International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 3 Mar 2022, pp: 72-78 www.ijaem.net ISSN: 2395-5252

Optimization and Prediction of Heat Input of Mild Steel Weldment, Using Response Surface Methodology

Sibete.G[1] and Eyitemi. T[2]

Department of Mechanical Engineering, Niger Delta University, Wilberforce Island, Bayelsa state, Nigeria.
Department of Mechanical Engineering,Nigeria Maritime University, Okerenkoko, Delta State, Nigeria.

Submitted: 01-03-2022 Revised: 07-03-2022 Accepted: 10-03-2022

ABSTRACT
Most welded joint fail due to the utilization of poor welding process. This poor welding process produces a low heat input that could cause insufficient melting of the electrode. Insufficient melting of electrode is responsible for inadequate penetration of liquid metal into the welded joint. Literature has shown that welded joints produced by insufficient penetration of liquid metal have low bearing capacity. This indicates that such welded joints would not be able to sustain the design load. In order to achieve deep liquid metal penetration, the optimization and prediction of heat input of mild steel weldment, using RSMis studied. The aim of this study, therefore, is to develop models that would minimize heat input. The design of experimental matrix was developed, using the design expert software. This is determined by the input factors and its parametric levels.The Response surface method was employed to analyse the data collected from the experiment. The second order polynomial model was adopted having current, voltage, welding speed, welding time and feed rate as input factors, heat input is the target response. To test for the model significance, adequacy and validity, the analysis of variance was done and goodness of fit was determined. From the result, the p-value of the heat input model is 0.001, which is lower than 0.05, indicating that the model developed is significant. The determination coefficient(R^2), the conformity between the experimental result and the theoretical expectation, which measures the goodness of fit for heat input is 92%.The result shows that a combination of current 160.2A, voltage 25.03V, welding speed 57.72 mm/s, welding time 80 sec, feed rate 70.11, will produce optimal heat input 64.795KJ at a desirability of 0.739.s

I. INTRODUCTION AND LITERATURE REVIEW

Welding is the act of combining two metal pieces or plastic together by heating to their melting temperature in the company of or without the application of pressure and in the company of or without the application filler metal. The filler metal possess a melting point almost the same as the base metal.When a welded joint becomes too hot, it dissipates the heat quickly, cooling too quickly, causing internal stress in both the weld and base metal (https://www.the fabricator.com/art). Ordinarily, quick cooling rates have adverse effect on a weldment due to the fact that it causes it to break or crack easily at the heat affected zone. According to Tekriwal and Mazumder (1988), the effort to quantify heat movement and residuum stresses during welding moves back to the 1930's when Rosenthal and Boulton and Martin developed analytical model for welding theory. The reason heat input is extremely important in certain application is because it has a huge bearing on the cooling rate. Funderburk(1999) described heat input as a relative measure of the energy transferred per unit length of weld. Just like preheat and the interface temperature, it is a vital factor as it clouts the cooling rate, which can affect the mechanical properties and the metallurgical structure of the weld and also the heat affected zone (HAZ). It is generally well known that increased heat input amounts in fissuring of weld metals and the vicinity of the HAZ(Carlos,2016 and Epub,2016). The fissuring occurs as an outcome of the adverse development of residual stress and the unwanted metallurgical alterations in the weldment, high heat input may also introduce a higher amount of ferrite content in the weld deposit, which reduces the corrosion resistance and leads to premature failure during service (Carlos,2016 and Epub , 2016)

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 3 Mar 2022, pp: 72-78 www.ijaem.net ISSN: 2395-5252

Evans(1982) investigated the result of changing the heat input effect of the microstructure, the manual metal arc deposits containing 0.6 – 1.8% Mn. He varied the heat between 0.6 and 4.3KJ/mm and observed an increase in bead size accompanied by a decrease in the volume of acicular ferrite and a general coarsening of the welded joint microstructure.

II. 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, and method of data analysis.

2.1 Research Design

Thisresearch study focused on heat input of mild steel weldment, using response surface methodology, to optimize and predict the output. The input process parameters are current, voltage, welding speed, welding time and feed rate. The method was employed because of its capability to accommodate complex experimental designs.

The Central Composite Design(CCD)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 specimen 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 Tungsten Inert Gas Welding (TIG) equipment was used to weld the plates after the edges have been beveled. The welding operation utilizes gas to shield the weld specimen from atmospheric interaction, 100% pure Argon gas was employed in thisstudy.The diagnostic case statistics which shows the experimentally obtained values of heat input against the predicted values is presented as shown in table 1 below.

