STATISTICAL EVALUATION OF THE IMPACT STRENGTH ON MILD STEEL CLADDING WELD METAL GEOMETRY

Abstract

The research focused on statistical evaluation of the impact strength on mild steel cladding weld metal geometry. The weld specimen of length 60 by width 40 and thickness of 10 was used for the experiment. A butt joint method was prepared and tungsten inert gas welding process was used to perform the twenty (20) experimental runs. A response surface method was applied to model and to analyze statistically the welded metal bead geometry. The statistical result expressed that the model developed is significance. However, there is only 4.29% chance that an F-Value could occur due to noise. Probability values that is less than 0.0500 indicate that the model terms are significant. In this research, there is 86.09% chance that a Lack of Fit of F-value which is this large could occur due to noise. Non-significant lack of fit is good for the model fitness. It was observed that 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 and a ratio greater than 4 is desirable. However, the computed ratio of 8.724 was observed which indicates an adequate signal. The results of response surface plots and contour plots observe that the process parameters influence the impact strength of the weld bead geometry except voltage, which has no effect on the output parameter. The statistical investigation reveals the statistical solutions necessary to portray the parameters under study.

Keywords: Mild steel, impact strength, response surface, ANOVA, bead geometry, welding and Statistics

1. Introduction

In today's Industrial world 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 makes the material a unique and irresistible materials in Industrialization. Industrialization world utilize these materials mainly because of their mechanical properties as well as their excellent corrosion resistance. Cladding weld has been the methods of joining these metals because of the low price and high quality of the welding process (Palani and Murugan, 2006b). On the other hand, it is also imperative to highlight that during welding overlaying many discontinuities are produced, which acts as stress raisers that can lead to a decrease in the life of the weld. Depending on weld parameters used, deposition rates, dilution rates and mild steel metal in use. The shape of weld bead would influence the weld metal cooling which would alter the weld, metal transformation. Welding parameters are to be carefully selected (Kannan and Murugan, 2006). This loss and pick-up in welding will influence the mechanical properties of the weld metal. Although weld metal properties are primarily controlled by the consumable composition of the shielding gas which can directly influence the strength and ductility of a weld. Its paramount to understand the statistical influence of process parameters in mild steel cladding weld bead geometry (Murugan and Gunaraj, 2005).

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

2. Processes of Welding

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

2.1 Review of Related Literature under Study

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

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

Marko et al (2017), express that the process of laser cladding has become more important during recent years because of its broad application for cladding, repair or additive manufacturing. For high quality and reliability of the repaired components, it is necessary to adjust the weld bead geometry to the specific repair task. The bead geometry influences the metallurgical bonding and the degree of dilution as well as the formation of defects like pores or cracks. The results show, the essential effects are detected with a full factorial test plan as well as with a central composite design. Merely the effect strength could not always be specified unambiguously. Mastanaiah et al (2014) described the Prediction of weld bead geometry is always an interesting and challenging research as it involves understanding of complex multi input and multi output system. The weld bead geometry has a profound impact on the load bearing capability of a weld joint. The results of investigation suggests the effective thickness of weld, a geometric parameter of weld bead has the most significant influence on tensile breaking load of dissimilar weld joint. The observations on bead geometry and the mechanical are correlated with detailed metallurgical analysis. Xu et al (2014) described the oscillating arc narrow gap all-position gas metal arc welding process was developed to improve efficiency and quality in the welding of thick-walled pipes. The developed models were checked for their adequacy and significance by ANOVA, and the effects of wire feed rate, travel speed, dwell time, oscillating amplitude and welding position on weld bead dimension were studied. Finally, the optimal welding parameters at welding positions of 0° to 180° were obtained by numerical optimization using RSM. Nuri et al (2013) study is aimed at obtaining a relationship between the values defining bead geometry and the welding parameters and also to select optimum welding parameters. The welding process parameters that have the most effect on bead geometry are considered and the other parameters are held as constant. Then, the relationship between the welding parameters is modeled by using artificial neural network and neurofuzzy system approach. The models developed are compared with regard to accuracy and the appropriate welding parameters values can be easily selected when the models improve.

