**Nigerian Journal of Technology (NIJOTECH)**
Vol. 37, No. 2, April 2018, pp. **407 – 415**

Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v37i2.15

# OPTIMIZATION OF WELD STRENGTH PROPERTIES OF TUNGSTEN INERT GAS MILD STEEL WELDS USING THE RESPONSE SURFACE METHODOLOGY

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## ABSTRACT
***The rise in the failure of mechanical components, some of which are attributable to poor weld joints has given rise to research study on the optimization of weld joint strengths. The quality of welds is highly dependent on the right combination of input process parameters. Irrespective of the welding process, the need for the right combination of input process parameters cannot be over emphasized. To achieve a desired weld quality, the weld features such bead geometry and the mechanical properties were examined and related to the weld input parameters. The Response Surface Methodology (RSM) was used to predict and optimize the weld strength properties (tensile strength and hardness) of a Gas Tungsten Arc Welded 10mm thick mild steel plate. Model adequacy checks, was done using analysis of variance (ANOVA) and found to be adequate. The ANOVA showed that current and gas flow rate had the most significant effect on the tensile strength, but on the Hardness, the gas flow rate and filler rod had the most significant effect. The model F-value of 12.69 at a P value of 0.0001 for the tensile strength and F-value of 8.51 at a P value of 0.0001 for the hardness, showed the significance of the model employed. The optimal tensile strength of 497.555N/mm$^2$ and Hardness of 192.556BHN was observed at a current of 170.12 amp, voltage of 19.84 volt, gas flow rate of 23.92 l/min and filler rod diameter of 2.4mm.***

***Keywords:*** *welding, gas tungten arc welding, tensile strength, hardness, response surface methodology,*

## 1. INTRODUCTION
Welding is a major need for most manufacturing industries, almost every industry where metals are used cannot survive without welding. Welding, which is a major means of fabrication is the back bone of all metal products. Among the various welding processes available, Tungsten Inert Gas (TIG) welding has become the process of choice for exotic metals and joints of high quality, as well as totally precise welds that can be done on any weldable metal [1]. Generally, the quality of a welded joint, (in terms of different features such as mechanical properties), is directly influenced by the weld input process parameters. By varying the input process parameters combination, the output would produce different welded joints with significant variation in their mechanical properties. Therefore, the essence of a control system in arc welding is necessary to eliminate much of the "guess work" often employed by welders to specify welding parameters for a given task [2].
The objective of this study is to predict and optimize weld strength properties of tungsten-inert gas welded mild steel plate using the Response Surface Methodology.

## 2. LITERATURE REVIEW
Investigation into the relationship between the welding process parameters and bead geometry began in the mid-1900s and regression analysis was applied to welding geometry research [3, 4]. Quite a large number of techniques have been developed by researchers to solve parameter optimization problems, amongst which are experimental techniques comprising statistical design of experiment, such as Taguchi method, and Response Surface Methodology (RSM). These techniques have become necessary in order to correlate the input parameters to the output variables and to optimize the welding process through the use of developed models. RSM is a collection of mathematical and statistical techniques for empirical model building, in which a response of interest is influenced by several variables and the objective is to optimize this response [5]. One of the goals for Response Surface Method is to find the optimum response. When there is more than one response then it is important to find the

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compromise optimum that does not optimize only one response [6]. Benyounis and Olabi [7] applied RSM to investigate the effect of laser welding parameters (laser power, welding speed and focal point position) based on four responses (heat input, penetration, bead width and width of heat affected zone) in $CO_2$ laser butt-welding of medium carbon steel plates of 5 mm thick. They found that the heat input plays an important role in the weld-bead parameters; welding speed has a negative effect while laser power has a positive effect on all the responses. The optimization of $CO_2$ Welding Process Parameters for Weld Bead Penetration of Mild Steel using RSM was reported by [8]. Mathematical models were developed correlating the welding process parameters such as voltage, travel speed and welding current with weld bead penetration. The optimized values of the various input parameters obtained, were recorded as follows: arc voltage – 20V, travel speed – 40cm/min, welding current – 230A, maximum bead penetration corresponding data is 0.88mm. Koleva [9] employed the use of RSM to establish the relationship between performance characteristics (weld depth, weld width and thermal efficiency) and its influencing factors (beam power, welding velocity, focus position, focusing current of the beam and the distance to the sample surface) for austenitic stainless steel. Optimal welding regimes were found through the thermal efficiency optimization.