2.4 Method of Data Collection

In this work , the CCD was undertaken, using the factor ranges in Table 1 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 shown 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)

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

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

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 3 Mar 2022, pp: 72-78 www.ijaem.net ISSN: 2395-5252

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

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 3 Mar 2022, pp: 72-78 www.ijaem.net ISSN: 2395-5252

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. Methodology of Data Analysis

In this research, the RSM was employed to optimize and predict heat input. RSM is the aggregation of mathematical and statistical methods which optimizes a targeted response from several input variables.

2.5.1. Fitting an Approximating Function

Let the relation between the factors and responses be represented by

$y = f(\boldsymbol{Xi}) + \varepsilon$
(2)

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

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

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

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

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 Squares

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob>F	
Mean vs Total	227487.4	1	227487.4			
Linear vs Mean	30246.38	5	6049.277	61.60185	< 0.0001	
2FI vs Linear	1735.432	10	173.5432	3.395492	0.0145	
Quadratic vs 2FI	789.5862	5	157.9172	61.66043	< 0.0001	Suggested
Cubic vs Quadratic	28.17187	6	4.695311	63660000	< 0.0001	Aliased
Residual	0	5	0			
Total	260287	32	8133.969			

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 3 Mar 2022, pp: 72-78 www.ijaem.net ISSN: 2395-5252

Table 5 shows the improvement derived from adding additional model terms to the model equation. The idea is to consider the highest order model that is significant and not aliased.
The quadratic model is significant with a p-value < 0.0001, a mean squared error of 157.9172 and a sum of squares error of 789.5862.

In accessing the strength of the quadratic model towards minimizing the heat input, ANOVA was done, the result is presented as shown in table 6 below.

Table 6: ANOVA table for validating the model significance towards minimizing the heat input.

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob>F	
Model	32765.51	10	3276.551	2020.164	< 0.0001	Significant
A - I	5369.847	1	5369.847	3310.789	< 0.0001	
B - V	4153.676	1	4153.676	2560.957	< 0.0001	
C - S	18197.67	1	18197.67	11219.81	< 0.0001	
D - T	0.119807	1	0.119807	0.073867	0.7884	
E - FR	1.173885	1	1.173885	0.723761	0.4045	
AB	161.7929	1	161.7929	99.75374	< 0.0001	
AC	649.3232	1	649.3232	400.3414	< 0.0001	
BC	581.7543	1	581.7543	358.6817	< 0.0001	
DE	9.785325	1	9.785325	6.03316	0.0228	
C^2	934.8127	1	934.8127	576.3605	< 0.0001	
Residual	34.0604	21	1.621924			
Lack of Fit	34.0604	16	2.128775			
Pure Error	0	5	0			
Cor Total	32799.57	31				

The Model F-value of 2020.16 infers the model is significant. There is just 0.01% likelihood that a "Model F-Value" this large could occur due to noise.

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.	1.273548		**R-Squared**	0.998962
Mean	84.31478		**Adj R-Squared**	0.998467
C.V. %	1.510468		**Pred R-Squared**	0.996797
PRESS	105.0597		**Adeq Precision**	18.7767

The "Pred R-Squared" of 0.9968 is in reasonable agreement with the "Adj R-Squared" of 0.9985. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 181.777 indicates an adequate signal. This model can be used to navigate the design space.

To obtain the optimal solution, the coefficient of the statistics was considered as presented in table 8 below.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 3 Mar 2022, pp: 72-78 www.ijaem.net ISSN: 2395-5252

Table 8: Coefficient Estimate

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	77.35933	1	0.358566	76.61366	78.10501	
A-I	17.48519	1	0.303882	16.85323	18.11715	1.031500942
B-V	17.18445	1	0.339574	16.47827	17.89063	1.323787636
C-S	-32.5309	1	0.307116	-33.1696	-31.8922	1.103099032
D-T	-0.10366	1	0.381387	-0.89679	0.689482	1.678720163
E-FR	-0.25764	1	0.302839	-0.88743	0.372151	1.072587707
AB	3.570571	1	0.357498	2.827114	4.314027	1.241045237
AC	-6.51458	1	0.32559	-7.19169	-5.83748	1.05188863
BC	-6.3487	1	0.33522	-7.04583	-5.65157	1.1514927
DE	-0.91703	1	0.373346	-1.69345	-0.14062	1.375030872
C^2	11.63469	1	0.484627	10.62685	12.64253	1.117717635

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

Final Equation in Terms of Coded Factors:
HI = 77.36 + 17.49*A + 17.18*B - 32.53*C - 0.10*D - 0.26 *E + 3.57*A*B - 6.51*A*C - 6.35*B*C - 0.92*D*E +11.63*C2

Final Equation in Terms of Actual Factors:
HI = - 16.84682 + 0.43869 *I +3.35811*V - 1.61026*S + 0.17650 *T + 0.10618*FR + 0.017853 *I*V - 8.14323E-003*I*S - 0.063487*V*S -1.74673E-003*T*FR + 0.029087*S2

To study the effects of combine input variables on the response, heat input, 3D surface plot is presented in the figure 1 below.

