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Application of Response Surface Methodology to Predict Arc Length of Tig Mild Steel Welds

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Abstract

TIG welding finds its application in aviation, marine and automobile industries. To ensure the safety of lives and properties, weld quality has continuously been experiencing improvement over the years. The arc length is the space measurement between the welding torch and the work piece during welding and this in turn affect the welder's comfortability as well as the weld product. This research study was carried out to optimize and predict the arc length in Tungsten inert gas welding using response surface methodology. The central composite design matrix was employed to collect data from the set of experiment. The samples were cut from mild steel plate, measuring 60mm x 40mm x 10mm. From the result, a model possessing an R-Squared value of 92% "Predicted R-Squared" value of 77% which is in reasonable agreement with the "Adj R-Squared" value of 85%. Adequate precision measuring the signal to noise ratio of 10.649 indicating adequate signal were observed. An optimal settings of input parameters; welding current 130Amps, welding voltage 20.94V, and welding speed 0.48m/s resulting in a minimized arc length of 2.0044mm was obtained.

1. Introduction

Tungsten inert gas (TIG) welding or gas tungsten arc welding (GTAW) is an inert gas shielding arc welding process using non consumable electrode. 'Arc length' is the "distance between the welding electrode tip and adjacent surface of the weld pool" [1]. The closeness of the welding torch tip to the work piece (arc length) during welding positively affect the welder's comfort and the weld product. Weld penetration has a relationship with arc length and welding current, such that increase or decrease in current can result in increase or decrease in both arc length and weld penetration depth. Studies have revealed that weld penetration is affected by welding current, polarity, arc travel speed, electrode diameter etc. [2]. Welding voltage affects the arc length. Increase in arc length leads to increase in the arc voltage due to the fact that extension of the arc exposes the entire arc column to the cool boundary of the arc [3]. When compared with short circuiting transfer, the arc length can be easily adjusted, without spatter welding seam using pulsed current, leading to the merits that the step of removing spatter on the base metal can be prevented and the manufacturing efficiency can be increased. However, the base current time (or datum current time) has not been regarded as a parameter that can affect ODPP but rather a parameter for adjusting the arc length. As a matter of fact, the arc length influences the arc shape directly, including the heat transfer and heat dissipation mode of the droplets [4–6]. For example, a certain arc space is required for a droplet from growth to detaching the wire. If the arc length is too small to provide sufficient space, the droplet would contact the molten pool but still on the wire, contributing to a short circuit [7] TIG welding is a multi-objective and multi factor metal fabrication technique. Tungsten Inert Gas (TIG) welding is often used in fabrication industries [8]. Distortion is a major problem due to reworks, time and cost are affected. Therefore, it has to be controlled. Argon or helium is used for shielding or protective purpose. The TIG welding process can be used for the joining of a number of materials though the most common ones are aluminum, magnesium and stainless steel done in almost all position metal thickness ranging 1 to 6 mm is generally joined by TIG process. Gas tungsten arc welding produce the high quality welds most consistently [9]. It can weld all metal in any configuration. But it is not economically competitive on heavy section. TIG welding is very strong process for improving quality characteristics of weld pool. A mathematical model was developed to predict the TIG weld bead characteristics [10]. In their work the weld bead was characterized with its quality features such as upper bead width, lower bead width, penetration depth etc and mathematically related to the input parameters such as welding speed, welding current, shielding gas flow rate and arc gap distance. Hence, in this study, application of the response surface methodology for predicting the arc length in mild steel welds will be considered.

2.0 Methodology

2.1 Materials

100 pieces of mild steel coupons measuring 60mm x 40mm x 10mm were used for the experiments. The experiment was performed 20 times, using 5 specimens for each run. The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined.

