IJIRR

International Journal of Information Research and Review
Vol. 06, Issue, 01, pp.6061-6066, January, 2019

RESEARCH ARTICLE

HEAT INPUT OPTIMIZATION ANDPREDICTION ANALYSIS FOR TIG WELDING PROCESS

Enegide Fergus Uche, Achebo J., and Osaremwinda, J.O.

Department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria

ARTICLE INFO

Article History:
Received 17th October, 2018
Received in revised form
08th November, 2018
Accepted 20th December, 2018
Published online 30th January, 2019

Keywords:
Heat input, Weldment,
RSM, weld and DOE.

ABSTRACT

Heat input during welding can compromise the final quality of a weld and also add to the shortening life span of the components. One of the major effect of excessive heat input on weldments is microstructure alteration of the weld area. Therefore to obtain a quality weld, one need to take into cognizance the amount of heat being introduced into a weld zone. This research is aimed to optimize and predict heat input needed for fusion welding of mild steel plate. Response Surface Methodology (RSM) using the central composite design was employed to analyze results gotten from the design of experiment, where twenty sets of experiments were carried out with weld samples measuring 60x40x10mm cut, welded and analyzed. At the end, RSM model was employed to optimize and predict the heat input of mild steel weldments. The model produced a numerical optimal solution of: current 120.00 Amp, voltage of 23.79 volt and a gas flow rate of 15.71 L/min resulting in a welded material having a heat input of 2.49985x106 J/m. the microstructural alteration produced by this heat input value obtained from this research is very minimal.

INTRODUCTION

It is often common for some welders or fabricators to pay less attention to the heat input introduced into a welded material. Heat input is basically referred to as the amount of electrical energy supplied to the fusion zone of a welded material to cause melting during welding. Excessive heat input has the ability to alter the microstructure of a welded material thereby compromising the final quality of the material while lack of adequate heat input result in a weak bond formation between the parent metals. Jatinder and Jagdev(2013), in their work, varied the weld speed of different samples using welding speeds of 94.83, 109.90, 120.00, 131.25, 140, 150 and 169.76 mm/min at a voltage of 20V, current of 110A, and wire speed of 5.918m/min with the aim of establishing the impact of weld speed and heat input on stress build-up or stress concentration factor of butt welded joint. Majumder, (2011) carried out research trying to establish the effects of heat input on HAZ of low carbon steel, where his remarkable discovery lead to the selection of correct bevel angle geometry process variables for achieving desired hardness of weld and HAZ. Oyetunji et.al, (2013) studied the effects of heat input rate on the weld zone and HAZ for mild steel weldments. Herring (2005) studied the influence of grain size on the materials properties and pointed out that grain size had a measurable effect on most mechanical properties.Oliverapopović, (2010) also observed that the welding heat input has a great influence on the weldments properties of steel. The most important characteristics of weld heat input is its ability to control the cooling rate of welds and also the heat affected zone.

***Corresponding author: Enegide,**
Department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria.

Rosenthal, (1946) worked on cooling rate that result from heat input from a moving heat source using the analytical approach, where he developed the most widely used and the best known analytical solutions to predict weld thermal history and cooling rate. This has helped researches to understand better how the microstructural properties, cooling rates are affected by the heat input and also increase the numeric prediction power of researchers to an appreciable degree. Eagar et.al (1983) went further to simplify the two limiting solutions derived by Rosenthal using the numerical approach to obtain temperature and time profiles in the HAZ. Babu et.al, (2012) worked on heat transferred on the parent metal and concluded that the base metal grain structureis alteredwhen there is excess heat input.Funderburk(1999), stated that the mechanical properties of welded joints depend on several factors including heat input. After heat input has altered the microstructure,Morris (2001) reported that the important mechanical properties of steel, such as yield strength and hardnesscan be enhanced if ductile-brittle transition temperature can be improved by refining the grain size. The all worked on trying to give better insight on how heat input affects the HAZ, microstructure and cooling rate. The purpose of the research is to establish the optimum heat input required to weld mild steel plate without significant negative effect on the weldment.