## 3. METHODOLOGY

Mild steel plate of 10mm thick was selected as the material used for the experiment. In order to produce weld specimens, a joint consisting of two mild steel coupons each cut to dimensions of 50mm x 100mm with the aid of a power hack saw and ground at the edges were prepared. The input and output parameters chosen for this study were as follows: Input Parameters: Welding current, Welding Voltage, Gas flow rate, Filler Rod Diameter. Output Parameters: Hardness, Tensile Strength. The range of the values of the process parameters are given as shown below in Table 1.

*Table 1: Welding Parameters and their levels*

| Parameters | Unit | Symbol | Coded Value Low (-) | Coded Value High (+) |
|---|---|---|---|---|
| Welding Current | Amp | A | 140 | 200 |
| Arc Voltage | Volts | V | 15 | 25 |
| Gas Flow Rate | Lit/min | F | 20 | 24 |
| Filler Rod | mm | T | 2.4 | 3.2 |

One of the conventional common approaches utilized by many engineers in manufacturing companies is one-variable-at-a-time (OVAT), where the engineer varies one variable at a time keeping all other variables involved in the experiment fixed. This approach requires large resources to obtain a limited amount of information about the process which is why methods with statistical bases have been developed [10]. It is important to know that some factors may have strong effects on the response, others may have moderate effects and some no effects at all. Therefore, the aim of a well designed experiment is to specify which set of factors in the process affects the process performance most, and then identify best levels for these factors capable of giving the desired quality level. Using the design expert software, a central composite design (CCD) of 30 experimental runs (6 center points, 8 axial points and 16 factorial points) was developed as shown in Table 2.

*Table 2: Central Composite Design Matrix (CCD)*

| Exp No | Current Amp | Voltage Volt | Gas flow Rate L/min | Filler Rod mm | Exp No | Current Amp | Voltage Volt | Gas flow Rate L/min | Filler Rod mm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 170 | 20 | 22 | 3.2 | 16 | 200 | 15 | 20 | 2.4 |
| 2 | 170 | 20 | 22 | 3.2 | 17 | 140 | 25 | 20 | 2.4 |
| 3 | 170 | 20 | 22 | 3.2 | 18 | 200 | 25 | 20 | 2.4 |
| 4 | 170 | 20 | 22 | 3.2 | 19 | 140 | 15 | 24 | 2.4 |
| 5 | 170 | 20 | 22 | 3.2 | 20 | 200 | 15 | 24 | 2.4 |
| 6 | 170 | 20 | 22 | 3.2 | 21 | 140 | 25 | 24 | 2.4 |
| 7 | 110 | 20 | 22 | 3.2 | 22 | 200 | 25 | 24 | 2.4 |
| 8 | 230 | 20 | 22 | 3.2 | 23 | 140 | 15 | 20 | 3.2 |
| 9 | 170 | 10 | 22 | 3.2 | 24 | 200 | 15 | 20 | 3.2 |
| 10 | 170 | 30 | 22 | 3.2 | 25 | 140 | 25 | 20 | 3.2 |
| 11 | 170 | 20 | 18 | 3.2 | 26 | 200 | 25 | 20 | 3.2 |
| 12 | 170 | 20 | 26 | 3.2 | 27 | 140 | 15 | 24 | 3.2 |

| Exp No | Current Amp | Voltage Volt | Gas flow Rate L/min | Filler Rod mm | Exp No | Current Amp | Voltage Volt | Gas flow Rate L/min | Filler Rod mm |
|---|---|---|---|---|---|---|---|---|---|
| 13 | 170 | 20 | 22 | 2.4 | 28 | 200 | 15 | 24 | 3.2 |
| 14 | 170 | 20 | 22 | 2.4 | 29 | 140 | 25 | 24 | 3.2 |
| 15 | 140 | 15 | 20 | 2.4 | 30 | 200 | 25 | 24 | 2.4 |

### 3.1 Welding of Steel Plates and Edge Preparation of Specimens

Three stages were followed for the experiment. First stage: the metal plate with the prepared edges was taken for forming the welded joint as displayed in the specimen sample shown in Figure 1. The second stage was the welding process and the joint formation using the design matrix. The third stage was the testing and recording of the responses (tensile strength and hardness).

With the thirty (30) experimental runs generated in table 2, thirty coupons were welded using the Gas Tungsten Arc Welding Process and thereafter allowed to cool naturally in open air, with all necessary precautions observed. The welded plates were sliced in transverse section as shown in Figure 2 to obtained samples for the tensile and hardness test.

### 3.2 Tensile Strength Test

Tensile samples as shown in Figure 3 were prepared by milling of the top and bottom surfaces to remove flashing and other surface irregularities in accordance with ASTM specification E8/E8M-11. The tensile test was performed on all the thirty welded specimens, using the universal testing machine.

