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The Effects of Welding Current Gas Flow Rate and Welding Voltage on the Metal Flow Velocity Using Response Surface Methodology

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ABSTRACT

The need for numerical models to further improve understanding of welding properties is of great importance to welding researchers. RSM is a very significant technique applied in the Manufacturing, Metallurgical and Materials industries that employ mathematical and artificial intelligent methods. This paper is on Tungsten inert gas process parameters. Effect of welding current, gas flowrate and welding voltage on metal flow velocity using RSM .The main input parameters considered are welding current, gas flowrate and welding voltage, whereas the response parameter is metal flow velocity. The statistical design of experiment was done using the central composite design technique. The experiment was carried out 20 times with 5 weldments per experiment. The response was measured and recorded. From the result, it was observed that current of 160Amp, Voltage of 9Volts, Gas Flowrate of 10Lit/min, results in welding process with the Metal Flow Velocity of 0.017m/s.

1. INTRODUCTION

1.1 Background to the study

The kinetics of reactions between metal and slag can be monitored by continuous measurements of the liquid's viscosity. According to Kaptay (2005), one of the technologically significant transport qualities required to develop and optimize metallurgical technologies is the viscosity of liquid metals and alloys. Boda et al. (2015) were of the opinion that fluid's viscosity is a measurement of how resistant it is to slow deformation caused by shear stress. According to the authors, a fluid's viscosity is a feature that results from collisions between nearby particles moving at various speeds. The fluid's constituent particles typically travels more swiftly near the weld pool axis and more slowly toward the walls of the work piece (liquid-solid interface)

Welding

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DIO

According to William and Kevin(1991), welding is a method of combining metals or plastics parts using various fusion processes in order to create or repair metal structures. The materials are typically joined together using heat. Heat can be generated by flames, electric arcs, or laser light in welding equipment. The Middle Ages are when welding first appears in written records (Bronze Age). Welded gold boxes are are a good example of this. Egypt developed early welding skills because many of their iron implements were produced by welding. Around this time, a group of skilled workers known as blacksmiths rose to prominence. According to Wemen (2023), the price of welding is a significant factor in manufacturing decisions. The entire cost is affected by a variety of factors, including energy cost, material cost labour cost and equipment cost.

By creating a model and using regression analysis and artificial neural networks Achebo and Eki (2021)predicted the properties of mild steel welds.The gas metal arc welding(GMAW) process was used, and experimental methods were used to obtain the Brinell Hardness Number, Ultimate Tensile Strength(UTS) and Bead Height(BH).Welding angle, welding speed, voltage, and welding current are input parameters. They came to conclusion that that prolonged heating of the weldment gave enough time for atmospheric air to mix with the molten metal, oxidizing the atoms, and causing them to transit from the microstructural to the macrostructural state. They also found that higher weld bead penetration led to higher bead heights. The amount of molten metal deposited between the parent metal and weld increases with increasing current.

Tungsten Inert Gas (TIG)

When electricity is applied to the tungsten electrode during TIG welding, an electric arc forms. The distance between the tungsten electrode's tip and the surface of the work piece will affect the passage of electrons, which will then result in an arc and intense heat needed to melt the metal. According to Narang et al.(2011), TIG welding is carried out in a controlled environment using a tungsten electrode that creates an arc to melt the metal. The ensuing continuous and stable arc can be created without coming in contact with the metal electrodes by using either direct current(DC) or Alternating Current of High Frequency(ACHF).TIG is quickly overtaking other technologies as the one that produces the cleanest weld beads. Fuzzy clustering technique was proven to be adequate for determining the relationship between the input process parameters and the outputs by other studies who analyzed TIG parameter utilizing fuzzy logic controller.

Eki et al. (2020) said harmful aerodisperse particles that are present during TIG welding processes can harm welders' lungs and respiratory systems. By methodically implementing the genetic algorithm methodology, they created a close to ideal solution to reduce the fume concentration in TIG welding. The sets of individual solutions under consideration, each of which is characterized by genes like current, voltage, and gas flow rate. Population, selection, rossover, and mutation techniques were used to arrive at the best answer. With function and constraint tolerances of 1e-06 and 1e-04, respectively, the iteration was carried out across 450 generations and 100 stall generations. The influence of heat input from from gas tungsten arc welding on the microstructure and mechanical characteristics of AZ91 magnisium alloy was examined by Assar et al., 2021. To assess the mechanical qualities, a tensile test was employed in conjuction with an optical microscope and scanning electron microscope with energy disperse x-ray spectroscopy. The outcome demonstrates that heat increased the thickness of the partially melted zone. Studying the fracture surface reveals that the formation of cleavage steps in the fracture mechanism during the tensile test. The tensile strength of base metal decreases with increasing input.

