

39 properties are primarily controlled by the consumable composition of the shielding gas which
40 can directly influence the strength and ductility of a weld. Its paramount to understand the
41 statistical influence of process parameters in mild steel cladding weld bead geometry (Murugan
42 and Gunaraj, 2005).

43 This study investigates the application of statistics to investigate and to analyze the influence of
44 cladding weld metal geometry in mild steel using response surface method with the application
45 of TIG welding method. Therefore, the main objective of the study is to determine and to
46 evaluate the statistical solutions and its influences of the impact strength in mild steel cladding
47 weld metal bead geometry.

48 **2. PROCESSES OF WELDING**

49 These processes use a welding power supply to create and maintain an electric arc between an
50 electrode and the base material to melt metals at the welding point. They can use either direct
51 current or alternating current and consumable or non-consumable electrodes. The welding region
52 is sometimes protected by some type of inert or semi-inert gas, known as a shielding gas, and
53 filler material is sometimes used as well (Lincoln, 2014).

54 **2.1 Review of Related Literature under Study**

55 Palani and Murugan (2006a) expressed the mechanical and corrosion-resistant properties of the
56 coated components depend on the geometries of the coated beads, which in turn are controlled by
57 the process parameters. Therefore, it is essential to study the effect of the process parameters on
58 the cord geometry to allow effective control of these parameters. The above objective can be
59 easily achieved by developing equations to predict the dimensions of the weld bead in terms of
60 process parameters. The models developed were reviewed for their suitability. Confirmation
61 experiments were also performed and the results show that the developed models can predict the
62 geometries and the dilution of the beads with reasonable precision. It was observed from the
63 research that the interactive effect of the parameters of the process in the geometry of the account
64 is significant and cannot be neglected. Eutimio et al (2013), shows that most of statistical tools
65 currently applied in the bioprocess area were classified. The main three categories were: fair
66 comparison of results, mathematical modeling for little studied systems and taking advantage of
67 large volume of data for enhance robustness and efficiency. However, a chart was constructed

68 for guiding researchers to select the correct statistical technique according to the specific
69 bioprocess problem.

70 Achebo (2016) describes the process of developing a model that relates the shear stresses in a gas
71 welded aluminum alloy weldment with the corresponding flux constituent elements that make up
72 the flux composition. The weldments made from the 13 flux compositions were subjected to
73 evaluation by some professional welders whose judgments about the quality of the weldments
74 were evaluated by using the rank correlation coefficient method. Stefano et al (2009) present the
75 results of a research through the design of an experimental technique on the influence of
76 temperature, the residence time and the pressure of the bar in the resistance to heat sealing of
77 oriented polypropylene films coated with a thin layer of gelatin. This chemo-metric approach
78 allowed to achieve a complete understanding of the effect of each independent factor in the two
79 different responses considered as a measure of the force required to break the link through the
80 sealed interface.

81 Marko et al (2017), express that the process of laser cladding has become more important during
82 recent years because of its broad application for cladding, repair or additive manufacturing. For
83 high quality and reliability of the repaired components, it is necessary to adjust the weld bead
84 geometry to the specific repair task. The bead geometry influences the metallurgical bonding and
85 the degree of dilution as well as the formation of defects like pores or cracks. The results show,
86 the essential effects are detected with a full factorial test plan as well as with a central composite
87 design. Merely the effect strength could not always be specified unambiguously. Mastanaiah et
88 al (2014) described the Prediction of weld bead geometry is always an interesting and
89 challenging research as it involves understanding of complex multi input and multi output
90 system. The weld bead geometry has a profound impact on the load bearing capability of a weld
91 joint. The results of investigation suggests the effective thickness of weld, a geometric parameter
92 of weld bead has the most significant influence on tensile breaking load of dissimilar weld joint.
93 The observations on bead geometry and the mechanical are correlated with detailed metallurgical
94 analysis. Xu et al (2014) described the oscillating arc narrow gap all-position gas metal arc
95 welding process was developed to improve efficiency and quality in the welding of thick-walled
96 pipes. The developed models were checked for their adequacy and significance by ANOVA, and

97 the effects of wire feed rate, travel speed, dwell time, oscillating amplitude and welding position
 98 on weld bead dimension were studied. Finally, the optimal welding parameters at welding
 99 positions of 0° to 180° were obtained by numerical optimization using RSM. Nuri et al (2013)
 100 study is aimed at obtaining a relationship between the values defining bead geometry and the
 101 welding parameters and also to select optimum welding parameters. The welding process
 102 parameters that have the most effect on bead geometry are considered and the other parameters
 103 are held as constant. Then, the relationship between the welding parameters is modeled by using
 104 artificial neural network and neurofuzzy system approach. The models developed are compared
 105 with regard to accuracy and the appropriate welding parameters values can be easily selected
 106 when the models improve.

