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ARTICLE

Internal Friction Peaks in Mg-0.6% Zr and Mg-Ni High Damping Magnesium Alloys

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Abstract: A broad relaxation peak, which contributes to the high damping capacity around room temperature, has been obtained in all high damping magnesium alloys. This peak is a dislocation-related relaxation peak, which is probably caused by the interaction between dislocation and point defects (vacancy and solid atoms) during the dislocation movement on the basal plane activated by heat. The grain boundary relaxation peak also has been observed in both Mg-Ni and Mg-0.6%Zr high damping alloys. However, it is necessary to point out that microstructure can affect the gain boundary relaxation. With Ni content increasing, the grain is refined and the grain boundary internal friction peak shifts to lower temperature. Compared with Mg-0.6%Zr alloy, the grain boundary internal friction peak shifts to higher temperature after adding a little yttrium (Y).

Key words: high damping; magnesium alloys; internal friction

The Mg-based high-damping alloy is one of the most potential materials served in the aeronautics, astronautics, missile and other important fields of high-technological military industry, as it combines excellent properties of high specific strength, high specific stiffness and outstanding damping capacity[1]. As we know, pure Mg exhibits extraordinary high damping properties but the low strength of pure Mg restricts its practical applications. Therefore, research focused on the damping capacity of Mg alloys[2]. Mg-Zr and Mg-Ni alloys have been found both combining high damping capacity and good mechanical properties, which are of great potential as damping materials[3-5]. Obviously, there is difference between their microstructure that Mg-Zr alloy belongs to peritectic type alloy while Mg-Ni alloy belongs to the eutectic type alloy. However, the previous internal friction study on those alloys could not provide such information as why those alloys with different microstructures could both obtain high damping capacity at room temperature; hence, it is necessary to reveal the internal friction mechanism of those high damping alloys. Thus, in this work, it will focus on the illustration of internal friction peaks observed in Mg-0.6%Zr and Mg-Ni high damping magnesium alloys.

1 Experiment

The high damping Mg-0.6%Zr and Mg-Ni series of hypo-eutectic alloys were fabricated from melting pure magnesium (99.5%), Mg-10wt%Zr master alloy and Mg-25wt%Ni master alloy in an electric-resistance furnace at 700 ℃. The melt was melted under the protection against CO_2+0.5vol%SF6 mixed gas and then poured into a steel model for cooling. The internal friction (IF) of the alloys was tested by dynamic thermomechanical analysis (DMA). The test-pieces for damping measurement were properly installed in the clamping heads. The resulting sinusoidal force and deflection data were recorded and the internal friction were evaluated by the loss tangent ($\tan\phi$), which was calculated from Eq.(1).

$$Q^{-1}=\tan\phi= E''/ E' \quad (1)$$

where E'' is the loss modulus, E' is the storage modulus[6]. The strain amplitude is 4E-05 and the tested frequencies are from 0.5 Hz to 10 Hz, as well as the tested temperature is from 200 K to 693 K with heating rate 3 K/min.

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2 Results and Discussion

2.1 Internal friction of Mg-Ni alloys

Fig.1 shows the IF spectrum of Mg-3%Ni hypoeutectic alloy. Two IF peaks are observed: the first peak (P1) is in the range of 300 K to 400 K; the second peak (P2) appears from 500 K to 550 K. Both peaks move toward higher temperature as the frequency increases, which indicates this relaxation is a thermal-activated relaxation; the thermal-activated relaxation could be explained by Arrhenius equation, which is described as follows: [7]

$$f = f_0 \exp(-H / kT_p) \quad (2)$$

where, f is frequency, f_0 is a constant, H is activation energy, k is the Boltzmann constant, and T_P is the peak temperature. The logarithm transformation was applied to Eq.(1) , which can be described as Eq.(3).

$$\ln f = \ln f_0 - \frac{H}{kT_p} \quad (3)$$

If the peak temperature values of different frequencies were determined, according to Eq.(3), the activation energy could be calculated. Peak Fit V4.12 software was employed to find out the exact value of the peak temperatures, and the results are shown in Table 1. Fig.2 shows the Arrhenius plots for P1 and P2 to Mg-3%Ni alloy. The activation energy is calculated to be 0.2 eV for P1 and 1.29 eV for P2. The activation energy for P1 is close to dislocation-solute atom interaction energy, so P1 is the dislocation related peak[8]. In the previous work by Hu, a damping peak was detected in Mg-Ni alloys at about 100 ℃, which is believed to be caused by the movement of dislocation. The sliding of grain boundaries creates P2 at 230 ℃; however, the activation energy was not calculated[2]. The activation energy calculated by us of P2 is similar to the grain boundary relaxation energy of pure magnesium, which can be a grain boundary IF peak[9].