3. Design of Experiment

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

3.1 Identifying the Range of Input Parameters

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

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

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

Fig. 1: Impact Testing Setup

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

3.5 Method of Data Collection

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

3.6 Method of Data Analysis

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

4.1 Modeling and Statistical evaluation using Response Surface Technique

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

Transform | Fit Summary | Model | ANOVA | Diagnostics

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

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2718.36	10	271.84	3.31	0.0429	significant
A-Gas flow ra	*04.50*	*1*	*04.50*	*1.03*	*0.3370*	
D-Welding sp	*351.13*	*1*	*351.13*	*4.27*	*0.0606*	
C-Welding vo	*7.54*	*1*	*7.54*	*0.092*	*0.7688*	
D-Current	*40.50*	*1*	*40.50*	*0.49*	*0.5003*	
AB	*25.30*	*1*	*25.30*	*0.31*	*0.5924*	
AC	*1809.01*	*1*	*1809.01*	*22.02*	*0.0011*	
AD	*1.70*	*1*	*1.70*	*0.021*	*0.8888*	
BC	*0.36*	*1*	*0.36*	*4.398E-003*	*0.9486*	
BD	*49.82*	*1*	*49.82*	*0.61*	*0.4561*	
CD	*14.85*	*1*	*14.85*	*0.18*	*0.6807*	
Residual	739.30	9	82.14			
Lack of Fit	*224.38*	*5*	*44.88*	*0.35*	*0.8609*	*not significant*
Pure Error	*514.91*	*4*	*128.73*			
Cor Total	3457.66	19				

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

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

Transform | Fit Summary | Model | ANOVA

Std. Dev.	6.91	R-Squared	0.8971
Mean	91.78	Adj R-Squared	0.7827
C.V. %	7.52	Pred R-Square	N/A
PRESS	N/A	Adeq Precisior	8.724
-2 Log Likeliho	118.08	BIC	151.03
		AICc	173.08

Case(s) with leverage of 1.0000: Pred R-Squared and PRESS statistic not defined

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 8.724 indicates an adequate signal. This model can be used to navigate the design space.

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

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 nill 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 computaed 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.

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

Response 5 weldment Transform: None

Diagnostics Case Statistics

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	0.876	0.190	0.179	0.023	0.477	8
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	1.000					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	0.876	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

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

The diagnostics case statistics report which shows the observed values of each response variable (impact strength) against their predicted values is presented in figure 4. The diagnostic case statistics actually give insight into the model strength and the adequacy of the optimal equation in terms of actual factors. To accept any model, its satisfactoriness must first be checked by an appropriate statistical analysis output.

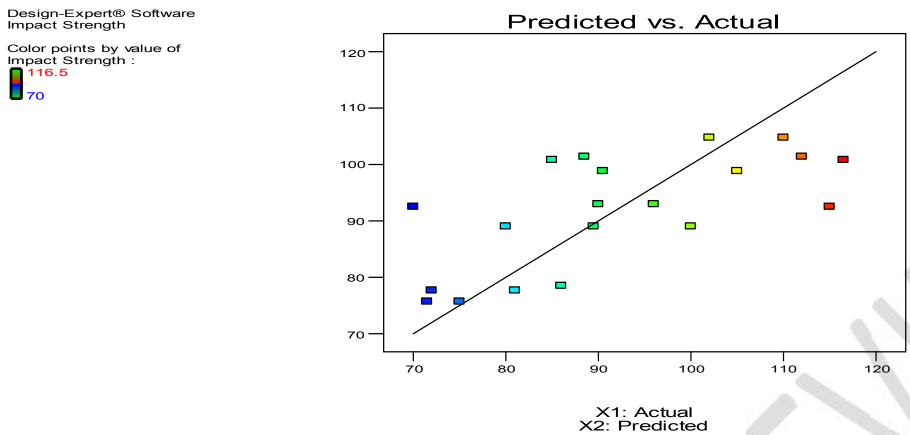

Fig. 5: Statistical Investigation of the Predticted versus Actual Residuals

Figure 5 shows the statistical plot of the predicted versus the the actual data in the response parameter. It reveals the variations in the predicted and the actual data using linear fitted line, to understand the differences between the predicted and actual response parameter variations.

