DISLOCATION BEHAVIOR IN THE SUPERPLASTIC DEFORMATION OF ALLOY Al-Li 2091①

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ABSTRACT The dislocation behavior in the superplastic deformation of alloy Al-Li 2091 has been studied. Both TEM observation and X-ray diffraction analysis revealed that: in the stuidied range of strain, the amount of dislocation in the grain interior decreases with the increase of strain. There also exist such dislocation configurations as network, subgrain boundaries, dislocation poles, helical dislocation, dislocation ring and grain boundary dislocations. In the softening stage of superplastic deformation, with the increase of strain, the velocity of dislocation motion increases and the activation energy of dislocations decreases.

Key words Al-Li alloy superplastic deformation dislocation behavior

1 INTRODUCTION

When Al-Li alloy consists of even stable and equiaxed fine grains, optimal superplasticity can be achieved through isothermo-deformations at a higher temperature and a lower strain rate. It is generally accepted that in the process of superplastic deformation of microcrystalline structure materials, the grain boundary slidding, which is caused by the movement of grain boundary dislocations, plays a key role[1, 2]. Few reports have been published on the dislocation behavior in the process of superplastic deformation and they are of different opinions. Some one pointed out that the density of dislocations icreases with the increase of strain[3]. While other invetigations suggested just the contrary, dislocation decreases with the increase of strain. We studied the dislocation behavior in the superplastic deformation of alloy Al-Li 2091 in order to have a further understanding on the role of dislocation in superplastic deformation.

2 MATERIALS AND EXPERIMENT

The material used in the experiment was pretreated plate of alloy 2091 Al-Li. The composition of the alloy(%) was Al-2.02 Li-2.22 Cu-0.98 Mg-0.12 Zr. The plate was worked into superplastic tensile sample, then recrystallized at 530 ℃ for 30 min.

The superplastic deformation was performed at the temperatures of 525 ℃ and 505 ℃, and at the strain rate of 8.33×10^{-4} s^{-1}. The samples were quenched to liquid nitrogen after being deformed to certain amount, then they were made into TEM samples by mechanical polishing and electrolytic polishing. The observation of dislocations was performed on the JEM-100CX analysis TEM. Other samples were made for X-ray measurement. The relation between strain and dislocation density was measured by X-ray using the method of reference[4]. In order to study the dislocation dynamic behavior, high temperature stress relaxation test was also performed. The precedure was as follows: When the deformation reached the proposed amount, the tension was immediately ceased and the change of stress with time was recorded in 1 s by tensile machine, the activation energy of dislocation movement and the relation between dislocation velocity and strain could be ob-

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tained by disposing these data.

3 EXPERIMENTAL RESULTS

3. 1 *Superplasticity of Alloy* Al-Li 2091

Table 1 shows the results of tension test for the materials used in this experiment. These results indicate that 2091 Al-Li alloy posesses good superplasticity.

3. 2 *Dislocation Configuratoin in Superplastic Deformation*

The samples were deformed to different amount, TEM observation showed that some grains consisted of no dislocatioins while some other grains consisted more and some less. The characters are summerized as follows: see Fig. 1.

(1) In the studied range of deformation, the number of dislocatioins decreases with the increase of deformation.

Table 1 Superplasticity of alloy Al-Li 2091

Number	Recrystallization temperature /℃	Tension temperature /℃	Strain rate /s^{-1}	Elongatoin /%
1#	530	525	8.33×10^{-4}	850
2#	450	525	8.33×10^{-4}	950

(2) In the process of superplastic deformation, there are the dislocation configura-

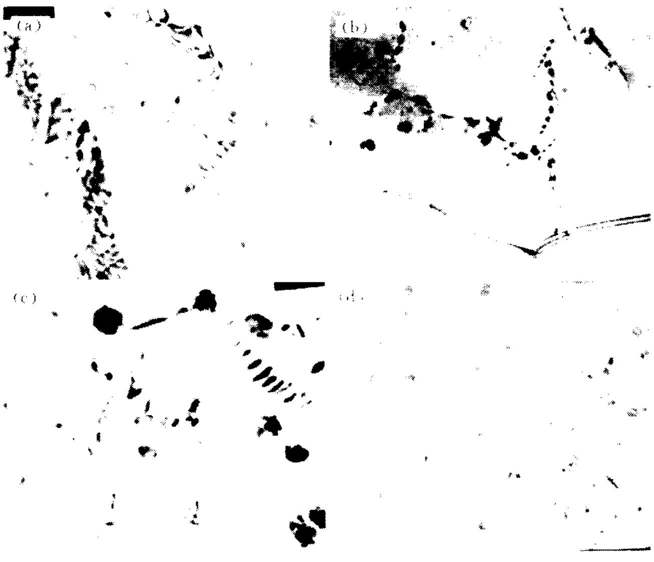

Fig. 1 Dislocation configuration at different deformation
(a)— $\varepsilon=0.81$; (b)— $\varepsilon=1.01$; (c)— $\varepsilon=1.18$; (d)— $\varepsilon=1.45$

tion as subgrain boundary, dislocation poles, helical dislocation, dislocation ring, grain boundary dislocation and dislocation network.