107 **3. DESIGN OF EXPERIMENT**

108 Design of experiment is a scientific approach of combining input parameters optimally so as to
 109 optimize a target response and this can be achieved by using computer software like design
 110 expert. For proper polynomial approximation, experimental designs are used to collect the data.
 111 In this research, central composite design in response surface method was used to generate the
 112 experimental runs. Furthermore, response surface method was used to evaluate, model and
 113 analyze the data statistically which generates the statistical results.

114 **3.1 Identifying the Range of Input Parameters**

115 The key parameters considered in this work are welding current, gas flow rate, welding speed
 116 and voltage. The range of process parameters obtain from literature is shown in the table below

117 **Table 1: Process parameters at Low and High Levels**

Parameter	Units	Symbol	Low	High
Current	Amp	A	180	240
Gas flow rate	Lit/min	F	10	16
Voltage	Volt	V	18	24
Welding speed	Mm/s	S	90	145

118 Impact testing machine is a machine used for the impact testing analysis. It is used to test the
 119 impact strength of the materials to determine the energy or strength of the materials at a specific
 120 location of the material basically at the weldment and other specified locations the researcher
 121 wished to determine the strength in that location. It measures the unit of the material strength in
 122 Joules.



123
124 **Fig. 1: Impact Testing Setup**

125 In the fabrication industry materials standard and specification plays a very vital role in
126 achieving good weld quality. The welding parameter specification is shown in the table below.

127 **3.5 Method of Data Collection**

128 The central composite design matrix was developed using the design expert software, producing
129 20 experimental runs. The input parameters and output parameters make up the experimental
130 matrix and the responses recorded from the weld samples was used as the data. The input process
131 factors are welding current, welding voltage, welding speed and gas flow rate. The output
132 process response is impact strength of the weldment. The input and output parameters were
133 analyzed statistically modeled and optimized.

134 **3.6 Method of Data Analysis**

135 Response Surface Methodology (RSM) Engineers often search for the conditions that would
136 investigate the process of interest. RSM is one of the techniques currently in widespread usage to
137 describe the performance of the welding process and find the statistical investigation of the
138 responses of interest. RSM is a set of mathematical and statistical techniques that are useful for
139 modeling and predicting the response of interest affected by several input variables with the aim
140 of optimizing this response.

141 **4.1 Modeling and Statistical evaluation using Response Surface Technique**

142 In this paper, the researcher revealed a mathematical relationship between selected process
143 factors, namely; current, speed, gas flow rate and voltage to the response variable. The response
144 variable of interest is impact strength of the material.

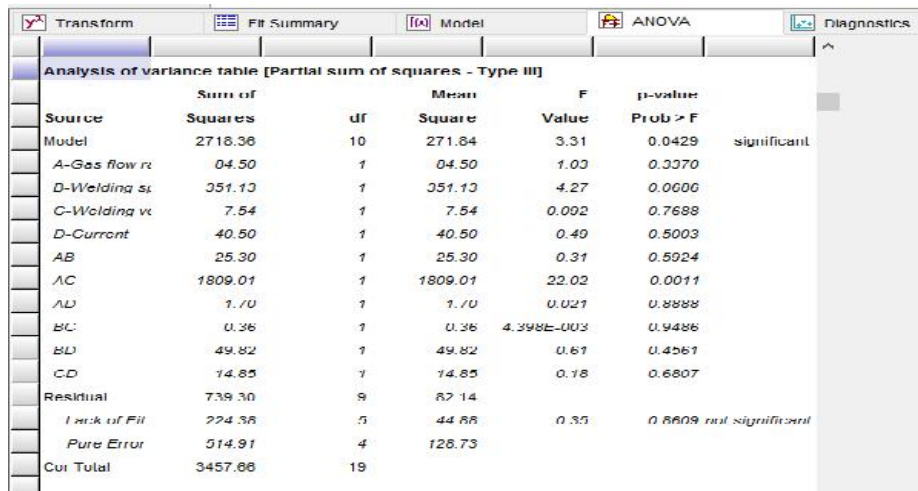


Fig. 2: Model Significance of the Impact Strength using ANOVA

145
 146
 147 Analysis of the model standard error was employed to assess the suitability of process factor and
 148 response variables using the central composite design-value model in response surface to optimize the
 149 impact strength on the weldment. The computed ANOVA of design responses was presented in
 150 figure 2. From the results of figure 2, the Model has ten (10) degree of freedom, with the model
 151 F-value of 3.31 which implies that the model is significant. There is only a 4.29% chance that an
 152 F-Value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate
 153 model terms are significant. In this case A, D, AC are significant model terms. Values greater
 154 than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 0.35
 155 implies the Lack of Fit is not significant relative to the pure error. There is 86.09% chance that a
 156 "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good for
 157 the model fitness.