MATERIALS AND METHODS

Materials

This study is centered on the experimental study of TIG mild steel welds, employing scientific design of experiments, expert systems, statistical and mathematical models and tests for thermal properties. The research data is made up of the gas tungsten arc welding input process parameters and the output process. The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined. Figure 1 shows the shielding gas cylinder and regulator, 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. Figure 2 shows the TIG welding setup. The key parameters considered in this work are welding current, gas flow rate, welding voltage as shown in table 1 with a low and high range values, the Central Composite Design (CCD) tool in design expert 7.01 was employed. One hundred (100) pieces of mild steel coupons measuring 60 x 40 x10mm were used for the experiments; it was performed 20 times, using 5 specimens for each run. Figure 3 and 4 shows the weld torch and the K type thermocouple used for the temperature measurement.

Table 1. Process parameters and their levels

Parameters	Unit	Symbol	Coded value	Coded value
			Low(-1)	High(+1)
Current	Amp	A	120	170
Gas flow rate	Lit/min	F	13	16
Voltage	Volt	V	18	24

Figure 1. Shielding gas cylinder and regulator

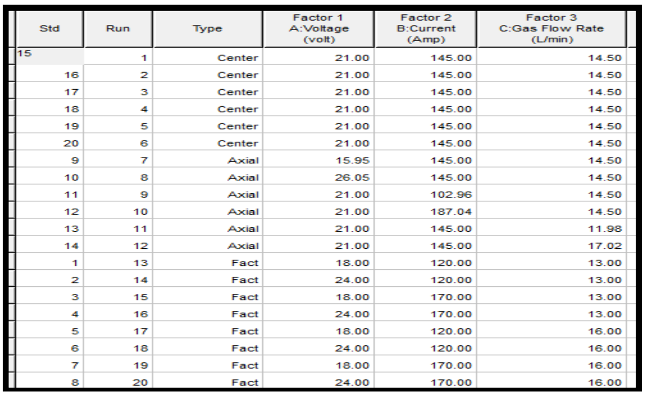
Figure 2. TIG equipment

Figure 3. TIG welding torch

Figure 4. K-Type Thermocouple

To generate the experimental data for the optimization process;

- First, statistical design of experiment (DOE) using the central composite design method (CCD) was done. Central composite design (CCD) is unarguably one of the most acceptable design for response surface methodology (RSM). The design and optimization was done using statistical software and for this particular problem, Design Expert 7.01 was employed.
- Secondly, an experimental design matrix having six (6) centre points, six (6) axial points and eight (8) factorial points resulting to 20 experimental runs was generated. Figure 3 shows the design matrix for the research work.



Std	Run	Type	Factor 1 A:Voltage (volt)	Factor 2 B:Current (Amp)	Factor 3 C:Gas Flow Rate (L/min)
15	1	Center	21.00	145.00	14.50
16	2	Center	21.00	145.00	14.50
17	3	Center	21.00	145.00	14.50
18	4	Center	21.00	145.00	14.50
19	5	Center	21.00	145.00	14.50
20	6	Center	21.00	145.00	14.50
9	7	Axial	15.95	145.00	14.50
10	8	Axial	26.05	145.00	14.50
11	9	Axial	21.00	102.96	14.50
12	10	Axial	21.00	187.04	14.50
13	11	Axial	21.00	145.00	11.98
14	12	Axial	21.00	145.00	17.02
1	13	Fact	18.00	120.00	13.00
2	14	Fact	24.00	120.00	13.00
3	15	Fact	18.00	170.00	13.00
4	16	Fact	24.00	170.00	13.00
5	17	Fact	18.00	120.00	16.00
6	18	Fact	24.00	120.00	16.00
7	19	Fact	18.00	170.00	16.00
8	20	Fact	24.00	170.00	16.00

Figure 5. Central Composite Design Matrix (CCD)

