International Journal of Innovative Research and Advanced Studies (IJIRAS)
Volume 7 Issue 8, August 2020

ISSN: 2394-4404

Numerical Study Of Weld Penetration Area Effect On Butt Joint To Prevent Weld Undercut At Gas Tungsten Arc Welding Using Response Surface Methodology

Kingsley – Omoyibo, Queeneth Adesuwa

Department of Mechanical Engineering,
College of Engineering, Igbinedion University Okada,Okada Town,
Edo State, Nigeria

***Abstract:** An optimal value of weld penetration area used for any welded joint produces a weld free from defect such as undercut and results in a good quality output. This study is aimed at preventing weld undercut in a Gas Tungsten Arc Welding process using a defined quantity of percentage dilution to produce welds with improved reliability and welds free from defects such as undercut. Responses Surface Methodology (RSM) model was used. selected optimum process parameters were recorded for current at 130.67amps, voltage at17volts, speed at100mm/min and gas flow rate at15.96 lit/min was used to determine weld penetration area with a main objective of reducing risk of design failure due to undercut defect in weld joints produced and developing a model to optimize weld penetration area using a 10mm mild steel plate to eradicate undercut defect. Optimal process parameter values obtained for weld penetration area (Ap)(mm^2) was 19.45mm^{2}and Heat Input Ratio of 23.10Kj/min. An established optimum input parameter values for welding current at 130.67ampere was selected in this study.*

IJIRAS

***Keywords:** Weld penetration area, under cut defect, gas tungsten arc welding, response surface methodology and V-groove butt joints.*

I. INTRODUCTION

Undercut defect occurs in welds as a results of excessive welding current used during gas Tungsten Arc welding, due to overlap as a result of excessive fuller metal melting into the weld pool causing a large groove in the parent metal due to the toe of the weld not filled up with molten weld(Jafari et al,2020). This can lead to catastrophic failures in welds as the penetration width is increased, leading to substandard welds(Norbetor,2006)(Lida,K.1998). The main objective of this study is to prevent undercut defect using a new approach, using responses surface methodology (RSM) and experimental results of weld penetration area based on a four factor, 2 level full experimental design (F.E.D)(Lu,et al 2008). Using this study, selection of optimum welding parameter values and finding the relationship between these values was achieved. In this study, the manual gas Tungsten Arc welding was used. The base metal and electrode must be carefully handled to prevent contamination as competent skills are required to operate the GTAW machine(Godfrey,2007). Tilting the GTAW torch slightly backwards to 15 degrees from a vertical align position, filler metal is added manually at the front of the weld pool as the welding operation progresses(Gulsen,1998). This was done skillfully in order to avoid undercut defect after solidification because at the end of the at the completion of the Gas Tungsten Arc welding process, a drastic reduction in current is done in order to allow the solidification of the welded joint and prevention of weld undercut at the toe of the weld(Hari,2013). A good and stable arc distance maintained helped to prevent variance in heat that causes undercut defect as current remained constant relatively but voltage varied(Dinesh et al,2012),(Harik,1997). Moderate current reduced the occurrence of undercut defect (Janikov et al,1991). Gas Tungsten Arc welding process welds are highly resistant to corrosion (Jeyaprakesh et al,2015). For a welded joint to be resistant to corrosion (Mathers,2002), the reinforcement area (AR) is determined with respect to the total area of the weldment (TA)(Karun et al,2014). Some features of a weld bead geometry are: width of bead, weld penetration and bead height (Meenu et al,2015).Weld undercut is eradicated as solidification of molten metal is controlled with the gradual reduction in arc current at the completion of the welding process(Kim et al,1996).