Figure 1: Welding torch

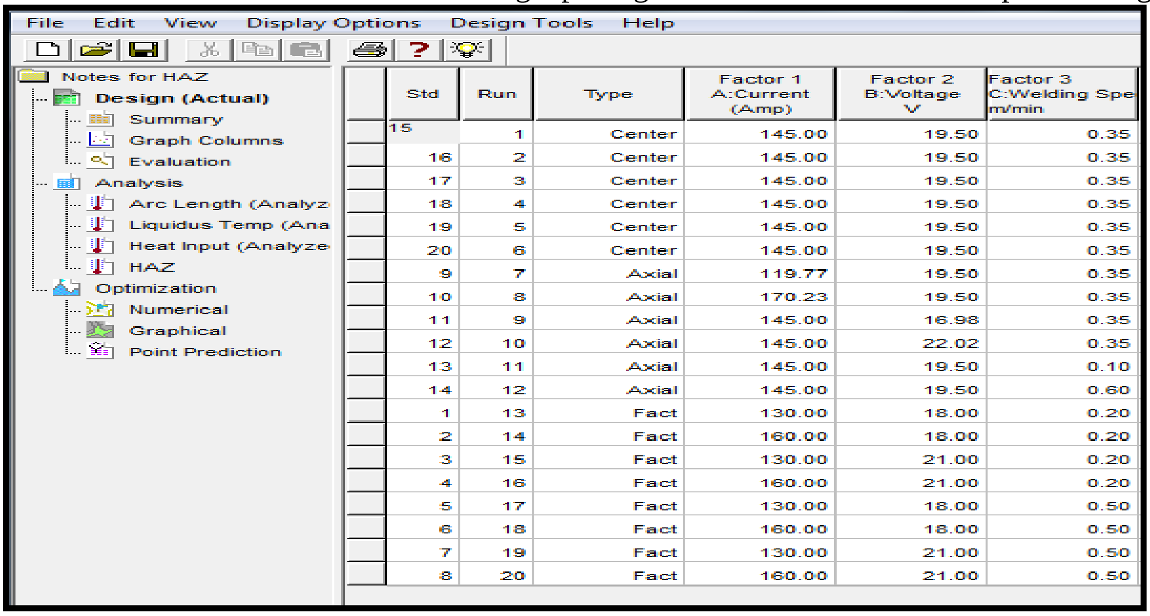
Figure 2: Welding in progress

Table 1: Process parameters and their levels

Parameters	Unit	Symbol	Coded value	Coded value
			Low(-1)	High(+1)
Current	Amp	A	100	180
welding speed,	M/min	F	0.10	0.6
Voltage	Volt	V	16	22

2.2 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 (arc length) recorded from the weld samples were used as the data. The arc length was measured with the aid of a measuring tape. Figure 3 shows the central composite design matrix.



Std	Run	Type	Factor 1 A:Current (Amp)	Factor 2 B:Voltage V	Factor 3 C:Welding Spe m/min
15	1	Center	145.00	19.50	0.35
16	2	Center	145.00	19.50	0.35
17	3	Center	145.00	19.50	0.35
18	4	Center	145.00	19.50	0.35
19	5	Center	145.00	19.50	0.35
20	6	Center	145.00	19.50	0.35
9	7	Axial	119.77	19.50	0.35
10	8	Axial	170.23	19.50	0.35
11	9	Axial	145.00	16.98	0.35
12	10	Axial	145.00	22.02	0.35
13	11	Axial	145.00	19.50	0.10
14	12	Axial	145.00	19.50	0.60
1	13	Fact	130.00	18.00	0.20
2	14	Fact	160.00	18.00	0.20
3	15	Fact	130.00	21.00	0.20
4	16	Fact	160.00	21.00	0.20
5	17	Fact	130.00	18.00	0.50
6	18	Fact	160.00	18.00	0.50
7	19	Fact	130.00	21.00	0.50
8	20	Fact	160.00	21.00	0.50

