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Optimization of friction stir welding parameters for improved corrosion resistance of AA2219 aluminum alloy joints

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Abstract

The aluminium alloy AA2219 (Al–Cu–Mg alloy) is widely used in the fabrication of lightweight structures with high strength-to-weight ratio and good corrosion resistance. Welding is main fabrication method of AA2219 alloy for manufacturing various engineering components. Friction stir welding (FSW) is a recently developed solid state welding process to overcome the problems encountered in fusion welding. This process uses a non-consumable tool to generate frictional heat on the abutting surfaces. The welding parameters, such as tool pin profile, rotational speed, welding speed and axial force, play major role in determining the microstructure and corrosion resistance of welded joint. The main objective of this work is to develop a mathematical model to predict the corrosion resistance of friction stir welded AA2219 aluminium alloy by incorporating FSW process parameters. In this work a central composite design with four factors and five levels has been used to minimize the experimental conditions. Dynamic polarization testing was carried out to determine critical pitting potential in millivolt, which is a criteria for measuring corrosion resistance and the data was used in model. Further the response surface method (RSM) was used to develop the model. The developed mathematical model was optimized using the simulated annealing algorithm optimizing technique to maximize the corrosion resistance of the friction stir welded AA2219 aluminium alloy joints.

Keywords: AA2219 alloy; Friction stir welding; Rotational speed; Welding speed; Axial force; Tool pin profile; Corrosion resistance; Design of experiments; Simulated annealing algorithm

1. Introduction

Friction stir welding (FSW), an innovative solid state welding technique, is finding greater use in defence and aerospace applications [1]. This environment-friendly and energy-efficient technique can be used to join high strength aluminum alloys and other metallic materials that are difficult to be joined using the conventional fusion welding processes. In FSW, a rotating tool is forced down into the joint line under the conditions where the frictional heating is sufficient to cause a local increase in the temperature of the material to the range where it is readily deformed plastically [2]. Despite the evolution of numerous models and investigations, the flow of material is not fully understood [3]. The tool used in FSW has two distinct parts, the shoulder and the pin, and is designed to serve three functions: (i) generate the frictional or deformational heat that softens the work material around and ahead of the pin, (ii) control the material flow to produce a defect-free joint, and (iii) confine the hot material under the shoulder. Understanding the material flow is critical for determining the

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accurate thermo-mechanical processing conditions during FSW. However, the material flow that occurs during the traverse of the rotating tool is reported to be chaotic and poorly understood [4]. Material flow analysis is important in developing a physical understanding of the mechanics of weld formation, which in turn is essential to manipulate the process parameters and produce the defect-free welds. Despite the fact that friction stir welded joints are now employed in a wide range of applications [5–12], many of the factors that control their microstructure and properties are still poorly understood, due to the complex nature of the metal-flow during welding. In addition to the process parameters, the effectiveness of the weld joint is strongly dependent on the geometric features of the tool. For instance, the height and shape of the pin [13–16], together with the shoulder diameter, exercise substantial influence on both the material-flow and heat generation caused by friction as well as rapid plastic deformation [17].

Extensive work on the influence of pin geometry on mechanical properties of 2014 aluminium alloy friction stir welds has been carried out by Zhao et al. [18]. Taper screw thread pin weld was reported to have the highest weld joint efficiency (75%) compared to the threaded cylindrical tool pin profile welds. The tools have all along been designed predominantly by the trial-and-error approach [19]. Most of the previous investigations on the design of tool geometry were focused on optimizing the tool pin profile with respect to microstructure and mechanical properties. However, the study did not provide any clear guidelines for the optimal design of tool geometry. While the effect of different pin profiles has been studied, very little effort has been made to study the influence of tool pin profile on the generation of heat during welding. Several studies concerning the calculation of thermal loading during FSW process are available in literature. Some of these studies [20,21] are based on the critical assumption that the heat generated due to pin-material interaction is very low compared to that generated by the shoulder and hence may be neglected. The influence of tool pin profiles on FSW was hardly discussed in the published literature.

In many industrial applications steels are readily replaced by nonferrous alloys and aluminium alloys. Some of these materials combine mechanical strength comparable with that of structural steels and low weight. While production of aluminium alloy component is not very complex, joining of these materials can sometimes cause serious problems. The friction stir welding, as a solid state joining technique, can be used to settle the problems appearing in joining of these materials, in which the joined material is plasticized by heat generated by friction between the surface of the plate and the contact surface of a special tool. The tool is composed of two main parts: shoulder and pin. The shoulder is responsible for generating the heat and containing the plasticized material in the weld zone, while the pin mixes the material of the components to be welded, thus creating a joint. This allows for producing defect-free welds characterized by good mechanical properties. However, the material flow behaviour is predominantly influenced by the FSW tool profiles, FSW tool dimensions and FSW process parameters [22].

In order to get the maximum corrosion resistance, FSW process parameters should be optimized. Tool pin profile plays a crucial role in material flow and, in turn, regulates the welding parameters of the FSW process [23]. Friction stir welds are characterized by well defined weld nugget and flow contours, almost spherical in shape, and these contours are dependent on the tool design, the welding parameters and the process conditions [24]. Hence, an attempt has been made to optimize the FSW process parameters to maximize the corrosion resistance of AA2219 aluminium alloy joints using the design of experiment concept, the response surface method and the simulated annealing algorithm.

2. Experimental details

2.1. Material and methods

In the present investigation, 240 mm × 160 mm × 7 mm rolled plates of high-strength aluminium–copper alloy AA2219-T87 were used for friction stir welding experiments. The chemical composition of the parent metal is given in Table 1. The plates were welded in a single pass, using the conical, square, triangle, pentagon and Hexagon pin profile tools (Fig. 1) on position controlled friction stir welding machine. Fig. 2 shows the weld beads of FS welds of five tool profiles. Keller's reagent is used for etching the polished surfaces and optical micrographs are recorded.

2.2. Pitting corrosion test

A software based GillAC electrochemical system was used for potentio-dynamic polarization tests to study the pitting corrosion behavior of the metal. A saturated calomel electrode (SCE) and platinum electrodes were used as reference and auxiliary electrodes respectively. All experiments were conducted in aerated 3.5% NaCl solutions with pH adjusted to 10 by adding potassium hydroxide. The potential scan was carried out at 0.166. The exposure area for these experiments was 1 cm^2. The potential at which current increased drastically was considered to be the critical pitting corrosion potential. The specimens exhibiting relatively more positive potential (or less negative potentials) were considered to have better pitting corrosion resistance.

2.3. Design of experiment

It is very difficult to form a mathematical equation for higher corrosion resistance values so for that we consider the ranges of friction stir parameters. The important factors influencing the corrosion properties of FSW joints and the working ranges of those factors for AA2219 aluminium alloy

Table 1
Chemical composition of AA2219 alloy.

Element	Cu	Mn	Zr	Si	Fe	Al
Wt.%	6.7	0.3	0.07	0.10	0.14	Bal