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Research Article

Microstructure and Damping Capacity of ZK60 Alloy Sheets Fabricated by Twin Roll Casting and Hot Rolling Process

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ZK60 magnesium alloy sheets with 0.65 mm thickness were successfully fabricated by twin roll casting (TRC) and subsequent hot rolling process. Fine equiaxed grains were obtained after T6 treatment by the short-term TRC and hot rolling process, and the grain size for different reduction ratio per pass was similar. The studied sheets exhibited high strength and elongation, and the tensile strength, yield strengths, and elongation for the 10% and 30% reduction per pass were above 400 MPa, 300 MPa, and 17.0 %, respectively. The damping capacity values at low strain decreased with increasing the reduction ration per pass and the values at high strain were similar for the different reduction ration per pass. The lower reduction ratio per pass and the heat treatment between rolling passes can improve the mobility of dislocations, which indicated that this process was beneficial for improving damping capacity. Compared with higher reduction ratio per pass, the high tensile properties and damping capacity were obtained by 10% reduction per pass hot rolling process.

1. Introduction

Recently the development of automobile lightweight is a big issue to improve fuel efficiency and to reduce CO_2 emission. The light metals for automotive applications have been widely used, instead of cast iron and traditional steel parts [1]. Aluminum alloys have already obtained the leading role for automotive structural materials [2]. However the application of magnesium for automobile industries is still limited due to low formability. Magnesium alloys with low density and high damping capacity were irreplaceable for automotive structural materials to control vibration.

The twin roll casting (TRC) technique is considered as a cost-efficient process to fabricate several mm thick magnesium alloys strips [3, 4]. The fine microstructure was obtained due to high cooling rate, and mechanical properties of TRC magnesium alloy sheets are significantly higher than those of warm rolling of conventional casting ingots [5, 6]. Therefore, the TRC magnesium alloys would be a candidate for automotive structural materials. The damping capacity for TRC magnesium alloys should be considered. However, the damping capacity of TRC magnesium alloys is seldom discussed.

Therefore, this work aimed to study the high strength and high damping capacity of the magnesium alloy by TRC and subsequent rolling process. The effects of reduction ratio per pass on the microstructure, mechanical properties, and damping capacity were investigated, and the damping mechanism will be discussed.

2. Experimental

The TRC ZK60 alloy strip with chemical composition of Mg-6.72Zn-0.343Zr (wt. %) was used in this study. The as-cast strip was heated to 300°C for 30 min. The rolling was done by heating the rollers to 250°C, and then the strip was rolled at the temperature of 300°C. The strip was reheated to 300°C for 5 min between rolling passes. The reduction ratios for each pass are designed to be 10%, 30%, and 50%, respectively. After a certain number of rolling passes, the thickness of the sheet changed from its original value to 0.65 mm, correspondingly 25 passes, 11 passes, and 8 passes (the thickness evolution

Table 1: The thickness evolution of the sheet during the rolling process.

Redution ratio per pass	**Thickness value after the following pass rolling (mm)**							
	Original thickness	**1**	**4**	**8**	**11**	**15**	**20**	**25**
10%	3.5	3.4	2.64	1.92	1.54	1.14	0.83	**0.65**
30%	3.5	3.14	1.31	0.84	**0.65**			
50%	3.5	2.65	1.04	**0.65**				

Table 2: Mechanical properties and damping capacity of the sheets after T6 treatment.

Reduction ratio per pass	Mechanical properties			Damping capacity	
	UT.S.	Y.S.	EL.	Q^{-1} ($\varepsilon = 10^{-5}$)	Q^{-1} ($\varepsilon = 10^{-3}$)
10%	414±4 MPa	315±13 MPa	17.6 ±3.5 %	0.00702	0.01816
30%	430±13 MPa	301±19 MPa	18.3 ±3.2 %	0.00522	0.01734
50%	382±15 MPa	281±20 MPa	17.8 ±2.6 %	0.00425	0.01759

during the rolling process is shown in Table 1). T6 treatment of hot rolled ZK60 alloy sheet was done at 350°C for 3 h and subsequently water quenched and artificially aged at 175° C for 18 h.