(3) Near grain boundaries and dislocatioins, there are few dislocation rings. That is to say, in the process of deformation dislocatioins and grain boundaries are vacancy traps.

(4) Lattice dislocations slide into grain boundaries, grain boundary sliding and migration, and micro crack at grain boundary occurs.

There are also similar results for dislocation behavior of superplastic deformation at 460 ℃.

3. 3 *Effect of Deformation on Dislocation Density*

The results of X-ray diffraction after different superplastic deformation are shown in Fig. 2. It is clear that the half height width of (222) diffraction peak decreases with the increase of strain. It had been indicated in Ref [5] that half height width of (222) diffration peak is correlated with the disclocation density. Thus we can infer from Fig. 2 that the decrease of half height width indicates the decrease of dislocation density in the superplastic deformation of alloy Al-Li 2091, see Fig. 3. This result corresponds to both the results of TEM observation and that of Al-Zn-Mg alloy[4] which also showed a decrease in dislocation density when strain increases.

3. 4 *Effect of Deformation on Dislocation Mobility*

Stress relaxation is the result of dislocation movement. The relationship between strain rate $\dot{\varepsilon}$ and effective stress σ which acts on dislocations is given by

$$\dot{\varepsilon} = 2b\mu\rho B\sigma^n = \beta\rho B\sigma^n \qquad (1)$$

where ρ is the density of movable dislocations, B is the mobility or the velocity of dislocations produced by a unit effective stress, n is the velocity-stress sensitive exponent of dislocation, β is a parameter related with structure. Both $\dot{\varepsilon}$ and σ exhibit a linear relation, n is the slope and $\ln(\beta\rho B)$ is the intercept. In the studied range of deformation in our experiment, $\ln(\beta\rho B)$ increases with ε as in Fig. 4. Under certain conditions, β can be regarded as a constant, thus, the increase of $(\beta\rho B)$ owes mainly to ρB. As the results showed above, the density of dislocations decreases with the increase of strain. Therefore, B increases more rapidly as strain increases. This means that the velocity of dislocations produced by the unit effective stress increases rapidly with the increase of strain, or, in other words, the resistance to the movement of dislocations decreases as the strain increases.

3. 5 *Effect of Deformation on Activation Energy of Dislocation Movement*

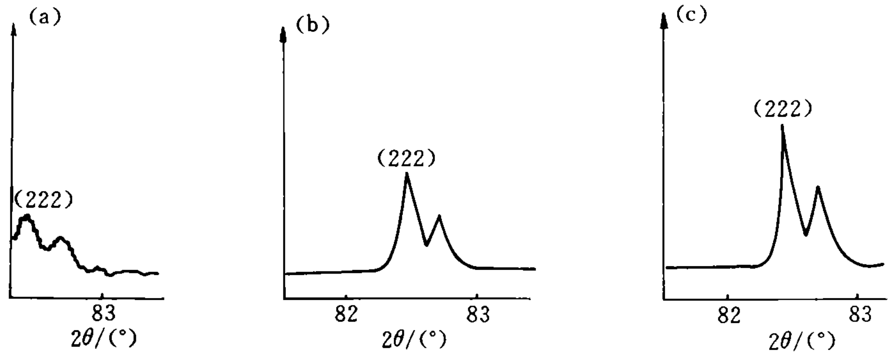

Fig. 2 X-ray diffraction at different deformation
(a)— $\varepsilon = 0.81$; (b)—$\varepsilon = 1.01$; (c)—$\varepsilon = 1.18$

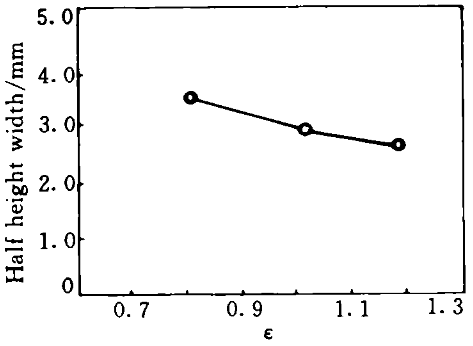

Fig. 3 Efect of strain on half height width of (222) diffraction peak

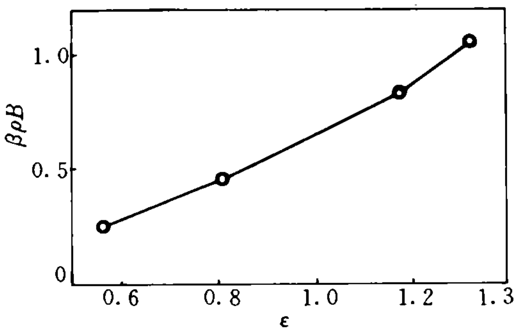

Fig. 4 $\beta\rho B$ changes with strain

In the process of superplastic tension, flow stress changes with temperature and strain rate. The relation between the strain rate $\dot{\varepsilon}$ and temperature is as follow:

$$\dot{\varepsilon} = \dot{\varepsilon}_0 \exp[-\Delta H/(KT)] \tag{2}$$

where ΔH is the activation energy of dislocations to overcome barriers. ΔH was measured by stress relaxation test. From tress relaxation we could also obtain $\dot{\sigma}(t)$:

$$\dot{\sigma}(t) = -E\dot{\varepsilon}(t) \tag{3}$$

thus, Equation (2) can be written as

$$\dot{\sigma} = \dot{\sigma}_0 \exp[-\Delta H/(KT)] \tag{4}$$

In our experiment, the samples were tensioned to the same strains at temperature 525 ℃ and 505 ℃, then the stress relaxation was performed, and the mean stress rate $\dot{\sigma}_1$ and $\dot{\sigma}_2$ in 1 s were measured. From equation (5) rewritten according to the above equations we can calculate ΔH as follow:

$$\Delta H = -K\ln(\frac{\dot{\sigma}_1}{\dot{\sigma}_2})\frac{T_1T_2}{T_2 - T_1} \tag{5}$$

Approximately, ΔH obtained from this method represents the activation energy of dislocations to overcome barriers at the time when superplastic tension is stopped. Further more, the activation energy at different strains had been also measured, Fig. 5 shows the results. It is clear in Fig. 5 that there is a linear decrease in ΔH as ε increases. This indicates that as ε increases, dislocations are more liable to be activated and the resistance to the dislocation movement decreases.

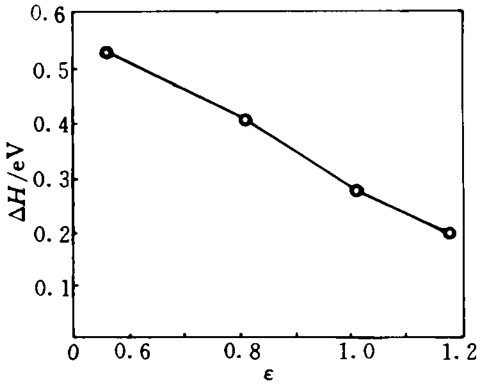

Fig. 5 Effect of strain on the activation energy

4 DISSCUSION

The deformation process at elevated temperature is a competition of hardening and softening. From the stress-strain curve of superplastic deformation the process can be divided into three stages, i. e. hardening, softening and stable stage (see Fig. 6). In our experiment, ε is at about 0. 6～1. 2, so the superplastic deformation is at the softening stage. Softening, on one hand, is due to the recovery of elevated temperature, on the other hand, owes to the decrease of true strain rate $\dot{\varepsilon}$ with elongation, which results in a longer time to reach the same strain, thus the effect of recovery is strengthened. At the early stage of tension, the strain rate is high, and hardening plays a key role, as a result, the amount

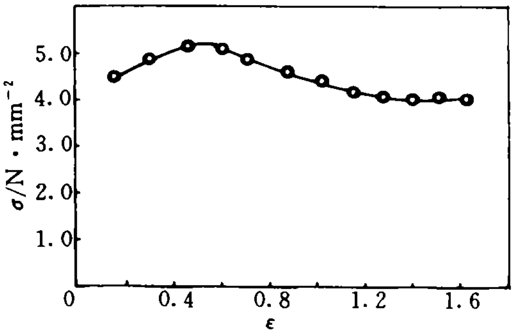

Fig. 6 The stress-strain curve of superplastic deformation

of dislocations increases. When the tension process passes through the peak of σ-ε curve, softening plays a key role, so the recovery speeds up, and the amount of dislocations decreases. During this period, dislocations of opposite mark counteract with each other, on the other hand, dislocations also slide into grain boundaries and cause the low angle boundaries to transform into high-angle boundaries as well as an increase in the grain boundary dislocations. This has increased the mobile grain boundaries and the ability of grain-boundary sliding. Therefore, the superplastic deformation changes from the grain interior deformation at the early stage into the grain-boundary sliding deformation. So, there is decrease of dislocations in the grain interior, and also a decrease in the resistance to dislocation motion. So the velocity of dislocation produced by unit effective stress increases.

5 CONCLUSION

(1) The alloy Al-Li 2091 exhibits good superplasticity after superplastic pretreating.

(2) In the softening stage of superplastic deformation, the amount of dislocations in the grain interior decreases as strain increases.

(3) In the softening stage of superplastic deformation, the velocity of dislocations produced by unit effective stress increases and the activation energy of dislocation motion decreases with strain increase.

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