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Predicting Lap-Joint bead geometry in GMA welding process

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ABSTRACT

Purpose: The prediction of the optimal bead geometry is an important aspect in robotic welding process. Therefore, the mathematical models that predict and control the bead geometry require to be developed. This paper focuses on investigation of the development of the simple and accuracy interaction model for prediction of bead geometry for lap joint in robotic Gas Metal Arc (GMA) welding process.

Design/methodology/approach: The sequent experiment based on full factorial design has been conducted with two levels of five process parameters to obtain bead geometry using a GMA welding process. The analysis of variance (ANOVA) has efficiently been used for identifying the significance of main and interaction effects of process parameters. General linear model and regression analysis in SPSS has been employed as a guide to achieve the linear, curvilinear and interaction models. The fitting and the prediction of bead geometry given by these models were also carried out. Graphic results display the effects of process parameter and interaction effects on bead geometry.

Findings: The fitting and the prediction capabilities of interaction models are reliable than the linear and curvilinear models. It was found that welding voltage, arc current, welding speed and 2-way interaction CTWD×welding angle have the large significant effects on bead geometry.

Practical implications: The model should also cover a wide range of material thicknesses and be applicable for all welding position. For the automatic welding system, the data must be available in the form of mathematical equations.

Originality/value: It has been realized that with the use of the developed algorithm, the prediction of optimal bead dimensions becomes much simpler to even a novice user who has no prior knowledge of the robotic GMA welding process and optimization techniques.

Keywords: Bead geometry; ANOVA analysis; Regression analysis; General linear model; Interaction model; GMA welding

TECHNICAL PAPER

1. Introduction

To get the desired weld quality in robotic GMA welding process, it is essential to know interrelationships between process parameters and bead geometry as a welding quality. Many efforts have been done to develop the analytical and numerical models to study these relationships, but it was not an easy task because there were some unknown, nonlinear process parameters [1]. For this reason, it is good for solving this problem by the experimental models. One of the experimental models was a multiple regression technique that was utilized to establish the empirical models for various arc welding processes [2,3]. Datta et al. [4] proposed multiple regression model for predicting bead volume of Submerged Arc Welding (SAW) process. Also, Gunaraj et al. [5-6] developed mathematical models using the five-level factorial technique for prediction and optimization of weld bead for the SAW process.

Recently, some researches have been concentrated on using these traditional models with AI (Artificial Intelligence) techniques to solve the problem [7-9]. Kim et al. [7] developed an intelligent system for GMA welding process based on multiple regression and neural network. Li et al. [8] studied the non-linear relationship between the geometric variables and welding parameters of SAW process using the Self-Adaptive Offset Network (SAON). Tang et al. [9] investigated the relationship between process parameters and the features of the bead geometry for TIG (Tungsten Inert Gas) welding process using a back-propagation neural network. Despite the large numbers of attempts to analyze arc welding process, interaction models to study interrelationships between input and output parameters in the arc welding process are still lacking.

The objectives of this study are to develop the interaction model to apply real-time control for bead geometry in GMA welding process.

2. Experimental procedure

In this study, full factorial design with two levels was employed to develop empirical models. The chosen welding parameters and their values employed in this study are given in Table 1.

Table 1.
Process parameters and values

Parameter	Symbol	Unit	Values
Welding voltage	*V*	Volt	17, 19
Arc current	*I*	Amp	100, 130
Welding speed	*S*	cm/min	4.5, 5.0
CTWD	*C*	mm	12, 20
Welding angle	*A*	o	55, 65

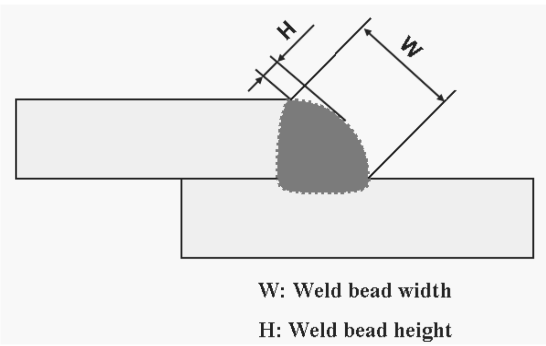


Fig. 1. Diagram for measurement of bead geometry

The base material used for this study was the 150x200x4.5mm SS400 mild steel. The experiment has been carried out using the robot welding facility for data collection and evaluation.

