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Interior dislocation behavior in superplastic deformation of 8090 Al-Li alloy①

Liu Zhiyi(刘志义)

Department of Mechanics, University of Petroleum, Dongying 257062, P. R. China

Abstract: The behavior of interior dislocation in superplastic deformation of 8090 Al-Li alloy was investigated. TEM observations showed that at initial stage of deformation, interior dislocation is created at grain boundary ledge and particle and dislocation slip is quite active; at middle stage of deformation the interior dislocation is created at triple junction of grain boundaries, which is recovered to form subboundary; up to last stage of deformation, dislocation slip becomes again active, which leads to a dislocation pile-up . The interaction between dislocation and voids does not stop untill last stage of deformation. It is indicated that the dislocation slip is a dominant mechanism of deformation at initial stage of deformation, the dynamic recovery and slip of dislocation can all accomodate grain boudary sliding. Furthermore, the immovable helical dislocations formed by the interaction of screw dislocation with voids increase the distortion energy in crystal lattice, and promote the local dynamic recrystallization at middle stage and last stage of deformation.

Key words: dislocations; superplasticity; recovery; recrystallization **Document code**: A

1 INTRODUCTION

Interior dislocation slip is one of the important accomodation mechanism in superplastic deformation[1~10], in which the grains are refined by dynamic recrystallization. But the superplastic deformation process leads to different grain sizes at various stages and causes a change in grain boundary sliding quantity, it also makes the accommodating mechanisms at various stages show different functions, especially dislocation slip mechanism. Therefore, it is significant for this investigation to replenish the current theory of superplastic deformation.

2 EXPERIMENTAL MATERIALS AND METHODS

8090 Al-Li alloy was made by vaccum melting, its chemical comopsitions (mass fraction, %) are: 1.91 Li, 0.46 Mg, 1.25 Cu, 0.21 Zr, 0.031 Fe, 0.032 Si, balance Al. After 510 ℃, 42 h homogenization; 530 ℃, 0.5 h resolution; 400 ℃, 8 h overaging, the alloy was cold rolled to 2 mm thick plate from 12 mm thick ingot, with larger than 20% reduction per pass. The sample was superplastically tensed on a Shimadzu DSS-10T electron tension machine. Dynamic recrystallization refining grain at initial stage of deformation was observed by an optical metallographic microscopy. The microstructures at optimum condition of deformation($t = 500$ ℃, $\dot{\varepsilon}_1 = 3.33 \times 10^{-3} s^{-1}$) and various strain($\varepsilon = 0.09$, 0.22, 1.10, 2.00) were observed under Philips-CM12 TEM. Grain boundary angle at various stage of deformation was measured with the method suggested by Liu and Meng[11].

3 EXPERIMENTAL RESULTS

TEM observations showed that at the initial stage of superplastic deformation interior dislocation is created at grain boundary ledge and particle, up to middle stage it begins to form at triple junction of grain boundaries(Fig. 1). A lot of dislocations slip at the initial stage of deformation

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and recover to a dislocation wall at middle stage, and pile up at grain boundary up to the last stage, as shown in Fig. 2. It can be seen that the interaction of interior dislocation with voids takes place at all stage of superplastic deformation. Optical metallographic observations show that the grains are rapidly refined at initial stage of deformation (Fig. 3). Grain boundary angle measured value shows that after a rapid increase in high angle boundary fraction and average boundary angle, it is nearly in a stable equilibrium with the strain increasing (Fig. 4). TEM observation shows (Fig. 5) the large grains in local position are dynamically recrystallized at the middle and the last stage of deformation.