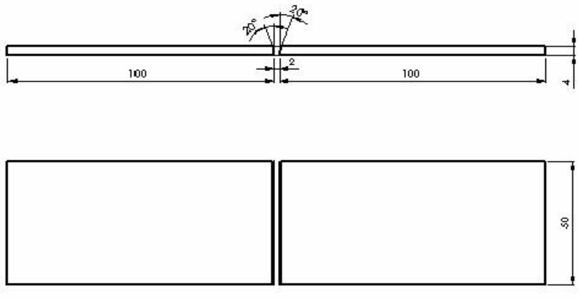


*Figure 1: Sample Specimen*

*Figure 2: Welded Specimens*

*Figure 3: Tensile test specimen*

### 3.3 Hardness Test

Hardness is a measure of how resistant a solid matter is to various kinds of permanent shape change when a force is applied. Rockwell hardness testing is a general method for measuring the bulk hardness of metallic and polymer materials. With the use of a Rockwell hardness testing machine, thirty welded samples were tested for hardness. Response Surface Methodology (RSM): The basic concept of RSM include experimental design, regression analysis and optimization algorithms which are used to investigate the empirical relationship. RSM allows you to specify and fit a model up to the second order, usually a second order model is utilized in response surface methodology [11] and is given by Equation (1).

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{j=1}^{k} \beta_{ii} X_i^2 + \sum_{i}^{k} \sum_{j}^{k} \beta_{ij} X_j X_i + \varepsilon \quad for\ i < j \tag{1}$$

The $\beta$ parameters of the polynomials are estimated by the method of least squares. Where: $y$ is the response factor, $\beta_o$ is the intercept value, $\beta i$ $(i= 1, 2, k)$ is the first order model coefficient, $\beta_{ij}$ is the interaction effect, and $\beta_{ii}$ represents the quadratic coefficients of $x_i$, and $e$ is the random error.

### 4. PRESENTATION OF RESULTS AND DISCUSSION

The randomized design which contains the welding variables and their range of values as well as the experimental results of the response variables (tensile strength and hardness) is presented in Table 3.

Analysis of variance (ANOVA) was needed to check whether or not the model is significant and also to evaluate the significant contributions of the controlling variables towards each response. It uses the F-value which is the variance of the group means and P-value which is the probability of obtaining a result at least as extreme as the one that was actually observed. A large F-value along with a low P-value (0.05% and below) signifies the absence of external influence on the variance as well as confirms that the model is significant [12].

Figure 4 shows a Model F-value of 12.69 along with a p-value of 0.01%, which implies the model is significant, an indication that there is only a 0.01% chance a "Model F-Value" this large could have occured due to noise. Values of "P-value" less than 0.0500 indicate model terms are significant as stated earlier. Current and gas flow rate from oberservation had the most significant effects on the response.

Figure 5 which is the ANOVA observation for the hardness depicts a Model F-value of 8.51 with a p value of 0.01%. This implies that the model is significant, based on the theory that there is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of p value less than 0.0500 indicate model terms with significant effect on the response. From Figure 5, observation shows that gas flow rate and filler rod, had the most significant efffect on the response.