II. METHODOLOGY

A. MATERIALS AND METHODS

This study was carried out using the following procedures;

- ✓ Developing a design matrix
- ✓ Recording input and out process parameters as per design matrix
- ✓ Factor levels and their notation
- ✓ Recording significant coefficient of the model
- ✓ Validation of\ results

B. DEVELOPING THE DESIGN MATRIX

The design matrix was developed using the linear combination

Experimental Coded matrix				
Run	**I**	**V**	**S**	**F**
1	-	-	-	-
2	+	-	-	-
3	-	+	-	-
4	+	+	-	-
5	-	-	+	-
6	+	-	+	-
7	-	+	+	-
8	+	+	+	-
9	-	-	-	+
10	+	-	-	+
11	-	+	-	+
12	+	+	-	+
13	-	-	+	+
14	+	-	+	+
15	-	+	+	+
16	+	+	+	+

Source: Douglas Montgomery 2001.

Table 1: A 2^4 Matrix Design

Low values are represented with the - (minus) sign and the high values are represented with the + (plus) sign. The defining relation for the design is I = IVSF, consequently every main effect is licensed and provides main effect and two factor interacts. Recording input and output, process parameters as per design matrix.

Input parameters	**Name**	**Low level** –	**High level** +	**Units (Symbols)**
I	Welding current	100	180	Amperes (I)
V	Welding voltage	14	20	Volts (v)
S	Welding speed	90	110	mm/min(S)
N	Gas flow rate	10	19	Lit/min(F)

Table 2: Table of Input Process Parameters

The input process parameters selected were welding current (I) with a range of (100-180) ampere, welding voltage (v) with a range of (14 – 20) volts, welding speed (s) with a range of (90-110) mm/min and Gas flow rate(F) with a range of (10-19) lit/min. The out- put process parameters selected where weld penetration area (mm^2) and recorded depth of Undercut respectively as shown in Table 3.

S/N	Response	Symbol	Unit	Range of value
1	Weld penetration area	WPA	mm^2	$19mm^2$-$27mm^2$
2.	Recorded depth of undercut	undercut	mm	0.01-0.03mm

Table 3: Table of response, symbol and unit

A 20mm mild steel plate was used with each of the 16 samples of the oxyacetylene gas cut samples, cleaned using acetone. Each of the 16 samples were grinded and grooved at the side in a V-shape with the samples placed side by side with V-shape in the middle, ready for foot passing. The root gap was fixed at 2mm with a single pass performed on all the welded samples. Beads with uniform shape having bead width and height of mm were presented as stringer beads.

IJIRAS

C. MATHEMATICAL ANALYSIS

$$Y = (X_1, X_2, X_3, X_{4\ldots}X_n) + \mathcal{E} \qquad (1)$$

Y = responses

Where Ɛ =random error or noise factors in the response

X_1-X_n = input process parameters

The response surface = $Y = f\,(X_1, X_2, X_{3\ldots}\ Xn)$ (2)

Using a second order model (Correia et al., 2005).

Using a regression model with coefficient estimate, equation 3.6 is used to analyze the system.

$$Y = \beta_o + \sum_{i=0}^{k} \beta_i x_i + \sum_{i=0}^{k} \beta_i x_i^2 + \sum\sum_{i<1} \beta_{ij} X_{ij} + \varepsilon \qquad (3)$$

The main idea of Response Surface Methodology (RSM) is to use a sequence of designed experiment to obtain an optimal response. It explores optimum operating conditions using experiments. This was the second order (quadratic) function of the input parameters to one or more than one responses with coding factors levels to generate designs that are standard. The Design Expert (Stat-Ease, Inc. 2010) was the software used for the design analysis of the response surface experiments and visualization of the response surface. The essence of the second order model is to optimize (max, min, or achieve a target) using an important property of Response Surface Methodology (RSM) called orthogonality.

$$Ap = \beta_o + \beta_1 I + \beta_2 V + \beta_3 S + \beta_4 F + \beta_2 IV + \beta_{13} IS + \beta_{14} IF + \beta_{23} VS + \beta_{24} VF + \beta_{34} SF + \varepsilon_{1-}\ - \qquad (4)$$

