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Magnesium and Aluminium alloys dissimilar joining by Friction Stir Welding

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Abstract

Multi-material lightweight structures are gaining a great deal of attention in several industries, in particular where a trade-off between reduced weight, improved performances, and cost compression is required. Magnesium alloys, such as the zinc-rare earth elements ZE41A alloy, fulfill the first two requirements; however, they are susceptible to corrosion and relatively expensive. Lightweight structures hybridization, for instance combining Magnesium alloys and Aluminium alloys, is currently under consideration as a potential solution to this problem. Nevertheless, dissimilar joining of Magnesium and Aluminium alloys is challenging due to the significant differences in physical properties, as well as to the precipitation of brittle intermetallic compounds, such as $Al_{12}Mg_{17}$ and Al_3Mg_2. In this study, the dissimilar joining of Magnesium and Aluminium alloys by friction stir welding process is discussed. In particular, 4 mm thick plates of ZE41A Mg alloy and AA2024-T3 Al alloy were welded in the butt joint configuration. The feasibility of the process was assessed by means of microstructure and mechanical analysis. The formation of brittle intermetallic compounds was investigated as well.

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Keywords: Friction stir welding; dissimilar joining; Magnesium alloys; Aluminium alloys; intermetallic compounds.

1. Introduction

Magnesium and Aluminum are two of the lightest structural metals and their alloys are finding increasing applications in industries mainly for their high strength to weight ratio. More specifically Aluminium alloys are widely used in many industrial fields because of their low density, good corrosion resistance, good workability, high

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thermal and electrical conductivity [1, 2]. As extremely light alloys, Magnesium alloys have good castability, hot formability and recyclability [3-5]. Combining Al and Mg alloys in one hybrid structure would make possible the use of these alloys for even more applications which will result in desirable weight saving. Due to the large amount of potential applications of Al/Mg hybrid structures, the joining of these dissimilar materials is an important issue. For this aim several conventional welding techniques such as gas tungsten arc welding [6], electron beam welding [7], and laser beam welding [8] have been adopted. All of these conventional fusion welding techniques used to join Al to Mg alloys however frequently have some defects such as liquation induced cracking and porosity, developed as a consequence of entrapped hydrogen inside of the weld bead during solidification [9]. Furthermore the resulting formation of various types of intermetallic compounds (IMC) in the weld zone undermines the weld integrity. For these reasons many alternative welding practices have been studied and developed in order to obtain defect free joining of light alloys. These include solid state welding techniques such as diffusion bonding [10, 11], ultrasonic welding [12], resistance spot welding [13], linear friction welding [14], and friction stir welding (FSW). FSW is a solid-state welding technique that may provide a feasible process to join dissimilar Al to Mg alloys [15, 16]. Since FSW takes place below the melting temperature of the alloy several defects due to the solidification of the metals are avoided [17, 18]. Despite these advantages the literature indicates the formation of brittle intermetallic compounds at the Al-Mg dissimilar weld interface, which results in weakening of the joint with negligible ductility [19]. Indeed according to the Al-Mg phase diagram, when Al and Mg are heated up together, Al_3Mg_2 and $Al_{12}Mg_{17}$ intermetallic compounds may form. Upon further heating, the eutectic reaction $Mg+Al_{12}Mg_{17}\rightarrow L$ occurs at the eutectic temperature 437 °C and the eutectic reaction $Al+Al_3Mg_2\rightarrow L$ at the eutectic temperature 450 °C. This liquid formation is called constitutional liquation [20]. The eutectic temperatures 437 and 450 °C are about 200 °C below the melting points of Al and Mg, and they can be reached easily during FSW to form liquid films along the interface, and hence, lead to cracking.

Due to the aforementioned reasons the joining of dissimilar Al/Mg alloys clearly poses a unique set of challenges and the FSW process between these selected alloys is expected to produce a weld bead with a very complex metallurgy. In literature, to the authors' best knowledge, there are very few papers dealing with the dissimilar FSW between Magnesium and Aluminium alloys and no article can be found in the bibliography on the dissimilar joining between AA2024-T3 Al-alloy and ZE41A Mg-alloy. AA2024-T3 is a very common high strength Alluminium alloy extensively used in the aircraft and defence areas because of its light strength to weight ratio and good corrosion properties, while ZE41A is a popular Mg-Zn-RE alloy that exhibits a moderate strength, creep resistance and many other advantages related to rare earth (RE) elements addition, such as purifying alloy melt, modifying castability, refining the microstructure, improving the mechanical properties and anti-oxidation properties. ZE41A Mg alloy is used for components such as aircraft gearbox and generator housings, particularly in military helicopters, which are exposed to corrosive environments during service [21].

This paper studies the dissimilar joining by FSW between ZE41A Mg alloy and the high-strength Aluminium alloy AA2024-T3. The aims of this paper are to assess the feasibility of the FSW process to provide sound joints and to study the microstructure and the metallurgy of the joint.

2. Materials and methods

AA2024-T3 and ZE41A 4 mm thick sheets were used as base material. AA2024-T3 was supplied as rolled sheets. ZE41A was manufactured by cast gravity process and supplied in form of strips by a foundry of the FINMECCANICA industrial group. The plate edges were deburred to prevent any prior inhomogeneities. ZE41A sheet was fixed in the advancing side of the butt joint in order to lower the welding heat input and to reduce as minimum as possible the brittle IMCs formation [15, 22].

Friction stir welding was carried out offsetting the tool of 1 mm towards the magnesium side using a machining center (MCX 600 ECO). The adopted high speed steel tool, consists of a shoulder with 20 mm in diameter with a conical unthreaded pin (height 3.80 mm, major diameter 6.20 mm, and cone angle 30 deg). A scheme of the experimental welding configuration is provided in Fig. 1.a. The following FSW processing parameters were adopted: rotating speed ranging from 1000 to 1400 rpm; feed rate ranging from 20 to 80 mm/min; tilt angle 2 deg; shoulder plunge depth 0.48 mm. The processing parameters reported in Fig. 1.b were chosen on the basis of the available literature and taking into account a previous investigation by some of the authors [22, 23].