The dislocation relaxation is actually complicated in pure magnesium and magnesium alloys. Up to recent, some peaks even have not been properly illustrated. It is strongly related to the purity and processing history to the magnesium alloys[10,11]. Tsui[8] observed a wide peak covered from 20 K to 240 K in pure magnesium, which is considered as an overlapped peak, consisting of some sub peaks, because the activation energy has a certain distribution leading to be a wide peak. Based on the above analysis, the P1 in as-cast high damping Mg-Ni alloys is very wide, which might be associated with dislocation movement in the basal plan and the broad peak was thought to be formed by several sub peaks with different activation energies distribution. Low-temperature subpeak is considered to be caused by the interaction between dislocation and vacancy; high-temperature subpeak is believed to be caused by interaction between dislocation and solute atoms caused by thermal depinning.

Grain boundary internal friction is caused by grain sliding in a transition layer of adjacent grains[9]. Grain boundary IF peak is famous for Ke peak, which is observed at medium temperature in polycrystalline pure Al [9]. Grain

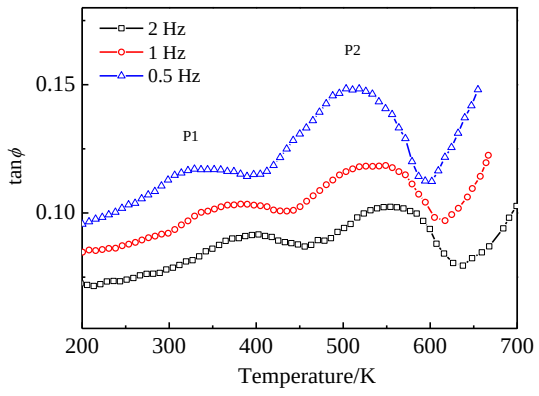

Fig.1 Damping as a function of temperature from 200 K to 693 K

Table 1 Peak temperature (T_{P1}, T_{P2}) of internal friction peak at different frequencies for Mg-3%Ni alloy

Frequency/Hz	T_{P1}/K	T_{P2}/K
0.5	327	508
1	363	521
2	401	533

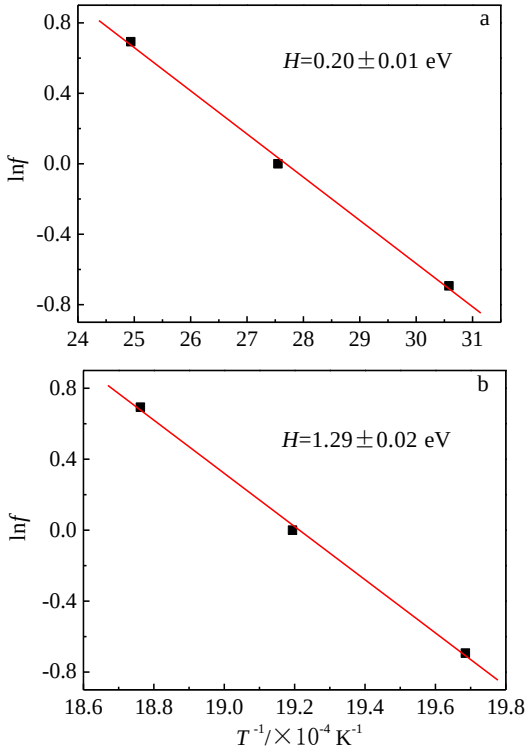

Fig.2 Arrhenius plots of P1 (a) and P2 (b) peaks for Mg-3%Ni alloy

boundary IF and peak is affected by a number of factors, such as grain size and grain boundary segregation. Table 2 lists grain boundary IF peak temperature of Mg-Ni hypoeutectic alloys with different Ni contents. The testing frequency is 1 Hz and the strain amplitude is 4E-05. It was found that when the Ni content is more, the grain boundary IF peak moves to lower temperature. Sugimoto[3] showed that the more the Ni, the finer the grains of Mg-Ni hypoeutectic alloy. Effect of the grain size on grain boundary IF peak can be illustrated by Eq.(4) [9].

$$t = \frac{\mu}{G(T)d_0} L \quad (4)$$

where t is the relaxation time; μ is the viscosity coefficient; $G(T)$ is shear modulus; d_0 is the thickness of grain boundaries; L is the interface area, approximately equal to the average grain size. Thus, the refined grains cause grain boundary IF peak offset to lower temperature.

