*Original Research Article*

# Parametric Prediction and Optimization of Mild Steel Geometry Composition using TIG Welding Methods

**Abstract**

The research focused on the application of tungsten inert gas (TIG) welding method on mild steel metal materials and its optimization of the welding input factors along with its mechanical response parameters using response surface method (RSM). The study have reviewed several research works along side with literatures related to the study, and also revealed that the specific studied mild steel weld bead geometry mechanical properties on its weldment have not being studied to the best of the researchers knowledge. The material under study is IS 2062, why the method applied for the analysis is response surface method of optimization. The result shows the optimal solutions of both the input factors and the response parameters. The optimization results shows that the optimal solutions for input process factors are: gas flow rate 16.00m$^3$/s, welding speed is 113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress and 118.00 J for impact energy response. The overall desirability of the models developed to achieve the optimal solutions result is 78.41%. The results will serve as bases for mild steel companies and in industrialization. The research will also serve as a decision making system in engineering and in industrialization.

**Keywords**: optimization; response surface method; mild steel; bead geometry; Tungsten Inert Gas (TIG); Welding

## 1. Introduction

Nowadays Industry and its economy, metals and steels have been employed for domestic, agricultural, construction and several other purposes due to its variations in ductility, corrosion and rust resistance, and its other properties that make the material unique and irresistible materials in Industrialization. Industrialization world utilize these materials mainly because of their mechanical properties as well as their excellent corrosion resistance (Achebo, Ezeliora, & Umeh, 2019; Ezeliora, Mbanusi & Aguh 2019; Ezeliora & Nwufo 2021). Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the work pieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld (Akash & Satyam, 2014). Tungsten Inert Gas (TIG) welding is one of the most widely used processes in industry. The input parameters play a very significant role in determining the quality of a welded joint. In fact, weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices. Therefore, these parameters affecting the arc and welding (Achebo, Ezeliora, & Umeh, 2019; Ezeliora, Mbanusi & Aguh 2019) should be estimated and their changing conditions during process must be known before in order to obtain optimum results; in fact a perfect arc can be achieved when all the parameters are in conformity (Pasupathy, & Ravisankar, 2013). Weld bead geometry is

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severely negatively affected by the occurrence of the undercut phenomenon. Weld bead geometry defects not only affect the appearance of weld beads, but also cause a severe stress concentration at the weld edges, which has a great effect on the reliability of the weld joints. Whatever the category, insufficient penetration of molten weld metal which is a major cause of undercuts, lowers the strength of the weldments, and this has led to structural failures of engineering projects. Major structural failures could lead to significant safety hazards (Achebo, & Salisu, 2015). The study literature gap shows that the selected mild steel materials (IS 2062) mechanical composition properties and its application of tungsten inert gas to produce weldment has not being studied. The study reveals an experimental study of the parametric prediction and optimization of mild steel geometry composition using TIG welding methods.

## 2. Literature Review

Achebo, and Omoregie, (2015) determine the relationship between the input parameters and the output parameters and the application of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) has successfully used to optimize the input process parameters which has produced the most desired mechanical properties. Achebo, and Salisu (2015) shows that the use of Taguchi method has been able to reduce the depth of undercut as shown in this study. Izzatul, (2012) performed experiments in the effects of different parameters on welding penetration, The hardness measurement and micro structure was measured in mild steel of the base metal by using the robotic gas welding (Achebo, Ezeliora, & Umeh, 2019; Ezeliora, Mbanusi & Aguh 2019). The changes in welding process parameters are influenced the effect of the microstructure of weld metal. As increased welding current, welding speed and arc voltage on the grain size of microstructure. Achebo, Ezeliora, & Umeh, (2019) research on statistical evaluation of the impact strength on mild steel cladding weld metal geometry.

### 2.1 Knowledge Gap

The research has reviewed several studies along with literatures on mild steel materials and the optimization of its weld bead geometry, but no researcher have completely experiment on the mechanical properties of the weld bead geometry on the selected mild steel material. The researchers therefore try to enhance the necessary mechanical properties and its impact on the weld bead geometry. This serves as the knowledge gap.

## 3. Materials and Methods

### 3.1 Research Method

The research method adopted in this work is a quantitative research approach. The parent material is characterized and analyzed to unveil the chemical compositions of the mild steel. The results of the mechanical composition properties of the base metal serve as the response parameters of the experimental trials. The application of the response surface method (RSM) is use for the experimental trials analysis. The statistical analysis, results, and optimization

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solutions of the input process factors and the response parameters were revealed and recommended.

### 3.2 Work Material

The work material used for present work is a mild steel plate of IS2062 E-250 the dimensions of the work piece specimens were cut into 60 x 10 x 10 by machining. Square butt joint configuration was prepared according to welding standard. Argon inert gas was used as shielding gas. The filler metal was an ASW classification E71T-1C with a 1.2 mm diameter electrode. The chemical composition and mechanical composition properties of base metal & filler metal are listed in Table 1 & Table 2 respectively.

Table 1: %age Chemical composition of Mild Steel base metal material's element of IS 2062

| Material | C | SI | Mn | P | S | Al | Cr | Mo | Ni |
|---|---|---|---|---|---|---|---|---|---|
| IS 2062 | 0.150 | 0.160 | 0.870 | 0.015 | 0.016 | 0.031 | - | - | - |
| ER 308L | 0.03 | 0.57 | 1.76 | 0.021 | 0.008 | - | 19.52 | 0.75 | 10.02 |

Image 1: Mild steel plate of IS2062 E-250 and its accessories

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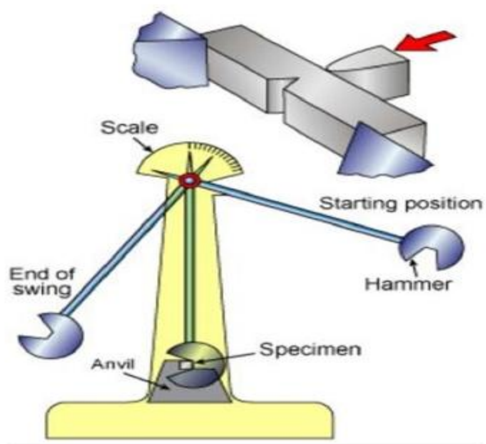