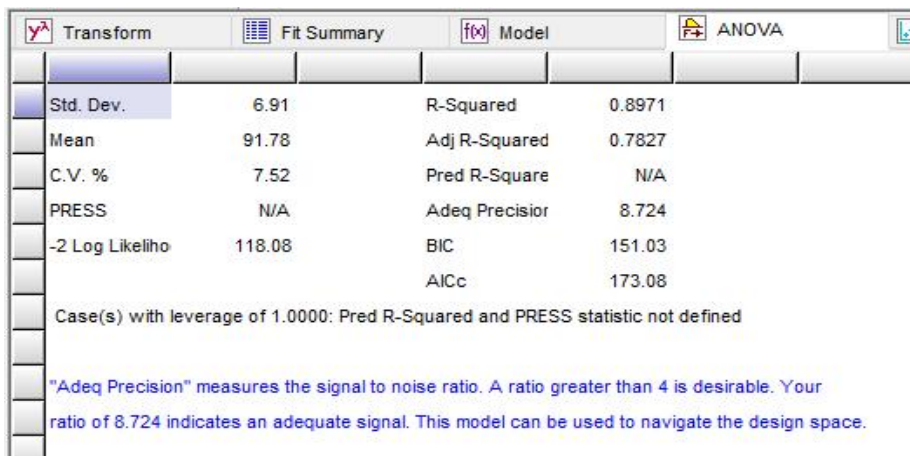


Fig. 3: Model Summary Analysis for validating Model Significance in Impact Strength

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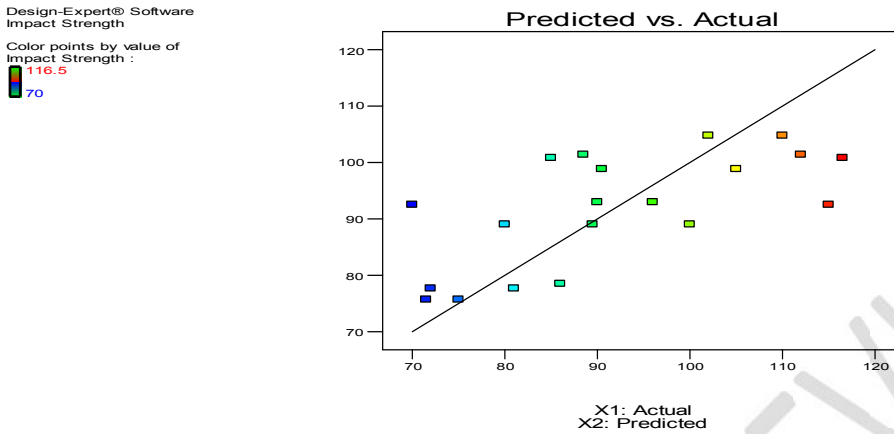
To validate the adequacy of the model based on its ability to maximize the impact strength, the goodness of fit statistics was presented in figure 3. From the result of figure 3, it was observed that the "Predicted R-Squared" value of null is obtained. In case(s) where leverage of 1.0000 is obtained, Predicted R-Squared and PRESS statistic are not defined. However, the R-Squared value of the model is 0.8971 while the Adjusted R-Squared value of the model is 0.7827. "Adequate Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The computed ratio of 8.724 as observed in figure 3 indicates an adequate signal. This model can be used to navigate the design space. Variance inflation factor (VIF) less than 10.00 calculated for all the terms in the design indicate a significant model in which the variables are correlated with the response.

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Cook's Distance	Influence on Fitted Value (DFFITS)	Standard Order
1	80.00	75.42	4.58	0.553	0.991	0.990	0.110	1.101	15
2	75.00	74.54	0.46	0.076	0.190	0.179	0.023	0.477	0
3	110.00	109.54	0.46	0.876	0.190	0.179	0.023	0.477	4
4	90.50	88.68	1.82	0.876	0.748	0.729	0.359	1.935	7
5	112.00	111.54	0.46	0.876	0.190	0.179	0.023	0.477	5
6	72.00	70.18	1.82	0.876	0.748	0.729	0.359	1.935	6
7	70.00	70.00	0.000	1.0000					9
8	85.00	90.81	5.81	0.260	0.977	0.974	0.030	0.577	13
9	90.00	92.92	-2.92	0.053	-0.435	-0.414	0.001	-0.098	18
10	100.00	98.67	1.33	0.553	0.288	0.273	0.009	0.303	12
11	88.50	87.17	1.33	0.553	0.288	0.273	0.009	0.303	11
12	96.00	92.92	3.08	0.053	0.458	0.437	0.001	0.103	19
13	71.50	71.04	0.46	0.076	0.190	0.179	0.023	0.477	2
14	81.00	92.92	-11.92	0.053	-1.774	-2.073	0.016	-0.489	21
15	115.00	110.42	4.58	0.553	0.991	0.990	0.110	1.101	16
16	102.00	92.92	9.08	0.053	1.351	1.426	0.009	0.336	17
17	105.00	103.18	1.82	0.876	0.748	0.729	0.359	1.935	1
18	116.50	114.68	1.82	0.876	0.748	0.729	0.359	1.935	3
19	89.50	92.92	-3.42	0.053	-0.509	-0.487	0.001	-0.115	20
20	86.00	95.04	-9.04	0.260	-1.521	-1.664	0.074	-0.985	14