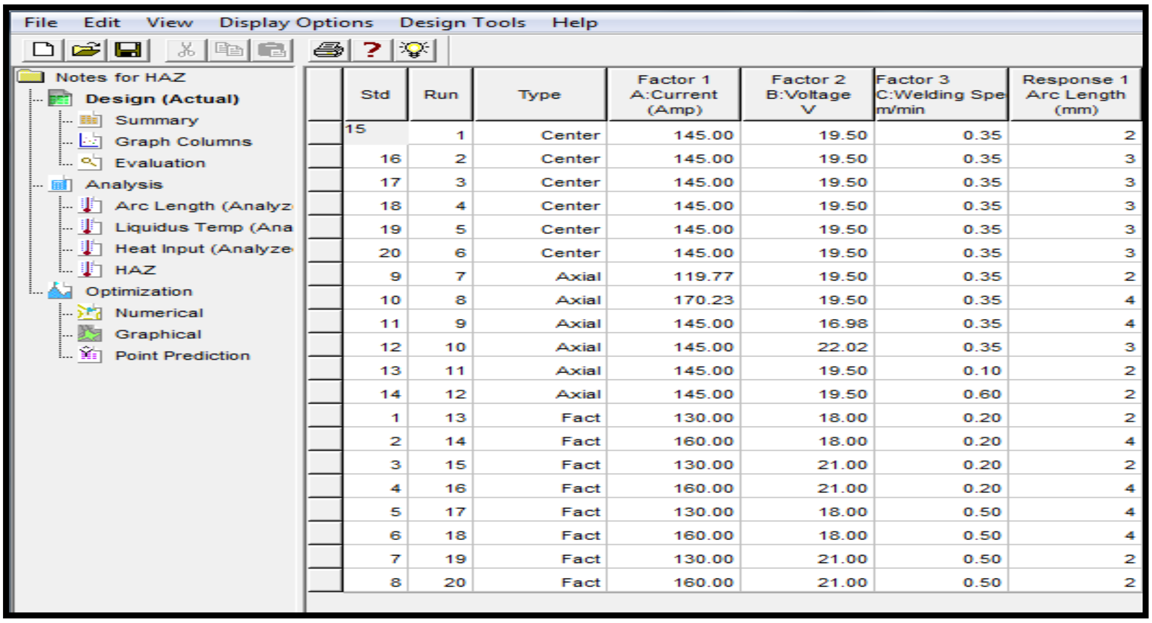
Figure 3: Central Composite Design Matrix (CCD

When there is a curvature in the response surface the first-order model is insufficient. A second-order model is useful in approximating a portion of the true response surface with parabolic curvature. The second-order model includes all the terms in the first-order model, plus all quadratic terms like $\beta_{11} x_{1i}$ and all cross product terms like $\beta_{13} x_{1i}$. It is usually expressed as:

$$y = \beta_0 + \sum_{j=1}^{q} \beta_{jj} x_j^2 + \sum \sum_{kj} \beta_{ij} x_i x_i + \varepsilon \tag{1}$$