4 ANALYSES AND DISCUSSIONS

TEM observations show that interior dislocation in the superplastic deformation of 8090 Al-Li alloy is created at boundary ledge, particle and triple junction of grain boundaries, which is in agreement with the previous experimental results[12-13], but the difference is that the interior dislocation at triple junction of grain boundaries takes place when the strain $\varepsilon = 1.10$, rather than $\varepsilon = 0.22$. These interior dislocations show different behaviors at various stages of superplastic deformation, such as dislocation slip at initial stages of deformation ($\varepsilon = 0.22$), interior dislocation recovery at middle stage, and interior dislocation pile up at last stage (Fig. 2). These behaviors of the interior dislocation could be understood as follows.

The essence in superplastic deformation is grain boundary sliding (GBS). The dislocation slip is only a sort of mechanism to accommodate grain boundary sliding. The finer the grain is, the more freely the grain boundary slides, and the greater the sliding amount is. When grain size is large, its boundary sliding is limitted, i. e. the grain boundary once slids slightly, a corresponding plastic deformation on grain boundary is needed to accommodate and keep the continuity of grain boundary, which leads to creat the interior dislocation as shown in Fig. 1. At these state of strain the grains are not completely refined, as shown in Fig. 3. Once grain is refined, atomic diffusions tend to be active, little obstacle exits on grain boundary, and grain boundary can slide freely. Consequently, no plastic deformation on grain boundary is needed to accommodate grain boundary sliding, and no interior dislocation is created on sliding grain boundary. At such a condition, triple junction of grain boundaries becomes the obstacle that blocks grain

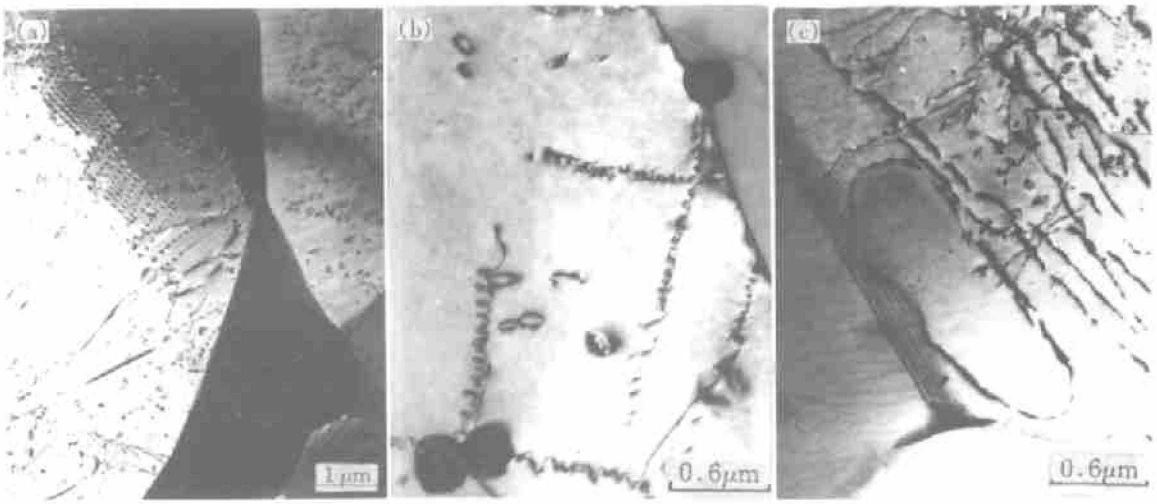

Fig. 1 Dislocations created at boundary ledge, particles and triple junction of boundary.
(a)—Boundary ledge; (b)—Particles, (C)—Triple junction of grain boundaries