ISSN: 2394-4404

Weld Penetration Area (Ap) (mm^2)

Ap Maximization

S.t $100 \leq I \leq 180$

$14 \leq V \leq 20$

$90 \leq S \leq 110$

$10 \leq F \leq 19$

Where β_0 = free regression coefficient/intercept

$\beta_{1-}\beta_{34}$ = regression coefficient for interaction effects

$$Ap = \beta_o + \beta_1 I + \beta_2 V + \beta_3 S + \beta_4 F + \beta_2 IV + \beta_{13} IS + \beta_{14} IF + \beta_{23} VS + \beta_{24} VF + \beta_{34} SF + \varepsilon_i \quad (5)$$

$$Ap = 19.329 + 2.156\,(I) - 0.029\,(V) - 0.017\,(S) + 0.611\,(F) + 0.079\,(IV) + 0.054\,(IS) - 0.73\,(IF) - 0.24\,(VS) + 0.403\,(VF) + 0.333\,(SF) \quad (6)$$

III. RESULTS AND DISCUSSION

S/N	Coefficients of regression	(β_0 – β_{34})	Experimental Matrix				Design matrix Coded			
	β_0	(mm^2)	I	V	S	F	I	V	S	F
β_0	19.3260	19.3260	100	14	90	10	-	-	-	-
β_1I	+2.1560	21.4820	180	14	90	10	+	-	-	-
β_2V	-0.0290	19.2970	100	20	90	10	-	+	-	-
β_3S	-0.0970	19.2290	180	20	90	10	+	+	-	-
β_4N	+0.6110	19.9370	100	14	110	10	-	-	+	-
IV	+0.0790	19.4050	180	14	110	10	+	-	+	-
IS	+0.0540	19.3800	100	20	110	10	-	+	+	-
IGf	-0.7300	18.5960	180	20	110	10	+	+	+	-
VS	+0.2400	19.5660	100	14	90	19	-	-	-	+
VGf	+0.4030	19.7290	180	14	90	19	+	-	-	+
SGF	+0.3330	19.6590	100	20	90	19	-	+	-	+

Table 4: Table of coefficient of regression for weld penetration area

$$WP_A = \beta_0 + \beta_1 I + \beta_2 V + \beta_3 S + \beta_4 N + \beta_{12} IV + \beta_{13} IS + \beta_{14} IN + \beta_{23} VS + \beta_{24} VN + \beta_{34} SN + \varepsilon_i \quad (7)$$

$$WP_A = 19.3260I + 2.156V - 0.0290V + 0.05401S - 0.730IV - 0.2400VS + 0.4030VN + 0.330SN \quad (8)$$

The confidence intervals are determined using the coefficient estimates. The standard error for each coefficients estimate is recorded with high and low values of confidence interval in percentage (%). An equation in terms of actual factors is recorded for weld penetration area. Four input process parameters namely welding current, welding voltage, welding speed and gas flow rate were used. The goal for optimality for weld penetration area for the purpose of this research was to max water. It from the table of coefficient of regression, the regression estimator $(\hat{\varepsilon}) = 19.45mm^2$, indicating that WP_A optimal value from the table is $19.45mm^2$.

Hence, as welding current increases by Amperes, welding voltage decreased welding speed decreased and gas flow rate increased with all other factor kept constant. The interactions between welding current, welding voltage, welding speed and gas flow rate had coefficient that were either negative showing decrease or positive showing increase in the units, indicating factors that affect weld penetration area. The key factors that were positive affected and played a key role in maximum weld Penetration Area were welding current and welding speed gas flow rate the interactions that played a key role. In maximization weld penetration area were IF, SF and IS. After determining the significant coefficient estimates, which were: Welding current, Welding speed and gas flow rate. A final mathematical model to estimate the response is thus: Weld penetration area (WP_A) = f (I, V, S, F) where steepest ascent and steepest descent plots were used to determine the optimizing response surface showing contour plots with distinct shapes. Input parameters such as I, V, S, F are shown along -side the response, weld penetration area. The plots identify stationary points, maximum response, minimum responses, saddle point response, ridge point response and the design space. The saddle point is represented on a response surface plot where one point is maximum with the other point minimum.

