MECHANICAL ENGINEERING | SHORT COMMUNICATION

Corrosion behavior of friction stir welded AZ31B Mg alloy - Al6063 alloy joint

B. Ratna Sunil*1 and G. Pradeep Kumar Reddy2

Abstract: In the present work, AZ31B Mg alloy and Al6063 alloy rolled sheets were successfully joined by friction stir welding. Microstructural studies revealed a sound joint with good mechanical mixing of both the alloys at the nugget zone. Corrosion performance of the joint was assessed by immersing in 3.5% NaCl solution for different intervals of time and the corrosion rate was calculated. The joint has undergone severe corrosion attack compared with both the base materials (AZ31B and Al6063 alloys). The predominant corrosion mechanism behind the high corrosion rate of the joint was found to be high galvanic corrosion. From the results, it can be suggested that the severe corrosion of dissimilar Mg-Al joints must be considered as a valid input while designing structures intended to work in corroding environment.

Subjects: Corrosion-Materials Science; Mechanical Engineering; Metals & Alloys

Keywords: FSW; Mg alloys; Al alloys; dissimilar weld joints; corrosion

1. Introduction

Recently, friction stir welding (FSW), a solid state joining technique has gained wide popularity as a promising method to join similar and dissimilar metals without melting the base materials (Bergmann, Petzoldt, Schürer, & Schneider, 2013; Mishra & Ma, 2005). Joining of light metals such as magnesium (Mg) alloys and aluminium (Al) alloys by conventional welding techniques is complex due to their high reactive nature and the difference in solidification behavior of each base material (Messler, 2014). FSW has shown its potential as a promising welding technique to join Mg and Al alloys as reported in the literature. Formation of intermetallics was observed in the weld joint of AZ31B–AA5083 (McLean, Powell, Brown, & Linton, 2003; Sato et al., 2010). Very recently, Shen, Li, Zhang, Peng, and Wang (2015) demonstrated joining of AZ31B/Al6061 alloys by FSW and reported that the strength of the dissimilar weld joints was reduced. Gerlich, Su, and North (2005) have done

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PUBLIC INTEREST STATEMENT

Welding of dissimilar non-ferrous metals is complex by liquid state methods. Recently, FSW, a solid state joining method has been developed to join similar and dissimilar metals. FSW is gaining wide popularity in the welding industry as a promising method to address many issues which are associated with the liquid state joining methods. The corrosion mechanisms of the weld joint are different compared with the base metals when two dissimilar metals are joined and exposed to corroding environment. In the present study, magnesium and aluminium alloy sheets were successfully joined by FSW and the corrosion behavior of the weld joint was investigated by immersing the weld joints in a corroding solution.
spot welding of AZ91 and Al6111 alloy sheets by friction stir spot welding (FSSW) and distribution of α-Mg and Mg17Al12 as eutectic mixture was noticed in the joint. AA 2024-T3/AZ31B-H24 (Cao & Jahazi, 2010), AZ31B-Al6061-T6 (Fu et al., 2015; Masoudian, Tahaei, Shakiba, Sharifianjazi, & Mohandesi, 2014) and AZ31B-Al6022 (Rao, Yuan, & Badarinarayan, 2015) are the other combinations of Mg and Al alloys which have been successfully joined by FSW. However in the literature, information on the corrosion behavior of Mg-Al dissimilar joint is insufficient. Since Mg is highly reactive metal compared with Al, understanding the corrosion behavior of Mg-Al joint is crucial particularly if the weld structure is intended to work in a corroding environment. Therefore, in the present study, AZ31B and Al6063 alloy sheets were joined by FSW and the corrosion behavior of the joint was assessed by immersion studies.

2. Experimental details
AZ31B Mg alloy sheets (2.75% Al, 0.91% Zn, 0.01% Mn and remaining being Mg) were obtained from Exclusive Magnesium, Hyderabad, India; and Al6063 alloy sheets (0.5% Mg, 0.3% Si and remaining being Al) were purchased from Metro Aluminium, Vijayawada, India. FSW was carried out by using a non consumable FSW tool made of H13 tool steel. The tool has a shoulder diameter of 15 mm and a tapered pin with 3–1 mm diameter over 3 mm length. FSW was done using an automated universal milling machine (Bharat Fritz Werner Ltd., India). The work pieces (3 × 50 × 100 mm³) were fixed on the work table of the milling machine as shown in Figure 1 and the rotating FSW tool was inserted into the joint and plunged along the joint. Initial trial experiments were conducted to optimize the process parameters and defect free joint was successfully obtained at 1,100 tool rotational speed with 15 mm/min tool travel speed. Specimens were cut at different regions of the joint using a CNC wire cut electric discharge machine (EDM, Electronica Machine Tools, India). The specimens were then metallographically polished and etched with picric acid reagent. Microstructural observations were carried out using a polarized optical microscope (Leica, Germany). Specimens of size 10 × 10 × 3 mm³ were cut from both the base materials (AZ31B and Al6063 alloys) and from the centre of the weld joint. Weight of the specimens was measured by using a simple electronic balance. Corrosion studies were carried out by immersing the specimens in 3.5% NaCl solution. After 12, 24 and 36 h, the specimens were collected, dried and respective weights were measured. Experiments were conducted in triplicates (n = 3). The corrosion rate of the samples was calculated as per the ASTM standard G31-72 as given below (ASTM Standard G31-72, 2004).