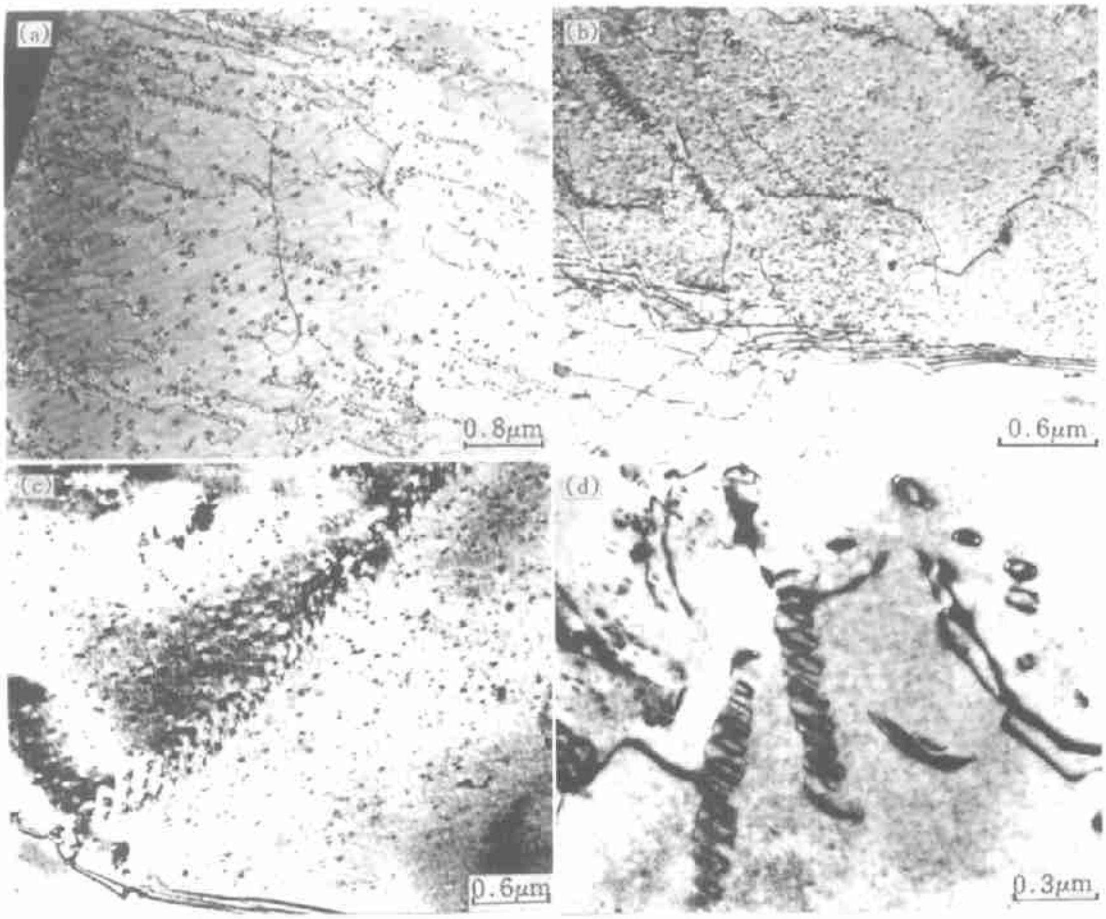

Fig.2 Interior dislocations
(a)—$\varepsilon = 0.09$; (b)—$\varepsilon = 1.10$; (c)—$\varepsilon = 2.00$; (d)—$\varepsilon = 2.00$

