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Contributed Paper

Effect of Heat Treatment on High Temperature Damping Capacity of ZK60 Sheet Produced by Twin-roll Casting and Hot-rolling

Chen Hongmei* [a], Liu Zhongming [a], Zang Qianhao [a, b], Yu Xin [a], Zhang Jing [c] and Jin Yunxue [a]

[a] Provincial Key Lab of Advanced Welding Technology, Jiangsu University of Science and Technology, Zhenjiang, 212003, China.

[b] Key Laboratory for Liquid-Solid Structural Evolution & Processing of Materials, Ministry of Education,, Shandong University, Jinan 250061,China.

[c] School of Metallurgical and Materials Engineering, Jiangsu University of Science and Technology, Zhangjiagang, 215600, China.

*Author for correspondence; e-mail: hmchen@just.edu.cn

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ABSTRACT

ZK60 alloy sheet with 1mm thickness which produced by twin roll casting and hot rolling was used in this paper. The effect of heat treatment on microstructure and damping capacity of the hot rolled ZK60 alloy sheet was studied by using optical microscope (OM) and dynamic mechanical analyzer (DMA). The microstructure of as rolled ZK60 alloy sheet was fibrous deformed structure with elongated grains, with a high density of shear bands along the rolling direction. The small and equiaxed recrystallized grains were obtained after annealing treatment, T4 and T6 treatment in hot rolled ZK60 alloy sheet. There is no P2 (around 280°C) damping peak in the hot rolled ZK60 alloy sheet. The damping peak P0 (around 50°C) was present in hot rolled ZK60 alloy sheet after annealing treatment. The damping peak P1 (around 150°C) was present in hot rolled ZK60 alloy sheet before and after heat treatment. The damping peaks P0 and P2 were not relaxation processes, but the damping peak P1 was relaxation processes. The activation energy for high temperature damping background (HTDB) after T6 treatment was higher than that after T4 treatment. The values of activation energy for high temperature damping background (HTDB) and damping peak P1 after annealing treatment was the lowest among different heat treatment.

Keywords: microstructure, damping peak, high temperature damping background, activation energy

1. INTRODUCTION

Magnesium alloys are the lightest structural material[1,2], with high specific strength, high specific elastic modulus and high damping capacity. Magnesium alloys are becoming increasingly attractive for a widely use in various fields[3]. The twin roll cast (designated as TRC in short) technique[4,5] has been applied to manufacture magnesium alloy strips. Compared to traditional casting, twin roll casting can produce strips with higher solid supersaturation, finer microstructure, dispersed compounds and lighter element segregation.

Pure magnesium has the best damping capacity, but with poor mechanical properties. Therefore, higher strength and higher damping of magnesium alloys can be achieved through alloying or plastic deformation to meet the needs of modern industrial engineering.

In many magnesium alloys, the internal friction presents a high temperature damping background(HTDB)[6]. The damping increases exponentially with increasing of temperature at constant measuring frequency. Meanwhile, damping peaks were observed for a temperature-dependent damping test. The damping peaks play an important role in the magnesium alloys with high damping capacity[7].

The effect of hot rolling technique and heat treatment on the microstructure and high temperature damping capacities of TRC ZK60 alloy sheet was studied in this paper.

2. EXPERIMENTAL

The material used in this study was TRC and hot rolled ZK60 alloy sheet. The chemical composition of the ZK60 alloy sheet was analyzed as 6.72Zn-0.343Zr-Mg balance in weight percent by Optical Emission Spectrometer (SPECTRO MAXx) apparatus. The as-cast strip was heated to 300°C for 30min, and rolled at the temperature of 300°C with the rollers heated to 250°C, and reheated again to 300°C for 10 min to maintain the the sheet temperature at about the rolling temperature during other inter-pass rolling processes. The rolling reduction ratio was 50% per pass. This process was continually carried out over four passes to reduce the strip thickness to 1mm. Annealing heat treatment of hot rolled ZK60 alloy sheet was done at 350°C for 103s. T4 treatment was done at 375°C for 3hrs and subsequently artificial aging, the artificial aging heat treatment was performed at 175°C for 18hrs.

For optical examination, the samples were sectioned, cold mounted, polished by silicon dioxide paste with grain size of 1 μm and finally etched in picric acid (5 g), acetic acid (5 ml), distilled water (10 ml) and ethanol (100 ml) solution. Damping samples were machined to dimensions of 35mm×12mm×1mm. Damping capacity was measured by dynamic mechanical analyzer (NETZSCH DMA-242C) in single cantilever deformation mode. The measurement frequencies were 0.5 Hz, 1Hz, 5 Hz and 10 Hz, respectively. The temperature range was from 25°C to 400°C and the heating rate was 5°C/min.