To measure the bead geometry as shown in Fig. 1, the specimen was cut transversely from the middle position using a wire-cutting machine. It was then etched by 3% HNO3 and 97% H20 nital solution to display bead width. A metallurgical microscope interfaced with an image analysis system can be employed to measure the bead geometry.

3. Development of empirical models

3.1. Weld bead width

To maximize adjusted R-Squared with the smallest number of independent variables, multiple regression analysis (with Enter, Remove, Forward, Backward, or Stepwise method) can be employed to determine the best fit model. This can be done if the interaction terms had been created beforehand. However, creating these variables can be tedious when analyzing models that contain a large number of interaction terms. In this study, General Linear Model (GLM) was employed to test interaction terms and the fit of the model. Table 2 is the results of GLM analysis output from this analysis.

The factors of interaction model were chosen based on observed Fisher's values or p values (probability of significant) and adjusted R square from GLM analysis.

Table 2.
ANOVA for the model of weld bead width

Source	DF	F	p	Probability level	
				$\alpha = 0.05$	$\alpha = 0.01$
Intercept	1	85727.397	.000	Sig.	Sig.
V	1	100.163	.000	Sig.	Sig.
I	1	200.848	.000	Sig.	Sig.
S	1	120.875	.000	Sig.	Sig.
C	1	6.352	.019	Sig.	Insig.
A	1	.646	.430	Insig.	Insig.
V * I	1	6.916	.015	Sig.	Insig.
C * A	1	38.105	.000	Sig.	Sig.
Error	24				

$[F_{0.05}(1,24)] = 4.2597$, $[F_{0.01}(1,24)] = 7.823$, DF: Degrees of freedom

According to Table 2, the following interaction model was developed with assumption that it was adequate at the 95% confidence level:

$$W = 9.68021 - 0.17375 \times V - 0.03783 \times I - 0.7525 \times S - \\ - 0.01756 \times C + 0.003 \times VI + 0.000472 \times CA \quad (1)$$

To see the fitting of interaction model, the linear and curvilinear models were also been developed as the follow:

Linear model:

$$W = 3.30521 + 0.17125 \times V + 0.01617 \times I - 0.7525 \times S + \\ + 0.01078 \times C + 0.00275 \times A \quad (2)$$

Curvilinear model:

$$W = 0.37446 \times V^{0.60535} \times I^{0.36761} \times S^{-0.71219} \times \\ \times C^{0.03375} \times A^{0.02864} \quad (3)$$

3.2. Weld bead height

Table 3 is the ANOVA analysis output for the weld bead height. As seen in Table 3, it can be assumed that the following interaction model for the weld bead height was adequate at the 95% and 99% confidence level.

$$H = 5.455622 - 0.056875 \times V + 0.008958 \times I - \\ - 0.895 \times S + 0.000118 \times CA \quad (4)$$

Linear model:

$$H = 5.493542 - 0.056875 \times V + 0.008958 \times I - 0.895 \times S + \\ + 0.006094 \times C - 0.000375 \times A \quad (5)$$

Curvilinear model:

$$H = 36.40916 \times V^{-0.81152} \times I^{0.8209} \times S^{-3.30484} \times \\ \times C^{0.09126} \times A^{0.00268} \quad (6)$$