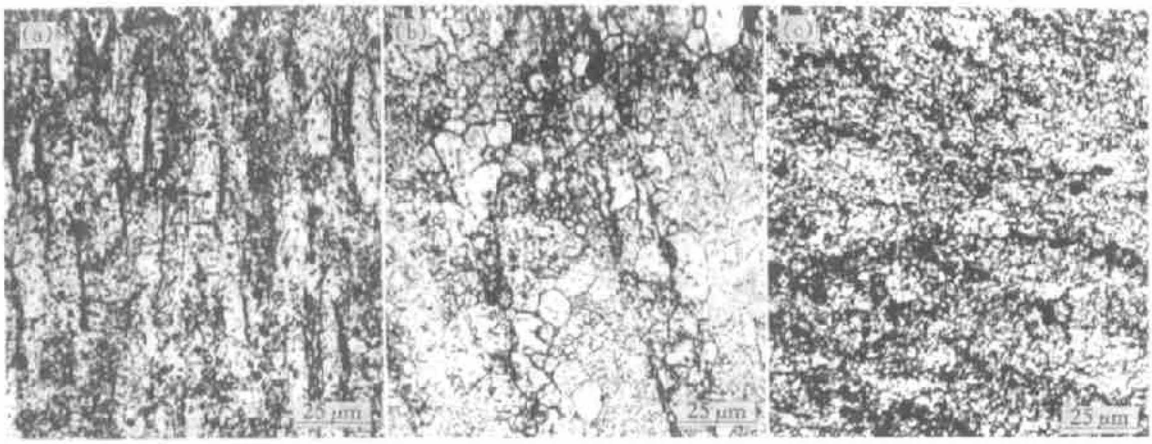

Fig.3 Grains refined by dynamic recrystallization
(a)—$\varepsilon = 0.06$; (b)—$\varepsilon = 0.09$; (c)—$\varepsilon = 0.22$

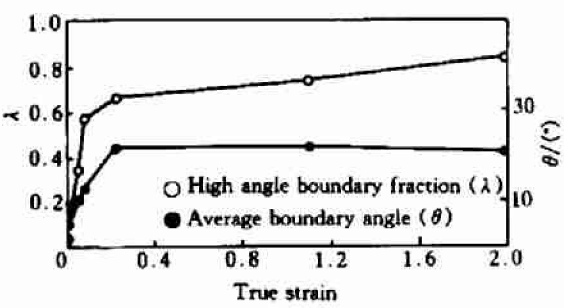

Fig.4 Relation of high angle boundary and average grain boundary angle with strain

boundary sliding, and a corresponding plastic deformation is taken place to accommodate grain boundary sliding as shown in Fig.1(c).

The different behaviors of interior dislocations shown at various stages of superplastic deformation could be analyzed from the grain size and boundary structure. It can be seen from optical metallographic experimental results that before $\varepsilon = 0.22$, the grain is not refined, even at $\varepsilon = 0.06$, the grain still remains rolled fibre state (Fig.3). Both average boundary angle and high angle boundary fraction are very small at this state of strain (Fig.4). It is impossible for this kind of microstructure and grain boundary sturcture to create grain boundary sliding. What can be adapted to the exerted plastic deformation is the interior dislocation slip and diffusion creep, as shown in Fig. 2(a). Meanwhile, it should be mentioned that the helix dislocation in Fig.1(a) is an expression of atomic diffusion, as well as an immobile character increasing the driving force for dynamic recrystallized refining grains at initial stage of deformation.

Up to middle stage of superplastic deformation ($\varepsilon = 1.10$), in which grain has been sufficiently refined and high angle boundary fraction and average boundary angle increased to a high value (Fig.3(a), Fig.4), the grains can be easily rotated and rearranged, which leads to grain boudary sliding become the dominant mechanism in the deformation. At such a condition, dislocation slip only plays an assistant role in accommodation and becomes the secondary mechanism. At this stage, the interior dislocations that are created and dominated the deformation mechanisms at initial stage of superplastic deformation compose dislocation walls by slip and climb, which is a process of the decrease in system free energy, and has an important function to relax too high distorted energy in crystal and stress concentration at triple junction of grain boundary. Subsequently, the subgrains that are formed in the above process act as nuclei for the local dynamic recrystallization in the superplastic deformation, which can completely annihilate the local stress concentration as obstacle to grain boundary sliding and large grains refining, as