RESULTS AND DISCUSSIONS

Results

The experimental design, numerical and graphical optimization was done with the aid of thedesign expert 7.1 software. Table 2 shows the experimental results for the heat input, the experiments was performed using the central composite design matrix. The design expert software was used to generate the experimental runs obeying the principles of experimental design. The model summary, which shows the factors and their lowest and highest values including the mean and standard deviation, is presented as shown in table 3. The result revealed that the model is of the quadratic type which requires the polynomial analysis order as depicted by a typical response surface design. The minimum value of heat input was observed to be 1.836 J/m with a maximum value of 3.520 J/m, mean value of 2.613 and standard deviation of 0.440. In assessing the strength of the quadratic model towards minimizing the heat input, one way analysis of variance (ANOVA) was done for each response variable and result is presented in Table 4. Analysis of variance was needed to check whether or not the model is significant and also to evaluate the significant

Table 2. The Experimental results for heat input

Std	Run	Voltage (Volt)	Current (Amp)	Gas Flow Rate (L/min)	Heat Input
15	1	21.00	145.00	14.50	2.381
16	2	21.00	145.00	14.50	2.381
17	3	21.00	145.00	14.50	2.382
18	4	21.00	145.00	14.50	2.381
19	5	21.00	145.00	14.50	2.382
20	6	21.00	145.00	14.50	2.381
9	7	15.95	145.00	14.50	2.550
10	8	26.05	145.00	14.50	3.179
11	9	21.00	102.96	14.50	2.244
12	10	21.00	187.04	14.50	2.618
13	11	21.00	145.00	11.96	2.805
14	12	21.00	145.00	17.02	3.179
1	13	18.00	120.00	13.00	1.836
2	14	24.00	120.00	13.00	3.060
3	15	18.00	170.00	13.00	2.142
4	16	24.00	170.00	13.00	3.486
5	17	18.00	120.00	16.00	2.448
6	18	24.00	120.00	16.00	2.448
7	19	18.00	170.00	16.00	2.601
8	20	24.00	170.00	16.00	3.520

Table 4. ANOVA table for validating the model significance towards optimizing the heat input

Response 1	WPSF					
ANOVA for Response Surface Quadratic Model						
Analysis of Variance table [Partial Sum of Squares-Types III]						
Source	Sum of Square	df	Mean Square	F Value	P-Value Prob>F	
Model	3.46	9	0.38	9.07	0.0009	Significant
A-Voltage	1.62	1	1.62	38.20	0.0001	
B-Current	0.55	1	0.55	12.98	0.0048	
C-GFR	0.069	1	0.069	1.63	0.2312	
AB	0.098	1	0.098	2.32	0.1588	
AC	0.28	1	0.28	6.61	0.2928	
BC	0.052	1	0.052	1.23	0.2928	
A^2	0.31	1	0.31	7.38	0.0217	
B^2	5.363E-004	1	5.363E-004	0.013	0.9126	
C^2	0.53	1	0.53	12.59	0.0053	
Residual	0.42	10	0.042			

Table 5: GOF statistics for validating model significance in optimizing the heat input

Std. Dev	0.21	R-Squared	0.8909
Mean	2.61	Adj R-Squared	0.7927
C.V%	7.87	Pred R-Squared	0.1507
PRESS	3.29	Adeq Precision	9.478

contributions of each individual variable and their combined and quadratic effects towards each responseFrom the result of table 4 the model F-value of 9.07 with computed p-value of 0.0009 implies the model is significant. There is only a 0.09% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, AC, A^2, C^2 are significant model terms. 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 your model. In this case A, B, C, AB, AC, A^2, C^2 are significant model terms. 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 your model. To validate the adequacy of the model based on its ability to optimize the heat input to a desired range, the goodness of fit statistics presented in table 5 were employed; Coefficient of determination (R-Squared) value of 0.8909 as observed in table 5 shows the strength of response surface methodology and its ability to minimize the heat input to a desired value. Adjusted (R-Squared) value of 0.7927 as observed in table 5 indicates a model with 79.27% reliability. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision values of 9.478 as observed in table 5indicate an adequate signal. This model can be used to navigate the design space and minimize the heat input to the desired value. The optimal equation, which shows the individual effects and combine interactions of the selected variables against the mesured responses (heat input), is given in equation (1).

$$H.I = 19.46795 - 0.18367V - 0.051380A - 1.67006G + 1.47667 \times 10^{-3}VA - 0.041556VG + 2.15333 \times 10^{-3}AG + 0.016352V^2 - 9.76067 \times 10^{-6}A^2 + 0.085441G^2 \quad (1)$$

Where

H.I = Heat input
V = voltage
A = current
G = Gas flow rate

To asses the accuracy of prediction and established the suitability of response surface methodology using the quadratic model, a reliability plot of the observed and predicted values of each response were obtained as presented in Figure 6.