Table 2: The Designed Matrix Input Factors and the Responses Experimental Results

| S/N | Control Factors | | | | Responses | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Runs | Gas Flow Rate(L/min) | Welding Speed (mm/s) | Welding Voltage (V) | Welding Current (A) | Hardness (BHN or HRB) | Yield Strength (MPa) | Percentage Elongation (%) | Tensile Strength (MPa) | Shear Stress (MPa) | Impact Energy (J) |
| 1 | 13 | 110 | 20.5 | 210 | 263 | 280 | 28 | 480 | 361 | 91 |
| 2 | 10 | 130 | 18 | 230 | 305 | 310 | 15 | 520 | 382 | 110 |
| 3 | 10 | 130 | 23 | 230 | 274 | 356 | 25 | 503 | 387 | 70 |
| 4 | 16 | 90 | 18 | 230 | 250 | 162 | 35 | 443 | 394 | 113 |
| 5 | 16 | 90 | 23 | 230 | 348 | 270 | 28 | 524 | 301 | 71 |
| 6 | 13 | 110 | 20.5 | 190 | 230 | 282 | 26 | 335 | 305 | 82 |
| 7 | 10 | 90 | 23 | 190 | 204 | 202 | 21 | 436 | 390 | 90 |
| 8 | 13 | 130 | 20.5 | 210 | 234 | 224 | 27 | 397 | 344 | 89 |
| 9 | 16 | 90 | 23 | 190 | 277 | 230 | 24 | 432 | 303 | 90 |
| 10 | 10 | 90 | 18 | 190 | 226 | 237 | 23 | 354 | 365 | 83 |
| 11 | 13 | 130 | 23 | 210 | 320 | 294 | 26 | 435 | 392 | 82.5 |
| 12 | 10 | 90 | 18 | 230 | 206 | 219 | 28 | 528 | 335 | 96 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 13 | 110 | 20.5 | 210 | 251 | 242 | 22 | 440 | 321 | 91 |
| 14 | 13 | 110 | 18 | 210 | 341 | 312 | 21 | 456 | 382 | 107 |
| 15 | 16 | 130 | 23 | 190 | 237 | 349 | 33 | 422 | 335 | 101 |
| 16 | 13 | 110 | 20.5 | 230 | 208 | 248 | 22 | 485 | 349 | 92 |
| 17 | 10 | 90 | 23 | 230 | 299 | 289 | 26 | 523 | 320 | 81 |
| 18 | 16 | 110 | 20.5 | 210 | 293 | 297 | 28 | 472 | 302 | 107 |
| 19 | 10 | 110 | 20.5 | 210 | 239 | 282 | 23 | 468 | 307 | 84 |
| 20 | 16 | 130 | 18 | 190 | 311 | 372 | 24 | 411 | 412 | 115 |
| 21 | 16 | 130 | 23 | 230 | 286 | 341 | 27 | 516 | 360 | 92 |
| 22 | 10 | 130 | 23 | 190 | 221 | 295 | 29 | 440 | 401 | 93 |
| 23 | 16 | 110 | 18 | 230 | 293 | 303 | 25 | 474 | 417 | 118 |
| 24 | 16 | 90 | 18 | 190 | 284 | 271 | 31 | 410 | 405 | 85 |
| 25 | 10 | 130 | 18 | 190 | 305 | 312 | 20 | 398 | 393 | 76 |

**Results and discussion**

Table 2 shows the design matrix input parameter used and its experimental results of the twenty five (25) experimental trials performed in this research work. The input process factors are gas flow rate, welding speed, welding voltage, and welding current. The output process responses are; Hardness strength, Yield Strength, Percentage Elongation, Ultimate Tensile Strength, Shear Stress, Impact Energy of the weld bead geometry. The input and output parameters were analyzed statistically modeled and optimized. The results were revealed and discussed. The statistical analysis of the input and output parameters of the experiment were represented in figures 1 to 12.

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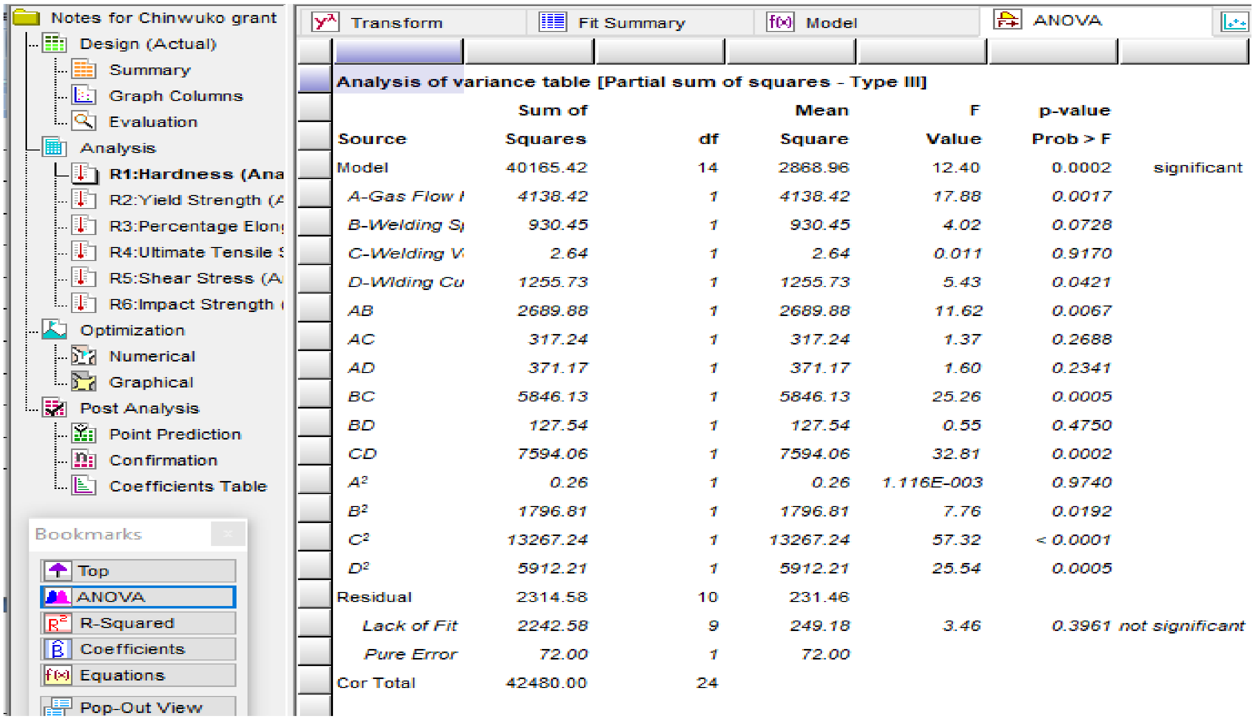
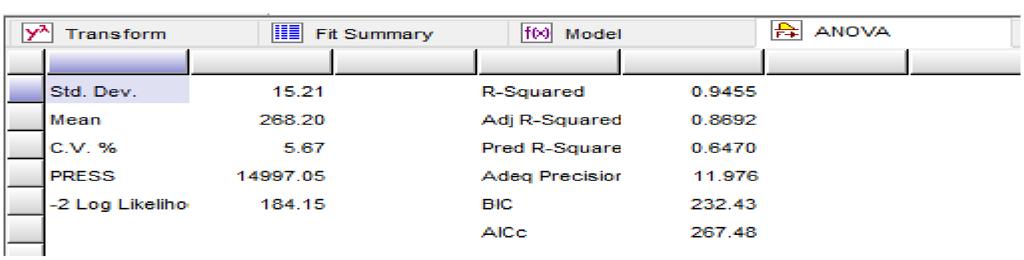