Response Surface Methodology

Response Surface Methodology(RSM) was used by Murugan and Parmar(1997) to create mathematical models for analyzing the direct and interaction impacts of SAW parameters(open circuit voltage,nozzle to work distance, wire feed rate and welding speed).developed mathematical models using response surface methodology (RSM) to study the direct and interaction effects of SAW parameters (open circuit voltage, wire feed rate, welding speed and nozzle-to-work piece distance) on the geometry of cladding (depth of penetration, height of reinforcement, weld width and dilution percentage). 31L stainless steel plate utilizing the process parameters derived from the generated models. They came to the conclusion that a low dilution of 22.57% could be created using either high voltage and rapid welding or low voltage and slow welding. Due to the carbon content in the cladding, it was found that the existing martensitic structures in the intermediate mixed zones in overlays had a hardness below 400 VHN. The use of RSM to create mathematical models and draw contour graphs linking key input factors, such as the open-circuit voltage, wire feed rate, and welding parameters, was emphasized by Gunaraj and Murugan in

Gunaraj and Murugan (1999) said RSM can be used to create mathematical models and plot contour graphs that relate key input parameters like open-circuit voltage, wire feed rate, welding speed, and nozzle-to-plate distance to outcomes like weld bead penetration, reinforcement width, and percentage dilution in SAW of pipes. They showed that when welding speed increases, all reactions diminish as the nozzle-to-plate distance rises, while reinforcemet rises. In addition, all reactions grow when the wire input rate increases, while input rate increases, the breadth stays the same. Using two joint types, bead-on-plate and bead on joint, Gunaraj and Murugan investigated the impact of SAW parameters on the heat input and the area of HAZ for low carbon steel in 1999 utilizing RSM's mathematical models.For the same heat input, they discovered that the HAZ area for bead on plate is larger than that for bead- on- joint. They discovered that the impact of SAW settings on the HAZ area in both scenarios follows a similar pattern. Eki et al. (2023) predicted TIG mild steel weld property, using response surface methodology, the model considered were gas flow rate, voltage and current as input parameters, the output variable is thermal conductivity, an appropriate experimental design and test samples were produced for this study, they concluded that gas flow rate of 10Lit/min, voltage of 9Volts and current of 160Amp produces, thermal conductivity of 42.96123W/m.

Modeling of Weld Bead Geometry submerged Arc Welding

Submerged arc welding (SAW) is preferred over other welding techniques for pipes and boilers according to Hould (1989), because of its inherent advantages such as simple process variables control, high quality, deep penetration, mooth finish, ability to weld thicker sections, and prevention of atmospheric contamination of weld pool. According to Brien (1978), SAW is used in industry in semiautomatic or automatic mode due to the increasing emphasis on the usage of automated welding systems. Because mechanical weld strength is affected by the form of the weld bead as well as the composition of the metal, such automated applications now require a precise method of selecting the process variables and controlling it. The geometry of the bead is revealed by the shape of the weld bead. The acceptable or proper weld bead shape depends on a number of variables, including joint preparation, welding speed, and line power, which is the amount of heat energy the arc supplies to the base plate per unit length of weld. The analysis and management of weld bead form is therefore absolutely crucial. This require creating a precise link between the process parameters, which regulate the the shape of the beads. This can be accomplished by creating mathematical formulas that can be entered into a computer and link the dimensions of the weld bead to the crucial process control variables impacting these dimensions. Moreover, process parameter optimization to regulate and achieve the desired form and quality of weld beads is possible with this expression.

2. METHODOLOGY

2.1. Research Design

This is the general approach selected to combine the many research components logically and coherently in order to solve the research problem. The experimental examination of TIG mild steel welds is the focus of this research study, which also makes use of expert systems statistical and mathematical models and testing for mechanical properties.