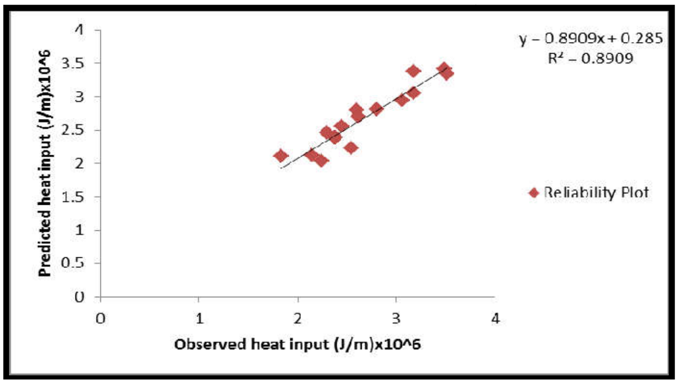


Figure 6. Reliability plot of observed versus predicted heat input

To asses the accuracy of prediction and establish the suitability of response surface methodology using the quadratic model, a reliability plot of the observed and predicted values of each response were obtained as presented in Figure 6. The high coefficient of determination ($r^2 = 0.8909$) as observed in Figure 6 were used to established the suitability of response surface methodology in otpimizing the heat input to the desired range.

To accept any model, its satisfactoriness must be checked by an appropriate statistical analysis. To diagnose the statistical properties of the model for heat input, the normal probability plot of residual presented in Figure 7 were employed.

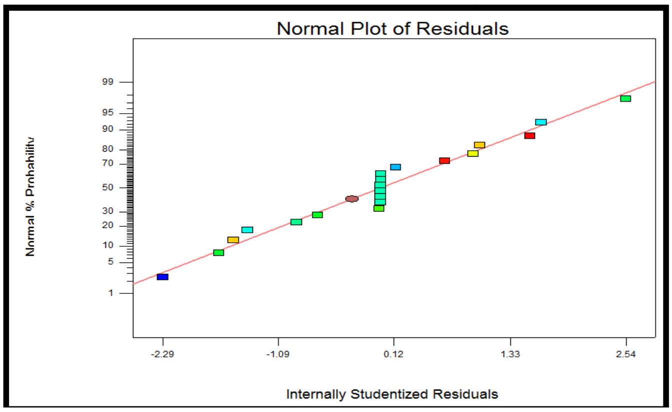


Figure 7. Normal probability plot of studentized residuals for heat input

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 deviation of actual values based on the predicted values was employed to ascertain if the residuals (observed – predicted) follows a normal distribution. It is the most significant assumption for checking the sufficiency of a statistical model. Result ofFigure 7 revealed that the computed residuals are approximately normally distributed an indication that the model developed is satisfactory. In addition, result of the normal probability plot of residual also indicates that the data used are devoid of possible outliers. To study the effects of combine variables on each response (heat input current and voltage), 3D surface plots presented in Figure 8 were employed. The 3D surface plot as observed in Figure 8 shows the relationship between the input variables (voltage, current and gas flow rate) and the response variables (heat input). It is a 3 dimensional surface plot which was employed to give a clearer concept of the response surface. As the colour of the curved surface gets darker, heat input decreases proportionately. Finally, numerical optimization was performed to ascertain the desirability of the overall model. In the numerical optimization phase, we ask design expert to optimize the heat input to a desired range while also determining the optimum value of voltage, current and gas flow rate. The interphase of the numerical optimization is presented as shown in Figure 9.