**Analysis of variance table [Partial sum of squares - Type III]**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 40165.42 | 14 | 2868.96 | 12.40 | 0.0002 | significant |
| *A-Gas Flow I* | *4138.42* | *1* | *4138.42* | *17.88* | *0.0017* | |
| *B-Welding S* | *930.45* | *1* | *930.45* | *4.02* | *0.0728* | |
| *C-Welding V* | *2.64* | *1* | *2.64* | *0.011* | *0.9170* | |
| *D-Wlding Cu* | *1255.73* | *1* | *1255.73* | *5.43* | *0.0421* | |
| *AB* | *2689.88* | *1* | *2689.88* | *11.62* | *0.0067* | |
| *AC* | *317.24* | *1* | *317.24* | *1.37* | *0.2688* | |
| *AD* | *371.17* | *1* | *371.17* | *1.60* | *0.2341* | |
| *BC* | *5846.13* | *1* | *5846.13* | *25.26* | *0.0005* | |
| *BD* | *127.54* | *1* | *127.54* | *0.55* | *0.4750* | |
| *CD* | *7594.06* | *1* | *7594.06* | *32.81* | *0.0002* | |
| $A^2$ | *0.26* | *1* | *0.26* | *1.116E-003* | *0.9740* | |
| $B^2$ | *1796.81* | *1* | *1796.81* | *7.76* | *0.0192* | |
| $C^2$ | *13267.24* | *1* | *13267.24* | *57.32* | *< 0.0001* | |
| $D^2$ | *5912.21* | *1* | *5912.21* | *25.54* | *0.0005* | |
| Residual | 2314.58 | 10 | 231.46 | | | |
| *Lack of Fit* | *2242.58* | *9* | *249.18* | *3.46* | *0.3961* | *not significant* |
| *Pure Error* | *72.00* | *1* | *72.00* | | | |
| Cor Total | 42480.00 | 24 | | | | |

Figure 1.1: Analysis of Variance for the Hardness Strength Modeling

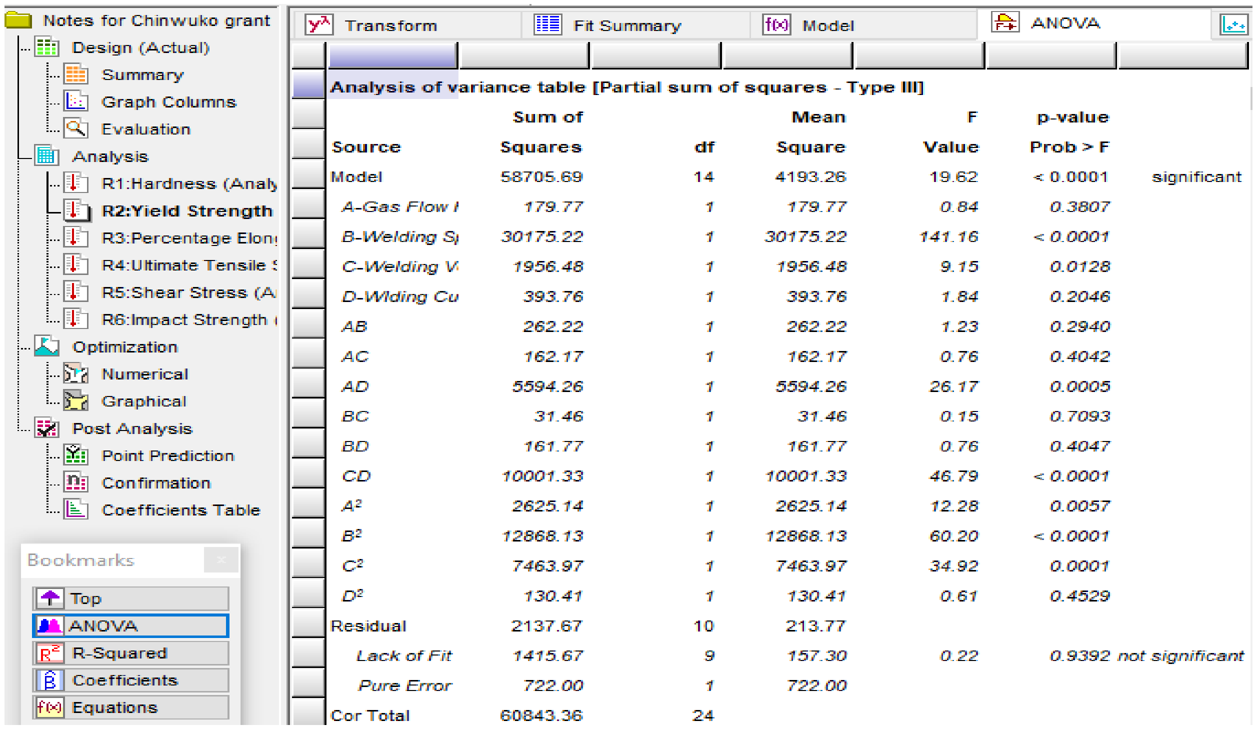
Figure 1.1 is the analysis of variance for the hardness strength modeling which shows that the model developed is significant and fit to achieve an appropriate solution. The Model F-value of 12.40 implies the model is significant. There is only a 0.02% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 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 3.46 implies the lack of fit is not significant relative to the pure error. There is a 39.61% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.




| | | | |
|---|---|---|---|
| Std. Dev. | 15.21 | R-Squared | 0.9455 |
| Mean | 268.20 | Adj R-Squared | 0.8692 |
| C.V. % | 5.67 | Pred R-Square | 0.6470 |
| PRESS | 14997.05 | Adeq Precisior | 11.976 |
| -2 Log Likeliho | 184.15 | BIC | 232.43 |
| | | AICc | 267.48 |

Figure 1.2: Model Summary for Hardness Strength Test

The models summary shows that the coefficient of determination for the factors and the response (R-Square) is 94.55%. This shows that 94.55 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.6470 and the adjusted R-Squared of 0.8692 are good percentage explanation and expectations of good experimental data. Adequate Precision is used to measure the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 11.976 indicates an adequate signal. This model can be used to navigate the design space.




