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Applicability of the Method Proposed to Determine the High Temperature Deformation Mechanism

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Applicability of the method recently proposed by the present authors to determine the high temperature deformation mechanism in crystalline materials is examined with a solution-hardened Al-Mg alloy. The method is based on the theoretical concept that the mechanical response of materials to an abrupt change in deformation rate depends upon the deformation controlling mechanism. The deformation mechanism of the Al-Mg alloy used is known to be dislocation glide. It is presented that the observed mechanical response of the alloy agrees well with the theoretical prediction for glide control, demonstrating that the method is well applicable.

1. Introduction

There still exists a controversy as to the controlling mechanism of high temperature deformation; some researchers believe that the deformation of pure metals is of recovery control, while others believe that it is of dislocation glide control. Either of the two mechanisms can explain the fundamental deformation characteristic that the flow stress depends strongly on temperature and strain rate, which makes it difficult to determine which of the two mechanisms is the case [1].

A method to identify the controlling mechanism is the strain rate change test [2], where the imposed strain rate, $\dot{\varepsilon}_a$, is abruptly changed from $\dot{\varepsilon}_{a1}$ to $\dot{\varepsilon}_{a2}$ during deformation. The rate $\dot{\varepsilon}_a$ is determined by the cross-head displacement rate of the test machine and thus includes the elastic strain rate of the machine/specimen assembly. The plastic strain rate $\dot{\varepsilon}$ is determined by subtracting the elastic strain rate from $\dot{\varepsilon}_a$. Then, it is examined whether the change in plastic strain rate is continuous or discontinuous, by measuring the plastic strain rates, $\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$, immediately before and after the change in $\dot{\varepsilon}_a$, respectively. It is theoretically predicted that if the rate-change is continuous, the deformation is glide-controlled, whereas if the rate-change is discontinuous, the deformation is recovery-controlled [2].

The measurement of $\dot{\varepsilon}_2$, however, requires some flow-stress change $\Delta\sigma_2$ from the stress at the very instant of $\dot{\varepsilon}_a$-change. The experimental error due to $\Delta\sigma_2$ may lead to a wrong conclusion as pointed out by Gibeling et al. [3]. In a previous paper [4], therefore, we have put forward an improved method to remove the effect of such experimental limitations.

According to the theoretical prediction in the improved method [4], for recovery control $\Delta\dot{\varepsilon}$ ($\equiv \dot{\varepsilon}_2 - \dot{\varepsilon}_1$) depends linearly on the changed strain rate, $\dot{\varepsilon}_{a2}$, whereas for glide control $\Delta\dot{\varepsilon}$ is independent of $\dot{\varepsilon}_{a2}$ and uniquely determined by $\Delta\sigma_2$ as long as the change

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in dislocation structure due to the plastic deformation corresponding to $\Delta\sigma_2$ is negligible; in the case of solute atmosphere dragging of dislocations being rate controlling, e.g., as in solution-hardened Al-Mg alloys [2, 5 — 15], $\Delta\dot{\varepsilon}$ varies in proportion to $\Delta\sigma_2$. It has been shown that in the high temperature deformation of pure aluminium $\Delta\dot{\varepsilon}$ depends linearly on $\dot{\varepsilon}_{a2}$ providing that the extrapolated value of $\dot{\varepsilon}_2$ to $\Delta\sigma_2=0$ is used [4], indicating that the deformation of pure aluminium is recovery controlled.

The objective of the present paper is to examine the applicability of the method to a solution-hardened Al-Mg alloy. It will be shown that the experimental results obtained agree well with the theoretical prediction for the mechanical response.

2. Experimental

High purity polycrystals of an Al-5.7at%Mg alloy were used. The stress change test [11, 12, 15] was also conducted as well as the strain rate change test [2]. The details of the specimen preparation and mechanical tests are the same as those described in previous papers [2, 4, 15].