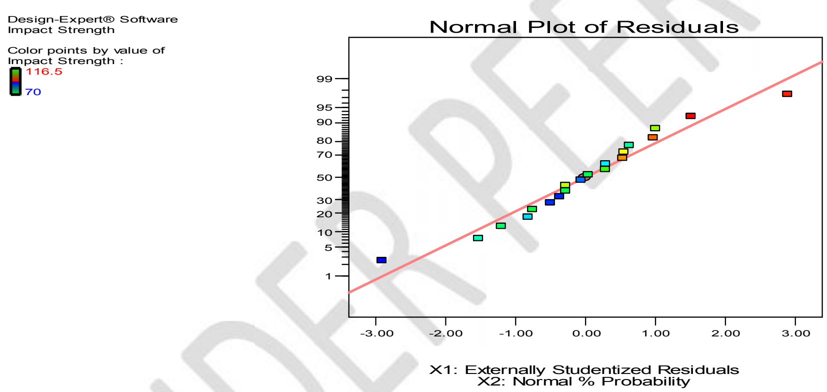

Fig. 6: Normal Probability Plot of Residuals for Impact Strength

To diagnose the statistical properties of the input factor design, the normal probability plot of residual for impact strength is presented in figure 6. The normal probability plot of studentized residuals was employed to assess the normality of the calculated residuals. The normal probability plot of residuals which is the number of standard deviations of actual values based on the predicted values was employed to ascertain if the residuals (observed – predicted) follows a normal distribution. It is the most significant assumption for checking the sufficiency of a statistical model. Result of figure 6 revealed that the computed residuals are approximately normally distributed which is an indication that the model developed is satisfactory.

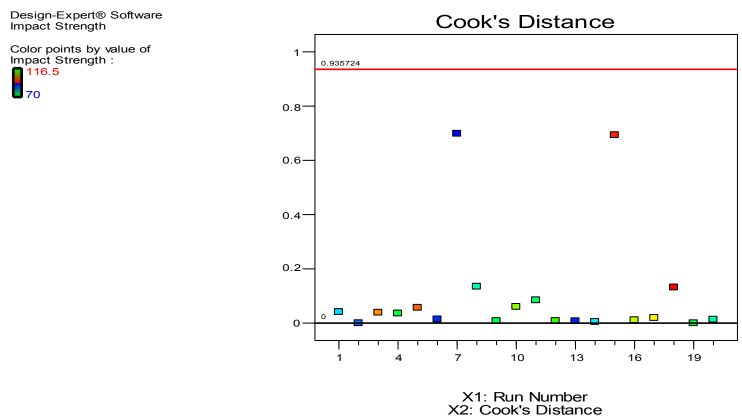

Fig. 7: Generated Cook Distance-Versus-Impact Strength

To determine the presence of a possible outlier in the experimental data, the cook's distance plot was generated for the different responses. The cook's distance is a measure of how much the regression would change if the outlier is omitted from the analysis. A point that has a very high distance value relative to the other points may be an outlier and should be investigated. The generated cook's distance is presented in figure 7. The cook's distance plot has an upper bound of 1.00 and a lower bound of 0.00. Experimental values smaller than the lower bound or greater than the upper bounds are considered as outliers and must be properly investigated. Result of figure 7 indicates that the data used for this analysis are devoid of any possible outliers thus revealing the adequacy of the experimental data.