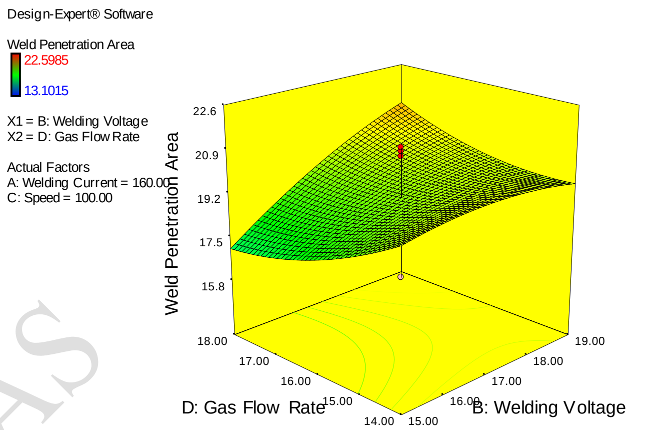

Figure 1

Figure 1: response surface plot for Gas flow rate Vs. welding voltage at saddle point with WP_A at maximum value of $20.9mm^2$ and minimum value of $17.5mm^2$.

At minimum point, the steepest descent is a low value where interactions are traced from Y axis to X axis at the point where the optimal value is minimum.

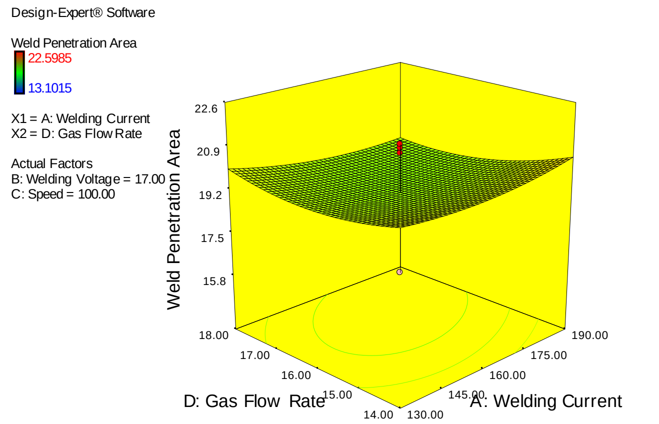

Figure 2

Figure 2: Response surface plot for Gas flow rate Vs. welding Current at ridge point with WP_A at maximum value of $20.9mm^2$ and minimum value of $17.5\ mm^2$.

At a maximum point, the steepest ascent X axis optimization is a maximum and bears high values. Interactions

IJIRAS

are traced from Y axis to at the point where the optimal value is maximum

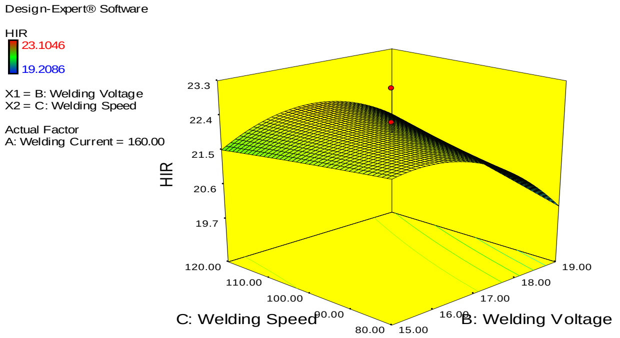

Figure 3

Figure 3: Response surface plot for Welding speed Vs. welding Voltage at maximum point with WP_A at maximum value of 23.3 mm^2 and minimum value of 19.7 $mm^{2.}$ At ridge point, the response surface shows the absolute maximum point is at a point and the absolute minimum point is at another point. In Fig 3 The ridge point shows absolute maximum value of 23.3mm^2 and absolute minimum value of 19.7mm^2.

