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An experimental study on optimizing for tandem gas metal arc welding process

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ABSTRACT

Purpose: To enhance productivity and provide high quality production material in a GMA welding process, weld quality, productivity and cost reduction affects the number of process variables. In addition, a reliable welding process and conditions must be implemented to reduce weld structure failure.

Design/methodology/approach: The research investigates the interaction between the welding parameters (welding speed, distance between electrodes, and flow rate of shielding gas) and bead geometry for predicting the weld bead geometry (bead width, bead height). Taguchi techniques are applied to bead shape to develop curve equation for predicting the optimized process parameters and quality characteristics by analysing the S/N ratio.

Findings: The experimental results and measured error is within the range of 10% presenting satisfactory accuracy. The curve equation was developed in such a way that you can predict the bead geometry of constructed machinery that can be used for making tandem welding process.

Research limitations/implications: In various industries the welding process mathematical model is not fully formulated for the process parameter and on the welding conditions, therefore only partial variables can be predicted.

Originality/value: This paper focused on the anode-cathode distance that can prevent arc blow in tandem GMA welding process. We also analysed the welding quality characteristics according to the bead geometry and welding parameters through S/N ratio dependent on the welding speed and flow rate variation of shielding gas. Finally, a mathematical model being able to predict the welding quality based on the given welding parameters using statistical method has been developed.

Keywords: GMA welding; Mathematical model; S/N ratio; Taguchi techniques; Tandem welding

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METHODOLOGY OF RESEARCH

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1. Introduction

The welding process is one of the most important techniques for production of electronic component, small product, and heavy structure through whole industry fields. Not only such welding technique has a role of the key technique of industries, but also applies in facilities from job shop outfits to highly-automated computer-controlled factories. Therefore, the welding process has progressed remarkably in the past 30 years as a result of technological innovation aimed at increases in productivity, stabilization of weld quality and labor saving [1-5]. Recently, Automatization and robotization are beginning to be taken as key technologies to secure improved productivity and consistent quality [6-9]. Some novel welding processes such as twins, tandem and laser-MIG hybrid welding are developed for a higher productivity.

One of the advanced welding process which called Tandem welding process that two independent electrodes (early electrode and delayed electrode) are arranged parallel to weld line and that welding is performed by controlling them individually under separate welding conditions (current and voltage) while keeping the distance between the early and delayed electrodes at constant has been developed [10-15]. Unlike single-torch welding process, however, tandem welding process should be considered many welding parameters which affected the welding quality. Until now, a technique that can reduce defects such as undercut, overlap, unbalance leg length, blowhole, and pit by setting these welding parameters according to the work conditions on the experiences of the welding operator is required [16-17]. Nomura [18] has conducted a research using the weld-seam tracking using high speed rotation torch and arc sensor to increase welding speed. Sharma et al. [19] studied the behavior of leading and trailing arcs in twin-wire submerged arc welding with help of transient heat transfer analysis. The model was simulated with different combinations of model parameters with an appropriate heat transfer model. The simulation indicated that the leading arc had a major share in producing penetration whereas the trailing arc was more responsible for melting. Kim [20] has carried out Tandem arc welding with large heat input on the steel for shipbuilding and investigated the material property of weld zone according to the variations of the heat input.

On the contrast, in most of the cases, the maximum melting current of a certain process is fixed for its work piece due to a fixed geometry of the work piece. The welding current could not go over the maximum limit in order to avoid burn through of the base metal. Even though various techniques for the prediction of the optimal welding parameter for welding automation and robotization are have been studied, there are few researches about the mathematical models for Tandem GMA (Gas Metal Arc) welding process which is widely used in the industrial field [21-25].

This paper focused on the anode-cathode distance that can prevent arc blow in tandem GMA welding process. And we analyzed the welding quality characteristics according to the bead geometry and welding parameters through S/N ratio dependent on the welding speed and flow rate variation of shielding gas. Finally, a mathematical model being able to predict the welding quality based on the given welding parameters using statistical method has been developed.