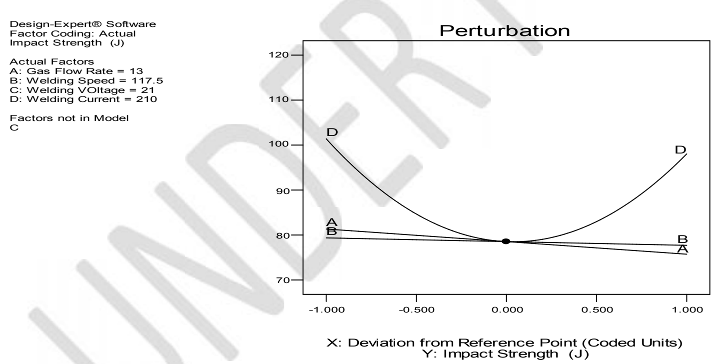

Fig. 8: Perturbation Analysis of the Impact Strength

To ascertain the influence of the alterations of process factors to the response variable, perturbation analysis were employed as shown in figure 8. From the results of figure 8, it shows that the disturbances in the response factors by the process factors, and the alterations of the function of the external or internal means of the process factors in the response variables does not make any of the responses to deviate from its reference points. This shows that the deviation of the process factors does not disengage the responses from obtaining a good model and adequate optimization results.

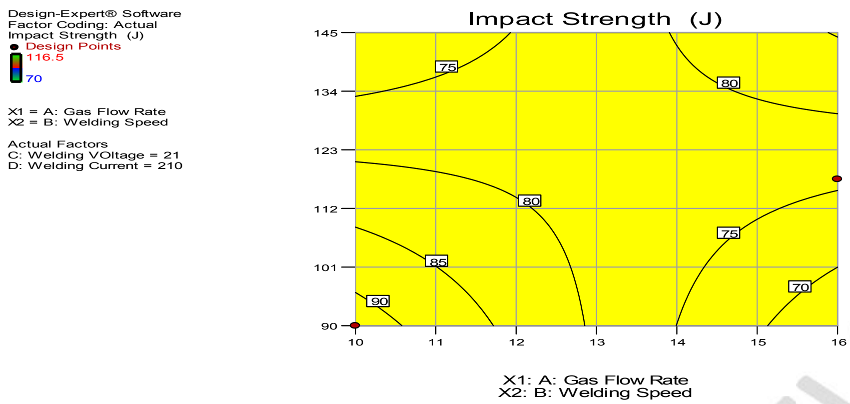

Fig. 9: Contour Plot of Impact Strength Influenced by Gas Flow Rate and Speed

From the results, the analyses in figure 9 express the influence of the input factors in the responses from the minimum bounded region of the response to the maximum bounded region of the response. It expressed that decrease in gas flow rate and welding speed will increase the impact strength.

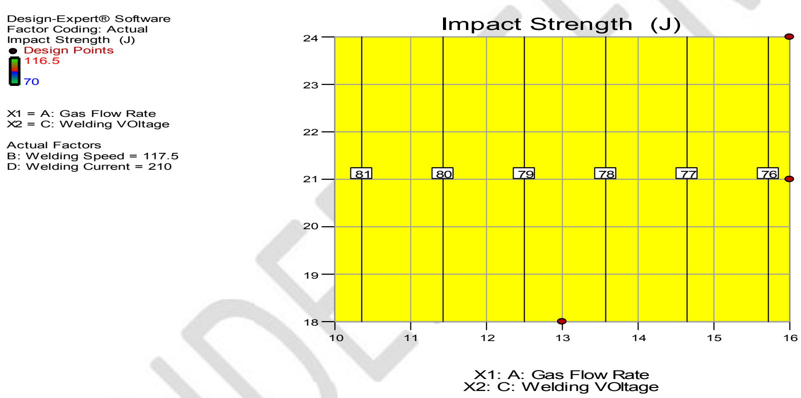

Fig. 10: Contour Plot of Impact Strength Influenced by Gas Flow Rate and Voltage

From the results, the analyses in figure 10 express the influence of the input factors in the responses from the minimum bounded region of the response to the maximum bounded region of the response. It expressed that decrease in gas flow rate increase the impact strength while voltage has no influence in the increase or decrease of the impact strength.