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

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 58705.69 | 14 | 4193.26 | 19.62 | < 0.0001 | significant |
| A-Gas Flow I | 179.77 | 1 | 179.77 | 0.84 | 0.3807 | |
| B-Welding S | 30175.22 | 1 | 30175.22 | 141.16 | < 0.0001 | |
| C-Welding V | 1956.48 | 1 | 1956.48 | 9.15 | 0.0128 | |
| D-Wlding Cu | 393.76 | 1 | 393.76 | 1.84 | 0.2046 | |
| AB | 262.22 | 1 | 262.22 | 1.23 | 0.2940 | |
| AC | 162.17 | 1 | 162.17 | 0.76 | 0.4042 | |
| AD | 5594.26 | 1 | 5594.26 | 26.17 | 0.0005 | |
| BC | 31.46 | 1 | 31.46 | 0.15 | 0.7093 | |
| BD | 161.77 | 1 | 161.77 | 0.76 | 0.4047 | |
| CD | 10001.33 | 1 | 10001.33 | 46.79 | < 0.0001 | |
| $A^2$ | 2625.14 | 1 | 2625.14 | 12.28 | 0.0057 | |
| $B^2$ | 12868.13 | 1 | 12868.13 | 60.20 | < 0.0001 | |
| $C^2$ | 7463.97 | 1 | 7463.97 | 34.92 | 0.0001 | |
| $D^2$ | 130.41 | 1 | 130.41 | 0.61 | 0.4529 | |
| Residual | 2137.67 | 10 | 213.77 | | | |
| Lack of Fit | 1415.67 | 9 | 157.30 | 0.22 | 0.9392 | not significant |
| Pure Error | 722.00 | 1 | 722.00 | | | |
| Cor Total | 60843.36 | 24 | | | | |

Figure 2.1: Analysis of Variance for the Yield Strength Modeling

Figure 2.1 is the analysis of variance for the yield strength modeling which shows that the model developed is significant and fit to achieve an appropriate solution. The Model F-value of 19.62 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 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 0.22 implies the lack of fit is not significant relative to the pure error. There is a 93.92% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

| | | | |
|---|---|---|---|
| Std. Dev. | 14.62 | R-Squared | 0.9649 |
| Mean | 279.16 | Adj R-Squared | 0.9157 |
| C.V. % | 5.24 | Pred R-Square | 0.7841 |
| PRESS | 13133.60 | Adeq Precisior | 17.792 |
| -2 Log Likeliho | 182.16 | BIC | 230.44 |
| | | AICc | 265.50 |

Figure 2.2: Model Summary for Yield Strength Test

Figure 2.2 reveals the yield strength model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 96.49%. This shows that 94.55 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.7841 and the adjusted R-Squared of 0.9157 are good percentage explanation and expectations of good experimental data. Adequate Precision is used to measure the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 17.792 indicates an adequate signal. This model can be used to navigate the design space.

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

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 382.93 | 10 | 38.29 | 9.04 | 0.0002 | significant |
| A-Gas Flow I | 75.95 | 1 | 75.95 | 17.93 | 0.0008 | |
| B-Welding S | 34.88 | 1 | 34.88 | 8.23 | 0.0124 | |
| C-Welding V | 28.24 | 1 | 28.24 | 6.67 | 0.0217 | |
| D-Wlding Cu | 3.18 | 1 | 3.18 | 0.75 | 0.4008 | |
| AB | 2.64 | 1 | 2.64 | 0.62 | 0.4433 | |
| AC | 6.55 | 1 | 6.55 | 1.55 | 0.2341 | |
| AD | 1.95 | 1 | 1.95 | 0.46 | 0.5090 | |
| BC | 161.12 | 1 | 161.12 | 38.03 | < 0.0001 | |
| BD | 83.60 | 1 | 83.60 | 19.74 | 0.0006 | |
| CD | 0.17 | 1 | 0.17 | 0.039 | 0.8463 | |
| Residual | 59.31 | 14 | 4.24 | | | |
| Lack of Fit | 41.31 | 13 | 3.18 | 0.18 | 0.9667 | not significant |
| Pure Error | 18.00 | 1 | 18.00 | | | |
| Cor Total | 442.24 | 24 | | | | |

Figure 3.1: Analysis of Variance for the Percentage Elongation Modeling

Figure 3.1 is the analysis of variance for the percentage elongation modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 9.04 implies the model is significant. There is only a 0.02% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 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 0.18 implies the lack of fit is not significant relative to the pure error. There is a 96.67% % chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

| | | | |
|---|---|---|---|
| Std. Dev. | 2.06 | R-Squared | 0.8659 |
| Mean | 25.48 | Adj R-Squared | 0.7701 |
| C.V. % | 8.08 | Pred R-Square | 0.7233 |
| PRESS | 122.36 | Adeq Precisior | 14.037 |
| -2 Log Likeliho | 92.54 | BIC | 127.95 |
| | | AICc | 134.85 |

Figure 3.2: Model Summary for Percentage Elongation Analysis

Figure 3.2 reveals the percentage elongation model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 96.49%. This shows that 86.59 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.7233 and the adjusted R-Squared of 0. 7701 are good percentage explanation and expectations of good experimental data. Adequate Precision is used to measure the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 14.037 indicates an adequate signal. This model can be used to navigate the design space.

