Journal of Materials Engineering, Structures and Computation 2(3) 2023 pp. 114-121 ISSN-1115-5825

NIPES

Journal of Materials Engineering, Structures and Computation

Journal homepage: www.nipesjournals.org.ng

Optimization of Hardness Strength in Tungsten Inert Gas Mild Steel Weld Using Response Surface Methodology

Ogbeide O.O[a] and Ebhota L.M[b]

[a]Department of Production Engineering, University of Benin, Benin City, Nigeria
[b]Groove Engineering &Intergrated services Limited
email: osarobo.ogbeide@uniben.edu

ARTICLE INFORMATION

Article history:
Received 24 August 2023
Revised 06 September 2023
Accepted 06 September 2023
Available online 12 September 2023

Keywords:
Welding, Mild Steel, Hardness, TIG, RSM, Contour Plot, Surface plot

https://doi.org/ 10.5281/zenodo.8337327

ISSN-1115-5825/

ABSTRACT

During welding operation, excessive heat input or limited heat input can compromise the quality of welded joint which affect the hardness strength. This study was carried out to optimize the factors responsible for achieving maximum hardness strength using Tungsten Inert Gas (TIG) welding. An experimental matrix was developed with the design expert software, which resulted in central composite design.100 pieces of Mild steel plate was cut into dimension 27.5mm in length,10mm diameter and 10mm thick for the Experiment. Thereafter hardness test was carried out for all the weld samples, the experimental results obtained was used as data for the Analysis. The Response Surface Methodology (RSM), was applied to optimize the responses from input parameters which includes current, voltage and gas flow rate. The experimental results showed that the minimum value for current is 120 Ampere, voltage 20 volts, gas flow rate 12 Lit/min and the maximum value are 170 Amperes, 25 volts, 14 Lit/mm. The RSM model selected the quadratic model as the suitable model for the test because it has a P – value less than 0.05. The goodness of fit statistics gave R^2, value of 86.07%. From the optimization results it was observed that a current of 120 amperes, voltage of 20 volts, and gas flow rate of 12.00 Lit/min will produce Hardness of 299.269N/mm^2.

1. Introduction

Hardness is the ability of a material to resists denting from impact or penetration. It is the property by which material resists permanent deformation [1]. The automobile and ship building industries employs substantial amount of mild steel in making parts, some of this parts involves bending and forming. The relative malleability and softness of mild steel materials, gives room to an outstanding ductility and toughness of the material [2] and[3]. Mild steel material also has a good Machinability and Weld ability. Mild steel is the most versatile and common form of steel as it provides mechanical properties that are acceptable for many applications Welding is the most extensively used method of metal joining, in various industries like oil and gas, rig design and marine transportation, construction, automobile industries etc [4]. It is a process of joining two metals together by creating a metallugical bond between them. The structural integrity of the welded joint is greatly influence by its process parameters and usually, it is expected for a welded joint to be stronger than its parent metal, but in actual fact, most failures occurs at the welded joints and it is mostly due to poor combination of poor process parameters or inexperienced of the welder [5, 6,7]. Poor weld reduces the hardness and scratch resistance of weldment, it also encourages high corrosion activities [8, 9, 10]. It has been proven by several researchers that the choice of welding input process parameters can alter the quality of the weldment, therefore, optimizing these process parameters to obtain the best weld quality and multi-response properties cannot be over emphasized [11] and [12]. This research aim at optimizing and predicting hardness of mild steel welded joint using Tungsten Inert Gas.

2. Materials and Methods

2.1 Materials

The material used in this work is mild steel pipe. 100 pieces of mild steel coupons was cut into dimension 27.5mm in length, 10mm diameter and 10mm thick. Two pieces of the mild steel pipes were welded together using the input process parameters contained in Tungsten Inert Gas welding machine. The input parameters considered in the experiment are Current, Voltage and Gas flow rate. These parameters and their levels are shown in Table 1.

