less than 0.05 indicates that the model is significant.

Table 3: Analysis of variance results

Source	Sum of Squares	df	Mean Square	F Value	p-value
Block	9.600E-4	1	9.6E-4		
Model	0.022	14	1.539E-3	3.18	0.0191
A-Current	0.012	1	0.012	25.11	0.0002
B-Voltage	6.667E-5	1	6.667E-5	0.14	0.7160
C-Welding	1.667E-5	1	1.667E-5	0.034	0.8554
D-Gas flow rate	6.0E-4	1	6.0E-4	1.24	0.2842
AB	9.0E-4	1	9.0E-4	1.86	0.1941
AC	9.0E-4	1	9.0E-4	1.86	0.1941
AD	1.0E-4	1	1.0E-4	0.21	0.6563
BC	2.5E-5	1	2.5E-5	0.052	0.8235
BD	2.025E-3	1	2.025E-3	4.19	0.0600
CD	2.025E-3	1	2.025E-3	4.19	0.0600
A^2	1.905E-5	1	1.905E-5	0.039	0.8456
B^2	4.762E-4	1	4.762E-4	0.98	0.3380
C^2	4.762E-6	1	4.762E-6	9.843E-3	0.9224
D^2	2.305E-3	1	2.305E-3	4.76	0.0466
Residual	6.773E-3	14	4.838E-4		
Lack of Fit	4.623E-3	10	4.623E-4	0.86	0.6167
Pure Error	2.150E-3	4	5.375E-4		
Cor Total	0.029	29			

3.2. Numerical Optimization

The optimal solution for the undercut experiment, the result shows that a current of 180.04 A, combines with a voltage of 18 V, welding speed of 3.01 cm/s and gas flow rate of 21.94 L/min to produce the least undercut of 0.0299626 at a desirability value of 1.00. The effect of the interactions of the input variables on the measured response (undercut) was evaluated using the 3D surface plot as shown in Figure 3.

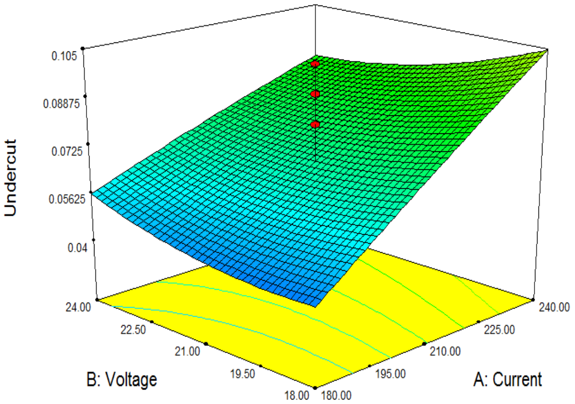

Figure 3: Effect of voltage and current on undercut

3.3. Model Validation

To validate the significance and adequacy of the model based on its ability to optimize the undercut, the goodness of fit statistics presented as shown in Table 4. Coefficient of determination (R-Squared) of

0.7608 indicates the strength of the model and its suitability for predicting the values of the selected variables that will minimize the undercut. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 7.491 indicates an adequate signal. The optimal equation which shows the individual effects and combine interactions of the selected factors against the measured reponse (undercut) is presented based on the coded variables and the actual factors as shown in Equation 2.

$$\begin{aligned} y &= 0.070 + 0.022A - 1.667E-3B + 8.33E-4C - 5.E-3D - 7.5E-3AB + 7.5E-3AC \\ &+ 2.5E-3BD - 1.25E-3BC + 0.011BD + 0.011CD - 8.33E-4A^2 + 4.167E-3 \times B^2 \\ &+ 4.167E-4C^2 + 9.167E-3D^2 \end{aligned} \tag{2}$$

Table 4: Statistical information

Parameter	Value
Std. Dev.	0.022
Mean	0.082
C.V. %	26.82
R-Squared	0.7608
Adj R-Squared	0.5217
Adeq Precision	7.491

4. CONCLUSION

In this study, the response surface methodology was used to optimize weld beads undercut. The relationship between the process parameters and the undercut is quadratic and shows a strong correlation between the current and undercut formed. The other factors, which are welding speed, voltage and gas flow rate showed a low correlation with the undercut and this indicates little or no influence on the undercut.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Achebo, J. and Salisu, S. (2015). Reduction of Undercuts in Fillet Welded Joints Using Taguchi Optimization Method. *Journal of Minerals and Materials Characterization and Engineering* 3(1), pp. 171-179.

Box, G. E. P. and Wilson, K.B. (1951). On the Experimental Attainment of Optimum Conditions. *Journal of the Royal Statistical Society Series,* (13)1, pp. 1–45.

Chen, M.J., Chen, K.N. and Lin, C.W. (2005). Optimization on response surface models for the optimal manufacturing conditions of dairy tofu. *Journal of Food Engineering*, 68), pp. 471- 480.

Arya, D.M., Chaturvedi, V. and Vimal, J. (2013). Parametric Optimization of MIG Process Parameters Using Taguchi and Grey Taguchi analysis. *International Journal of Research in Engineering & Applied Sciences,* 3(6), pp. 1-17.

Elangovan, S., Venkateshwaran, S. and Prakasan, K. (2012). Experimental investigations on optimization of ultrasonic welding parameters for copper to brass joints using response surface method and genetic algorithm. *International Journal of Advanced Engineering Research and Studies,* 3(1), pp. 55-64

Gunaraj, V. and Murugan, N. (1999). Application of response surface methodology for predicting weld bead quality in submerged arc welding of pipes. *Journal of Materials Processing Technology*, 88(1), pp. 266-275.

Janosch, J.J. and Debiez, S. (1998). Influence of the shape of undercut on the fatigue strength of fillet welded assemblies, application of the local approach. *Welding in the World,* 41(4), pp. 350-360.

Murugan, J. (2011). Investigations on the Influence of Surfacing Process Parameters Over Bead Properties During Stainless Steel Cladding. *European Journal of Pain Supplements*, 5(1), pp. 76-77.

Patel, C.N. and Chaudhary, S.J. (2012). A review on optimization of Mechanical Properties for AISI1020 on MIG welding. *International Journal of Advanced Engineering Research and Studies*, 2(1), pp. 97- 99.

Petershagen, H. (1990). The influence of undercut on the fatigue strength of welds, a literature survey. *Welding in the World*, 28(7-8), pp. 114-125,

Tarng, Y.S., Yang,W.H. and Juang, S.C. (2000). The use of fuzzy logic in the Taguchi Method for the optimization of the submerged arc welding process. *International Journal of Advanced manufacturing technology*, 16(9), pp. 688-694

Yang, L.J., Bibby, M.J. and Chandel, R.S. (1993). Effects of process variables on bead width of submerged arc weld deposits. *Journal of Material Processing Technology*, 29(1-3), pp. 133-144.