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Application of Response Surface Methodology (RSM) TO Optimise the Heat Input During TIG Welding at Steady State Condition

Ikponmwosa-Eweka O*. and Achebo, J.I
Department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria
*Corresponding Author Email: Eweka.egie@uniben.edu

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Abstract

This study examines an application of response surface methodology to optimize heat input during TIG welding at stead state condition. The parameters considered in this study are welding current, welding voltage and welding speed. 100 pieces of mild steel coupons measuring 80 x 40 x10 were used for the experiment. The experiment was performed 20 times, using 5 specimens for each run and Argon was used as the shielding gas. Tungsten inert gas machine was utilized in joining the weld materials. The heat input was consequently determined for the weldment using results gotten from experimental process as data. RSM was used to optimize heat input from the input parameters stated above. The numerical optimal solution produced welded material having heat input of 3807.69KJ/MM with a welding speed of 2.6mm/s, a current of 190Amp and voltage of 20.73 volt. RSM model selected the quadratic model as the suitable model for the heat input because it has a P value of < 0.05 as analyzed by analysis of variance table.

1. Introduction

Welding heat input is one of the vital factors for regulating the heat transfer and liquid flow in molten weld pool [1]. It changes the chemistry of weld metals on solidification. In welding process, heat input has an overwhelming influence on the yield strength, ductility and ultimate tensile strength [2]. Tungsten Inert gas welding (TIG) is known to be the best quality means for welding.

Different types of steel products are fabricated using this method for higher quality weld at reduced cost. The different process parameters of Tungsten Inert gas welding (TIG) affect the weld quality, and the result [3] shows that an increase in the welding current has a positive influence on the deposition rate and hardness of the weld. The energy level supplied to a weld during an arc welding process is regarded as the heat input. It is an all-important process that must be properly considered, adequately measured and controlled so as to ensure the quality of welded materials meets outlined standard [4].

Welding heat input has a tremendous effect on the thermal and mechanical properties of welded materials and the Heat affected zone (HAZ). It plays a significant role in determining the cooling rates in welds which causes a visible change in the microstructural configuration and the hardness of the weld metal [5]. Welding parameters such as welding current, voltage, and welding speed control heat input which determine the melting of base metal and filler wire [6].

When the level of heat input is high, the cooling rate is slow, and this implies that the lower the heat input, the faster the cooling rate [4,5]. During the arc welding process, it has been established that energy is transmitted through the welding electrode to the base metal by an electric arc. Upon starting the arc, sufficient amount of power (energy transferred per unit time) and energy density is supplied to the electrode. Consequently, both the base metal and the filler metal are melted to create the weld [6,8].

The aim of this study is to apply Response Surface Methodology (RSM) to optimize the heat input during TIG welding process at steady state condition.

2. Materials & Methods

In this experiment, an optimal experimentation to maximize heat input was conducted. Tungsten Inert gas welding process was used to join the specimen made of mild steel. The first step taken was to cut the mild steel coupons with the use of a power hacksaw and grinding machine was used on edge to smoothen the surfaces to be joined. The coupon surface was polished with emery paper.

Thereafter the mild steel plates were fixed on the work table using the flexible clamp to weld the joints of the specimen. A TIG welding process was used with alternate current to perform the experiments as it concentrates the heat in the welding area, using 100% argon shielding gas.
Using the optimal experimental matrix as a guide, five set of welded samples were made for each experimental run which amounted to a total of one hundred weld samples.

2.1. Identification of Range of Input Parameters

The key parameters considered in this work are welding current (I), welding voltage (V), and welding speed (mm/sec). The range is shown in Table 1.

Table 1: Process parameters and their levels

Process parameters	Unit	Symbol	Low (-)	High (+)
Welding Current	Amp	I	170	190
Welding Voltage	Volts	V	20	22
Welding Speed	mm/Sec	M	2.6	3.0

2.2. Method of Data Collection

20 sets of experimental runs were conducted, considering the heat input as output parameter. The heat input was calculated for each sample. The input parameters and the output parameter make up the experimental matrix, and the measured response from the weld samples were recorded. Table 2 shows the experimental result.

Table 2: Experimental result

Runs	Input Parameters			Output Parameter
	Current I, Amp	Speed mm/sec	Voltage, Volts	Heat Input (KJ/mm)
1	190	2.63	20.73	3807.69
2	190	2.63	20.72	2496.15
3	190	2.63	20.70	8500.00
4	190	2.63	20.68	1017.86

5	190	2.62	20.78	1029.81
6	170	2.80	20.00	1150.96
7	170	3.00	21.00	8925.00
8	170	3.00	22.00	1050.96
9	170	3.00	20.00	1012.50
10	180	2.60	21.00	1050.96
11	180	2.60	22.00	1090.38
12	180	2.60	20.00	9450.00
13	180	2.80	21.00	9642.86
14	180	2.80	22.00	1060.71
15	180	2.80	20.00	952.50
16	180	3.00	21.00	1012.50
17	180	3.00	22.00	9642.86
18	180	3.00	20.00	1012.50
19	190	2.60	21.00	1011.00
20	190	2.60	22.00	1012.50

2.3. Experimental procedure

100 pieces of mild steel coupons measuring 80 x 40 x10 mm was used for the experiment. The experiment was performed 20 times, using 5 specimens for each run. Mild steel plates was selected as the test piece material and the material was cut into pieces using a power hack saw. The samples were cut longitudinally, cleaned, grinded and the edges machined.