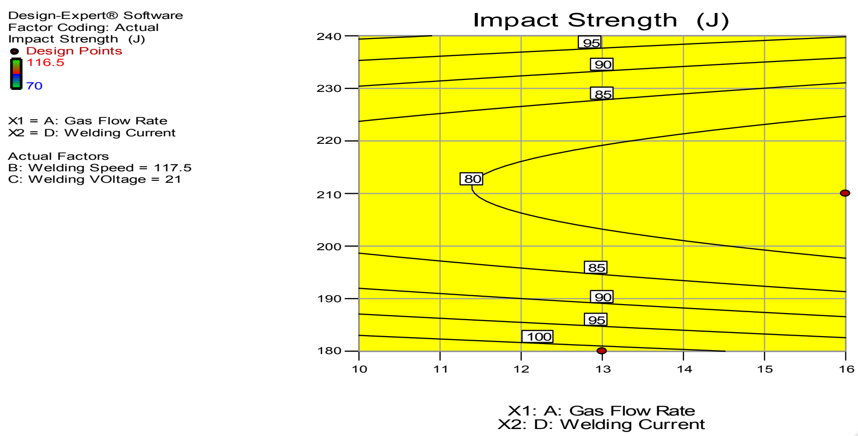

Fig. 11: Contour Plot of Impact Strength Influenced by Gas Flow Rate and Current

From the results, the analyses in figure 11 expressed that increase in gas flow rate increase the impact strength while current from its initial decrease the impact strength and at a point starts to increase the impact strength. This shows that the selection of the current will be carefully done due to its effects to impact strength.

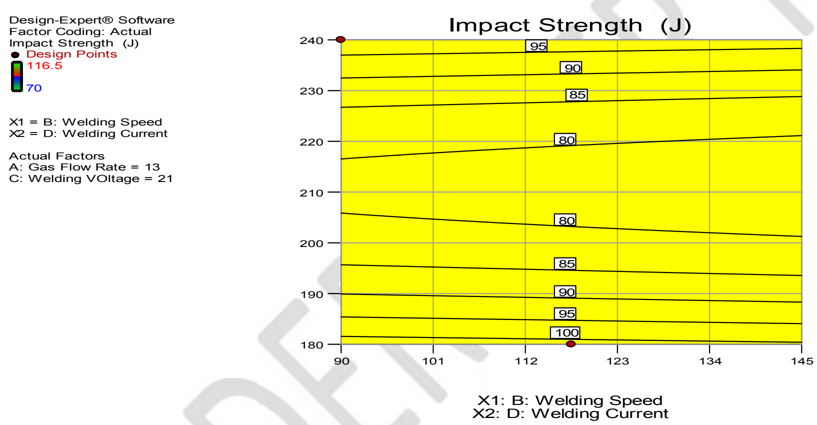

Fig. 12: Impact Strength Contour Plot Influenced by Speed and Current

From the results, the analyses in figure 12 expressed that increase in gas flow rate increase the impact strength while current from its initial decrease the impact strength and at a point starts to increase the impact strength. This shows that the selection of the current will be carefully done due to its effects to impact strength. However, the decrease in welding speed will increase the impact strength.

