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OPTIMIZATION AND PREDICTION OF MELTING EFFICIENCY OF MILD STEEL WELDMENT, USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Melting efficiency is one among the vital factors regarded in Tungsten Inert Gas (TIG) welding while appraising the quality of welds. In the welding field, proper melting efficiency brings about the development of a weld pool that is dense. This research is done to optimize and predict melting efficiency of mild steel weldment, utilizing Response Surface Method (RSM).

Central composite design(CCD) matrix was used to gather data from the sets of experiments, the specimen was produced from mild steel plates and welded with the TIG process, thereafter the RSM was employed for the optimization and the prediction of the responses from the process parameters.

Response Surface Methodology was used to predict melting efficiency of TIG welds. The model had p-values less than 0.05 which shows the significance of the model and “predict R-Squared” value of 0.790025 is in moderately good agreement with the “Adj R-Squared” value of 0.9985. One way analysis of variance (ANOVA) was done and the result showed that it is a significant model and possess a very good fit. To validate the significance and adequacy of the model, a coefficient of determination (R-Squared) of 0.904201 indicating the appreciable strength of the model. The computed signal to noise ratio of 19.41136 as observed in Table 7 shows an acceptable signal.

1. INTRODUCTION AND LITERATURE REVIEW

The TIG welding operation is completely utilized in current industrial manufacturing, this operation is acknowledged for its ability to join similar and dissimilar metals at very high temperature, economy, high quality weld, low heat affected zone, good weld appearance, high heat concentration with little or no smoke or fumes made it suitable for both ferrous metals, absence of slag. Generally, the quality of TIG weld is strongly distinguished by the weld bead geometry.

Urena et al(2014)investigated the effect of the reaction of the interface in the space separating the SiC particle reinforcing of the fracture action in TIG joined AL matrix made of different elements and AL alloy matrix. TIG joining was done on 4mm thick AA2014/SiC/Xp plates utilizing the setting of current in the limit of 37-155A and the voltage in the limit of 14-16V. From experimental results it was discovered that, the failure happened in the welded metal sheet with strength of tensile less than 50% of the base metal. Failure of the joint welded was regulated by the boundary removal through the boundary response layer. Probability of interface failure rises in the zone weld due to formation of Aluminium-carbide which lowers the matrix/reinforcement interface strength.

Simhachalam et al(2015) carried out studies on the influence of welding operation variable parametals on the mechanical features of stainless steel-316(18Cr-8N) been welded by the TIG welding. The length of the specimen is 40 X 15 X 5mm for the experimentation that is observed that the welding current has a major effect ,though filler rod do have some effect similar to current but when compared to current it is less significant. MINITAB software is utilized in the forecasting of the impact strength ‘hardness and depth of penetrations.

Sanjeev(2016) did the experiment for optimizing of the condition for the performance of the welding on Ultra-90 specimen where he changes the welding current and the welding voltage and maintaining the flow rate of gas constant then, noticed that the joint welding not properly made below 50A and 200A from that time burning of the specimen stated.

Ravinder(2016) TIG welding on stainless steel 202 and mild steel parametric optimizing was studied using the Taguchi method and the regulating factor that had changing influence upon the arc voltage, tensile strength consisting of the greatest effect was found, also found was the optimum variable for 80A tensile strength current, arc voltage 30A and GFR 6 lt/min.

2. METHODOLOGY AND THEORY

The method of achieving the objectives of the research is explained in this chapter. It comprises of research design, population, sampling techniques, method of data collection, with technique of analysis of data.

2.1 RESEARCH DESIGN

This research study focused on melting sufficiency of mild steel weldment, utilizing response surface methodology, for the optimization and the prediction of the output.The input process parameters are current, voltage, welding speed, welding time and feed rate. The method was employed due to its capability to accommodate complex experimental designs.

The Central Composite Design was developed for this study, using the design expert software. This design is for any input parameters considered within the range of 3-5 levels.

2.2 POPULATION

160 pieces of mild steel coupons measuring 60mm×40mm×10mm was used for the experiments, the experiment was performed 32times, using 5 specimens for each run.

