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AZ31B/7075-T6 alloys friction stir lap welding with a zinc interlayer

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ABSTRACT

Pure zinc foil was selected as an interlayer to improve the strength of the AZ31B Mg/7075-T6 Al dissimilar alloys friction stir lap welding joint. Compared with the conventional lap joint, the joint with the zinc interlayer has a higher effective sheet thickness, a larger effective lap width and a wider stir zone. The dispersed Mg-Zn intermetallic compounds are achieved instead of the continuous Mg-Al intermetallic compounds, improving the tensile shear load. The maximum fracture load of the joint with the zinc interlayer reaches 6.6 K N at the rotating velocity of 1000 rpm.

1. Introduction

Friction stir welding (FSW), a new solid state joining process, has the advantage to join Al alloys (Li et al., 2018), Mg alloys (Li et al., 2014), and their dissimilar alloys (Mohammadi et al., 2015a,b) due to low heat input and high joint quality (Huang et al., 2017). The joining of Mg/Al dissimilar alloys can meet the demand of high-performance structures in transportation, aerospace and other industries. FSW of Mg/Al dissimilar alloys has become a research hot-spot. Venkateswaran and Reynolds (2012) joined 6063 Al and AZ31B Mg alloys via FSW and found that the butt joint strength was influenced by the interface length and the intermetallic compounds (IMCs) layer thickness. Similar to friction stir butt welding, friction stir lap welding (FSLW) of Mg/Al dissimilar alloys has a great scientific research value. The research contents of Mg/Al alloys dissimilar FSLW mainly consist of joint formations, microstructures and mechanical properties. Ji et al. (2016) reported that the hook defect existed at both the advancing side (AS) and retreating side (RS) of 6061 Al/AZ31 Mg alloys dissimilar FSLW joint, and the crack initiated at the hook tip during tensile shear test. Chen and Nakata (2008) joined 6061 Al and AZ31 Mg alloys and found that $Al_{12}Mg_{17}$ and Al_3Mg_2 IMCs were observed at the Mg/Al interface of the FSLW joint. Rao et al. (2016) studied the effect of process parameters on tensile shear behavior of 6022-T4 Al and AM60B Mg alloys FSLW joint and pointed out that the highest quasi-static failure load of 3.3 K N was achieved at 1500 rpm and 50 mm/min or 75 mm/min.

Besides the hook (Meng et al., 2017) defect, the hard and brittle IMC is the key factor that greatly affects the mechanical properties of Mg/Al dissimilar FSLW joint. The binary phase diagram of Mg and Al indicates that the eutectic reactions of Mg and Al occur at the eutectic temperatures of 450 °C and 437 °C which are lower than the peak welding temperature during FSW process, resulting in the formation of the brittles Mg-Al IMCs (Chen and Nakata, 2008). The Mg/Al IMCs layer in the stir zone (SZ) leads to a severe reduction of butt or lap joint strength. Mohammadi et al. (2015b) reported that the formation of the IMCs in the Mg/Al FSLW joint resulted in the high microhardness in the SZ and the cracks originated from the IMCs during tensile shear test. There are two main methods to overcome the negative effects caused by the Mg-Al IMCs. One is to change the morphology and distribution of the IMCs in the joint, the other is to reduce or avoid the formation of the brittle Mg/Al IMCs. Ji et al. (2017) stated that ultrasonic vibration was propitious to improving the mixing degree of Mg/Al alloys and breaking partial IMCs into pieces or particles, thereby increasing the joint strength. Zhao et al. (2016) indicated that the amount of the IMCs in the SZ was reduced via underwater FSW and the corresponding tensile strength of the joint (152 MPa) was higher than that of the joint welded in air. Other metal elements that react with Mg and Al can be added into the interface between Mg and Al alloys to reduce or eliminate the formation of the Mg-Al IMCs, producing the relatively favorable eutectic structures. Chang et al. (2011) studied the hybrid laser-friction stir welding of 6061-T6 Al and AZ31 Mg alloys and found that the addition of a Ni foil increased the FSW joint strength from 95 MPa to 115 MPa. Gan and Jin (2017) reported that friction stir-induced diffusion bonding of Al and Mg alloys with a zinc foil was realized only by atomic diffusion. The zinc foil acting as a barrier layer restrained the

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Table 1
Chemical compositions of 7075-T6 and AZ31B alloys (mass. %).

Material	Cu	Fe	Si	Mg	Mn	Zn	Cr	Ni	Al
7075-T6	1.64	0.24	0.42	2.49	0.3	5.72	0.21	–	Bal.
AZ31B	0.0015	0.0027	0.12	Bal.	0.48	0.88	–	0.0005	3.1

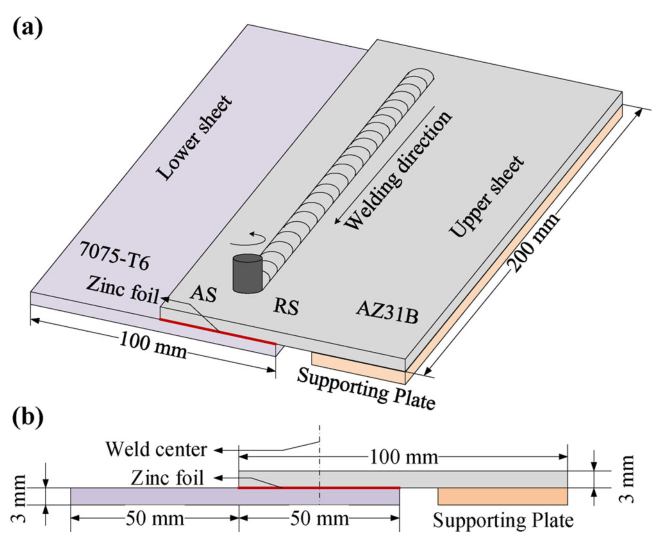

Fig. 1. Schematics of FSLW process with the zinc interlayer: (a) welding process; (b) joint configuration.

reaction between Al and Mg atoms, forming the Al-Mg-Zn and Mg-Zn eutectic structures instead of Mg-Al IMCs.