Notes for Chinwuko grant
Design (Actual)
Summary
Graph Columns
Evaluation
Analysis
R1:Hardness (Analy
R2:Yield Strength (A
R3:Percentage Elon
R4:Ultimate Tensi
R5:Shear Stress (A
R6:Impact Strength (
Optimization
Numerical
Graphical

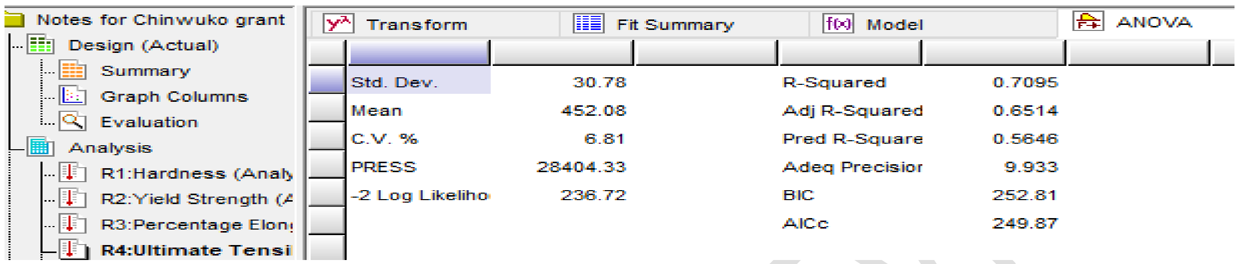
Transform | Fit Summary | Model | ANOVA

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

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 46291.99 | 4 | 11573.00 | 12.21 | < 0.0001 | significant |
| *A-Gas Flow I* | *259.69* | *1* | *259.69* | *0.27* | *0.6064* | |
| *B-Welding S* | *102.60* | *1* | *102.60* | *0.11* | *0.7455* | |
| *C-Welding V* | *3209.80* | *1* | *3209.80* | *3.39* | *0.0806* | |
| *D-Wlding Cu* | *42443.08* | *1* | *42443.08* | *44.79* | *< 0.0001* | |
| Residual | 18951.85 | 20 | 947.59 | | | |
| *Lack of Fit* | *18151.85* | *19* | *955.36* | *1.19* | *0.6284* | *not significant* |
| *Pure Error* | *800.00* | *1* | *800.00* | | | |
| Cor Total | 65243.84 | 24 | | | | |

Figure 4.1: Analysis of Variance for the Ultimate Tensile Strength Modeling

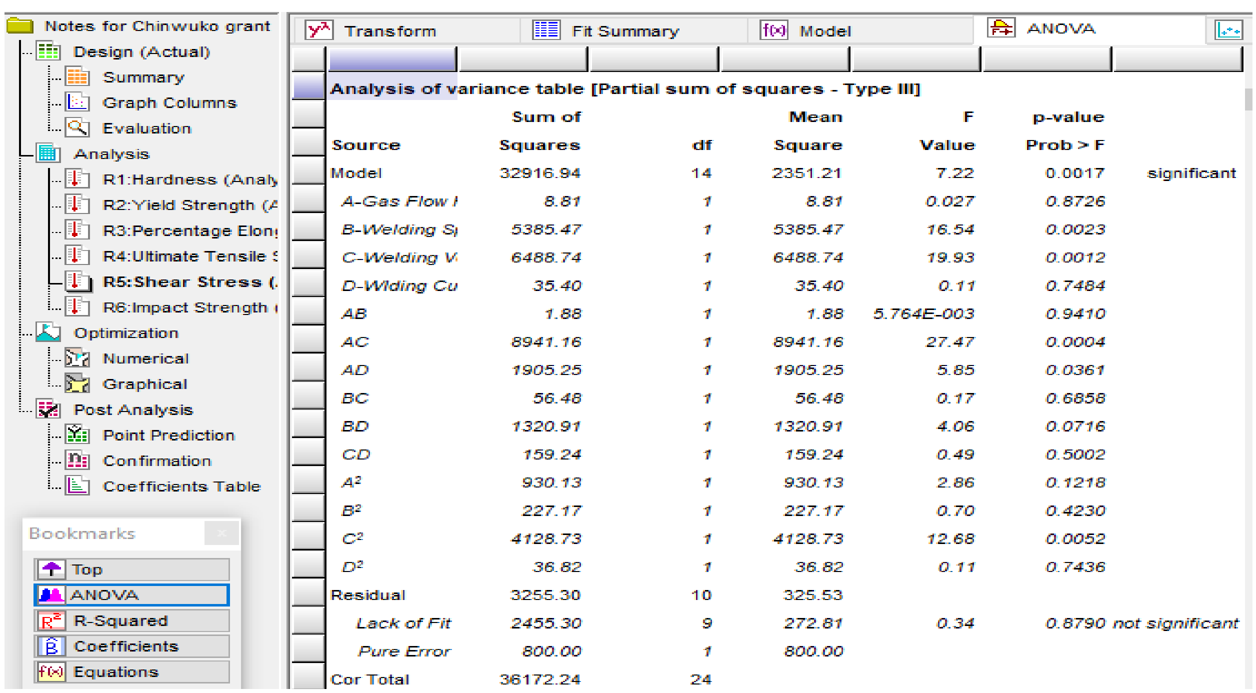
Figure 4.1 is the analysis of variance for the ultimate tensile strength modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 12.21 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 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 0.18 implies the lack of fit is not significant relative to the pure error. There is a 62.84% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.




| | | | |
|---|---|---|---|
| Std. Dev. | 30.78 | R-Squared | 0.7095 |
| Mean | 452.08 | Adj R-Squared | 0.6514 |
| C.V. % | 6.81 | Pred R-Square | 0.5646 |
| PRESS | 28404.33 | Adeq Precisior | 9.933 |
| -2 Log Likeliho | 236.72 | BIC | 252.81 |
| | | AICc | 249.87 |

Figure 4.2: Model Summary for Ultimate Tensile Strength Test

Figure 4.2 reveals the ultimate tensile strength model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 70.95%. This shows that 70.95 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.5646 and the adjusted R-Squared of 0.6514 are good percentage explanation and expectations of good experimental data. Adequate Precision is used to measure the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 9.933 indicates an adequate signal. This model can be used to navigate the design space.




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

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 32916.94 | 14 | 2351.21 | 7.22 | 0.0017 | significant |
| *A-Gas Flow I* | *8.81* | *1* | *8.81* | *0.027* | *0.8726* | |
| *B-Welding S* | *5385.47* | *1* | *5385.47* | *16.54* | *0.0023* | |
| *C-Welding V* | *6488.74* | *1* | *6488.74* | *19.93* | *0.0012* | |
| *D-Wlding Cu* | *35.40* | *1* | *35.40* | *0.11* | *0.7484* | |
| *AB* | *1.88* | *1* | *1.88* | *5.764E-003* | *0.9410* | |
| *AC* | *8941.16* | *1* | *8941.16* | *27.47* | *0.0004* | |
| *AD* | *1905.25* | *1* | *1905.25* | *5.85* | *0.0361* | |
| *BC* | *56.48* | *1* | *56.48* | *0.17* | *0.6858* | |
| *BD* | *1320.91* | *1* | *1320.91* | *4.06* | *0.0716* | |
| *CD* | *159.24* | *1* | *159.24* | *0.49* | *0.5002* | |
| *$A^2$* | *930.13* | *1* | *930.13* | *2.86* | *0.1218* | |
| *$B^2$* | *227.17* | *1* | *227.17* | *0.70* | *0.4230* | |
| *$C^2$* | *4128.73* | *1* | *4128.73* | *12.68* | *0.0052* | |
| *$D^2$* | *36.82* | *1* | *36.82* | *0.11* | *0.7436* | |
| Residual | 3255.30 | 10 | 325.53 | | | |
| *Lack of Fit* | *2455.30* | *9* | *272.81* | *0.34* | *0.8790* | *not significant* |
| *Pure Error* | *800.00* | *1* | *800.00* | | | |
| Cor Total | 36172.24 | 24 | | | | |

