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Improving weld strength of arc-assisted ultrasonic seam welded Mg/Al joint with Sn interlayer

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ABSTRACT

Welding of Mg and Al alloys is hugely challenging due to the formation of hard and brittle Mg—Al intermetallic compounds (IMCs). In this research, gas tungsten arc welding (GTAW) assisted hybrid ultrasonic seam welding with Sn interlayer was designed to join Mg to Al alloys. Effects of Sn interlayer and GTAW current on the microstructure and mechanical properties of the joints were investigated in detail. The results indicated that Sn interlayer could restrain the formation of Mg—Al IMCs, which were replaced by Mg_2Sn and Sn-based solid solution. The peak load of the joints increased with the GTAW current increasing and then decreased dramatically at higher GTAW current. The maximum peak load of the joints with Sn interlayer was approximately 1.3 kN, which about 30% increase over the joints without Sn interlayer. All the joint failures occurred by the interface mode at the Al/Sn interface and the fracture patterns exhibited entirely brittle fracture mode with cleavage facet feature surface.

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1. Introduction

The successful joining of dissimilar light materials of Mg and Al alloys is advantage for producing lightweight structures, pushing forward the project of energy-saving and emission-reduction in the transportation and aerospace industries [1–3]. Unfortunately, traditional fusion welding technologies, such as resistance spot welding, arc welding and laser welding, are difficult to apply successfully to the joining of Mg and Al dissimilar metals [4–6]. The fusion welding between Mg and Al alloys usually results in large amount of brittle Mg—Al intermetallic compounds (IMCs) formation, which preferentially acts as the source of microcracks to deteriorate the mechanical properties of the joint [7–9]. In order to achieve a good combination of the properties of Mg and Al alloys, the development of reliable joining process between these metals is crucial. Therefore, solid state technologies including friction stir welding and ultrasonic welding, have received much attention as alternative joining technologies for Mg—Al [10–11].

Friction stir welding was a relatively new solid-state joining technique developed and patented by Thomas in The Welding Institute in 1991 [12]. In the process of FSW, a rotating shouldered tool with a profiled pin moved between the sheets of pieces to be joined. As the rotating tool traveled along the weld line, frictional heat was generated between the base material and the tool shoulder. However, this heat was significantly lower than in fusion welding methods, which could help FSW to avoid many defects appearing in fusion welding [13]. In consequence, FSW was demonstrably better than traditional welding technique in joining dissimilar material combinations such as Mg—Al. However, the FSW technique had undesirable aspects including the keyhole left by the tool probe and the reduction of the top sheet thickness [14].

Ultrasonic welding was another kind of solid state joining technique that used high-frequency ultrasonic vibrations under a modest pressure to induce oscillating shears between the faying surfaces to produce metallurgical bonds [15–16].The weld defects, such as formation of brittle IMCs, high levels of welding distortions and HAZ damage in fusion welding could be typically avoid. In addition, ultrasonic welding was an attractive point joining technique for light alloy, as it is far more efficient than resistant spot welding, using only 0.6–1.5 kJ per weld [17–18]. It was also more efficient than FSW, because the energy was predominantly generated at the weld-line. Recently, a number of researches reported on the joining of dissimilar light metals by ultrasonic spot welding [19–21]. A sound joint without defects could be obtained at usual welding conditions. However, there were surprisingly few researches in joining dissimilar metals by ultrasonic seam welding, even though it possessed higher efficiency and weld continuity characteristics. Conventional ultrasonic seam welding could only be applied to join metal foils or thin plate (<0.5 mm) due to the limitation of power of the welding system. For joining thicker dissimilar metal sheets, the development of high power ultrasonic welding equipment was a key factor [22]. Unfortunately, the high ultrasonic power welding systems

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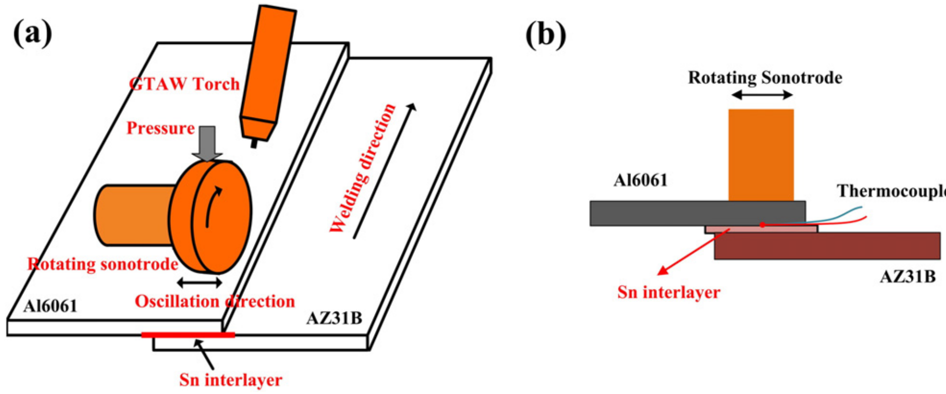

Fig. 1. Schematic diagram of (a)arc-assisted hybrid ultrasonic seam welding system; (b)thermal couple position for temperature measurement.