Where $(x_{1i}, x_{2i}, .., x_{iq})$, $\beta = (\beta_1, \beta_2, .., \beta_q)$

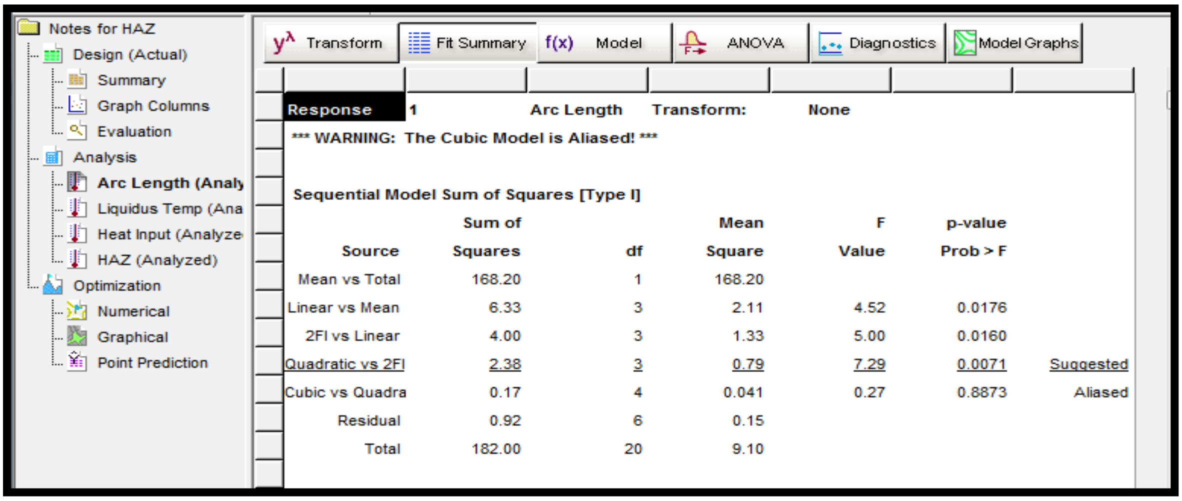
3.0 Result and discussion



Std	Run	Type	Factor 1 A:Current (Amp)	Factor 2 B:Voltage V	Factor 3 C:Welding Spe m/min	Response 1 Arc Length (mm)
15	1	Center	145.00	19.50	0.35	2
16	2	Center	145.00	19.50	0.35	3
17	3	Center	145.00	19.50	0.35	3
18	4	Center	145.00	19.50	0.35	3
19	5	Center	145.00	19.50	0.35	3
20	6	Center	145.00	19.50	0.35	3
9	7	Axial	119.77	19.50	0.35	2
10	8	Axial	170.23	19.50	0.35	4
11	9	Axial	145.00	16.98	0.35	4
12	10	Axial	145.00	22.02	0.35	3
13	11	Axial	145.00	19.50	0.10	2
14	12	Axial	145.00	19.50	0.60	2
1	13	Fact	130.00	18.00	0.20	2
2	14	Fact	160.00	18.00	0.20	4
3	15	Fact	130.00	21.00	0.20	2
4	16	Fact	160.00	21.00	0.20	4
5	17	Fact	130.00	18.00	0.50	4
6	18	Fact	160.00	18.00	0.50	4
7	19	Fact	130.00	21.00	0.50	2
8	20	Fact	160.00	21.00	0.50	2

Figure 4: Experimental result for arc length in real values

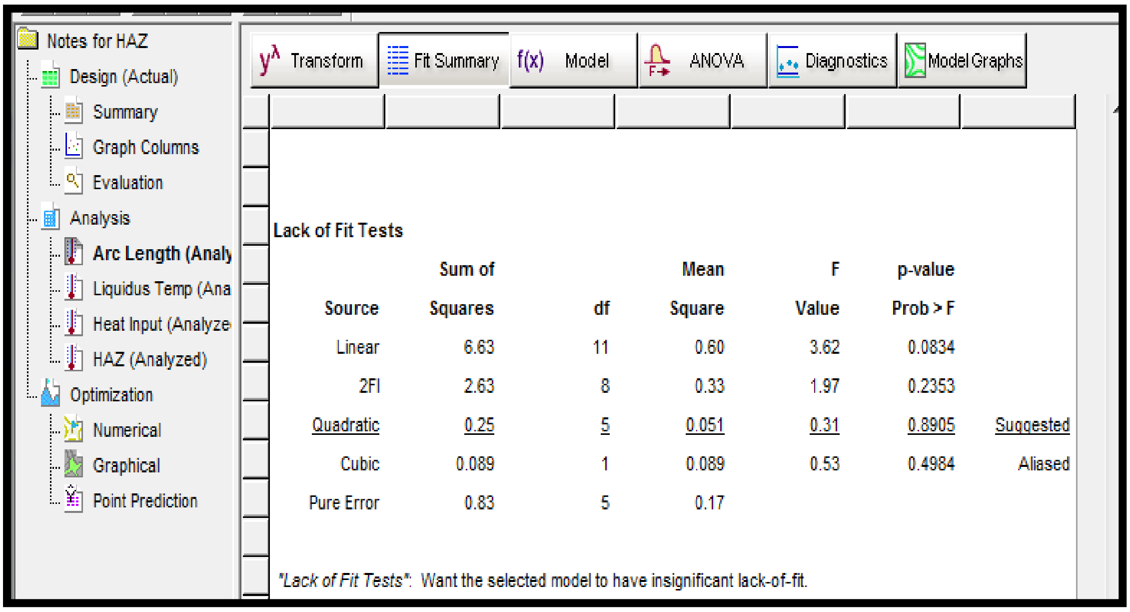
To validate the suitability of the quadratic model in analyzing the experimental data, the sequential model sum of squares was calculated for the arc length is presented in Figure 5.



Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	168.20	1	168.20			
Linear vs Mean	6.33	3	2.11	4.52	0.0176	
2FI vs Linear	4.00	3	1.33	5.00	0.0160	
Quadratic vs 2FI	2.38	3	0.79	7.29	0.0071	Suggested
Cubic vs Quadra	0.17	4	0.041	0.27	0.8873	Aliased
Residual	0.92	6	0.15			
Total	182.00	20	9.10			

Figure 5: Sequential model sum of square for arc length

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 arc length. Results of the computed lack of fit is presented in Figure 6.



Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	6.63	11	0.60	3.62	0.0834	
2FI	2.63	8	0.33	1.97	0.2353	
Quadratic	0.25	5	0.051	0.31	0.8905	Suggested
Cubic	0.089	1	0.089	0.53	0.4984	Aliased
Pure Error	0.83	5	0.17			

Figures 6: Lack of fit test for arc length

The model statistics computed for arc length based on the different model sources is presented in Figure 7.

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.68	0.4590	0.3576	0.0447	13.18	
2FI	0.52	0.7489	0.6329	0.5230	6.58	
Quadratic	0.33	0.9212	0.8502	0.7733	3.13	Suggested
Cubic	0.39	0.9332	0.7884	-0.5040	20.75	Aliased

"Model Summary Statistics": Focus on the model maximizing the "Adjusted R-Squared" and the "Predicted R-Squared".

Figure 7: Model summary statistics for arc length

In assessing the strength of the quadratic model towards minimizing the arc length one way analysis of variance (ANOVA) table was generated for minimizing the heat input and result obtained is presented in Figure 8.

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

Response 1 Arc Length

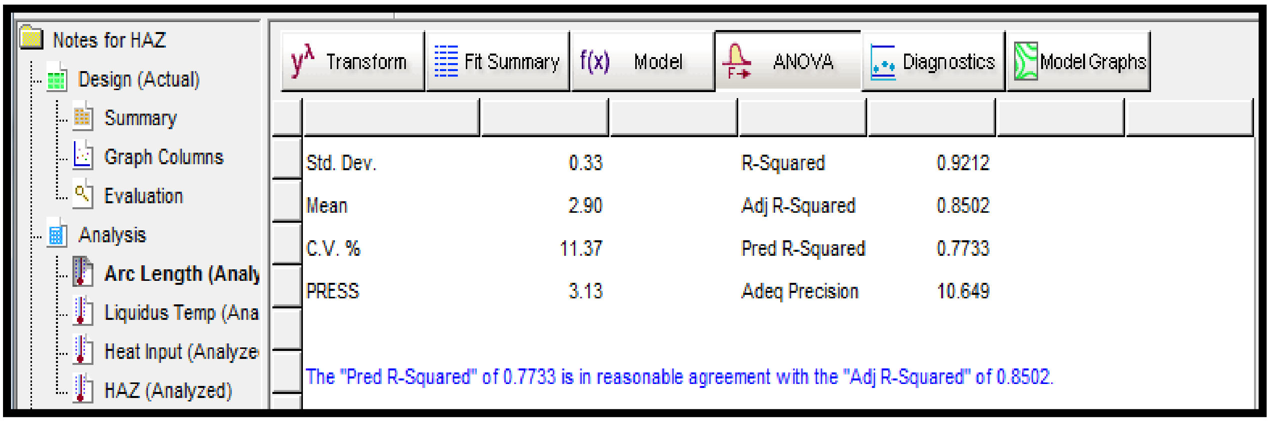
ANOVA for Response Surface Quadratic Model

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

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	12.71	9	1.41	12.98	0.0002	significant
A-Current	*3.97*	*1*	*3.97*	*36.50*	*0.0001*	
B-Voltage	*2.36*	*1*	*2.36*	*21.73*	*0.0009*	
C-Welding Speed	*0.000*	*1*	*0.000*	*0.000*	*1.0000*	
AB	*0.000*	*1*	*0.000*	*0.000*	*1.0000*	
AC	*2.00*	*1*	*2.00*	*18.38*	*0.0016*	
BC	*2.00*	*1*	*2.00*	*18.38*	*0.0016*	
A^2	*0.13*	*1*	*0.13*	*1.17*	*0.3042*	
B^2	*1.06*	*1*	*1.06*	*9.72*	*0.0109*	
C^2	*0.97*	*1*	*0.97*	*8.92*	*0.0137*	
Residual	1.09	10	0.11			
Lack of Fit	*0.25*	*5*	*0.051*	*0.31*	*0.8905*	*not significant*
Pure Error	*0.83*	*5*	*0.17*			
Cor Total	13.80	19				

Figure 8: ANOVA table for validating the model significance towards minimizing the arc length

To check for how fit is the said fit model, the goodness of fit statistics was employed. This is presented in figure 9



Std. Dev.	0.33	R-Squared	0.9212
Mean	2.90	Adj R-Squared	0.8502
C.V. %	11.37	Pred R-Squared	0.7733
PRESS	3.13	Adeq Precision	10.649