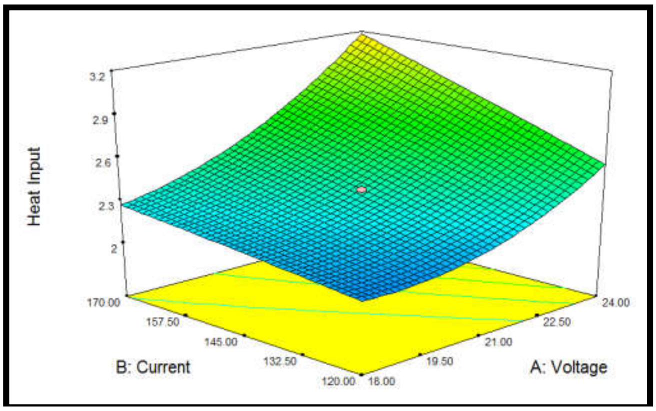


Figure 8. Effect of current and voltage on heat input

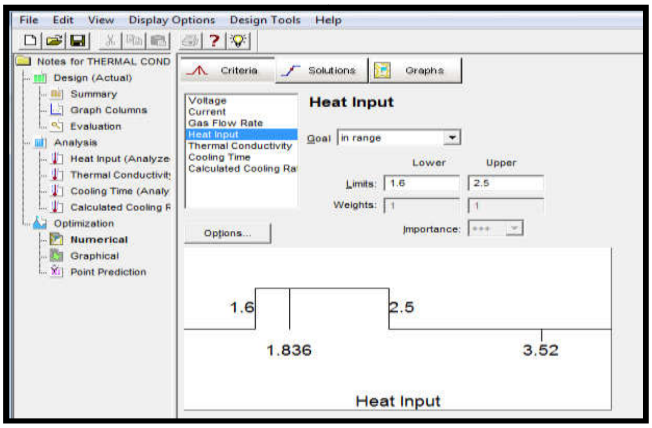
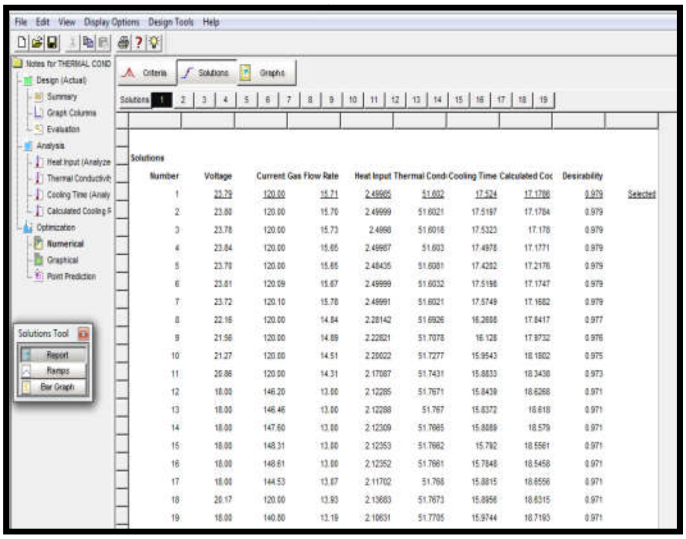


Figure 9. Interphase of numerical optimization model for optimizing the heat input

The numerical optimization produces about nineteen (19) optimal solutions which are presented as shown in Figure 10.



Number	Voltage	Current	Gas Flow Rate	Heat Input	Thermal Condi	Cooling Time	Calculated Coo	Desirability	
1	23.79	120.00	15.71	2.49985	51.602	17.524	17.1786	0.979	Selected
2	23.80	120.00	15.70	2.49999	51.6021	17.5187	17.1784	0.979	
3	23.78	120.00	15.73	2.4998	51.6016	17.5323	17.178	0.979	
4	23.84	120.00	15.65	2.49987	51.603	17.4978	17.1771	0.979	
5	23.70	120.00	15.65	2.48435	51.6081	17.4282	17.2176	0.979	
6	23.81	120.09	15.67	2.49999	51.6032	17.5198	17.1747	0.979	
7	23.72	120.10	15.78	2.49991	51.6021	17.5749	17.1682	0.979	
8	22.16	120.00	14.84	2.28142	51.6926	16.2688	17.8417	0.977	
9	21.56	120.00	14.89	2.22821	51.7078	16.128	17.9732	0.976	
10	21.27	120.00	14.51	2.20022	51.7277	15.9543	18.1802	0.975	
11	20.86	120.00	14.31	2.17087	51.7431	15.8833	18.3438	0.973	
12	18.00	146.20	13.00	2.12285	51.7671	15.8439	18.6268	0.971	
13	18.00	146.46	13.00	2.12288	51.767	15.8372	18.618	0.971	
14	18.00	147.60	13.00	2.12309	51.7665	15.8089	18.579	0.971	
15	18.00	148.31	13.00	2.12353	51.7662	15.792	18.5561	0.971	
16	18.00	148.61	13.00	2.12352	51.7661	15.7848	18.5458	0.971	
17	18.00	144.53	13.07	2.11702	51.768	15.8815	18.6556	0.971	
18	20.17	120.00	13.93	2.13683	51.7673	15.8956	18.6315	0.971	
19	18.00	140.80	13.19	2.10631	51.7705	15.9744	18.7193	0.971	