2.3 SAMPLES AND SAMPLING TECHNIQUES

Mild steel plate 10 mm thickness was selected for the experiment. The mild steel work piece was cut to 60mm X 40mm dimension using power hacksaw and the edges ground to evenness with a grinding tool. The TIG welding equipment was used to weld the plates after the edges have been beveled. The welding operation utilizes a shielding gas to shield the weld specimen from atmospheric interaction, 100% pure Argon gas was used in this research study.

The diagnostic case statistics which shows the experimentally obtained values of melting efficiency against the predicted values is presented as displayed in table 1 below.

Table 1: Diagnostic Case Statistics

Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Fitted Value DFFITS	Cook's Distance	Run Order
45	44.31277	0.687228	0.452279	1.813073	1.92658	1.750696	0.246766	1
46	45.26171	0.73829	0.193935	1.605596	1.672947	0.820587	0.056385	2
44	43.47328	0.526717	0.479376	1.425311	1.463552	1.404379	0.170051	3
46	45.43616	0.56384	0.059534	1.135217	1.1435	0.287705	0.007416	4
47	46.79806	0.201936	0.52721	0.57342	0.564034	0.595612	0.033333	5
45	44.8342	0.1658	0.506467	0.460808	0.451993	0.457878	0.01981	6
46	45.61318	0.386825	0.195835	0.84224	0.836186	0.412645	0.015705	7
46	45.7932	0.206797	0.201556	0.451872	0.443142	0.222648	0.004686	8
44	44.91562	-0.91562	0.191324	-1.98802	-2.15329	-1.04737	0.085005	9
46	46.36162	-0.36162	0.506394	-1.00499	-1.00524	-1.01818	0.094198	10
42	42.22929	-0.22929	0.509277	-0.63908	-0.62983	-0.64163	0.038533	11
43	43.60066	-0.60066	0.43394	-1.55882	-1.61772	-1.4164	0.169342	12
45	45.80192	-0.80192	0.189825	-1.73954	-1.83496	-0.88821	0.064454	13
46	45.43616	0.56384	0.059534	1.135217	1.1435	0.287705	0.007416	14
45	44.60266	0.397338	0.523077	1.12339	1.130822	1.184276	0.125831	15
46	45.43616	0.56384	0.059534	1.135217	1.1435	0.287705	0.007416	16
45	45.43616	-0.43616	0.059534	-0.87815	-0.87317	-0.21969	0.004438	17
47	47.28896	-0.28896	0.520512	-0.81478	-0.80802	-0.84187	0.065515	18
42	42.25354	-0.25354	0.501275	-0.70098	-0.69223	-0.694	0.044899	19
45	45.08447	-0.08447	0.185742	-0.18277	-0.17851	-0.08526	0.000693	20
46	46.00888	-0.00888	0.350944	-0.02152	-0.021	-0.01544	2.28E-05	21
45	45.11879	-0.11879	0.178267	-0.25586	-0.25008	-0.11648	0.001291	22
44	43.94909	0.050911	0.50019	0.140605	0.137281	0.137334	0.001799	23
46	45.94817	0.051833	0.192028	0.11259	0.10991	0.053582	0.000274	24
45	45.43715	-0.43715	0.504123	-1.21209	-1.22656	-1.23672	0.135781	25
45	45.43616	-0.43616	0.059534	-0.87815	-0.87317	-0.21969	0.004438	26
48	48.05814	-0.05814	0.464955	-0.15519	-0.15153	-0.14126	0.001903	27
44	44.00067	-0.00067	0.471276	-0.00181	-0.00177	-0.00167	2.66E-07	28
45	45.11952	-0.11952	0.512828	-0.33435	-0.32717	-0.33567	0.010698	29
47	46.92998	0.070016	0.492041	0.191812	0.187353	0.184394	0.00324	30
44	43.8585	0.1415	0.45772	0.37518	0.367372	0.337515	0.010801	31
44	44.16517	-0.16517	0.459934	-0.43882	-0.43023	-0.39703	0.014909	32

2.4 Method of Data Gathering.

In this research , the central composite design was undertaken, using the factor ranges in Table 2 below.

Table 2: Welding Parameters and their levels

Factors	**Unit**	**Symbol**	**Low (-1)**	**High (+1)**
Welding Current	Ampere	I	160	240
Welding Voltage	Volts	V	20	30
Welding Speed	mm/sec	S	35	75
Welding time	Seconds	T	50	80
Feed Rate	mm/sec	FR	70	140

A design matrix for the response surface analysis was generated as displayed in Table 3.The equivalent design matrix in actual factors is shown table 4.

