Advances in Engineering Design Technology Vol. 4(1) 2022 pp. 11-16 ISSN-2682-5848

NIPES

Advances in Engineering Design Technology

Journal homepage: www.nipesjournals.org.ng

Optimization of Tensile Strength of Butt Joint Weldment on Mild Steel Plate Using Response Surface Methodology

[1]Ogbeide, O.O and [2]Akeredolu, K.

[1,2]Department of Production Engineering, University of Benin, Benin City, Nigeria
E-mail addresses: [1]osarobo.ogbeide@uniben.edu and [2]akeredolu.kolawole@yahoo.com

ARTICLE INFORMATION

Article history:
Received 24 February 2022
Revised 03 March 2022
Accepted 07 March 2022
Available online 27 March 2022

Keywords:
Mild steel plate, ANOVA, RSM, TIG, tensile test, Contour plot, Surface plot

https://doi.org/10.37933/nipes.a/4.1.2022.2

https://nipesjournals.org.ng

ABSTRACT

The service life of engineering structures is affected by the quality and strength of the welded joints. Tensile tests are performed for several reasons. The results obtained are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. This tests often are measured during development of new materials and processes, so that different materials and processes can be compared. Tensile tests often are used to predict the behavior of a material/ weldment under forms of loading other than uniaxial tension. This study was carried out with the aim of improving the tensile properties of a mild steel weldment from thermal effect of the welding process. Mild steel plate was cut into dimension 60mmx40mmx10mm with a power hacksaw, grinded and cleaned before the welding process. The experimental matrix was made of twenty (20) runs, generated by the design expert 11.1.0.1 software adopting the central composite design. The response was measured, which is the tensile strength and then modelled using the response surface methodology. In this study the response surface methodology was applied to optimize and predict the maximum tensile strength of a butt joint weldment on an I-section mild steel plate. The result obtained in this study shows that the current and voltage has a very strong influence on the tensile strength. Based on the findings, it is summarized that the Maximum tensile strength is 526.316MPa when a welding voltage of 24V, current of 170A and gas flow rate of 13lit/min.

1. Introduction

Steel is an important engineering material. It has found applications in many areas such as vehicle parts, truck bed floors, automobile doors, domestic appliances etc. It is capable of presenting economically a very wide range of mechanical and other properties. Mild steel is cheap and malleable but has a relatively low tensile strength. Surface hardness can be increased through carburizing which involves heating the alloys in a carbon rich environment [1]

Mohammed et al [2] investigated the mechanical and metallurgical properties of medium carbon steel using shielded metal arc welding process (SMAW) with reference to the weld metal, heat affected zone and parent metal. From the results, shielded metal arc welding (SMAW) of medium carbon steel increased the strength of the welded joint in particular the heat affected zone (HAZ), as revealed by lower impact strength, higher tensile strength and hardness values as compared with the parent and weld metal which is attributed to the fine ferrite matrix and fine pearlite distribution as compared to the weld and parent metal. However, there was a loss of ductility at the welded joint resulting to brittleness of the material.

Ramchandran [3] studied the various effect of the TIG welding on the Austenitic stainless steel 316L on micro structural changes through destructive and nondestructive method and various parameters such as tensile strength, hardness on varying the current, voltage and gas flow ratio respectively. Hooda et al [4] have developed a response surface model to predict tensile strength of inert gas metal arc welding of AISI 1040 medium carbon steel joint. In this research the welding voltage, current, wire speed and gas flow rate are considered as input parameter. The experiment was designed by face centered composite design matrix. From the experiment they conclude that the optimum values of process parameter such as welding voltage 22.5 V, wire speed 2.4 m/min and gas flow rate 12 l/min for maximum yield strength both transverse and longitudinal are remain same but the current value is 190 A and 210 A respectively. Samples of engineering materials are subjected to a wide variety of mechanical tests to measure their strength or other properties of interest. Such samples, called specimens, are often broken or grossly deformed in testing. Among the various mechanical tests conducted are tensile and notch-impact tests. Khoushid et al. [5] studied the mechanical properties of welded aluminum 6061pipe using three different types of welds. Weldments with rotation speed (1800 RPM) and travel speed 4mm/min of MIG, TIG and Friction welding were compared. The microstructure of the welds, including the nugget zone and heat affected zone, has been compared and concluded that the micro hardness values are higher in the weld region of FSW joints compared to MIG and TIG. Furthermore, FSW welds exhibit higher strength values compared to others. The mechanical properties of materials are determined by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. In the real life, there are many factors involved in the nature in which loads are applied on a material. The following are some common examples of how these loads might be applied: tensile, compressive and shear, just to name a few. These properties are important in materials selections for mechanical design. Other factors that often complicate the design process include temperature and time factors. Lakshminarayan and Shanmugam[6] evaluated the tensile and impact properties, micro hardness , microstructure, and fracture surface morphology of continuous current gas tungsten arc welding (CCGTAW), pulsed current gas tungsten arc welding (PCGTAW), and plasma arc welding (PAW) joints and investigated that the PAW joints of fss steel shows superior tensile and impact properties when compared with CCGTAW and PCGTAW joints and this is mainly due to lower heat input, finer fusion zone grain diameter, and higher fusion zone hardness. The tensile test is used to access some key mechanical properties such as yield stress, ultimate tensile stress, modulus of elasticity and ductility of structural materials. It consists of slowly pulling a sample of material uni-axially along its axis with a tensile load until fracture. Two specimen geometries, cylindrical and flat, are recommended by the American Society for Testing and Materials (ASTM) for tensile testing of metals. The choice of specimen geometry and size often depends on the product form in which the materials is to be used or the amount of material available for samples. Flat specimen geometry is preferred when the end product is a thin plate or sheet. Round cross-section specimens are preferred for products such as extruded bars, forgings and castings [7]. This study aim at improving the mechanical properties of a mild steel weldment using Response Surface methodology.

