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Effects of Friction Stir Process on the Tensile Properties of AZ61 Magnesium Alloy at Room Temperature to 200 °C

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Keywords: AZ61 Mg alloy, Friction stir process , tensile mechanical property

1. Introduction

Friction stir welding (FSW) possesses more advantages than other traditional welding processes because it is a solid-state joint process [1]. In addition, friction stir processing is adopted as a new surface modification approach. It is acceptable that the dynamic recrystallization phenomenon during FSW/FSP results in the generation of fine and equiaxed grains in the stir zone [2-3].

Magnesium alloys are regarded as poor formability due to their limited available slip systems at room temperature. Increasing deformation temperature can improve the ductility of magnesium alloys. In addition, the distribution of (0002) basal planes dominates the deformation behavior of magnesium alloys. Woo et al. [4] and Lee et al. [5], discussed the tensile properties of friction stir processed AZ31 alloy, and showed that its flow stress and elongation were influenced by the texture variation after FSP.

In this study, the main aim is to discuss the deformation behavior of full-annealed and friction stir processed AZ61 Mg alloy, especially in their tensile ductility. Meanwhile, the influence of deformation temperatures on the tensile ductility is investigated as well.

2. Experimental procedures

A commercial AZ61 billet was hot extruded to a plate of 55 mm in width and 3 mm in thickness. Its nominal chemical composition in weight percent was 6.3% Al, 0.48% Zn, 0.37% Mn and balance Mg. The as-extruded plate was subjected to annealing at 345 °C for 12 hours. The microstructure of the full-annealed (AZ61-O) sample was shown in Fig.1. The full-annealed plate was also adopted as the substrate of the friction stir processing as shown in Fig. 2. The FSPed samples were designated as AZ61-FSP. The FSP was performed using these parameters: tool rotating speeds were fixed at 1243 rpm; tool moving speeds were fixed at 46 mm/min with 1.5° of tool angle; the downward push force was controlled at 14.7 MPa. The tool size used in FSP was 16 mm in shoulder diameter, 7 mm in pin diameter and 1.5 mm in pin height.

The AZ61-O and AZ61-FSP specimens were machined to tensile specimens shown in Fig. 3, and their tensile direction was parallel to extrusion direction (ED) or process direction (PD). In this study, tensile tests of AZ61-O and AZ61-FSP specimens were performed at an initial strain rate of 1.67×10^{-3} s^{-1} from room temperature to 200 °C.

Microstructure samples for optical microscopy were polished and then etched with a solution of 4.2 g picric acid, 70 mL ethanol, 5 mL acetic acid and 5 mL water. The information of texture and precipitation of the particles was identified by X-ray diffraction spectra.

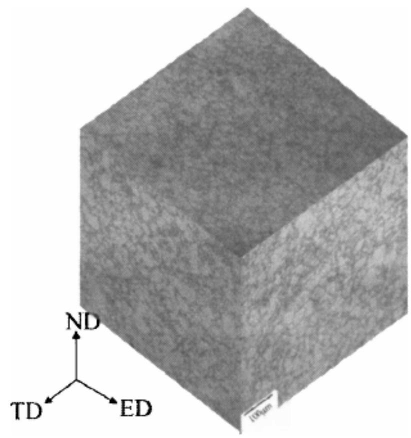

Fig.1. Microstructures of AZ61-O. The orientations are referred to extrusion direction (ED), normal direction (ND) and transverse direction (TD).

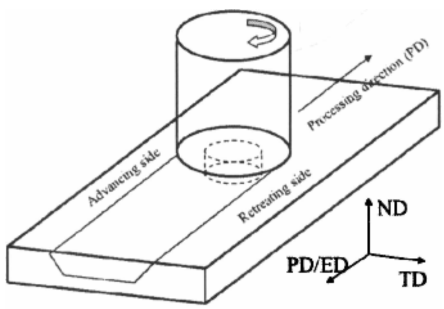

Fig.2. Schematic illustration of friction stir processing. The process direction was parallel to extrusion direction.

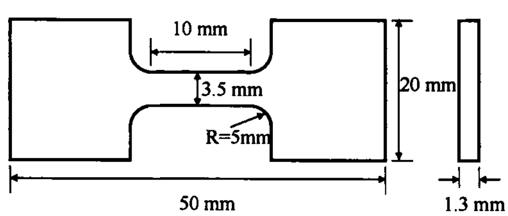

Fig.3. Schematic illustration of the dimensions of tensile specimens.