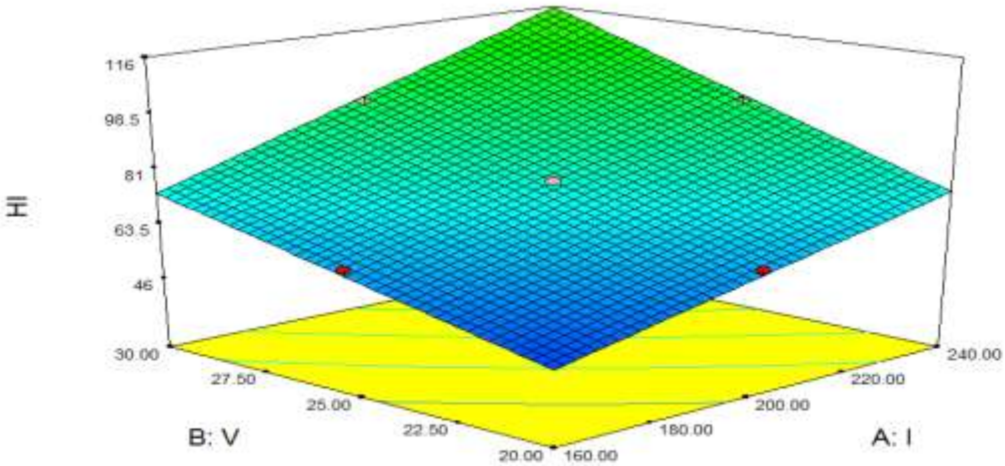

Figure 1: Effect of current and voltage on heat input.s

III. RESULTS AND DISCUSSION

In this research, the Response Surface Method was used to predict the heat input of TIG welds. The model had p-values less than 0.05 which indicate that the model is significant and "Predicted R-Square" value of 0.9968 is in reasonable 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. Tovalidate the significance and adequacy of the model a coefficient of determination (R-Squared) of 0.9989 indicating the appreciable

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 3 Mar 2022, pp: 72-78 www.ijaem.net ISSN: 2395-5252

strength of the model. The computed signal to noise ratio of 18.7767 as observed in table 7 indicates an adequate signal. This model can be used to navigate the design space and adequately predict the heat input. The model graph shows the interactions of the combine variables on the measured response, heat input as presented in a 3-dimensional surface.

IV. CONCLUSION

The quality of a weld is determined by the degree of heat input of the weld metal, the lower the heat input the better the quality of the weld. In this study, model to optimize and predict heat input has been developed. In this study,an approach using the RSM for optimizing and predicting weld heat input of mild steel weldment to improve the integrity of welded joints has been successfully introduced and its effectiveness and efficiency well demonstrated.

REFERENCES

[1]. Arun Narayanan, Cijo Mathew, VinodYeldo Baby, JobyJoseph(2013), Influence of Gas Tungsten Arc Welding Parameters in Aluminium 5083 Alloy, International Journal of Engineering Science and Innovative Technology, 2 (5).

[2]. Atma Raj M.R, Joy Varghese V.M(2014), Determination of deformation formed in TIG welding of low carbon steel plate,International Journal of Engineering Research and General Science, 2 (5).

[3]. Box. G. E. P..and Wilson, K. B. (1951). "On the Experimental Accomplishment of Optimum Conditions." Journal of the American Statistical Society. Ser. B. 13. l-45.

[4]. Box.G. E. P and Draper. N. R. (1959). "A Basis for the Selection of a Response Surface Design Journal of the Statistical Association. .54, 622-654.

[5]. Gadewar, Paravliswaminadhan, M.G.Harkare, S.H.Gawande," Experimental Investigation of weld characteristcs for a single pass TIG welding with SS304". International journal of Engineering science and Technology, Vols2(8) 2010, 3676-3686

[6]. Huei-Sen Wang(2003) : Effect of Welding Parameters on Cooling Rate and Pitting Corrosion Resistance in Super Duplex Stainless Weldments‖, Materials Transactions, Vol. 46, pp. 593- 601.

[7]. Juang.S.C and Tarng.Y.S(2012) , The selection of process variables for the optimization of the weld pool geometry in TIGwelding of stainless steel.. Materials process technology Journal,122-240

[8]. Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. . Response Surface Methodology Product, Process Optimization using Designed Experiments (Fourth ed.). Wiley,2016.

[9]. Myers, R.H, Khuri, A.I and Carter, W.H.(1989). Response Surface Methodology:1966 -1988. Technometrics 31,137-157 MR1007291.

[10]. Myers, R.H. Montgomery, D.C and Anderson-Cook C.M, RSM process and product optimization using Designed Experiments. John Wiley and Sons Pg 78, 2009.