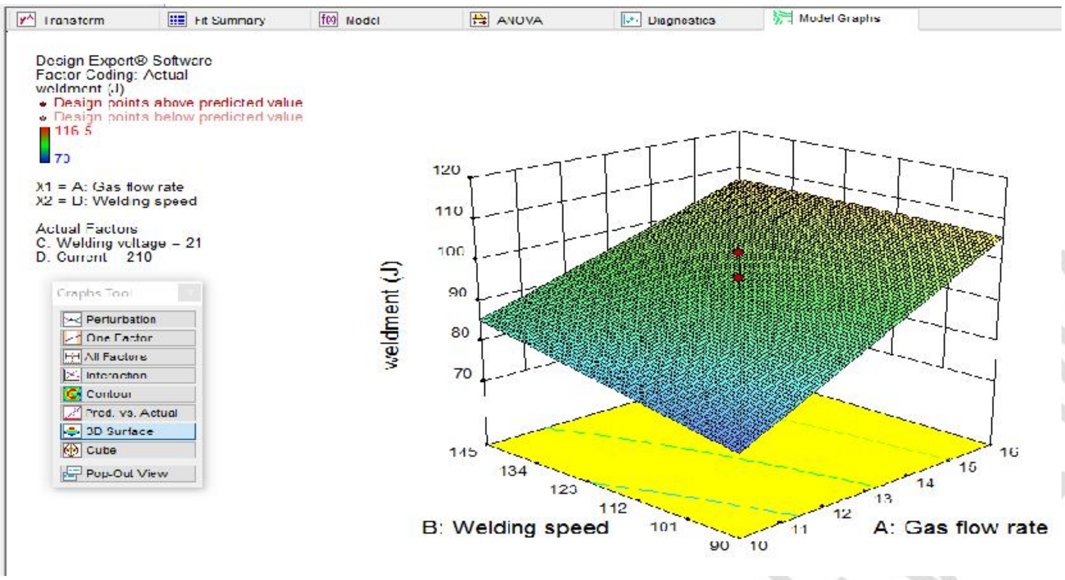

Fig. 13: Effects of Process Factors (with CD factors ratio of 50:50) on the Impact Strength

To study the effect of process factors with welding voltage and welding current at its average, figure 13 was presented.

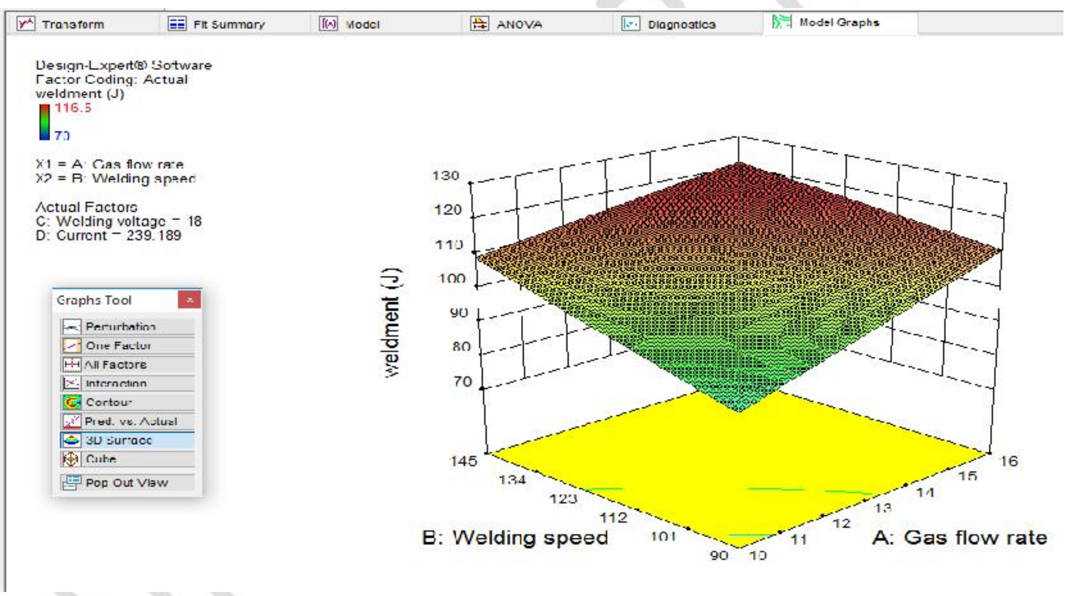

Fig. 14: Effects of Process Factors (with CD factors ratio of 10:90) on the Impact Strength

To study the effect of process factors with welding voltage and welding current at its ratio of 10:90, figure 14 was presented.