3. Results and discussion

The microstructure of AZ61-O is shown in Fig. 1, and its average grain size is 13 μm. On the other hand, the metal flow resulted from the friction stir processing can be observed in Fig. 4. The microstructure of AZ61-FSP consists of fine and coarse grains, and the grain size of fine grains is similar to that of AZ61-O. The macrostructure of metal flow is similar to the rotation trace of the stir pin because the inhomogeneous friction heat is introduced into the AZ61 specimen during friction stir processing [6]. The microstructures of AZ61-FSP specimens (Fig. 5) also reveal an inhomogeneous structure on the normal plane in the center of stir zone. Fine grains were fully recrystallized during FSP and the coarse grains are partially recrystallized. In Fig. 6, the schematic illustration of the grains structure is adopted to depict the microstructure evolution in the stir zone of the AZ61-FSP specimen [6]. On the other hand, comparing the X-ray diffraction patterns of AZ61-O and AZ61-FSP, the decrease in the peaks of γ-phase reveals the dissolution of the γ-phase $Mg_{17}Al_{12}$ during FSP (see in Fig. 7).

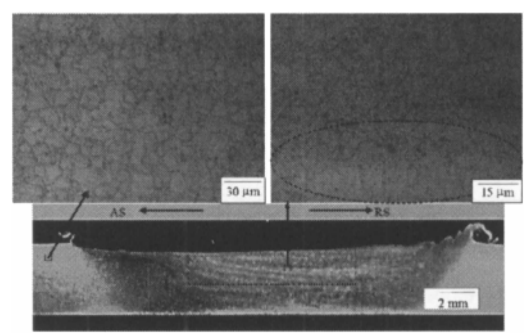

Fig.4. Microstructures of inhomogeneous structure of the base metal and the stir zone. Dot line refers to the coarse grains in the stir zone.

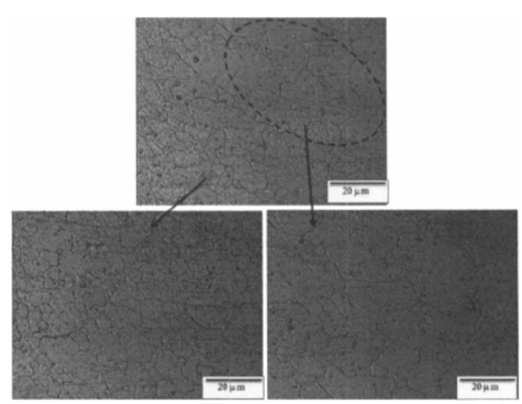

Fig.5. Microstructures of inhomogeneous structure in the center of stir zone, which is observed on the normal plane. The coarse grains are highlighted (dot line).

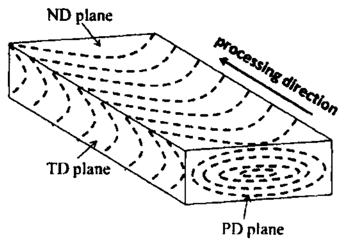

Fig.6. Schematic illustration of metal flow in the stir zone [6].

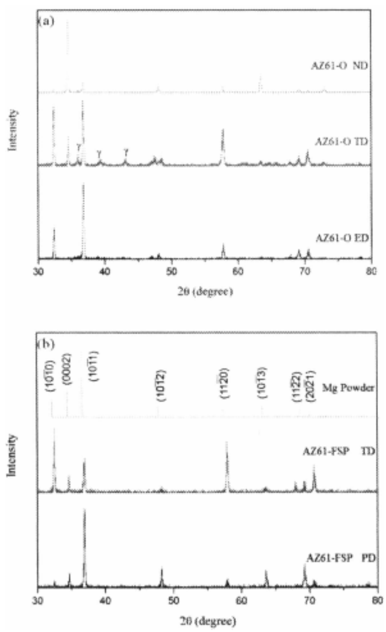

Fig.7. X-ray diffraction spectra: (a) AZ61-O and (b) AZ61-FSP detected on different planes. The samples of AZ61-FSP were cut from the center area of stir zone.

Fig. 8 and Fig. 9 show the tensile properties of AZ61-FSP and AZ61-O. It should be noted that the tensile flow stress of the AZ61-FSP specimen significantly decreased, which reveals the texture effect on the deformation behavior of AZ61-FSP and AZ61-O. As (0002) basal planes were rotated and rearranged during friction stir processing, (0002) basal planes were surrounded with the stir pin surface [4]. This texture is also identical with the metal flow illustrated in Fig. 6. The X-ray diffraction spectra of AZ61-FSP in Fig. 7 revealed that the texture feature of AZ61-FSP is beneficial to basal slip or twinning as tensile direction is parallel to process direction [5]. The microstructures of the fractured AZ61-FSP specimens have large numbers of deformation twins formed at room temperature to 100 °C (Fig. 10). Increasing test temperature, the flow stress of AZ61-O decreases more rapidly than that of AZ61-FSP.

