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Microstructural and corrosion behaviours of dissimilar friction stir welded aluminium alloys

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Abstract. In this study, the friction stir welding (FSW) process was employed to investigate the effect of tool geometry on the corrosion behaviour and microstructure of friction stir welded AA7075-7651 and AA1200-H19 using Central Composite Design. The workpieces were machined and welded, and the interfaces were milled. A 2-level full factorial experimental design was deployed using Response Surface Methodology (RSM). A rotational speed of 1500 rpm, welding speed of 30, 60, and 90 mm/min, and a 2° tilt angle of the tool with a plunge force of 7 kN were utilized. The results show that regardless of the tool geometry, multi-response optimum weldment can be achieved at 60 mm/min welding speed and a tilt angle. The microstructure of the optimal weldments presents an 'onion ring' pattern, indicating proper mixing of the alloys during FSW. Analysis of the corrosion behaviour revealed a decrease in the polarization resistance when the transverse speed increased from 30 to 90 mm/min, as polarization resistance has a direct relationship with corrosion rate. It can be concluded that FSW ensures excellent weldment, as evident in the microstructural evolution of the resulting weldments, and that tool geometry plays a significant role in the corrosion inhibition efficiency of the alloys.

Keywords: Friction stir welding / microstructure properties / aluminium alloy / central composite design / corrosion behaviour

1 Introduction

Improved technology for excellent joining of dissimilar metallic materials is in high demand for 21st-century industrial applications [1]. The superior corrosion susceptibility and conductivity of aluminium (Al) and copper (Cu), for instance, make them important in this enterprise. Nevertheless, the thermal properties of these two materials qualify them as difficult-to-weld metals as far as conventional welding processes are concerned. Common conventional welding methods form hard and brittle intermetallic phases at the interface of the joint [2]. This eventually introduces potential failure sites, which undermine the integrity of the welded joint. However, friction stir welding (FSW) helps to address the associated challenges [3]. This welding process produces high-quality welds at optimized energy consumption in the absence of gas or flux; hence, it is a safer and more eco-friendly process. Leal et al. [4] and Mohan and Wu [5] submitted that this improvement could significantly reduce energy consumption for implementation on a large scale. And Singh et al. [6] highlighted fixed, adjustable, and self-retracting as FSW types based on the pieces making the tools. In addition, the challenges encountered during the welding of non-ferrous metals are grave in fusion, causing cracks and porosity as well as emitting poisonous gases, compared to solid-state welding. However, the FSW process is adjudged appropriate for welding aluminium alloys, especially in high-performance industrial applications.

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Numerous metallic ancillary parts are used in the aerospace industry. Aside from their weight contribution, they are liable for crevice corrosion, according to Caio-Palumbo et al. [7]. Therefore, deploying the FSW technique eliminates additional weight tendency and eliminates the poisonous gases associated with conventional welding techniques as a green and sustainable technology. It is important to acknowledge that the functionality of friction stir welded links is contingent upon the selection of process variables. If these factors are chosen incorrectly, it might result in the formation of defective joints [8]. The work published by Pankaj et al. [9] is ranked among several researchers who have successfully joined dissimilar materials using the FSW process. They welded plates of AA7075-T6 alloy and found an initial decrease in tensile strength as welding speed increased up to 75 mm/min. In a comparable investigation, Fereiduni et al. [10] conducted an examination of the friction stir spot-welding process, including the joining of ferrous and non-ferrous alloys. According to their findings, a limited duration of dwell time has the potential to impede the formation of welded joints of superior quality. Sezhian et al. [11] and Yoo et al. [12] conducted research on the microstructure and mechanical attributes of dissimilar non-ferrous joints, employing rotational and travel speeds as operational factors. The researchers observed that an increase in travel or rotation speed leads to the emergence of irregular border shapes. Similarly, it was observed that the occurrence of faults was attributed to the inadequate duration available for material mixing in the region of high traverse speed.