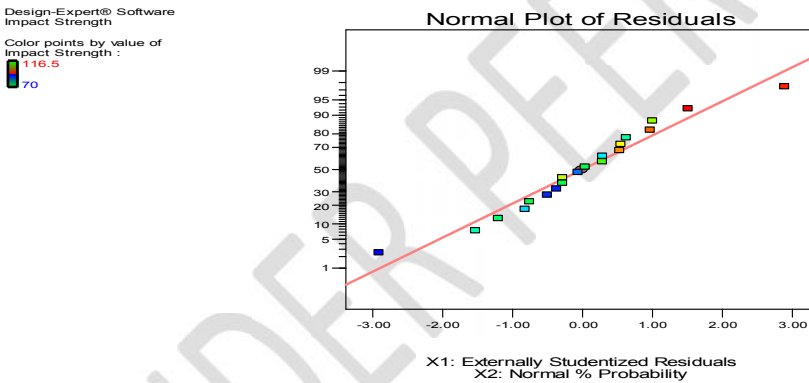
171
 172 **Fig. 4: Diagnostics Statistics Report of Impact Strength (J)**

173 The diagnostics case statistics report which shows the observed values of each response variable
 174 (impact strength) against their predicted values is presented in figure 4. The diagnostic case
 175 statistics actually give insight into the model strength and the adequacy of the optimal equation

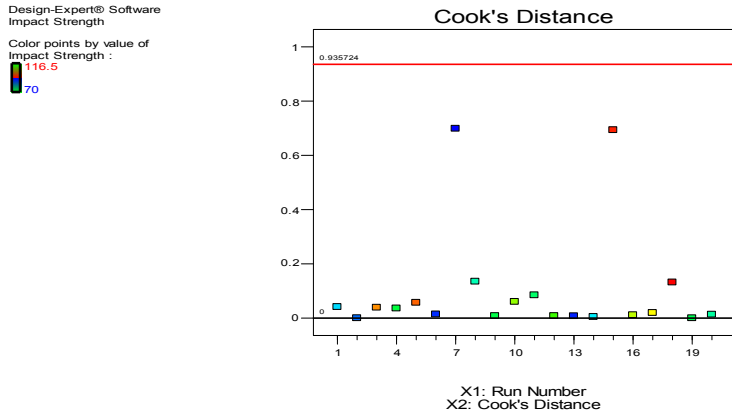
176 in terms of actual factors. To accept any model, its satisfactoriness must first be checked by an
177 appropriate statistical analysis output.



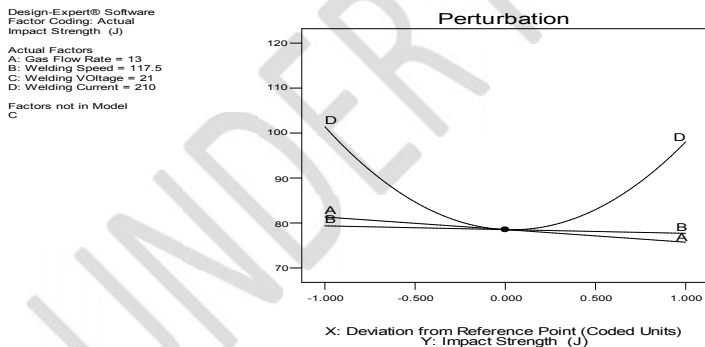
178
179 **Fig. 5: Statistical Investigation of the Predicted versus Actual Residuals**
180 Figure 5 shows the statistical plot of the predicted versus the the actual data in the response
181 parameter. It reveals the variations in the predicted and the actual data using linear fitted line, to
182 understand the differences between the predicted and actual response parameter variations.