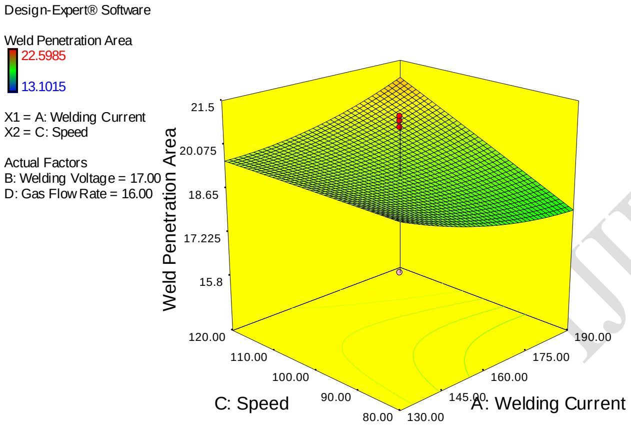

Figure 4

Figure 4: Response surface plot for Welding speed Vs. welding Current at saddle point with WP_A at maximum value of 21.5 mm^2 and minimum value of 18.6 $mm^{2.}$. From the contour plots figure 4, the WP_A optimal value is 21.5 mm^2 at a speed of100mm/min, Voltage of 17volts.

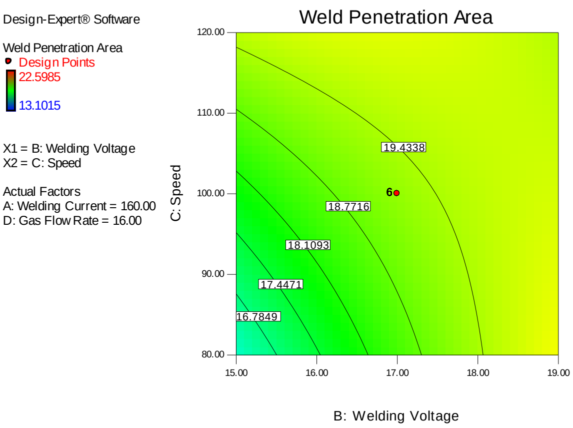

Figure 5: Contour plot of weld penetration area

Weld penetration area is 19.48mm^2 at a speed of 100mm/min and voltage of 17volts. From design point in figure 5, the stationary point showed, is optimally obtained in the centre region with an optimal value of (19.0384 + 19.6961) = 38.75 with an average value of 19.37mm^2 which is equivalent to 19.4 mm^2.

A. MODEL VALIDATION

(A) The weld penetration area (WP_A) (mm^2) was checked for normality assumption using normal plot of residuals with calculated values and experimental values. This checked the data if it followed a normal distribution for the data when plotted. The data obtained for this research clustered around the mean, indicating that the data can be used for statistical modeling,

(B) Outliers and influential data points were obtained by subtracting the fitted values from the observation values. Leverage values, internally studentized residual values, studentized residual value are a measure of how far away the independent variable value of an observation are from those of the other observations; studentized residuals, internally studended residuals have equal variables when the model is an adequate model.

Leverages with values less than 1, present with low degree of noise, hence, a value of 0.583333 showed a low degree of noise in the model. Since the observation is less than one, leverage has low leverage point with less influential observation.

