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Creep mechanism and creep constitutive model of aluminum silicate short-fiber-reinforced magnesium matrix composite

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Abstract: By the constant stress tensile creep test method, creep tests were performed on aluminum silicate short fiber-reinforced AZ91D magnesium matrix composite with volume fraction of 30% and its matrix alloy AZ91D under different temperatures and stresses. The results indicate that the composite and the matrix have the same true stress exponent and true activation energy for creep, which are 3 and 144.63 kJ/mol, respectively. The creep of the composite is controlled by the creep of its matrix, which is mainly the controlling of viscous slip of dislocation, and the controlling of grain boundary slippage as a supplement. The creep constitutive model obtained from the experiment data can well describe the creep deformation pattern of the composite.

Key words: magnesium matrix composites; threshold stress; effective stress; constitutive model

1 Introduction

The great importance placed on light materials by the automobile, aerospace, and electronic industries necessarily introduces magnesium alloy as a promising candidate for extensive use in these fields [1−4]. AZ91 is the most commonly used magnesium alloy due to its good property profile, but suffers from its poor creep behaviour at elevated temperatures, especially under long-term loading conditions, and is restricted at temperatures above 423 K [5−7]. An effective way to improve the creep properties of alloys is to add reinforcement to alloys forming composites [8−11]. Recent tests have confirmed that the AZ91D magnesium matrix composite, which is fabricated by the squeeze-casting method with aluminum silicate short fibers as reinforcement, has a good bonding interface, and could enhance the composite significantly [12]. Several studies have been conducted in the high temperature creep of short fiber reinforced metal matrix composites. For example, the assessment of back-stress and load transfer approaches for rationalizing creep of short fiber reinforced aluminum alloys has been demonstrated [13]. CHMELÍK et al [14] studied creep properties and behaviors of an unreinforced AZ91 magnesium alloy and a similar alloy reinforced with short alumina fibers, and the results showed that the introduction of short alumina fibers into an AZ91 magnesium alloy improved the creep resistance due to the introduction of a threshold stress that served to reduce the effective stress acting on the material. SKLENIČKA et al [15] conducted creep tests on an AZ91−20%Al_2O_3 (volume fraction) short fiber composite and on an unreinforced AZ91 matrix alloy, and the results showed that the creep resistance of the reinforced material improved considerably compared with the matrix alloy; the creep-strengthening arose primarily from the effective load transfer between plastic flow in the matrix and the fibers. OLBRICHT et al [16] studied mechanical and microstructural observations during compression creep of a short fiber reinforced Al−Mg metal matrix composite, and it was concluded the orientation of Al_2O_3 fibers with respect to the loading axis affected minimum creep rates, and fiber breakage represented an important damage mechanism. SPIGARELLI and MEHTEDI [17] investigated microstructure-related equations for the constitutive analysis of creep in magnesium alloys, and a new model, developed by relating a modified form of the Garofalo's which was equation and the concentration of aluminum in a solid solution, had been used to describe the

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minimum creep rate dependence of applied stress and temperature. Although the creep behavior of short fiber reinforced metal matrix composites and the creep constitutive relation of metal alloys were studied, the creep constitutive relation of short fiber reinforced metal matrix composites was not studied.

In order to ensure the safe use of the composite at high temperatures, it is an urgent matter to study the creep properties of the material, and in particular to obtain the model which precisely describes the constitutive relations between the creep parameters during the creep deformation process.

This study performed an investigation into the creep behavior of the aluminum silicate short-fiber-reinforced AZ91D composite by the constant stress tensile creep test method under different temperatures and stresses. Based on the creep test data and the electronic test, the creep mechanisms of the composite and its matrix as well as the load transfer mechanism of short fiber were analyzed. Subsequently, a high-temperature creep constitutive model of the composite was established, with the purpose of using these findings to guide the practical application of this material and enrich the theoretical creep studies of short-fiber-reinforced magnesium matrix composites.

