STATISTICAL ANALYSIS OF SERRATION SIZE IN AL-LI SINGLE CRYSTALS

Baohui TIAN*, Changqi CHEN and Yonggang ZHANG****

*Beijing Institute of Aeronautical Materials, PO Box 81-2, Beijing 100095, P.R. China
**Department of Materials Science and Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100083, P.R. China

ABSTRACT Stress drops and elapsed time for serrations in Al-Li single crystals were investigated statistically. The number of serrations with small stress drops and short elapsed time increases with increasing ageing time until attainment of peak aged condition, but decreases as ageing time increases further . It corresponds to the low level of average stress drops and elapsed time within a limited strain range in the peak aged condition. Slip lines appear step like features as serrated flow occurs. It seems that the sizes and dispersion character of δ ' particles have some influences on the serration sizes in Al-Li single crystals.
Keywords: *serration, Portevin-Le Chatelier effect, aluminum-lithium alloy, single crystal*

1. INTRODUCTION

Serrated flow in Al-Li alloys has attracted some attentions in recent years for it may be related to shearing of δ ' particles as compared to the conventional Portevin-Le Chatelier(PLC) effect caused by dynamic strain aging(DSA) of solute atoms. However, controversial conclusions drawn from polycrystal alloys make explanations for serrated flow in Al-Li alloys difficult[1-4]. This may be due to the influences of complicated microstructures induced by different experimental procedures. The experiment employing single crystal alloys is deserved for the complicated and undesirable influencing factors may be excluded. The results from Al-Li single crystals have verified a relationship between serrated flow and the shearing of δ ' particles[5]. Besides general interest in critical strains(ε_c) for the occurrence of serrated flow, investigation of serration size, i.e. stress drops and elapsed time during serrated flow may provide instructive information related to the mechanism of the plastic instability. In this paper stress drops as well as elapsed time during serrated flow in Al-Li single crystals are investigated, with the aim to provide new information on the serrated flow.

2. EXPERIMENTAL PROCEDURES

Preparation of Al-Li single crystals was reported previously[5]. The crystal with a Li content of 2.11wt.% and orientation of [134] was used. It was cut into samples with a dimension of 6.2mm x 3.4mm x 3.4mm. The samples were solution treated in a salt bath at 793K for 30 minutes, water quenching at room temperature, followed by artificially aged in an oil bath at 448K for 2, 10, 20, 48 and 100 hours(h), respectively. Peak aged condition was accomplished after 48 h aging, depended on the variations in the critical resolved shear stress with ageing time.

Compressive deformation tests were performed with a MTS-880 machine at 293K at a strain rate ($\dot{\varepsilon}$) of 5.6×10^{-4} per second(s^{-1}). The resolution of the testing system is 0.5MPa, which means that no serrations can be detected when stress drops for serrations are smaller than this magnitude. Stress drops($\delta\sigma$) for individual serrations were defined as the true stress difference between the highest and the lowest points of individual serrations. The time interval between the onset of two successive serrations was defined as elapsed time(δt) for serrations. In view of the irregular variations in $\delta\sigma$ and δt, we defined Δt in the form of $\Delta t=\Delta\varepsilon/(\dot{\varepsilon}\times f)$ as the average elapsed time for serrations within a limited strain range, where $\Delta\varepsilon=0.017$ corresponding to a displacement of 0.1mm, f is the number of serrations in $\Delta\varepsilon$, $\dot{\varepsilon}$ is the nominal strain rate. The corresponding variations in flow stresses were defined as the average stress drops($\Delta\sigma$) in the form of $\Delta\sigma=\Sigma\delta\sigma/f$, $\Sigma\delta\sigma$ is the total sum of stress drops for individual serrations within the same strain limit.

Several samples aged for 20 h to underaged conditions were electrically polished before deformation. The tests were interrupted at certain strains during the deformation of each sample to observe slip lines on its surface under S-530 scanning electron microscope(SEM).

3. RESULTS

The load-displacement curves for the naturally aged samples and the samples aged from 10 h to 100 h have been reported in previous paper in which serrated flow was exhibited only for the artificially aged samples[5]. The load-displacement curve for the sample aged for 2 h is shown in Fig.1 as a supplement of previous results. Only few serrations were observed. It is indicated that serrated flow could occur successively when the crystal was aged at 448K at least for 10 h.