*Table 3: Central Composite Design of Experiment*

| Exp No | Type | Current Amp | Voltage Volt | Gas flow Rate L/min | Filler Rod mm | Response 1 Tensile Strength (MPa) | Response 2 Hardness RHB |
|---|---|---|---|---|---|---|---|
| 1 | Center | 170 | 20 | 22 | 3.2 | 496.5 | 190.2 |
| 2 | Center | 170 | 20 | 22 | 3.2 | 496.3 | 189.4 |
| 3 | Center | 170 | 20 | 22 | 3.2 | 496.4 | 189.6 |
| 4 | Center | 170 | 20 | 22 | 3.2 | 495.9 | 189.3 |
| 5 | Center | 170 | 20 | 22 | 3.2 | 496.3 | 189.6 |
| 6 | Center | 170 | 20 | 22 | 3.2 | 496.2 | 189.2 |
| 7 | Axial | 110 | 20 | 22 | 3.2 | 496.8 | 173.4 |
| 8 | Axial | 230 | 20 | 22 | 3.2 | 489.9 | 186.5 |
| 9 | Axial | 170 | 10 | 22 | 3.2 | 485.9 | 179.2 |
| 10 | Axial | 170 | 30 | 22 | 3.2 | 483.4 | 189.4 |
| 11 | Axial | 170 | 20 | 18 | 3.2 | 462.3 | 171.3 |
| 12 | Axial | 170 | 20 | 26 | 3.2 | 490.2 | 191.2 |
| 13 | Axial | 170 | 20 | 22 | 2.4 | 480.35 | 192.3 |
| 14 | Axial | 170 | 20 | 22 | 2.4 | 478.2 | 174.5 |
| 15 | Fact | 140 | 15 | 20 | 2.4 | 468.7 | 182.4 |
| 16 | Fact | 200 | 15 | 20 | 2.4 | 469.6 | 184.2 |
| 17 | Fact | 140 | 25 | 20 | 2.4 | 460.3 | 181.3 |
| 18 | Fact | 200 | 25 | 20 | 2.4 | 486.35 | 185.4 |
| 19 | Fact | 140 | 15 | 24 | 2.4 | 494.6 | 190.5 |
| 20 | Fact | 200 | 15 | 24 | 2.4 | 496.1 | 185.4 |
| 21 | Fact | 140 | 25 | 24 | 2.4 | 472.3 | 190.2 |
| 22 | Fact | 200 | 25 | 24 | 2.4 | 488.1 | 187.6 |
| 23 | Fact | 140 | 15 | 20 | 3.2 | 477.8 | 178.2 |
| 24 | Fact | 200 | 15 | 20 | 3.2 | 472.9 | 173.4 |
| 25 | Fact | 140 | 25 | 20 | 3.2 | 485 | 169.8 |
| 26 | Fact | 200 | 25 | 20 | 3.2 | 475.7 | 174.9 |
| 27 | Fact | 140 | 15 | 24 | 3.2 | 492.3 | 187.7 |
| 28 | Fact | 200 | 15 | 24 | 3.2 | 482.1 | 182.3 |
| 29 | Fact | 140 | 25 | 24 | 3.2 | 486.35 | 185.4 |
| 30 | Fact | 200 | 25 | 24 | 2.4 | 480.2 | 190.4 |

Use your mouse to right click on individual cells for definitions.

Response 1 Tensile Strength

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 3170.68 | 14 | 226.48 | 12.69 | < 0.0001 | significant |
| A-Current | 121.05 | 1 | 121.05 | 6.78 | 0.0199 | |
| B-Voltage | 25.63 | 1 | 25.63 | 1.44 | 0.2494 | |
| C-Gas Flow Ra | 956.34 | 1 | 956.34 | 53.58 | < 0.0001 | |
| D-Filter Rod | 6.00 | 1 | 6.00 | 0.34 | 0.5707 | |
| AB | 95.55 | 1 | 95.55 | 5.35 | 0.0353 | |
| AC | 8.70 | 1 | 8.70 | 0.49 | 0.4957 | |
| AD | 349.69 | 1 | 349.69 | 19.59 | 0.0005 | |
| BC | 199.52 | 1 | 199.52 | 11.18 | 0.0044 | |
| BD | 36.30 | 1 | 36.30 | 2.03 | 0.1743 | |
| CD | 83.72 | 1 | 83.72 | 4.69 | 0.0468 | |
| $A^2$ | 442.75 | 1 | 442.75 | 24.81 | 0.0002 | |
| $B^2$ | 217.77 | 1 | 217.77 | 12.20 | 0.0033 | |
| $C^2$ | 663.33 | 1 | 663.33 | 37.17 | < 0.0001 | |
| $D^2$ | 475.00 | 1 | 475.00 | 26.61 | 0.0001 | |

*Figure 4: ANOVA table for validating the model significance in optimizing tensile strength*

Use your mouse to right click on individual cells for definitions.

Response 2 Hardness

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 1177.08 | 14 | 84.08 | 8.51 | < 0.0001 | significant |
| A-Current | 24.60 | 1 | 24.60 | 2.49 | 0.1355 | |
| B-Voltage | 18.90 | 1 | 18.90 | 1.91 | 0.1869 | |
| C-Gas Flow Ra | 501.42 | 1 | 501.42 | 50.73 | < 0.0001 | |
| D-Filter Rod | 270.01 | 1 | 270.01 | 27.32 | 0.0001 | |
| AB | 39.38 | 1 | 39.38 | 3.98 | 0.0644 | |
| AC | 12.78 | 1 | 12.78 | 1.29 | 0.2733 | |
| AD | 0.18 | 1 | 0.18 | 0.018 | 0.8943 | |
| BC | 13.14 | 1 | 13.14 | 1.33 | 0.2670 | |
| BD | 0.60 | 1 | 0.60 | 0.061 | 0.8086 | |
| CD | 52.93 | 1 | 52.93 | 5.35 | 0.0353 | |
| $A^2$ | 140.02 | 1 | 140.02 | 14.16 | 0.0019 | |
| $B^2$ | 37.67 | 1 | 37.67 | 3.81 | 0.0699 | |
| $C^2$ | 102.63 | 1 | 102.63 | 10.38 | 0.0057 | |
| $D^2$ | 53.52 | 1 | 53.52 | 5.41 | 0.0344 | |