The microstructure of the specimens was examined with a ZEISS optical microscope. The specimens were polished and etched in a solution of picric acid (5 g), acetic acid (5 mL), distilled water (10 mL), and ethanol (100 mL). The dislocation morphology was further examined by a JEM-2100F transmission electron microscope (TEM). The TEM foils were prepared by jet electron polishing using a solution of nitric acid (6%) and ethanol (94%), followed by ion beam thinning. Tensile test was conducted at an ambient temperature on a standard universal testing machine with a crosshead speed of 1.25 mm/min. The sheets along the rolling direction were machined to the subsize tensile specimen of ASTM E8M. Damping samples of 35 mm × 12 mm × 0.65 mm were machined by electric spark cutter. Damping capacity was measured by dynamic mechanical analyzer (NETZSCH DMA-242C) in single-cantilever vibration mode. To determine strain amplitude dependence of damping capacity, the measurement temperature was 25°C. The range of strain amplitude was from $4{\times}10^{-6}$ to 10^{-3}, and the measurement frequency was 1 Hz.

3. Results and Discussion

Figure 1 shows the microstructure of TRC ZK60 sheets with different reduction ration per pass after T6 treatment and average grain size of the studied sheets. Fine equiaxed grains were observed after rolling process and T6 treatment, which indicated that the fine grain structure sheets can be fabricated by short-term TRC and hot rolling process. The grain size for different reduction ration per pass was similar due to the same total reduction.

The tensile properties of the sheets after T6 treatment were shown in Figure 2(a) and Table 2. The tensile strength, yield strengths, and elongation for the 10% and 30% reduction per pass were above 400 MPa, 300 MPa, and 17.0 %, respectively. The high strength and elongation were obtained for the sheets fabricated by TRC and subsequent rolling process. Compared with rolled ZK60 sheets fabricated by conventional casting and hot rolling process [7], the higher strength and equivalent elongation were obtained after TRC and hot rolling process. The similar strength and elongation were obtained with different reduction ration per pass. This was attributed to the similar grain size after the rolling process and heat treatment (as shown in Figure 1(d)). The grain refinement can improve the strength and plasticity [8, 9], and the effect of precipitation hardening was also similar due to the same heat treatment condition [10]. Figure 2(b) shows strain-dependent damping capacity of the sheets. The damping mechanism for magnesium alloys was considered as dislocation type damping [11, 12], which was abided by G-L theory [13, 14]. The damping of the studied sheets can be divided into two components, a strain-independent part Q_0^{-1} at low strain and a strain-dependent part Q_H^{-1} at high strain which increases with rising strain amplitude. The damping capacity values at the low strain of 10^{-5} and at the high strain of 10^{-3} were also shown in Table 2. The damping capacity values at low strain decreased with increasing the reduction ration per pass and the values at high strain were similar for the different reduction ration per pass.

In the lower strains region, the dislocations were pinned by the weak pinning points (i.e., solution atom, vacancies, etc.). The damping capacity at low strain came from the energy dissipation of dislocation movement between weak pinning points [15, 16]. With the increase of stress, the dislocations would bow out until the breakaway stress was reached. Further stress increasing led to the creation and expansion of new dislocations according to Frank-Read mechanism [17]. In the higher strains region, the dislocations were pinned by the strong pinning points (i.e., grain boundaries, network nodes of dislocations, etc.) [18]. Thus the movement of dislocations between strong pinning points contributed the damping capacity at high strain. The damping mechanism for Mg alloys was considered as energy dissipation of dislocation movement, and the distance of dislocation movement had a great influence on damping capacity [19]. The similar grain size means the distance between strong pinning points was similar. Meanwhile, the same T6 treatment condition leads the precipitation distribution that was similar,