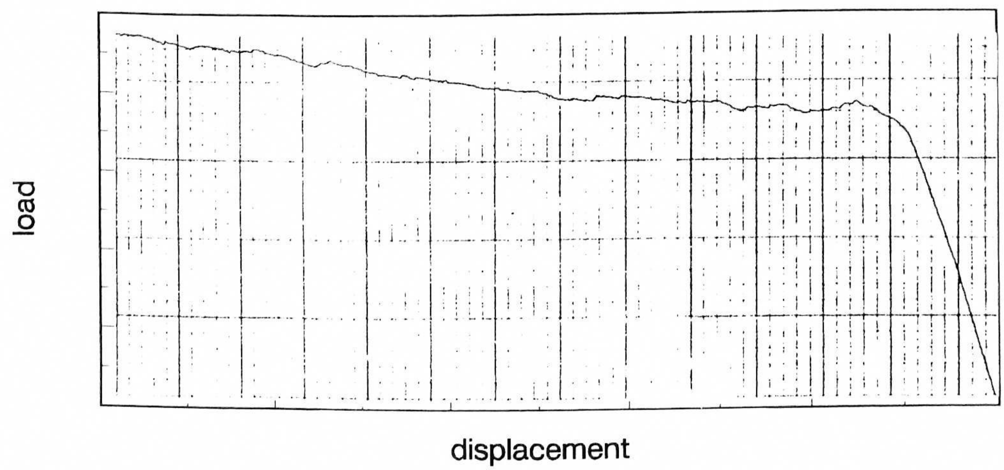


Fig.1 Load-displacement curve for Al-Li single crystals aged at 448K for 2 h

The effect of ageing time on distributions of stress drops($\delta\sigma$) is shown in Fig.2 (a) - (d). It seems that the peaks of distributions of $\delta\sigma$ are located in the small stress drop region when attaining the peak aged condition. $\delta\sigma$ distribute on both sides of the peaks except an asymmetrical distribution in the overaged state. With increasing ageing time from 10 h to 20 h, the number of $\delta\sigma$ increases while primarily within the stress drop limits of 1.0-5.0 MPa. The number of $\delta\sigma$ ranging from 1.0 to 3.0 MPa persistently increases with further increasing ageing time to 48 h, accompanied by decrease in the number of large $\delta\sigma$. The number of serrations decreases with transition from the peak aged to the overaged condition, but, the number of small $\delta\sigma$ reduces more, as compared to the number of large $\delta\sigma$ that even increases in the overaged state.

The effect of ageing time on distributions of elapsed time(δt) is shown in Fig.3 (a) - (d). δt appears an approximately symmetrical distribution before attaining the peak aged condition. The peaks of distributions of δt move into short time intervals with increasing ageing time from 10 h to 20 h, and then stagnate within the time limit between 1.5 and 2.0 s. The number of δt increases persistently at short time intervals($\delta t<2.0$ s), but decreases at long time intervals with increasing ageing time from 10 h to 48 h. It primarily increases within the time limits of $\delta t >2.0$ s with further increasing ageing time to 100 h.