183
184 **Fig. 6: Normal Probability Plot of Residuals for Impact Strength**
185 To diagnose the statistical properties of the input factor design, the normal probability plot of
186 residual for impact strength is presented in figure 6. The normal probability plot of studentized
187 residuals was employed to assess the normality of the calculated residuals. The normal
188 probability plot of residuals which is the number of standard deviations of actual values based on
189 the predicted values was employed to ascertain if the residuals (observed – predicted) follows a
190 normal distribution. It is the most significant assumption for checking the sufficiency of a
191 statistical model. Result of figure 6 revealed that the computed residuals are approximately
192 normally distributed which is an indication that the model developed is satisfactory.

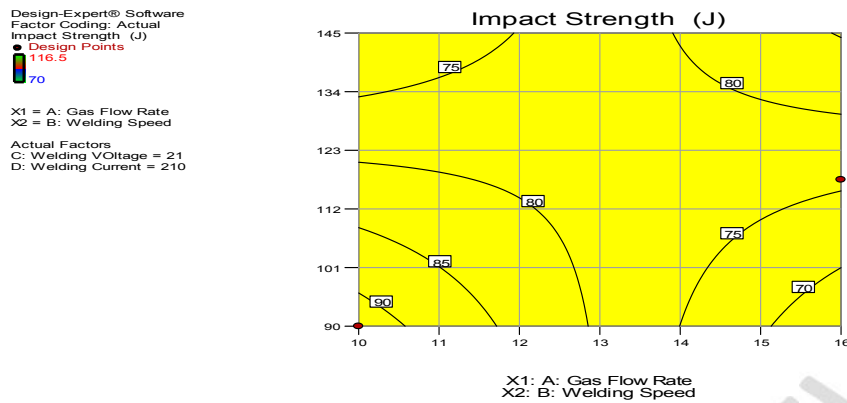


193
194 **Fig. 7: Generated Cook Distance-Versus-Impact Strength**
195 To determine the presence of a possible outlier in the experimental data, the cook's distance plot
196 was generated for the different responses. The cook's distance is a measure of how much the
197 regression would change if the outlier is omitted from the analysis. A point that has a very high
198 distance value relative to the other points may be an outlier and should be investigated. The
199 generated cook's distance is presented in figure 7. The cook's distance plot has an upper
200 boundary of 1 and a lower boundary of 0. Experimental values smaller than the lower boundary
201 or greater than the upper boundary are considered as outliers and must be properly investigated.
202 Result of figure 7 indicates that the data used for this analysis are devoid of any possible outliers
203 thus revealing the adequacy of the experimental data.

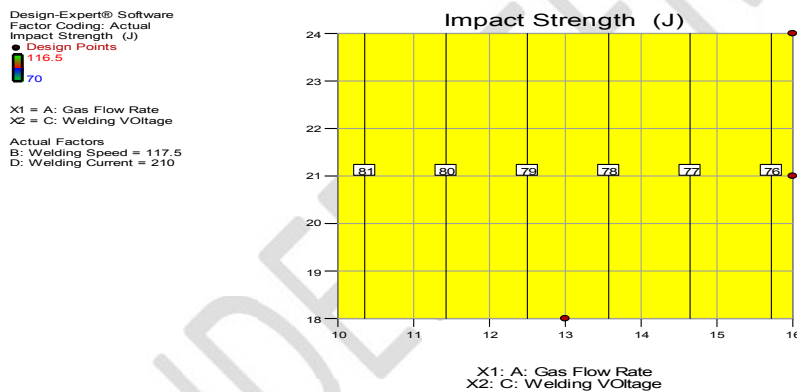


204
205 **Fig. 8: Perturbation Analysis of the Impact Strength**
206 To ascertain the influence of the alterations of process factors to the response variable,
207 perturbation analysis were employed as shown in figure 8. From the results of figure 8, it shows
208 that the disturbances in the response factors by the process factors, and the alterations of the
209 function of the external or internal means of the process factors in the response variables does
210 not make any of the responses to deviate from its reference points. This shows that the deviation

211 of the process factors does not disengage the responses from obtaining a good model and
 212 adequate optimization results.

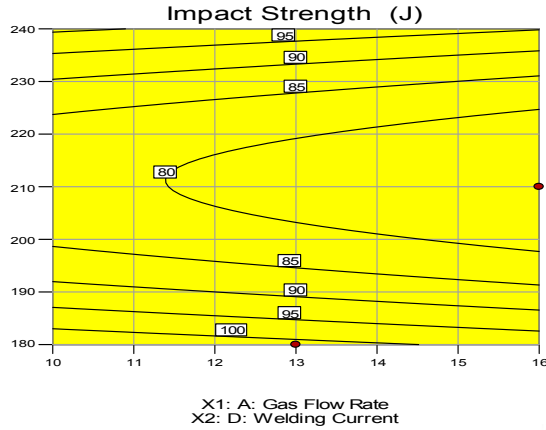


213
 214 **Fig. 9: Contour Plot of Impact Strength Influenced by Gas Flow Rate and Speed**
 215 From the results, the analyses in figure 9 express the influence of the input factors in the
 216 responses from the minimum bounded region of the response to the maximum bounded region of
 217 the response. It expressed that decrease in gas flow rate and welding speed will increase the
 218 impact strength.



