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Cyclic bending and the damping behaviour of short fibre-reinforced magnesium alloy AZ91

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Abstract

The influence of cyclic bending on the damping behaviour of AZ91 magnesium alloy-based composite was determined at room temperature. The logarithmic decrement of free decaying vibrations of bending beams as a function of the number of cycles exhibits four regions. In the first region, damping increases due to an increase of the dislocation density. Then steady state, a constant logarithmic decrement follows. The third region is characterised by a rapid decrease of the logarithmic decrement. Cracks nucleation in the matrix was manifested by a rapid increase of damping with increasing number of cycles and finally by failure of the sample – the fourth region.

Keywords: Metal matrix composite; Fatigue; Anelasticity; Non-destructive testing; Squeeze casting

1. Introduction

The mechanical properties of magnesium alloys and Mg-based composites have been the object of many detailed studies during recent years. In industry applications, there are used alloys based on Mg–Al–Zn–Mn system. They are considered for use at ambient temperature because of a rapid decrease of their mechanical properties at elevated temperatures (above about 120 °C) [1,2]. Magnesium alloy AZ91 (Mg–9Al–1Zn–0.2Mn) is very often used as structural material.

A considerable improvement of the mechanical properties of Mg alloys can also be achieved by reinforcing with ceramic particles or fibres. In comparison to unreinforced magnesium alloys, metal matrix composites (MMCs) offer a substantial increase in the strength and stiffness. However, the ductility of composites is significantly reduced in comparison to unreinforced alloys. Magnesium matrix composites exhibit better wear resistance, keep low density and good machinability [3]. Investigations of their mechanical and physical properties are important not only for applications but also for better understanding of processes responsible for their behaviour.

When the coefficients of thermal expansion (CTE) of both composite components are different, internal thermal stresses are generated in the vicinity of the reinforcement/matrix interface. The thermal stresses may relax and new dislocations are formed. The dislocation density near the interfaces was found to be significantly higher than that elsewhere in the matrix. Plastic zones containing tangled dislocations generally result along fibres [4]. An estimation of the average stresses and strains in each component is very important because they can influence many material properties. There are two stress parameters of interest, namely the average stress in each constituent and the mean internal stress defined as the difference between the average stress

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and external stress. The mean internal stress is a useful parameter, since it expresses the sense and effectiveness of the load transfer taking place. A higher dislocation density in composite materials invokes a higher level of the internal stress. An increase in the dislocation density near reinforcement fibres has been calculated as [5]

$$\rho = \frac{Bf\Delta\alpha\Delta T}{b(1-f)t}, \quad (1)$$

where f is the volume fraction of the reinforcement, t is its minimum size, b is the magnitude of the Burgers vector of dislocations, B is a geometrical constant, $\Delta\alpha$ is the difference in the CTEs of the matrix and the reinforcement and ΔT is the temperature change. New dislocations arise directly in the production process of the composites. Therefore, the dislocation density in the composites is higher than in the monolithic alloy.

If a material containing dislocations is submitted to a harmonic applied stress $\sigma = \sigma_0 \sin \omega t$ with an angular frequency $\omega = 2\pi f$, one can define the mechanical loss factor η by the following relation:

$$\eta = \frac{1}{2\pi}\frac{\Delta W_{\text{diss}}}{W_{\max}}, \quad (2)$$

where ΔW_{diss} is the mechanical energy dissipated per one cycle of the applied stress in a volume unit, and $W_{\max}$ is the maximum stored energy per unit volume during the course of a cycle. The lost energy ΔW_{diss} depends only on the anelastic strain. In the case of an anelastic dislocation strain, ε_d,

$$\Delta W_{\text{diss}} = \oint \varepsilon_d \, d\sigma. \quad (3)$$

The maximum stored energy can be well approximated by the maximum stored elastic energy

$$W_{\max} = \int_0^{\sigma_0} \sigma \, d\varepsilon_{\text{el}} = \frac{1}{2} J_{\text{el}} \sigma_0^2, \quad (4)$$

where J_{el} is the relevant elastic compliance (it may be related to Young's modulus $E^{-1} = J_{\text{el}}$). The mechanical loss factor due to the presence of dislocations in the material may be written as

$$\eta = \frac{1}{\pi J_{\text{el}} \sigma_0^2} \oint \varepsilon_d \, d\sigma. \quad (5)$$

The logarithmic decrement, δ, as another quantity, may characterise the damping behaviour. It can be measured in resonant experiments (the frequency is of the order of the resonant frequency). By using free vibrations, the logarithmic decrement δ is given as

$$\delta = \frac{1}{n} \ln \frac{A_i}{A_{i+n}}, \quad (6)$$

where A_i and A_{i+n} are the amplitudes of the ith cycle and $(i+n)$th cycle, respectively, separated by n periods of the free vibrations of the specimen. Between the above mentioned quantities, the following relationship holds: $\pi\eta = \delta$ (for small δ).

The objective of the present paper is to estimate the influence of cyclic bending on the damping behaviour of AZ91 magnesium alloy-based composite. The logarithmic decrement is used as a measure of the damping.

2. Experimental procedure

2.1. Composite preparation

Composites were prepared by the squeeze casting method. Commercial magnesium alloy AZ91 (9 wt%Al, 1 wt%Zn, 0.2 wt%Mn, balance Mg) was used as the matrix material. The alloy was reinforced with δ-Al_2O_3 short fibres (Saffil®). The preform consisting of Al_2O_3 short fibres showing a planar isotropic fibre distribution and a binder system (containing Al_2O_3 and starch) was preheated to a temperature higher than the melt temperature of the alloy and then inserted into a preheated die. The two-stage application of the pressure resulted in MMCs with a fibre volume fraction of ≈15 vol%. Fig. 1 shows the microstructure of undeformed AZ91 alloy with 15 vol% Saffil. Many broken fibres as a consequence of squeeze casting are visible. The mean fibre length measured after squeeze casting was 78 μm. The fibre length was measured in the micrographs and evaluated using statistical methods. The mean fibre diameter (given by the producer) was 3 μm. The microstructure of the composite contains, similar as in the case of unreinforced AZ91 alloy, $Mg_{17}A_{12}$ precipitates.

2.2. Damping measurements

Damping measurements were carried out on bending beams (80 mm long with thickness of 3 mm) in

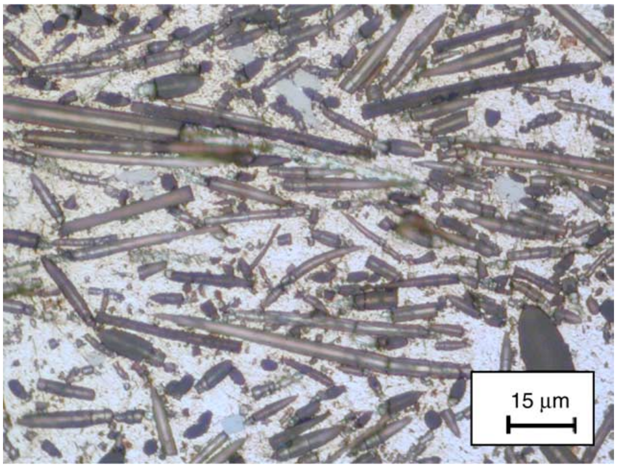

Fig. 1. Microstructure of as received AZ91 alloy reinforced with Saffil fibres (longitudinal section). Diameter of fibres is ~3 μm.