2. Welding experiment

2.1. Experimental method and procedure

For the optimization of tandem GMA welding process for bead geometry as welding quality, two commercial GMA welding machines, a two-electrode torch driving part, CO_2, monitoring system, and interface module were employed. To reduce welding defects, the solid wire (SM-70 wire, 1.2∅) was used as the pre-torch. And the flux cored wire (K-71T wire, 1.2∅) was used as the post-torch because it enables the weld deposited rate to be high. The system of shielding gas was also built using two bombs to supply gas separately to the welding machine. Fig. 1 shows the whole system used in the welding experiment. Fig. 2 shows the schematic diagram for tandem GMA welding process. Welding parameters such as ER70S-G wire, the shielding gas of 100% CO_2, and 18mm CTWD Contact Tip to Work Distance (CTWD) may be relatively fixed in experiment. Since the accurate measurement of welding current and arc voltage is required, the arc voltage and welding current were measured using the monitoring system. The 200x400x16mm SS400 materials were employed for the experiment. For the optimization of tandem GMA welding process on the required bead geometry as welding quality in this study, welding currents and arc voltages for pre-torch and post-torch were selected as the fixed variables. The experimental data that included welding speed, anode-cathode distance, and flux of shielding gas on bead geometry were chosen which based on factorial design techniques. Bead geometry (bead height, bead width) was selected as the output parameters because the welding quality is regarded being accepted when the proper bead geometry is formed through the visual inspection of weldment.

Besides the most affecting primary parameters (welding speed, interval between torches, flux of shielding gas), there are many process parameters. However, the values of other parameters for the more effective and systematic experiment were fixed. Fig. 3 shows the diagram of the measurement of bead shape (bead height, bead width). Thus, there are twelve degree of freedoms which are from three level of welding speed, three level of anode-cathode distance, and two level of flux of shielding gas. As the degree of freedom of the orthogonal array is not fewer than the degree of freedom of three process parameter, Fig. 4 shows the model of welding process containing the input and output parameter of tandem GMA welding process.

Fig 5. represents the setting of the anode-cathode distance condition. The process parameters and their values employed in this study are given in Table 1. Total twelve welding experiments were conducted using the technique of 2k factorial experiment to obtain values of bead width and bead height as welding quality.