3. RESULTS AND DISCUSSION

3.1 Microstructure

The microstructure of hot rolled ZK60 alloy sheet was fibrous deformation structure with elongated grains and high density of shear bands along the rolling direction (Figure 1a). The small and equiaxed recrystallized grains were obtained after annealed at 350°C for 10^3s in hot rolled ZK60 alloy sheet (Figure 1b). The microstructure of hot rolled ZK60 alloy after T4 treatment (375°C× 3hrs) was homogenized (Figure 1.c). The mall and equiaxed recrystallized grains was present after T6 treatment (375°C× 3 hrs+175°C× 18 hrs) (Figure 1d).

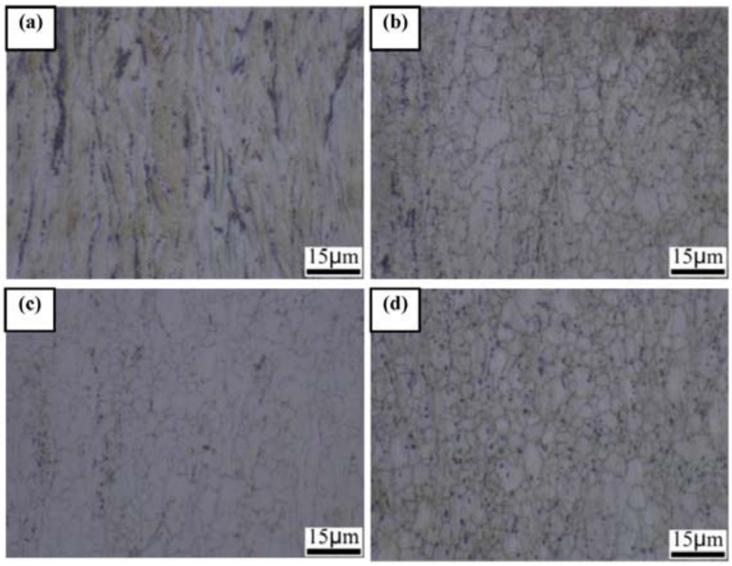

Figure 1. Microstructure of hot rolled ZK60 alloy sheet at various treatment: (a) as rolled sheet; (b) Annealing treatment; (c) T4 treatment; (d) T6 treatment

3.2 High Temperature Damping Capacity

Temperature-dependent damping capacity of hot rolled ZK60 sheet after different heat treatment (the measurement frequencies f=1 Hz) were shown in Figure 2. The curves of hot rolled ZK60 alloy sheet had two peaks (P_1 were around 150°C, P_2 were around 300°C)(shown in Figure 2). The curves of temperature-dependent damping capacity of hot rolled ZK60 sheet only had the damping peak P_1 (shown in Figure 2). The damping peak P_2 is a recrystallization damping peak. The damping peak P_2 after hot rolling was restrained by the fibrous deformation structure. Temperature-dependent damping capacity of hot rolled ZK60 sheet after different heat treatment with different measurement frequencies (the measurement frequencies f=0.5 Hz, 1 Hz, 5 Hz and 10 Hz) were shown in Figure 3. The damping peak P_1 is a relaxation process, but the damping peak P_2 is not a relaxing process [8]. The curves of temperature-dependent damping capacity of hot rolled ZK60 sheet after annealing treatment also had the damping peak P_0 (shown in Figure 3c). The damping peak P_0 is not a relaxing process, and it mainly attributes to the damping values increased caused by increasing the temperature. The dislocation could break away from pinning point more easily with increasing the temperature from room temperature to 50°C.

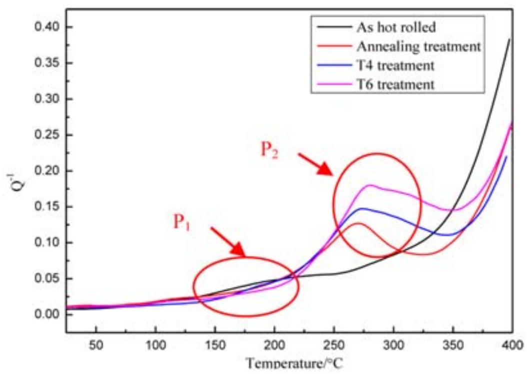

Figure 2. Temperature-dependent damping capacity of hot rolled ZK60 sheet at various treatment