2 Experimental

Aluminum silicate short-fiber-reinforced AZ91D composite was fabricated by the squeeze-casting method from aluminum silicate short fiber and AZ91D magnesium alloy (Mg−9%Al−1%Zn−0.3%Mn (mass fraction)). The aluminum silicate short fiber preform was formed by aluminum silicate short fibers (Al_2O_3−SiO_2, ~5 μm in diameter with varying lengths up to ~80 μm) in random distribution, and the volume fraction of short fibers in the squeeze cast composite is about 30%. For convenient expression, hereinafter the aluminum silicate short-fiber-reinforced AZ91D composite with 30% short-fiber (volume fraction) was written as 30%Al_2O_3−$SiO_{2(sf)}$/AZ91D or referred to as the composite, and the AZ91D magnesium alloy is referred to as the matrix alloy or the matrix for short. The composite and matrix alloy were performed tensile creep tests up to the final creep facture on the GWT105 durable testing machine under temperatures of 473, 523 and 573 K, and with applied stresses of 30−100 MPa. The test sample is shown in Fig. 1.

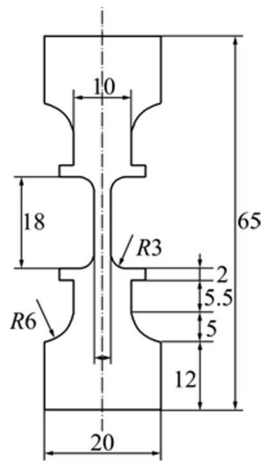

Fig. 1 Creep testing sample (unit: mm)

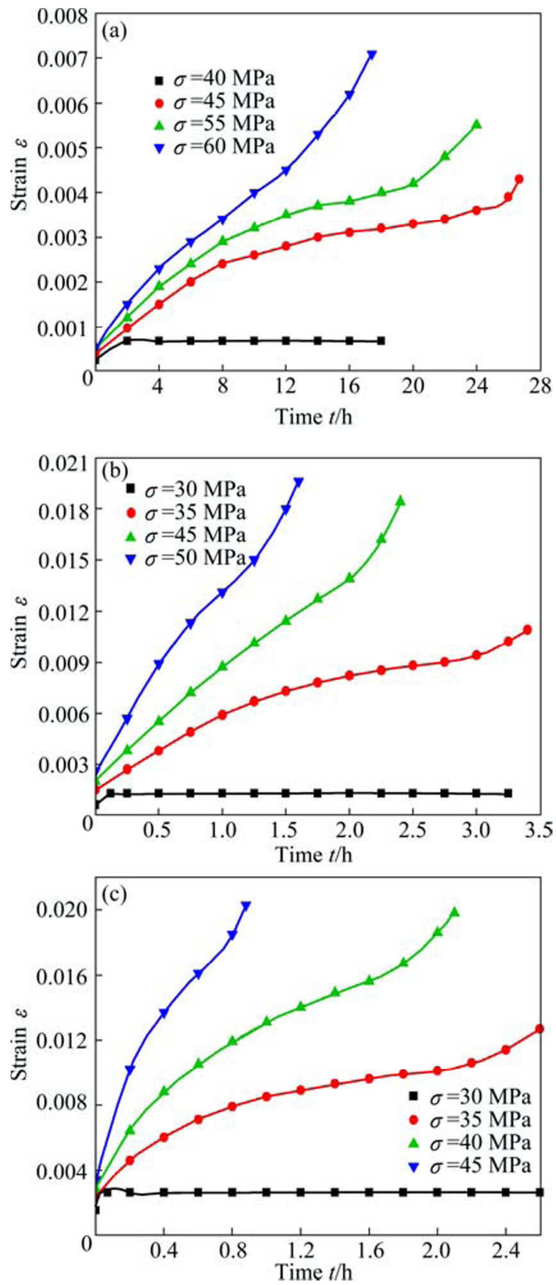

Fig. 2 Creep curves of AZ91 magnesium alloy under different stresses and temperatures: (a) 473 K; (b) 523 K; (c) 573 K

3 Results and discussion

3.1 Analysis of high-temperature creep curves

The strain−time curves of the matrix and the composite under different temperatures and loads are shown in Figs. 2 and 3. It can be seen that under the