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Study on Damping Capacities of ZK60-2.8Nd Magnesium Alloy

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Abstract. Damping properties of ZK60-2.8Nd magnesium alloys as-cast, solution and extrusion were investigated by dynamic mechanical thermal analyzer. The results show that ZK60-2.8Nd magnesium alloy extrusion and solution exhibit almost the same strain independent damping value as that of alloy as-cast, the critical strain amplitude is about 5×10^{-5}. Solution treatment effects the distribution of solution atoms, and dynamic re-crystallization during the hot extrusion increases movable dislocation density ρ, which makes the dislocations easier to move on the basal plane. Within the strain range of $5\times10^{-5}\leq\varepsilon\leq4\times10^{-4}$, the strain dependent damping value of ZK60-2.8Nd magnesium alloy as-solution is the highest, and that of the alloy as-cast is the least due to the grain sizes increase of the alloy as-solution and dynamic re-crystallization of the alloy as-extrusion leading the increase of movable dislocation density. Within scope of the experiment, the maximum damping value of alloy as-cast, solution and extrusion is 0.03371, 0.01546 and 0.01392, respectively.

1. Introduction

Lightweight structure design has been an increasingly outstanding status in modern industries, and magnesium alloys have been widely used with their high strength and good damping performance [1]. However, pure magnesium exhibits extraordinary high damping properties but poor mechanical properties [2]. At present, there are many high strength magnesium alloys reported on processing technology, mechanical properties and strengthening mechanism, etc. [3-7]. For many years, there are more and more reported on damping properties of high strength magnesium alloys, including Mg-Al alloy such as AZ31, AZ61, AZ80, Mg-Zn alloy such as ZK60, Mg-Re alloy such QE22, WE43 [8-12]. However, there are various factors effecting on damping properties of magnesium alloy including alloy elements, grain size and grain orientation, heat treatment and deformation, strain amplitude and temperature. Meantime, damping mechanism of the magnesium is rather complex [13-18]. The rare earth neodymium (Nd) can reinforce magnesium alloy at room temperature and high temperature which makes the magnesium alloy containing Nd present good application prospect [19]. Therefore, in this investigation, the magnesium alloy containing Nd is to be prepared to test the damping performance, which would be useful for the further analysis of the damping mechanism and obtaining high strength and high damping magnesium alloy.

2. Experiments

The testing alloys were prepared from commercial Mg (99.96%), Zn (99.91%), Mg-29.98%Nd and Mg-30.96%Zr master alloys in an electric resistance furnace under the protection of mixed SF_6 and CO_2 protection atmosphere with the ratio of 100:1. The ingots with a cylindrical mould of Φ60 mm × 135 mm were on solution treatment at 420℃ for 24h, and then quenched into water at room temperature. Then hot extrusion samples were conducted at 360℃ with extrusion ratio 16:1. The chemical compositions of these Mg alloys are given in Table 1.

Table 1. Chemical compositions of test alloys (mass fraction, %)

	Mg	Zn	Nd	Zr
ZK60-2.8Nd	91.21	5.50	2.75	0.54

Microstructure observation was conducted on a POLYVAR-MET optical microscope. The phase analysis was carried out by D/MAX2500PC X ray diffractometry (XRD) with copper target.

The damping capacity was determined by $Q^{-1} = \tan\varphi$. The specimens for damping measurements with dimensions of 38 mm×6 mm×1 mm were machined out by an electric spark cutting method. The damping tests were carried out using a TA Q800DMA.

3. Results and discussion

3.1. Microstructures

Fig.1 shows the XRD patterns of the alloy as-cast, solution and extrusion. There are three phases in three states of ZK60-2.8Nd alloy including α-Mg, MgNdZn and MgZn phases.

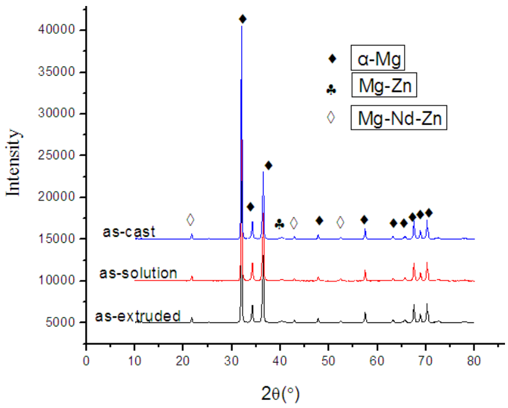

Figure 1. XRD patterns of ZK60-2.8Nd magnesium alloys.

Fig.2 shows the microstructure of the testing alloys as-cast, solution and extrusion. The microstructure of the as-cast alloy is comprised of dendrites of magnesium matrix phases separated by the continuous or discontinuous networks of eutectic compounds. The average grain sizes are measured to be about 35 μm for ZK60-2.8Nd alloy, shown in Fig.2 (a). Considering the Fig. 1 showed the XRD patterns of the alloys as cast, the continuous or discontinuous networks of eutectic compounds may be MgNdZn and MgZn phases.