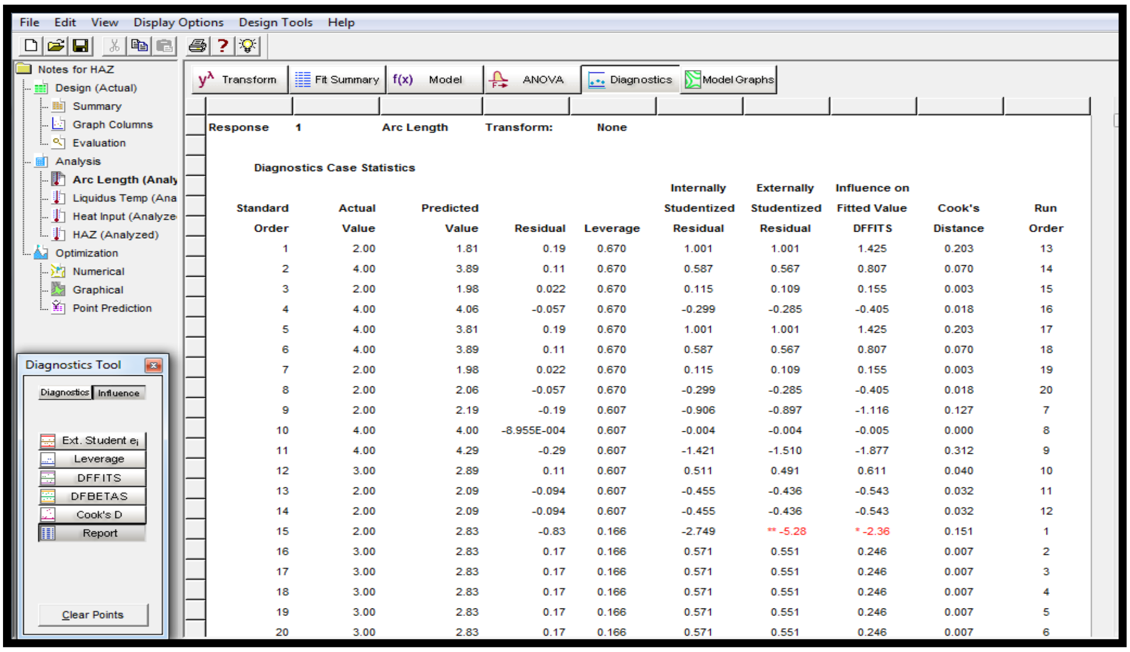
The "Pred R-Squared" of 0.7733 is in reasonable agreement with the "Adj R-Squared" of 0.8502.

Figure 9: GOF statistics for validating model significance towards minimizing arc length

From the result of Figure 10, it was observed that the "Predicted R-Squared" value of 0.7733 is in reasonable agreement with the "Adj R-Squared" value of 0.8502. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The computed ratio of 10.649 observed in Figure 10 indicates an adequate signal. This model can be used to navigate the design space and adequately minimize the arc length.

The diagnostics case statistics which shows the observed values of arc length against the predicted values is presented in Figure 10.

The diagnostic case statistics actually give insight into the model strength and the adequacy of the optimal second order polynomial equation.



Response 1 Arc Length Transform: None

Diagnostics Case Statistics

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	2.00	1.81	0.19	0.670	1.001	1.001	1.425	0.203	13
2	4.00	3.89	0.11	0.670	0.587	0.567	0.807	0.070	14
3	2.00	1.98	0.022	0.670	0.115	0.109	0.155	0.003	15
4	4.00	4.06	-0.057	0.670	-0.299	-0.285	-0.405	0.018	16
5	4.00	3.81	0.19	0.670	1.001	1.001	1.425	0.203	17
6	4.00	3.89	0.11	0.670	0.587	0.567	0.807	0.070	18
7	2.00	1.98	0.022	0.670	0.115	0.109	0.155	0.003	19
8	2.00	2.06	-0.057	0.670	-0.299	-0.285	-0.405	0.018	20
9	2.00	2.19	-0.19	0.607	-0.906	-0.897	-1.116	0.127	7
10	4.00	4.00	-8.955E-004	0.607	-0.004	-0.004	-0.005	0.000	8
11	4.00	4.29	-0.29	0.607	-1.421	-1.510	-1.877	0.312	9
12	3.00	2.89	0.11	0.607	0.511	0.491	0.611	0.040	10
13	2.00	2.09	-0.094	0.607	-0.455	-0.436	-0.543	0.032	11
14	2.00	2.09	-0.094	0.607	-0.455	-0.436	-0.543	0.032	12
15	2.00	2.83	-0.83	0.166	-2.749	** -5.28	* -2.36	0.151	1
16	3.00	2.83	0.17	0.166	0.571	0.551	0.246	0.007	2
17	3.00	2.83	0.17	0.166	0.571	0.551	0.246	0.007	3
18	3.00	2.83	0.17	0.166	0.571	0.551	0.246	0.007	4
19	3.00	2.83	0.17	0.166	0.571	0.551	0.246	0.007	5
20	3.00	2.83	0.17	0.166	0.571	0.551	0.246	0.007	6