*Figure 5: ANOVA table for validating the model significance in optimizing hardness*

| | | | |
|---|---|---|---|
| Std. Dev. | 4.22 | R-Squared | 0.9221 |
| Mean | 483.53 | Adj R-Squared | 0.8495 |
| C.V. % | 0.87 | Pred R-Squared | 0.5518 |
| PRESS | 1541.13 | Adeq Precision | 12.092 |

*Figure 6: Goodness of fit statistics for validating Model (Tensile Strength)*

Transform | Fit Summary | Model | ANOVA | Diagnostics | Model Graphs

| | | | |
|---|---|---|---|
| Std. Dev. | 3.14 | R-Squared | 0.8881 |
| Mean | 184.14 | Adj R-Squared | 0.7837 |
| C.V. % | 1.71 | Pred R-Squared | 0.3577 |
| PRESS | 851.32 | Adeq Precision | 10.441 |

*Figure 7: Goodness of fit statistics for validating Model (Hardness Value)*

Coefficient of determination (R-Squared) of 0.9221 and 0.8881 as observed in Figure 6 and 7 shows the strength of response surface methodology and its ability to predict the optimal values of the selected variables that will maximize the tensile strength and hardness value. The Coefficient of determination (R-Squared) of 0.9221 and 0.8881 as observed indicates that 92.2% and 88.8% of the total variations as in the case of the responses (tensile strength and hardness) can be explained by the model. The values of the adjusted coefficient of determination Adj. R-Squared value of 0.8495 and 0.7837 as observed in figure 6 and 7 indicates a model with 84.95% and 78.37% reliability. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision value of 12.092 and 10.441 as observed indicates an adequate signal, indicating that the model can be used to maximize the tensile strength and hardness value.

## 5. OPTIMAL EQUATIONS BASED ON CODED VARIABLES

The optimal equation which shows the individual effects and combined interactions of the selected variables against the measured responses (tensile strength and hardness are presented in equations (3) and (4) respectively:

$$\begin{aligned} \textit{Tensile strength} &= 496.27 + 2.25A - 1.03B + 6.31C \\ &+ 0.05D + 2.44AB - 0.74AC \\ &- 4.67AD - 3.53BC + 1.51BD \\ &- 2.29CD - 4.02A^2 - 2.82B^2 \\ &- 4.92C^2 - 4.16D^2 \end{aligned} \quad (3)$$

$$\begin{aligned} \textit{Hardness} &= 189.55 + 1.01A + 0.89B + 4.57C \\ &- 3.35D + 1.57AB - 0.89AC \\ &+ 0.11AD + 0.91BC - 0.19BD \\ &- 1.82CD - 2.26A^2 - 1.17B^2 \\ &- 1.93C^2 - 1.40D^2 \end{aligned} \quad (4)$$

where A, B, C and D represents Current, Voltage, Gas flow rate and D- Filler rod dia respectively.

The diagnostics case statistics which shows the observed values of tensile strength and hardness against their predicted values is presented in Tables 4 and 5 respectively.

**Final Equation in Terms of Actual Factors:**

Tensile Strength =
-672.69780
+2.00475 * Current
+8.39708 * Voltage
+69.83438 * Gas Flow Rate
+71.09792 * Filter Rod
+0.016292 * Current * Voltage
-0.012292 * Current * Gas Flow Rate
-0.15583 * Current * Filter Rod
-0.35312 * Voltage * Gas Flow Rate
+0.30125 * Voltage * Filter Rod
-1.14375 * Gas Flow Rate * Filter Rod
-4.46412E-003 * Current$^2$
-0.11271 * Voltage$^2$
-1.22943 * Gas Flow Rate$^2$
-4.16146 * Filter Rod$^2$

**Final Equation in Terms of Actual Factors:**

Hardness =
-118.66354
+0.99521 * Current
-1.60292 * Voltage
+21.55521 * Gas Flow Rate
-14.80625 * Filter Rod
+0.010458 * Current * Voltage
-0.014896 * Current * Gas Flow Rate
+3.54167E-003 * Current * Filter Rod
+0.090625 * Voltage * Gas Flow Rate
-0.038750 * Voltage * Filter Rod
+0.90938 * Gas Flow Rate * Filter Rod
-2.51042E-003 * Current$^2$
-0.046875 * Voltage$^2$
-0.48359 * Gas Flow Rate$^2$
-1.39688 * Filter Rod$^2$

