FSW between magnesium and aluminum alloys

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Dissimilar friction stir welding between magnesium and aluminum alloys

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ABSTRACT

Dissimilar friction stir welding between magnesium and aluminum alloy plates with thicknesses of 2 mm was performed. The tool for welding was rotated at speeds ranging from 800 to 1600 rpm under a constant traverse speed of 300 mm/min. For tool rotation speeds of 1000, 1200, and 1400 rpm, defect-free welds were successfully obtained and the surface morphology of the welds became smoother as the tool rotation speed was increased. The relatively simple bonded interface was clearly evident and had a zigzag pattern. A mixed microstructure of magnesium and aluminum alloys was formed near the bonded interface. The maximum tensile strength of about 132 MPa was obtained at the tool rotation speed of 1000 rpm. However, there were not noteworthy changes in the tensile strength as a function of the tool rotation speed. The elongation was 2% or less, regardless of the tool rotation speed.

1. Introduction

Recently, in many industrial fields, much attention has been focused on aluminum and magnesium alloys because of various unique properties. For their practical applications, bonding and welding technologies should also be established in addition to considering issues such as alloy design, microstructure control, plastic forming, casting, and surface treatment. It is common knowledge that friction stir welding (FSW) is an attractive technology for the welding of aluminum [1–8] and magnesium [9–12] alloys. In addition, FSW between dissimilar materials has recently received much attention [13–19]. However, there is not a lot of research on dissimilar FSW between aluminum and magnesium alloys and most previous research [17–19] involves commercially pure aluminum alloys with relatively low strength. There is little research on dissimilar FSW of aluminum alloys with relatively high strength such as the 5xxx series. In addition, it is difficult to fully understand the effects of principal processing parameters such as tool rotation speed and tool traverse speed on the dissimilar FSW between aluminum and magnesium alloys.

In this study, dissimilar FSW between A5052P-O and AZ31B-O alloy plates was performed. Then, the influences of the tool rotation speed on surface appearance, microstructure, and tensile properties of the friction-stir-welded (FSWed) plates were experimentally investigated.

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2. Experimental procedure

The dimensions of the base metal plates were 30 mm wide × 160 mm long × 2 mm thick. During the FSW, the AZ31B-O and A5052P-O alloy plates were located on the retreating side (RS) and the advancing side (AS), respectively. The shoulder diameter of the tool for FSW was 10 mm. The probe had a diameter of 4 mm and a height of 1.7 mm. The tool was rotated in a clockwise direction at speeds ranging from 800 to 1600 rpm, and the probe was then inserted into the materials. The rotating tool was traversed at a constant speed of 300 mm/min along the weld line perpendicular to the rolling direction of the base metal plates.

For tensile tests, the FSWed plates were cut perpendicularly to the tool traverse direction and then machined into the tensile test specimens with a parallel portion of 4 mm wide × 24 mm long × 1 mm thick and a fillet radius of 5 mm. The tensile tests were carried out at room temperature under a constant crosshead speed of 1 mm/min.

3. Results and discussion

3.1. Appearances

Fig. 1 shows the surface appearances of the FSWed plates. For the (a) 800 rpm sample, large defects with valley-like structures were formed in the friction-stir-welded zone (SZ) with a very rough surface. Defect-free welds were successfully obtained for the (b) 1000, (c) 1200, and (d) 1400 rpm samples. In addition, the surface morphology of the SZ became smoother with an increase in the tool rotation speed. At (d) 1600 rpm, however, large defects presenting as cracks were again formed along the tool traverse direction near the center region of the SZ. These results show that there are optimum tool rotation speeds in order to obtain defect-free welds for the dissimilar FSW between AZ31B-O and A5052P-O alloy plates.