Table 1. Welding parameters and their Levels

Parameters	**Unit**	**Symbol**	**Coded value Low (-1)**	**Coded value High (+1)**
Current	Ampere	I	120	170
Voltage	Volt	V	20	25
Gas Flow Rate	Lit/min	F	12	14

2.2 Methods of Data Collection

The central composite design was adopted with design expert software producing twenty (20) experimental runs. Twenty experimental runs of eight (8) factorial points, six (6) center points and six (6) axial points were carried out to dig out Maximum Hardness on tungsten inert gas weld joints of mild steel pipe. The input parameters and output parameters make up the experimental matrix and the responses recorded from the weld samples were used as the data. The Experiment was repeated five times for hardness test specimen presented in figure 1. The hardness strength was measured by means of Brinell hardness tester. The procedure adopted is as follows. The test was performed by pressing a specific dimensioned and loaded object (indenter) into the surface of the material. Then hardness was obtained by measuring the depth of the indenter penetration or by measuring the size of the impression left by the indenter.

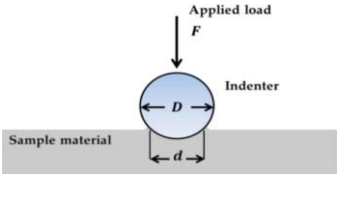

Figure 1. Working Principle of Brinell Hardness

2.3 Methods of Data Analysis

Response Surface Methodology was used to analyze the data obtained. Statistical software package design-expert was used to determine the regression coefficient which help to optimize and predict the process response (hardness).

3. Results and Discussion

The hardness strength was determined and measured and results is presented in Table 2. The in-depth analysis involving the interaction of the process parameters was carried out. Data obtained are presented. The optimum values of the process parameters were gotten by solving the regression equation. The response surface plots and contour plot were analyzed.

Table 2. Experimental Results

Run	A: Current Ampere	B: Voltage Volt	C: Gas Flow Rate Lit/min	Hardness Strength N/mm^2
1	145.0000	22.5000	13.0000	255.4930
2	145.0000	22.5000	13.0000	246.7920
3	187.0450	22.5000	13.0000	281.5960
4	145.0000	22.5000	11.3182	280.0140
5	170.0000	20.0000	12.0000	254.7020
6	145.0000	18.2955	13.0000	249.9560
7	170.0000	25.0000	14.0000	288.4780
8	120.0000	20.0000	14.0000	256.2840
9	170.0000	25.0000	12.0000	264.1940
10	120.0000	25.0000	12.0000	293.4610
11	120.0000	20.0000	12.0000	295.8340
12	102.9550	22.5000	13.0000	302.1620
13	170.0000	20.0000	14.0000	238.0910
14	145.0000	22.5000	14.6818	252.3290
15	145.0000	22.5000	13.0000	250.7470
16	145.0000	22.5000	13.0000	276.0590
17	145.0000	26.7045	13.0000	271.3130
18	145.0000	22.5000	13.0000	259.4480
19	120.0000	25.0000	14.0000	283.9690
20	145.0000	22.5000	13.0000	238.0910

Analysis of variance (ANOVA) was needed to check whether or not the model is significant and also to evaluate the significant contributions of each individual variable, the combined and quadratic effects towards each response. From the result of Table 4 the Model F-value of 24.32 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case X1, X1X2, X2^2, X3^{2}are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 0.70 implies the Lack of Fit is not significant relative to the pure error. There is a 64.74% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good as it indicates a model that is significant.

Table 4. ANOVA for Quadratic model of the Hardness Test

Source	Sum of Squares	Df	Mean Square	F-value	P-Value	
Model	6294.7400	9	699.4200	6.8700	0.0029	**Significant**
X_1-current	1031.1900	1	1031.1900	10.1200	0.0098	
X_2- voltage	1073.9900	1	1073.9900	10.5400	0.0088	

X_3- Gas Flow Rate	566.1400	1	566.1400	5.5600	0.0401	
X_1X_2	149.3600	1	149.3600	1.4700	0.2538	
X_1X_3	402.0700	1	402.0700	3.9500	0.0750	
X_2X_3	629.2900	1	629.2900	6.1800	0.0322	
$X1^2$	2356.0200	1	2356.0200	23.1300	0.0007	
$X2^2$	43.6100	1	43.6100	0.4281	0.5277	
$X3^2$	196.9800	1	196.9800	1.9300	0.1945	
RESIDUAL	1018.5800	10	101.8600			
Lack of Fit	185.5900	5	37.1200	0.2228	0.9375	**Not significant**
Pure Error	832.9900	5	166.6000			

To validate the adequacy of the quadratic model based on its ability to optimize the hardness, the goodness of fit statistics presented in Table 5

Table 5. Fit Statistics for the Hardness test

Std. Dev.	10.0900	R2	0.8607
Mean	266.9500	Adjusted R2	0.7354
C.V.%	3.7800	Predicted R2	0.6403
		Adeq Precision	8.7792