Design of Experiment

A crucial component of scientific research is experimentation, which may be developed with the aid of programs like Minitab and design expert. The data is collected using an experimental methodology to ensure correct polynomial approximation. Experimental designs come in a variety of forms, including Central Composite, Taguchi, D-optimal, and Latin Hyper Cube designs.

Idenfication of the Range of input parameters

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

Population

200 pieces of mild steel coupons measuring 60 x 40 x10mm were used for the experiments which were performed 20 times, using 5 weld samples for each run.

Samples and sampling technique

The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined. Figure 1 shows the TIG welding setup.

The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined. Figure 1 shows the TIG welding setup.

Table 1: Process parameters and their levels

Parameters	Unit	Symbol	Coded value	Coded value
			Low (-1)	High (+1)
Current	Amp	A	130	160
Gas flow rate	Lit/min	F	10	13
Voltage	Volt	V	16	19

Figure 1: *TIG equipment*

The welding process uses a shielding gas to protect the weld specimen from atmospheric interaction, 100% pure Argon gas was used in this research study.

The Figure 2 shows the weld samples.

Figure 2: Weld Samples

2.2 Method of Data Collection

The central composite design matrix was developed using the design expert software, producing 20 experimental runs. The input and output parameters make up the experimental matrix and the response recorded from the weld samples were used as the data. The table 2 below shows the central composite design matrix.

2.3 Method of Data Analysis

The data obtained were analysed using the following techniques: Response surface methodology.

Response Surface Methodology

Engineers often search for the conditions that would optimize the process of interest. In other words, they want to determine the values of the process input parameters at which the responses reach their optimum. The optimum could be either a minimum or a maximum of a particular function in terms of the process input parameters. RSM is one of the optimization techniques currently in widespread usage to describe the performance of the welding process and find the optimum of the responses of interest. RSM is a set of mathematical and statistical techniques that are useful for modelling and predicting the response of interest affected by several input variables with the aim of optimizing this response.

Testing the adequacy of the models developed

The analysis of variance (ANOVA) was used to test the adequacy of the models developed. The statistical significance of the models developed and each term in the regression equation were examined using the sequential F-test, lack-of-fit test and other adequacy measures (i.e. R^2, Adj- R~, Pred. R^2 and Adeq. Precision ratio) using the same software to obtain the best fit. The Prob.>F (sometimes called p-value) of the model and of each term in the model can be computed by means of ANOVA. If the Prob.> F of the model and of each term in the model does not exceed the level of significance (say a = 0.05) then the model may be considered adequate within the confidence interval of (1 − a). For the lack-of-fit test, it could be considered insignificant if the Prob.>F of the lack of fit exceeds the level of significance.

Modelling and Optimization using RSM

In this study, twenty experimental runs were carried out, each experimental run comprising the current, voltage and gas flow rate, used to join two pieces of mild steel plates measuring 60 x40 x 10mm. The response surface methodology uses a computer software such as design expert to develop mathematical models and the steps taken to develop the models include the sequential sum of squares, lack of fit test, model summary statistics, analysis of variance and goodness of fit. The sequential sum of square developed for the molten metal flow velocity response is shown in Table 3.

To test how well the quadratic model can explain the underlying variation associated with the experimental data, the lack of fit test was estimated for each of the responses. Model with significant lack of fit cannot be employed for prediction.

Results of the computed lack of fit for the molten metal flow velocityis presented in table 4.

3. PRESENTATION OF RESULTS AND DISCUSSION

Table 2: Experimental results

Run	I(Amp)	V (Volt)	GFR (Lit/min)	MoltenWeld MetalFlow Velocity (m/s)
1	130	16	10	0.0090
2	140	17	11	0.0120
3	150	18	12	0.0056
4	160	19	13	0.0085
5	130	16	11	0.0100
6	140	17	12	0.0060
7	150	18	13	0.0142
8	160	19	10	0.0121
9	130	16	12	0.0095
10	140	17	13	0.0078
11	150	18	10	0.0092
12	160	19	11	0.0110
13	130	16	13	0.0146
14	140	17	10	0.0152
15	150	18	11	0.0062
16	160	19	12	0.0073
17	130	19	13	0.0098
18	140	18	10	0.0108
19	150	17	11	0.0128
20	160	16	12	0.0149