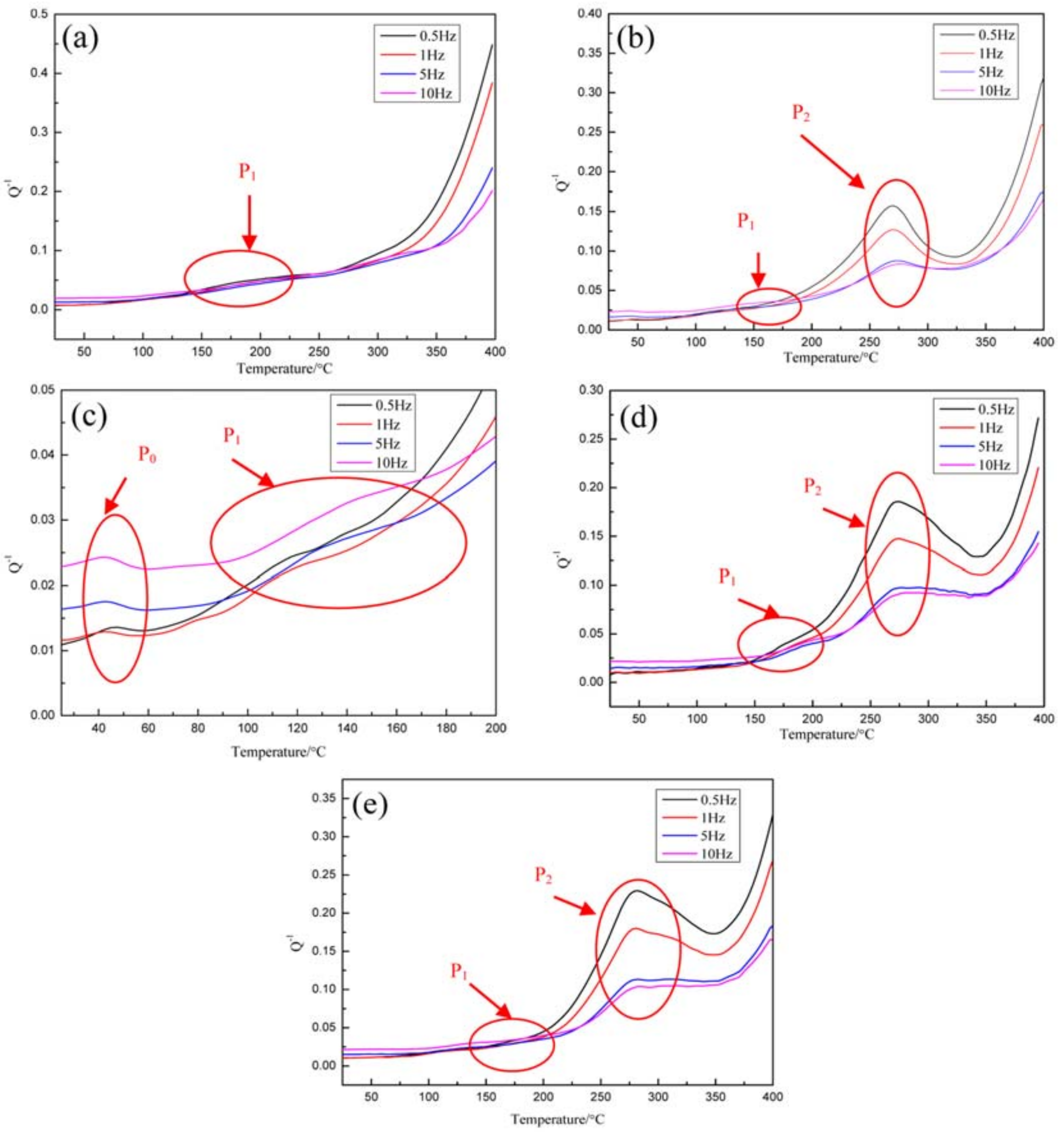

Figure 3. Temperature-dependent damping capacity of hot rolled ZK60 sheet at various treatment with different measurement frequencies (f=0.5, 1, 5, 10Hz): (a) as rolled sheet; (b) annealing treatment; (c) at low temperature after annealing treatment (d) T4 treatment; (e) T6 treatment.