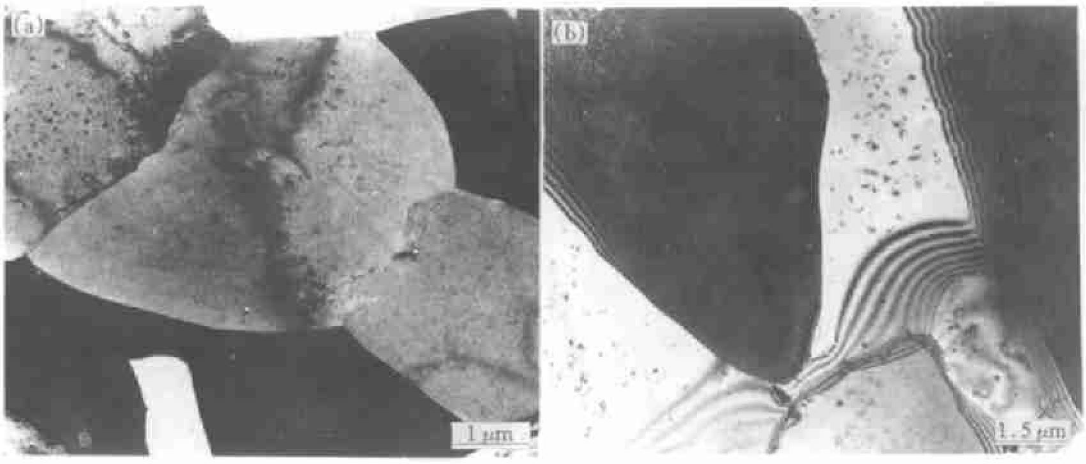

Fig.5 Local dynamic recrystallization at strain of $\varepsilon = 1.10$(a), $\varepsilon = 2.00$(b)

shown is Fig.5.

Up to the last stage of deformation ($\varepsilon=2$), grains have grown up, and grain boundary sliding is restrained, which creates the effects about two sides, one is that the decresing of the amount in grain boundary sliding needs the compensation of other deformation mechanisms to be adapted to the exerted strains, which makes the interior dislocation slip active again under the condition of grown grains and unactive atomic diffusion; the other is that the grown grains lead to a comparative unactive atom diffusions, which decreases the annihilation rate of the interior dislocation that slips to grain boudary and climbs into the boundaries by atomic diffusion. These two sides of the effects create the interior dislocation pile-up at grain boundary at the last stage of the superplastic deformation.

The observations also find that at all stage of the deformation there exists the immobile helix dislocations created by the interaction between dislocations and voids, as shown in Fig.2. These helix dislocations show the existence of atom diffusion, meanwhile, more helix dislocations at initial and middle stage of the deformation show a more active atom diffusion, and less helix dislocations at last stage of the deformation show a comparative less amount of atom diffusion at this stage, which is related to the grain growth. Moreover, the immobility of the helix dislocation increases the distortion energy in crystal, and promotes the local dynamic recrystallization(Fig.5), The value of grain boundary angle measuring also show that there is a part of subgrain in microstructure from beginning to end, and displays the existence of local dynamic recrystallization (Fig.4), which is favourable to the annihilation of the local stress concentration created by grain boundary sliding.

Consequently, at the initial stage of deformation the interior dislocation becomes the dominating deformation mechanism in the form of slip because the grains are not completely refined, high angle boundary fraction and average grain boundary angle are comparative low, and the amount of grain boundary sliding is small; at the middle stage of deformation, grain boundary sliding becomes active, and the interior dislocation accommodates grain boundary sliding in the form of recovery; up to the last stage of deformation, the grown grains restrain the grain boundary sliding to some extent, the interior dislocation slip becomes active, but piled up due to the relative difficulty for atom diffusion. It is pointed out that the helix dislocations at all stage of deformation promote the local dynamic recrystallization due to the immobility of dislocations.

5 CONCLUSIONS

(1) At the initial stage of deformation the interior dislocation is created at boundary ledge and particles. At the middle stage it is created at the triple junction of grain boundaries.

(2) The interior dislocation behaves as a dominating deformation mechanism in slip at the initial stage of deformation. It accommodates the deformation respectively by recovery and slip at the middle and the last stages of deformation.

(3) The immobile helix dislocations promote local dynamic recrystallizatin.

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