



# Electrochemical corrosion behaviour of stir zone of friction stir welded dissimilar joints of AA6061 aluminium–AZ31B magnesium alloys



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**Abstract:** Joining of dissimilar metals will offer many advantages in transportation sectors such as fuel consumption, weight reduction and emission reduction. However, joining of aluminium (Al) alloys with magnesium (Mg) alloys by fusion welding process is very complicated. Friction stir welding (FSW) is a feasible method to join these two dissimilar alloys. Mixing these two metals together in stir zone (SZ) leads to poor corrosion resistance. In this investigation, an attempt has been made to understand the corrosion resistance of SZ of FSWed dissimilar joints of AA6061 Al alloy and AZ31B Mg alloy. Potentiodynamic polarization test was conducted by varying chloride ion concentration, pH value of the NaCl solution and exposure time. The corroded surfaces were analyzed using optical microscopy, scanning electron microscopy and XRD techniques. Of these three factors investigated, exposure time is found to be the most significant factor to influence the corrosion behaviour of SZ of friction stir welded dissimilar joints of Al/Mg alloys.

**Key words:** friction stir welding; aluminium alloy; magnesium alloy; dissimilar joint; corrosion behaviour

## 1 Introduction

In recent times, much attention has been shifted towards dissimilar joints, especially in automotive industries; aluminium (Al)/magnesium (Mg) dissimilar joints are to be used in automobiles to reduce the mass of the vehicles. But joining of these alloys by fusion welding techniques is very difficult task due to differences in crystal structures [1]. The formation of intermetallic compounds is also a major problem in dissimilar joints, which leads to extremely brittle joints [2]. In order to reduce volume fraction of the intermetallic compounds, low heat processes are required. Under these circumstances, friction stir welding (FSW) and variants of FSW process can be used to join the dissimilar alloys [3–5]. FSW joints exhibit different zones like stir zone (SZ), thermomechanically affected zone (TMAZ) and heat affected zone (HAZ). Due to the presence of inhomogeneous structure across the welded cross-section of FSW joint, it is necessary to study the corrosion behaviour of the FSW joint. ALIREZA et al [6] reported that the intercalated microstructure could be observed in the stir zone due to mixing of two metals

during welding. This complex flow pattern present in the stir zone creates galvanic coupling due to differences in potential between the two metals. Therefore, it is more vital to study the corrosion behaviour of stir zone of the dissimilar FSW joints.

LIU et al [7] studied the galvanic corrosion behaviour of dissimilar friction stir welded joint made of AZ31 magnesium alloy and AA2024 aluminum alloy. They reported that the predominant locations of the corrosion attack were observed in the narrow regions of Mg alloy adjacent to Al alloy areas, where there was a low ratio of anode-to-cathode surface area. The corrosion was mainly due to the establishment of a strong galvanic couple between Al and Mg alloys in the dissimilar FSWed joints. ESTHER et al [8] studied the influence of friction stir welding process parameters on dissimilar joints between Al alloy and pure copper alloy. They revealed that corrosion resistance of the welds was improved as the rotational speed was increased. DONATUS et al [9] investigated the corrosion susceptibility of dissimilar friction stir welds of AA5083-O and AA6082-T6 alloys. They revealed that the faster welding speed resulted in increased susceptibility to corrosion because of the reduced tool

rotational rate per weld length for generating heat and mixing of materials. In addition, they reported that, grain boundary sensitization in the HAZ of both alloys, distribution of  $Mg_2Si$  particles along the boundary between the two alloys and the galvanic contacts between the AA5083-rich zones and the AA6082-rich zones were responsible for the corrosion susceptibility in the welds.

From the literature review, it is understood that the published information on the effect of corrosion test parameters (chloride ion concentration, pH of the solution and exposure time) on corrosion behaviour of friction stir welded aluminium and magnesium dissimilar joints is very scant. Hence, the present investigation was carried out to study the effect of pH, chloride ion concentration and exposure time on corrosion resistance of stir zone of friction stir welded dissimilar joints of AA6061 Al and AZ31B Mg alloys.