Figure 5.1: Analysis of Variance for the Shear Stress Modeling

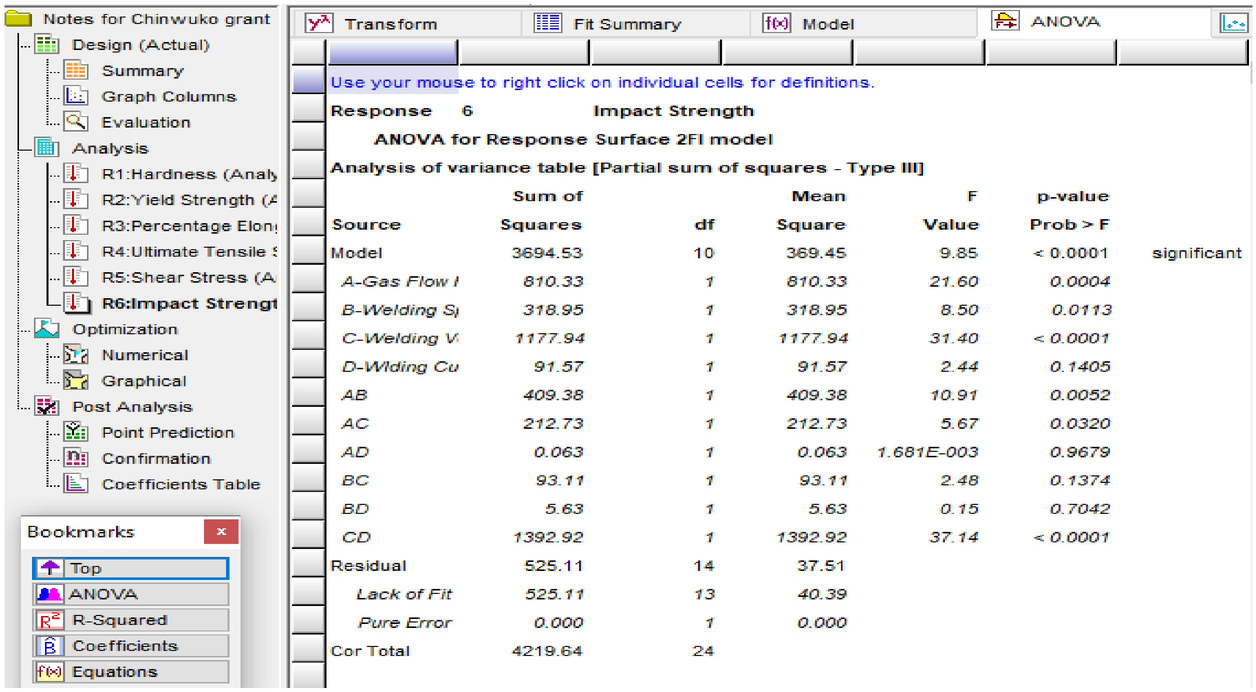
Figure 5.1 is the analysis of variance for the shear stress modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 7.22 implies the model is significant. There is only a 0. 17% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 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 0.34 implies the lack of fit is not significant relative to the pure error. There is an 87.90% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

Transform | Fit Summary | Model | ANOVA

| | | | |
|---|---|---|---|
| Std. Dev. | 18.04 | R-Squared | 0.9100 |
| Mean | 358.52 | Adj R-Squared | 0.7840 |
| C.V. % | 5.03 | Pred R-Square | 0.5871 |
| PRESS | 14934.11 | Adeq Precisior | 8.312 |
| -2 Log Likeliho | 192.68 | BIC | 240.96 |
| | | AICc | 276.01 |

Figure 5.2: Model Summary for Shear Stress Test

Figure 5.2 reveals the shear stress model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 91.00%. This shows that 91.00 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.5871 and the adjusted R-Squared of 0.7840 are good percentage explanation and expectations of good experimental data. Adequate Precision is used to measure the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 8.312 indicates an adequate signal. This model can be used to navigate the design space.




**Response 6 Impact Strength**

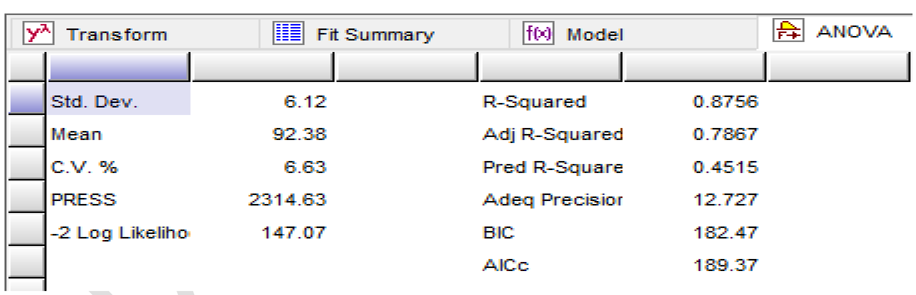
**ANOVA for Response Surface 2FI model**

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

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 3694.53 | 10 | 369.45 | 9.85 | < 0.0001 | significant |
| *A-Gas Flow I* | *810.33* | *1* | *810.33* | *21.60* | *0.0004* | |
| *B-Welding S* | *318.95* | *1* | *318.95* | *8.50* | *0.0113* | |
| *C-Welding V* | *1177.94* | *1* | *1177.94* | *31.40* | *< 0.0001* | |
| *D-Wlding Cu* | *91.57* | *1* | *91.57* | *2.44* | *0.1405* | |
| *AB* | *409.38* | *1* | *409.38* | *10.91* | *0.0052* | |
| *AC* | *212.73* | *1* | *212.73* | *5.67* | *0.0320* | |
| *AD* | *0.063* | *1* | *0.063* | *1.681E-003* | *0.9679* | |
| *BC* | *93.11* | *1* | *93.11* | *2.48* | *0.1374* | |
| *BD* | *5.63* | *1* | *5.63* | *0.15* | *0.7042* | |
| *CD* | *1392.92* | *1* | *1392.92* | *37.14* | *< 0.0001* | |
| Residual | 525.11 | 14 | 37.51 | | | |
| *Lack of Fit* | *525.11* | *13* | *40.39* | | | |
| *Pure Error* | *0.000* | *1* | *0.000* | | | |
| Cor Total | 4219.64 | 24 | | | | |

Figure 6.1: Analysis of Variance for the Impact Energy Modeling

Figure 6.1 is the analysis of variance for the impact energy modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 9.85 implies the model is significant. There is only a 0. 01% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 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.