2.2 Internal friction of Mg-0.6%Zr alloy

The IF spectrum of the material is close to the microstructure of the material. Zr-rich core could be produced during peritectic reaction in Mg-0.6%Zr alloys, which could affect IF of this alloy. Fig.3a shows IF spectrum of Mg-0.6%Zr alloy. Two peaks are also observed throughout the testing temperature ranges. Similarly, the first wide peak is observed in the range from 200 to 400 K. The second peak is located from 500 to 600 K. The peaks moves to high temperature and it decreases with increasing frequency. Yttrium (Y) is one of an important alloy elements in magnesium alloys, which could easily dissolve into the matrix. Hence, Mg-Zr-Y alloy was selected as reference. Fig.3b shows the IF spectrum of Mg-0.6%Zr- 0.5%Y. Similar to Mg-0.6%Zr alloy, in the range of 200 to 650 K, it has two IF peaks. However, the first peak is wider than Mg-0.6%Zr peak, which indicates that the solid solution atoms will affect the internal friction peak shape; the second peak temperature is slightly higher than Mg-0.6%Zr.

The IF spectrum at 2Hz of both alloys is amplified in Fig.4. As it seen, in terms of the Mg-0.6%Zr-0.5%Y alloy, P1 peak is significantly wider than that of the Mg-0.6%Zr, which further illustrates solute atoms will affect the shape of P1. As mentioned, the P1 may consist of a number of subpeaks, each peak exhibits difference due to their activation energies, the higher temperature peak is believed to be caused by thermal depinning of solute atoms from dislocation.

The higher temperature IF peak of Mg-0.6%Zr and Mg-0.6%Zr-0.5%Y alloys are grain boundary IF peaks;

Table 2 Peak temperature of grain boundary internal friction peak at 1 Hz for Mg-Ni alloys (K)

Mg-3%Ni	Mg-6%Ni	Mg-10%Ni
521	516	508

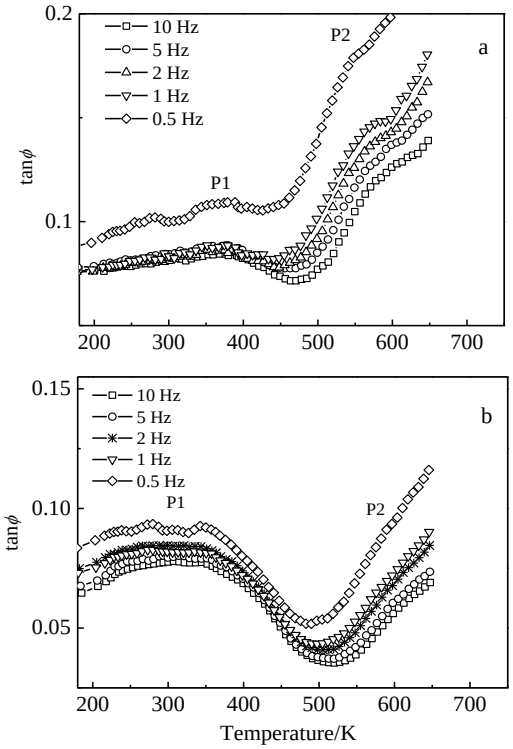

Fig.3 Temperature dependent damping of as-cast Mg-0.6Zr (a) and Mg-0.6%Zr-0.5%Y (b) alloys

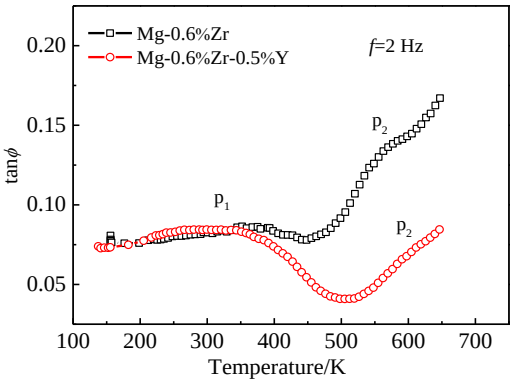

Fig.4 Temperature dependent damping of as-cast Mg-0.6%Zr and Mg-0.6%Zr-0.5%Y alloys at 2 Hz

peak temperature values at different frequencies are shown in Table 3. Basically, the maximum value of grain boundary IF is influenced by the amount of the impurity atoms; because the solute atoms segregation in grain boundary often prevents the grain boundaries sliding[9].