Table 3.
ANOVA analysis for the model of weld bead height

Source	DF	F	p	Probability level	
				$\alpha = 0.05$	$\alpha = 0.01$
Intercept	1	8805.598	.000	Sig.	Sig.
V	1	16.255	.000	Sig.	Sig.
I	1	90.737	.000	Sig.	Sig.
S	1	251.578	.000	Sig.	Sig.
C	1	2.986	.096	Insig.	Insig.
A	1	.018	.895	Insig.	Insig.
C * A	1	44.166	.000	Sig.	Sig.
Error	25				

$[F_{0.05}(1,25)] = 4.2417$, $[F_{0.01}(1,25)] = 7.770$

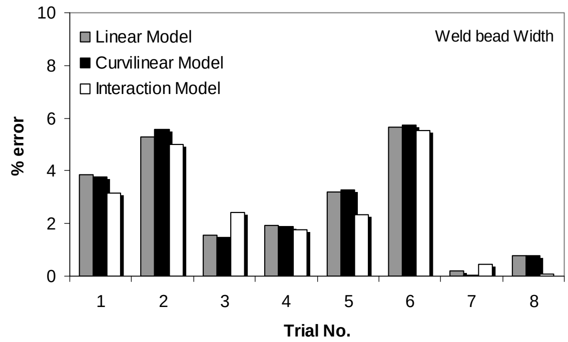
Table 4.
Analysis of variance tests for developed models

Bead geometry	Model	Adj. R Square	F value	P value	Adequate of model
W	Lin.	0.835	32.312	0.000	Adequate
	Cur.	0.841	33.816	0.000	Adequate
	Int.	0.857	31.871	0.000	Adequate
H	Lin.	0.809	27.183	0.000	Adequate
	Cur.	0.803	26.274	0.000	Adequate
	Int.	0.820	36.202	0.000	Adequate

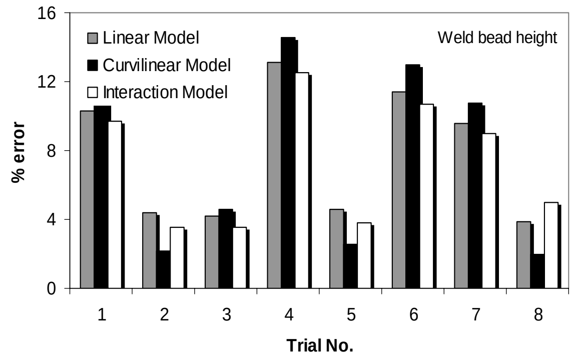
The variance tests for all developed equations are given in Table 4. From Table 4, with highest adjusted R square of 85.7% for weld bead width (W) and 82% for weld bead height (H), it is evidence that the interaction models (Int.) do have a better fitting on the experimental data than the linear (Lin.) and curvilinear models (Cur.). And all the models are adequate since the adjusted R square for the developed equations show agreement of greater than 80%.

4. Results and discussion

To verify the developed models, the additional experiments were performed. The percentage deviation was employed to judge the predictive power of all developed models. The results of this analysis for the bead geometry are presented in Fig. 2. This analysis indicates that the interaction produced better predicting on weld bead geometry than the linear and curvilinear models.



(a) Weld bead width



(b) Weld bead height

Fig. 2. Predictable accuracy of the developed models

Interaction models were employed to show graphically the interaction effects of process parameters on bead geometry within the range studied. The interaction effects of welding voltage and arc current on weld bead width have been shown in Fig. 3. The process parameters such as welding speed at 4.8 cm/min, CTWD of 16mm, welding angle of 60^o are taken as constant. Because the positive effects of welding voltage (arc current), the weld bead width increases as welding voltage (arc current) increase for all values of arc current (welding voltage). As a result from surface plot, observed weld bead width becomes minimum (4.6 mm) when welding voltage is at 17 Volts and arc current is at 100 Amps. For the value of welding voltage (19 Volts), the bead width is maximum (5.43 mm) when the value of arc current is at 130 Amps.

The effects of CTWD and welding angle on weld bead geometry have been shown in Figs. 4-5. From these observed surface plots, the effect between CTWD and welding angle on bead geometry also is significant.