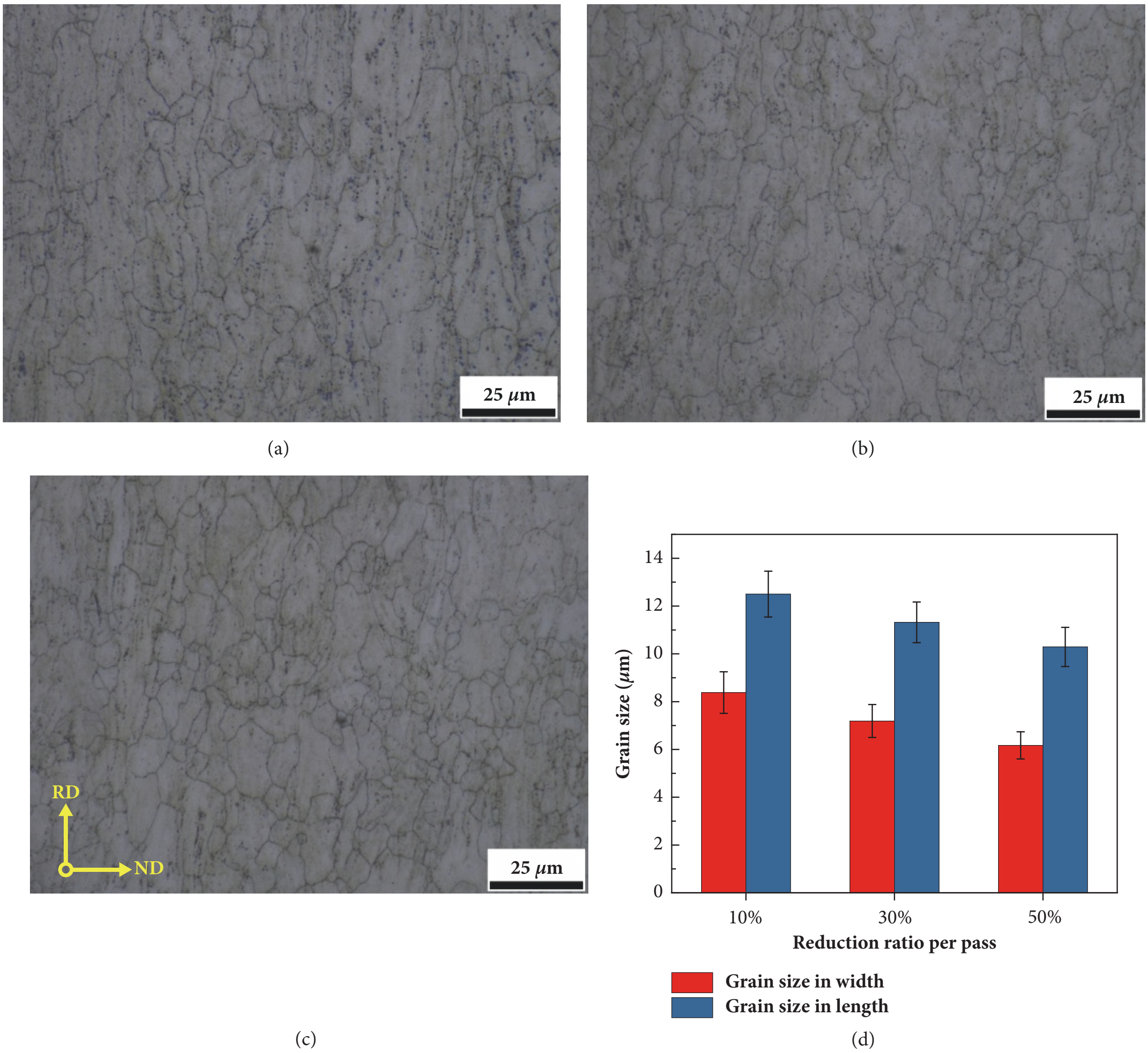


Figure 1: Microstructure for the sheets of (a) 10% reduction per pass, (b) 30% reduction per pass, (c) 50% reduction per pass after T6 treatment, and (d) average grain size of the sheets.