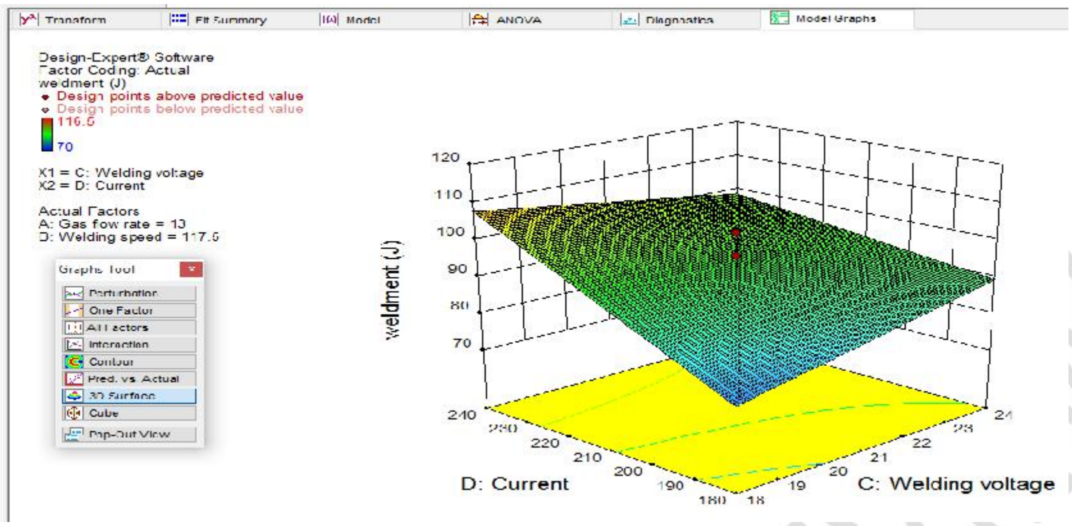

Fig. 15: Effects of Process Factors (with AB Factors Ratio of 50:50) on the Impact Strength

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

4. Discussion of Results

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

From the result of figure 3, it was observed that the "Predicted R-Squared" value of nill 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 computaed 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.

Experimental values smaller than the lower bound or greater than the upper bounds are considered as outliers and must be properly investigated. Result of figure 7 indicates that the data used for this analysis are devoid of any possible outliers thus revealing the adequacy of the experimental data.

Figure 13, shows the process factors ratio of 50 to 50 (in current and voltage). It was observed that increase in response (impact strength) increases welding speed (B) and gas flow rate (A). This shows that increase or decrease on the process factors affect the response variable. In Figure 14, gas flow rate (A) and welding speed (B) were hold at a mix ratio of 50 to 50 or at its mean which was used to determine the influence of other process factors to the response. It was observed that increase in current (D), will increase the response(impact strength on weldment). In addition the geometry of the surface was observed to be concave.

In Figure 15, a ratio of 10 to 90 in welding voltage (C) and welding current (D) was used. It was observed that increase in welding speed (B) and gas flow rate (A) process factors,increases the response(impact strength on weldment). This shows the lower the welding voltage (C) and higher the welding current (D) will increase the impact strength on weldment which will influence and enhance the increase on welding speed and gas flow rate of the process factors to its response. The 3D surface plot as observed in figures 13-15, show the relationship between the process factors (current, gas flow rate, speed and voltage), against the response variable (impact strength). It is a 3-dimensional surface plot which was employed to give a clearer concept of the surface. Although not as useful as the contour plot for establishing coordinates, this view provides a clearer picture of the surface. It was observed from Figures 13-15 that the input factors has significant influence on the surface geometry and the overall contributions towards the response variable (impact strength).

5.1 Conclusions

A close examination of the mild steel cladding weld metal was experimented with the input parameters of current, voltage, speed and gas flow rate to predict and to analyze the mild steel cladding weld metal response parameter (impact strength) using response surface method. Welding parameters were carefully selected. The results of the statistical investigation revealed the model F-value of 3.31 is significant. There is only a 4.29% chance that an F-Value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. The "Lack of Fit F-value" of 0.35 implies the Lack of Fit is not significant relative to the pure error. There is 86.09% 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 fitness. It was observed that 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 and a ratio greater than 4 is desirable. The computaed ratio of 8.724 as observed which 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. In response surface plots and contour plots, the process parameters influence the impact strength except voltage, which has no effect on the response parameter.

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

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