Prediction of Optimum Weld Tensile Strength Using Response Surface Methodology

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Abstract — Metals are often subjected to various types of stresses, usually under tensile stress, quick failure of material can be encouraged especially when poor combinations of process parameters are employed in joining of the material. Tensile strength is regarded as the maximum stress that a material can sustain under tension. The aim of this study is to predict the weld tensile strength of tungsten inert gas (TIG) mild steel welds using Response Surface Methodology (RSM), with the purpose of achieving optimum results.

The input parameters considered were current, voltage, and gas flow rate. The TIG welding process was used to join two pieces of mild steel plates, after which tensile test was conducted on the specimen. The experimental result was analyzed using the RSM.

Weld Tensile test of 596.218MPa with a desirability value of 95.70% was observed to be the best, resulting from the optimized process parameters of current of 120.00 Amp, voltage of 20.00 volt and gas flow rate of 12.00 L/min.

Index Terms — Mild Steel, RSM, surface Plot, Tensile test, TIG.

I. INTRODUCTION

The importance of mild steel in our daily activity cannot be over emphasized. Usually, this materials are subjected to different form of stresses and in other to prevent sudden failure, it is imperative to determine the strength of the material through subjecting it to various forms of test [1]. According to [2], the failure of structural materials especially steel is of great concern globally. Some material properties affected due to welding includes tensile strength, hardness, macro and micro-structural features and toughness [3]. Tensile strength described as the maximum stress that a material can sustain under tension. In other words, it can be defined as the amount of applied load per cross sectional area that a material can withstand before failure. Mathematically it is calculated as the ratio of maximum tensile load to the original cross section area. Mild steel or low carbon steel offers numerous applications in fields of construction and engineering. The carbon in steel affects the material's ductility and strength; steel with higher percentage of carbon are stronger compared to low carbon steel [4]. On the other hand, high carbon steel are less ductile when compared to low carbon steel. Mild steel is the most versatile and common form of steel as it provide mechanical properties that are acceptable for many applications [5]. No doubt that mild steel has become an indispensable class for different applications

like construction of large ships; oil, water and gas pipelines; drilling platforms; pressure vessels; building constructions; bridges; storage tanks etc. Welding on the other hand is a joining process of two or more metals [6]. This process usually introduce large amount of heat into the welded zone, thereby altering the microstructure around the area of the welded material [7]. If not properly controlled, it could reduce the tensile strength around the welded vicinity and alter the factor of safety initially designed for. Tungsten inert gas (TIG) welding is one of the best arc welding processes currently in used. This research work was aimed at prediction and optimization of tensile strength of mild steel specimen with the use of response surface methodology (RSM) tool.

II. MATERIALS AND METHODS

A. Materials

Mild steel plate of 10mm and 100% argon gas were purchased locally and transferred to the Department of Welding and fabrication technology, Petroleum Training Institute (PTI), Warri, Delta State, Nigeria. The 10mm plate was cut into 200 pieces of dimension 140mm by 30mm by 10mm with a power hacksaw and welded. After welding, the specimens were trimmed with an angle grinder to take a dog bone shape, so it could fit into the tensometer. Response surface methodology (RSM) was employed to analyze the results obtained. The input ranges of parameters used for the research is presented in Table I.

TABLE I: WELDING PROCESS PARAMETERS LIMITS

Process parameters	Unit	Symbol	Low (-)	High (+)
Welding Current	Amp	I	120	170
Welding Voltage	Volts	V	20	25
Gas Flow Rate	Lit/mill	F	12	14

The selected input parameters have the upper (+) and lower limits (-). The limits of the four welding variables are shown in Table I.

B. Method

After welding, the sample was reduced to 100 pieces, prepared with the following dimensions as presented in Fig. 1. $l_2 = 280$ mm, $b_1 = 30$ mm, $l_0 = 80$ mm, $b = 15$ mm $l_1 = 100$ mm and $t = 10$ mm. The experimental process was performed 20 times, with five (5) specimens for each run.

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Fig. 1. Measurement of Tensile Test Piece.

