EFFECT OF STRESS AMPLITUDE ON THE GRAIN BOUNDARY DEFORMATION BEHAVIOR DURING CYCLIC CREEP AT 573K IN AN Al-Mg ALLOY

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Effects of stress amplitude ratio on the grain boundary deformation behavior during cyclic stressing at 573 K in Al-2.9%Mg alloy was studied. Creep behavior of this alloy is found to be dominantly controlled by the applied minimum stress, not by the applied peak stress under a cyclic stress. Therefore, the creep deformation behavior is believed to be changed from class A type to class M type with increasing stress amplitude ratio, and also for higher stress amplitude ratio grain boundary cracking(GBC) is obviously exhibited. These phenomena are expected to be resulted from the effect of the internal stress at the applied minimum stress during cyclic stressing.

INTRODUCTION

According to the high temperature creep behavior, solid solution alloys are often classified(1) either class A (or class I) which is controlled by the viscous glide motion of dislocations accompanied by the solute atom atmosphere, or class M (or class II) which is controlled by dislocation climb. In addition, the class A alloys differ from the class M alloys by several other features of creep behavior(2,3). The main features of the former are as follows ; inverse primary creep, a stress exponent of about 3, no significant tendency to form subgrain except in the vicinity of grain boundaries and a higher internal stress. By contrast, the latter, in general, has a normal primary creep, a stress exponent of about 5, a well developed substructures and a lower internal stress.

It is well known that high temperature creep behavior of Al-Mg solid solution alloys can be divided into three regions, *i.e.*, two class

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M and one class A in a range of power-law creep region. In other words dislocation creep mechanism of Al-Mg alloys can change from class M to class A and again to class M with increasing applied stress.

Recently, the effects of cyclic tensile stress which alternates in a periodic fashion (peak stress, σ_{peak}, and minimum stress, $\sigma_{\min}$) on creep behavior of Al-Mg solid solution alloys at high temperature have been investigated(4-6). In general, under a power-law creep, grain boundary deformation behavior of a statically crept Al-Mg alloy shows grain boundary serrations and/or grain boundary migrations (GBM) which are dependent on the grain size or on the applied stress level. On the contrary, Hong and Nam(4), for the first time, observed a very peculiar phenomenon of grain boundary cracking (GBC) for a cyclically crept Al-Mg alloy, not for statically crept one, with a stress amplitude ratio of 0.9 under the same applied peak stress level. Stress amplitude ratio, δ, is defined as $\Delta\sigma / \sigma_{peak}$ (where $\Delta\sigma$ is the difference between the applied peak stress, σ_{peak}, and the applied minimum stress, $\sigma_{\min}$). And they have concluded that the formation of GBC is resulted by the effect of the enhanced grain boundary sliding through an accelerated recovery with the help of mechanically generated excess vacancies during cycling. However, in addition to the above effect, the formation of GBC is thought to be affected by the internal stress level, σ_i, of the applied minimum stress, $\sigma_{\min}$, of cyclic stressing. The level of the internal stress during creep is one of the most important parameters in identifying the rate-controlling process of the deformation. When creep deformation is controlled by a recovery process as in the case of pure metals, the internal stress is supposed to be very close to the applied stress.

In this paper, we investigate the effect of stress amplitude ratio on the grain boundary deformation behavior, that is, GBM or GBC during cyclic creep at the temperature of 573 K with varying applied peak stress level (15 to 40 MPa) and measuring the internal stresses under cyclic stresses. And we also study to interrelate a difference of grain boundary deformation behavior by a change of stress amplitude ratio with the measured internal stress for a cyclic creep.

EXPERIMENTS

The experiments were conducted on an Al-2.9%Mg alloy of the following chemical composition in wt.% : Mg-2.90, Si-0.03, Cu-0.002, Mn-0.001, Ni-0.001, Cr-0.001, Ti-0.002, Zn-0.01 and Fe-0.03, and the remainder being is Al. The creep specimens were annealed at 773 K for 12 h in air to make the grain size of about 0.12 mm. Before the creep test, the specimen surface was mechanically polished to obtain a mirror-like surface.

Both static and cyclic creep tests were performed in air atmosphere at 573 K, using a creep machine equipped with an Andrade-Chalmer constant stress arm allowing to keep the tensile stress constant during the test up to a creep strain of 0.18. The cyclic stress condition can be obtained with a specially designed cyclic loading machine with which peak stress (15-40 MPa), stress amplitude ratio (0 to 0.9) and frequency (3 cycle per minute) are kept constant throughout the cyclic test(7).

The internal stress of the applied minimum stress during cyclic stressing was measured by the strain transient dip test technique(8). The crept specimen was examined by scanning electron microscopy (SEM) to observe the grain boundary cracking.

RESULTS and DISCUSSION

Creep Behavior

To show the effects of the applied stress on the steady-state creep rate of the Al-2.9%Mg solid solution alloy with various stress amplitude ratio δ (δ=0 and δ>0 mean a static and a cyclic creep, respectively) under a range of the applied peak stress (15 to 40 MPa) at 573 K, the steady-state creep rates, $\dot{\varepsilon}$, are measured at two different δ conditions and plotted as a function of the applied peak stress in Fig. 1 to show the form of power law creep

$$\dot{\varepsilon} = A\sigma^n \qquad (1)$$

where A is a structure dependent constant and n is a stress exponent. As shown in Fig. 1, the stress exponent n's value increases with increasing δ, that is, from n = 3.68 at δ = 0 (static) to n =4.73 at δ = 0.9 (cyclic). That is, class A behavior is observed obviously for static creep while class M behavior is exhibited significantly for cyclic creep. From this result, it is expected that, under a cyclic stressing, the creep behavior of this alloy is controlled not by the applied peak stress, but by the applied minimum stress. Accordingly, macroscopic creep behavior of this alloy can be considered to change from class A behavior to class M behavior with increasing stress amplitude ratio under the same applied peak stress level. This transition is in good agreement with Yang *et al.*(6). In other words the rate-controlling creep mechanism can be thought to change from the dislocation viscous-glide process to the dislocation climb process as the value of δ increases.