2. Material and Method

2.1 Material

The materials used in this study contain mild steel plate. Mild steel used has Carbon content of 0.18% with a melting point of 1490^{o}C.100 pieces of mild steel Coupons measuring 80mmx40mmx10mm was cut with a power hacksaw, grinded and cleaned before the welding process. Two pieces of the mild steel plate were welded together using the input process parameters contained in Tungsten Inert Gas welding machine to form an I-section. 100% Argon gas was the shielding gas. The experiment was performed 20 times using 5 specimens for each run. The input process parameters comprise of the welding voltage, welding current, and Gas flow rate. The layout of the input process parameters is made into a matrix design. The Design matrix shows the random distribution of input parameters.

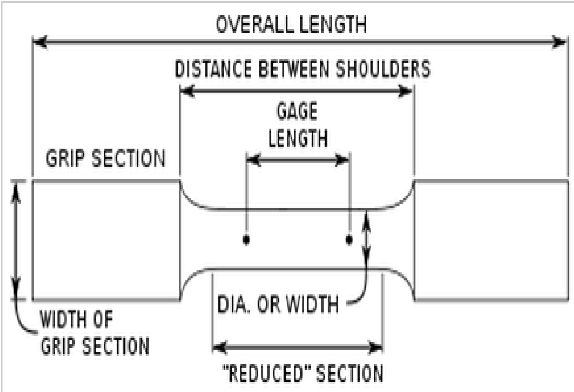

Figure 1: Test specimen

2.2. Methods

The input process parameters are current, voltage and gas flow rate. The range of the process parameters is shown in the Table 1.

Table 1: Experimental factors and levels

Factor	Units	Low Level (-1)	High Level (+1)
A – Current	I	120	170
B – Voltage	V	18	24
Gas Flow Rate	percent	13	16

3 Results and Discussion

3.1 Results and Discussion

Twenty (20) experimental runs were carried out. One hundred welded samples were produced per five samples for each run. Each experimental run comprises of the welding input parameters which are the welding current, voltage and gas flow rate. And the response (tensile strength) was measured and the result presented in Table 2.

Table 2: Design matrix showing the real values and the experimental values

Std	Block	Run	Space Type	Factor 1 A:current I	Factor 2 B:voltage V	Factor 3 C:Gas Flow rate Lit/min	Response1 Tensile Strength MPa
4	Block1	1	Center	145	21	14.5	315.789
6	Block1	2	Center	145	21	14.5	319.298
5	Block1	3	Center	145	21	14.5	324.561
8	Block1	4	Center	145	21	14.5	319.298
3	Block1	5	Center	145	21	14.5	322.807
19	Block1	6	Center	145	21	14.5	324.561
18	Block1	7	Axial	145	15.95	14.5	350.877
17	Block1	8	Axial	145	26.05	14.5	456.14
12	Block1	9	Axial	102.96	21	14.5	280.702
13	Block1	10	Axial	187.04	21	14.5	398.421

16	Block1	11	Axial	145	21	11.96	368.421
9	Block1	12	Axial	145	21	17.02	456.14
7	Block1	13	Factorial	120	18	13	263.158
1	Block1	14	Factorial	120	24	13	403.509
10	Block1	15	Factorial	170	18	13	298.246
15	Block1	16	Factorial	170	24	13	526.316
20	Block1	17	Factorial	120	18	16	385.965
2	Block1	18	Factorial	120	24	16	298.246
14	Block1	19	Factorial	170	18	16	438.596
11	Block1	20	Factorial	170	24	16	511.404