The tungsten inert gas welding equipment was used to produce the weld specimen after the edges have been machined. After this, the mild steel plates were clamped so as to weld the joints of the specimen. Tungsten inert gas welding process was used in joining the samples while 100% Argon was used as shielding gas to prevent the weldment from atmospheric reactions or influence. Experimental work was carried out and the results obtained was used to calculate the heat input.

3.0 Results and Discussions

Statistical analysis was carried out to analyze the variability in the experimental design of the model.

3.1 Modelling of Heat Input

To check for model suitability, the analysis of variance and goodness of fit statistics were employed. This are shown in Tables 3 and 4.

Table 3: Analysis of Variance table for Heat Input

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	8.989E+007	3	2.996E+007	12.84	0.0002	significant
A-current	1.989E+007	1	1.989E+007	0.51	0.4929	
B-welding speed	4.602E+007	1	4.602E+007	0.98	0.3466	
C-voltage	2.398E+007	1	2.398E+007	1.78	0.2119	
AB	15.85	1	15.85	10.27	0.0094	
AC	3.00	1	3.00	1.95	0.1933	
BC	11.09	1	11.09	7.19	0.0230	
A^2	72.58	1	72.58	47.05	< 0.0001	
B^2	45.53	1	45.53	29.51	0.0003	
C^2	8.40	1	8.40	5.45	0.0418	
Residual	15.43	10	1.54			
Lack of Fit	3.37	5	0.67	0.28	0.9058	not significant
Pure Error	12.05	5	2.41			

Table 3 represents analysis of variance which shows that the process parameter has a significant influence on the welding heat input. The model is significant because it has a P- value of 0.0002 which is less than 0.05. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. To further validate the adequacy of the quadratic model based on its ability to optimize heat input, the goodness of fit statistics presented as shown in table 4 was used.

Table 4: Goodness of fit for Heat Input

Std. Dev.	1.24	R-Squared	0.9204
Mean	7.88	Adj R-Squared	0.8487
C.V. %	15.75	Pred R-Squared	0.7495
PRESS	48.52	Adeq Precision	9.934

Table 4 shows the goodness of fit. It measures the strength and adequacy of the quadratic model. The results obtained shows that the model has 92% capacity to optimize the heat input, when any change occurs in any of the input parameters. The optimal equation which shows the individual effects and combine interactions of the selected input variables (current (X_1), voltage(X_2) and welding speed(X_3)) against the welding heat is presented below in equation 1.

$$\text{Heat input} = +53655.81754 - 120.68583X_1 + 9177.94044X_3 - 2650.44468X_2 + 6.00300X_1X_3 + 0.53600X_1X_2 + 6.88700X_3X_2 - 0.0437X_1^2 - 2.594\,00X_3^2 + 4.16000X_2^2 \quad (1)$$

X_1 = Current
X_2 = Voltage
X_3 = Welding Speed

The 3D surface plot below demonstrates the combined interaction between two input variables and the output response parameter. Figure 2 shows the effects of welding speed and current on heat input.