Grain Boundary Deformation Behavior

In order to find the critical value of the stress amplitude ratio, δ, which is responsible for the GBC, the creep test was performed with varying stress amplitude ratio at various peak stress and the grain boundary structures of each specimen were observed using SEM to see whether GBC is formed or not.

The minimum stress at which GBC is occuring, σ_{GBC} and the measured internal stress of a given σ_{GBC} during cycling is plotted against the applied peak stress in Fig. 2. As shown in Fig. 2, σ_i is nearly equal to or slightly higher than σ_{GBC}. This means that the GBC is related to the internal stress. It is well known that the effective stress can be responsible for the dislocation glide while the internal stress is the driving force for the dislocation recovery. Fig. 2 also shows that σ_i increases with increasing $\sigma_{\min}$ for cyclic creep. Fig. 3 shows a representative grain boundary cracking at a stress amplitude ratio of 0.9 under 20 MPa.

From a microscopic view, at the value of the low stress amplitude ratio, dislocations can glide over the barrier regardless of cyclic stress because the effective stress is always higher than σ_i. And, due to the continuous dislocation motion, some of the dislocations will be piled-up in the vicinity of grain boundary. This circumstance is, as discussed in the introduction, similar to the characteristics of substructure developed in the statically crept specimen. Accordingly, a cyclic creep with a small enough stress amplitude can be controlled by the dislocation glide motion to show a class A behavior, though the steady-state creep rate of cyclic creep is lower than that of the static creep. Whereas, for higher stress amplitude ratio such as $\sigma_{peak} > \sigma_i$ and $\sigma_{\min} < \sigma_i$, dislocations can move and Mg solute atoms which make the cohesive strength between the grains weak can be transported by the Cottrell clouds around the moving dislocation to grain boundaries under σ_{peak} but not under $\sigma_{\min}$. Under this repeated cyclic stressing, it is expected that the dislocations piled-up near a grain boundary during the period of σ_{peak} are recovered to be moved into grain boundaries during $\sigma_{\min}$ period and the transported Mg solute atoms are distributed homogeneously along the grain boundaries. Therefore, GBC will occur and be accelerated by both the recovery process and the homogeneous distribution of Mg solute atoms. This expectation is confirmed by Hong and Nam(4) and Lee(5).

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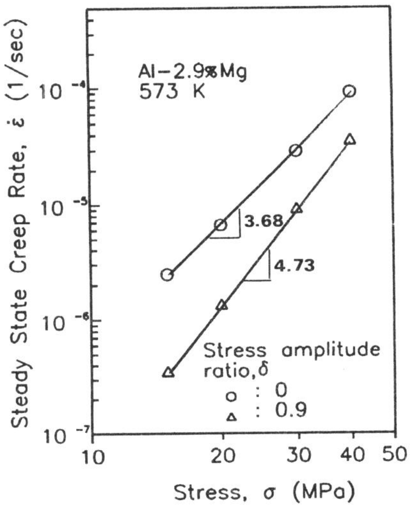

Figure 1 The steady state creep rate vs. the applied stress

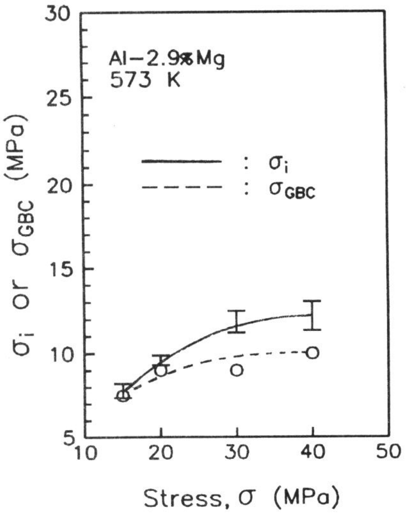

Figure 2 Relations between σ_i or σ_{GBC} and applied stress σ

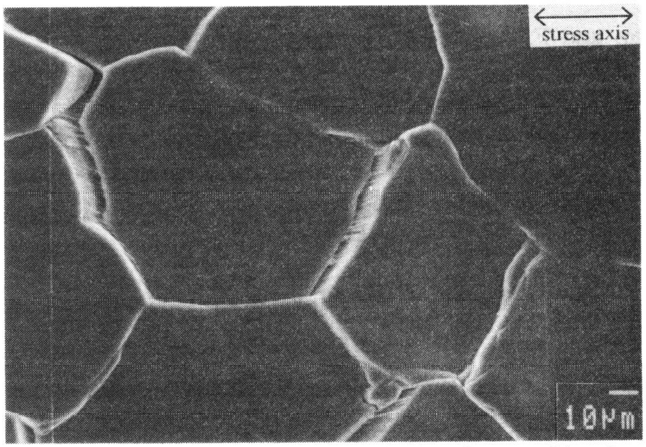

Figure 3 A representative type of grain boundary cracking for a cyclically crept(δ = 0.9) Al–2.9%Mg alloy at 573K under 20MPa