The relaxing process is content to Arrhenius equation[9]:

$$\tau = \tau_0 e^{H/kT} \quad (1)$$

Where the τ is the relaxation time, the $\tau 0$ is exponent factor, the k is the Boltzmann constant, the H is activation energy, the ω is the angular frequency ($\omega=2\pi f$, f is the applied frequency), and the T is the absolute temperature. When the T is the temperature of damping peak (TP), $\omega\tau = 1$. The following equation can be obtained from Eq(1):

$$\ln\omega + \ln\tau_0 + \frac{H}{k} \times \frac{1}{T_p} = 0 \quad (2)$$

The activation energy H can be calculated by the slope of lnω-1000/T_p. For the future fitting (shown in Figure 4), The activation energy H for P1 of hot rolled ZK60 sheet was shown in Table 1. The activation energy values of as hot rolled, T4 treatment and T6 treatment were beyond grain boundary diffusion energy (92 KJ/mol) and lattice self-diffusion energy (135 KJ/mol)[10] of magnesium. The process of boundary slipping was more difficult than that after annealing treatment.

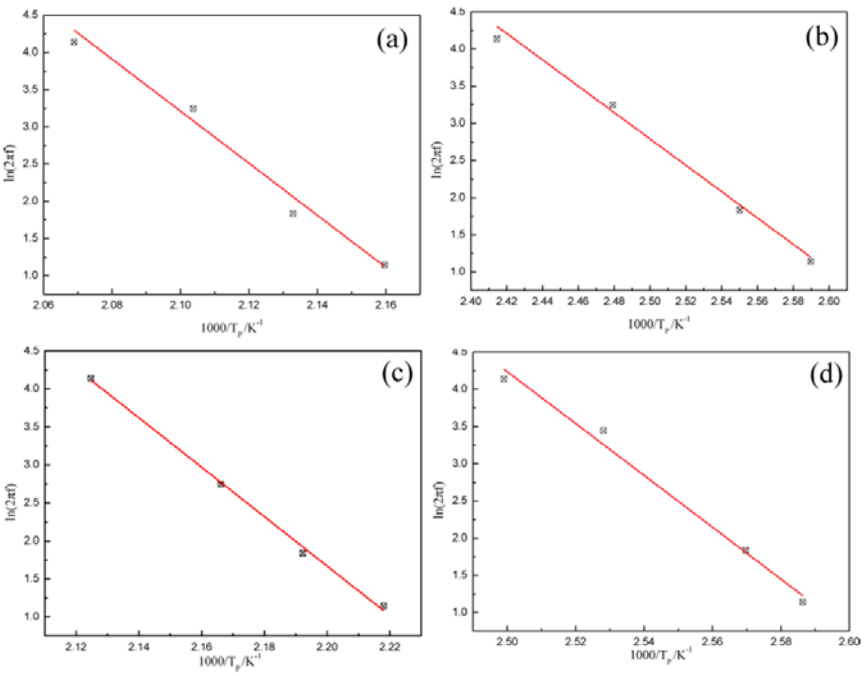

Figure 4. Arrhenius plot between frequency and peak temperature for P1 of hot rolled ZK60 sheet at various heat treatment: (a) as rolled sheet; (b) annealing treatment; (c) T4 treatment; (d) T6 treatment.

Table 1. The activation energy H for P_1 of hot rolled ZK60 sheet.

Treatment	As hot rolled	annealing	T4 treatment	T6 treatment
H(KJ/mol)	291	111	270	290

Temperature-dependent damping capacity contains two parts: the athermal damping background (ADB) and the exponential damping background. The exponential damping background is named as high-temperature damping background (HTDB). The temperature-dependent damping capacity can be described by Schoeck's equation as[11]:

$$Q^{-1}(T) = Q^{-1}_{at} + \frac{K}{[\omega\exp(H/kT)]^{n}} \qquad (3)$$

Where Q^{-1}_{at} is the damping capacity of the ADBH is the activation energy, ω is the angular frequency (ω=2πf, f is the applied frequency), k is the Boltzmann constant, T is the absolute temperature, n and K are constants. For the analysis of the experimental data, it is convenient to use the logarithmic representation of Eq.(3).

$$\ln[Q^{-1}(T) - Q^{-1}_{at}] = \ln K - n\ln\omega - \frac{nH}{kT} \quad (4)$$

The parameter n can be calculated from the slope of a straight line in the $\ln[Q^{-1}(T) - Q^{-1}_{at}]$ versus lnω plot at constant temperature. The temperatures were selected at 250°C, 260°C and 270°C. The Q^{-1}_{at} is the damping capacity of the ADB measured at 0.5Hz and 25°C. The n values measured at different temperature can be determined, and then take the average of the n values. When lnω = 0, the parameter nH/k can be calculated from the slope of a straight line in the $\ln[Q^{-1}(T) - Q^{-1}_{at}]|_{\ln\omega = 0}$ versus 1000/T plot. Figure 5 and Figure 6 are the $\ln[Q^{-1}(T) - Q^{-1}_{at}]$ versus lnω plot and the versus 1000/T plot after annealing treatment, respectively. The n values and H values after different heat treatment are shown in Table 2.