It is found that the continuity of eutectic networks is seemingly weakened after solution treatment, and the average grain sizes increase a little, about 40 μm, seen in Fig.2 (b).

The microstructures of the ZK60-2.8Nd alloy as-extruded are shown by the optical micrographs in Fig.2 (c). It shows the average grain sizes of 10 μm, grain refinement much more than that of alloy as-cast and solution.

Grain sizes of three states of ZK60-2.8Nd alloy are listed in Table 2.

Table 2. Grain size of three states of ZK60-2.8Nd alloy (μm)

	As-cast	As-solution	As- extrusion
Grain size	35	40	10

3.2. Damping capacities

Strain amplitude dependence of damping capacity in ZK60-2.8Nd magnesium alloys as-cast, solution and extrusion are shown in Fig.3.

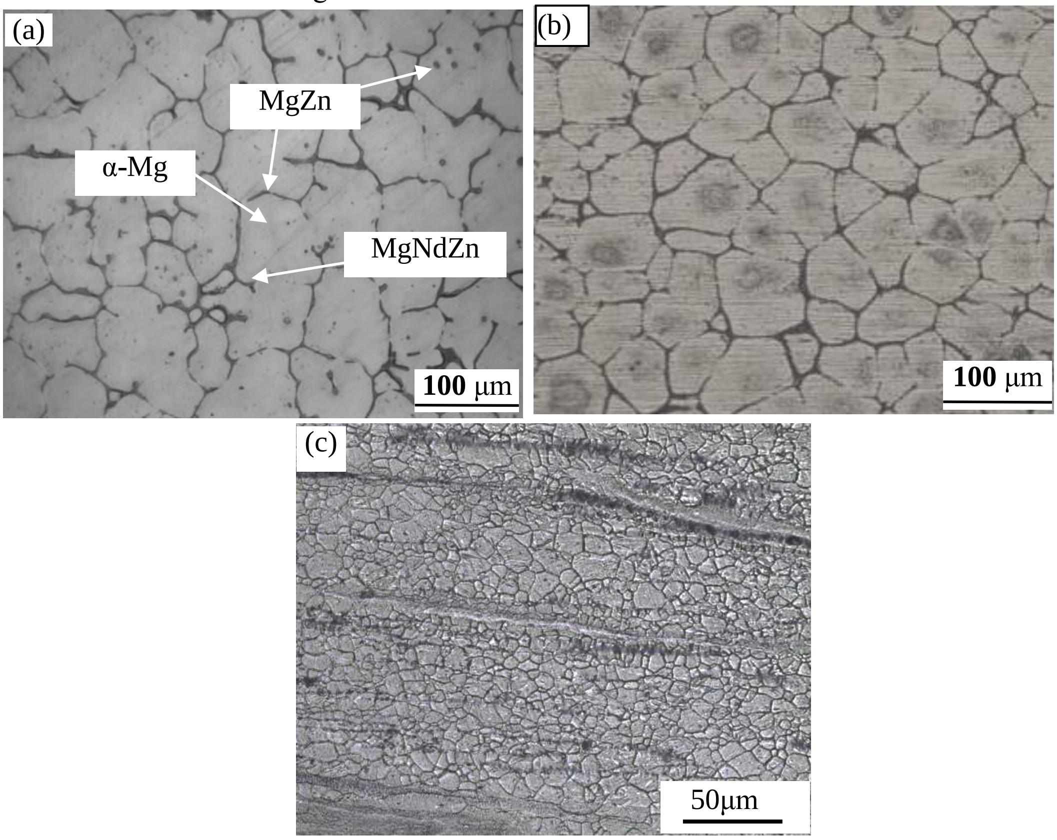

Figure 2. Microstructures of ZK60-2.8Nd magnesium alloys (a) as-cast; (b) solution; (c) extrusion.

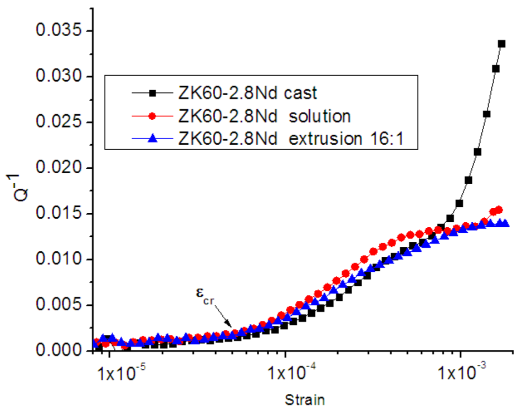

Figure 3. Strain amplitude dependence of damping capacity at room temperature for ZK60-2.8Nd magnesium alloys as-cast, solution and extrusion.