3.2 Modelling using Response Surface Methodology (RSM)

A second order mathematical model presented in equation was developed to describe the tensile strength measurement during welding operation of mild steel plate, using TIG welding process. The input variables of the model include current (A),Voltage (B) and Gas flow rate (C).

$$\textbf{Tensile Strength} = 321.02 + 45.52A+38.83B+21.43C+31.03AB+13.49AC-47.92BC+6.94A^2+29.49B^2+32.48C^2 \qquad (1)$$

The model developed in Equation (1)describes a polynomial response behavior having a highest order of two for the model and also preventing model alias. In assessing the strength of the quadratic model towards maximizing the tensile strength, ANOVA was applied and result is presented in Table 4.

Table 3: Model summary showing highest and lowest values of factors

Name	Units	Type	Changes	Std. Dev.	Low	High
Current	I	Factor	Easy	0	120	170
Voltage	V	Factor	Easy	0	18	24
Gas Flow Rat	Lit/min	Factor	Easy	0	13	16
Tensile Stren	MPa	Response		16.1298	263.158	526.316

Result of Table 3 revealed that the model is of the quadratic type which requires the polynomial analysis order as depicted by a typical response surface design. The minimum value of tensile strength was observed to be 263.158MPa with a maximum value of 526.316MPa and standard deviation of 16.1298.

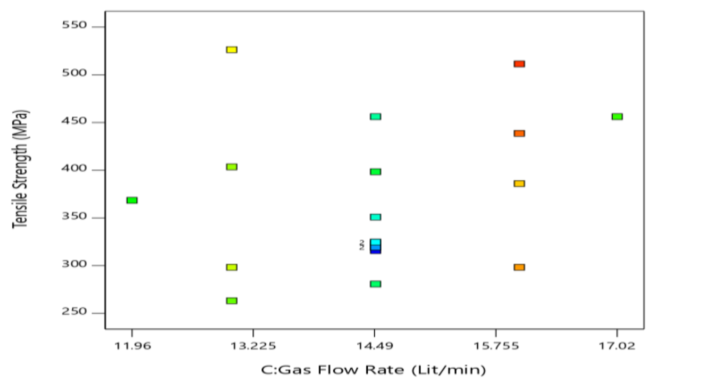

Figure 2: Graph Columns feature for design layout

Before focusing on modeling the response as a function of the factors varied in this RSM experiment, it will be good to assess the impact of the blocking via a simple scatter plot. The correlation grid that pops up with the Graph Columns can be very interesting. First off, observe that it exhibits red along the diagonal—indicating the complete (r=1) correlation of any variable with itself (Run vs Run, etc). The graph in Figure 2 is used to visually show or compare in the cases whereby more than one blocks is selected for our design, to see if there is a difference between block 1 and 2 or as the case may be and to see how strong the correlation between blocks factors and responses are.

Table 4: ANOVA for quadratic model

Source	Sum of squares	Df	Mean square	F-value	p-value	
Model	1.080E+05	9	11997.81	46.12	< 0.0001	significant
A	28298.85	1	28298.85	108.77	< 0.0001	
B	20607.36	1	20607.36	79.21	< 0.0001	
C	6288.42	1	6288.42	24.17	0.0006	
AB	7703.26	1	7703.26	29.61	0.0003	
AC	1455.14	1	1455.14	5.59	0.0396	
BC	18367.93	1	18367.93	70.60	< 0.0001	
A^2	693.01	1	693.01	2.66	0.1337	
B^2	12565.58	1	12565.58	48.30	< 0.0001	
C^2	15343.42	1	15343.42	58.97	< 0.0001	
Residual	2601.70	10	260.17			
Lack of Fit	2540.14	5	508.03	41.26	0.0005	significant
Pure Error	61.56	5	12.31			
Cor Total	1.106E+05	19				

The Model F-value of 46.12 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Lack of Fit F-value of 41.26 implies the Lack of Fit is significant. There is only a 0.05% chance that a Lack of Fit F-value this large could occur due to noise. Significant lack of fit is bad -- we want the model to fit.