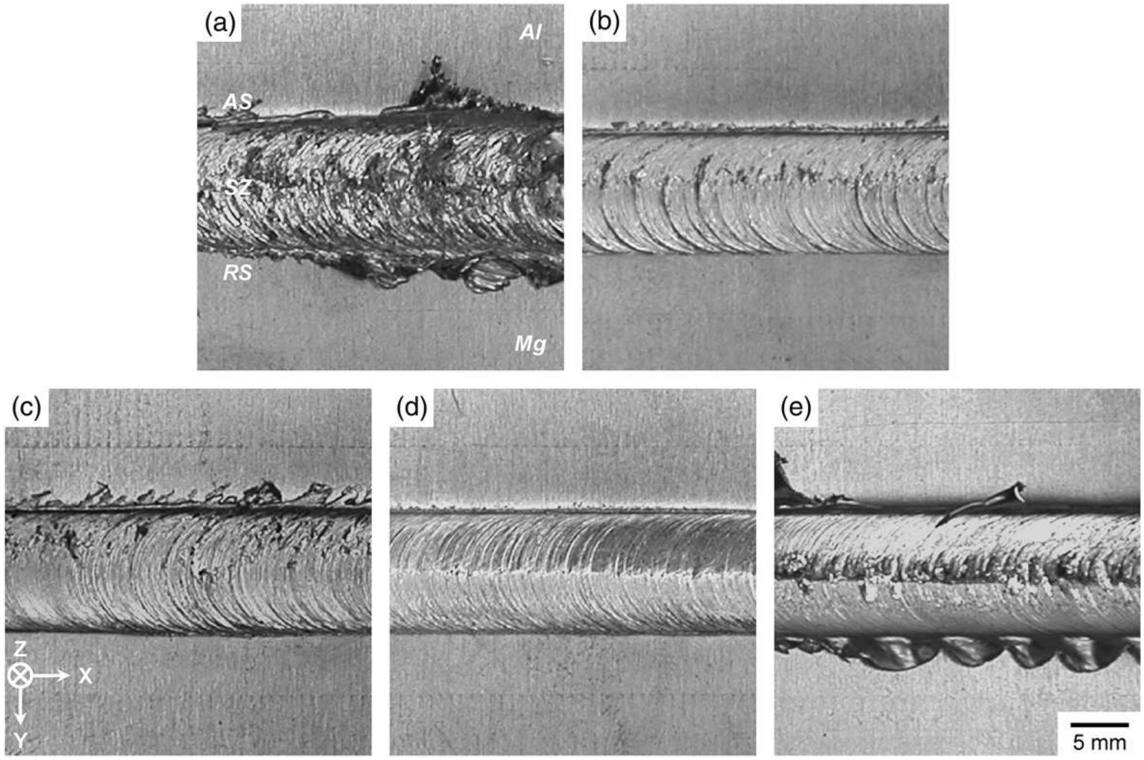

Fig. 1. Surface appearances of the plates friction-stir-welded with tool rotation speeds of (a) 800, (b) 1000, (c) 1200, (d) 1400, and (e) 1600 rpm. The friction-stir-welded zone, the advancing side, and the retreating side are labeled SZ, AS, and RS, respectively. *X*, *Z*, and *Y* represent the tool traverse direction, the tool rotation axis direction, and the rolling direction of base metals, respectively.

3.2. Microstructures

Fig. 2 shows the optical micrographs of the cross-sections perpendicular to the tool traverse direction of the FSWed plates. Yan et al. [19] have reported that cracks developed in the SZ when the rotating probe was traversed along the center of weld line. In this study, however, no bonding defects were formed near and in the SZ for tool rotation speeds ranging from 1000 to 1400 rpm, even though the rotating probe was traversed along the center of the weld line. This result shows that there are certain optimum welding conditions for the dissimilar FSW. In all cases, the bonded interface was clearly evident as zigzags near the center of the SZ. It is believed that there was no specific correlation between the tool rotation speed and the microstructure. No onion ring pattern was observed, which is sometimes observed in the SZ of similar alloy plates [6–8]. Although a precise conclusion is not yet possible, it is likely that the no formation of an onion ring pattern results from differences in mechanical properties between the A5052P-O and AZ31B-O alloys.