*Figure 8: Optimal equation in terms of actual factors for maximizing the Tensile Strength and hardness*

*Table 4: Experimental and predicted Tensile Strength Values*

| Run Order | Experimental Value | Predicted Value | Residue | Leverage | Internally Studentized | Externally Studentized Residual | Cook's Distance | Influence on Fitted value |
|---|---|---|---|---|---|---|---|---|
| 1 | 468.70 | 465.05 | 3.65 | 0.583 | 1.340 | 1.380 | 0.168 | 1.633 |
| 2 | 469.70 | 475.48 | -5.88 | 0.583 | -2.154 | -2.505 | 0.433 | -2.96 |
| 3 | 460.30 | 462.14 | -1.84 | 0.583 | -0.675 | -0.663 | 0.043 | -0.784 |
| 4 | 486.35 | 482.35 | 4.00 | 0.583 | 1.468 | 1.533 | 0.201 | 1.814 |
| 5 | 494.60 | 490.78 | 3.82 | 0.583 | 1.400 | 1.450 | 0.183 | 1.716 |
| 6 | 496.10 | 496.26 | -2.16 | 0.583 | -0.793 | -0.783 | 0.059 | -0.926 |
| 7 | 472.30 | 473.75 | -1.45 | 0.583 | -0.533 | -0.520 | 0.027 | -0.615 |
| 8 | 488.10 | 491.01 | -2.91 | 0.583 | -1.066 | -1.072 | 0.106 | -1.268 |
| 9 | 477.80 | 476.96 | 0.84 | 0.583 | 0.309 | 0.299 | 0.009 | 0.354 |
| 10 | 472.90 | 468.69 | 4.21 | 0.583 | 1.545 | 1.627 | 0.223 | 1.926 |
| 11 | 485.00 | 480.08 | 4.92 | 0.583 | 1.804 | 1.970 | 0.304 | *2.33 |
| 12 | 475.70 | 481.58 | -5.88 | 0.583 | -2.157 | -2.510 | 0.434 | *-2.97 |
| 13 | 492.30 | 493.55 | -1.25 | 0.583 | -0.457 | -0.444 | 0.019 | -0.526 |
| 14 | 482.10 | 482.32 | -0.22 | 0.583 | -0.083 | -0.080 | 0.001 | -0.094 |
| 15 | 486.35 | 482.54 | 3.81 | 0.583 | 1.397 | 1.446 | 0.182 | 1.711 |
| 16 | 480.20 | 481.10 | -0.90 | 0.583 | -0.329 | -0.319 | 0.010 | -0.377 |
| 17 | 469.80 | 475.70 | -5.90 | 0.583 | -2.165 | -2.523 | 0.438 | *-2.96 |

*Table 5: Experimental and predicted Hardness Values*

| Run Order | Experimental Value | Predicted Value | Residue | Leverage | Internally Studentized Residual | Externally Studentized Residual | Cook's Distance | Influence on Fitted value |
|---|---|---|---|---|---|---|---|---|
| 1 | 182.40 | 182.96 | -0.58 | 0.53 | -0.287 | -0.278 | 0.008 | -0.329 |
| 2 | 184.20 | 183.45 | 0.75 | 0.53 | 0.372 | 0.361 | 0.013 | 0.427 |
| 3 | 181.30 | 180.20 | 1.10 | 0.53 | 0.544 | 0.531 | 0.028 | 0.628 |
| 4 | 185.40 | 186.93 | -1.53 | 0.53 | -0.758 | -0.744 | 0.053 | -0.861 |
| 5 | 190.50 | 188.48 | 2.04 | 0.53 | 1.004 | 1.004 | 0.094 | 1.188 |
| 6 | 185.40 | 185.35 | 0.05 | 0.53 | 0.025 | 0.024 | 0.000 | 0.028 |
| 7 | 190.20 | 189.30 | 0.90 | 0.53 | 0.443 | 0.431 | 0.018 | 0.510 |
| 8 | 187.60 | 192.46 | -1.86 | 0.53 | -2.396 | -2.946 | 0.536 | *-3.49 |
| 9 | 178.20 | 172.81 | 5.39 | 0.53 | 2.655 | 3.522 | 0.658 | *4.17 |
| 10 | 173.40 | 173.70 | -0.30 | 0.53 | -0.146 | -0.143 | 0.002 | -0.169 |
| 11 | 169.80 | 169.25 | 0.55 | 0.53 | 0.271 | 0.282 | 0.007 | 0.311 |
| 12 | 174.90 | 176.41 | -1.51 | 0.53 | -0.745 | -0.734 | 0.052 | -0.866 |
| 13 | 187.70 | 185.57 | 2.13 | 0.53 | 1.051 | 1.055 | 0.103 | 1.248 |
| 14 | 182.30 | 182.88 | -0.58 | 0.53 | -0.285 | -0.276 | 0.008 | -0.327 |
| 15 | 185.40 | 185.63 | -0.23 | 0.53 | -0.113 | -0.109 | 0.001 | -0.129 |
| 16 | 190.40 | 189.22 | 1.18 | 0.53 | 0.583 | 0.570 | 0.032 | 0.874 |
| 17 | 173.40 | 178.49 | -5.09 | 0.53 | -2.507 | -3.177 | 0.587 | *3.76 |