IJIRAS

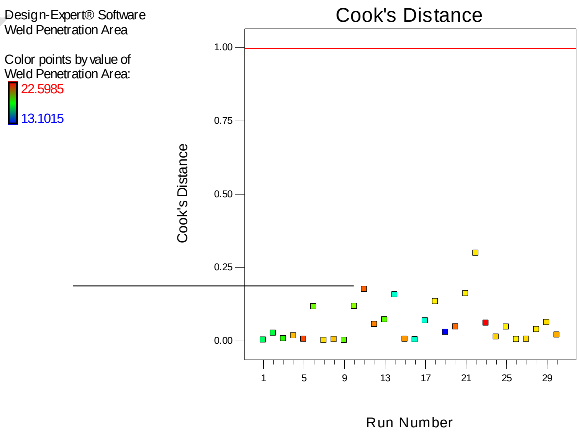

Figure 6: Measure of Cook's distance for weld penetration area

The cooks distance measures the changes in regression coefficient when an observation is deleted. Data points with large residual cut – off value, have cook distance greater than 1. Data point with low residual cut – off value have cooks distance less than 1. Hence, having residual values that are minimal from the table 6, residual cook distance is 0.046645 showing that the model is correct.

a. POINT PREDICTION FOR WELD PENETRATION AREA (AP)

Weld penetration area is the maximum square distance between the base plate (mild steel plate) to surface and the depth of fusion into the base plate. It is measured in square millimeters (mm^2). To achieve a weld free from undercut defect, weld penetration you area is maximized using the selected optimal values of welding current, welding voltage, welding speed and this is achieved at not too high current, medium voltage, high gas flow rate and at a low speed as a low welding speed will result in a controlled cooling with highest strength, the design expert software helped in carrying out a point prediction. The point prediction for welding penetration area recorded optimal values for WP_A using 19.82 mm^2 as a guide as shown in table

Response	Prediction	SE mean	95% CI low	95% CI high	Sepred	95% PI low	95% PI high
Weld penetration area (mm^2)	19.82	1.0630	17.05	19.58	1.935	17.69	19.91

CI = Confidence Interval
Goal = maximization

Table 5: Point prediction for weld penetration area (AP)

Model	Coefficient of determination	Adjusted coefficient of determination	Predicted coefficient of determination	
2FLD weld penetration area (mm^2)	Rsq (R^2)	Adj Rsq ($AdjR^2$)	R-sq (Pred)	S
	87.97%	75.09%	42.07%	1.0995

Table 6: Diagnostic Checks for model developed for weld penetration area (WP_A) pp169

From Table 6,the coefficient of determination 87.97% which is equivalent to 0.8797, is close to one (1) but less than 1, hence it predict the model target value of 19.82mm^2 from the point prediction. Only 12.03% of the model is left, But 87.97% of the model explains the model.

Properties	Selected Authors	Kingsley-Omoyibo (2017)
Input process parameters Welding current Welding voltage Welding speed Gas flow rate Desirability	Jafari .A. et al(2020)	160.00 amperes 17.00 volts 100.00 mm/min 16.00lit/min 0.999979
Undercut depth Thickness of mild steel plate	0.015mm 10mm	0.021mm 10mm

Table 7: Results in this investigation compared with results from some selected authors

Input process parameters		Kingsley-Omoyibo (2017) values in literatures	Reported	References
Welding current Welding voltage Welding speed Gas flow rate	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min	157 amperes 16.8volts 100 mm/min 16,5 lit/min	Hari et al., (2013)
Welding current Welding voltage Welding speed Gas flow rate	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min	1673amperes 17volts 104 mm/min 16 lit/min	Jeyaprakesh et al., (2015)
Welding current Welding voltage Welding speed Gas flow rate	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min	155 amperes 16.9volts 110 mm/min 16,5 lit/min	Karun et al., (2014)
Welding current Welding voltage Welding speed Gas flow rate	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min	167 amperes 18volts 100 mm/min 17 lit/min	Kim et al., (1996)
Welding current Welding voltage Welding speed Gas flow rate	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min	165 amperes 18volts 110 mm/min 16 lit/min	Meenu et al., (2015)

Table 8: Comparing results of other researchers in undercut prevention using input process parameters

