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Microstructure and properties of friction stir butt-welded AZ31 magnesium alloy

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Abstract

Friction stir welding (FSW) is a relatively new joining technique particularly for magnesium and aluminum alloys that are difficult to fusion weld. In this paper, an excellent friction stir weld of AZ31 magnesium alloy was obtained at proper parameter. In the friction stir zone (FSZ), the microstructure of the base material (BM) is replaced by fine grains and small particles of intermetallic compounds. The average microhardness of the friction stir zone is higher than that of the base material. The maximum tensile strength of joint can reach 93% that of the base material. And the failure locations are almost at the heating affected zone.

Keywords: Friction stir welding; Magnesium alloys; Microstructure; Grain refinement; Mechanical properties

1. Introduction

Friction stir welding (FSW) is a solid-state joining process that was invented by The Welding Institute, UK, in 1991 [1]. The technique is a variant of the friction welding processes, but utilizes a rotating tool with a shoulder and a profiled probe that is plunged into the work pieces and traversed along the weld centerline. The motion of the tool generates frictional heat within the work pieces, extruding the softened plasticized material around it and forging the same in place so as to form a solid-state seamless joint. No melting takes place in the process, thus keeping the temperatures relatively low and producing good quality welds with significantly lower residual stresses [2]. The biggest advantage of the method, however, is its capability to weld light structural materials like certain aluminum alloys and magnesium alloy that used to be considered unweldable or difficult to weld by conventional fusion welding techniques [3].

Magnesium alloys have many attractive properties, such as low density and high specific strength. It is predicted that the application of magnesium alloys will grow rapidly in the near future; Park et al. [4] discussed the microstructural evolution of Mg alloy AZ91D during FSW. However, the effects of FSW parameters, especially travel speed and rotation speed on the microstructure changes and mechanical properties of FSW welded Mg alloy have not rigorously studied. The present author examined mechanical properties, such as hardness and tensile properties in defect-free FSW welded AZ31 Mg alloy to evaluate the effects of the FSW parameter on the microstructure changes and mechanical properties [5–9].

2. Experimental procedures

The plate of AZ31 magnesium alloy was friction stir welded. Friction stir welded plates with nominal composition (3.0–4.0)Al–(0.2–0.8)Zn–(0.15–0.5)Mn remaining Mg. Nominal dimensions of the plates were 250 mm (length) × 250 mm (width) × 4 mm (thick). The tensile strength of base material is 275 MPa.

Tool of friction stir welding was made on CNC lathe from 65 Mn steel, varying welding parameters such as tool rotation speed and travel speed was used in this investigation. Rotation speed was 375–2250 rpm, and travel speed was 20–375 mm/min. The probe diameter of the tool measured 4 mm and the shoulder 12 mm. The penetration depth was adapted to fully penetrated butt joint in a material of 4 mm thickness.

Microstructural examination was carried out on cross sections perpendicular to the welding direction. After being mechanically ground and polished, the specimens were etched in a solution of 5 g picric acid + 5 ml acetic acid + 20 ml

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water + 150 ml ethanol. Microhardness profiles were measured on the specimen. Tensile test and SEM scanning on fracture surface of friction stir weld in a tensile test were carried out.

3. Results and discussion

3.1. Macrostructure and microstructure of friction stir weld

Fig. 1 shows the macrostructure of the cross section in friction stir weld at a rotation speed 1200 rpm, a travel speed 90 mm/min and a welding pressure 150 N. The width of the friction stir zone (FSZ) of the experimental material was about 4 mm, equal to the diameter of the pin. Fig. 2 shows the optical microstructure of the FSW welded Mg alloy at rotation speed 1500 rpm, travel speed 90 mm/min and a 150 N welding pressure. In addition, the tool advance vector in line with tangent vector of a shoulder fringe calls advancing side (AS), and the contrary vector calls retreating side (RS). The macrostructure of the cross section in retreating side and advancing side is different, which is relative the flow field of friction stir welds. The tunnel defect usually can be seen near the RS zone.

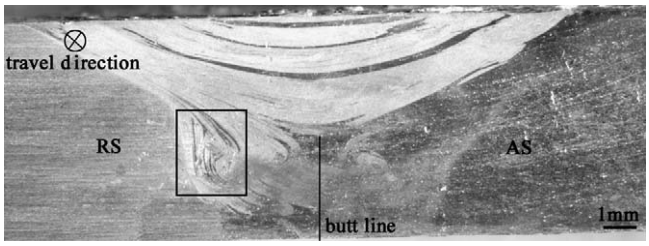

Fig. 1. Cross section of friction stir weld in AZ31 magnesium alloy.