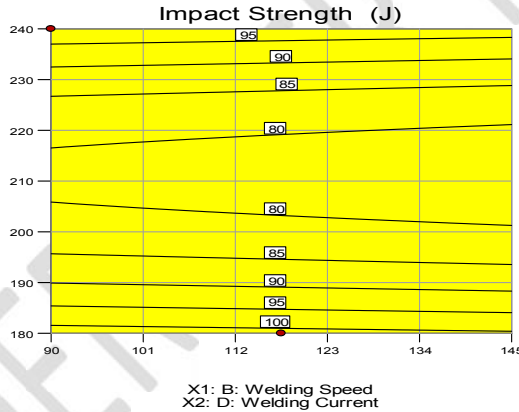
219
 220 **Fig. 10: Contour Plot of Impact Strength Influenced by Gas Flow Rate and Voltage**
 221 From the results, the analyses in figure 10 express the influence of the input factors in the
 222 responses from the minimum bounded region of the response to the maximum bounded region of
 223 the response. It expressed that decrease in gas flow rate increase the impact strength while
 224 voltage has no influence in the increase or decrease of the impact strength.

Design-Expert® Software
 Factor Coding: Actual
 Impact Strength (J)
 ● Design Points
 116.5
 70
 X1 = A: Gas Flow Rate
 X2 = D: Welding Current
 Actual Factors
 B: Welding Speed = 117.5
 C: Welding Voltage = 21

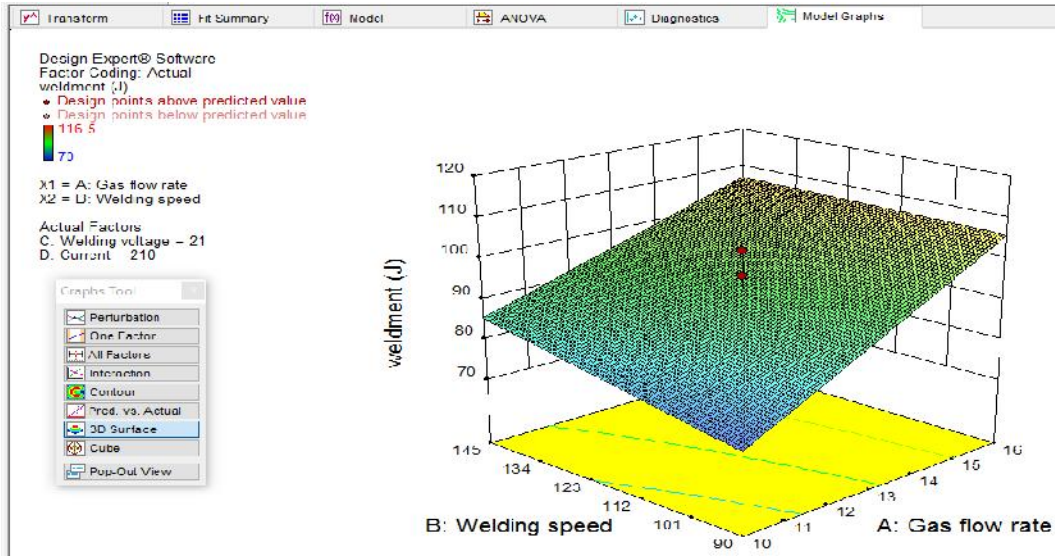


225
 226 **Fig. 11: Contour Plot of Impact Strength Influenced by Gas Flow Rate and Current**
 227 From the results, figure 11 indicates that an increase in gas flow rate increase the impact strength
 228 while current from its initial decrease the impact strength and at a point starts to increase the
 229 impact strength. This shows that the selection of the current will be carefully done due to its
 230 effects to impact strength.