## 2 Experimental

Rolled plates of AZ31B Mg alloy and AA6061-T6 Al alloy plates with 6 mm in thickness were used as base materials in this study. The chemical compositions of these alloys are presented in Table 1. To fabricate FSW joint, the plates were sliced to the required size (150 mm × 75 mm) by power hacksaw. A square butt joint was obtained by securing the plates in position using mechanical clamps. The welding direction was normal to the rolling direction of the plates. Figure 1(a) shows the positioning of the plates during welding, where AA6061 Al alloy was placed on the advancing side and AZ31B Mg alloy on retreating side. Taper threaded cylindrical tool made of super high speed steel (Fig. 1(b)) was used to fabricate the joints.

**Table 1** Chemical composition of AA6061 Al and AZ31B Mg alloys (mass fraction, %)

| Alloy  | Al   | Zn  | Si  | Mn  | Cu   | Cr  | Mg   |
|--------|------|-----|-----|-----|------|-----|------|
| AA6061 | Bal. | –   | 0.6 | –   | 0.25 | 0.2 | 1.0  |
| AZ31B  | 3.0  | 1.0 | 0.1 | 0.6 | 0.04 | –   | Bal. |

A computer numerical controlled (CNC) friction stir welding machine (22 kW, 4000 r/min, 60 kN) was used to fabricate the joints. From Ref. [10], the optimized welding parameters and tool dimensions were taken to

fabricate the joints. The specimens were extracted from weld nugget region of the FSW joints for conducting potentiodynamic polarization test with the dimensions of 20 mm × 20 mm × 6 mm. The scheme of extraction of corrosion test samples is shown in Fig. 1(c). Before corrosion test, the specimens were ground and polished with 600- to 1500-grit SiC paper. Finally, it was cleaned with acetone and rinsed in distilled water and then dried by warm flowing air. The photograph of the polished corrosion test specimen is shown in Fig. 1(d). The sample placed in a corrosion test cell is shown in Fig. 1(e). The Gill-AC potentiostat instrument was used to conduct the potentiodynamic polarization test in NaCl solution under different conditions as shown in Fig. 1(f).

A central composite rotatable three-factor, five-level factorial design matrix was chosen to minimize number of experimental conditions.

The experimental design matrix consisting of 20 sets of coded conditions, comprising a full replication three-factor factorial design of eight points, six star points, and six center points was used. Table 2 presents the range of factors considered and the lower and upper limits of the parameters were coded as −1.68 and +1.68, respectively. NaCl solutions with concentrations of 0.2, 0.36, 0.6, 0.84 and 1 mol/L were prepared. The pH value of the solution was measured using a digital pH meter and varied from 3 to 11 as prescribed by design matrix.

The microstructural examination in the stir zone was carried out before and after corrosion test using a light optical microscope. Corroded surfaces were analyzed by scanning electron microscope (SEM). XRD analysis was carried out to characterize the corrosion products formed on the surface of the specimen. The optical micrographs of parent metals and stir zone of dissimilar friction stir welded joint are shown in Fig. 2.

## 3 Development of empirical relationship

### 3.1 Corrosion rate evaluation

The polarization tests were carried out in corrosion cell containing 500 mL of NaCl solution. The electrochemical cell consists of stir zone as the working electrode, saturated calomel as reference electrode and platinum as counter electrode. The specimens were exposed in the NaCl solution, and a polarization scan was carried out towards more noble values at a rate of 1 mV/s.

**Table 2** Important factors and their levels

| Series No. | Factor                     | Notation | Unit  | Level |      |     |      |       |
|------------|----------------------------|----------|-------|-------|------|-----|------|-------|
|            |                            |          |       | −1.68 | −1   | 0   | +1   | +1.68 |
| 1          | Chloride ion concentration | <i>c</i> | mol/L | 0.2   | 0.36 | 0.6 | 0.84 | 1     |
| 2          | pH value                   | <i>P</i> |       | 3     | 4.62 | 7   | 9.38 | 11    |
| 3          | Exposure time              | <i>t</i> | min   | 5     | 15   | 30  | 45   | 55    |

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