Tables 3 and 4 can be inter-converted by using the relation (Myers et al, 2009)

$$\text{Coded} = \frac{\text{Actual Value} - \text{Mean}}{\text{half of range}} \qquad (1)$$

Table 3: Design Matrix in coded factors

I	**V**	**S**	**T**	**FR**
0	0	-1.75	0	0
1.70	0	0	0	0
-1	1	1	1	-1
0	0	0	0	0
1	-1	1	-1	1
1	1	1	-1	-1
-1.725	0	0	0	0
0	-1.8	0	0	0
0	0	0	0	-1.743
1	1	-1	-1	1
1	1	-1	1	-1
0	0	1.7	0	0
0	0	0	-1.733	0
0	0	0	0	0
-1	1	1	-1	1
0	0	0	0	0
0	0	0	0	0
-1	1	-1	1	1
1	-1	-1	1	1
0	0	0	1.667	0
-1	-1	-1	-1	-1
0	1.6	0	0	0
1	-1	1	1	-1
0	0	0	0	1.714
-1	-1	1	1	1
0	0	0	0	0
-1	-1	-1	1	-1
-1	1	-1	-1	-1

Table 4: Design Matrix in actual factors

Runs	I	V	S	T	FR
1	200	25	20	65	105
2	268	25	55	65	105
3	160	30	75	80	70
4	200	25	55	65	105
5	240	20	75	50	140
6	240	30	75	50	70
7	131	25	55	65	105
8	200	16	55	65	105
9	200	25	55	65	44
10	240	30	35	50	140
11	240	30	35	80	70
12	200	25	89	65	105
13	200	25	55	39	105
14	200	25	55	65	105
15	160	30	75	50	140
16	200	25	55	65	105
17	200	25	55	65	105
18	160	30	35	80	140
19	240	20	35	80	140
20	200	25	55	90	105
21	160	20	35	50	70
22	200	33	55	65	105
23	240	20	75	80	70
24	200	25	55	65	165
25	160	20	75	80	140
26	200	25	55	65	105
27	160	20	35	80	70
28	160	30	35	50	70
29	240	30	75	80	140
30	240	21	35	50	70
31	170	20	75	50	70
32	170	20	35	50	140

2.5. Technique of Analysis of Data

In this research, the RSM was used to optimize and predict melting efficiency. RSM is the gathering of mathematical and statistical msthods which optimizes a targeted response from several input variables.

2.5.1. Fitting an Approximating Function

Let the connection between the factors and responses be represented by

$$y = f(\mathbf{X}i) + \varepsilon \qquad (2)$$

Where $\mathbf{X}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} = \begin{bmatrix} \mathbf{I} \\ \mathbf{V} \\ \mathbf{S} \\ \mathbf{T} \\ \mathbf{FR} \end{bmatrix}$

The true nature of the functional relationship is not known. We attempt to fit a second order polynomial to the experimental data. Applying Taylor's series expansion through second order to equation 2, we obtain

$$\begin{aligned} y = {} & \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_{11} {X_1}^2 + \beta_{22} {X_2}^2 + \beta_{33} {X_3}^2 \\ & + \beta_{44} {X_4}^2 + \beta_{55} {X_5}^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \beta_{15} X_1 X_5 + \beta_{23} X_2 X_3 \\ & + \beta_{24} X_2 X_4 + \beta_{25} X_2 X_5 + \beta_{34} X_3 X_4 + \beta_{35} X_3 X_5 + \beta_{45} X_4 X_5 \qquad \dots \quad (2.1a) \end{aligned}$$

$$= \beta_0 + \sum_{i=1}^{5} \beta_i X_i + \sum_{i=1}^{5} \beta_{ii} {X^2}_i + \sum_{i<j=2}^{5} \beta_{ij} X_i X_j \qquad \dots \quad (2.1b)$$

Equation 3.2 is a second order response surface model to be fitted to the experimental data.

To develop the model for the heat input, the sequential sum of squares is determined and the results are shown in table 5 below.