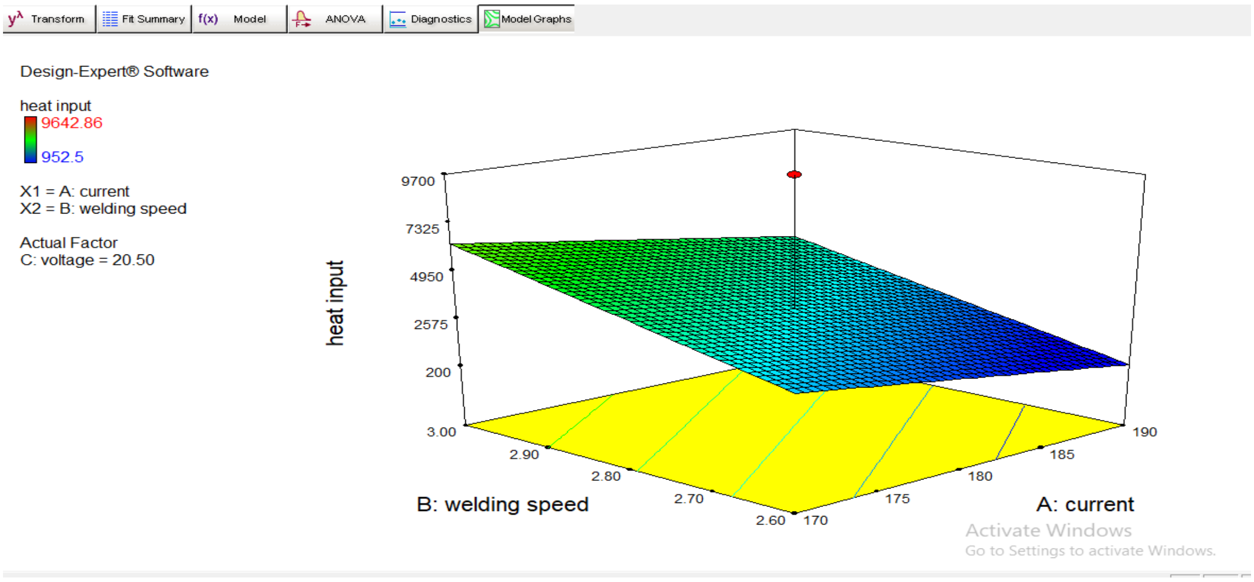

Figure 1: Effect of Welding speed and Current on Heat Input

The surface plots in figure 1 above shows that the combined interaction that occurs between welding speed and current, from the 3D surface plot. As it can be seen here, an increase in current (from 170 - 190) had significant effect on the heat input which also recorded an increase (from 200 – 9700kj/mm). It can be therefore concluded that current has a significant effect on heat input.

The 3D surface plot below demonstrates the combined interaction between two input variables and the output response parameter. Figure 2 shows the effects of voltage and current on heat input.

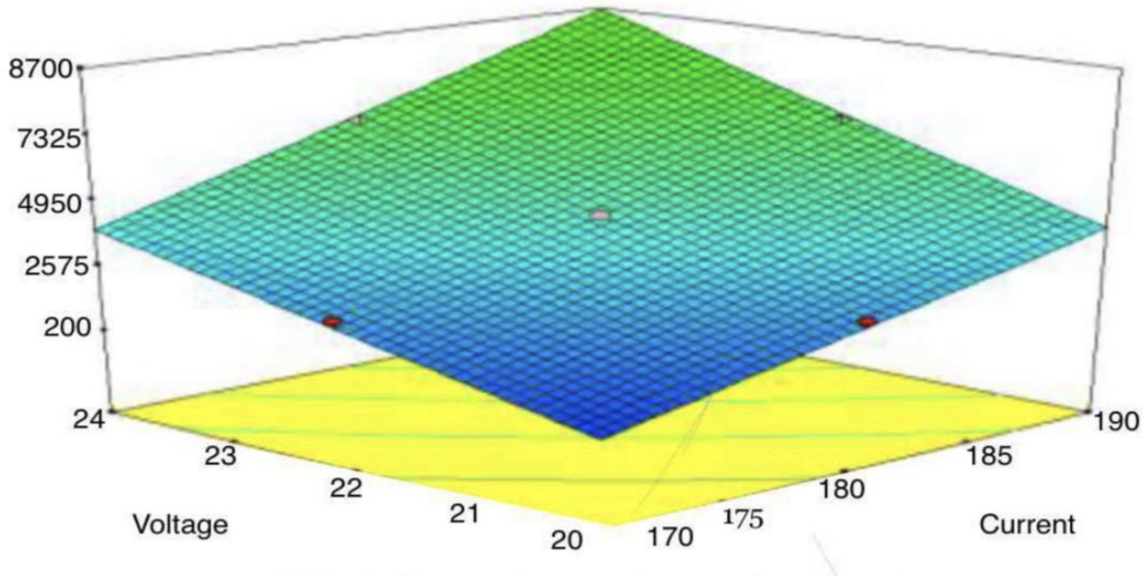

Figure 2 shows the effects of voltage and current on heat input

The surface plots in figure 2 shows the combined interaction that occurs between voltage and current, from the 3D surface plot. As it can be seen here, an increase in voltage (as it increases from 20 – 24volts) and increase in current (from 170 – 190amp) had visible effect on the heat input which also recorded an increase (from 200 – 8700kj/mm). It can be therefore concluded that voltage and current has a significant effect on heat input. The final numerical optimal solution was obtained showing optimal results for current, welding speed and voltage, which will produce maximum heat input as shown in Table 5.

Table 5: Table Showing Numerical Optimization of Response

Number	Current (Amp)	welding speed (mm/s)	Voltage (volt)	heat input (KJ/mm)	Desirability	
1	190.00	2.63	20.73	3807.69	0.829	Selected
2	190.00	2.63	20.72	9642.86	0.629	
3	190.00	2.63	20.70	1090.38	0.629	
4	190.00	2.63	20.68	1150.96	0.628	
5	190.00	2.62	20.78	9642.86	0.628	

Table 5 shows that a welding current of 190amp, a welding speed of 2.63mm/s and welding voltage 20.73volt will produce heat input of 3807.69kj/mm. This solution was selected by design expert as the optimal solution having a desirability value of 0.829.

4.0 Conclusion

In this research, we have successfully used Response Surface Methodology to optimize the heat input during TIG welding process. The effect of welding speed, voltage and current on heat input was successfully investigated. The results from the numerical optimization of the heat input shows that increasing the current and voltage, increases the heat input. The numerical optimal solution produced welded material having heat input of 3807.69KJ/mm with a welding speed of 2.6mm/s, a current of 190Amp and voltage of 20.73volts. RSM model selected the quadratic model as the suitable model for the heat input because it has a P value of < 0.05 as analyzed by analysis of variance table.

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