Deformation Mechanism of Mg-4Sn-1.5Pb Alloy

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Abstract. The hot deformation behavior of Mg-4Sn-1.5Pb Magnesium Alloy was investigated by hot compression test in the temperature range 250 ℃-400 ℃ and strain rate range 0.001 s^{-1}-10 s^{-1} on Gleeble-3500 simulator. The calculated hot deformation activation energy *Q* is 158.144 KJ/mol. Stress exponent is 6.6. The deformation mechanism of the material is determined by calculating the threshold stress.

Introduction

Magnesium is the lightest structural metal in engineering application. It also has some other excellent properties such as high specific strength, high specific modulus, good seismic and noise reduction, recyclables. It is known as the “21st century green engineering metal structure material” [1,2]. However, Magnesium alloy has low elongation to fracture at room temperature due to the hexagonal closed-packed structure of magnesium, so magnesium alloys usually were hot forming at elevated temperature.

In the present work, the deformation mechanism of Mg-4Sn-1.5Pb prepared by stir casting was investigated. Based on the results of hot compression testing and the derived constitutive equation, the deformation mechanism of this alloy was determined at elevated temperature by calculating the threshold stress.

Experimental procedures

Mg-4Sn-1.5Pb alloy was prepared by the stir casting process in a magnesium alloy melting furnace. The ingots were homogenization annealing and then they were machined into specimens for hot compression tests (12 mm in height, 8 mm in diameter) and the hot compression tests were carried out on Gleeble-3500 testing machine, and the strain rate is 0.001-10 s^{-1}, the deformation temperature is 250-400 ℃, the heating rate is 10 ℃/s. The experiment was stopped when true strain reached 0.9.

Results

It is found that the form of the hyperbolic sine function constitutive equation is good agreed with the experiment in our previous work. Therefore the hyperbolic sine function constitutive equation to describe the elevated temperature deformation of Mg-4Sn-1.5Pb is used in this paper. The stress exponent *n* is 6.6. The calculated hot deformation activation energy *Q* is 158.144 KJ/mol.

The deformation mechanisms of magnesium alloy at elevated temperature are controlled by stress exponent *n* and hot deformation activation energy *Q*. Nieh et al [3] indicated that various stress exponents *n* relate to different deformation mechanism, as shown in Tab.1.

The calculated stress exponent of the Mg-4Sn-1.5Pb alloy is 6.6. However, no deformation mechanism associated with n=6.6 has been proposed in the available literature. Therefore, the hot deformation mechanism of Mg-4Sn-1.5Pb alloy may be dislocation climb creep or dispersion strengthened or the combination of both modes. We need to make further calculation and analysis to judge the deformation mechanism. One simple approach to confirm that if the value of stress exponent is reasonable or not (which suggests the deformation mode of the materials following either dislocation climb creep or dispersion strengthened) is to find the threshold stress [4-9]. The threshold stress is calculated to confirm whether there is a threshold stress σ_0 in Mg-4Sn-1.5Pb alloy. The threshold stresses at various temperatures were estimated using the linear extrapolation technique, based on plotting $\dot{\varepsilon}^{1/n}$ versus σ in double linear coordinates, by its extrapolation to $\dot{\varepsilon}^{1/n}=0$ the value of σ_0 is obtained [10].

Tab.1 The relationship between *n* and deformation mechanisms

n	deformation mechanism
1	diffusion creep
2	grain boundary sliding
3	dislocation glide controlled creep
4-5	dislocation climb controlled creep
≥8	dispersion strengthened alloys