Table 5: Sequential Sum of the Squares

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Mean vs Total	65160.5	1	65160.5			
Linear vs Mean	6.191882	5	1.238376	0.627538	0.6803	
2FI vs Linear	41.73511	10	4.173511	6.975465	0.0004	
Quadratic vs 2FI	6.026179	5	1.205236	3.737874	0.0319	Suggested
Cubic vs Quadratic	2.346827	7	0.335261	1.117537	0.4853	Aliased
Quartic vs Cubic	0	0				Aliased
Fifth vs Quartic	0	0				Aliased
Sixth vs Fifth	0	0				Aliased
Residual	1.2	4	0.3			
Total	65218	32	2038.063			

Table 5 above shows the sequential sum of the squares for melting efficiency with respect to the possible candidate models ranging from mean, to linear to the sixth order polynomial model.

The table shows the accumulated enhancement of the model fit as additional terms are included to the model. The linear row represents the enhancement in the model as a result of adding linear terms to the mean. The 2FI row similarly shows improvement due to adding 2-factor interaction (2FI) terms to both the linear and the mean. Terms similarly, the significance of adding quadratic terms to preceding terms is shown in the quadratic row or line. The goal of the activity is to get the most high order polynomial model that is significant and at the same time not aliased. The highest order model that is not aliased is the quadratic model and ie significant with a p-value of 0.0319, and F-value of 3.737874.The small sum of square, and mean square errors of 6.026179 and 1.205236 indicate that is a more suitable model for the data than the other models.

In assessing the potency of the quadratic model towards maximizing the melting efficiency, ANOVA was done, the result is presented as shown in the table below.

Table 6: ANOVA table for confirming the significance of the model towards the maximization of the melting efficiency

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	51.99153	10	5.199153	19.8208	< 0.0001	significant
A-I	0.228162	1	0.228162	0.869826	0.3616	
B-V	0.873724	1	0.873724	3.33091	0.0822	
C-S	1.212611	1	1.212611	4.622852	0.0434	
D-T	1.003307	1	1.003307	3.824919	0.0639	
E-FR	2.016878	1	2.016878	7.688971	0.0114	
AC	5.12766	1	5.12766	19.54825	0.0002	
AD	24.12721	1	24.12721	91.98047	< 0.0001	
BE	10.55475	1	10.55475	40.238	< 0.0001	
CE	3.900153	1	3.900153	14.86861	0.0009	
C^2	4.540846	1	4.540846	17.31113	0.0004	
Residual	5.508467	21	0.262308			
Lack of Fit	4.308467	17	0.253439	0.844797	0.6467	not significant
Pure Error	1.2	4	0.3			
Cor Total	57.5	31				

The Model F-value of 19.82 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could happen as a result of snoise.
Values of "Prob> F" less than 0.0500 indicate model terms are significant.
In this case C, E, AC, AD, BE, CE, C2 are significant model terms.
Values greater than 0.1000 indicate the model terms are not significant.
The "Lack of Fit F-value" of 0.84 implies the absence of Fit is not significant relative to the pure error. There is a 64.67% probability that an “absence of Fit –value” this large could happen as a result of noise. insignificant lack of fit is good -- we desire the model to fit.

Table 7 below shows the summary statistics of the various polynomial model. Here the focus is on the model maximizing the “Adjusted R-Squared” and the “Predicted R-Squared”.

Table 7 Model Summary Statistics

Std. Dev.	0.51216		R-Squared	0.904201
Mean	45.125		Adj R-Squared	0.858582
C.V. %	1.134981		Pred R-Squared	0.790025
PRESS	12.07354		Adeq Precision	19.41136

The "Pred R-Squared" of 0.7900 is in moderately good agreement with the "Adj R-Squared" of 0.8586. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 19.411 shows a moderately good signal. This model can be empioyed to navigate the design space.
To obtain the optimal solution, the coefficient of the statistics was considered as presented in table 8 below.

Table 8: Coefficient Estimate

Factor	Coefficient Estimate	Df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	45.43616	1	0.124965	45.17628	45.69604	
A - I	-0.10262	1	0.110029	-0.33144	0.1262	1.014539
B - V	-0.19836	1	0.108684	-0.42438	0.027664	1.009115
C - S	-0.23136	1	0.107605	-0.45514	-0.00758	1.011651
D - T	-0.21101	1	0.107895	-0.43539	0.013365	1.0095
E - FR	0.298671	1	0.107711	0.074674	0.522668	1.014757
AC	0.572062	1	0.129387	0.302988	0.841137	1.027129
AD	-1.23564	1	0.128838	-1.50358	-0.96771	1.019926
BE	0.805744	1	0.127022	0.541587	1.069901	1.022298
CE	0.484903	1	0.125754	0.223385	0.746422	1.023007
C^2	-0.49903	1	0.119939	-0.74845	-0.2496	1.001842

The optimal equation which shows the individual effects and combine interactions of the selected factors against the measured response (melting efficiency) is presented base on the coded variables and the actual factors has shown in the following equations.