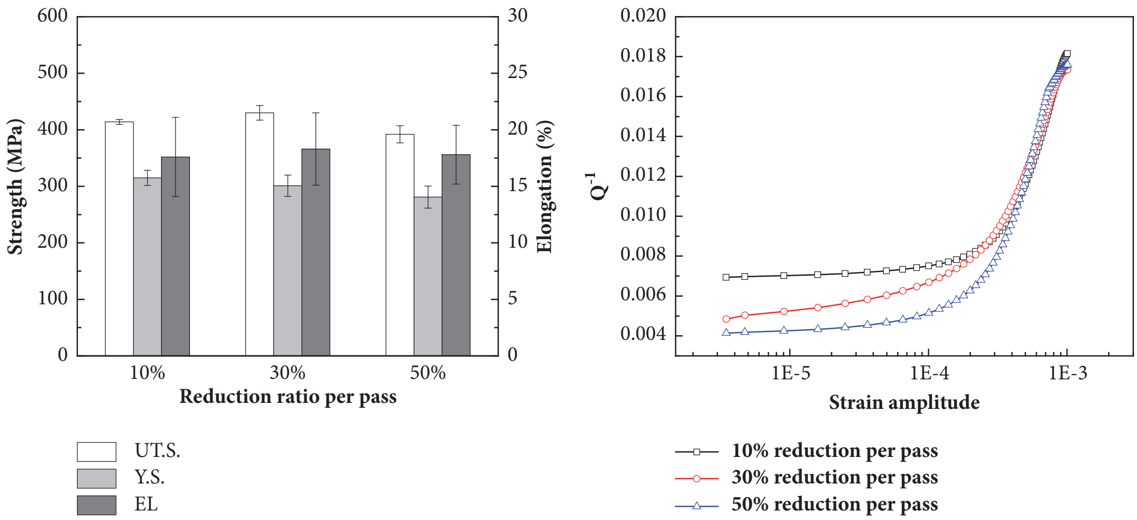
which suggested similar distance between weak pinning points [20]. It was considered that the distance for dislocation movement between weak pinning points or strong pinning points had slight influence on damping capacity of ZK60 sheets for the different reduction ratio per pass. The mobility of dislocations can also affect the damping capacity at the low strain [21]. The dislocations morphology in the sheets for 10% and 50% reduction per pass was shown in Figure 3. A number of tangly dislocations were observed in 50% reduction per pass condition, and the movable dislocations were presented in 10% reduction per pass condition. Lower reduction ratio per pass and the heat treatment between rolling passes can improve the mobility of dislocations, which led to the increasing damping capacity values with decreasing reduction ration per pass. The damping capacity value at high strain was similar, which was attributed to the similar grain size. Compared with higher reduction ratio per pass, the high tensile properties and damping capacity were obtained by 10% reduction per pass hot rolling process.

4. Conclusion

(1) Fine equiaxed grains were obtained after T6 treatment by the short-term TRC and hot rolling process, and the grain size for different reduction ration per pass was similar.

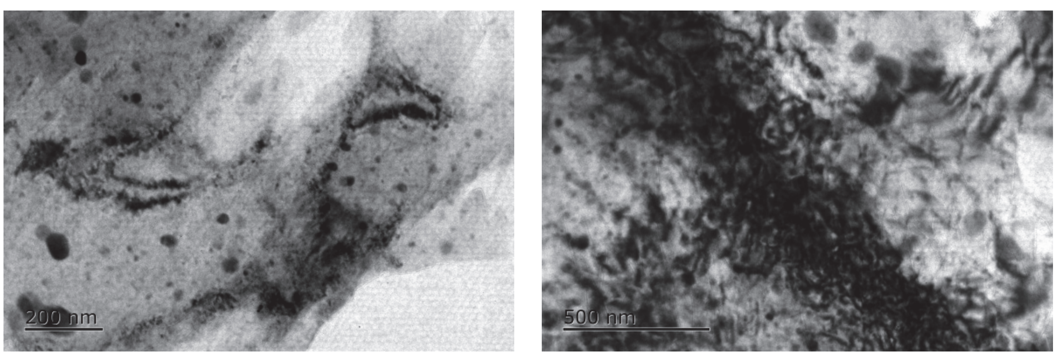
(2) The tensile strength, yield strengths, and elongation for the 10% and 30% reduction per pass were above 400 MPa, 300 MPa, and 17.0 %, respectively. The damping capacity values at low strain decreased with increasing the reduction ration per pass and the values at high strain were similar for the different reduction ration per pass.

(3) Compared with higher reduction ratio per pass, the high tensile properties and damping capacity were obtained by 10% reduction per pass hot rolling process.



(a) (b)

Figure 2: (a) Strain-dependent damping capacity and (b) tensile properties of the sheets after T6 treatment.



(a) (b)

Figure 3: Dislocations morphology in the sheets after T6 treatment: (a) 10% reduction per pass and (b) 50% reduction per pass.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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