Input process parameters		Kingsley-Omoyibo (2017) values	Reported values in literatures	References
Welding current Welding voltage Welding speed Gas flow rate Weld penetration area	I V S F	150 amperes 17 volts 100 mm/min 16 lit/min 22.50mm^2	135 17 101 16 22.48mm^2	Omi et al., (2013)
Welding current Welding voltage Welding speed Gas flow rate Weld penetration area	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min 22.50mm^2	130 16 100 15 22.36mm^2	Osayi et al (2015)
Welding current Welding voltage Welding speed Gas flow rate	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min 22.50mm^2	140 16 110 16 22.40mm^2	Sree raj (2013)
Welding current Welding voltage Welding speed Gas flow rate Weld penetration area	I V S F	160 amperes 17 volts 100 mm/min 16 lit/min 22.50mm^2		
WPA		22.50mm^2		

Table 9: Comparing results of other researchers in undercut prevention using weld penetration results

Acceptable undercut depth	Reported values in literatures	References
0.01mm-0.05mm Plate thickness	0.021mm 10mm mild steel plate 0.02mm 10mm mild steel plate	Kingsley-Omoyibo (2017) Lida, K. (1998)
	0.015mm 10mm mild steel plate	Jafari, A. et al(2020)

Table 10: Comparing results of other researchers in undercut prevention using undercut depth

The results obtained from the author, Kingsley-Omoyibo (2017) compared favourably with reported values in literatures. Records from the work of Lida, K (1998) recorded acceptable undercut depth as 0.02mm and in comparism with the values of Kingsley-Omoyibo (2017) with 0.021mm acceptable depth of undercut, indicating that acceptable undercut depth is a quality of weld for producing welding joints. Free from defect. The acceptable undercut depths were within the acceptable range specified by International standards (ASTM) as stated in Lida, K (1998), undercut=0.02mm, Jafari, A. et al (2020) undercut 0.015mm and Petershagen, H. (1991) undercut 0.08mm for 40mm plate thickness.

A numerical optimization of weld penetration area by authors: Peterhagen, H. (1991), Jafari, A. et al (2020), Lida, K. (1993) and Kingsley-Omoyibo (20017) produced the least undercut measurement to be 0.0800mm, 40mm mild steel plate, 0.015mm for 10mm and 0.0210 for 10mm respectively with a desirability value of 1.00, 1.000, 0.99999 and 0.999979 respectively with achieved properly selected input process parameters established for welding current 159.6amperes for PeterHagen, H. (1991), 160amperes for Kingsley-Omoyibo(2017).

B. DETERMINATION OF UNDERCUT

The undercut measurement for the 16 specimens were measured using weld gauge (model). The weld gauge measured the undercut in millimetres within the acceptable undercut depth range from 0.01mm – 0.05mm for plate thickness of 10mm with a weld penetration area range of $19mm^2$ – $27mm^2$.

IV. CONCLUSION

Welding operations carried out using the established results from the optimization, prediction and evaluation of weld penetration area using gas Tungsten Arc welding process will improved the integrity of welded joints characterized with strength and were undercut – free. It is therefore concluded that;

- ✓ Optimized values of weld penetration area with a value of $19.45mm^2$ has been established
- ✓ Optimized values of the input process parameters obtained from welding current, welding voltage, welding speed and shielding gas flow rate were 130.67 amperes, 17volts 100mm/min and 15.95 lit/min respectively
- ✓ A database for Weld Penetration Area has been created.

IJIRAS

REFERENCES

[1] Dinesh, K.,and Sunil,P, (2012) Dilution Control by Advanced SAW, International journal of Advanced material science. 488(489), 1737-1741

[2] Godfrey Co. Paulo D, Carlos O. Cardoso A. (2007). Prediction of clad angle in laser cladding by powder using response surface methodology and scatter search. International Journal of Optics Laser Technology. 139:1130-1134.