3. Results and Discussion

The relationship between $|\Delta\dot{\varepsilon}|$ and $\dot{\varepsilon}_{a2}$ for various values of $|\Delta\sigma_2|/\sigma_s$ (σ_s is the flow stress at the steady state deformation) is shown in **Fig. 1**, which was obtained at 673K by changing $\dot{\varepsilon}_a$ at various points in steady state deformation at $\dot{\varepsilon}_{a1}$ ($=\dot{\varepsilon}_1$) and $\sigma_s=10$MPa to four different strain rates of $\dot{\varepsilon}_{a2}$. The broken line represents the average value of $\dot{\varepsilon}_{a1}$, because $\dot{\varepsilon}_{a1}$ decreases with increasing the specimen elongation and varied from 5.74×10^{-5} to $5.25\times10^{-5}\text{s}^{-1}$ at the four different points in the steady-state deformation. It is

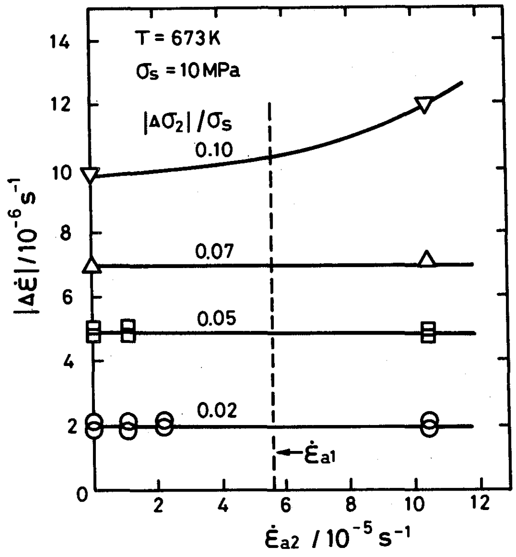

Fig. 1 The relation between $|\Delta\dot{\varepsilon}|$ and $\dot{\varepsilon}_{a2}$ for different values of $|\Delta\sigma_2|/\sigma_s$ obtained by the strain rate change test in an Al-5.7at%Mg alloy.

apparent from the figure that in the region of $|\Delta\sigma_2| \leqq 0.07\sigma_s$, $|\Delta\dot{\varepsilon}|$ is independent of $\dot{\varepsilon}_{a2}$ and uniquely determined by the value of $\Delta\sigma_2$. This behaviour accords well with the theoretical prediction for glide control and is quite different from that of pure aluminium of recovery control [4]. However, when $|\Delta\sigma_2| = 0.10\sigma_s$, $|\Delta\dot{\varepsilon}|$ is seen to depend on $\dot{\varepsilon}_{a2}$. This suggests that an appreciable change in dislocation structure occurred due to the plastic deformation during the stress change of $\Delta\sigma_2$.

As mentioned above, in the case of solute atmosphere dragging of dislocations being rate controlling, the theory for glide control predicts that $\Delta\dot{\varepsilon}$ should be proportional to $\Delta\sigma_2$. To examine the validity of the prediction, $\Delta\dot{\varepsilon}$ is replotted in **Fig. 2** against $\Delta\sigma_2$ with a wider range of -2.5MPa ($\Delta\sigma_2/\sigma_s = -0.25$) to 2.0MPa ($\Delta\sigma_2/\sigma_s = 0.20$). It is seen that the proportionality really holds between $\Delta\dot{\varepsilon}$ and $\Delta\sigma_2$ in the stress range of $-$2.5MPa to 0.7MPa where no $\dot{\varepsilon}_{a2}$-dependence was observed. However, when $\Delta\sigma_2$ exceeds 0.7MPa, a departure from the proportionality is clearly observed; $\Delta\dot{\varepsilon}$ becomes larger than the predicted value.

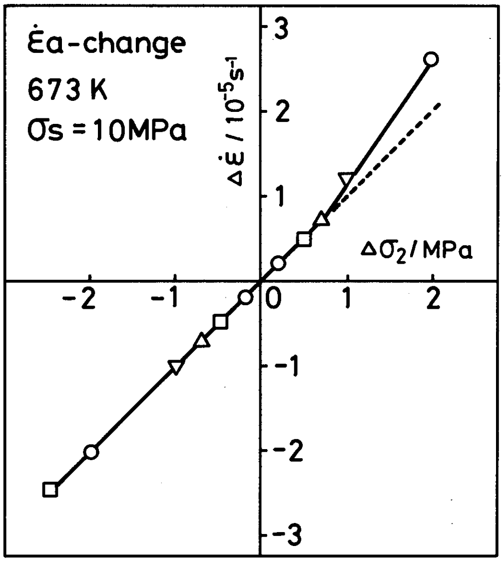

Fig. 2 Dependence of $\Delta\dot{\varepsilon}$ on $\Delta\sigma_2$ obtained by the strain rate change test in an Al-5.7at%Mg alloy.

