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Effects of Friction Stir Processing on Mechanical Properties and Damping Capacities of AZ31 Magnesium Alloys

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Abstract. AZ31 base alloy were subjected to friction stir processing (FSP) with different rotating speed. The effect of FSP on the microstructure, mechanical properties and damping capacities of AZ31 alloy was discussed in this paper. The fine and equiaxed grains were obtained in the SZ for FSPed samples with the rotating speed from 1300rpm to 1700rpm with the average grain size of 11.82μm, 12.93μm and 14.50μm, respectively. The FSPed samples had higher ductility and damping capacities compared with the AZ31 base alloy. The ductility and damping values $Q_0^{-1}(\varepsilon=10^{-4})$ and $Q_H^{-1}(\varepsilon=10^{-3})$ of 1500rpm FSPed sample were increased by 121.44%, 5.02% and 7.49%, respectively.

1. Introduction

Magnesium alloys are gaining increasing importance in aerospace, defence and automobile applications owing to their low density, high strength to weight ratio , high damping capacity and high recycling capability [1,2]. Friction stir processing (FSP) was developed by adapting the concept of FSW to obtain a fine grain size in a stirred zone [3]. After the successful advent of FSP, the application of arena of this technology has been growing rapidly [4]. Some if its most recent applications involve surface modifications, enhancement of surface and bulk properties and generation of in-situ and ex-situ nanocomposites in number of aluminum and magnesium-based alloys [1,5-9].

However, few studies have been conducted to excogitate the effect on damping properties of FSPed magnesium alloys possessing the modification of grain size and grain orientation which is an important factor that affects the damping capacity of magnesium alloys [10,11]. Therefore, there is a great possibility of resolving the contradiction between the mechanical properties and damping capacity of magnesium alloys by FSP.

2. Materials and Methods.

The material used in this study was AZ31 magnesium alloy of hot rolling state with composition of (in wt.%): Al-2.14, Zn-0.967, Mn- 0.307, Si-0.096, Mg-balance. The base material was cut into specimen of 250 mm× 170 mm×4 mm. The shoulder diameter, pin diameter and pin height were 16.0 mm, 4.0 mm and 3.8 mm, respectively. The FSP tool was rotated in 1300, 1500, 1700 rpm in the clock-wise direction, severally. The traverse speed was 50 mm/min. The tilted angle was 2.5°.

For optical examination, the samples were sectioned, cold mounted, polished by silicon dioxide paste with grain size of 1μm and finally etched in a solution of oxalic acid(2g), nitric acid (1mL) and distilled water (98mL), and then examined by using a ZEISS optical microscope. The cross-section were subjected to micro hardness testing employing Vicker's hardness indentation at 100g load. Specimens for tensile test and damping test were machined from the center region in the SZ. Tensile testing was performed on a SANS CMT5205 material testing machine at a stretching rate of 2mm/min at ambient conditions. Damping samples were machined to dimensions of 35 mm×10 mm×1 mm. Damping capacity was measured by dynamic mechanical analyzer (NETZSCH DMA-242C) in single cantilever deformation mode. For the measurements of strain amplitude dependence of damping capacity, the range of strain amplitude was from 1 μm to 200 μm, and the measurement frequency was 1 Hz.

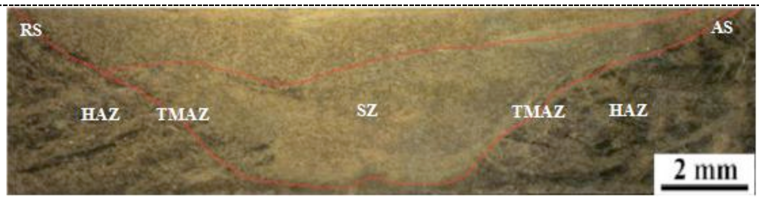

Figure 1. Electronic cross-sectional macro-image of FSPed sample with a rotating speed of 1500 rpm.