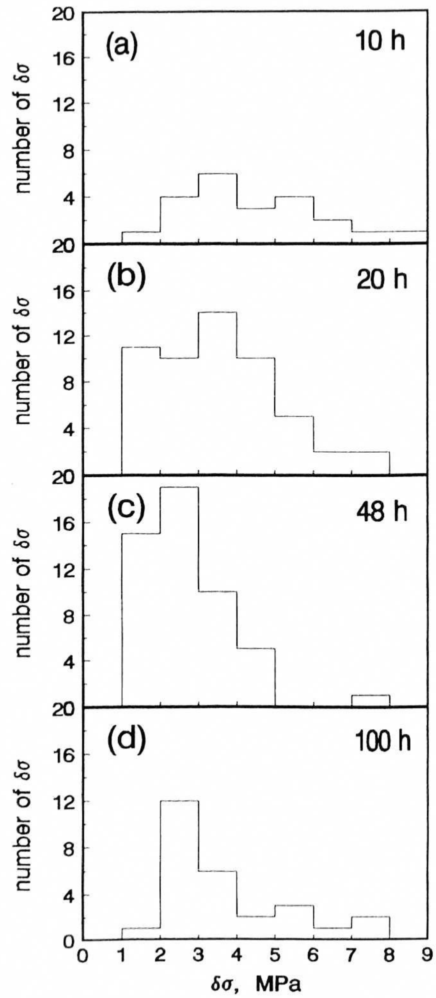


Fig. 2 Distributions of $\delta\sigma$ at different ageing time

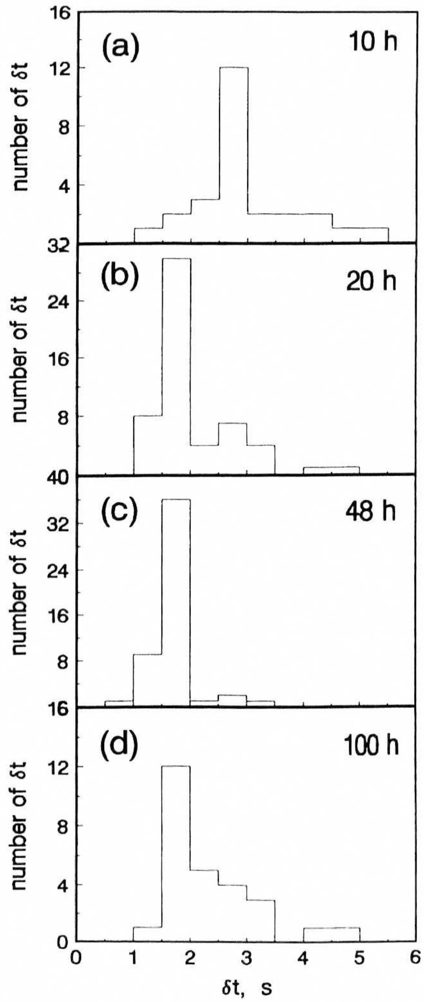


Fig.3 Distributions of δt at different ageing time

The average stress drops($\Delta\sigma$) and the average elapsed time(Δt) are indifferent to increasing strain, as shown in Fig.4 (a) and (b) respectively. $\Delta\sigma$ appear low in the peak aged condition except few points. The level of Δt decreases with increasing ageing time until the peak aged condition, but increases a little in the overaged state. Both $\Delta\sigma$ and Δt are low in the peak aged condition, which can be correlated with variations in the distributions of $\delta\sigma$ and δt with increasing ageing time.

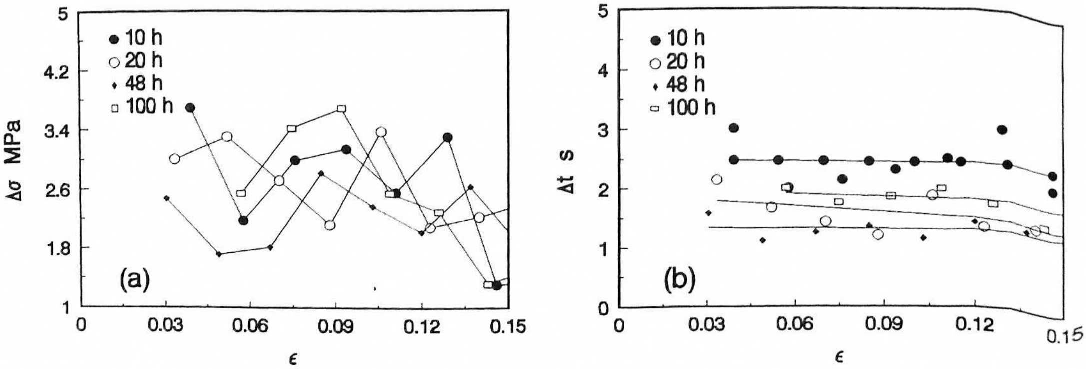
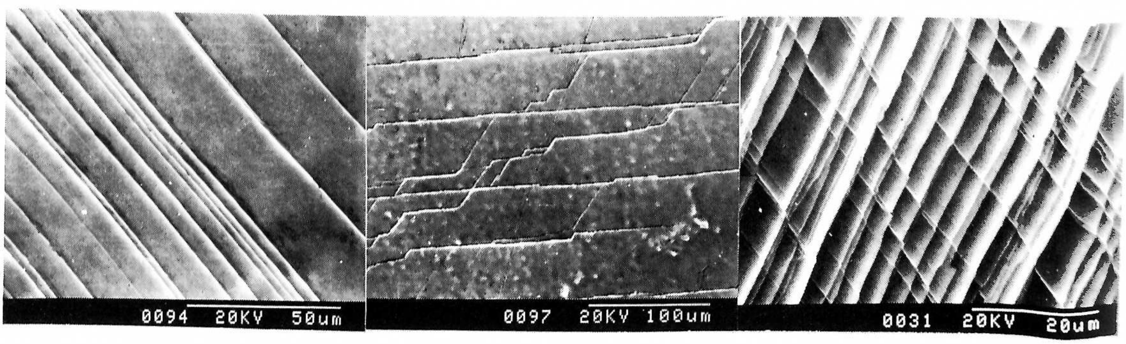


Fig. 4 Variations in $\Delta\sigma$ (a) and Δt (b) versus strains

The slip patterns for the samples aged for 20 h are shown in Fig.5. Straight slip lines were observed during the initial stage of deformation. Secondary slips were motivated with increasing strains, corresponding to the appearance of step like slip patterns. It seems that slips became difficult on the primary slip plane, so that the secondary slips were initiated on another plane. The secondary slips frequently returned to the primary slip plane as the consequence of a favorable crystal orientation. The slip bands, indicated as planar slip, were occasionally observed as the deformation proceeds.