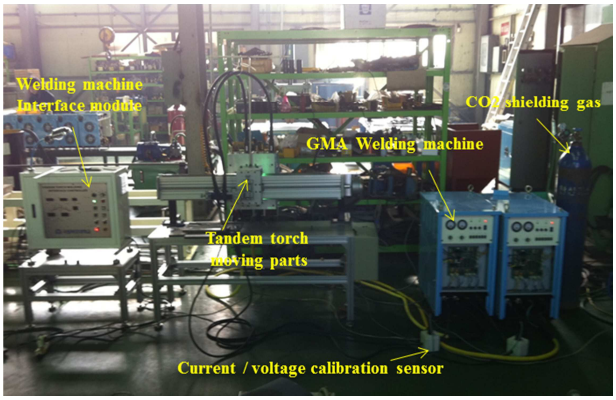

Fig. 1. Tandem GMA welding experimental setup

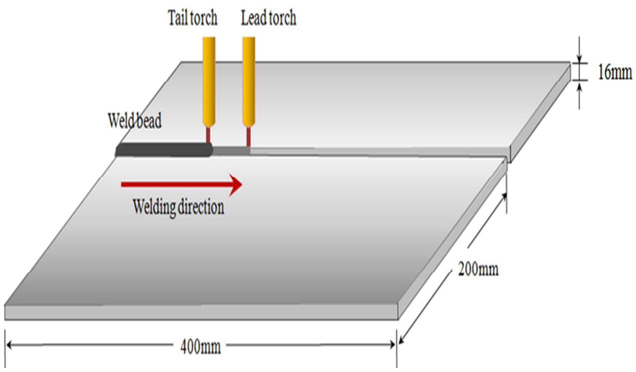

Fig. 2. A schematic diagram for tandem GMA weld process

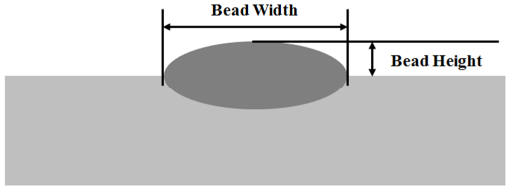

Fig. 3. A schematic diagram of bead geometry

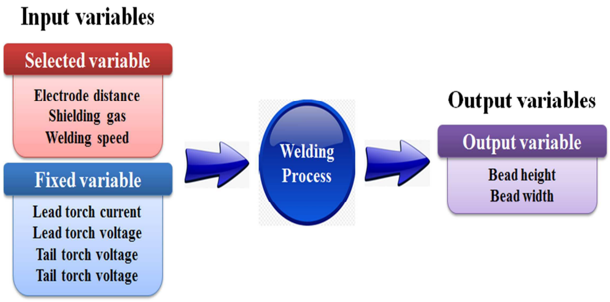

Fig. 4. Input and output variables of the welding process

(a) 25mm

(b) 35mm

(c) 45mm

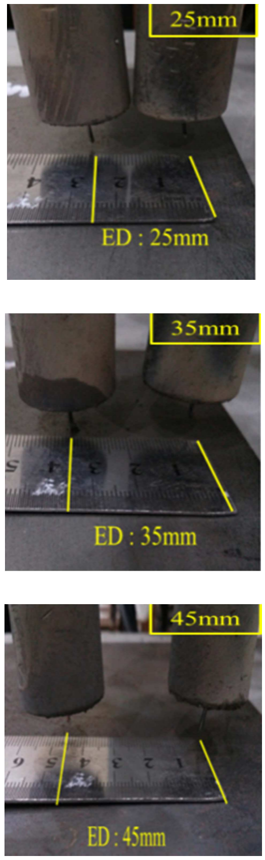

Fig. 5. The setting of inter-electrode torch distances

Table 1.
Process parameters and their levels

Parameter	Unit	Level		
Welding current	Amp.	Lead troch : 270 Tail torch : 324		
Arc voltage	Vol.	Lead torch : 25 Tail torch : 31		
Welding speed	cm/min	40		50
Electrode distance	mm	25	35	45
Shielding gas	l/min	9		18

2.2. Experimental results

The fixed welding current and arc voltage of the pre-torch and post-torch were 270A, 25V and 324A, 31V, respectively. The values of anode-cathode distance were 25 mm, 35 mm, and 45 mm and the values of flux of shielding gas were 40cpm, 50cpm. So, total twelve experiments were conducted, and values of each condition by using the current-voltage measured instrument were observed. The results of experiment showed that the measured bead geometry was stable and no external defects appeared under all welding conditions. According to the variations of welding current and arc voltage obtained from the measured system, variations which can cause the welded joint in the observation of waveforms were not detected. In addition, there were no problems such as molten down in terms of the bead shape so that it is considered to be satisfied from WPS requirements. Also, to identify the effect of the fusion area on the bead geometry according to the anode-cathode distance, the macro was filmed and then the characteristics were analyzed. To measure the bead geometry of weldment, the horizontal middle section of welded specimen was cut into a smaller piece using the laser cutting machine, whose size was 60 x 30mm. The cut edge of that was grinded and then polished. Among the measured bead geometry such as bead width and bead height according to each welding condition were shown in Table 2.

The values of arc voltage and welding current represent the averaged values over whole section, which were measured using the monitoring equipment during the tandem GMA welding process. The results of experiment were employed to study the relationships between process parameter and bead geometry and to develop the mathematical models for optimization of the bead geometry as welding quality.