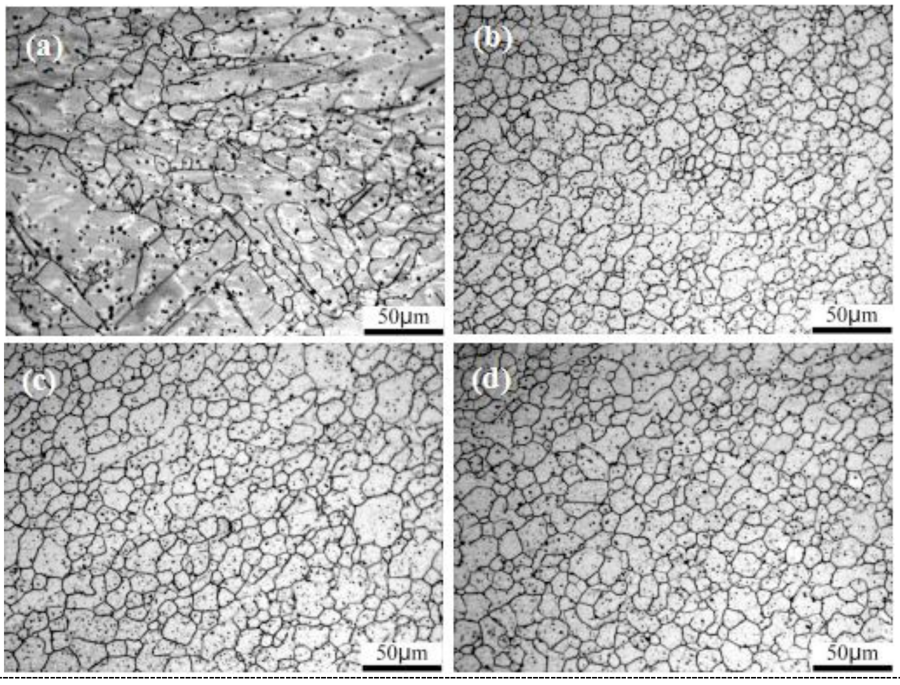

Figure 2. Microstructure of AZ31 base alloy and SZ of FSPed samples.
(a) AZ31 base alloy (b) 1300rpm (c) 1500rpm (d) 1700rpm

3. Results and Discussion

3.1. Macrostructure and microstructure

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Figure 1 shows the cross-sectional macrostructure of the FSPed sample with a rotating speed of 1500 rpm.Three distinct regions are present in the final macrostructure: heat affected zone (HAZ), thermo-mechanically affected zone (TMAZ) and stir zone (SZ)[12]. Compared with the retreating side (RS), the advancing side (AS) has a much clearer and sharper boundary which can be visible to the naked eye.

The microstructure of AZ31 magnesium alloy consisted of elongated, uneven distributed grains along the rolling directions (as shown in figure 2 (a)). The equiaxed grains were found in the SZ after FSP. Compared with the AZ31 base alloy, the FSPed samples had significantly refined grains. At a constant traverse speed, the average grain size was respectively 11.82μm, 12.93μm and 14.50μm (as shown in figure 2 (b),(c),(d)), getting larger with the increasing of rotating speed.

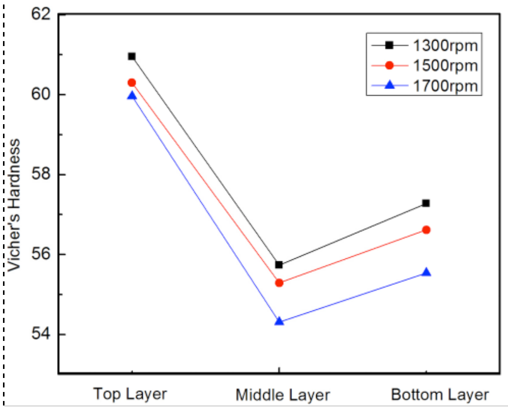

Figure 3. The Vicher's hardness of different layers of FSPed AZ31 alloys.

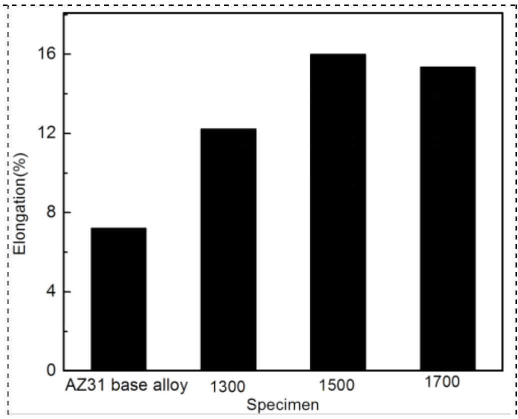

Figure 4. The ductility of AZ31 base alloys and FSPed samples.

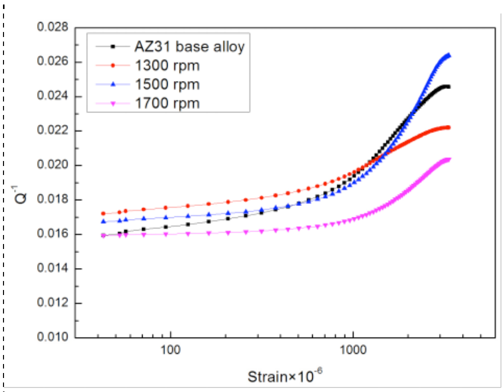

Figure 5. Strain amplitude dependence damping capacity of AZ31 base alloy and FSPed samples.