Lower residual values resulting to lower leverages as observed in Table 4 and 5, are indicators of a well fitted model. To assess the accuracy of prediction and establish the suitability of response surface methodology using the quadratic model, a reliability plot of the experimental and predicted values of the responses were obtained as shown in Figures 8 and 10 respectively. The figures indicate that the developed models are adequate because the residuals in prediction of each response are negligible.

The high coefficient of determination ($r^2$ = 0.9221 and 0.8881) observed in Figures 9 and 10 were used to establish the suitability of RSM in optimizing the tensile strength and hardness value. The model graphs which shows the interactions of the combine variables on the measured responses were evaluated using the 3D surface plot as shown in Figures 11, 12, 13 and 14 respectively.

Figure 11 shows that variation of current and voltage remarkably affected the tensile strength of the material. As the voltage and current increased, the tensile strength displayed a corresponding increase until a certain point where further increase in voltage and current signified a decrease.

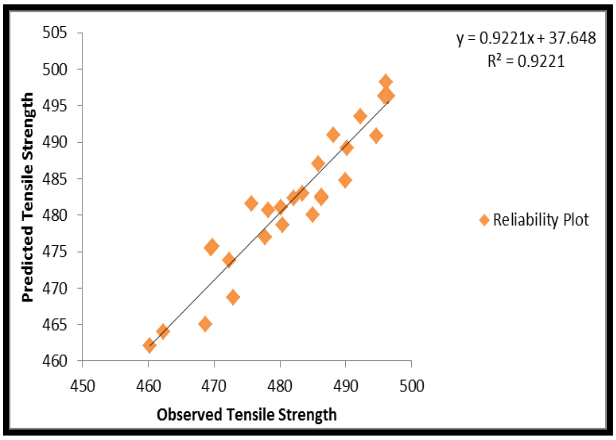


*Figure 9: Observed versus predicted tensile strength*

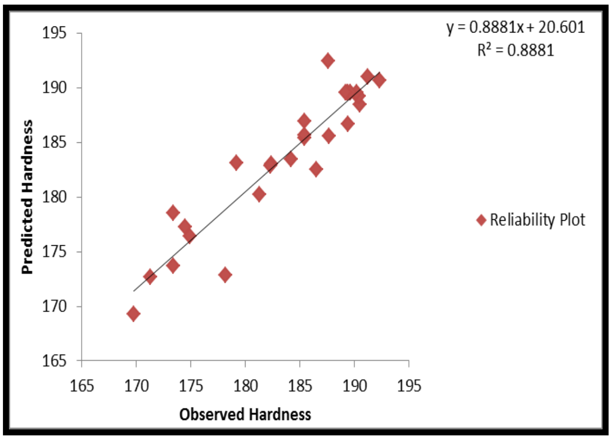


*Figure 10: Observed versus predicted hardness*

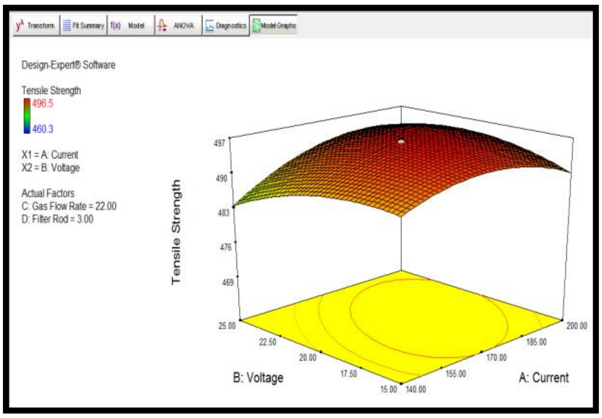


*Figure 11: Effect of voltage and current on the tensile strength.*

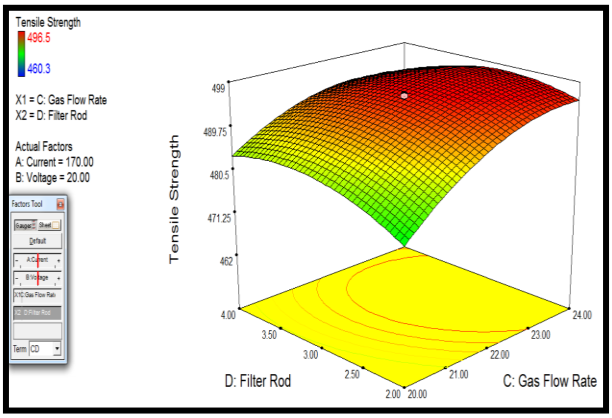


*Figure 12: Effect of filter rod and gas flow rate the tensile strength*

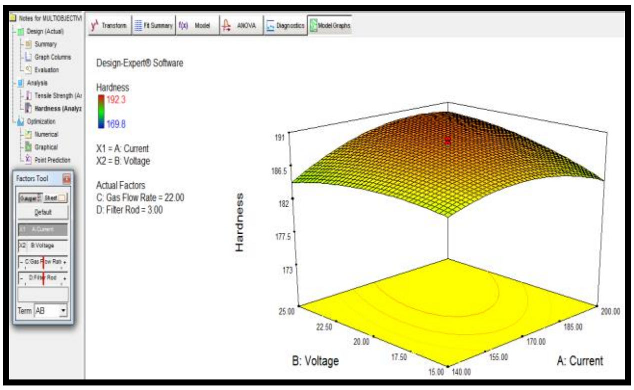


*Figure 13: Effect of voltage and current on the hardness value.*

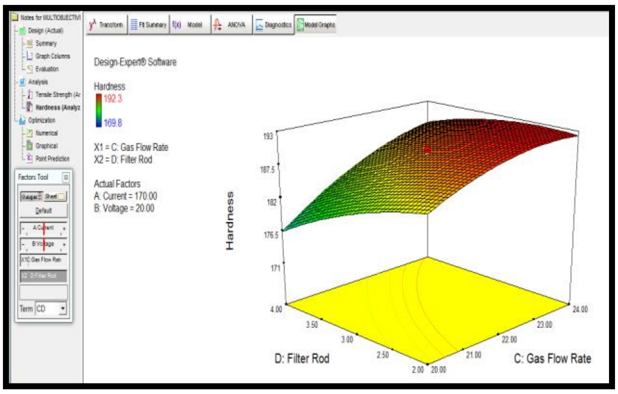


*Figure 14: Effect of filler rod and gas flow rate on the hardness value.*

