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Optimization and Analysis of Tungsten Inert Gas Arc Welding Process Parameter of Mild Steel

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A B S T R A C T

In the arc welding process, the liquid weld pool structure plays a significant role to investigate the mechanical properties of the weld joint. In the present analysis, the investigation was carried out on the 10 mm thick mild steel plate having length 200 mm and width 70 mm. The input process parameter for TIG welding of mild steel plate were modelled for achieving acceptable welds. The process variables such as welding current, voltage and welding speed has been selected as the most effective process parameters. Furthermore the mathematical model has been developed to investigate the optimal set of process parameters for the desire weld pool structure. Also case study has been conducted to validate the developed mathematical model. The optimized set of input process variables were experimentally verified by comparing the measured and predicted optimized target responses.

Keywords:TIG welding; weld width; weld penetration; depth of HAZ; interaction effects

1. Introduction

There is different type of arc welding process such as shielded metal arc (SMAW), gas metal arc (GMAW), flux cored arc (FCAW), gas tungsten arc (GTAW), submerged arc (SAW), electro slag (ESW), electro gas (EGW), plasma arc (PAW), and arc stud welding (ASW). Arc welding process, it is heat-type welding process, is one of the most important manufacturing process for the joining of structural elements for a wide range of applications, including trains, ships, bridges, building structures, automobiles, and nuclear reactors etc. It needs a continuous supply of either direct or alternating electric current, which create an electric arc to generate enough heat GAS TUNGSTEN ARC welding (GTAW) is comes under the category of an arc welding process. In GTAW process, the arc is initiated between the electrode and the work pieces. GTAW process, tungsten electrode is non-consumable during the process. Here the role of electrode is for just complete the circuit to create the arc.Kim et al. [1] proposed a method for determining the near-optimal settings of welding process parameters namely wire feed rate, welding voltage, and welding speed to obtain the desired bead geometry in GMA welding using a CRS algorithm. The search range of each welding parameter was determined based on a previous work and authors' experience. With each welding condition determined through CRS algorithm, the welding was carried out and the front bead height, back-bead width, and penetration were measured. The objective function was formulated based on the desired and measured bead geometry.

Raveendra et al. [2] and Yang et al. [3] employed multiple regression techniques to establish the empirical models for various arc welding processes.

Datta et al. [4] developed a statistical model for predicting bead volume of submerged arc butt welds in mild steel plates. Experiments based on a 33 full factorial design, without replication, were conducted with 3 levels of 3 process parameters namely welding current, welding voltage, and electrode extension. The ANOVA was employed to evaluate quantitatively the significant of the main and interaction effects of 3 process parameters on bead volume. Three empirical models: linear, curvilinear, and a second degree response surface model have been developed. The effects of 3 process parameters were also represented graphically and it is shown that these process parameters are to represent significant effects on bead volume.

Also, Gunaraj et al. [5] developed empirical models using the five-level factorial design for prediction and optimization of weld bead for the SAW process of 6- mm-thick structural steel plates. The second degree response surface models were developed to have relationships between the important control process parameters: welding voltage; wire feed rate; welding speed; and nozzle-to-plate distance; and 5 bead-quality parameters: penetration; reinforcement; bead width; total volume of the weld bead; and dilution. ANOVA analysis was used to check the adequacy of all the empirical models. The main and interaction effects of the process parameters on bead geometry were determined quantitatively and presented graphically.Furthermore, Gunaraj et al. [6] highlighted the use of RSM by designing a central composite rotatable design matrix to develop empirical models for predicting weld bead quality in SAW for pipelines. The experiment was designed based on a four factor five level factorial central composite rotatable design. The second degree response surface models, which relate the important process parameters such as the open-circuit voltage, the wire feed rate, the welding speed and the nozzle-to-plate distance, to the penetration, the reinforcement, the width and the percentage dilution of the bead geometry, were developed. ANOVA analysis was effectively used to test the adequacy of the all the developed models.In this present research work, the input process parameters of TIG has been optimized by using CCD method

