Journal of Alloys and Compounds 429 (2007) 163–166

Journal of ALLOYS AND COMPOUNDS

www.elsevier.com/locate/jallcom

The characteristic of damping peak in Mg–9Al–Si Alloys

Lihua Liao [a,b], Xiuqing Zhang [a], Haowei Wang [a,*], Xianfeng Li [a], Naiheng Ma [a]

[a] *School of Materials Science and Engineering, Shanghai Jiaotong University, 1954 Huashan Road, Shanghai 200030, China*
[b] *School of Mechanical Engineering, Yangzhou University, Yangzhou 225009, China*

Received 23 February 2006; received in revised form 12 April 2006; accepted 13 April 2006
Available online 23 May 2006

Abstract

The damping capacity of as cast Mg–9Al–Si alloys was investigated. A damping peak exhibits at around 420 K for a frequency of about 1 Hz and it was correlated to the characteristic grain boundary peak of magnesium. The activation energy of damping peak is lower than self-diffusion activation energy of pure magnesium, but higher than activation energy of AZ91 reported. The effect of measurement conditions including strain amplitude, heating rate and consecutive measurement number on damping peaks has also been discussed.

Keywords: Cast; Grain boundary; Damping

1. Introduction

Magnesium (Mg) alloys, the lightest commercial alloys developed so far, have great potential for automotive applications and electronic industries [1], however, Mg alloys have not achieved its full potential as a structural metal for those critical applications requiring elevated temperature performance because Mg alloys exhibit poor creep properties at temperatures above 120 °C. Recent researches indicate that addition of silicon (Si) to Mg–Al alloys can produce substantial increases in strength and toughness [2]. Because Mg_2Si, formed by the addition of Si, constructs very effective strengthening particles that exhibit high melting temperature, low density, high elastic modulus and low thermal expansion coefficient [3].

The proper combination of the strength and damping capacity has been a major challenge for wide use of Mg alloys in automotive and electronic industries. The microscopic mechanism responsible for dissipation of the vibration energy is independent of the strength mechanism [4]. There are three different methods for strengthening materials: (1) solution hardening, (2) precipitation hardening and (3) hardening by use of natural composites materials. Of the three methods, (1) and (2) seem to be not suitable for the present purpose, because dislocations in Mg would be limited to a large extent by the pining of solute atoms and hence the damping capacity would be very much reduced. However, (3) seems to be the only way to improve the mechanical strength of the Mg alloy without reducing the damping capacity [5]. Si is used to prepare the natural Mg based composites materials, and the research results has certified those composite materials have good damping capacities and mechanical properties [6–10], but its damping characteristic has not been discussed.

The purpose of the present paper is to prepare Mg–Al–Si alloys, to study the features of damping. Lots of researches show damping peak is related to measurement conditions [11–13]. The damping peaks have been studied as a function of heating rate, number of thermal cycles, frequency and strain amplitude in the paper. The research results on damping characteristics are also helpful for studying changes in microstructure because it is well known that the damping of materials depends on both chemical composition and microstructure.

2. Experiments

1.5 wt.% and 2.0 wt.% Si were added to Mg–9Al alloy to prepare two kinds of Mg–9Al–*x*Si alloys. The ingots were remelt in an electric resistance furnace under the protection of mixture gas of 10 vol.% SF_6 and 90 vol.% CO_2 followed by casting in a permanent mold preheated at 473 K. Ageing treatment was engaged at 473 K for 8 h after solid solution at 693 K for 12 h under gas protection.

Damping capacity was carried out using dynamic mechanical thermal analysis (DMTA) in three-point flexure mode. The test-pieces for damping were machined with dimension of 40 mm × 5 mm × 1 mm on electric spark cutter and properly installed in the DMTA testing head. Each end is constrained by a clamping bar arrangement. The resulting sinusoidal force and deflection data

* Corresponding author. Tel.: +86 21 62932569; fax: +86 21 62932004.
E-mail address: hwwang@sjtu.edu.cn (H. Wang).