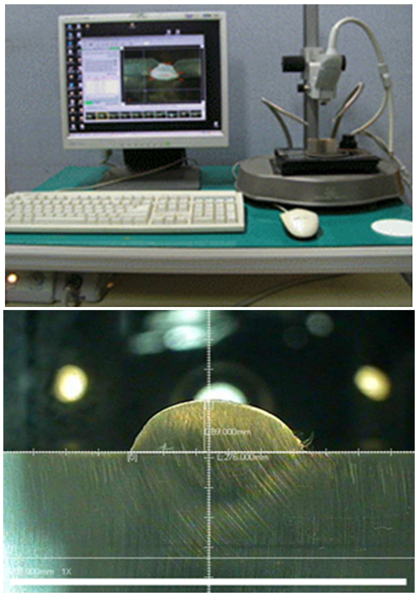

Fig. 6. Measurement of bead geometry

Table 2.
Experimental results of tandem GMA welding

No	Lead torch current 270(A), Lead torch voltage 25(V) Tail torch current 324(A), Tail torch voltage 31(V)				
	Weldin g speed (cm)	Shieldin g gas (l/mm)	Electrod e distance (mm)	Bead width (mm)	Bead height (mm)
1	40	9	25	20.65	2.74
2	40	18	25	18.67	3.43
3	40	9	35	20.55	3.12
4	40	18	35	20.48	3.52
5	40	9	45	20.31	2.48
6	40	18	45	18.29	2.65
7	50	9	25	19.89	4.74
8	50	18	25	19.58	5.37
9	50	9	35	17.37	3.63
10	50	18	35	18.79	6.32
11	50	9	45	18	5.05
12	50	18	45	17.37	5.68

3. Result and discussion

3.1. Analysis using Taguchi Method

By using L_{12} array designed for the welding experiment, experimental results were analyzed. Based on the measured bead geometry, the quality characteristics of bead geometry such as bead width and bead height can be expressed as an S/N ratio equation;

$$n_{ij} = -10 \log y_{ij}^2 \quad (1)$$

Where n_{ij} is the S/N ratio of the $_i$th quality characteristic of the $_j$th experiment and y_{ij} is the experimental value of the $_i$th quality characteristic of $_j$th experiment. S/N rates of each bead geometry acquired from the calculation of data of welding experiment using the equation (1) is shown in Table 3. Figs. 7-8 are graphs showing the S/N ratios of bead geometry. Fig. 9 is the graph showing the selection of the optimal condition for the bead geometry, which was acquired by comparing each mean values of S/N ratio of the experiments.

