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Effect of small tensile deformation on damping capacities of Mg-1%Al alloy

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Abstract: Tensile tests with small deformation amounts of 0.5%, 1%, 3% and 5% were performed at room temperature on as cast Mg-1%Al alloy. Microstructures of the Mg-1%Al alloys before and after deformation were observed by optical microscopy (OM) and transmission electron microscopy (TEM). The strain amplitude dependent and temperature dependent damping capacities of the as-cast and deformed Mg-1%Al alloys were investigated by dynamic mechanical analysis (DMA). The mechanism of deformation on damping capacity of Mg-1%Al alloy was discussed. The results show that the as-cast Mg-1%Al alloy has high damping value at high strain. When the tensile elongation is higher than 3%, the damping values of this alloy in high strain region are significantly decreased at room temperature. But the large amount of dislocations produced by tensile deformation are activated by heat, and then increase the damping value at high temperature.

Key words: Mg-1%Al alloy; tensile deformation; damping capacity; dislocations; temperature

1 Introduction

Magnesium alloys are very attractive in applications for aerospace, automotive and other transport industries due to their low density, high specific strength and high damping capacity. As-cast polycrystalline pure magnesium exhibits extraordinary high damping capacity [1], but the low mechanical properties restrict its practical applications.

The damping capacity of metallic materials is considered to be connected with the presence, movement and interaction of crystal lattice defects, such as dislocations, grain boundaries, secondary phases and impurity atoms[2−8]. The amount of these crystal defects and their movability codetermine the damping capacity of a metallic material under certain vibration conditions. For Mg alloys, the key mechanism is dislocation damping. The damping capacity of magnesium alloys has been recognized to be dependent on the maximum strain amplitude, and considered to be caused by the movement of dislocations which were pinned by impurity atoms, the second phase and nodes of dislocation network on the basal plane[8−10]. Therefore, the type, the amount and the distribution condition of dislocations and those point defects in magnesium alloys could dramatically influence their damping capacities. In the present study, dislocations are artificially produced by tensile tests on Mg-1%Al alloy, and the damping capacities of these tensile deformed alloys were studied.

2 Experimental

2.1 Materials

The chemical composition of the experimental alloy was Mg-1.17%Al (mass fraction) and micro-scale Si, Fe, Zn and S. The detailed casting procedure could be seen elsewhere[10]. The yield strength and ultimate strength of this Mg-1%Al alloy were 21 MPa and 135 MPa, respectively, and its failure elongation was 11.5%. In order to prepare samples for damping tests, specimens with gauge length of 40 mm and rectangular cross section of 10 mm×1.3 mm were used for tensile deformation tests with an INSTRON machine. The tensile tests were carried out at room temperature with constant tensile speed of 1 mm/min. The actual pictures of tensile deformed Mg-1%Al alloy is shown in Fig.1. We can see that the deformation on the samples is very uniform. The damping test specimens were cut from the evenly deformed part of these tensile deformed samples.

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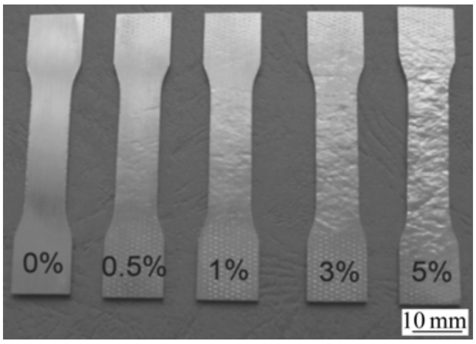

Fig.1 Actual pictures of tensile deformed Mg-1%Al alloys with different elongations

2.2 Damping test

The damping capacities of as-cast and deformed Mg-1%Al alloys were investigated via TA Q800 dynamic mechanical analyzer (DMA) with single cantilever vibration mode. Rectangular bending beam specimens for damping measurement with dimension of 38 mm×8 mm×1 mm were machined out by an electric spark cutting method. The damping capacity was determined by Q^{-1}=tanφ, where φ was the lag angle between the applied strain and the response stress. Measurements were made at various maximum strain amplitudes from 4×10^{-6} to 8×10^{-4} and the vibration frequency was 1 Hz. For the measurements of temperature dependent damping capacities, the test conditions were that the maximum strain amplitude was 4×10^{-5}, the vibration frequency was 1 Hz, the temperature range was from 25 ˚C to 400 ˚C and the heating rate was 5 ˚C/min.