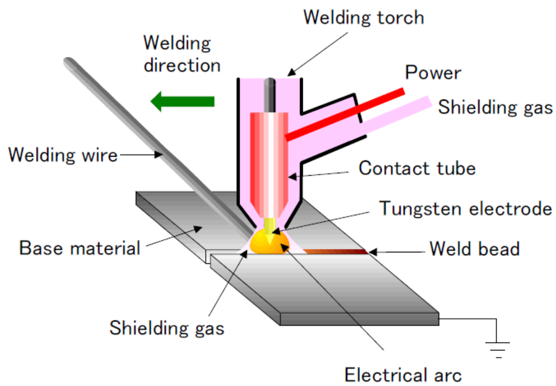

Figure 1 Gas Tungsten Arc Welding

2. Experimental Procedure

Experimental setup of tungsten inert gas welding has arc image magnifying system, work piece base system, setup for speed control, TIG welding machine and LVDT for arc length measurement. The arc image magnifying system is used to calculate and measure the arc length and arc spread during TIG/GMA welding process. The arc image magnifying system contains input and output lens to magnify the welding arc. The input lens captures the arc image and output lens magnify this image to required extent. For the movement of image magnifier in X, Y,Z direction there is provision in setup by which movement of magnifier can be easily controlled in required direction. The speed control unit control the movement of work piece base system by which speed of work piece can be easily controlled.

Four Welding parameters values were used for the experiment of the TIG welding process as shown in Table 1. The argon gas flow rate was not as influential on weld width, welds penetration and so could be set easily. However, the other four parameters had a significant influence on the weld width, penetration and HAZ differed depending on the particular steel plat used and its thickness.

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2.1work piece material

Mild steel has been identified as suitable engineering materials for application in many industries fields such as automotive industries, aerospace industries, defense and nuclear science.

Table 2 Chemical Composition of the mild steel

Elements	C%	Si%	Mn%	P%	S%	Ni%	Cr%	Fe%
Composition	0.15	0.17	0.46	0.18	0.066	0.14	0.014	98.8

2.2 Specimen Preparation

The geometry and dimensions of the test specimens used in present work are shown in Figure 2. Specimen for spot weld process was developed by following steps:

2.3 Pilot experiments to identify the process parameters level and their range

Pilot experiment was conducted in order to determine the appropriate range of input process parameters. The working range is decided by their bead width and penetration of the weld joint and also inspecting the weld joints for a smooth appearance and the absence of any visible defects.

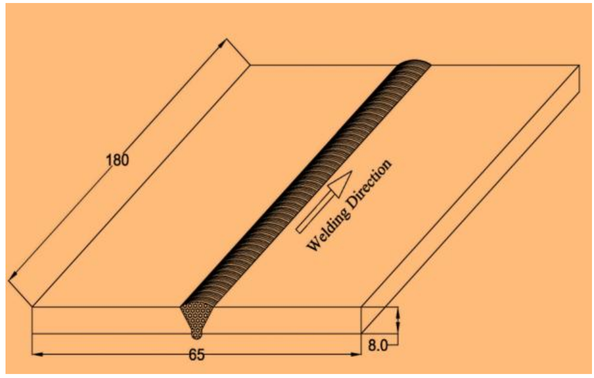

Figure 2 Dimension of the specimen for TIG process [2]

Table 1 Range and level of process parameters

S.N	Parameter	Low	Medium	High
1	Current (I)	50	70	90
2	Voltage (V)	10	10.5	11
3	Travelling speed (m/mm)	14	29	44

3. Results and Discussion

3.1 Statistical Analysis

Statistical techniques it is a combinations of different tool which helps to developed the mathematical relation between the input process parameters and their responses. It also helps design the experiments for defining the range of the independent input variables, empirical mathematical model to explore an appropriate approximating relationship between responses and process variables, and the optimization of the response variables influenced by various process parameters.

3.2 Analysis of Variance

Analysis of variance (ANOVA) method was used to assessment the capability of the developed model. This method is also shown whether the developed model is meaningful or not. In the Table 7 it shown the analysis of variance of input process parameters on penetration of weld joint. In the Table 7, the model value F value is 432.4 it shows the adequacy of the developed model. This model is quadratic model. The mode may be linear and quadratic. It is depends upon the independent variable and dependent variable. In this work, there is quadratic model has been used. Furthermore, in the table 7 the p value is less the 0.05 in all parameters. It is probability value of the model. The square term also consider in the analysis. Welding Current (A)* Welding Current (A), Welding Speed (mm/min)* Welding Speed (mm/min) and Welding Voltage (V)* Welding Voltage (V). This all square terms p value is less than 0.05. The model summary in which the standard deviation S = 0.0223790 has been observed. The coefficient of variance R-sq = 99.74% has been observed during the analysis. The adjustant coefficient square is R-sq (adj) = 99.51% observed and predicted coefficient R square R-sq(pred) = 98.13% has been observed. This above term has higher side values, which also shown the adequacy of the developed model in this analysis.