From the result of Table 5 it was observed that the "Predicted R-Squared" value of 0.6403 is in reasonable agreement with the "Adj R-Squared" value of 0.7354. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The computed ratio of 8.7792as observed indicates an adequate signal. This model can be used to navigate the design space and adequately optimize the hardness test. Model fit statistics developed shows with a standard deviation of 10.09, R-squared of 0.8607, Adjusted R -squared of 0.7354, predicted R-squared of 0.6403and predicted error sum of square (PRESS) of 2630.83 obtained from the analysis suggesting a quadratic polynomial model . Standard error of 0.27 for the individual terms, 0.35 for the combine effects and 0.26 for the quadratic terms less than the model basic standard deviation of 1.0 suggests that response surface methodology was ideal for the optimization process. Variance inflation factor (VIF) value of 1.00 for the individual and combine terms, 1.02 for the quadratic terms indicate a significant model in which the variables are highly correlated with the responses. Prediction of Hardness test can be done using the Equation (1), the plot of the predicted versus the experimental is presented in Figure 2.

$$\mathbf{Y = 254.51 - 8.69x_1 + 8.87x_2 - 6.44x_3 + 4.32x_1x_2 + 7.09x_1x_3 + 8.87x_2x_3 + 12.79x^2_1 + 1.74x^2_2 + 3.70x^2_3} \quad \mathbf{(1)}$$

From the plot presented in Figure 2, the predicted and actual, have the same minimum value of 220 N/mm^2 and maximum of 320 N/mm2. The positive slope with minimal scattering along the slope shows a good agreement between our model and the experimental Results.

The 3D surface plot as observed in Figure 3 shows the relationship between the input variables (current and voltage) against te response variable (Hardness). It is a 3 dimensional surface plot which was employed to give a clearer concept of the response surface. Although not as useful as the contour plot for establishing responses values and coordinates, this view may provide a clearer picture of the surface. As the colour of the curved surface gets darker, hardness increase proportionately. The presence of a colored hole at the middle of the upper surface gave a clue that more points lightly shaded for easier identification fell below the surface. In Figure 3 it was observed that the colour of the surface gets dark towards the current and voltage and indication that increasing current and voltage will bring about a corresponding increase in hardness of the material.

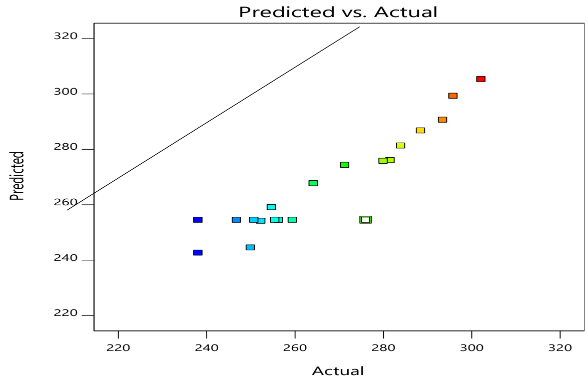

Figure 2. Plot of predicted versus actual hardness test

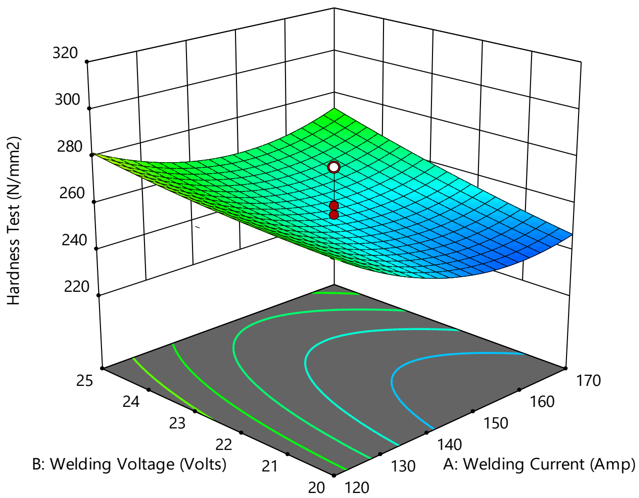

Figure 3. Surface plot forEffect of current and voltage on the hardness test

Finally, numerical optimization was performed to ascertain the desirability of the overall model. In addition, the optimum current, voltage and gas flow rate was determined simultaneously. The interphase of the numerical optimization showing the objective function is presented in Figure 4