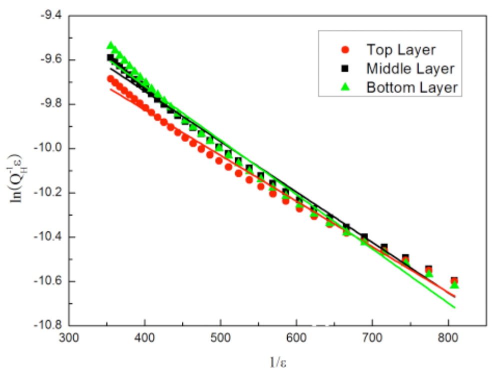

Figure 6. G-L plots of SZ in different layers after FSP of 1500rpm.

3.2. Mechanical properties

Figure 3 shows the Vicher's hardness of different layers of FSPed AZ31 alloys with the rotating speed of 1300rpm, 1500rpm and 1700rpm, respectively. Compared to the AZ31 base alloy, the FSPed had lower hardness values significantly. As the rotating speed increased, the grain size increased, while the hardness values decreased at the same time which were relatively in good accordance with the Hall-Petch Relationship. The Vicher's hardness of FSPed samples of different rotating speed had the similar trends, decreased at the middle layer and then rebounded at the bottom layer. This is because the softening caused by the dynamic recrystallization in the SZ was much stronger than the strengthen caused by the grain refining.

The tensile strength did not get promoted though the average grain size of the SZ of fine grained materials is much less than the AZ31 base alloy. The elongation has been significantly improved as shown in figure 4. The reason for this phenomenon may be related to the changes of texture of the material after FSP. Hung and Shih [13] in their investigation identified that the grain orientation has changed after FSP, causing the increase of the residual stress. AZ31 magnesium alloy has a HCP structure which has less slip systems at room temperature. Therefore, the effect of the texture was much more than the average grain size on the strength of the AZ31 alloy.

3.3. Damping capacities

Figure 5 shows the strain amplitude dependence damping capacity of AZ31 base alloy and FSPed samples. The damping values $Q_0^{-1}(\varepsilon=10^{-4})$ of AZ31 base alloy at low strain amplitude was 0.01594, and that of the samples subjected to 1300rpm FSP (0.01721), 1500rpm FSP (0.01674) and 1700rpm (0.01595) were increased by 7.97%、5.02% and 0.06%, respectively. The damping values $Q_H^{-1}(\varepsilon=10^{-3})$ at high strain amplitude of AZ31 base alloy and FSPed samples were 0.02456, 0.0222(1300rpm FSP), 0.0264(1500rpm FSP) and 0.02037(1700rpm FSP), respectively. Compared to the AZ31 base alloy, only the 1500rpm FSPed sample had a increase by 7.49 %. When the damping capacity is bigger than 0.01, it is generally considered that the alloys exhibit high damping capacity [14]. The 1500rpm FSPed samples obtained higher damping capacity.

According to the G-L theory[15, 16] ,

$$C_1/C_2^2=\rho L_N^3/6F_B. \qquad (1)$$

Where C_1 and C_2 are the material constants; ρ is the dislocation density; F_B is the binding force between dislocation and weak pinning points; L_N is the average dislocation distance between strong pinning points.

Table 1. Values of C_1 and C_2 according to G-L plots.

Treatment	Top Layer	Middle Layer	Bottom Layer
$C_1\times10^{-4}$	1.23	1.46	1.60
$C_2\times10^{-3}$	2.06	2.27	2.45
C_1/C_2^2	28.98	28.33	26.66

Strain amplitude dependence damping capacity of SZ in different layers after FSP of 1500rpm abided by the G-L model from Figure. 4(b). The values of C_1 and C_2 calculated according to G-L plots[17] are shown in Table 1.

From equation 1, the C_1/C_2^2 value is proportional to ρL_N^3. The C_1/C_2^2 values of SZ in different layers after FSP of 1500rpm were decreased due to the decrease of the average grain size from the top layer to the bottom layer while the L_C was increased according to the change of C_2.

4. Conclusions

The fine and equiaxed grains were obtained in the SZ for FSPed samples with the rotating speed from 1300rpm to 1700rpm with the average grain size of 11.82μm, 12.93μm and 14.50μm, respectively.

The FSPed samples had higher ductility and damping capacities compared with the AZ31 base alloy. The ductility and damping values $Q_0^{-1}(\varepsilon=10^{-4})$ and $Q_H^{-1}(\varepsilon=10^{-3})$ of 1500rpm FSPed sample were increased by 121.44%, 5.02% and 7.49 %, respectively.

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