Threshold Stresses of Mg-4Sn-1.5Pb Magnesium Alloy

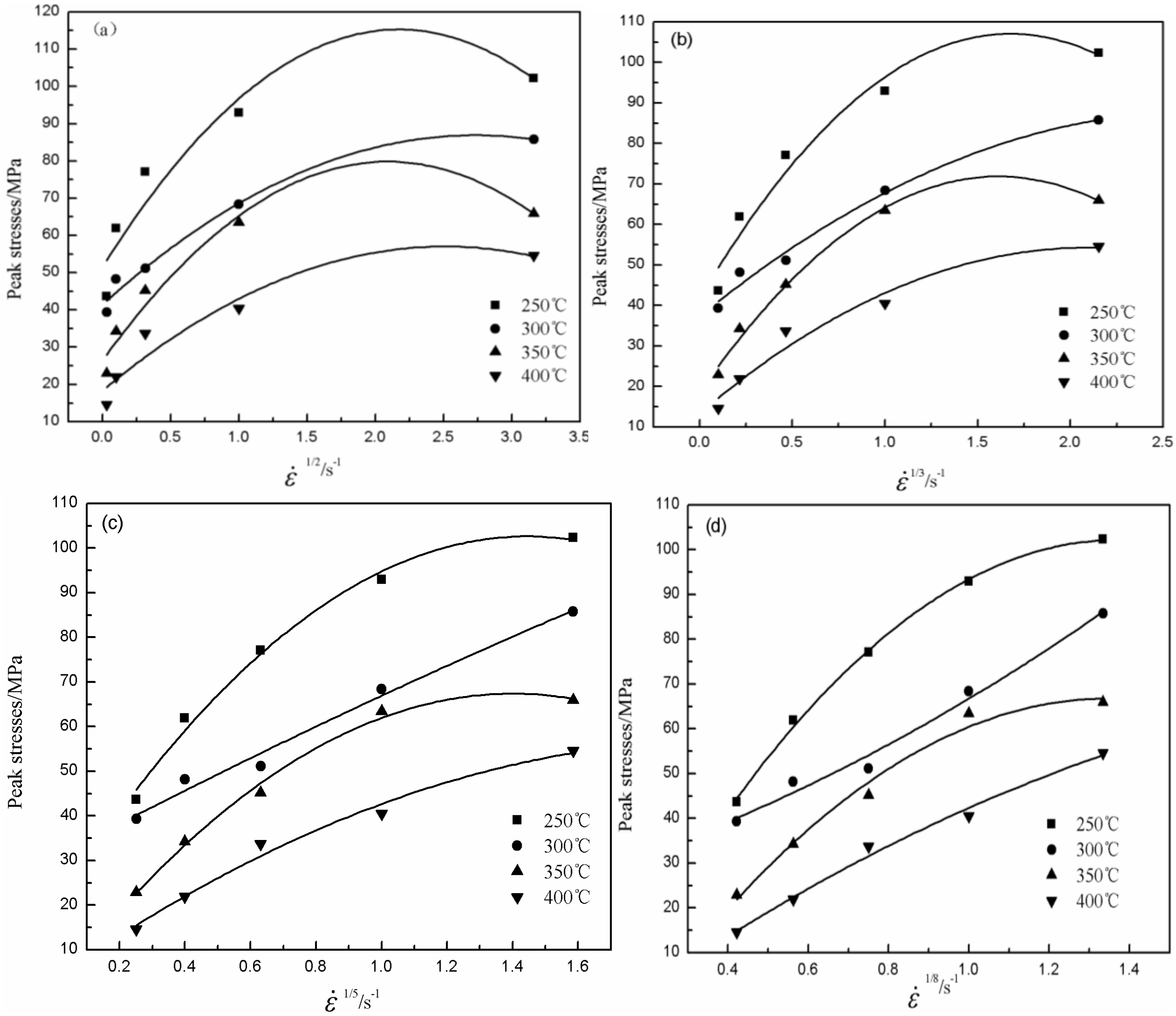

Fig.1 Plots of $\dot{\varepsilon}^{1/n}$ and σ at given temperatures of Mg-4Sn-1.5Pb magnesium alloy
(a) *n*=2， (b) *n*=3，(c) *n*=5，(d) *n*=8

The $\dot{\varepsilon}^{1/n}$ versus σ fitting curves at various temperatures for *n*=2, *n*=3, *n*=5 and *n*=8 are presented in Fig.1(a)-(d), respectively. Fig.1 shows that there is not a linear relationship in these curves of $\dot{\varepsilon}^{1/n}$ versus σ for n=2 and 3. Therefore, n=2 and 3 are not suitable for as the stress exponent to calculate the threshold stress values. It is not hard to see that for n=5 and 8, $\dot{\varepsilon}^{1/n}$ has a linear relationship with σ. However, the threshold stress values are negative when n is 8. This is contradict with the threshold stress cannot be negative. So in our study, 5 should be taken as the value of n to analysis the deformation mechanism. Which means the deformation mechanism of Mg-4Sn-1.5Pb magnesium alloy is dislocation climb controlled creep.

The calculated hot deformation activation energy Q of the Mg-4Sn-1.5Pb alloy is 158.144 KJ/mol. Which is very close to the activation energy Q_L for the lattice diffusion in pure Mg, i. e. , 135 KJ/mol [11]. Taking both Q and n into our consideration, it is therefore concluded that the deformation mechanism of the Mg-4Sn-1.5Pb alloy is lattice diffusion controlled dislocation climb.

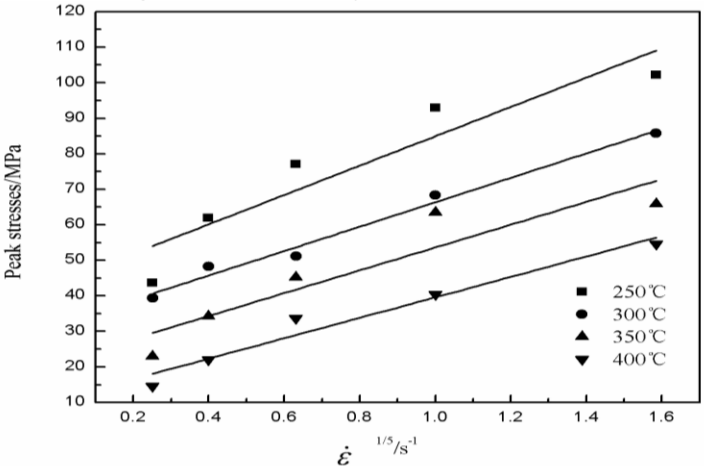

Fig.2 Plots of $\dot{\varepsilon}^{1/5}$ and σ at various temperatures of Mg-4Sn-1.5Pb magnesium alloy