The granular, dispersed Mg-Zn eutectic structures effectively prevent the eutectic reaction between Mg and Al substrates, improving the lap joint strength (Dai et al., 2016). There are a few studies on the Mg/Al dissimilar FSLW with the zinc interlayer. The FSLW processes of Mg/Al dissimilar alloys with and without the zinc interlayers were carried out in this study. The effects of the zinc interlayer on lap joint formations, microstructures and mechanical properties were explored.

2. Experimental procedure

The base materials (BMs) were 7075-T6 Al and AZ31B Mg alloys, whose dimensions were 200 mm × 100 mm × 3 mm. The chemical compositions of the two BMs are listed in Table 1. A pure zinc foil with a thickness of 0.1 mm was selected as the interlayer based on the reported researches of Gan and Jin (2017) and Xu et al. (2015). There were two processes to investigate how the addition of the zinc interlayer influenced the FSLW joint of Mg/Al dissimilar alloys. One was called as the conventional FSLW without the zinc interlayer, and the other was the FSLW with the zinc interlayer (Fig. 1). These two welding processes were carried out by the same joint configuration presented in Fig. 1b, which indicated that the materials at the RS bore the external loads during tensile shear test. The welding direction was perpendicular to the rolling direction of substrates. A rotating tool was composed of a concentric-circle-flute shoulder and a right-screwed pin. The diameters of the shoulder, the pin bottom and tip were respectively 13 mm, 6 mm and 4 mm. The length of the pin was 4 mm. A tilt angle with respect to Z-axis and a plunge depth of the rotating tool shoulder were 2.5° and 0.15 mm, respectively. Welding parameters are the key factors to determine the heat input which affects the materials flow and the IMCs formation. On the basis of previous studies by Gan and Jin (2017) and Shah et al. (2017), the welding speed of 50 mm/min was fixed, while the rotating velocities were respectively 600 rpm, 800 rpm, 1000 rpm and 1200 rpm. The rotating tool and the welding parameters used in the two FSLW processes were the same.

The specimens for metallographic observation, micro-hardness test and tensile shear test were cut perpendicular to the welding direction, and the dimensions of the tensile shear specimen were 160 mm × 30 mm. After burnished and polished in accordance with the standard of metallography, the metallographic specimens were etched by a solution (5 ml acetic acid, 4.2 g picric acid, 10 ml distilled water and 100 ml ethanol) for 12 s, and then observed by the optical microscope (OM, OLYMPUS GX71). The microstructures of the typical regions were analyzed by the scanning electron microscope (SEM VEGATE-Scan) equipped with an energy-dispersive x-ray spectrometer (EDS). The tensile shear tests were carried out by a universal testing machine at a crosshead speed of 3 mm/min at room temperature. Three tensile specimens for each joint were prepared and the average values were used to analyze. The fracture positions and surface morphologies of specimens were observed by the stereoscopic microscope (ZSA403) and SEM, respectively.

3. Results and discussion

3.1. Joint formations

Figs. 2 and 3 present the cross-sections of the joints at different welding processes. Sound joints were attained, while the SZ of the joint mainly presented a "bowl" shape because of the rotating tool geometry

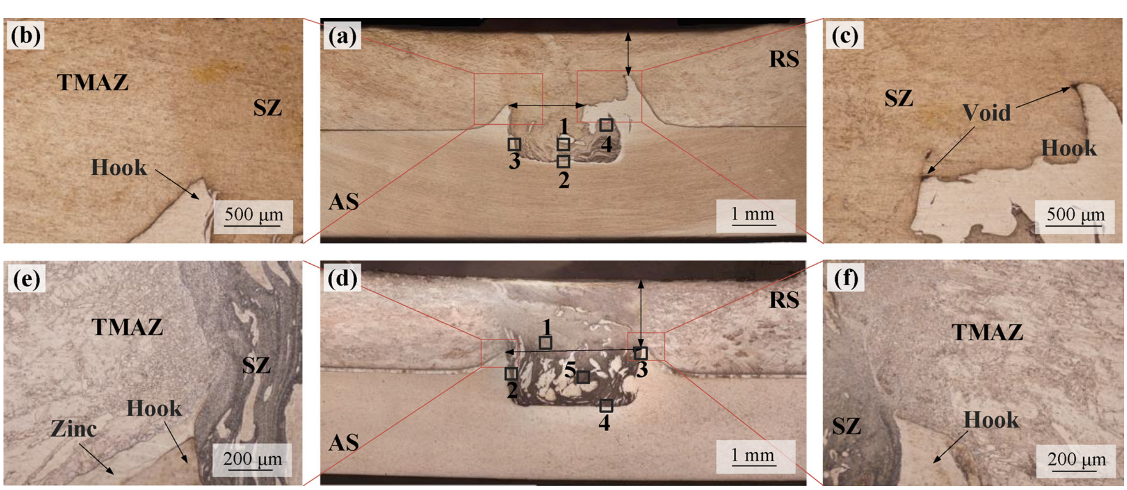

Fig. 2. Cross-sections of the joints at 1000 rpm: (a) the conventional joint; (d) the joint with the zinc interlayer; (b) and (e) enlarged views of hooks at the AS; (c) and (f) enlarged views of hooks at the RS.