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Principal component analysis for multiple quality characteristics optimization of metal inert gas welding aluminum foam plate

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ABSTRACT

Principal component analysis (PCA) coupled with Taguchi methods are employed in the study for multiple quality characteristics optimization of metal inert gas (MIG) arc welding aluminum foam plates. The quality characteristics investigated are the micro-hardness and the bending strength of the weldments. Eight control factors selected are the type of filler material, MIG current, welding speed, MIG gas flow rate, workpiece gap, MIG arcing angle, groove angle, and electrode extension length.

It is shown by the experimental results that the optimal parameter combination of the MIG welding process is A_2 (filler material: Type No. 5356), B_3 (MIG current: 100 A), C_1 (welding speed: 80 mm/min), D (MIG gas flow rate: 13 L/min), E_2 (workpiece gap: 1.7 mm), F_3 (MIG arcing angle: 50°), G_3 (groove angle: 20°), and H_1 (electrode extension length: 15 mm). Moreover, it is ascertained from the analysis of variance (ANOVA) results that B (MIG current), C (welding speed), and E (workpiece gap) are the most important control factors in the process design, and thus strict control must be applied to the three factors. The experimental results likewise show that the optimal process design could indeed improve the multiple quality characteristic values of the MIG-welded aluminum foam plates.

1. Introduction

Metal foams are the relatively new materials which have especially attracted the increasing attention of automotive industries due to their novel physical and mechanical properties, such as extremely low specific density (0.2–1.0 g/cm^3), high specific strength, high rigidity, and high performance in energy absorbance. They are thus suitable for being used as the components and parts of vehicles that require high safety and ride quality. A disadvantage of metal foam is the inhomogeneity due to the stochastic nature of production process, leading to a significant difficulty in joining by welding techniques [1,2].

At present, although research on the welding technology for aluminum foam plate has remained in its infancy, several studies using laser technology have already been conducted. For instance, Haferkamp et al. [3] employed laser machine to weld aluminum foam plate, and found that a large part of the cellular structure inside the aluminum foam may be destroyed due to high temperature, thus making laser welding a difficult process. Klausecker et al. [4] applied both CO_2 laser and Nd:YAG laser to weld aluminum foam sandwich, and found that a great number of pores inside the weld bead were due to the high temperature during the welding. Thus, no quality weldment by laser welding is accessible [5].

Metal inert gas (MIG) arc welding process is a type of arc welding in which the metal electrode is melted, then dripping and solidifying to form welds on the material to be jointed. MIG welding is very applicable to thicker plate materials (thickness $\geqslant$1.6 mm) such as stainless steel, aluminum, and aluminum alloy [6]. The MIG machine has long been used in the welding process because of its small volume size, easy set-up, and low equipment cost.

To achieve maximum efficiency and effectiveness in the technology development process, Taguchi developed procedures that apply orthogonal arrays of statistically designed experiments to efficiently obtain the best model with the fewest possible experiments. So far, the use of the so-called Taguchi method for improving the design and quality of products and processes has become widespread among different industries [7,8].

The traditional Taguchi method focused on one characteristic to optimize a combination of parameter conditions. Successful applications in a wide variety of areas were reported [9,10]. In practice, most products have more than one quality characteristic. The methods of multiple quality characteristics (MQCs) design have become very important for industries because the MQCs are usually correlated. However, traditional Taguchi method seems to be not suitable to optimize the system with the best MQCs. For example, the MQCs of a process/product usually consist of three or more characteristics with different categories and their importance may differ from case to case. When optimizing such a system, the objective is to determine the best design conditions to meet all of the customer requirements. A weighting assigned for

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