Table 2 Analysis of variance of the input process parameters on penetration

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1.94825	0.21647	432.24	0.000
Linear	3	1.75749	0.58583	1169.75	0.000
Welding Current (A)	1	0.23104	0.23104	461.33	0.000
Welding Speed(mm/min)	1	1.34689	1.34689	2689.38	0.000
Welding Voltage(V)	1	0.17956	0.17956	358.53	0.000
Square	3	0.08531	0.02844	56.78	0.000
Welding Current (A)*Welding Current (A)	1	0.01178	0.01178	23.53	0.001
Welding Speed(mm/min)*Welding Speed(mm/min)	1	0.00255	0.00255	5.09	0.048
Welding Voltage(V)*Welding Voltage(V)	1	0.00846	0.00846	16.89	0.002
2-Way Interaction	3	0.10545	0.03515	70.19	0.000
Welding Current (A)*Welding Speed(mm/min)	1	0.09245	0.09245	184.60	0.000
Welding Current (A)*Welding Voltage(V)	1	0.01280	0.01280	25.56	0.000
Error	10	0.00501	0.00050		
Lack-of-Fit	5	0.00501	0.00100		
Total	19	1.95325			

Model Summary

S = 0.0223790

R-sq = 99.74%

R-sq (adj) = 99.51%

R-sq (pred) = 98.13%

3.3 Regression Equation of penetration

Penetration (mm) =20.76 + 0.03708 Welding Current (A) - 0.0142 Welding Speed (mm/min) - 4.13 Welding Voltage (V)

+ 0.000164 Welding Current (A) *Welding Current (A) + 0.000135 Welding Speed (mm/min) *Welding Speed (mm/min) + 0.2218 Welding Voltage (V)*Welding Voltage (V) -0.000358 Welding Current (A)*Welding Speed (mm/min) -0.004000 Welding Current (A)*Welding Voltage (V) + 0.00067 Welding Speed (mm/min)*Welding Voltage (V)

Table 3 Analysis of variance of the input process parameters on bead width

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	10.8043	1.20048	149.10	0.000
Linear	3	9.6958	3.23193	401.41	0.000
Welding Current (A)	1	2.0735	2.07353	257.53	0.000
Welding Speed(mm/min)	1	6.9436	6.94356	862.40	0.000
Welding Voltage(V)	1	0.6787	0.67871	84.30	0.000
Square	3	0.6791	0.22636	28.11	0.000
Welding Current (A)*Welding Current (A)	1	0.4385	0.43848	54.46	0.000
Welding Speed(mm/min)*Welding Speed(mm/min)	1	0.0481	0.04813	5.98	0.035
2-Way Interaction	3	0.4294	0.14314	17.78	0.000
Welding Current (A)*Welding Speed(mm/min)	1	0.4088	0.40879	50.77	0.000
Error	10	0.0805	0.00805		
Lack-of-Fit	5	0.0805	0.01610		
Total	19	10.8848			

Model Summary

S = 0.0897299

R-sq = 99.26%

R-sq(adj) = 98.59%

R-sq(pred) = 92.68%

3.4 Regression equation of bead width

Bead width (mm) = 24.3 - 0.0468 Welding Current (A) + 0.0613 Welding Speed (mm/min) - 4.01 Welding Voltage (V) + 0.000998 Welding Current (A) Welding Current (A) -000588 Welding Speed (mm/min)*Welding Speed (mm/min) + 0.235 Welding Voltage (V)*Welding Voltage (V) - 0.000754 Welding Current (A)*Welding Speed (mm/min) - 0.00461 Welding Current (A)*Welding Voltage (V) - 0.00286 Welding Speed (mm/min)*Welding Voltage (V)

Figure 3 shown the Contour plot between the welding voltage and welding current on bead width at the constant value of welding speed 29 mm/min. As increasing the welding current form 50 to 90 A, the value of bead width increases. It is due to the more heat and liquid metal generated. Figure 4 Contour plot between the welding voltage and welding speed on bead width at constant value of welding current 70 A.