[3] Gulsen, M. and Smith, A.E. (1998). A hierarchical Genetic Algorithm for system Identification and Curve Fitting with a supercomputer Implementation, appeared in IMA volumes in mathematics and its application –issue on Evolutionary Computation (Springer-verlag).

[4] Hari .O. and Pandey .S. (2013). Effect of heat Input on dilution and heat affected zone in submerged arc welding process, Indian Academy of science, 38, (6): 1369-1391

[5] Harik, G. (1997). Learning linkage to efficiently solve problems of bounded difficulty using genetic algorithms. Ph.D thesis, Dept. Computer Science University of Michigan, Arbour, retrieved from (http://portal.qcm.org/citation.cfm?id=269517) retrieved on Feb. 24th 2016

[6] Ibrahim IBN Shaibu (2009) Statistical Analysis for Decision Making (first Edition). Broadgate Publishers, Benin City.

[7] Jafari.A. and Mohsen .R.(2020) Stress intensity factor expression for welded butt joint with undercut and inclined lack of penetration defect considering the effect of joint shape. journal of material processing Technology 6(4),878-892

[8] Janikov, C.Z., and Michalewicz, Z. (1991).An experimental comparison of Binary and floating point representations in genetic Algorithms retrieved from (http://www.cs.umsl.edu/-janikow/publications/1991/GAbin/text.pdf)(PDF). Proceedings of the fourth international conferences on Genetic Algorithms: 31-36. Retrieved Jan 4th 2016.

[9] Jeyaprakash .N., Haile .A. and Arrunprasath, M. (2015). The paremeters and Equipments used in TIG welding: A review. The International Journal of Engineering and science (IJES). 4 (2) : 11- 20

[10] Karun, M.S. and Deepak G. (2014).Submerged Arc welding: A Review. International Journal of Current engineering and Technology, 4(3): 23-47

[11] Kim IS, Basu A, Siores E (1996). Mathematical models for control of weld bead penetration in the GMAW process. International Journal. Advanced. Manufacutring. Technology. 12:303-401.

[12] Kingsley-Omoyibo, Q.A.(2017) Optimization of weld penetration area, Percentage dilution and heat input ratio using Gas Tungsten Arc welding to prevent weld porosity. unpublished Thesis.

[13] Lu.H. and Chen W. (2008).Self adaptive velocity particle swarm optimization for constrained optimization problems, International Journal of Global Optimization. 41:427-445.

[14] Mathers, G. (2002).The Welding of Aluminum and its alloys. Woodhead Publishing Limited, Cambridge, England, pp 66.

[15] Meenu, S. and Khan, M.I. (2015). Optimization of SAW process parameters for bead geometry of bead-on-plate welds deposited on structural steel IS-2062using Taguchi Method. Paper ID: SUB152654, 1 (3) (www.ijrs.net)

[16] Norberto, P.J., Loureiro, A. and Bolmsjo, G.(2006). Welding Robots – Technology, System Issues and Applications Springer- Verlag, London Ltd., U.K.

[17] Nuran, B. (2007). The response surface methodology. Master of Science, department of Mathematical Science, Indiana University of South Bend

[18] Omi et al (2013). Effect of Heat Input on Dilution and Heat Affected Zone in Submerged Arc Welding Process. Sadhana American Journal of Mechanical Engineering 36(6): 1369-1391

[19] Osayi, A.O; Egbe, A.P and Lawal, S.A (2015). Optimization of Process Parameters of Manual Arc Welding of Mild Steel Using Taguchi Method. American Journal of Mechanical Engineering 3(1): 93-97.

[20] PeterHagen,H., (1991) Application of local approach to the fatigue strength assessment of welded structure in

ship. Annual assembly of international institution of welding .Volume: ll W-Doc X111- 1409-91

[21] Sreeraj P, Kannan,T., (2013) Prediction and optimization of weld bead geometry in gas tungsten arc welding process using RSM. journal of Mechanical Engineering Research,15(8),154-165

IJIRAS