3 Results and discussion

3.1 Microstructures of as-cast and deformed Mg-1%Al alloys

The optical microstructures of as-cast (0% elongation) and tensile deformed Mg-1%Al alloys are shown in Fig.2. The mean grain size of Mg-1%Al alloy is about 800 μm. Tensile deformation did not change the grain size but increased a great amount of twins in Mg-1%Al alloy. Especially for the alloys with elongation of 3% and 5%, a large number of twins could be clearly seen in Figs.2(d) and (e).

The TEM microstructures of tensile deformed Mg-1%Al alloys with elongation of 1% and 5% are shown in Fig.3. Despite the large quantity of twin crystals, intensive dislocations could also be found in tensile deformed alloys. 1% deformed alloy has long and smooth dislocations in it, and 5% deformed alloy has intensive and relatively short dislocations in it. In both of the optical and TEM images, no recrystallization was found in tensile deformed Mg-1%Al alloy.

3.2 Damping capacities of as-cast and deformed Mg-1%Al alloys

Many damping test results of Mg and Mg alloys [4, 11] show that the strain dependent damping can be divided into two regions. The first is strain independent or weakly dependent region, which usually exists in low strain region. In high strain region, the damping value increases rapidly with increasing the strain. According to the G-L dislocation damping model[12−13], the strain independent damping is proportional to ρl^4, where ρ is the dislocation density and l is the mean distance of the weak pinning points on a dislocation. The critical strain (ε_c) corresponds to the joint of these two strain regions.

Fig.4 shows the strain dependent damping capacities of Mg-1%Al alloys. We can see that the damping capacities of the as-cast and the tensile deformed Mg-1%Al alloys could be divided into two regions as described above. When the strain is lower than 1×10^{-4}, the damping values of the as-cast and tensile deformed alloys are both about 0.002 and they are not dependent on the magnitude of strain. Compared with pure Mg, the addition of 1%Al significantly decreases the strain independent damping of Mg. When strain is larger than 1×10^{-4}, the damping capacities for both the as-cast and the tensile deformed alloys are increased rapidly with increasing strain amplitudes. For the as-cast Mg-1%Al alloy, the damping value in high strain range could reach 0.1−0.2, which is 10−20 times higher than the high damping standard ($Q^{-1}\geq0.01$) for metals. In this strain range, the damping values of tensile deformed Mg-1%Al alloys are decreased with increasing the tensile elongation. For the samples with tensile elongation lower than 1%, the damping values are only slightly lower than those of the as-cast alloy. For the samples with tensile elongation larger than 3%, the decrease of damping values could be obviously observed. That is to say, simply increasing the amount of dislocations is not a proper way to provide large damping value for Mg alloys. The short and intensive dislocations, as seen in Fig.3(b), will decrease the damping capacity of Mg alloy.

Fig.5 shows the temperature dependent damping of Mg-1%Al alloys with vibration frequency of 1 Hz, strain of 4×10^{-5} and heating rate of 5 ˚C/min. In pure Mg, Mg-Si and Mg-Ni alloys, two damping peaks P_1 and P_2 have been found at about 80 ˚C and 230 ˚C, respectively [9−10, 14]. P_1 is considered to be related to the interaction between dislocations and impurity atoms or vacancies in Mg, and P_2 is caused by the grain boundaries