Table 1
Optimized welding parameters.

	GTAW current(A)	GTAW voltage(V)	Welding speed(mm/s)	Pressure (MPa)	Amplitude (μm)	Vibration frequency (kHz)
S1	30	9.5	8	0.44	20	20
S2	35	9.5	8	0.44	20	20
S3	40	9.5	8	0.44	20	20
S4	45	9.5	8	0.44	20	20
S5	50	9.5	8	0.44	20	20

results in high cost and inconvenient manipulation of the equipment. An effective solution to this problem was to utilize an additional form of energy. Therefore, in our previous study [23], gas tungsten arc welding (GTAW) was introduced into ultrasonic seam welding for the first time. The preceding arc with relatively low heat input could preheat the sheet to enhance the ultrasonic weldability. And reliable joining of Mg and Al sheets with 1 mm thickness was achieved without improving the ultrasonic power. Unfortunately, the hard and brittle Mg—Al IMCs such as $Al_{12}Mg_{17}$ and Al_3Mg_2 were still formed, which deteriorated the mechanical properties of the joint. To restrict the formation of Mg—Al IMCs, other elements should be introduced into the weld to serve as alloying elements or barrier materials. In most researches [24–26], Zn interlayer was used for the welding of dissimilar Mg alloys to Al alloys and the lap shear strength of the joints was improved obviously. These studies could be extended to some other interlayers which could interact with Mg and Al. Liu et al. [27] in TIG welding of Mg-to-Al used Sn to improve the wettability of Mg and Al alloys during the welding process. Patel et al. [28] improved the strength of dissimilar joints of Mg-to-Al by using Sn interlayer during ultrasonic spot welding. However, it is still unclear how Sn interlayer would affect the microstructure of arc-assisted ultrasonic seam welded Mg-to-Al joints, whether the intermetallic layer would form and improve the mechanical properties of the joints.

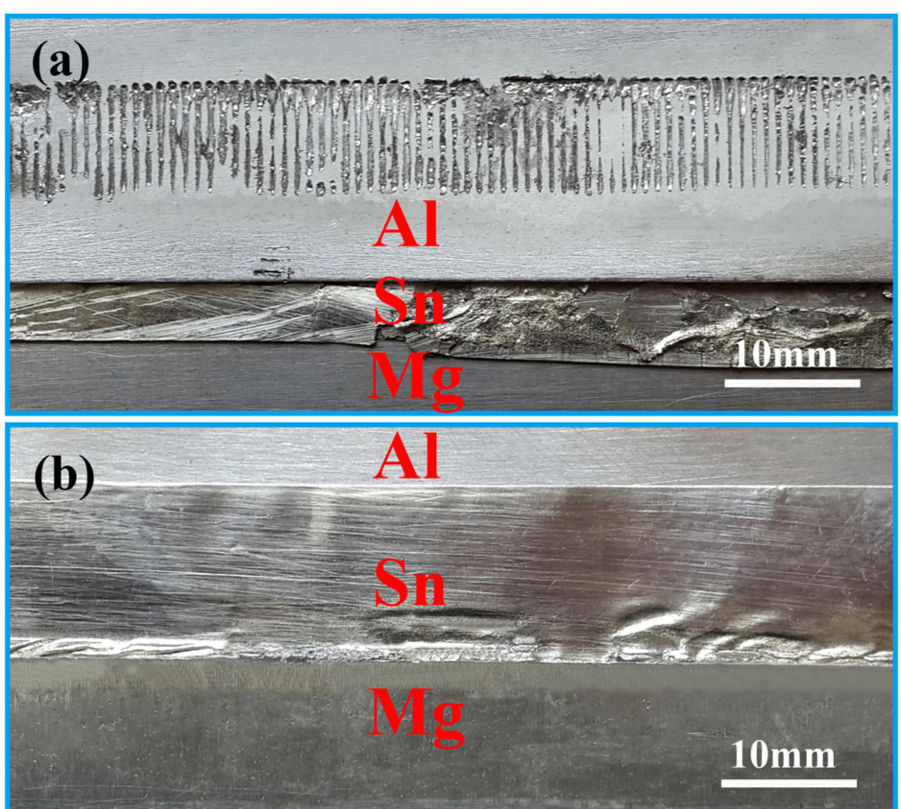

Fig. 2. Weld appearance of the joint produced at GTAW current of 35 A: (a)front; (b)back.

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