Table 3: Sequential model sum of squares for molten metal flow velocity

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	2.226E-003	1	2.226E-003			
Linear vs Mean	1.237E-004	3	4.122E-005	2.13	0.1364	
2FI vs Linear	4.599E-005	3	1.533E-005	0.76	0.5382	
Quadratic vs 2FI	2.405E-004	3	8.015E-005	34.77	< 0.0001	Suggested
Cubic vs Quadratic	6.660E-006	4	1.665E-006	0.61	0.6712	Aliased
Residual	1.639E-005	6	2.732E-006			
Total	2.659E-003	20	1.330E-004			

Table 4: Lack of fit test for molten metal flow velocity

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	2.940E-004	11	2.673E-005	8.62	0.0138	
2FI	2.480E-004	8	3.100E-005	10.00	0.0107	
Quadratic	7.552E-006	5	1.510E-006	0.49	0.7756	Suggested
Cubic	8.921E-007	1	8.921E-007	0.29	0.6147	Aliased
Pure Error	1.550E-005	5	3.100E-006			

From the results of Table 4 it was again observed that the quadratic polynomial had a non-significant lack of fit and was suggested for model analysis while the cubic polynomial had a significant lack of fit hence aliased to model analysis. The model summary statistics computed for molten metal flow velocity response based on the model sources is presented in Table 5

Table 5: Model summary statistics for molten metal flow velocity

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	4.398E-003	0.2855	0.1515	-0.1218	4.859E-004	
2FI	4.502E-003	0.3917	0.1109	-0.4605	6.327E-004	
Quadratic	1.518E-003	0.9468	0.8989	0.8131	8.096E-005	Suggested
Cubic	1.653E-003	0.9622	0.8802	0.4946	2.189E-004	Aliased

The summary statistics of model fit shows the standard deviation, the r-squared, adjusted r-squared, predicted r-squared and predicted error sum of square (PRESS) statistic for each complete model. Low standard deviation, R-Squarednear one and relatively low PRESS is the optimum criteria for defining the best model source. Based on the results of Table 5 the quadratic polynomial model was suggested while the cubic polynomial model was aliased hence, the quadratic polynomial model was selected for this analysis.

In assessing the strength of the quadratic model towards maximizing the metal flow velocity, a one-way analysis of variance (ANOVA) table was generatedwhich is presented in Table 6.

Table 6: ANOVA table for maximizing metal flow velocity.

	Sum of		Mean	F	p-value	
Source	Squares	Df	Square	Value	Prob > F	
Model	4.101E-004	9	4.557E-005	19.77	< 0.0001	Significant
A-current	8.514E-005	1	8.514E-005	36.94	0.0001	
B-voltage	2.462E-005	1	2.462E-005	10.68	0.0085	
C-gas flow rate	1.391E-005	1	1.391E-005	6.03	0.0339	
AB	5.000E-009	1	5.000E-009	2.169E-003	0.9638	
AC	2.738E-005	1	2.738E-005	11.88	0.0063	
BC	1.860E-005	1	1.860E-005	8.07	0.0175	
A^2	2.307E-004	1	2.307E-004	100.06	< 0.0001	
B^2	9.658E-006	1	9.658E-006	4.19	0.0679	
C^2	1.862E-005	1	1.862E-005	8.08	0.0175	
Residual	2.305E-005	10	2.305E-006			
Lack of Fit	7.552E-006	5	1.510E-006	0.49	0.7756	not significant
Pure Error	1.550E-005	5	3.100E-006			
Cor Total	4.332E-004	19				

Analysis of variance (ANOVA) was needed to check whether or not the model is significant and also to evaluate the significant contributions of each individual variable, the combined and quadratic effects towards each response. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, AB, BC, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. Non-significant lack of fit is good as it indicates a model that is significant.To validate the adequacy of the quadratic model based on its ability to maximize molten metal flow velocity, the goodness of fit statistics is presented in Table 7.

To obtain the optimal solution, we first consider the coefficient statistics and the corresponding standard errors. The computed standard error measures the difference between the experimental terms and the corresponding predicted terms. Coefficient statistics for molten metal flow velocity response variable is presented in Table 8.

Table 7:Goodness of fit statistics for molten metal flow velocity

Std. Dev.	1.518E-003	R-Squared	0.9468
Mean	0.011	Adj R-Squared	0.8989
C.V. %	14.39	Pred R-Squared	0.8131
PRESS	8.096E-005	Adeq Precision	14.451

Table 8: Coefficient estimates statistics generated for minimizing molten metal flowvelocity.

