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The effect of heat treatment on damping characterization of TiC/AZ91 composites

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Abstract

Magnesium matrix composites prepared by in situ synthesis methods were managed with heat treatment. The damping capacity of foundry composites and heat-treated composites is described. In order to investigate the relation between damping capacity and strain amplitude, temperature, a series of experiments is given. The research results confirmed that heat treatment is advantageous to improving damping capacity of the composites. In addition, heat treatment can change the location of temperature–damping peak on temperature–damping curve. The effect of heat treatment on damping capacity and the damping mechanism is explained through dislocation motion and grain boundary slip.

Keywords: Magnesium matrix composites; Heat treatment; Damping characterization; Dislocation; Boundary

1. Introduction

There are much damage at automotive industry, architectural industry, bridge construction, machine, housings and aerospace due to mechanical vibration. Therefore, it is necessary to seek for light metallic materials that exhibit good mechanical properties and high damping capacity. Such a compromise between two contradictory properties can be achieved using metal matrix composites. Magnesium materials are known to exhibit a very high damping capacity [1,2]. Therefore, magnesium matrix reinforced with high strength reinforcements is a good candidate for a high damping composite. In order to improve the damping capacity of magnesium matrix composites, some researches have been impressed on the effect of heat treatment on damping capacity of magnesium matrix composites. Those research reckoned that the heat treatment is advantageous of improving the damping capacity [3,4]. Trojanova et al. [3] investigated the changes of microstructure in magnesium reinforced by Al_2O_3 particles using internal friction measurement. Their result revealed the heat treatment influences the amplitude-dependent component of the damping in composite. Couteau and Schaller [4] investigated the thermal stress relaxation in magnesium matrix composites using mechanical spectroscopy. The results discovered that the transient damping due to thermal relaxation can be interpreted by the motion of dislocations.

Accordingly, the primary aim of the present work is to synthesize magnesium matrix composite reinforced by TiC particulate using the in situ synthesis method. Moreover, the effect of heat treatment on damping capacity of the composites is examined.

2. Experimental procedures

The composite based on 8 wt.% TiC/AZ91 was prepared with the process of remelting and dilution (RD) technique. Al, Ti and C powder of which purity is up to 99.5% are used as the base materials of master alloy in our study. Firstly, the Al, Ti and C powder with ratio of 50 wt.%, 36.2 wt.% and 14.8 wt.% were mixed by a ball mill under argon atmosphere protection. The mixed powder was pressed into blocks 30 mm in diameter and 50 mm in height under 15 MPa pressure. Then, the blocks reacted at high temperature under argon atmosphere protection to synthesize master alloy.

After pure magnesium has been molten, it was superheated to 750 °C under SF_6+CO_2 gas atmosphere protection in an iron crucible. The master alloy was put into the magnesium melt. Moreover, the magnesium melt was stirred to facilitate the incorporation and uniform distribution of TiC particulates in

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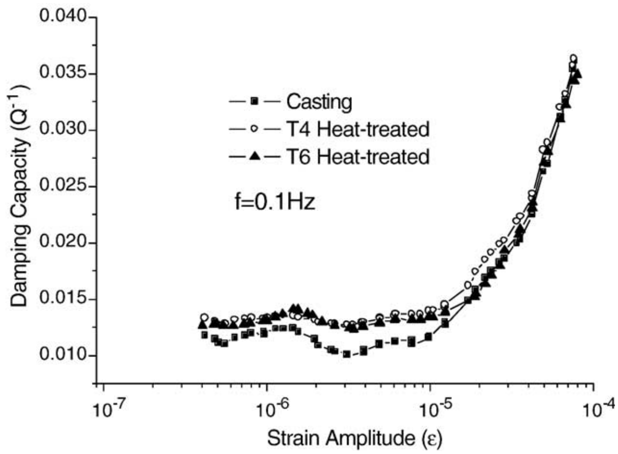

Fig. 1. Damping capacity of 8 wt.% TiC/AZ91 composites corresponding to strain amplitude.

the metallic melt. Finally, magnesium melt was poured into an iron sample mould to synthesize 8 wt.% TiC/AZ91 composites. The composites samples were treated with heat treatment such as T4 and T6. The T4-treatment is managed as solution at 420 °C. The T6-treatment is aged for 14 h after T4-treatment. Damping capacity of TiC/AZ91 composites was measured using Mark IV dynamic mechanical thermal analyzer with the machined samples (size of 40 mm × 5 mm × 1.5 mm).