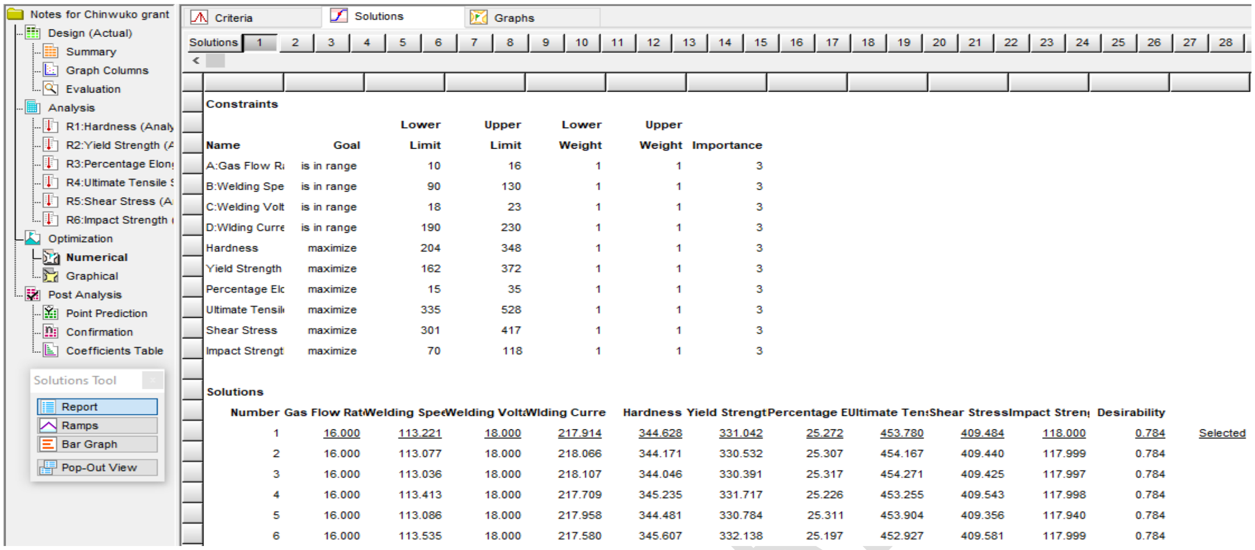



| | | | |
|---|---|---|---|
| Std. Dev. | 6.12 | R-Squared | 0.8756 |
| Mean | 92.38 | Adj R-Squared | 0.7867 |
| C.V. % | 6.63 | Pred R-Square | 0.4515 |
| PRESS | 2314.63 | Adeq Precisior | 12.727 |
| -2 Log Likeliho | 147.07 | BIC | 182.47 |
| | | AICc | 189.37 |

Figure 6.2: Model Summary for Impact Energy

Figure 6.2 reveals the impact energy model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 87.56%. This shows that 87.56 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.4515 and the adjusted R-Squared of 0.7867 are good percentage explanation and expectations of good experimental data. Adequate Precision is used to measure the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 12.727 indicates an adequate signal. This model can be used to navigate the design space.

4. Optimization Solutions




**Constraints**

| Name | Goal | Lower Limit | Upper Limit | Lower Weight | Upper Weight | Importance |
|---|---|---|---|---|---|---|
| A:Gas Flow Ra | is in range | 10 | 16 | 1 | 1 | 3 |
| B:Welding Spe | is in range | 90 | 130 | 1 | 1 | 3 |
| C:Welding Volt | is in range | 18 | 23 | 1 | 1 | 3 |
| D:Wlding Curre | is in range | 190 | 230 | 1 | 1 | 3 |
| Hardness | maximize | 204 | 348 | 1 | 1 | 3 |
| Yield Strength | maximize | 162 | 372 | 1 | 1 | 3 |
| Percentage Elc | maximize | 15 | 35 | 1 | 1 | 3 |
| Ultimate Tensil | maximize | 335 | 528 | 1 | 1 | 3 |
| Shear Stress | maximize | 301 | 417 | 1 | 1 | 3 |
| Impact Strengt | maximize | 70 | 118 | 1 | 1 | 3 |

**Solutions**

| Number | Gas Flow Rat | Welding Spe | Welding Volt | Wlding Curre | Hardness | Yield Strengt | Percentage E | Ultimate Ten | Shear Stress | Impact Stren | Desirability | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 16.000 | 113.221 | 18.000 | 217.914 | 344.628 | 331.042 | 25.272 | 453.780 | 409.484 | 118.000 | 0.784 | Selected |
| 2 | 16.000 | 113.077 | 18.000 | 218.066 | 344.171 | 330.532 | 25.307 | 454.167 | 409.440 | 117.999 | 0.784 | |
| 3 | 16.000 | 113.036 | 18.000 | 218.107 | 344.046 | 330.391 | 25.317 | 454.271 | 409.425 | 117.997 | 0.784 | |
| 4 | 16.000 | 113.413 | 18.000 | 217.709 | 345.235 | 331.717 | 25.226 | 453.255 | 409.543 | 117.998 | 0.784 | |
| 5 | 16.000 | 113.086 | 18.000 | 217.958 | 344.481 | 330.784 | 25.311 | 453.904 | 409.356 | 117.940 | 0.784 | |
| 6 | 16.000 | 113.535 | 18.000 | 217.580 | 345.607 | 332.138 | 25.197 | 452.927 | 409.581 | 117.999 | 0.784 | |

Figure 7.1: The Report of the Optimal Solutions Found

The report of the optimization shows that the iteration found six hundred and ninety two (692) solutions. The optimization results shows that the optimal solutions for input process factors are: gas flow rate 16.00m$^3$/s, welding speed is 113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress and 118.00 J for impact energy response. The overall desirability of the models developed to achieve the optimal solutions result is 78.41%.