ε=0.025 ε=0.045 ε=0.10

Fig.5 Slip patterns observed under SEM for the samples aged for 20 h critical strain for appearance of serrations(ε_C) is 0.034

4. DISCUSSIONS

4.1 Features of serrated flow

The experimental results seem to be different between Al-Li monocrystal[5] and polycrystal alloys[1,4,6]. It has been reported that serrated flow did occur in the as-quenched Al-Li polycrystal alloys, but, was not observed during the deformation of the naturally aged Al-Li single crystals. This discrepency may not be caused by the low resolution of testing system in the investigation of Al-Li single crystals. Small precipitates were formed during the naturally aged and a bit artifically aged processes. They were sheared by dislocations during deformation. The disappearance or sporadic appearance of serrated flow in Al-Li single crystals means that its apparent occurrence needs the shearing of certain amount of δ ' particles with their sizes large enough. For polycrystal alloys, even the trend of natural age was depressed[6], or deformation tests began at once after quenching the samples, the precipitation induced by deformation can not be prohibited, and, may be accelerated by the existing dislocation structures formed by experimental procedures. The various microstructures may account for the controversy between monocrystal and polycrystal alloys even the alloys were treated to the same conditions. Recently, Kumar and Pink found that weak serrrated flow caused by DSA of solute atoms still exhibited during the deformation of bianry Al-Li alloys[7], the serration amplitude was less than 0.5MPa. Considering that serration amplitude increases as grain sizes decrease for the conventional PLC effect in Al-Mg single crystals[8], it is easy to understand why the conventional serrated flow was not observed in the naturally aged Al-Li single crystals.

There are several differences between serrated flow in Al-Li and Al-Mg alloys as follows:
(1) unlike the gradual reduce of serration amplitude as ageing proceeds in Al-Mg alloys[9], serrations in Al-Li single crystals appear strong in the moderate artifically aged conditions, as compared to the naturally aged or a bit artifically aged conditions.
(2) stress drops as well as elapsed time for serrations irregularly vary with increasing strain, as compared to the fact that $\delta\sigma$ attained a maximum at the end of the second hardening stage in Al-Mg single crystals[8].
(3) stress drops for serrations in Al-Li single crystals did not appear an asymmetrical distributions with increasing deformation temperature as those in Al-Mg single crystals[10,11].
(4) the average stress drops and elapsed time are low in the peak aged condition even compared to those in the overaged condition, which seems abnormal in the conventional PLC effect such as that in Al-Mg alloys.
(5) strain rate sensitivity for Al-Li polycrystal alloys increases with flow stress followed by a sudden decrease[1], rather than a continuouse decrease in Al-Mg alloys[9].

4.2 Variations in stress drops for serrations

A proper model for serrated flow in Al-Li alloys is debatable up to date. Brechet and Estrin suggested that the shearing of δ ' particles itself could induce dissolution of the particles and a negative strain rate sensitivity of flow stress, followed by the occurrence of serrated flow[12]. DSA of solute atoms was unnecessary to induce serrated flow in Al-Li alloys. Kumar and Pink proposed that serrated flow in Al-Li alloys may result from DSA of solute Li atoms when δ ' particles were sheared to dissolution or partial dissolution[7], but, as the interaction between DSA and shearing of pariticles is unkown, the micromechanisms for serrated flow in Al-Li alloys remain obscure. Although the normal or inverse dependence of ε_c on temperature and strain rate may be explained by the two models proposed, variations and distributions in stress drops and elapsed time for serrations need to be treated, while, the difficulty is, the microstuctures related to stress drops are complicated and obscure even in the conventional PLC effect.

It is clear that serrated flow in Al-Li single crystals is associated with the shearing of δ ' particles. It could be deduced from the step like slip patterns in Fig.5 that, dislocations meet difficulties during their movement. Once their movement was initiated, dislocations may pass a relatively long distance, possibly corresponding to appearance of a serration.

Sizes as well as degrees of dispersion of δ ' particles increase with increasing ageing time. Statistically, δ ' particles are more difficult to be sheared in the peak aged condition compared to the underaged conditions, and, the distance among the particles is short compared to the overaged condition. Thus, the distance passed by mobile dislocations during one jerk movement seems to have a statistical minimum in the peak aged condition. It colud be suggested that the free path of mobile dislocation may be one of influencing factors on stress drops for serrations, in view of the variations in the distributions of stress drops as well as the average stress drops with increasing ageing time.

5. CONCLUSION

Shearing of δ ' particles with certain volumn fractions and sizes is necessary for the occurrence of serrated flow in Al-Li single crystals. Stress drops and elapsed time for individual serrations mainly distribute within the limits of their low magnitude in the peak aged condition as compared to the underaged and overaged conditions, corresponding to the low level of the average stress drops and the average elapsed time for serrations.

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