Two possibilities are considered to be responsible for the departure. One possibility is the breakaway of dislocations from their solute atmospheres by the stress increase [14], and the other is a significant change in dislocation structure during $\Delta\sigma_2$. The former possibility, however, will be ruled out, as given below.

The occurrence of the breakaway of dislocations from their solute atmospheres can be determined by the presence of instantaneous plastic strain associated with the sudden stress increase [11, 12, 15]. The abrupt stress change test [11, 12] was then performed during creep deformation of Al-5.7at%Mg at 673K under $\sigma = 9$MPa with the stress increase up to 2.5MPa. No instantaneous plastic strain was observed, indicating that no breakaway of dislocations from their solute atmospheres occurred in the stress range studied.

The latter possibility may be responsible for the departure. Then, it is expected that if $\Delta\sigma_2$ is forced to be changed by using the stress change test [15] so rapidly that any significant plastic strain and thus any significant change in dislocation structure is not introduced during the stress change, $\Delta\dot{\varepsilon}$ should vary in proportion to $\Delta\sigma_2$ even in the high stress range where the departure from the proportional relationship was observed in **Fig. 2**.

The result is shown in **Fig. 3**. It should be noted that even in the stress range where the clear departure from the proportionality occurred in the strain rate change test, $\Delta\dot{\varepsilon}$ varies in proportion to $\Delta\sigma_2$. This observation shows that the departure is attributed to the change in dislocation structure. Thus, it is concluded that the method proposed in the previous paper [4] is applicable not only to the deformation of recovery control but also to the deformation of glide control. The proposed method is useful to identify the high temperature deformation mechanism in the materials whose deformation controlling mechanism is still open to question.

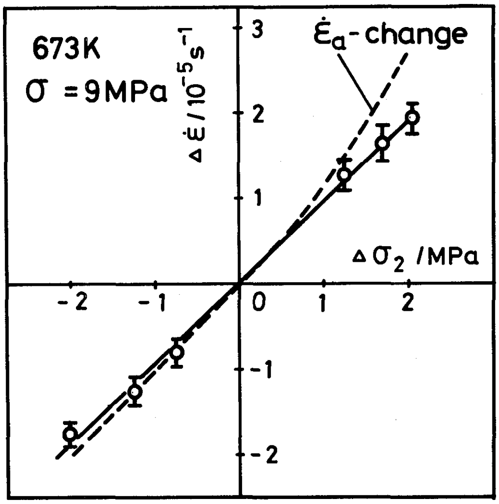

Fig. 3 Dependence of $\Delta\dot{\varepsilon}$ on $\Delta\sigma_2$ obtained by the abrupt stress change test in an Al-5.7at% Mg alloy. For comparison, the result by the strain rate change test is also shown.

4. Conclusion

For the high temperature deformation of a solution-hardened Al-Mg alloy, the plastic strain rate change, $\Delta\dot{\varepsilon}$, after the change in imposed strain rate (which includes the elastic component) is independent of the changed strain rate, $\dot{\varepsilon}_{a2}$, and uniquely determined by the flow stress change, $\Delta\sigma_2$, as long as the change in dislocation structure during $\Delta\sigma_2$-change is negligible. In addition, $\Delta\dot{\varepsilon}$ varies in proportion to $\Delta\sigma_2$. These behaviour agrees well with the theoretical prediction for the dislocation-glide-controlled deformation. This result, together with the previous result reported for pure aluminium, shows that the proposed method [4] based on the strain rate change test is useful to determine the high temperature deformation mechanism in crystalline materials.

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