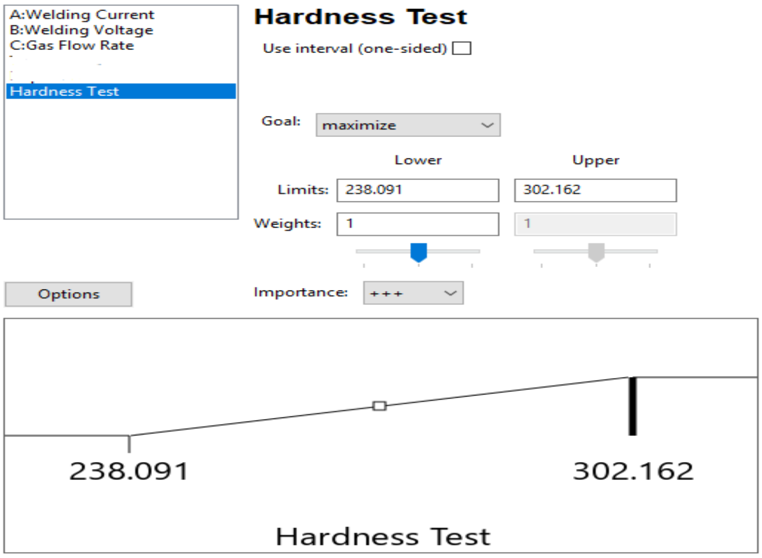

Figure 4. Interphase of numerical optimization model for Hardness test

In other to maximize the material hardness, the weight leans towards the higher limit of 302.162 as seen in Figure 4. The numerical optimization from Figure 4 was employed in producing eighteen (18) optimal solutions presented in Table 6.

Table 6. Optimal Solutions

Number	Current	Voltage	Gas Flow Rate	Hardness	Desirability	
1	120.0000	20.0000	12.0000	299.2690	0.9560	Selected
2	120.0000	20.0360	12.0000	299.1570	0.9540	
3	120.0100	20.0000	12.0070	299.0390	0.9520	
4	120.1770	20.0000	12.0000	298.9460	0.9510	
5	120.0000	20.1190	12.0000	298.9000	0.9490	
6	120.0000	20.0000	12.0150	298.8380	0.9490	
7	120.0000	20.1620	12.0000	298.7710	0.9470	
8	120.4620	20.0000	12.0000	298.4290	0.9430	
9	120.0000	20.0000	12.0290	298.4070	0.9420	
10	120.7150	20.0000	12.0000	297.9720	0.9360	
11	121.0460	20.0000	12.0000	297.3820	0.9260	
12	120.0000	20.7180	12.0000	297.1710	0.9180	
13	122.7050	20.0000	12.0000	294.4770	0.8800	
14	120.0000	21.7730	12.0000	294.6120	0.8740	
15	120.0000	21.8380	12.0000	294.4740	0.8720	
16	120.0000	22.3180	12.0000	293.5320	0.8560	
17	120.0000	22.5990	12.0000	293.0390	0.8480	
18	120.0000	22.6270	12.0000	292.9940	0.9480	

From the results of Table 6, it was observed that a current of 120ampere, voltage of 20volts, and gas flow rate of 12.00 L/min will result in a welding process with a Hardness Strength of 299.269N/mm2. This solution was selected by design expert as the optimal solution with a desirability value of 95.70%. It can be deduced from the result of Figure 4 that the model developed based on response surface methodology and optimized using numerical optimization method, predicted the Hardness Strength by an accuracy level of 100%. Finally, based on the optimal solution, the contour plots showing hardness response variable against the optimized value of the input variable is presented in Figure 5