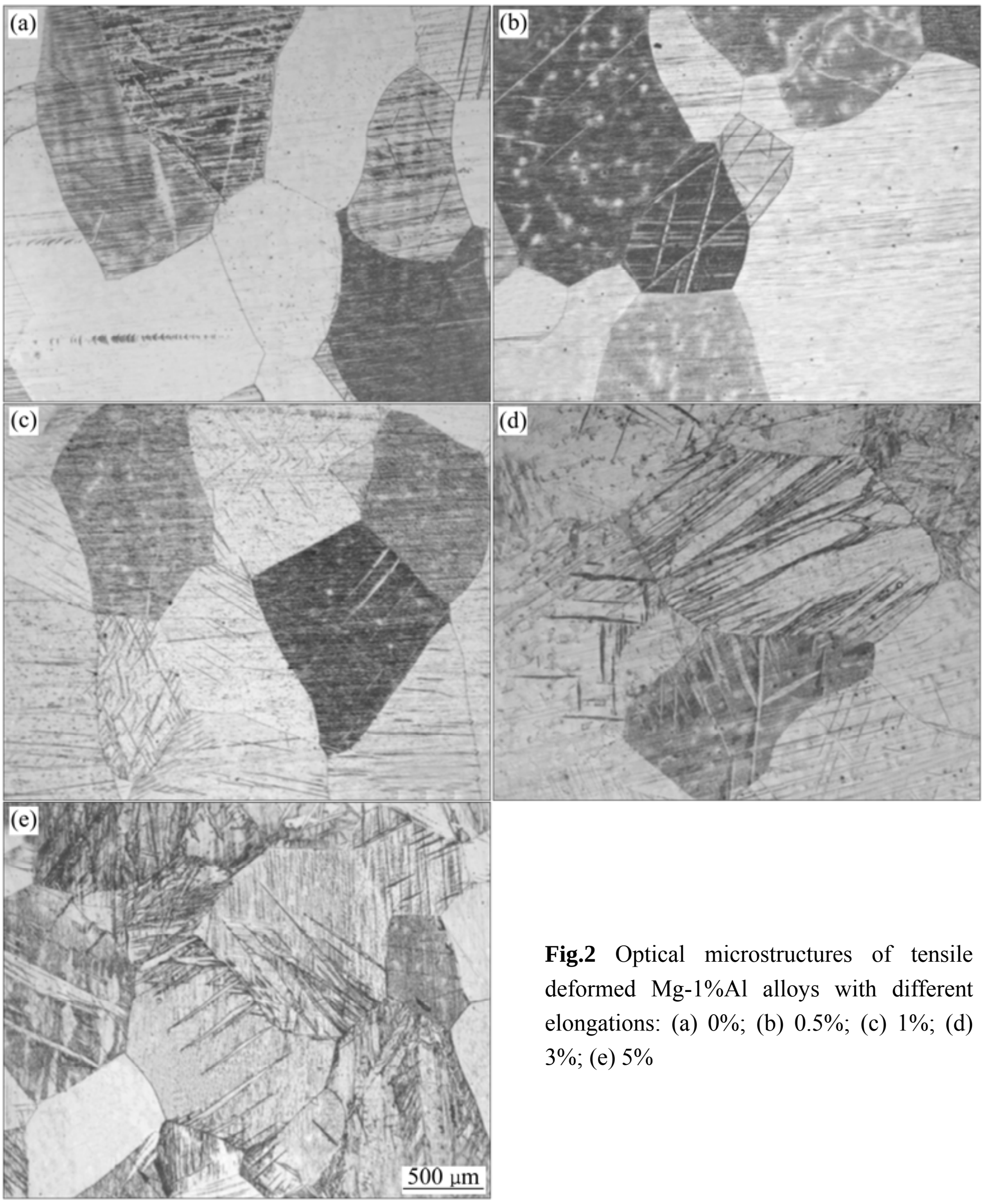

Fig.2 Optical microstructures of tensile deformed Mg-1%Al alloys with different elongations: (a) 0%; (b) 0.5%; (c) 1%; (d) 3%; (e) 5%