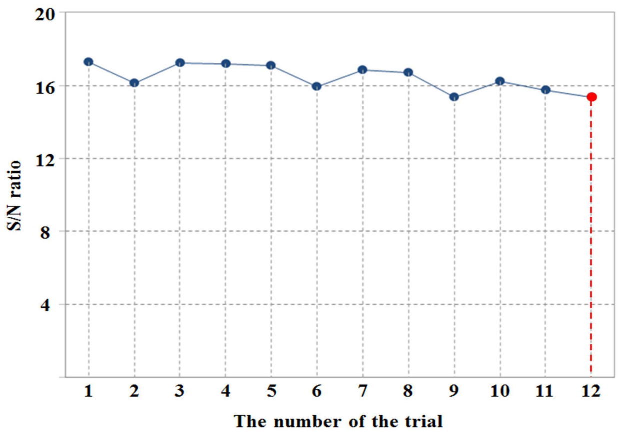

Fig. 7. S/N ratio for the bead width

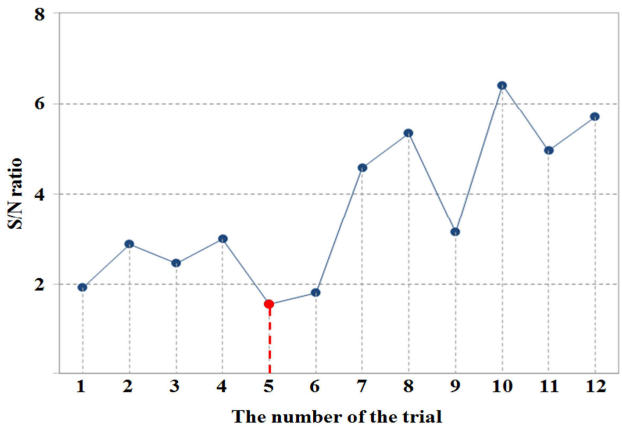

Fig. 8. S/N ratio for the bead height

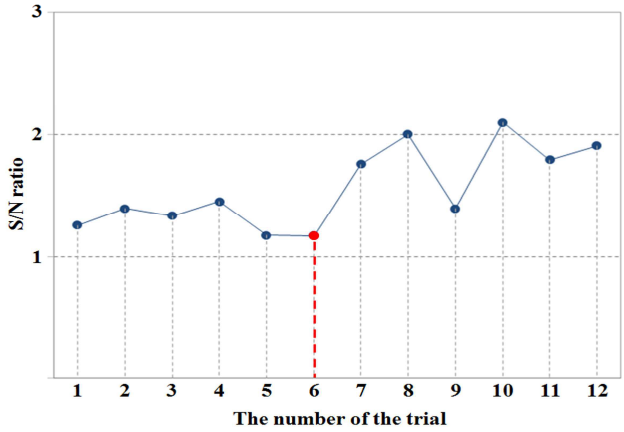

Fig. 9. S/N ratio for the bead geometry

Table 3.
S/N response table for the bead geometry

No. of trial	S/N ratio	
	η_w	η_h
1	-17.291	-1.920
2	-16.159	-2.868
3	-17.237	-2.449
4	-17.198	-2.992
5	-17.103	-1.558
6	-15.932	-1.796
7	-16.867	-4.563
8	-16.687	-5.327
9	-15.370	-3.137
10	-16.229	-6.407
11	-15.757	-4.949
12	-15.370	-5.695

3.2. Correlation between process parameter and bead shape

Since the anode-cathode distance of 25 mm, 35 mm, and 45 mm, the welding speed of 45 cm/min, the flux of shielding gas of 91/min, 121/min, 151/min, and 181/min were chosen, the effects of the welding speed on bead width is shown in Fig. 10. According to Fig. 10, the bead width increases with the decrease of welding speed. The graph of effects of the flux of shielding gas on bead width is presented in Fig. 11. It can be verified that the bead with decreases with the increase of flux of shielding gas. We can know that effects of the welding speed and flux of shielding gas on the bead width decrease by comparing the case of different anode-cathode distances of 25 mm, 35 mm, and 45 mm. The coupled effects of the welding speed on bead width are represented in Fig. 12. It is evident that the anode-cathode distance decreases with the increase of speed of welding. Fig. 13 shows the effect of the flux of shielding gas on bead. It can be seen from Fig. 13 that the anode-cathode distance decreases with the increase of flux of shielding gas. The coupled effects of the welding speed and flux of shielding gas increase with the increase of the bead height by comparing the case of different anode-cathode distances of 25 mm, 35 mm, and 45 mm.