Fig. 3 shows the EPMA results of the SZ in the cross-section perpendicular to the tool traverse direction. As shown in (a), (b), and (c), magnesium alloy particles were distributed in the A5052P-O alloy region. Aluminum alloy particles were distributed in the AZ31B-O alloy region as shown in (d), (e), and (f). This result shows that a mixed microstructure of magnesium and aluminum alloys was formed near the bonded interface during the FSW. This result proves that the rotating tool induces the plastic flow between the base metals by the mechanical stirring action. On the other hand, Sato et al. [18] have reported that a eutectic microstructure was formed in the SZ with some pores by constitutional liquation through a eutectic reaction between aluminum and magnesium. In this study, however, no eutectic microstructure was formed. This result demonstrates that the SZ was not heated up to a temperature above the liquidus line during the FSW and that the dissimilar FSW was carried out in the solid state of the base metals.

3.3. Tensile properties

Fig. 4 shows the influences of the tool rotation speed on the tensile strength and elongation of the FSWed plates. The AZ31B-O alloy exhibited a tensile strength (about 256 MPa) higher than that of the A5052P-O alloy (about 200 MPa). For the FSWed

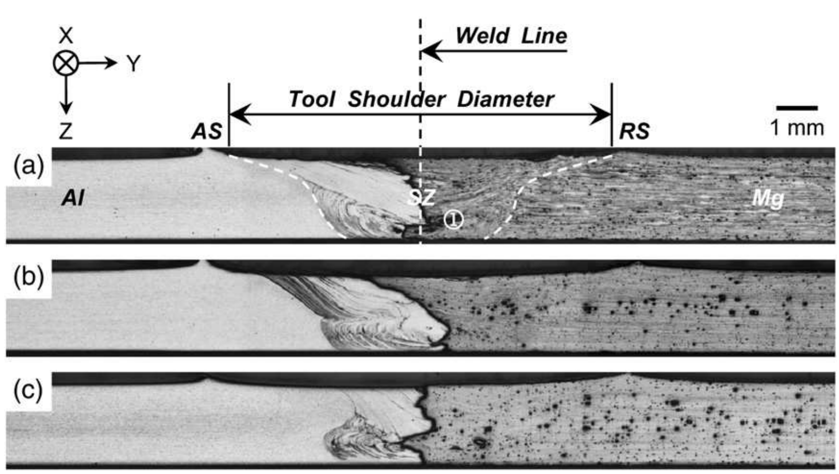

Fig. 2. Optical micrographs of the cross-sections perpendicular to the tool traverse direction of the plates friction-stir-welded with tool rotation speeds of (a) 1000, (b) 1200, and (c) 1400 rpm.

