journal of materials processing technology 202 (2008) 500–507

journal homepage: www.elsevier.com/locate/jmatprotec

Sensitivity analysis of submerged arc welding process parameters

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ARTICLE INFO

Article history:
Received 1 May 2007
Received in revised form
28 September 2007
Accepted 10 October 2007

Keywords:
Submerged arc welding
Sensitivity analysis
Weld bead geometry
Mathematical modelling
Regression analysis

ABSTRACT

Selection of process parameters has great influence on the quality of a welded connection. Mathematical modelling can be utilized in the optimization and control procedure of parameters. Rather than the well-known effects of main process parameters, this study focuses on the sensitivity analysis of parameters and fine tuning requirements of the parameters for optimum weld bead geometry. Changeable process parameters such as welding current, welding voltage and welding speed are used as design variables. The objective function is formed using width, height and penetration of the weld bead. Experimental part of the study is based on three level factorial design of three process parameters. In order to investigate the effects of input (process) parameters on output parameters, which determine the weld bead geometry, a mathematical model is constructed by using multiple curvilinear regression analysis. After carrying out a sensitivity analysis using developed empirical equations, relative effects of input parameters on output parameters are obtained. Effects of all three design parameters on the bead width and bead height show that even small changes in these parameters play an important role in the quality of welding operation. The results also reveal that the penetration is almost non-sensitive to the variations in voltage and speed.

1. Introduction

Submerged Arc Welding (SAW) is a high quality welding process with a very high deposition rate. It is commonly used to join thick sections in the flat position. SAW is usually operated either as fully mechanized or automatically processed. However, it can be used semi-automatically as well. During SAW process, operator cannot observe the weld pool and not directly interfere with the welding process. As the automation in the SAW process increases, direct effect of the operator decreases and the precise setting of parameters become much more important than manual welding processes. In order to obtain high quality welds in automated welding processes, selection of optimum parameters should be performed according to engineering facts. Generally, welding parameters are determined by trial and error, based on handbook values, and manufacturers' recommendations. However, this selection may not yield optimal or in the vicinity of optimal welding performance. Furthermore, it may cause additional energy and material consumption resulting in low quality welding. Besides, in the industrial welding robots, even smaller changes in the welding process parameters may cause unexpected welding performance. Therefore, it is important to study stability of welding parameters to achieve high quality welding.

Optimum process parameters selection has been investigated by some significant studies via establishing a

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0924-0136/$ – see front matter
doi:10.1016/j.jmatprotec.2007.10.035

mathematical model correlating welding parameters with quality characteristics using different approaches. In principle, weld bead geometry (weld bead characteristic) is one of the major quality properties mainly due to its influence on energy and electrode consumption. Determination of SAW process parameters to achieve desired weld bead geometry and the prediction of weld bead characteristics, such as bead width, bead height and penetration for the given input parameters, have been accomplished (Tarng et al., 2000; Chandel and Bala, 1988; Gupta and Parmar, 1989; Chan et al., 1994; Gunaraj and Murugan, 1999a, 2000a; Kim et al., 2003; Tarng et al., 2002). Additionally, the area of Heat Affected Zone (HAZ) has also been used as a performance characteristic for parameter optimizations in SAW (Gunaraj and Murugan, 1999b, 2002; Lee et al., 2000).

Predicting the effects of small changes in design parameters provide very important information in engineering design. Therefore, by using a mathematically modeled prediction system, effect of any changes in the parameters on the overall design objective can be determined. This kind of analysis is known as Design Sensitivity Analysis (DSA). Basically, Sensitivity Analysis (SA) yields information about the increment and decrement tendency of design objective function with respect to design parameters. There are few studies performed sensitivity analysis using mathematical model for different welding methods. For example, Kim et al. (2003) conducted a sensitivity analysis in order to compare relative impact of process parameters on bead geometry of Gas Metal Arc (GMA) welding using a mathematical model. They found that width and height of weld bead are more sensitive to changes in process parameters relative to penetration. Gunaraj and Murugan (2000b) carried out a different procedure to optimize bead volume formed by SAW process. They used sensitivity analysis as a post optimization procedure to calculate variations in the objective function due to the small changes from the optimum values of constraints. In addition to these investigations, there is still need for optimization studies in all welding processes, especially for automated welding systems. Because of its simplicity in implementing to all mathematical models and inclusion of cross tendency information between process parameters, sensitivity analysis is a very useful tool.

In this study, mathematical relations (empirical equations) between SAW process parameters and weld bead characteristics (SAW mathematical models) were constructed based upon the experimental data obtained by three parameters-three levels factorial analysis. The empirical equations, simulating the SAW process approximately, were carried out by Multiple Regression Analysis (MRA) and sensitivity equations were derived from these basic models. An analysis generally requires a definition of an objective function and design parameters. In this study, the objective function (quality function) was chosen as weld bead characteristics (the width, height and penetration of the weld bead) whereas process parameters (arc current, voltage and welding speed) were selected as the design variables. The methodology used in this paper for SAW is similar to that used by Kim et al. (2003) for GMA welding. The present study mainly focuses on the determination of sensitivity characteristics of design parameters and the prediction of fine-tuning requirements of these parameters in SAW process. The results revealed considerable information about process parameter tendencies and optimum welding conditions. Similar process parameter behaviors were obtained for GMA welding by Kim et al. (2003). However, our study does not only provide valuable results for SAW like for GMA welding (Kim et al., 2003), but also aims to present a sensitivity characteristic map for SAW process.

2. Mathematical modelling

2.1. *Experimental data*

In the experimental part of this study, welding process parameters, namely, arc current (I), voltage (U) and welding speed (S) were used as input parameters. Bead width (W), bead height (H) and bead penetration (P) (Fig. 1) were measured and used as output parameters. Contact tube-to-work distance was kept constant (25 mm) throughout the experiment. Performed SAW conditions and corresponding weld bead values are presented in Table 1.

The 3^3 factorial designs including main and interactive effects of three parameters with three levels were used for experimentation. Number of welds required to obtain data for mathematical modeling is 27. Bead-on-plate type welds were made by using 3.2 mm diameter wire electrodes. Mild steel plates with dimensions of 180 mm × 80 mm × 10 mm were utilized as the test material. A semi-automatic submerged arc-welding machine with a constant-current power source was employed in this study. After cutting transverse sections of the welds, metallographic samples were prepared using standard methods such as grinding, polishing and etching. Sections of welds were examined using an optical microscope. Magnified photographs were taken and images were processed digitally to measure the weld bead geometry parameters including bead width, bead height and depth of penetration.

2.2. *Construction of the mathematical models of SAW process and statistical evaluation*

Mathematical modeling of SAW process may be constructed using multiple curvilinear regression analysis. In this regard, first, a mathematical form simulating the relation between weld bead characteristics (bead width, bead height and penetration) and process parameters (welding current, welding voltage, welding speed) should be selected. The regression coefficients are calculated based on this selected form by

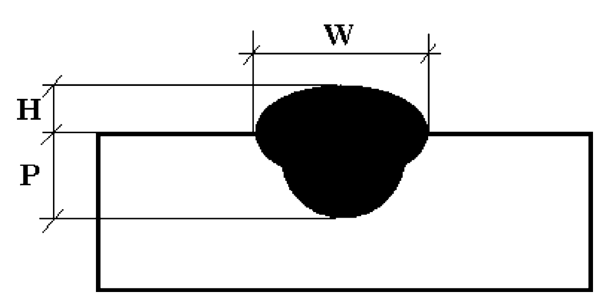

Fig. 1 – A schematic representation of weld bead geometry parameters (*W*: width, *H*: height, *P*: penetration).