0925-8388/$ – see front matter
doi:10.1016/j.jallcom.2006.04.020

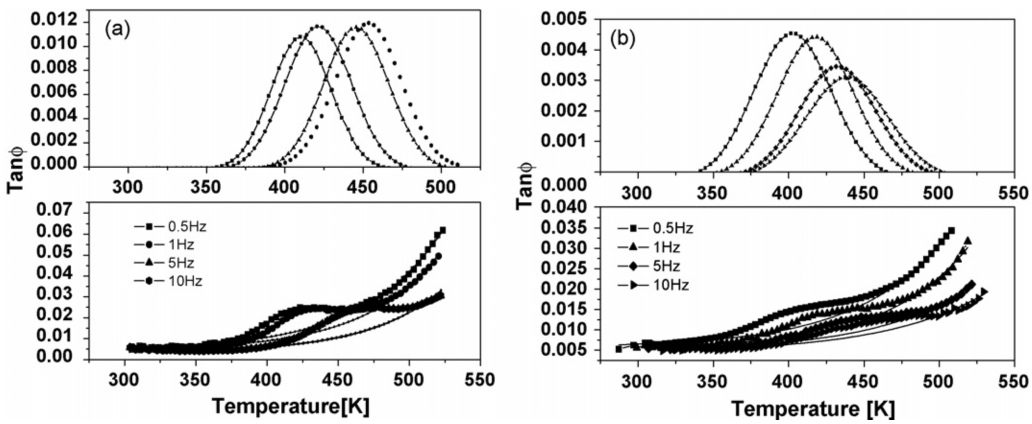

Fig. 1. Damping capacity at elevated temperatures for: (a) Mg–9Al–1.5Si and (b) Mg–9Al–2.0Si.

are recorded and damping capacity is evaluated by the loss tangent (tan φ). tan φ is calculated from

$$\tan\varphi = \frac{E''}{E'} \quad (1)$$

where E'' is loss modulus and E' is storage modulus or dynamic modulus.

3. Results and discussion

Fig. 1(a and b) shows the damping capacities at elevated temperature for both composites under the condition of $f = 1$ Hz, $\varepsilon = 10^{-4}$ and $dT/dt = 5$ K/min. Net damping peaks after the background subtraction are also shown in Fig. 1. It is clear that damping capacities are independent of testing temperature at low temperature, and when temperature is beyond 350 K, damping values increase gradually with temperature. Apparent damping peaks are observed at 400–450 K for two different alloys. Damping peaks shift to higher temperatures as the increasing frequencies, which show the peaks are thermally activated. There is no obvious rule for the effect of frequency on the height and width of damping peak.

Above results show that damping peaks are frequency dependent and peak temperatures (T_p) increase with increasing frequencies, but the peak height is frequency independent, which suggests that peaks have the characteristic of thermally activation relaxation processes. So the relaxation time and activation energy should follow the Arrhenius law [14]:

$$\tau = \tau_0 \exp\left(\frac{H}{kT}\right) \quad (2)$$

where τ_0 is the pre-exponential factor and H is the activation energy of the relaxation process. At the peak position, $\omega\tau = 1$ is satisfied. From the Arrhenius plot for damping peaks according to Eq. (2), where x-axis corresponds to $1000/T_p$ and y-axis the values of $\ln(2\pi f)$, activation energy and relaxation time can be obtained according to the slope and intercepts of the plot. The calculated activation energy for Mg–9Al–1.5Si and Mg–9Al–2.0Si are 115 kJ/mol and 114 kJ/mol, respectively. The activation energies are lower than self-diffusion activation energy of pure Mg (134 kJ/mol).

There exists a wide controversy about the mechanisms that control the grain boundary peak in metal and alloys. Lambri and Riehemann think that the relaxation peak at about 420 K in AlMgSi may be interpreted by the dragging of Mg solute atoms or Mg–Si complexes by dislocation loops [15]. However, Nó et al. think the damping peak of Mg–Al alloys at 420 K is correlated to the grain boundary peak of Mg, and grain boundary peak height may be controlled by the solute atoms and precipitates [16].

In the paper, probable reasons for existing damping peaks are discussed. Based on the activation energy and peak temper damping peaks of Mg–9Al–Si alloys are typical grain boundary relaxation, and are also related to the dislocation glide controlled by jog climb around grain boundary and vacancy diffusion, yielding activation energy of 115 kJ/mol. The activation energy is close to the values provided by Arebault and Shi [17].

In polycrystalline materials the grain boundary slide leads to the appearance of a grain boundary peak with activation energy

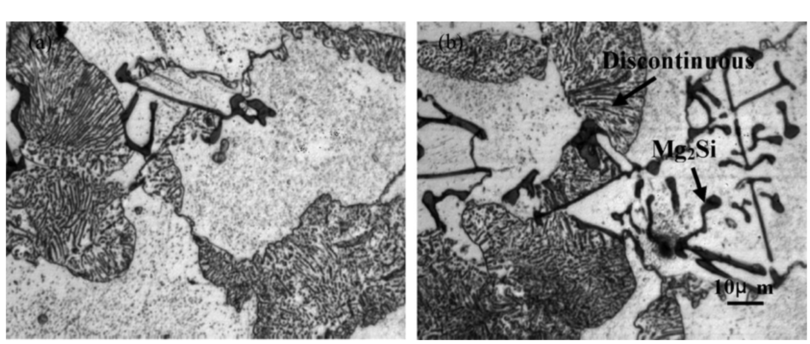

Fig. 2. The optical microstructure for Mg_2Si after ageing treatment: (a) Mg–9Al–1.5Si and (b) Mg–9Al–2.0Si.