3. Experimental results

The effect of heat treatment on damping capacity of the TiC/AZ91 composites was described. Damping capacity of these composites is dependent on strain amplitude under low vibration frequency. At the strain amplitude below 1E-5, damping capacity of these composites improves slowly. Nevertheless, there are damping peaks on the damping–strain curve of those composites. Compared to the foundry composites, damping peaks of those heat-treated composites move to high strain amplitude (as shown in Fig. 1). At the strain amplitude up 1E-5, damping capacity of these composites increases quickly. In any case, damping capacity of heat-treated composites is higher than that of the foundry composites, and the damping capacity of T6-treated composites is the highest.

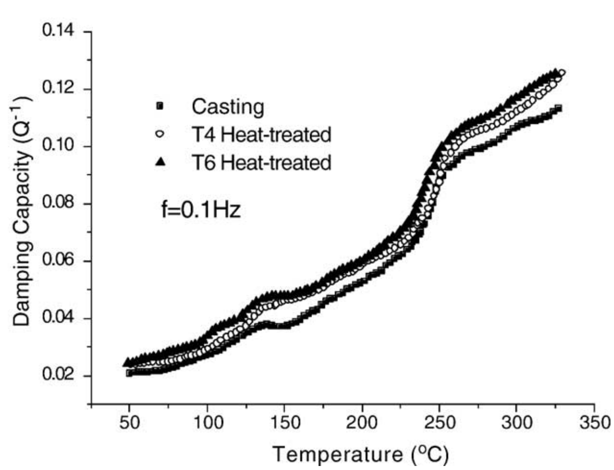

Fig. 2. Damping capacity of 8 wt.% TiC/AZ91 composites corresponding to temperature.

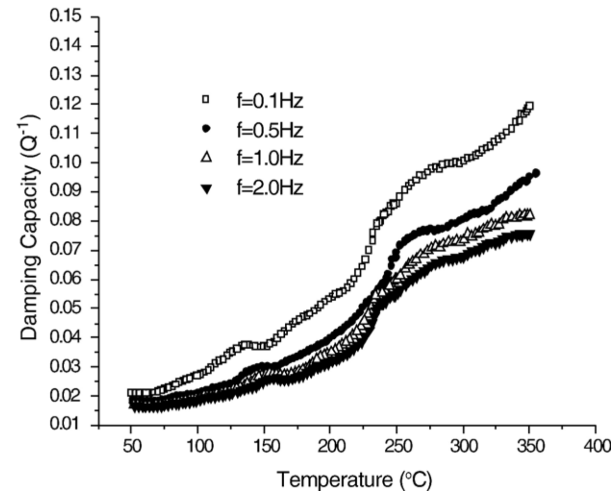

Fig. 3. Damping capacity of foundry TiC/AZ91 composites corresponding to temperature.

Damping capacity of TiC/AZ91 composites is dependent on temperature intensively. They increase quickly when the testing temperature goes up. It is observed the present of damping peak on damping–temperature curve of these composites around 150 °C or 250 °C (as shown in Figs. 2–5). Damping capacity of these composites is also dependent on vibration frequency at high temperature. With the increasing of vibration frequency, damping capacity of these composites decreases. Moreover, the present of damping peak around 150 °C is discovered firstly at low vibration frequency. In contrast, the damping peak of these composites at about 250 °C is discovered at the same testing temperature (as shown in Figs. 3–5). The results also revealed that damping capacity of heat-treated composites is higher than that of the foundry composites, and the damping capacity of T6-treated composites is also the highest (as shown in Fig. 2).