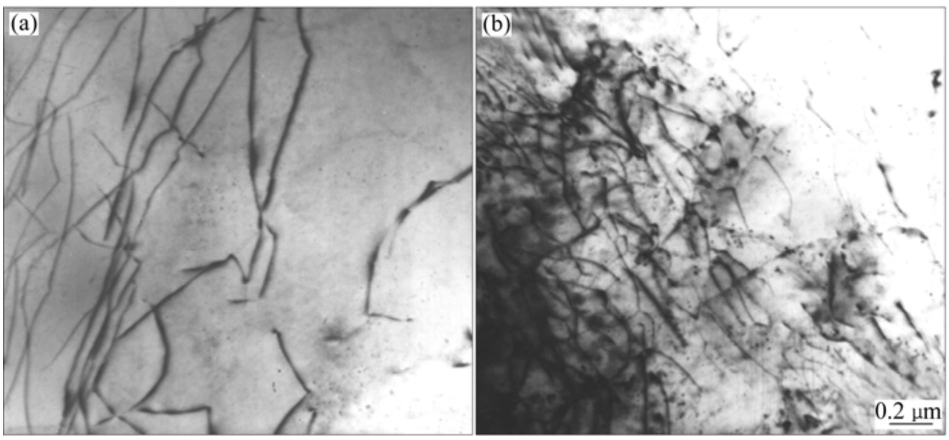

Fig.3 TEM images of tensile deformed Mg-1%Al alloys with different elongations: (a) 1%; (b) 5%

sliding. For Mg-1%Al alloy, no obvious damping peaks have been detected out. That is to say, the addition of 1% amount of Al atoms could restrict the movement of dislocations and then completely inhibits the presence of

P_1. When the temperature is higher than 230 ˚C, the damping values increase with increasing tensile elongations. This phenomenon of high damping values at high temperature in Mg alloys has also been reported in ECAP processed Mg alloys[15]. The high damping of ECAP processed Mg alloys is ascribed to the reconfiguration of dislocations and recrystallization occurred during DMA test. Once the stored deformation energy is consumed out, the damping values at high temperature will decrease again. For there are no recrystallization in small tensile deformed Mg-1%Al alloys, the increase of damping values at high temperature should be caused by the heat activity of increasing twins and dislocations within a certain temperature range.

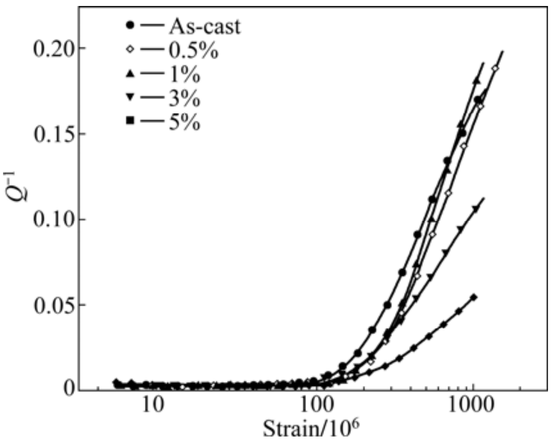

Fig.4 Strain dependent damping of as-cast and tensile deformed Mg-1%Al alloys

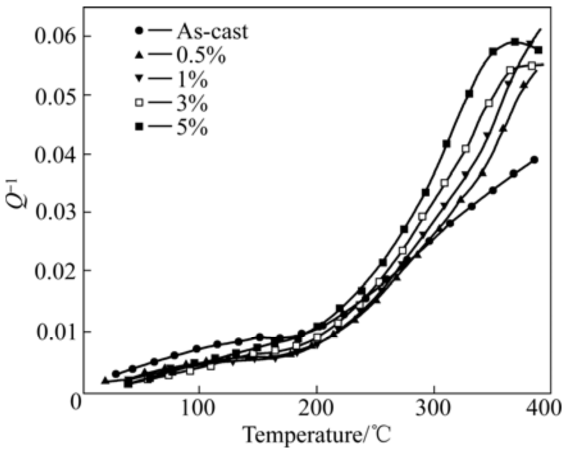

Fig.5 Temperature dependent damping of as-cast and tensile deformed Mg-1%Al alloys

4 Conclusions

1) As-cast Mg-1%Al alloy possesses high damping value at high strain and room temperature.

2) In tensile deformation, especially when the tensile elongation is larger than 3%, the damping values of Mg-1%Al alloy in high strain region are significantly decreased for the decrease of the length and the movability of dislocations at room temperature.

3) When the temperature is higher enough, the large amount of dislocations which are produced by tensile deformation will be heat activated, and then increase the damping value at high temperature.

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