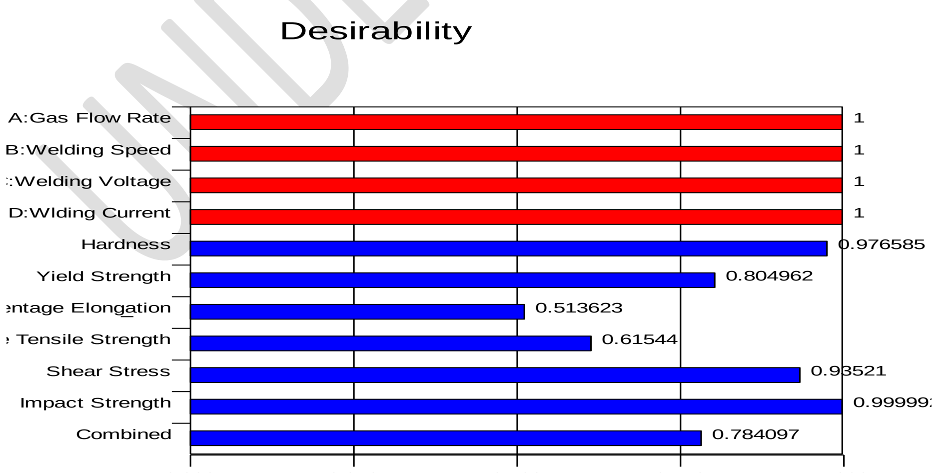



Figure 7.2: The Desirability Plot for the Optimal Solutions

The desirability plot shows the percentage desirability of the input process factors and the response parameters. The input process factors show that there is a hundred percent (100%) desirability of the average input process factors to achieve the desired goals. In the responses, the hardness strength test shows 97.66% desirability result, the yield strength test shows 80.50% desirability result, the percentage elongation response shows 51.36% desirability result, the ultimate tensile strength test shows 61.54% desirability result, the shear stress test shows 93.52% desirability result, and the impact energy response shows 100.00% desirability result. However, the average result of the response parameters is 78.41%.

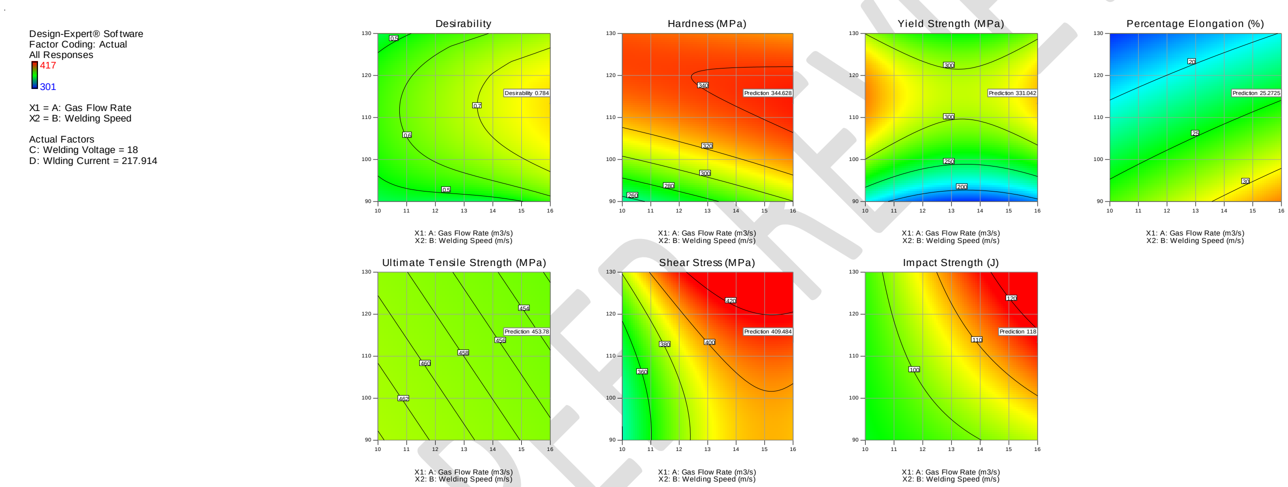



Figure 7.3: Contour Plots of the Response parameters and Desirability

Figure 7.3 shows the contour analysis and results of the response parameters and its optimal surface response solutions. The figure also reveals the optimal desirability solution on the contour surface plot. The desirability plot shows that where the optimal solution will occur in the base material (that is the mild steel metal) is at its average range. The hardness strength, shear stress and impact energy responses will occur at their maximum of their experimental trial results. The yield strength, ultimate tensile strength and the percentage elongation response parameters shows that their optimal solutions will occur at their average range on their experimental trial results.

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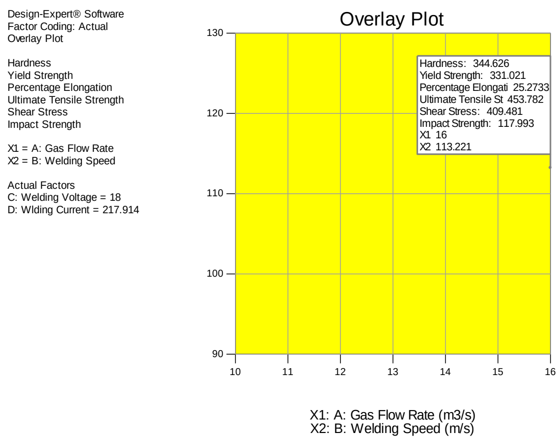


Figure 7.4: The Overlay Plot of the Responses and the Input Process Factors

Figure 7.4 above shows the overlay plot of the optimal solutions for the responses and the input factors. The responses show that the optimal solutions will occur at the pick of the selected experimental range for the gas flow rate, and welding speed. The result also shows that the welding current optimal solution for the responses will occur at the welding current average experimental range. Finally, the welding voltage optimal solution for the responses will occur at the welding voltage minimum selected experimental range. The optimal solutions for the gas flow rate is 16.00m$^3$/s, welding speed is 113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress and 118.00 J for impact energy response.

## Conclusion

In conclusion, the research has shown the optimal solutions of the input factors and the response parameters. The response surface optimization method results show that the optimal solutions for input process factors for gas flow rate is 16.00m$^3$/s, welding speed is 113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress and 118.00 J for impact energy response. The overall desirability of the models developed to achieve the optimal solutions result is 78.41%. The research has revealed the appropriate optimal results for the mechanical properties of the optimization solutions for the IS 2062 mild

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steel material under study. The researchers recommend the results for industrial usage and decision making in companies and in industrialization sectors.

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