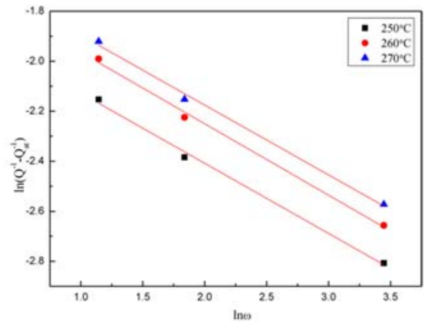

Figure 5. The plot of $\ln[Q^{-1}(T) - Q^{-1}_{at}]$ versus lnω after annealing treatment

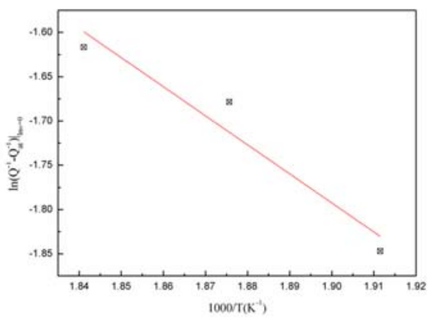

Figure 6. The plot $\ln[Q^{-1}(T) - Q^{-1}_{at}]|_{\ln\omega = 0}$ versus 1000/T after annealing treatment

Table 2. Values of n and H for HTDB of TRC ZK60 alloy

Treatment	Annealing	T4	T6
n	0.28179	0.29434	0.32505
H(KJ/mol)	97	118	152

The activation energy H of high temperature damping background (HTDB) decreased after artificial aging treatment. The dislocation climb controlled by lattice self-diffusion made contribution to the HTDB[12]. The dislocation climb controlled by lattice self-diffusion was more difficult because of the increase of the activation energy. The process of lattice self-diffusion is more easily after annealing treatment.

4. Conclusions

(1) The small and equiaxed recrystallized grains were obtained after annealed at 350°C for 10^3s. The microstructure of hot rolled ZK60 alloy after T4 treatment and T6 treatment was homogenized. The small and equiaxed recrystallized grains was present after T4 treatment and T6 treatment.

(2) The damping peaks P_0 and P_2 were not relaxation processes, but the damping peak P1 was relaxation processes.

(3) The activation energy for high temperature damping background (HTDB) after T6 treatment was higher than that after T4 treatment. The values of activation energy for high temperature damping background (HTDB) and damping peak P_1 after annealing treatment were the lowest among different heat treatment.

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REFERENCES

[1] Nie J.F., *Metall. Mater. Trans. A*, 2012; **43**: 3891-3939.

[2] Zhang Y., Wu Y.J. and Peng L.M, *J. Alloys Compd.*, 2014; **615**: 703-711.

[3] Yu H., Kim Y.M. and You B.S., *Mater. Sci. Eng. A*, 2013; **559**:798-807.

[4] Chen H.M., Yu H.S. and Kang S.B., *Mater. Sci. Eng. A*, 2010; **527**: 1236-1242.

[5] Wang Y.N., Kang S.B. and Cho J.H., *J. Mater. Process. Technol.*, 2010; **210**: 1270-1275.

[6] Wu S.K., Chang S.H. and Tsia H.Y. Bor, *Mater. Sci. Eng. A*, 2011; **528**: 6020-6025.

[7] Hu X.S., Zhang Y.K. and Zheng M.Y., *Scr. Mater.*, 2005; **52**: 1141-1145.

[8] Wu Y.W., Wu K. and Deng K.K., *Mater. Des.*, 2010; **31**: 4862-4865.

[9] Wang D.Q. and Wang J.C., *Mater. Lett.*, 2009; **63**: 391-393.

[10] Wu Y.W., Wu K. and Deng K.K., *Mater. Sci. Eng. A*, 2010; **527**: 6816-6821.

[11] Schoeck G., Bisogni E. and Shyne J., *Acta Metall.*, 1964; **12**: 1466-1468.

[12] Weller M., Clemens H. and Haneczok G., *Mater. Sci. Eng. A*, 2006; **442**: 138-141.