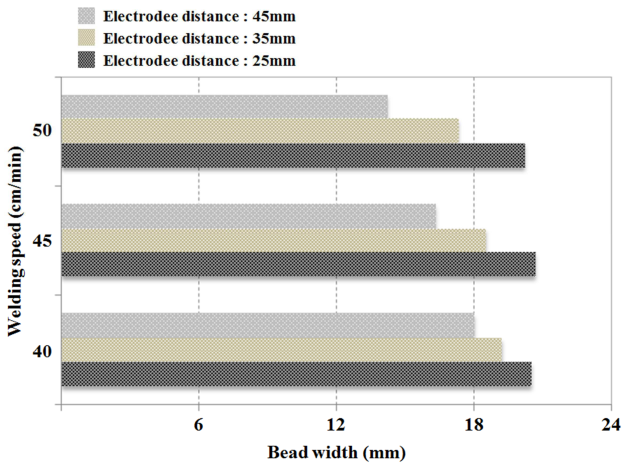

Fig. 10. The effect of welding speed on bead width

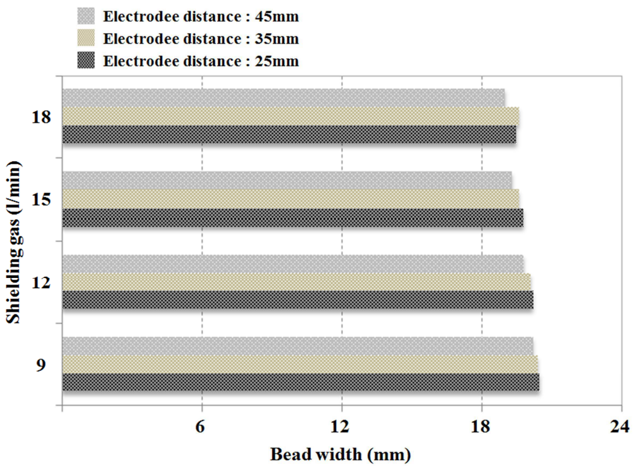

Fig. 11. The effect of shielding gas on bead width

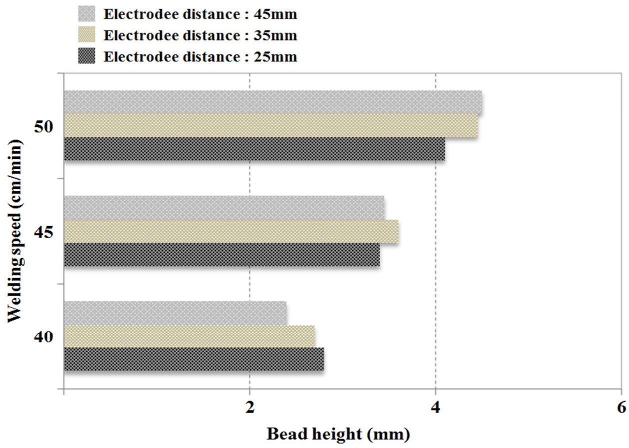

Fig. 12. The effect of welding speed on bead height

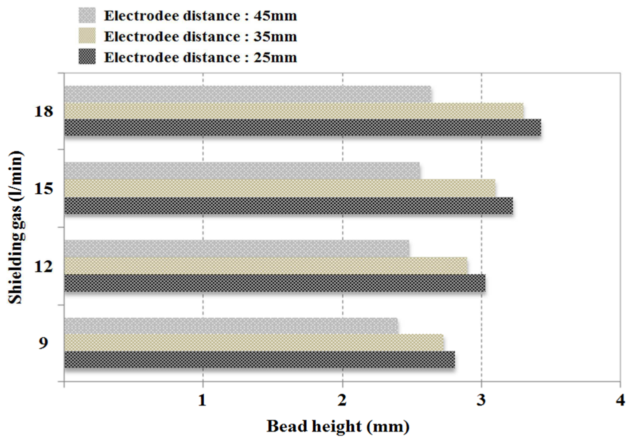

Fig. 13. The effect of shielding gas on bead height

3.3. Development of second order model

The process parameters for the optimization of bead geometry are defined as the welding speed (W_s), distance between torches (E_d), flux of shielding gas (S_g); the output parameters are defined as the bead width (W) and bead height (H); the relationships between the input and output parameter is assumed as the second order model as follows;

$$y_k = \beta_0 + \sum_{i=1}^{2} \beta_i x_i + \sum_{i=1}^{2} \beta_{ii} x_i^2 + \sum_{j=2}^{2} \sum_{i=1}^{2} \beta_{ij} x_i x_j + \varepsilon \qquad (2)$$

Where x_i is the coded unit of input parameter (distance between torches, flux of shielding gas), and y_k is the output parameter (bead height, bead width) representing the quality of welding, and β calculated using data of experiment is the regression coefficient. The value of β is acquired using the method of least squares. From the results of experiment, we could set up the mathematical models as follows;

(1) Bead width(B/W)

$$\begin{aligned} W^{cuv} &= 22.2419 - 0.0642W_s + 0.4753E_d \\ &- 0.7898S_g - 0.0000242W_s^2 - 0.002E_d^2 \\ &+ 0.00042S_g^2 + 0.0169W_sS_g \\ &- 0.0085W_sE_d - 0.001S_gE_d \end{aligned} \tag{3}$$