Final Equation in Terms of Coded Factors:

ɳ = + 45.44 - 0.10*A - 0.20*B - 0.23*C - 0.21*D + 0.30*E + 0.57*A*C - 1.24*A*D + 0.81*B*E + 0.48*C*E - 0.50*C^2

Final Equation in Terms of Actual Factors:

ɳ = 41.00197 + 0.091967*I - 0.52312*V - 0.090087*S + 0.39781*T - 0.14467*FR + 7.15078E-004*I*S - 2.05941E-003*I*T + 4.60425E-003*V*FR + 6.92719E-004*S*FR - 1.24756E-003*S^2

To study the effects of combine input variable on the response, melting efficiency, 3D Surface plot is presented in Figure 1 below.

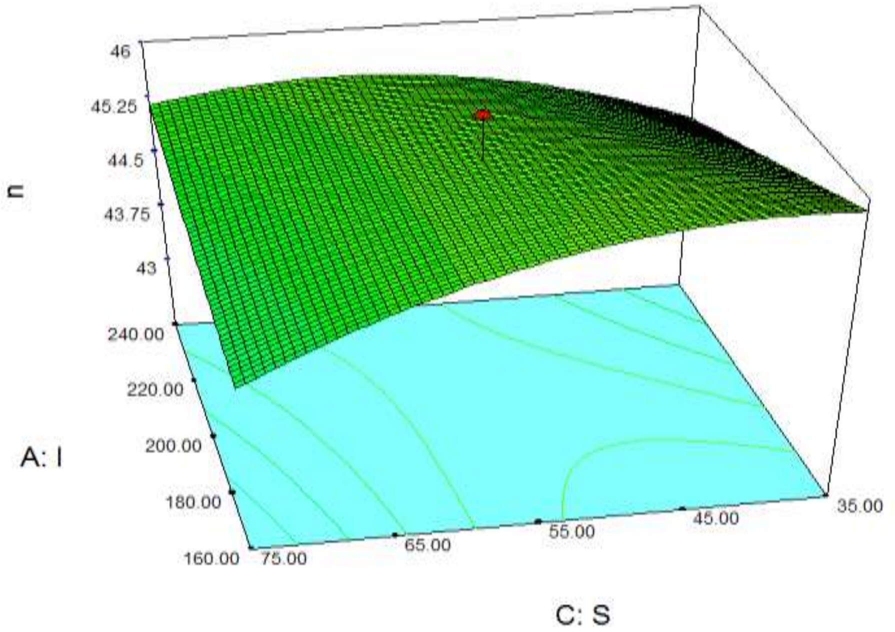

Figure 1: Influence of current and welding speed on melting efficiency

3. RESULTS AND DISCUSSION

In this research, the RSM was used for the prediction of the melting efficiency of TIG welds. The model had p-values less than 0.05 which indicates the significance of the model and "Predicted R-Square" value of 0.790025 is in moderately good agreement with the "Adj R-Squared" of 0.9985. ANOVA was done and the result showed that the models is significant and possess a very good fit. To validate the significance and adequacy of the model a coefficient of determination (R-Squared) of 0.904201 indicating the appreciable strength of the model. The computed signal to noise ratio of 19.41136 as observed in table 7 shows a moderately good signal. This model can be employed to navigate the design space and adequately predict the melting efficiency. The model graph indicates the relationship of the combine variables on the measured response, heat input as presented in a 3-Dimensional surface plot.

4. CONCLUSION

The integrity of a weld is determined by the quality of the weld bead geometry. Melting efficiency is a very important factor considered in assessing the integrity of a weld. In this study, model for the optimization and the prediction of melting efficiency of mild steel. In this study, an approach using RSM for optimizing and predicting the melting efficiency of mild steel weldment in a weld to improve the integrity of welded joints has been successfully introduced and its effectiveness and efficiency well demonstrated.

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