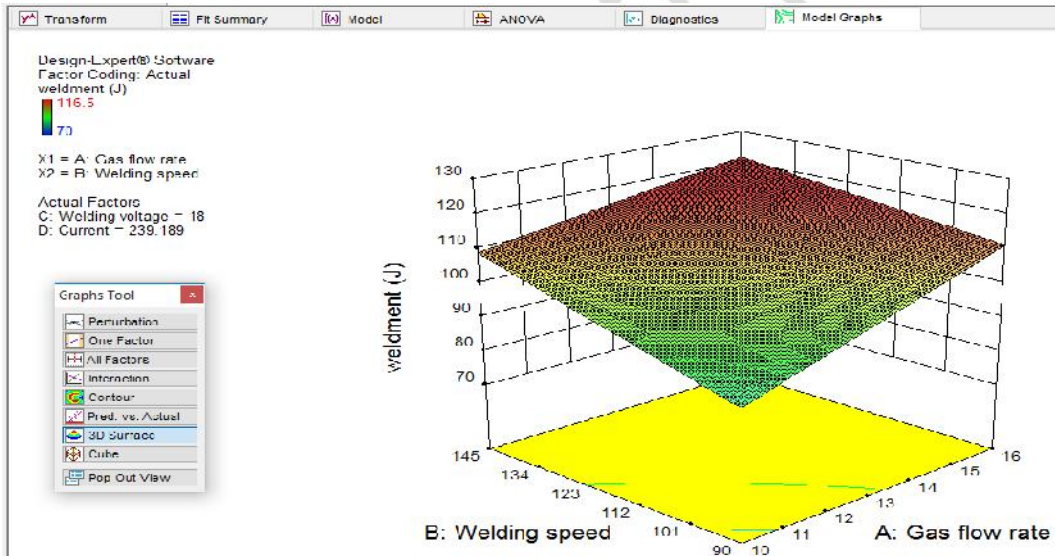
Design-Expert® Software
 Factor Coding: Actual
 Impact Strength (J)
 ● Design Points
 116.5
 70
 X1 = B: Welding Speed
 X2 = D: Welding Current
 Actual Factors
 A: Gas Flow Rate = 13
 C: Welding Voltage = 21



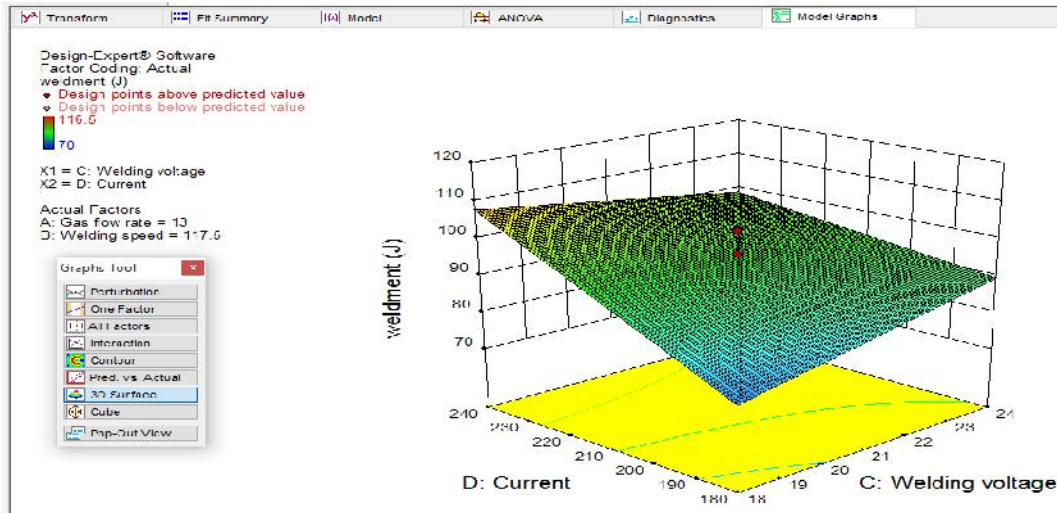
231
 232 **Fig. 12: Impact Strength Contour Plot Influenced by Speed and Current**
 233 From the results, the analyses in figure 12 expressed that increase in gas flow rate increase the
 234 impact strength while current from its initial decrease the impact strength and at a point starts to
 235 increase the impact strength. This shows that the selection of the current will be carefully done
 236 due to its effects to impact strength. However, the decrease in welding speed will increase the
 237 impact strength.



238
 239 **Fig. 13: Effects of Process Factors (with CD factors ratio of 50:50) on the Impact Strength**
 240 To study the effect of process factors with welding voltage and welding current at its average,
 241 figure 13 was presented.



242
 243 **Fig. 14: Effects of Process Factors (with CD factors ratio of 10:90) on the Impact Strength**
 244 To study the effect of process factors with welding voltage and welding current at its ratio of
 245 10:90, figure 14 was presented.



246
 247 **Fig. 15: Effects of Process Factors (with AB Factors Ratio of 50:50) on the Impact Strength**
 248

249 Figures 13-15 express the 3-dimensional (3D) response surface plots of impact strength on heat
 250 zone and its significant effects on process factors.