It can be seen that all the damping curves present almost the similar characteristics that the damping capacity can be divided into two parts as follows [14, 15]:

$$Q^{-1} = Q_I^{-1} + Q_H^{-1} \tag{1}$$

$$Q_I^{-1} \sim \rho L_C^{4} \tag{2}$$

$$Q_H^{-1} = (C_1/\varepsilon)\exp(-C_2/\varepsilon) \tag{3}$$

$$C_1 = \frac{\rho F_B L_N^3}{6bEL_C^2}\ ,\ C_2 = \frac{F_B}{bEL_C} \tag{4}$$

Where, Q_I^{-1} and Q_H^{-1} represent the strain independent damping and strain dependent damping, respectively; ρ is the dislocation density; L_C is the mean length of dislocations between the weak pinning points consisted of the soluble atoms or vacancies surrounding the dislocations; F_B is the binding force between a dislocation and a weak pinning point, E is the modulus, L_N is the mean length of dislocation segments between strong pinning points, and b is the magnitude of Burger vector.

Fig.3 shows that the strain independent damping Q_I^{-1} of alloy as-cast, solution and extrusion are all almost the same, which keep almost in horizontal lines exiting in lower strains on the damping strain curves; the critical strain amplitude (ε_{cr}) is about 5×10^{-5}. But when the strain amplitude is more than the critical strain amplitude, the strain dependent damping capacities increase rapidly with increase of the maximum strain amplitude, and the extrusion alloy rises faster than the alloy as-cast, but lower than solution alloy. When the strain is about $3\times10^{-4} \sim 4\times10^{-4}$, they show very high damping capacity of 0. 01. Especially, the damping value of alloy as-cast increases rapidly far ahead of the others, up to 0.03371 within the testing strain range, more than twice of that of alloy solution and extrusion, 0.01546 and 0.01392, respectively, seen in Fig.3.

General, solid solution treatment, as the same as the extrusion, could add the number of weak pinning point to the dislocation to make the movable dislocation segment much shorter, and decrease the strain independent damping capacity[13,18]. However, in this investigation, MgNdZn and MgZn phase included in the ZK60-2.8Nd magnesium alloy help decrease solid solution atoms in the magnesium matrix so that the alloy solution and extrusion posses the same Q_I^{-1} as that of alloy as-cast, owing to the MgNdZn phase. Certainly, solid solution treatment makes the grain sizes increase a little so as to increase the mean length of dislocation segments between strong pinning points. Although hot extrusion refined the grain size, sufficient dynamic re-crystallization improved movable dislocation density ρ, which made the dislocations easier to move on the basal plane. That is why the strain dependent damping capacity Q_H^{-1} of alloy as-cast is the least among the three states alloy in a certain strain range. According to the formula (3) and (4), the strain dependent damping capacity Q_H^{-1} increase with the increase of dislocation segments between strong pinning L_N and the dislocation density ρ. From figure 1 and table 2, the grains size of alloy as-solution are 40 μm more than that of alloy as-cast. Grain boundaries act as the strong pinning to dislocations, which offers more dislocation segments between strong pinning L_N, the strain dependent damping capacity Q_H^{-1} of alloy as-solution increase accordingly more than that of alloy as-cast. Although the grains size of alloy as-extrusion are 10 μm less than that of alloy as-cast, hot extrusion brought out the emergence of Dynamic re-crystallization to reduce dislocation tangles, which increase the movable dislocation density ρ, the strain dependent damping capacity Q_H^{-1} of alloy as-extrusion increase accordingly more than that of alloy as-cast. At higher strain amplitude, the alloy as-cast shows the maximum damping capacity owing to the coarser grain size, the continuous or discontinuous networks of eutectic compounds MgNdZn phases, and bigger density ρ of movable dislocation.

Two critical strain amplitude points in the damping strain spectrum has been studied on many alloys by some researchers [16, 17]. Present authors found it is associated with the medium intensity pinning points such as MgZn phases in the Mg-Zn magnesium alloys [18]. So it is MgZn phases in the ZK60-2.8Nd magnesium alloy to lead to the second strain amplitude points. Maybe it exits other reasons which would be further studied.

4. Conclusions

(1) The strain independent damping capacity of ZK60-2.8Nd magnesium alloys as-cast, solution and extrusion are almost the same when the strain amplitude is lower than 5×10^{-5}.They exhibits high strain dependent damping capacities ($Q_H^{-1}\geqslant0.01$) when the strain amplitude is higher than 4×10^{-4}, the maximum damping value of alloy as-cast, solution and extrusion is 0.03371, 0.01546 and 0.01392, respectively, within scope of the experiment.

(2) The strain dependent damping capacity Q_H^{-1} of ZK60-2.8Nd magnesium alloy as-solution is the highest, and that of the alloy as-cast is the least among the three states alloy within the strain range of $5\times10^{-5}\leqslant\varepsilon\leqslant4\times10^{-4}$ due to the grain sizes increase of the alloy as-solution and dynamic re-crystallization of the alloy as-extrusion leading the increase of movable dislocation density.

Acknowledgments
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