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Sensitivity analysis for process parameters in GMA welding processes using a factorial design method

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Abstract

Generally, the quality of a weld joint is strongly influenced by process parameters during the welding process. In order to achieve high quality welds, mathematical models that can predict the bead geometry and shape to accomplish the desired mechanical properties of the weldment should be developed. This paper focuses on the development of mathematical models for the selection of process parameters and the prediction of bead geometry (bead width, bead height and penetration) in robotic GMA (Gas Metal Arc) welding. Factorial design can be employed as a guide for optimization of process parameters. Three factors were incorporated into the factorial model: arc current, welding voltage and welding speed. A sensitivity analysis has been conducted and compared the relative impact of three process parameters on bead geometry in order to verify the measurement errors on the values of the uncertainty in estimated parameters. The results obtained show that developed mathematical models can be applied to estimate the effectiveness of process parameters for a given bead geometry, and a change of process parameters affects the bead width and bead height more strongly than penetration relatively.

1. Introduction

Recently automated and/or robotic welding systems have received a great deal of attention because they are highly suitable not only to increased production rate and quality, but also to decreased cost and time to manufacture for a given product. To get the desired quality welds, it is essential to have complete control over the relevant process parameters in order to obtain the required bead geometry and which is also based on weldability. However, mathematical models need to be developed to make effective use of automated and/or robotic arc welding. Previous work on the relationships between process parameters and bead geometry in the arc welding process can be grouped into two distinct areas; empirical methods based on studies of actual welding situations [1–3] and theoretical studies based on heat flow theory [4–6]. An early attempt at The Welding Institute [2] succeeded in selecting a statistical approach to evaluate the relationships between submerged-arc welding variables and bead geometry. Chandel [7] first applied this technique to a GMA welding process and investigated relationships between process parameters and bead geometry of bead-on-plate welds deposited by a GMA welding process. These results showed that arc current has the greatest influence on bead geometry, and that mathematical models derived from experimental results can be employed to predict bead geometry. Doumanidis et al. [8] have attempted to derive simple dynamic models in their attempt to control bead width, penetration, heat affected zone and cooling rate at the centerline of the weld. Despite the large numbers of attempts to analyze arc welding processes, mathematical models between input and output parameters in the arc welding process are still lacking.

Sensitivity analysis, a method to identify critical parameters and rank them by their order of importance, is

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paramount in model validation where attempts are made to compare the calculated output to the measured data. This type of analysis can study which parameters must be most accurately measured, thus determining the input parameters exerting the most influence upon model outputs. It differs considerably from the usual approach of perturbing a process parameter by a known amount and evaluating the new results. Chuang and Hou [9] developed a sensitivity formulation for a planar frame parameter joint and support locations as design parameters. Also, Son and Kwak [10] established a sensitivity formulation for eigenvalues, including repeated eigenvalues, with respect to the change of boundary conditions. The tangential design velocity component was employed to present the change of boundary conditions. Recently, Lee and Albright [11] proposed sensitivity analysis for laser surface treatment by the differentiation of the analytic solution with respect to the laser beam radius and beam scanning velocity. It is evident that the qualitative and quantitative effectiveness of process parameters can be determined using sensitivity analysis. However, they insisted that it is not accurate as it is simplistic and does not take into account of all the relevant parameters involved in the welding process. Since then, various models have been proposed to improve arc welding models for the prediction of process parameters. Although significant progress has been made, there is still the lack of a mathematical model that can predict bead geometry over a wide range of welding conditions.

In this paper, a methodology for understanding relationships between process parameters and bead geometry, and development of mathematical models for the GMA welding process is presented. The objective of the first part of this study is to find the optimal bead geometry in the GMA welding process. A statistical three-level factorial analysis for optimization of process parameters in bead geometry was performed, and mathematical models using a commercial statistical package SAS were developed. A sensitivity analysis based on the developed empirical equations has been carried out. Finally the sensitivity results have been compared to the experimental results.

2. GMA welding process

The GMA welding process is a welding process which yields coalescence of metals by heating with a welding arc between a continuous filler metal (consumable) electrode and the workpiece. The continuous wire electrode which is drawn from a reel by an automatic wire feeder, and then fed through the contact tip inside the welding torch, is melted by the internal resistive power and heat transferred from the welding arc. Heat is concentrated by the welding arc from the end of the melting electrode to the molten weld pool and by the molten metal that is being transferred to the weld pool.

Table 1
Process parameters and limits

Parameter	Symbol	Unit	Limits
Welding voltage	V	Volt	20, 25, 30
Welding speed	S	mm/min	250, 330, 410
Arc current	I	Amp	180, 260, 360

The chosen factors for this study were welding voltage, welding speed and arc current, and the responses were bead width, bead height and penetration. The 3^3 factorial designs provided the main effect and interaction effects of three parameters at three levels. The process parameters and limits employed in this study are given in Table 1. All other parameters except these parameters under consideration were fixed. Fig. 1 illustrates a model of a process parameter with input and output parameters in GMA welding. The factorial design required 27 weld runs for fitting each equation. The experimental materials for development of the mathematical equations were $200 \times 75 \times 12$ mm mild steel AS 1204 plates adopting the bead-on-plate technique. The selection of the welding electrode wire was based principally upon matching the mechanical properties and physical characteristics of the base metal, weld size, and existing electrode inventory. Steel wire with a diameter of 1.2 mm was employed as the welding consumable. The welding facility at the Intelligent Control Laboratory in Mokpo National University was chosen as the basis for the data collection and evaluation. Experimental test plates were located in the fixture jig by a robot controller and the required weld conditions were input for the particular weld steps in the robot path. With welder and argon shield gas turned on, the robot was initialized and welding was executed.

This continued until the predetermined-factorial-experimental runs were completed. To measure the bead geometry, transverse sections of each weld were cut using a power hacksaw from the mid-length position of the welds, and the end faces were machined. Specimen end faces were polished and etched using a 2.5% nital solution to display bead dimensions. The schematic diagram of bead geometry was employed as shown in Fig.

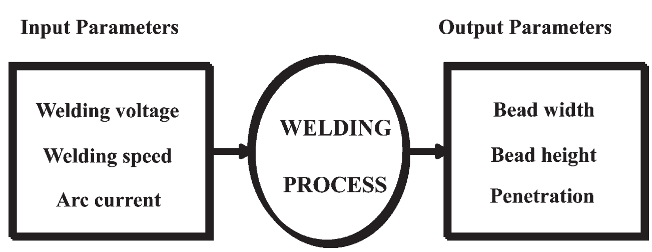

Fig. 1. Input and output parameters of the GMA welding process.