Figure 10. Optimal solutions of numerical optimization model

From the results of *Figure 10*, it was observed that a current of 120.00 Amp, voltage of 23.79 volt and a gas flow rate of 15.71 L/min will produce a welded material having heat input of 2.49985x106 J/m. This solution was selected by design expert as the optimal solution with a desirability value of 97.90%. Finally, based on the optimal solution, the contour plots showing each response variable against the optimized value of the heat input variable is presented in Figure 11.

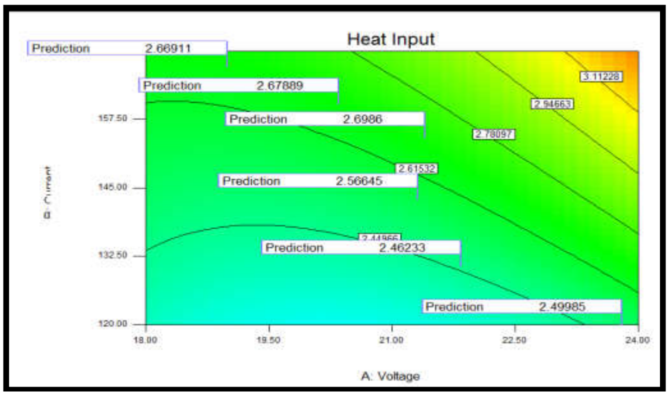


Figure 11. Prediction of heat input using contour plot

The optimal solution of numerical optimization revealed that a current of 120.00 Amp, voltage of 23.79 volt and a gas flow rate of 15.71 L/min will produce a welded material having heat input of 2.49985×10^6 J/m. This solution was selected by design expert as the optimal solution with a desirability value of 97.90%.

DISCUSSION

In this study, the response surface methodology was to optimize the heat input of gas tungsten arc mild steel welds. Thermal conductivity is dependent upon the input process parameters current voltage and gas flow rate. A model was developed using the RSM, Result of Table 3 revealed that the model is of the quadratic type which requires the polynomial analysis order as depicted by a typical response surface design. The interaction of current and voltage has a great effect on thermal conductivity, actually a high current input results in a high thermal conductivity and cooling rate, the welding voltage and gas flow rate has influence on the heat input and cooling time, a high voltage results in a high heat input and cooling time.Analysis of the model standard error was employed to assess the suitability of response surface methodology using the quadratic model to optimize the heat input to a desired range. In assessing the strength of the quadratic model towards minimizing the heat input, one way analysis of variance (ANOVA) was done for each response variable and result is presented in Table 4. To validate the adequacy of the model based on its ability to optimize the heat input to a desired range, the goodness of fit statistics presented in Table 5 was employed. Coefficient of determination (R-Squared) values of 0.8909 as observed in Figure 5 shows the strength of response surface methodology and its ability to minimize the heat input to a desired value. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision values of 9.478 as observed in Table 5indicate an adequate signal. The diagnostic case statistics actually give insight into the model strength and the adequacy of the optimal second order polynomial equation.To asses the accuracy of prediction and established the suitability of response surface methodology using the quadratic model, a reliability plot of the observed and predicted values of each response were obtained as presented in Figures 6.The high coefficient of determination ($r^2 = 0.8909$) were used to established the suitability of response surface methodology in otpimizing the heat input to the desired range. To study the effects of combine variables on each response (heat input), 3D surface plots presented in Figure 8 wasemployed.The 3D surface plot as observed in Figures 8 shows the relationship between the input variables (voltage, current and gas flow rate) and the response variables (heat input). It is a 3 dimensional surface plot which was employed to give a clearer concept of the response surface. As the colour of the curved surface gets darker, heat input decreases proportionately. Finally, numerical optimization was performed to ascertain the desirability of the overall model. In the numerical optimization phase, we ask design expert to minimize the cooling time and thermal conductivity, maximize the cooling rate and optimize the heat input to a desired range while also determining the optimum value of voltage, current and gas flow rate. From the results of Figure 10, it was observed thata current of 120.00 Amp, voltage of 23.79 volt and a gas flow rate of 15.71 L/min will produce a welded material having heat input of 2.49985x106 J/m. This solution was selected by design expert as the optimal solution with a desirability value of 97.90%.