Figure 13 and 14 shows that after a certain level of increase in current, as the hardness and voltage continues to increase, the current began to decrease. This correlates with the findings of [13], who investigated effect of welding current and voltage on the mechanical properties of wrought (6063) aluminum alloy. The dark colour area on the surface plot as observed in Figures 14 through 17 depicts areas of high tensile strength and high hardness respectively.

## 6. NUMERICAL OPTIMIZATION

Numerical optimization was performed to ascertain the desirability of the overall model using the design expert software. The responses were optimized and their corresponding optimum input process parameter values were determined. Maximized tensile strength of 497.555N/mm$^2$ and a hardness value of 192.556BHN were observed at current 170.12 amp, voltage 19.84 volt, gas flow rate 23.92 l/min and filter rod 2.42mm.

## 7. CONCLUSION

The Response Surface Methodology (RSM) was used successfully in carrying out the optimization process. The optimum values for the responses, as well as their corresponding input parameters were obtained. Using the Response Surface Methodology, the tensile strength and hardness were modeled with quadratic regression models as functions of the process parameters of current, voltage, gas flow rate and filler rod dia. Model adequacy checks was carried out using the analysis of variance ANOVA.

The ANOVA check showed that the parameter gas flow rate has the most significant effect on the tensile strength, followed by the welding current. A similar check on the Hardness showed that the gas flow rate and filler rod had the most significant effect on it. The experimentally obtained data were compared with the predicted values for both the responses and the errors were found to be within the acceptable level. The experiment was observed to have a VIF of 1 which signifies theres no multicollinearity. The optimal tensile strength and Hardness was observed at a current of 170.12 amp, voltage 19.84 volt, gas flow rate 23.92 l/min and filter rod 2.4mm with a desirability value of 1.00.

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