Figure10: Diagnostics case statistics report of observed and predicted arc length

To study the effects of combined input variables on the response variable (arc length), the 3D surface plot presented in Figure 12 was developed.

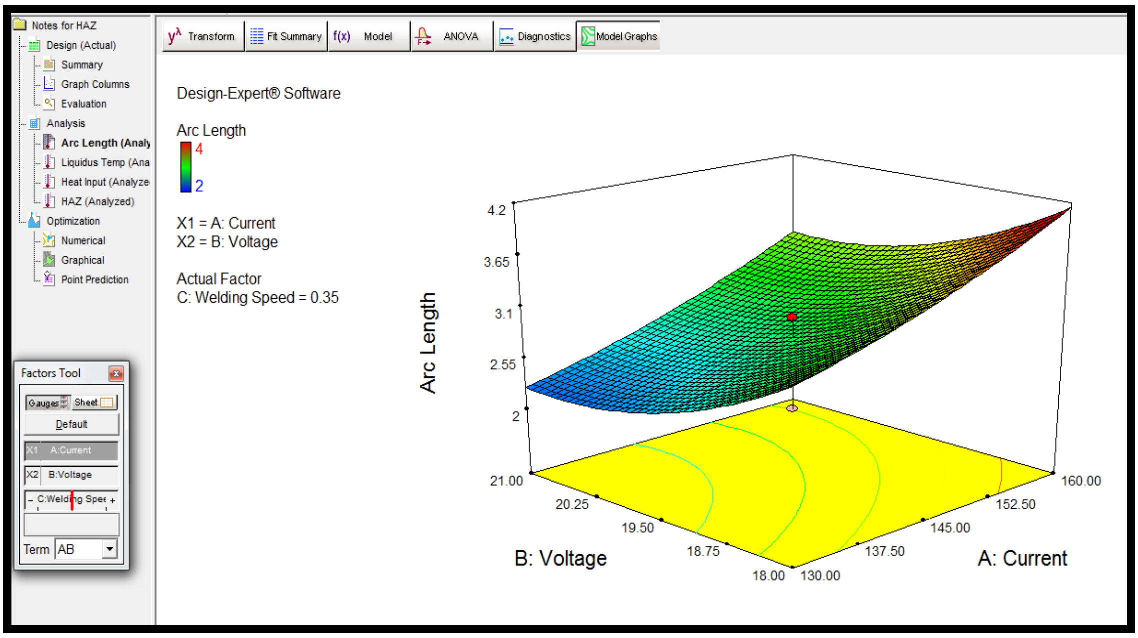


Figure 11: Effect of current and voltage on the arc length

The results from the study shows that the welding current has a very strong influence on the arc length thus, an increase in welding current will result in a corresponding increase in the arc length. This is in reasonable agreement with [2] in the literature review. The result also shows that the welding voltage has a slight influence on the arc length. This is also in reasonable agreement with [3] in the literature review.

4.0 Conclusion

The quality and integrity of welded joints is highly influenced by the optimal combination of the welding input parameters. This study developed a model using response surface methodology to optimize and predict weld arc length from input parameter such as welding current, welding voltage and welding speed. The result from response surface methodology shows that a current of 130Amps, voltage of 20.94V, speed of 0.48m/min will produce an arc length of 2.0044mm with a desirability of 0.962. It is therefore recommended that the optimal arc length with the input parameters be employed for the good of the welder's comfort towards a quality weld.

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