The microstructure of FSZ is greatly refined due to dynamic recrystallization. As going from base metal to welding boundary part and the central part of welding, crystal grain becomes small. Besides, FSZ is a thermomechanically affected zone (TMAZ) in which magnesium grains are severely deformed. The microstructure of BM, which is shown in Fig. 2(a), is mainly composed of granular phase of magnesium solid solution grains. Some tiny eutectic zones, which are shown by arrows in Fig. 2(a), could also be seen in the microstructure. A typical microstructure of TMAZ is shown in Fig. 2(b). It can be seen that magnesium grains in TMAZ show an elongated shape due to plastic defor-

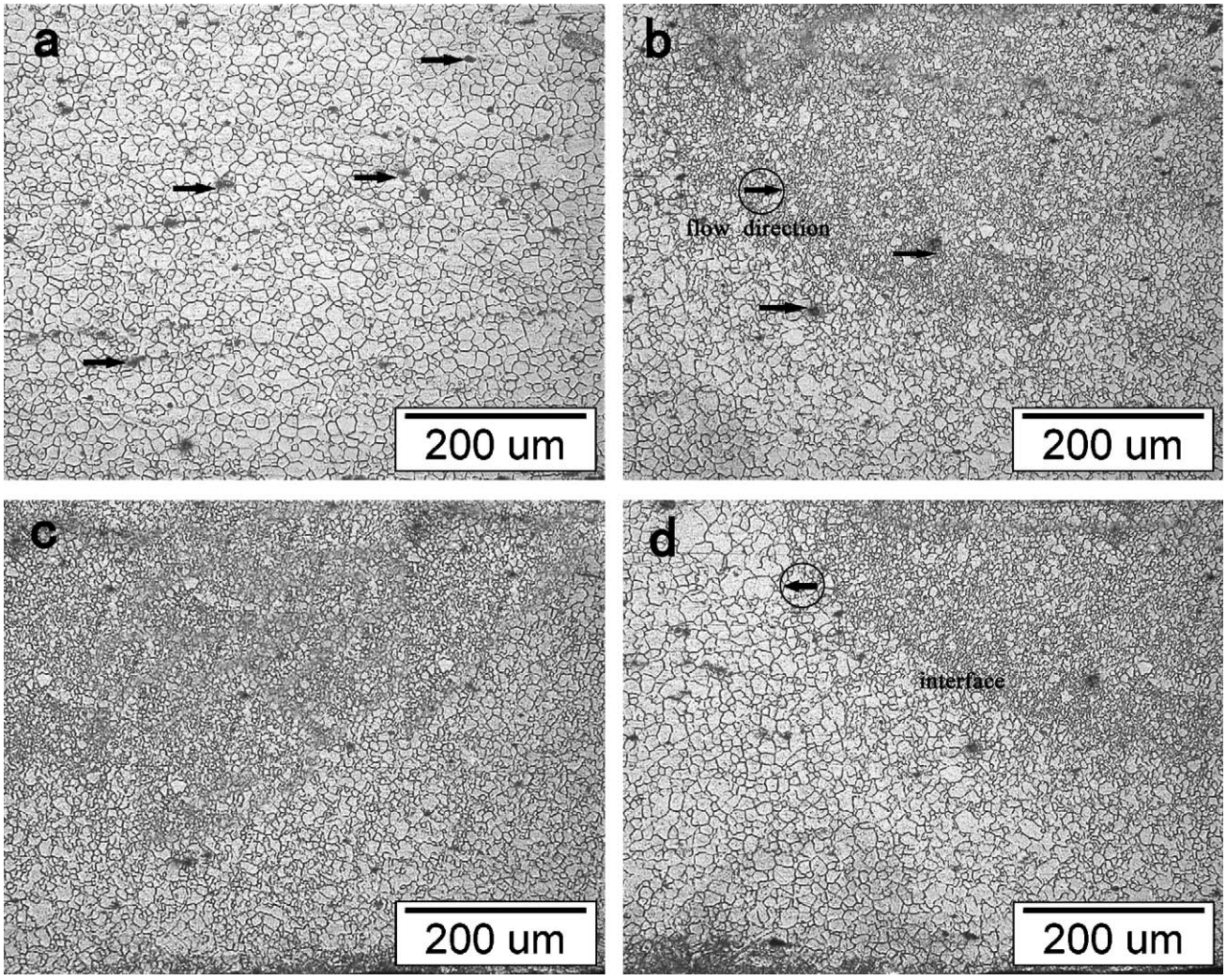

Fig. 2. SEM images showing the microstructures of cross sections of: (a) BM; (b) TMAZ; (c) FSZ; (d) TMAZ/FSZ interface.