Fig.2 is the $\dot{\varepsilon}^{1/n}$ versus σ linear fitting curves when n is 5. Intercepts of these lines on the ordinate are threshold stress values at various temperatures. From Fig. 2 we obtained threshold stress values at 250 ℃, 300 ℃, 350 ℃ and 400 ℃ are 43.61322 MPa, 31.98323 MPa, 21.46259 MPa and 10.80549 MPa, respectively. It is evident that the threshold stresses decrease by increasing the temperature.

As shown in Fig.3, there is a liner relationship between the threshold stresses and temperature of the Mg-4Sn-1.5Pb alloy. The threshold stress gradually tend to be zero above 400 ℃. There are two kinds of explanations for the disappearance of the threshold stress at high temperatures. One explanation is the threshold stress disappears because of the process not associated with the threshold stress dominates the other. Another explanation is as the temperature increases, the transition from athermal to thermally activated detachment of dislocations from small incoherent particles occured[11-13].

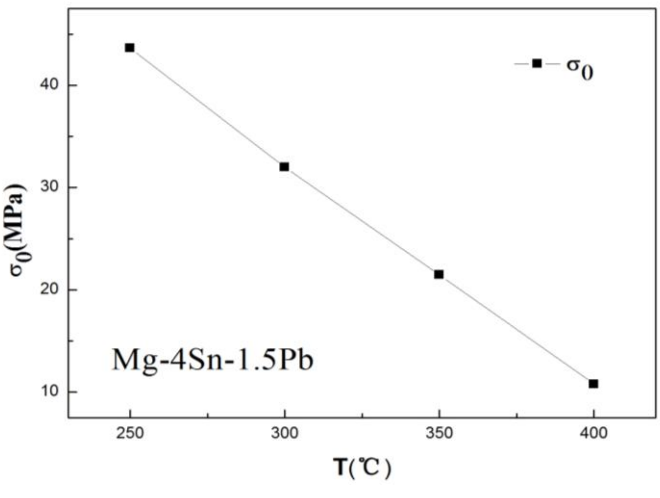

Fig.3 Temperature dependence of threshold stresses in Mg-4Sn-1.5Pb alloy

Deformation Behavior Analysis

From Fig.4 is not hard to see, the second phase particles (Mg_2Sn) of Mg-4Sn-1.5Pb alloy were precipitated along grain boundary during the solidification, which can make the dislocation motion pinned. So the deformation of this magnesium alloy is mainly by the combined effects of local dislocation climb mechanism and the second phase particles to prevent deformation. Due to the deformation, the second phase particles generate high density of dislocations, and dislocations accumulation cause stress concentration. Which lead to the second phase particles rupture or come off, and make the improvement of the creep properties of magnesium alloy.

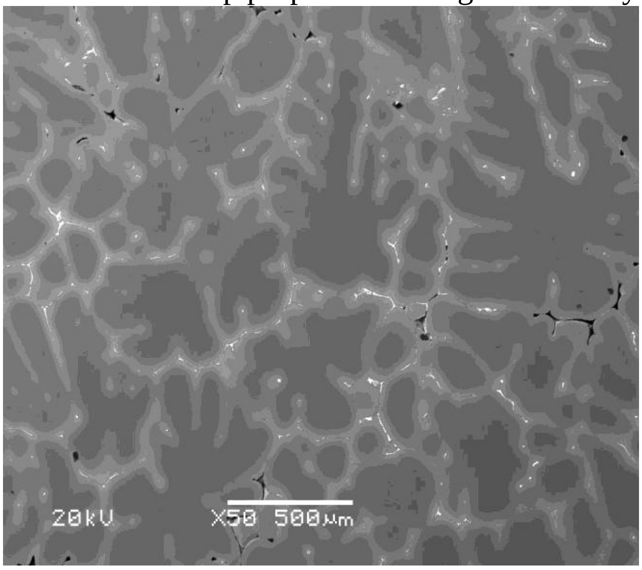

Fig.4 SEM observation on the as-cast Mg-4Sn-1.5Pb alloy

Summary

1. Through the calculation of the threshold stress, we obtained threshold stress values of Mg-4Sn-1.5Pb magnesium alloy corresponding to 250 ℃, 300 ℃, 350 ℃ and 400 ℃ are 43.61322 MPa, 31.98323 MPa, 21.46259 MPa and 10.80549 MPa, respectively. And the threshold stresses decrease by increasing the temperature.
2. Elevated temperature compression deformation mechanisms of Mg-4Sn-1.5Pb is lattice diffusion controlled dislocation climb.

Acknowledgement

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