Conclusion

Heat input is a very important factor considered in assessing the quality of welds.The lower the heat input the better the quality of the weld. In this study the Response SurfaceMethodology was employed to optimize and predict the heat inputduring welding of low carbon steel. This study has shown that the voltage and gas flow rate has a very strong influence on the heat input. The models developed possess a variance inflation factor of 1. And P- values < 0.05 indicating that the models are significant, the models also possessed a high goodness of fit with R^2(Coefficient of determination) values of 89% for heat input.Adequacy precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision values of 9.478 was observed. The model produced numerical optimal solution of current 120.00Amp, voltage of 23.79 volt and a gas flow rate of 15.71 L/min, which will produce a welded material having heat input of 2.49985x106 J/m. Therefore, It has been shown that the optimization and prediction of heat input have a significant effect on the quality and integrity of welded joints. Itis, therefore, recommended that welding and fabrication industries should endeavor to use the optimum welding process parameters obtained in this study to produce high quality welds in the Tungsten inert gas welding process for the class of materials considered in this study.

REFERENCES

Babu, P. D., Buvanashekaran, G., &Balasubramanian, K. R. 2012. Experimental Study on the Microstructure and Hardness of Laser Transformation Hardening of Low-alloy Steel. Transactions of the Canadian Society for Mechanical Engineering, 36(3), 241 – 245.

Eagar, T. W., and Tsai, N.S. 1983. Temperature fields produced by traveling distributed heat sources. Welding Journal 62(12): 346-s to 355-s.

Funderburk, R. S. 1999. Key Concept in Welding Engineering. Welding Innovation, XVI(1).

Herring, D.H. 2005: Grain size and its influence on materials properties, Industrial Heating.

Jatinder Gill,Jagdev Singh 2013. "Effect of welding speed and heat input rate On stress concentration factor of butt welded joint of is 2062 e 250 *International Journal of Advanced Engineering Research and Studies* E-ISSN2249–8974

Majumder, A. 2011. Study of the effect of bevel angle and welding heat input on mechanical properties of mild steel weldments. Agartala, Tripura West, Tripura, India, *International Journal of Mechanical and Materials Engineering* (IJMME), 6(2), 280 – 290.

Morris, J.W. 2001. The influence of grain size on the mechanical properties of steel, in: S. Takaki, T. Maki (Eds.), International Symposium on Ultrafine Grained Steels, Iron and Steel Inst., Tokyo, pp. 34-41.

Oliverapopović, radicaprokić-cvetković, 2010. " The effect of heat input on the weld metal toughness ofsurface welded joint, trends in the development of machinery and associated technology"tmt 2010, mediterranean cruise, pp11-18

Oyetunji, A., Kutelu, B. J. and Akinola A. O. 2013. Effects of welding speeds and power inputs on the hardness property of type 304L austenitic stainless steel heat affected zone (HAZ). *Journal of Metallurgical Engineering* (ME), 2(4). www.me-journal, 124 -129.

Rosenthal, D. 1946. The theory of moving sources of heat and its application to metal treatments. Trans. ASME 48: 848–866.

****