\[
Cr \text{ (mm/year)} = k \times \frac{\Delta W}{(A \times T \times D)}
\]

where \(k = 8.76 \times 10^4\), \(T = \text{time of exposure in hours}\), \(A = \text{surface area of the specimen in cm}^2\), \(\Delta W = \text{weight loss in g}\), \(D = \text{density in g/cm}^3\).
3. Results and discussion
Joining of Mg-Al alloys is a complex task in welding as they exhibit different heat conducting properties. If the heat dissipation through the base materials is not uniform, then residual stresses develop hot cracks as observed in the present study at 1,400 rpm tool rotation and 25 mm/min tool travel speed. However, by optimizing the process parameters, the amount of heat generation was altered in both the base materials and sound joint was achieved. Microstructural observations show that the joint formation between AZ31B and Al6063 sheets was mainly due to the mechanical mixing or interlocking of the material at the stir zone as shown in Figure 2(b) and (c) which is similar to what reported by Venkateswaran and Reynolds (2012). Additionally, fine grain structure can be seen in the nugget zone (Figure 2(d) and (e)) which is a general characteristic of FSWed joint.

Figure 3 shows typical photographs of the specimens after different intervals of immersion in 3.5% NaCl solution. The weld joint has undergone sever corrosion compared with both the base materials. As the immersion time was increased from 12 to 24 h and further 36 h, more amount of AZ31B alloy was degraded from the joint specimen due to the corrosion and the remaining material of the
specimen was identified as Al6063 alloy (Figure 3(i)). The corrosion rates of the samples calculated from the weight loss measurements are shown in Figure 4. The corrosion rate of the weld joint was found to be higher compared with the corrosion rate of AZ31B and Al6063 base materials. Galvanic corrosion is believed to be the prime mechanism behind rapid corrosion of the weld joint (Donatus et al., 2015; Liu, Chen, Bhole, Cao, & Jahazi, 2009). It is true that the galvanic interactions between Mg and other metals are a serious issue in corrosion of Mg (Pardo et al., 2008) when Mg is in contact with a metal of different electrode potential. In the present study, standard electrode potential of Mg is different compared with Al (Mg −2.36 V and Al −1.66 V vs. standard hydrogen) and therefore galvanic corrosion was initiated. Also, a decreasing trend in corrosion rate was observed for all the samples as immersion time was increased from 12 to 36 h. This may be due to the oxide film formed on the sample surfaces which partially protected the substrates from the corrosion when the immersion time was increased to 36 h (Bland, King, Birbilis, & Scully, 2015; Phillips & Kish, 2013; Taheri, Phillips, Kish, & Botton, 2012). However, this oxide layer is porous and cannot provide complete protection against the corroding environment and therefore further corrosion is inevitable.

In the present study, Al alloy acted as a cathode and Mg alloy acted as an anode and in the presence of 3.5% NaCl solution, the corrosion of AZ31B was accelerated and therefore the joint was severely degraded. It has also been suggested that within the nugget zone, formation of intermetallic compounds accelerate the corrosion of α-Mg (Song & Atrens, 1999). However, in the present study, predominant reason behind higher corrosion rate of the weld joint can be claimed to the mixing of both the AZ31B and Al6063 alloys which led to raise the galvanic intensities and resulted rapid corrosion. Therefore, in developing light weight structures, joining dissimilar metals such as Mg and Al alloys may address certain issues but it is suggested based on the present study, a careful consideration of working environment is crucial. If the targeted application of the weld structure is in corroding environment, the structure may experience a sudden failure due to the rapid corrosion. Hence, from the preliminary results, it is strongly suggested to consider the galvanic corrosion effect while designing structures with weld joints of dissimilar metals.

4. Conclusions
Joining of AZ31B and Al6063 alloys was successfully done by FSW. Weld joint was found to be formed due to the mechanical interlocking of the material. Corrosion behavior of the joint was observed as higher compared with the base materials from the immersion studies. Galvanic corrosion was found to be the main mechanism behind higher corrosion rates of the weld joint. Hence from the present study, it is strongly suggested that Mg-Al joints are not suitable for applications where corrosion is suspected.
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