4. Discussion

The relaxation process proceeds by atom diffusion, an the relaxation time is content to the Arrhenius equation [5]:

$$\tau = \tau_o e^{\frac{H}{kT}} \quad \text{or} \quad \tau^{-1} = \nu_o e^{-\frac{H}{kT}} \tag{1}$$

where the τ_o is exponent factor, the ν_o is frequency factor, the k is constant and the H is activation energy. According

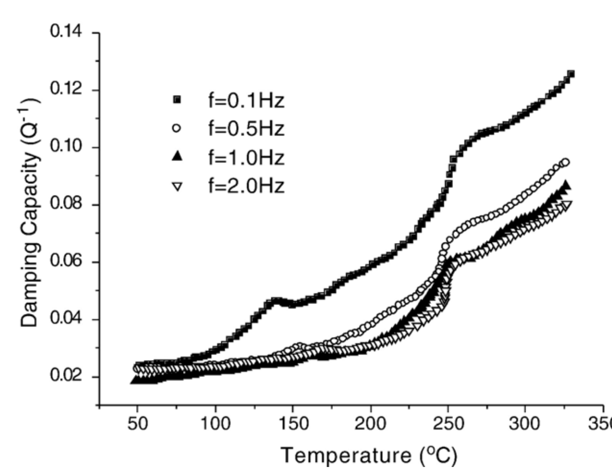

Fig. 4. Damping capacity of T4-treated composites corresponding to temperature.

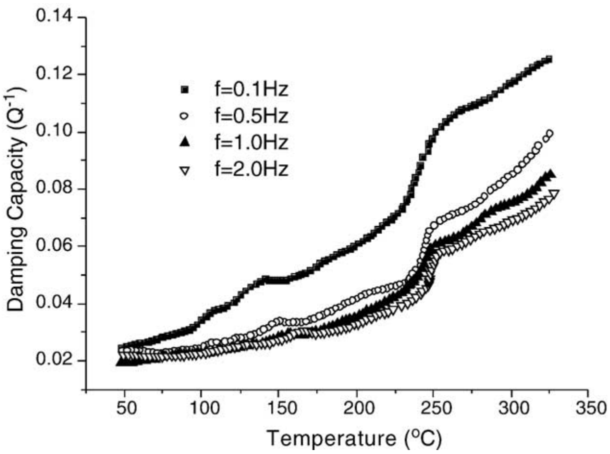

Fig. 5. Damping capacity of T6-treated composites corresponding to temperature.

to Eq. (1), the relaxation time is a function of temperature. Hence, the damping–temperature peak can be gained by changing temperature relating to specific testing frequency that satisfies the equation $\omega\tau=1$. The activation energy can be expressed as:

$$H=\left[k\ln\left(\frac{\omega_1}{\omega_2}\right)\right]\left(\frac{1}{T_{p2}}-\frac{1}{T_{p1}}\right) \tag{2}$$

where T_{p1} and T_{p2} are peak temperature under ω_1 and ω_2, respectively. Then the peak temperature T_{p} that related to testing frequency can be gained. The activation energy H can be calculated by the slope of $\ln\omega \sim T_{\mathrm{p}}$. In order to make the mathematical calculation simple, Eq. (2) is revised as:

$$\lg\omega+\lg\tau+\left(\frac{H}{2303k}\right)\left(\frac{1000}{T_{\mathrm{p}}}\right)=0. \tag{3}$$

According to Figs. 3–5 and Eq. (3), the relation between frequency and peak temperature and their fit liner are described in Fig. 6. The activation energies of these composites are calculated: 3.492×10^{-19} J for foundry composites, 2.436×10^{-19} J for T4-treated composites, and 3.142×10^{-19} J for T6-treated composites. It is the first time to calculate the activation energy of magnesium matrix composites reinforced by in situ particulates. These results are advantageous to research restructure and damping capacity of magnesium matrix composites.