Factor	Coefficient Estimate	Df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	6.483E-003	1	6.192E-004	5.103E-003	7.863E-003	
A-current	2.497E-003	1	4.108E-004	1.581E-003	3.412E-003	1.00
B-voltage	-1.343E-003	1	4.108E-004	-2.258E-003	-4.272E-004	1.00
C-gas flow rate	-1.009E-003	1	4.108E-004	-1.925E-003	-9.372E-005	1.00
AB	-2.500E-005	1	5.368E-004	-1.221E-003	1.171E-003	1.00
AC	-1.850E-003	1	5.368E-004	-3.046E-003	-6.539E-004	1.00
BC	-1.525E-003	1	5.368E-004	-2.721E-003	-3.289E-004	1.00
A^2	4.001E-003	1	3.999E-004	3.109E-003	4.892E-003	1.02
B^2	8.186E-004	1	3.999E-004	-7.250E-005	1.710E-003	1.02
C^2	1.137E-003	1	3.999E-004	2.457E-004	2.028E-003	1.02

Variance inflation factor (VIF) value of 1.00 for the individual and combine terms, 1.02 for the quadratic terms as observed in Table 8 indicate a significant model in which the variables are highly correlated with the responses.The optimal equation which shows the individual effects and combined interactions of the selected input variables (current, voltage,welding and gas flow rate) against the molten metal flow velocity is presented based on the coded variables in Figure3.

Final Equation in Terms of Coded Factors:

metal flow velocity =
+6.483E-003
+2.497E-003 * A
-1.343E-003 * B
-1.009E-003 * C
-2.500E-005 * A * B
-1.850E-003 * A * C
-1.525E-003 * B * C
+4.001E-003 * A^2
+8.186E-004 * B^2
+1.137E-003 * C^2

Figure 3: Optimal equation in terms of coded factors for maximizing metal flow velocity

The optimal equation which shows the individual effects and combine interactions of the selected input variables (welding current, voltage and gas flow rate) against the metal flow velocity is presented based on the actual variables in Figure 4.

Final Equation in Terms of Actual Factors:

metal flow velocity	=
+0.28150	
-4.02489E-003	* current
-5.67383E-003	* voltage
+0.011490	* gas flow rate
-1.11111E-006	* current * voltage
-8.22222E-005	* current * gas flow rate
-6.77778E-004	* voltage * gas flow rate
+1.77805E-005	* current^2
+3.63837E-004	* voltage^2
+5.05258E-004	* gas flow rate^2

Figure 4: Optimal equation in terms of actual factors for maximizing metal flow velocity

The diagnostics case statistics which shows the observed values of metal flow velocity and their predicted values is presented in Table 9.The diagnostic case statistics actually give insight into the model strength and the adequacy of the optimal second order polynomial equation.

Table 9: Diagnostics case statistics report for molten metal flow velocity

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Influence on Fitted Value DFFITS	Cook's Distance	Run Order
1	1.000E-002	8.894E-003	1.106E-003	0.670	1.268	1.313	1.870	0.326	14
2	0.017	0.018	-6.377E-004	0.670	-0.731	-0.713	-1.015	0.108	10
3	9.800E-003	9.309E-003	4.914E-004	0.670	0.563	0.543	0.773	0.064	12
4	0.018	0.018	4.759E-005	0.670	0.055	0.052	0.074	0.001	11
5	0.014	0.014	3.744E-004	0.670	0.429	0.411	0.585	0.037	4
6	0.015	0.015	-6.940E-005	0.670	-0.080	-0.075	-0.108	0.001	13
7	9.000E-003	7.940E-003	1.060E-003	0.670	1.215	1.248	1.777	0.299	17
8	8.500E-003	9.184E-003	-6.841E-004	0.670	-0.784	-0.768	-1.094	0.125	7
9	0.012	0.014	-1.599E-003	0.607	-1.681	-1.882	* -2.34	0.437	16
10	0.023	0.022	1.002E-003	0.607	1.054	1.060	1.318	0.172	1
11	0.011	0.011	-2.564E-004	0.607	-0.270	-0.257	-0.319	0.011	6
12	6.200E-003	6.540E-003	-3.403E-004	0.607	-0.358	-0.342	-0.425	0.020	8
13	0.011	0.011	-3.956E-004	0.607	-0.416	-0.398	-0.495	0.027	3
14	7.800E-003	8.001E-003	-2.012E-004	0.607	-0.211	-0.201	-0.250	0.007	9
15	6.000E-003	6.483E-003	-4.829E-004	0.166	-0.348	-0.333	-0.149	0.002	5
16	6.000E-003	6.483E-003	-4.829E-004	0.166	-0.348	-0.333	-0.149	0.002	19
17	6.000E-003	6.483E-003	-4.829E-004	0.166	-0.348	-0.333	-0.149	0.002	18
18	6.000E-003	6.483E-003	-4.829E-004	0.166	-0.348	-0.333	-0.149	0.002	15
19	1.000E-002	6.483E-003	3.517E-003	0.166	2.537	** 4.03	1.801	0.128	2
20	5.000E-003	6.483E-003	-1.483E-003	0.166	-1.070	-1.078	-0.482	0.023	20