In a separate study, Lienert et al. [13] conducted an investigation into the viability of employing the friction stir welding (FSW) technique for the purpose of connecting mild steel. Additionally, it was discovered that several process parameters, such as traverse speed and force, have a substantial impact on the quality of the welded joints. In a recent study conducted by Hadi et al. [14], a comprehensive analysis was performed using the ABAQUS software to develop a three-dimensional numerical model. The primary objective of this study was to estimate the maximum temperature and the distribution of plastic strain in friction stir welding (FSW) of AA5754 joints. The results of their study indicated that an increase in rotational speed is associated with a concurrent rise in peak temperature, whereas an increase in traverse speed leads to a decrease in peak temperature. This finding is consistent with the previous study conducted by Bhatt and Pillai [15], in which they utilized finite element analysis software to simulate the friction stir welding (FSW) process and acquire temperature profiles and flow stresses. The impact of variations in tool welding speed on the temperature profile and flow stresses during friction stir welding (FSW) of materials with constant tool rotational speed and equivalent tool geometry has been described.

Optimizing these parameters is necessitated by the need to produce non-defective welded joints. Hence, Jambulingam [16] examined AA7075 and AA3014 joined by FSW, optimizing the process speed, feed rate, and axial force. Speed was found to be the major factor influencing the physical properties of the joints. Similarly, Amit et al. [17] utilized RSM to optimize FSW parameters for AA3003 joints, focusing on the UTS of AA3003 joints. These authors achieved improved mechanical properties of AA3003 during the studies. In their study, Wang et al. [18] examined the impact of welding speed on the microstructure as well as the mechanical characteristics of a robotic friction stir welding (FSW) process. The researchers aimed to identify the optimal parameters for this process and also investigated the heat inputs associated with various parameter mixtures. Additionally, they explored the correlation between grain size in the stirred zone and the welding parameters. They concluded, like earlier researchers, that real-time tool force responds proportionately to an increase in welding speeds in a stable welding stage and also observed that the grains in the nugget zone became refined recrystallization grains from the initial elongated rolling type. Wang et al. [8] therefore concluded that the strain rate and deformation temperature of welded materials determine the overall grain size.

Therefore, this study is significant as it develops a FSW process to examine the effect of tool geometry on the evolving microstructure and corrosion behaviour of friction stir welded dissimilar Al alloys (AA7075-7651 and AA1200-H19) by utilizing CCD for high-performance applications. This, as far as the authors can tell, is a set of parameters scarcely reported in the literature, at least not in recent decades. The results, therefore, will spur on researchers and other stakeholders who might, hitherto, be sceptical or unaware of the reported possibilities.

2 Materials and methods

2.1 Materials

The primary materials utilized in this study consist of AA7075 and AA1200. The specimens were acquired from Bharat Aerospace Alloys, located in Gulalwadi, Mumbai, India, with the postal code 400:004. Additional materials utilized in the experiment encompassed 320-grit silicon carbide (SiC) paper, acetone, and stir-welding equipment obtained from ETA Technology PVT LTD, namely model WS004, originating from India. Some other examples of equipment used in this field include the electrical discharge machine (ED350/200SP; USA), the backing plate and clamping system (ETA Technology PVT LTD; India), and FSW tools (V3 Instruments; India). The workpieces utilized as basis materials for the welding process were machined to the necessary dimensions by the utilization of a band saw, after which they were subjected to the welding procedure. As a result, the interface underwent a milling process that resulted in an arrangement where, when positioned adjacent to each other, the visibility through the interface is obstructed.

2.2 Experimental design

The study's experimental approach was conducted using Minitab 17 software, employing Response Surface Methodology (RSM) through the use of Central Composite Design (CCD). The study utilized both a tapered tool (TT) and a tapered threaded tool (TTT). The Central Composite Design (CCD) was chosen over Box-Behnken's Design (BBD) due to its inclusion of a 2-level full factorial