(2) Bead height(B/H)

$$\begin{aligned} H^{cuv} &= 3.605 - 0.06558W_s - 0.0815E_d \\ &- 0.3013S_g - 0.0000154W_s^2 - 0.0013E_d^2 \\ &+ 0.00015S_g^2 + 0.00996W_sS_g \\ &+ 0.00415W_sE_d - 0.00144S_gE_d \end{aligned} \tag{4}$$

The adequacy of the developed models and significance of coefficients were tested by applying the analysis of variance techniques respectively. Table 4 show the Standard Error of Estimate (SEE), coefficient of multiple correlation (R) and adjusted R^2 for the above mentioned equations. It is noted that value of adjusted R^2 for bead width was 84.5%, while value of adjusted R^2 for bead height was 90.4 %, but all equations are adequate. To verity the developed model, the comparative analyses with experimental values have been carried out using the developed models. These graphs of the measured verse calculated values are presented in Figs. 14~15 for bead geometry(bead width and bead height) respectively.

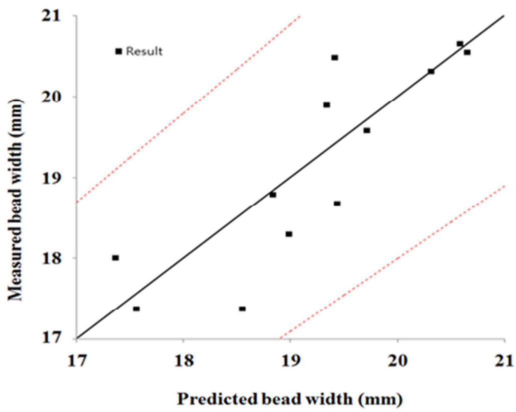

Fig. 14. Relationship between measured and predicted bead width on curvilinear model

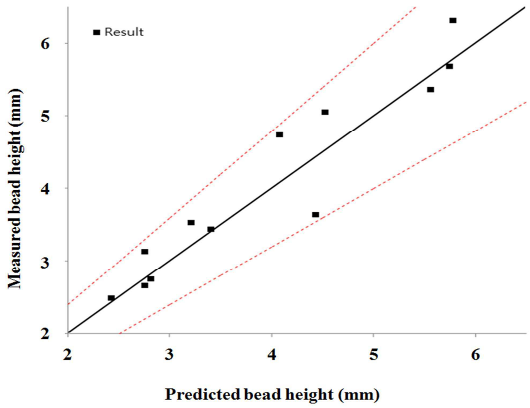

Fig. 15. Relationship between measured and predicted bead height on curvilinear model

Table 4.
Process analysis variance tests for curvilinear model

Bead geometry	Model	SSE	Coefficient of correlation	Adjusted R square (%)
Bead width	Curvilinear	4.290	1.036	84.5
Bead height	Curvilinear	1.804	0.672	90.4

4. Conclusions

To achieve the optimized Tandem GMA welding process, the comparative analysis on the correlation between the process parameter and bead geometry was conducted by analyzing the welding quality characteristics using S/N ratio which based on the Taguchi method.

As a result of analysis of correlation between process parameters (anode-cathod distance, flux of shielding gas, welding speed) and bead geometry (bead width, bead height), the value of S/N in the 6th experimental condition was higher than in any other conditions and the multi-characteristic has also been shown the most excellent.

To predict the optimal process parameters on the bead geometry based on the measured results of the welding experiment, not only the multi-regression analysis has been employed, but also the mathematical models called second-order model was developed using a commercial statistical program. The predictive values of the developed models were distributed in the 10 % of error range. Therefore, it can be concluded that the developed models are able to predict the process parameters required to achieve the desired bead geometry and weld criteria.

The works carried ourt in this paper was nainly aimed at the development of amthematical models for the automated tandem GMA welding system. It is desirable to interface sening system to establish a closed loop control system and to minimize the possible errors from uncontrolled variations

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