To accept any model, its suitability must first be checked by an appropriate statistical analysis output. To diagnose the statistical properties of the response surface model, the normal probability plot of residual for the metal flow velocity is presented in Figure 5.

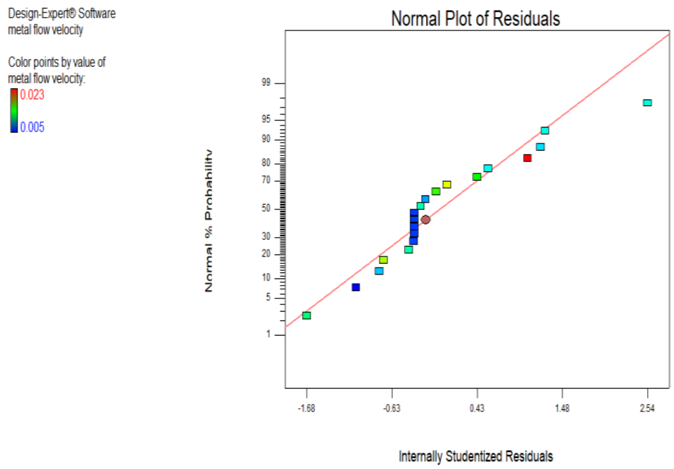
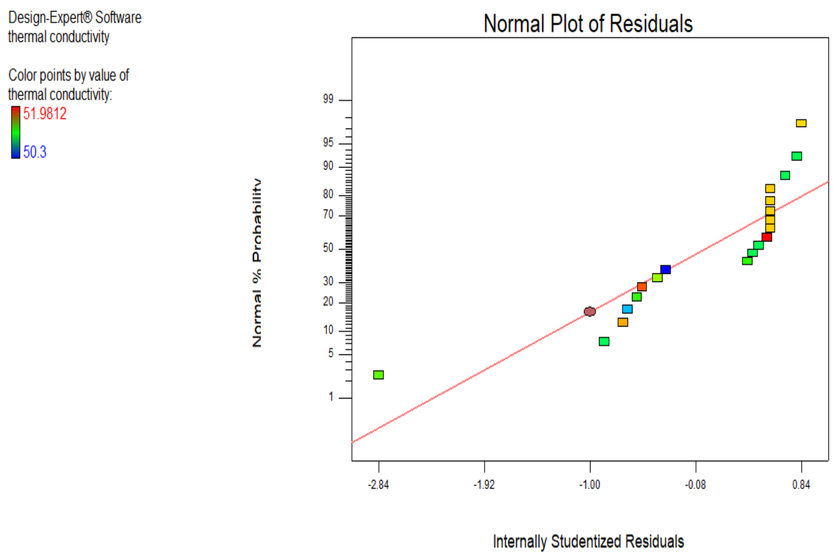


Figure 5: Normal probability plot of studentized residuals for molten metal flow velocity

To diagnose the statistical properties of the thermal conductivity response surface model, the normal probability plot of residual is presented in Figure 6.