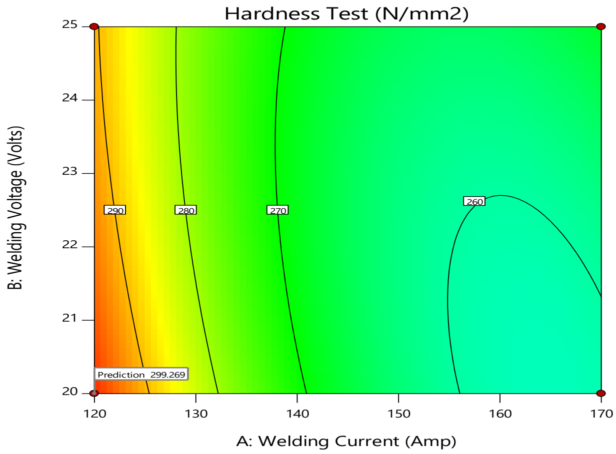

Figure 5. Contour plot for predicting the hardness of the material

4. Conclusion

In this study, Response Surface Methodology was employed to optimize and predict Hardness strength in mild steel weld. The results obtained showed that voltage has a strong influence on the hardness of the material. The models developed possess a variance inflation factor of 1 and P- value less than 0.05 indicating that the model is significant, the model also possessed a high goodness of fit with R^2 (Coefficient of determination) value of 86.07%. The signal to noise ratio was greater than 4, which indicates that the model has adequate strength and potency to predict its target response. The RSM model gave the numerical optimal solution that produced a good weld bead profile. Results of the study showed that RSM is an effective tool for the optimization and prediction of weld penetration, deposition rate and heat input in TIG welding.

Nomenclature

XI,X2, X3	Independent Variable
VIF	Variance Inflation Factor
I	Current in Ampere
V	Voltage in Volt
F	Gas flow rate in Lit/min
GOF	Goodness of Fit
ANOVA	Analysis of Variance
Y	Dependent variable (Regression)
R	Co-efficient of correlation
R^2	Co-efficient of determination
SNR	Signal to noise ratio
TIG	Tungsten Inert Gas

References

[1] Tomkowski. R, Jonsson .S, Lundin .P, and Nerman .P. (2017) Penetration depth investigation of Barkhausen noise signal for case-hardened components. Conference: 12th International Conference on Barkhasuen Noise and MicromagneticTestingAt: Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Dresden, GermanyVolume: ISBN 978-952-68852-0-9

[2] Achebo, J. I. (2011) Optimization of GMAW Protocols andParameters for Improving Weld Strength Quality. delivered at the 2011 World Congress on Engineering: International Conference of Manufacturing Engineering and Engineering

[3] Achebo, J.I. (2012) Complex Behavior of Forces Influencing Molten Weld Metal Flow based on Static Force Balance Theory 2012 International Conference on Solid State Devices and Materials Science Physics Procedia 25 pp. 317 – 324

[4] Kumar, V. (2011). Modeling of Weld Bead Geometry and Shape Relationships in Submerged Arc Welding Using Developed Fluxes. Jordan Journal of Mechanical and Industrial Engineering. Vol.5 (5) pp. 461-470.

[5] Olabi, A.G. and Hashmi, M.S.J (1995). The effect of post-weld heat-treatment on mechanical- properties and residual-stresses mapping in welded structural steel. J Material Process Technology; Vol 55 P 117–22.

[6] Etin-osa C.E and Achebo J.I (2017) Analysis of Optimum Butt Welded Joint for Mild SteelComponents Using FEM (ANSYS). American Journal of Naval Architecture and Marine Engineering. Vol 2(3) pp. 61-70
[7] Etin-Osa D, Etin-Osa C.E. (2019) Forensic Science and the Nigerian Society. Journal of Nuclear Sciences, p-ISSN: 2147-7736, e-ISSN:2148-3981, Available electronically at http:// jns.ankara.edu.tr
[8] Uwoghiren, F.O and Ogbeide, O.O (2021). Investigation of the Combined Effect of Input Parameters on Liquidus Temperature and Arc Length in TIG Welding. Journal of Science and Technology Research**.** Vol.3(1) pp. 126-131.
[9] E.C. Etin-Osa and O.O. Ogbeide (2021). Optimization of the Weld Bead Volume of Tungsten Inert Gas Mild Steel Using Response Surface Methodology. Journal of Science and Technology Research. 3(4): pp. 314-321
[10] Ogbeide, O.O and Akeredolu, K. (2022). Optimization of Tensile Strength of Butt Joint Weldment on Mild Steel Plate Using Response Surface Methodology. Advances in Engineering Design Technology. Vol. 4(1) pp. 11-16.
[11] Elgueder J, L. Roucoules, B, E. Rouhaud, C, F. Cochennec. (2011) Integration of residual stresses in the design of mechanical parts. Materials Science Forum. 681: pp. 255-260. https://www.scientific.net/MSF.681.255.
[12] Withers P. J and Bhadeshia.H. K. D. H. (2014). Residual stress: Part 1-Measurement techniques. Materials Science and Technology. 17(4) pp. 355-365.