In metals, only a limited number of damping mechanisms, such as dislocation or interface damping, can be used to achieve such performance. Granato–Lucke mechanism is a well-accepted theory that explains the damping mechanism by dislocations [6,7]. According to the G–L mechanism, dislocation is pinned by weak pinning such as point defect and strong pinning such as dislocation node, reinforcement particulates and precipitation. At low strain amplitude, dislocation string vibrates to dissipate energy, and then damping capacity generates (as shown in Fig. 7(a)–(c)). In the region, the damping capacity of these composites is only weakly dependent on strain amplitude. They improve slowly when strain amplitude increases (as shown in Fig. 1). When strain increases to a certain extent, the dislocations break away the weak pinning, and then the strain generates the unpinning process like an avalanche (as shown in Fig. 7(d)–(f)). Hence, the damping capacity of these composites increases quickly at the strain amplitude up 1E-5 (as shown in Fig. 1). In addition, the unpinning process of dislocations also generates when testing temperature increase. So the damping capacity of materials increases quickly when temperature increase, which also leads to the present of damping peak (as shown in Figs. 2–5). The damping peak at about 140 °C is contributed to the avalanche effect of anchoring of dislocation.

In particulate-reinforced metal matrix composites, there are high residual stresses around the particulates because of large difference in the thermal expansion coefficient of metal and reinforcements, which are responsible for the generation of high dislocation density at matrix [8]. The dislocation density is given as follows [9]:

$$\rho=\frac{9.6\Delta\alpha\Delta TV_{\mathrm{p}}}{bd} \tag{4}$$

where $\Delta\alpha$ is the difference of thermal expansion coefficient between matrix alloy and reinforcements, ΔT is the difference from working temperature to room temperature, b is the burger's vector, V_{p} is the volume fractions, and d is the grain diameter of reinforcements. For TiC/AZ91 composites, ΔT of T6-treated composites is the smallest, and ΔT of foundry composites is the largest. The dislocation density of T6-treated composites is the smallest, but its effective length of movable dislocation is the longest (as shown in Fig. 8). The investigative result of Yamashita et al. [10] also revealed that the dislocation density of heat-treated composites is lower than that of the foundry composites because the dislocation recombines at solution temperature. The effective length of dislocation in heat-treated composites is longer than that of the foundry composites. According to the G–L mechanism [6,7], the damping capacity of materials is a function of the dislocation density and effective length of movable dislocation. Therefore, the damping capacity of heat-treated composites is larger than that of the foundry composites. Moreover, the activation energy

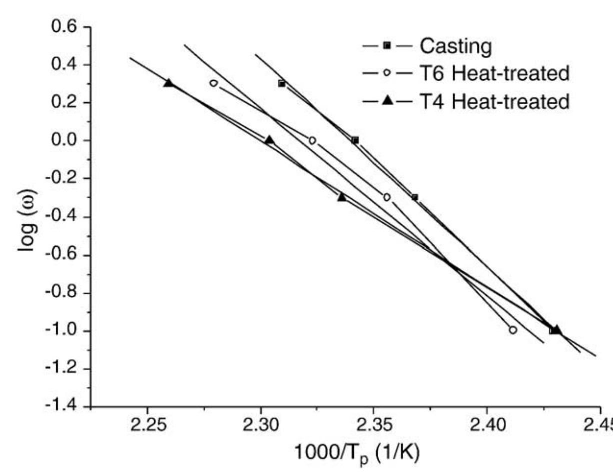

Fig. 6. The Arrhenius relation between testing frequency and temperature.

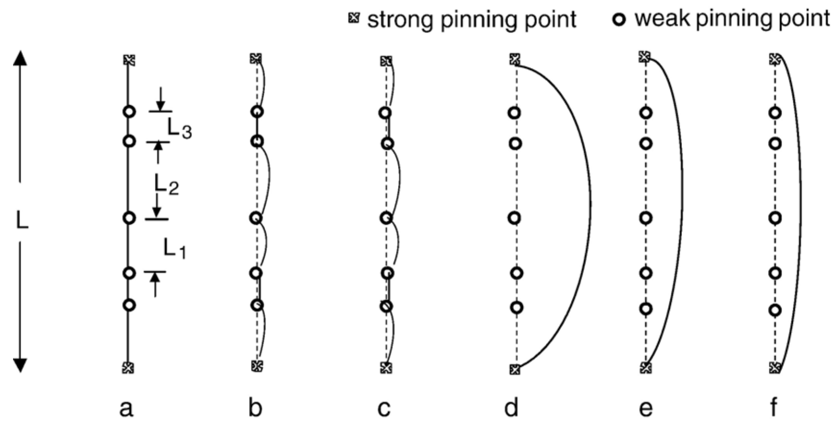

Fig. 7. The damping mechanism according to dislocation motion.

of heat-treated composites is smaller than that of the foundry composites.