As illustrated in Fig. 9, it should be noted that the AZ61-FSP specimens actually possess a better uniform elongation than AZ61-O at all test temperatures. Compared with AZ61-O specimens, the total elongation of the AZ61-FSP specimens is better from room temperature to 50 °C. It is pointed that the texture dependence is not only related to tensile flow stress but also affects the tensile elongation at room temperature [5]. Increasing the test temperature, the total elongation of the AZ61-O specimens increases more obviously than that of the AZ61-FSP samples. In the AZ61-O specimen tested at 100 °C, partially dynamic recrystallization phenomenon is observed on the grain boundaries as shown in Fig. 10(c). The dynamic recrystallization phenomenon occurrs in the high-temperature tensile test and the new grains initially nucleate on the original grain boundaries [7]. In Fig. 10(d), the AZ61-O specimen shows that the dynamic recrystallization produced the lots of new fine grains at 200 °C. The dynamic recrystallization occurring during tensile deformation decreases the flow stress and markedly raises the ductility at elevated temperatures [8]. It could be suggested that in the high-temperature tensile test, AZ61-O possessed a better elongation as a result of dynamic recrystallization.

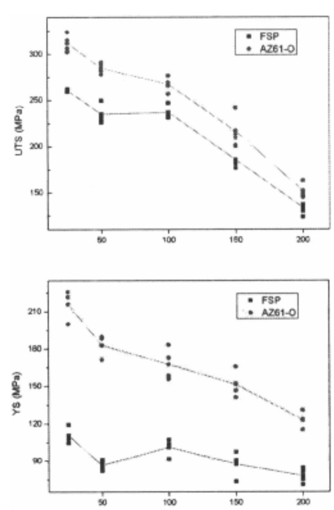

Fig.8. Flow stress of AZ61-O and AZ61-FSP against test temperatures: (a) ultimate tensile stress and (b) yield stress.

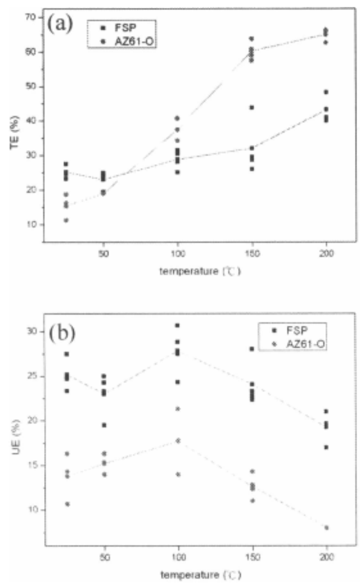

Fig.9. Elongation of AZ61-O and AZ61-FSP against test temperatures: (a) total elongation and (b) uniform elongation.

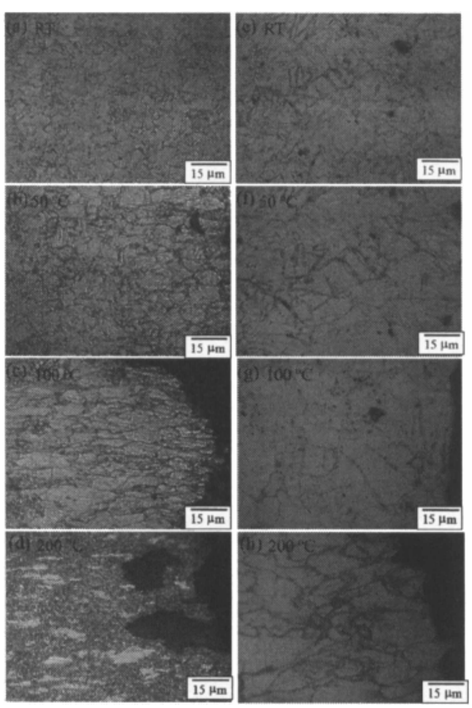

Fig.10. Subsurface of specimens deformed to fracture: (a)(b)(c)(d) AZ61-O tested from RT to 200 °C and (e)(f)(g)(h) AZ61-FSP tested from RT to 200 °C.

5. Conclusion

The effects of friction stir processing on the microstructure and tensile deformation behavior of the AZ61 magnesium alloy can be summarized as follows:

- Inhomogeneous structure resulted from the friction heat can be observed after friction stir processing.
- The AZ61-FSP specimen has a lower tensile flow stress than AZ61-O due to the texture generated by FSP.
- The total elongation of AZ61-FSP specimens is better than AZ61-O from room temperature to 50 °C.
- Dynamic recrystallization of the AZ61-O specimen during tensile test resulted in the new fine grains and markedly raised the total elongation of AZ61-O at the elevated temperatures.

Acknowledgements

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