251
 252 **4. Discussion of Results**

253 In this study, central composite design was employed owing to its simplicity and flexibility to
 254 variable adjustment and analysis of process interaction relating to process factors combination.
 255 The design and analysis was executed with the aid of statistical tool. For this particular problem,
 256 Design Expert 10.0.1 was employed. However, using response surface method, the results of the
 257 statistical evaluation for the selected process parameters and response parameter were observed.
 258 Analysis of the model standard error was employed to assess the suitability of process factor and
 259 response variables using the central composite design model in response surface to analyze
 260 statistically, the impact strength on the weldment. The computed ANOVA of design responses
 261 was presented in figure 2. From the results, the model F-value of 3.31 implies that the model is
 262 significant. There is only a 4.29% chance that an F-Value this large could occur due to noise.
 263 Values of "Prob > F" less than 0.0500 indicate model terms are significant. The "Lack of Fit F-
 264 value" of 0.35 implies the Lack of Fit is not significant relative to the pure error. There is 86.09%
 265 chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit
 266 is good for the model fitness.

267 From the result of figure 3, it was observed that the "Predicted R-Squared" value of null is
268 obtained. In case(s) where leverage of 1.0000 is obtained, Predicted R-Squared and PRESS
269 statistic are not defined. However, the R-Squared value of the model is 0.8971 while the
270 Adjusted R-Squared value of the model is 0.7827. "Adequate Precision" measures the signal to
271 noise ratio. A ratio greater than 4 is desirable. The computed ratio of 8.724 as observed in
272 figure 3 indicates an adequate signal. This model can be used to navigate the design space.
273 Variance inflation factor (VIF) less than 10.00 calculated for all the terms in the design indicate a
274 significant model in which the variables are correlated with the response.
275 Experimental values smaller than the lower bound or greater than the upper bounds are
276 considered as outliers and must be properly investigated. Result of figure 7 indicates that the data
277 used for this analysis are devoid of any possible outliers thus revealing the adequacy of the
278 experimental data.
279 Figure 13 shows the process factors ratio of 50 to 50 (in current and voltage). It was observed
280 that increase in response (impact strength) increases welding speed (B) and gas flow rate (A).
281 This shows that increase or decrease on the process factors affect the response variable. In Figure
282 14, gas flow rate (A) and welding speed (B) were hold at a mix ratio of 50 to 50 or at its mean
283 which was used to determine the influence of other process factors to the response. It was
284 observed that increase in current (D), will increase the response(impact strength on weldment).
285 In addition the geometry of the surface was observed to be concave.
286 In Figure 15, a ratio of 10 to 90 in welding voltage (C) and welding current (D) was used. It was
287 observed that increase in welding speed (B) and gas flow rate (A) process factors, increases the
288 response(impact strength on weldment). This shows the lower the welding voltage (C) and
289 higher the welding current (D) will increase the impact strength on weldment which will
290 influence and enhance the increase on welding speed and gas flow rate of the process factors to
291 its response. The 3D surface plot as observed in figures 13-15, show the relationship between the
292 process factors (current, gas flow rate, speed and voltage), against the response variable (impact
293 strength). It is a 3-dimensional surface plot which was employed to give a clearer concept of the
294 surface. Although not as useful as the contour plot for establishing coordinates, this view
295 provides a clearer picture of the surface. It was observed from Figures 13-15 that the input

296 factors has significant influence on the surface geometry and the overall contributions towards
297 the response variable (impact strength).

298 **5.1 CONCLUSIONS**

299 A close examination of the mild steel cladding weld metal was experimented with the input
300 parameters of current, voltage, speed and gas flow rate to predict and to analyze the mild steel
301 cladding weld metal response parameter (impact strength) using response surface method.
302 Welding parameters were carefully selected.

303 The results of the statistical investigation revealed the model F-value of 3.31 is significant.
304 There is only a 4.29% chance that an F-Value this large could occur due to noise. Values of
305 "Prob > F" less than 0.05 indicate model terms are significant. The "Lack of Fit F-value" of 0.35
306 implies the Lack of Fit is not significant relative to the pure error. There is 86.09% chance that a
307 "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good for
308 the model fitness. It was observed that the R-Squared value of the model is 0.8971 while the
309 Adjusted R-Squared value of the model is 0.7827. Adequate Precision measures the signal to
310 noise ratio and a ratio greater than 4 is desirable. The computed ratio of 8.724 as observed
311 which indicates an adequate signal. This model can be used to navigate the design space.
312 Variance inflation factor (VIF) less than 10 calculated for all the terms in the design indicate a
313 significant model in which the variables are correlated with the response. In response surface
314 plots and contour plots, the process parameters influence the impact strength except voltage,
315 which has no effect on the response parameter.

316 The performed experiment will appraise the knowledge of mild steel cladding weld formulation
317 and composition in tungsten inert gas (TIG) welding system and also in industrialization. The
318 experimental analysis and its statistical evaluation will help in decision making systematically
319 mostly in the industrialization where the product is more utilized.

320

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