Influence of Aluminium Alloy Grade on Dissimilar Friction Stir Welding of Aluminium to AZ31B

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Abstract

There is increasing research interest in joining lightweight metals, such as aluminium to magnesium, for potential applications in the transportation sector. The friction stir welding (FSW) technique may inhibit grain coarsening and the evolution of intermetallic compounds (IMCs) that evolve when using conventional fusion welding methods to join such dissimilar metals. The current investigation reports on the effect of using two different aluminium alloys on the joint quality in the FSW of Al to Mg grades (AZ31B). Aluminium grades AA5083 and AA6061 were separately welded to AZ31B at different tool rotational speeds (ω) and traverse speeds (v). The optimal process parameters for achieving defect-free joints were identified by examining the joints macro and microstructure, as well as assessing the presence and distribution of IMCs using energy dispersive spectroscopy and X-ray diffraction techniques. Additionally, the hardness distribution of different weld zones allowed for the joint mechanical strength to be predicted.

Dissimilar FSW of Al to AZ31B was influenced by the aluminium grade, in that the highest joint mechanical strength was achieved when AZ31B was FSWed to the harder aluminium grade (AA6061). Placing the AZ31B on the advancing side (AS) with no tool offset, 1000 rpm tool rotational speed and 100 mm/min traverse speed, delivered defect-free joints. Additionally, several IMCs such as Al_3Mg_2 and $Al_{12}Mg_{17}$ were identified at the weld nugget of the dissimilar joints, the presence of which resulted in higher hardness values at the weld nugget compared to the parent metals.

Keywords: friction stir welding, intermetallic compounds, joint integrity, dissimilar joining

1. Introduction

It is seen as important for a range of engineering applications to replace - where possible - aluminium alloys by suitable magnesium alloys, since the latter offer cost and weight reduction benefits compare to the former, while maintaining similar electrical and thermal properties. The formation of relatively larger brittle in nature intermetallic compounds (IMCs) and coarse grains in the weldment zone are the commonly reported drawbacks that limit traditional fusion welding of aluminium to magnesium alloys. Additionally, the reflectivity of aluminium and magnesium alloys further hinders the use of diverse fusion welding processes, e.g., electron beam welding (EBW), laser beam welding (LBW), and gas tungsten arc welding (GTAW). The FSW technique, based on its widely known capability to join a wide spectrum of hard to weld alloys, has recently been expanded to the dissimilar joining of aluminium to magnesium alloys, in an attempt to overcome the limitations of conventional fusion welding processes. This work investigates the effect of using two different aluminium alloys on the joint quality during FSW of Al to Mg grades. It also reports on the combined impact of the joint microstructure and IMC formation on the joint mechanical strength.

2. Experimental methodology

2.1. Experimental setup: A fully instrumented HT-JM16X8/2 static gantry FSW machine was used to butt weld 150 x 50 x 3 mm^3 plates of AA5083 to AZ31B and AA6061 to AZ31B, resulting in an overall welded plate width of 100 mm. This is a configuration which allowed for sub-sized tensile specimens to be manufactured. The FSW tool used in this work was made from high strength tool steel of hardness 50-70 HRC, with a featureless shoulder diameter (Ds) of 18 mm, a featureless pin diameter (Dp) of 4.5 mm, and a pin length of 2.7 mm.

2.2. Materials and FSW process details: The chemical composition and mechanical properties of aluminium alloys grade (AA5083, and AA6061), and magnesium alloy type AZ31B were established prior to FSW. Throughout this work, it has been found that positioning the softer material on the AS eliminates the additional complexity of offsetting the tool to either side of the FSW process, a condition which has been widely recommended to achieve defect-free joints. Following the herein proposed joint configuration of placing the softer material on the AS, FSW experiments were designed to investigate the impact of tool rotational speed and tool welding speed (ω/v ratio) on the dissimilar joints' mechanical integrity, employing a range of 800-1200 rpm tool rotational speeds and 80-120 mm/min welding speeds.

2.3. Microstructural characterisation and mechanical testing: Metallographic samples were prepared post-FSW using standard metallographic techniques in accordance with ASTM E407-09. A two-stage etching process was implemented to allow high resolution optical and scanning electron microscopy (SEM) to be undertaken. Energy dispersive spectroscopy (EDS) was used to analyse the composition of different weld zones. Further, X-ray diffraction (XRD) analysis was carried out to confirm the presence of IMCs as reported by the EDS elemental analysis. Subsequently, Vickers microhardness measurements were recorded to evaluate the dissimilar FSW butt joints and elucidate the relationship between IMC formation and joint mechanical strength. Finally, the developed joint mechanical strength was measured by testing sub-size specimens extracted transversely to each weld in accordance with ASTM-E8, with a minimum of three samples per weld.

3. Results and discussion

3.1. Weld appearance and macro/microstructure: The weld quality was analysed to identify the process parameters that resulted in defect-free joints. Typical top surface weld appearance and cross-sectional macrostructures of AA5083 to AZ31B and AA6061 to AZ31B dissimilar FSW joints at different welding conditions have both been considered to track the volumetric defects formation. The weld joint microstructure was analysed with the aid of high-resolution optical microscopy to establish the presence of possible weld defect such as micro-voids and cracks. It was found that AA5083 to AZ31B defect-free joints were obtained at the relatively low rotation speeds of 800 and 1000 rpm. Moreover, it was demonstrated that the aluminium alloy grade influences the dissimilar FSW of aluminium to AZ31B, since AA6061 to AZ31B defect-free joints were consistently obtained at the relatively high rotational speed of 1200 rpm.

3.2. Aluminium/magnesium interfacial zone: The influence of aluminium grade was also confirmed by analysing the Al/Mg interfacial zone. The higher heat input required to FSWed AA6061 to AZ31B resulted in a composite-like structure at the interface. On the other hand, lamella structures were found to dominant the AA5083 to AZ31B interfacial zone. According to the EDS results, the elemental distribution along the interface was also found to be susceptible to the welding conditions as well as the aluminium grade.

3.3. Intermetallic compound phases: XRD analysis across the dissimilar joints showed that several IMCs, such as Al_3Mg_2 and $Al_{12}Mg_{17}$, had formed at the weld nugget. It was found that the IMC intensity peaks, hence the quantity of these IMCs at the weld nugget, vary with the aluminium grade.

3.4. Dissimilar aluminium to AZ31B joint mechanical strength: Vickers microhardness measurements exhibited that the formation of the - brittle in nature - IMCs significantly increased the nugget zone hardness. Additionally, the high hardness values at the thermo-mechanical zone (TMAZ) were attributed to the material's recrystallisation originating from the severe plastic deformation in this region. Finally, AA5083 to AZ31B and AA6061 to AZ31B defect-free joints were also evaluated by assessing the yield strength, ultimate tensile strength (UTS), and joint efficiency relative to the parent metal. In this work, up to 91% joint mechanical efficiency was achieved by placing the softer material (AZ31B) on the AS.

4. Conclusions

- Defect-free joints of two aluminium alloys (AA5083 and AA6061) to AZ31B have been achieved by placing the softer material (AZ31B) on the advancing side, without implementing any tool offset.
- The aluminium alloy grade was found to influence the dissimilar FSW of aluminium to AZ31B, hence AA6061 to AZ31B defect-free joints required higher heat input.
- The joint mechanical strength significantly improved by the composite-like structure at the nugget zone; as a result, a joint mechanical efficiency of 91% of the AZ31B magnesium alloy was achieved.