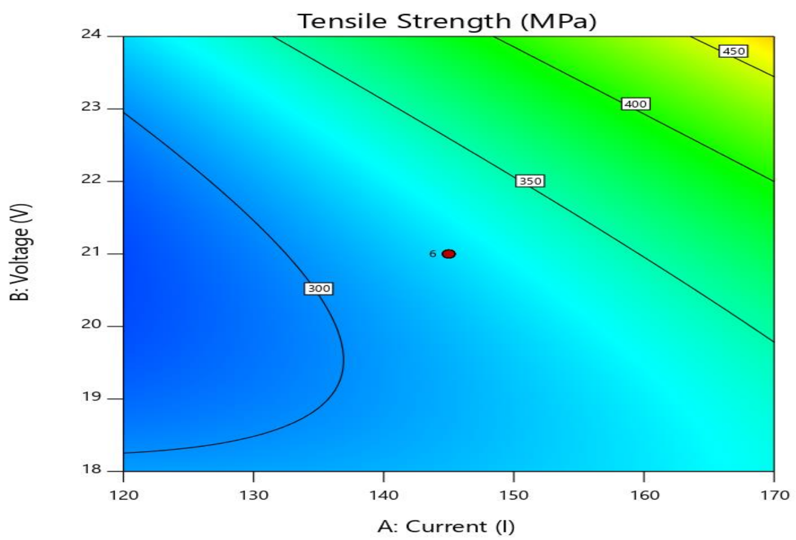

Figure 3: Contour plot

Figure 3 is a plot of tensile strength as a function of current and voltage at a mid-level slice of gas flow rate. This slice includes six center points as indicated by the dot at the middle of the contour plot. By replicating center points, you get a very good power of prediction at the middle of your experimental region.

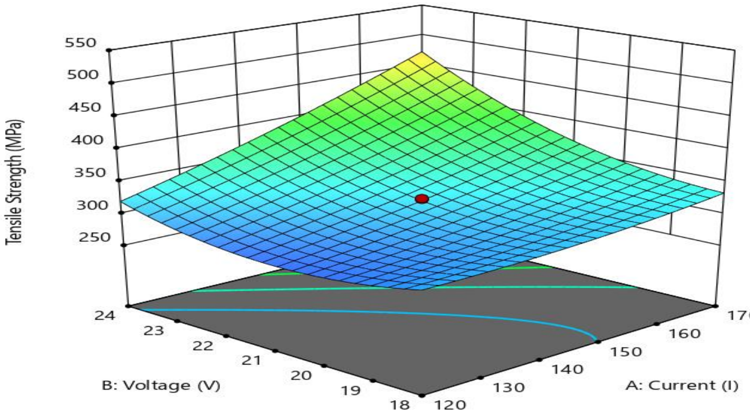

Figure 4: Surface plot

The 3D surface plot shows the relationship between the input variables (current, voltage and gas flow rate) and the response variables (tensile strength). 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 view of the surface. 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.

4. Conclusion

In this study the response surface methodology was applied to optimize and predict the maximum tensile strength of a butt joint weldment on an I-section mild steel plate. The result obtained in this study shows that the current and voltage has a very strong influence on the tensile strength. Based on the findings, it is summarized that the maximum tensile strength is 526.316MPa when a welding voltage of V = 24V, current = 170A and gas flow rate = 13lit/min.

References

[1] Arunkumar A, Ravichandran.S (2016) Theoretical and Experimental Analysis Of T-Joint In TIG Welding Process. International Journal of Scientific Engineering and Applied Science. Vol. 2, No. 6, pp. 237-247.

[2] Monohardas T, Reddy Madhusudan G, Mohamad N. A (1999) comparative evaluation of gas tungsten and shielded metal arc weld of a “ferritic” stainless steel, J Mater Process Technol. Vol. 88, pp.266–275p.

[3] Ramachandran, R (2015). Analysis and Experimental Investigations of Weld Characteristics For A TIG Welding With SS316L. International Journal of Advances in Engineering Research (IJAER),Vol. 10, No.2, pp.2454-1796.

[4] Ajit Hooda, Ashwani Dhingra and Satpal Sharma,(2012)“Optimization of MIG welding process parameter to predict maximum yield strength in AISI 1040”, International journal of Mechanical engineering and Robotics research, Vol.1, No. 3, pp.-203-213

[5] Khourshid AM, Ibraheem S (2016) Analysis of Welded Joints Using Friction Stir Welding, Metal Inert Gas and Tungsten Inert Gas. Engineering and Technology in India. Vol.7, No.1, PP. 1-7.

[6] Lakshminarayanan, A.K, Shanmugam K, V Balasubramanian.(2009), “Effect of Autogenous Arc Welding Processes on Tensile and Impact Properties of Ferritic Stainless Steel Joints” Journal of iron and steel research, international. PP. 62-68.

[7] Armentani, E., Esposito, R., Sepe, R. (2007). The effect of thermal properties and weld efficiency on residual stresses in welding, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 20, No. 1-2, pp.319-322.