With the temperature increasing, much energy is dissipated by the movable boundaries of the composites. A theory regarding the contribution of the boundaries to damping has been offered by Schoeck [11]. The contribution of a viscous boundary to damping is approximately given by:

$$Q^{-1} \approx [4.5(1-\gamma)V_f]/[\pi^2(2-\gamma)] \quad (5)$$

where γ is Poisson's ratio and V_f is volume fraction of reinforcements particulate. So the damping peak at about 250 °C can be contributed to the movable boundaries slip, such as grain boundary slip and interface slip. Primarily, grain refinement results from nucleation of more new crystals from the melt, and subsequent growth of the new crystals to a limited size. With the addition of TiC particulates, the grain size of TiC/AZ91 composites is smaller than that of AZ91 alloy for more nucleation form in the magnesium melts, which ensures more grain boundary in composites. More interfaces between TiC and magnesium also generate because of addition of TiC particulates. However, the amount of grain boundary and interface in a composite is stabile if there is liquid phase transition or recrystallization [12]. In our study, the solution temperature (415 °C) is below the recrystallization temperature, so the movable boundary amount of heat-treated composites is the same as that of the foundry composites. It shows that heat treatment has no effect on damping capacity of composites at high temperature. Therefore, the presence of a damping peak at high temperature in the three composites is the same as in the testing temperature (as shown in Figs. 2–5).

5. Conclusion

1) Damping capacity of materials is dependent on strain amplitude and temperature. The increase of strain and testing

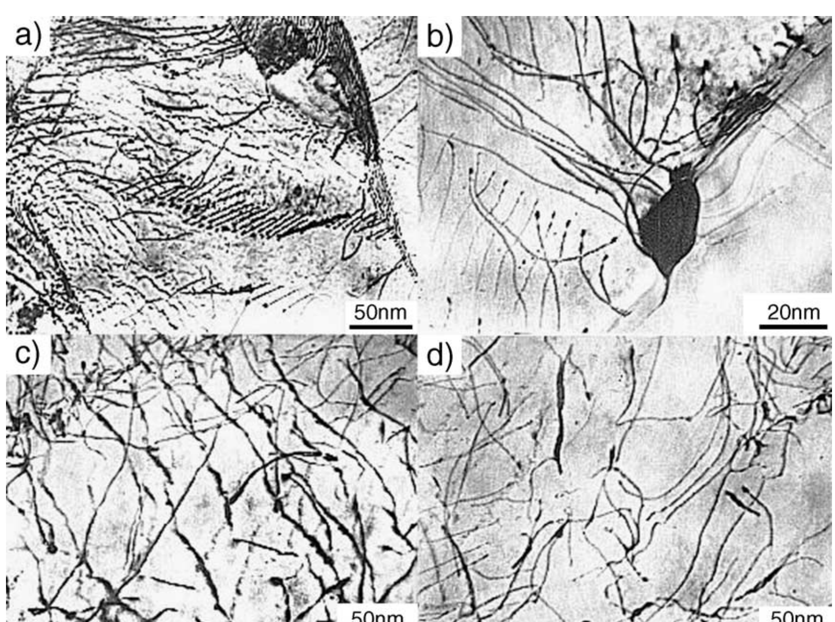

Fig. 8. The dislocation arrangement in the composites: (a and b) 8 wt.% TiC/AZ91 composites; (c) T4-treated composites; (d) T6-treated composites.

temperature leads to the present of damping peak, which is contributed to the avalanche effect of anchoring of dislocation.

2) When temperature increase, much energy is dissipated between the movable boundaries of composites, and the damping capacity of them is greatly improved. The presence of damping peak at 250 °C can be contributed to the movable boundaries slip.
3) Heat treatment is advantageous in increasing the damping capacity of composites because heat treatment can decrease the activation energy and thus lengthen the effective length of movable dislocation in matrix.
4) Heat treatment cannot change the location of damping peak at high temperature because the boundary amount of heat-treated composites is the same as that of the foundry composites.

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