It can be observed that the points follow a straight line despite the slight scatter. There is no defined pattern like an "s-shaped" curve aside the linear trend. This indicates that the residuals are normally distributed and no transformation of the response data is required for better analysis. 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) follow a normal distribution. It is the most significant assumption for checking the sufficiency of a statistical model. Result revealed that the computed residuals are approximately normally distributed,an indication that the model developed is satisfactory. To detect for the presence of mega patterns or expanding variance, a plot of residuals and the predicted was produced for the metal flow velocity which is shown in the Figure 7.

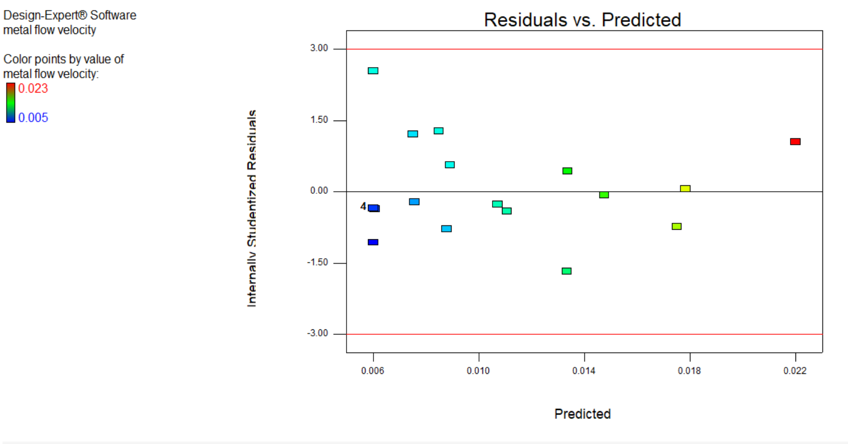


Figure 7: Plot of Residual vs Predicted for metal flow velocity

As can be seen from the graph, the points are close to the line of fit. The model essentially is able to predict most of the data points. In order to detect a value or group of values that are not easily detected by the model, the predicted values are plotted against the actual values for metal flow velocity response which is shown in the Figure 8.

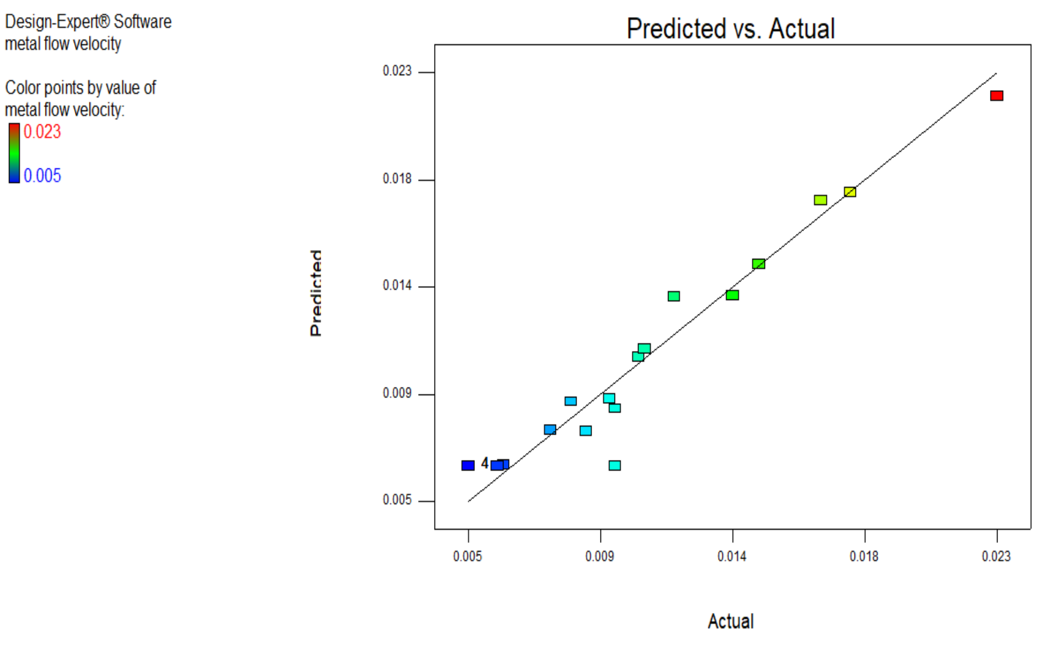


Figure 8: Plot of Predicted Vs Actual for the metal flow velocity

To study the effects of combined input variables on the metal flow velocity, the 3D surface plot presented in Figure 9 was generated as follows:

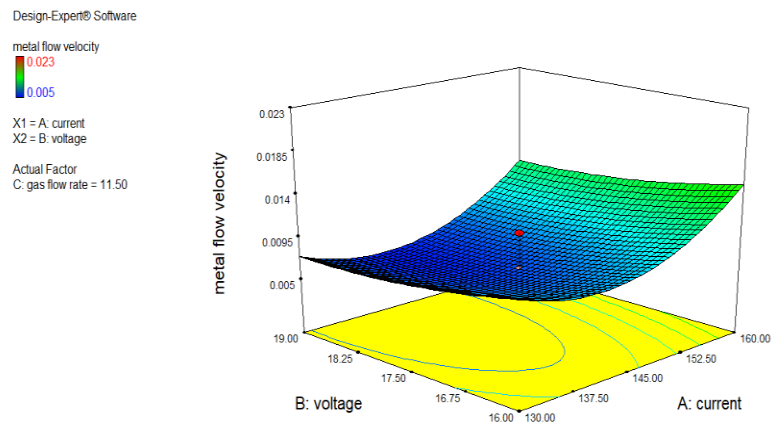


Figure 9: Effect of current and voltage on metal flow velocity

To study the effects of gas flow rate and current on the metal flow velocity, the 3D surface plot presented in Figure 10 was generated as follows:

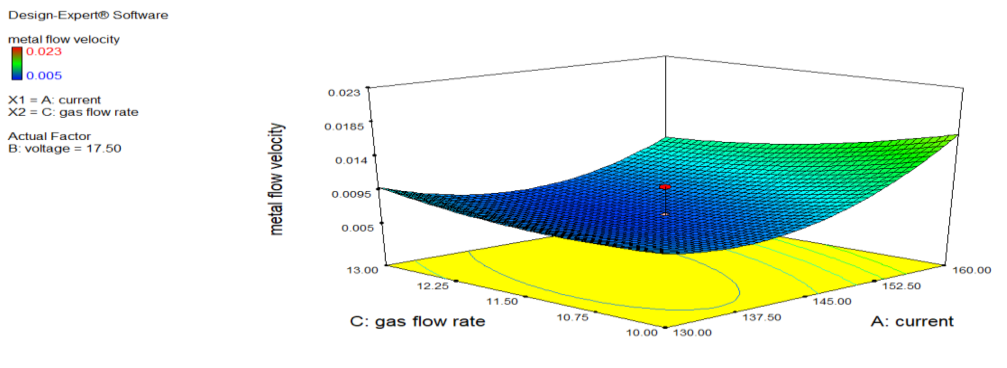


Figure 10: Effect of current and gas flow rate on metal flow velocity

The interphase of the numerical optimization metal flow velocity as the objective function is presented in Figure 11.

4. CONCLUSION

In this study Response surface Methodology have been applied in predicting the metal flow velocity of TIG mild steel weldment, current, voltage and gas flow rate, was the model considered as input variables, while the output parameter was metal flow velocity. A suitable experimental design and test samples produced for this study.

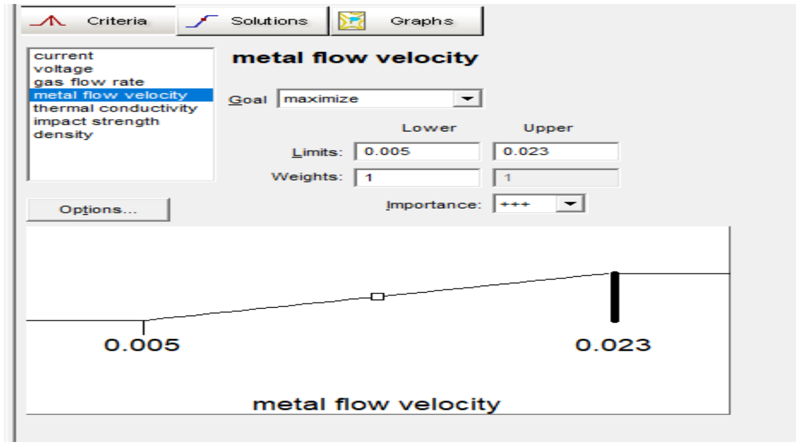


Figure 11: Interphase of numerical optimization model for metal flow velocit

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