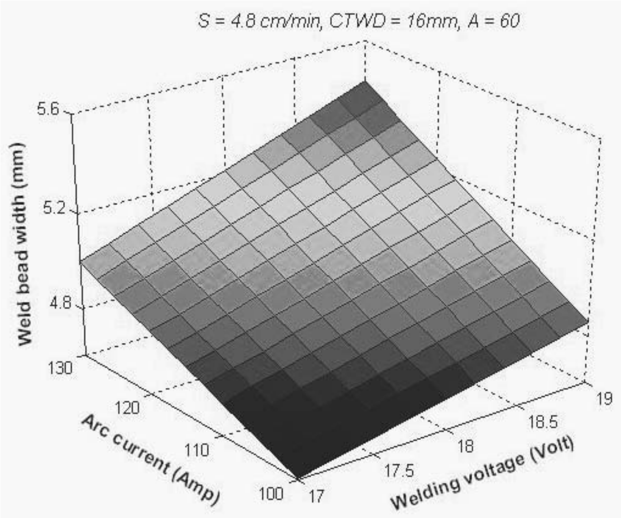


Fig. 3 Effect of welding voltage and arc current on bead width

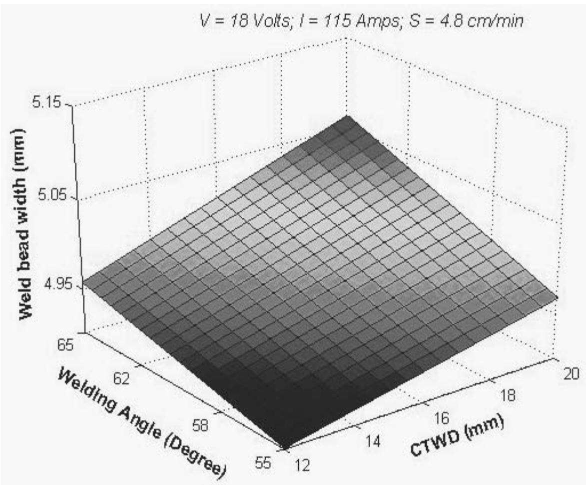


Fig. 4 Effect of CTWD and welding angle on bead width

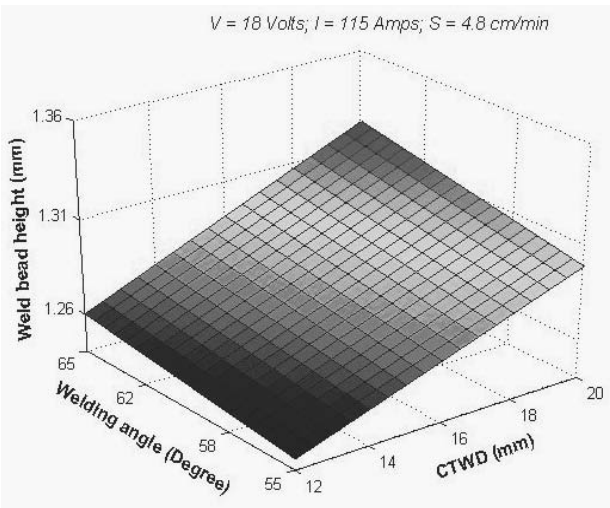


Fig. 5 Effect of CTWD and welding angle on bead height

5. Conclusions

In this study, the interaction models and the effects of process parameters on bead geometry and have been studied using experimental data, and the following conclusions have been reached:

1. The two-level factorial technique can be employed easily to d evelop the empirical models for prediction of bead geometry within the workable boundary.
2. The interaction factors, welding voltage x arc current, CTWD x welding angle, also imposes a significant effect on bead geo metry. With the experimental data of this study, the interactio n models have a more reliable fitting and better predicting tha n that of linear and curvilinear models.
3. SPSS for Windows can be effectively used to perform the Des ign of Experiments (DOE) analysis steps and solve optimizati on problems in GMA welding process.

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