III. RESULTS

Twenty (20) experimental runs were carried out, each experimental run comprising the weld current, weld voltage and gas flow rate. The tensile strength test, was measured and the responses presented in Table II.

TABLE II: EXPERIMENTAL RESULT FOR THE TENSILE STRENGTH TEST

Run	A: Welding Current Amp	B: Welding Voltage Volts	C: Gas Flow Rate Lit/min	Tensile Test MPa
1	145	22.5	13	508.725
2	145	22.5	13	491.4
3	187.045	22.5	13	557.7
4	145	22.5	11.3182	557.55
5	170	20	12	511.15
6	145	18.2955	13	497.7
7	170	25	14	574.403
8	120	20	14	510.3
9	170	25	12	526.05
10	120	25	12	584.325
11	120	20	12	589.05
12	102.955	22.5	13	601.65
13	170	20	14	474.075
14	145	22.5	14.6818	502.425
15	145	22.5	13	499.275
16	145	22.5	13	530.675
17	145	26.7045	13	540.225
18	145	22.5	13	516.6
19	120	25	14	565.425
20	145	22.5	13	474.075

The Analysis of Variance (ANOVA) obtained from Table III with P-value of 0.0004, shows that the model source for the tensile test is statistically significant. ANOVA is a tool in statistics employed to determine whether there are any significant differences of means among two (2) or more groups. Accuracy of the mathematical model greatly depends on the numbers of individual variables (i.e., A, B, C etc.) in the model with p-values less than 0.05.

TABLE III: ANOVA FOR TENSILE TEST RESPONSE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	25720.46	9	2857.83	11.06	0.0004	significant
A-Welding Current	4124.59	1	4124.59	15.96	0.0025	
B-Welding Voltage	4117.94	1	4117.94	15.93	0.0026	
C-Gas Flow Rate	2348.28	1	2348.28	9.08	0.0130	
AB	525.33	1	525.33	2.03	0.1845	
AC	1483.15	1	1483.15	5.74	0.0376	
BC	2638.19	1	2638.19	10.21	0.0096	
A ²	9911.53	1	9911.53	38.34	0.0001	
B ²	326.54	1	326.54	1.26	0.2873	
C ²	1080.29	1	1080.29	4.18	0.0682	
Residual	2585.08	10	258.51			
Lack of Fit	617.61	5	123.52	0.3139	0.8854	not significant
Pure Error	1967.47	5	393.49			
Cor Total	28305.55	19				

Coefficient of determination (R-Squared) values of 0.9087 as observed in Table 4 which shows the strength of response surface methodology (RSM) and its ability to maximize the weld tensile test. Adjusted (R-Squared) values of 0.8265 as observed in Table IV indicates a model with 82.65% reliability. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision values of 10.93 as observed in Table IV indicate an adequate signal. This model can be used to navigate the design space and maximize the weld tensile test (TT).

TABLE IV: MODEL SUMMARY STATISTICS FOR TENSILE TEST

Std. Dev.	16.08	R ²	0.9087
Mean	530.64	Adjusted R ²	0.8265
C.V. %	3.03	Predicted R ²	0.7297
		Adeq Precision	10.9300

The mathematical model representing the weld tensile test (TT) is presented in (1). A denotes the welding current, b represent the welding voltage and C represent the gas flow rate.

$$TT = 503.57 - 17.38A + 17.36B - 13.11C + 8.10AB + 13.62AC + 18.16BC + 26.23A^2 + 4.76B^2 + 8.66C^2 \quad (1)$$

To assess the correctness of forecast and established the fitness of response surface methodology using the quadratic model, a reliability plot of the predicted and actual values of the weld tensile test response were obtained as presented in Fig. 2.

Fig. 2. Reliability plot of predicted versus actual weld tensile test response.

To examine the effects of combine variables such as the weld current and voltage at constant gas flow rate of 13 L/min, on the weld tensile test, the 3D surface plots presented in Fig. 3 was employed.

Fig. 3. 3D surface plot showing theEffect of current and voltage on weld tensile test.