Fig.5 shows Arrhenius plots of grain boundary IF peak of Mg-0.6%Zr and Mg-0.6%Zr-0.5%Y alloys. The activation energy is calculated to be 1.33 eV for Mg-0.6%Zr alloys, which is close to the volume diffusion activation energy in pure magnesium, and the activation energy is 2 eV for Mg-0.6%Zr-0.5%Y, which is greater than the activation energy of pure magnesium grain boundaries sliding. For the peritectic type Mg-0.6%Zr alloy, because most Zr is of Zr-

Table 3 Peak temperature of grain boundary internal friction peaks at different frequencies for two alloys

Frequency/Hz	*T*(Mg-0.6%Zr)/K	*T*(Mg-0.6%Zr-0.5%Y)/K
0.5	537	583
1	547	593
2	563	605
5	584	618
10	596	630

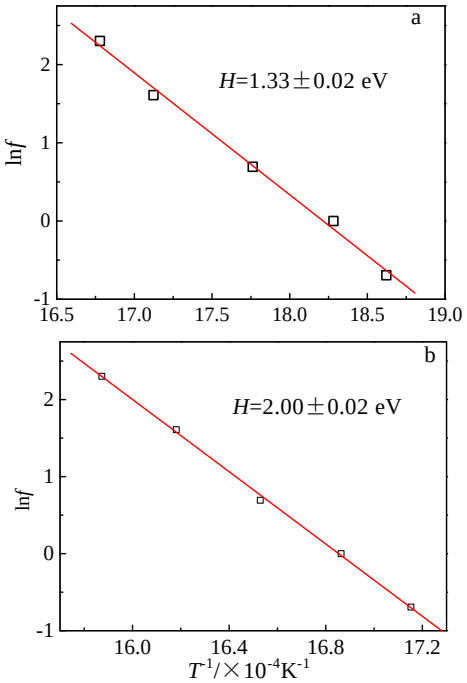

Fig.5 Arrhenius plots for Mg-0.6%Zr (a) and Mg-0.6%Zr-0.5%Y (b) alloys grain boundary internal friction peaks

core existing, little Zr segregation appears to grain boundaries, the dissolution of trace Zr on grain boundary effects is rare, thus activation energy is close to pure Mg. In terms of Mg-0.6%Zr-0.5%Y alloys, Y could segregate to grain boundaries, which must have the pinning effect, increasing the relaxation time, and the activation can also have a certain degree of increase in grain boundary.

3 Conclusions

1) The basic reason is revealed for the high damping capacity for Mg-Ni and Mg-Zr is a very broad relaxation peak around room temperature. This peak is probably caused by the dislocation movement on the basal plane activated by thermal activation.

2) The broad peak is superposition relaxation peak, in which the dislocation-vacancy related subpeak is located lower temperature than that of the dislocation-solid atoms subpeak due to the lower activation energy.

3) The grain boundary relaxation has been observed in both Mg-Ni and Mg-0.6%Zr high damping alloys. The activation energy of grain boundary is calculated to be 1.29 eV for Mg-3%Ni and 1.33 eV for Mg-0.6%Zr alloy, which is close to the volume diffusion activation energy of pure magnesium.

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高阻尼镁合金 Mg-0.6%Zr 和 Mg-Ni 中内耗峰分析

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摘 要：在高阻尼镁合金研究中，发现了与合金室温下高阻尼性能有关的宽弛豫内耗峰，该峰为位错内耗峰；弛豫内耗峰是基面位错在热激活作用下运动与点缺陷（空位与溶质原子）相互作用产生的。同时在高阻尼合金Mg-Ni和Mg-0.6%Zr中发现了晶界内耗峰。有必要指出的是合金的显微组织会影响晶界弛豫：随着Ni质量分数增加，晶粒细化同时晶界内耗峰向低温处迁移；同Mg-0.6%Zr合金相比，加入少量的Y后, Mg-0.6%Zr-Y合金晶界弛豫峰向高温处推进。

关键词：高阻尼；镁合金；内耗峰

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