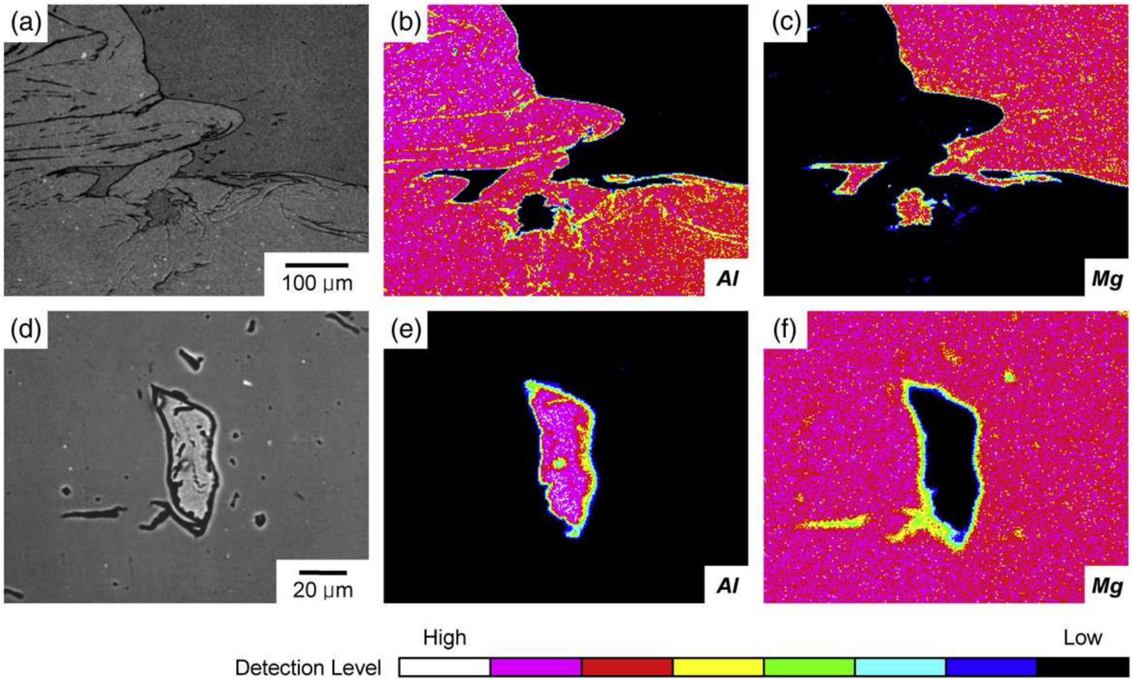

Fig. 3. EPMA results of the friction-stir-welded zone in the cross-section perpendicular to the tool traverse direction. Backscattered electron images: (a) near bonded interface and (d) in AZ31B-O magnesium alloy region (region ①in Fig. 2 (a)). Element distributions: (b) and (e) aluminum, (c) and (f) magnesium.

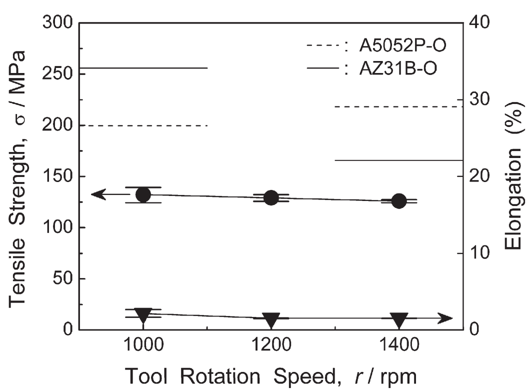

Fig. 4. Influences of the tool rotation speed on the tensile strength and elongation of the friction-stir-welded plates. The broken and solid lines show the tensile strength and elongation of the base metals, i.e., A5052P-O and AZ31B-O alloy plates, respectively.

plates, a maximum tensile strength of about 132 MPa was obtained at the tool rotation speed of 1000 rpm, which was about 66% of the tensile strength of the A5052P-O alloy. However, there were not noteworthy changes in the tensile strength as a function of the tool rotation speed. The FSWed plates showed very low elongation of 2% or less. The elongation did not significantly change as a function of the tool rotation speed, although a maximum elongation of about 2% was obtained at 1000 rpm.

4. Conclusions

In this study, dissimilar FSW between A5052P-O and AZ31B-O alloy plates with thicknesses of 2 mm was performed. The following results were obtained.

1. For tool rotation speeds of 1000, 1200, and 1400 rpm, defect-free welds were successfully obtained, suggesting that there are optimum tool rotation speeds for the dissimilar FSW. In addition, the surface morphology of the SZ became smoother with an increase in the tool rotation speed.
2. The relatively simple bonded interface is clearly evident as zigzags near the center of SZ. No formation of a eutectic microstructure suggests that the dissimilar FSW was carried out in the solid state of the base metals.
3. The mixed microstructure was formed near the bonded interface, in which magnesium and aluminum alloy particles were distributed in the A5052P-O and AZ31B-O alloy regions, respectively. This result proves, in practice, that the rotating tool induces the mass transfer phenomena between the base metals by the mechanical stirring action.
4. For the FSWed plates, the maximum tensile strength was about 132 MPa, which was about 66% of the tensile strength of the A5052P-O alloy. However, there were not noteworthy changes in the tensile strength as a function of the tool rotation speed. The elongations of the samples were 2% or less and did not significantly change as a function of the tool rotation speed.

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