Numerical optimization was accomplished to ascertain the attractiveness of the overall model. In the numerical optimization phase, design expert was instructed to maximize the weld tensile test while also determining the optimum value for voltage, current and gas flow rate. Fig. 4 presents the interphase of the numerical optimization with maximization goal target.

Fig. 4. Interphase of numerical optimization model for maximizing WPSF.

Table V shows the numerical optimization. Eighteen (18) optimal solutions where produced, but five where selected.

TABLE V: FIVE OPTIMUM SOLUTION FOR THE WELD TENSILE TEST

Number	Welding Current	Welding Voltage	Gas Flow Rate	Tensile Test	Desirability	
1	120.00	20.00	12.00	596.22	0.957	Selected
2	120.00	20.00	12.00	596.22	0.957	
3	120.03	20.00	12.01	595.59	0.952	
4	120.00	20.18	12.00	594.93	0.946	
5	120.00	20.00	12.02	594.77	0.945	

From the results of Table V, it was observed that current of 120.00 Amp, voltage of 20.00 volt, and gas flow rate of 12.00 L/min produced a weld tensile test of 596.218 MPa. This

solution obtained was selected by design expert as the optimal solution with a desirability value of 95.70%.

Finally, based on the optimal solution obtained, the contour plots showing the weld tensile test response variable against the optimized value of the input variable is presented in Fig. 5.

Fig. 5. Predicting weld Tesnsile test using contour plot.

IV. DISCUSSION

The responses obtained in Table II, was employed to develop the ANOVA table presented in Table III. The **Model F-value** of 11.06 was obtained which implies the model was significant, as only 0.04% could result due to noise in the system. The **P-values** obtained was less than 0.0500 indicating a significant model terms. From Table III, current, voltage and gas flow rate were represented with A, B and C coded symbols. A, B, C, AC, BC and A² had a p-value less than 0.05, which implies that the mathematical model formed using these combinations would produce a significant model terms with reduced prediction error. Those values greater than 0.1000 in Table III, are not significant. If there are too many insignificant model terms, it may affect the prediction accuracy of the model. In Table IV, it was observed that the **Predicted R²** of 0.7297 was in reasonable agreement with the **Adjusted R²** of 0.8265; having a difference of 0.0968 which was less than 0.2 in line with literature. **Adequate Precision** was used to measures the signal to noise ratio. A ratio greater than 4 was desirable, according to literature. In Table IV, a ratio of 10.930 was obtained, indicating a robust adequate precision. This model was applied to navigate the design space, and (1) was developed to predict the weld tensile test.

In establishing the correctness of the reliability for predicting the weld tensile test, a linear plot was used to fit the predicted and actual response as shown in Fig. 2, the results showed an acceptable positive slope with minimal noise along the slope. From the 3D surface plot provided in Fig. 3, it was also observed that an increase in current, greatly affect the tensile strength. The green area on the 3D mat denotes the area with good tensile strength, while the blue area shows the lowest tensile region. To maximize the tensile strength, process parameters that would result to responses in

the green zone should be targeted. The interphase of numerical optimization presented in Fig. 4, defines the lower and upper limit of the response with the level of importance indicated. In other to maximize the weld tensile strength, the weight leans towards the higher limit as seen in Fig. 4. The contour plots in Fig. 5 show the predicted optimization region of weld tensile test. The red region represents the area with the strongest tensile test. Just like in Fig. 3, it was also observed that the weld current had a stronger effect on the tensile test. From the results of Table V, it was observed that current of 120.00 Amp, voltage of 20.00 volt, and gas flow rate of 12.00 L/min produced an optimal weld tensile test of 596.218 MPa with a desirability value of 95.70%.

V. CONCLUSION

In this study, prediction and optimization of weld tensile test was conducted on mild steel welded specimen using tungsten inert gas (TIG) welding process. A mathematical model was developed to predict the weld tensile test in (1). Weld Tensile test of 596.218 MPa with a desirability value of 95.70% was observed to be the best, resulting from the optimized process parameters of current of 120.00 Amp, voltage of 20.00 volt and gas flow rate of 12.00 L/min. This process parameters produced the most reliable weldment on the specimen, with current having the highest effect on the quality of the weldment.

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