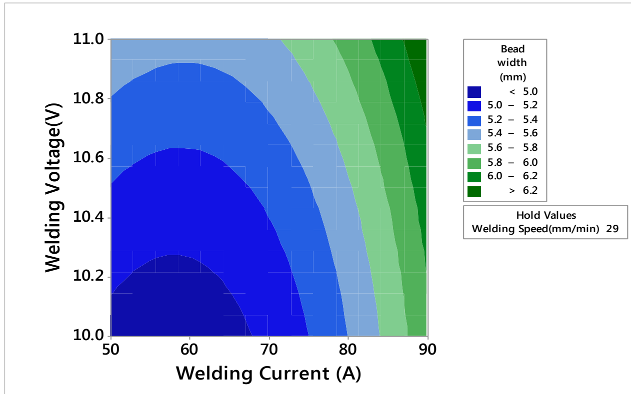

Figure 4 Contour plot between the welding voltage and welding current on bead width

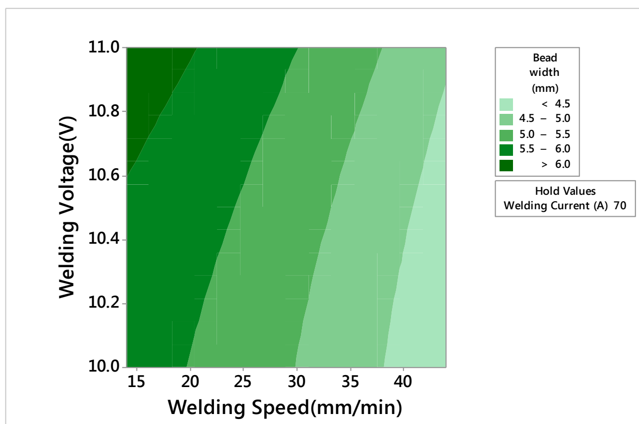

Figure 5 Contour plot between the welding voltage and welding speed on bead width

Figure 6 shown the response surface between the welding speed and welding voltage on bead width. Increasing welding voltage form 10 V to 11 V the bead width is increases. While the increasing the welding speed 10 mm/min to 40 mm/min decreases the bead width. Figure 7 depicts the response plot between the welding current and welding voltage for the bead width. Increasing the welding current value from 50 to 90 A increases the bead width value. Similar trends has been observed from the response plot for welding voltage

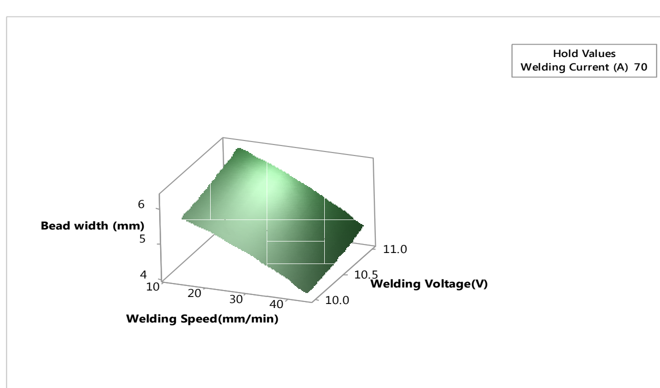

Figure 6 surface plot between the welding current and welding voltage

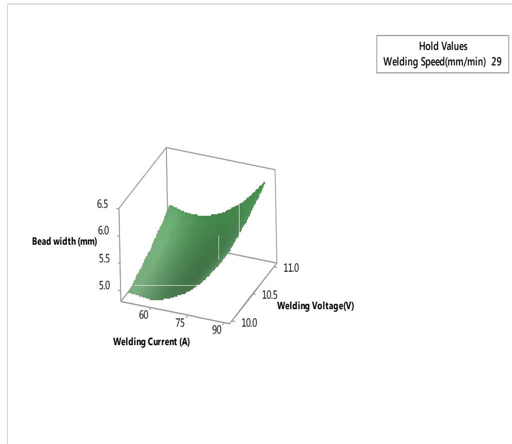

Figure 7 Response plot between the welding current and welding voltage

4. Conclusion

In this study, the effect of input process parameters on bead width and penetration has been investigated. The maximum bead width 7.64 mm has been measure at 11 V under the 90 A welding current and 14 mm/min weld speed. The minimum bead width 4.6 mm has been recorded at 10 V along with 50 A welding current and 44 mm/min weld speed

The developed mathematical model to optimize the input process parameters has been validated by test cases. The developed model has maximum 8.08 % error between the experimental and predicted value.

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