EFFECT OF PRECIPITATION HARDENING ON THE SERRATED FLOW CHARACTERISTICS IN AN Al−Li ALLOY

Z. Q. Zheng, M. G. Liu, D. F. Yin and C. Y. Tan
Central South University of Technology, Department of Materials Science and Engineering, Changsha 410083, P. R. China

Abstract

The serrated flow characteristics of an 8090 type Al−Li alloy during tensile testing and the effect of age hardening on serrated flow were inverstigated. The results indicated that in the as−quenched and under−aged conditions the serrated flow occurred and in the existence of serrated flow negative strain rate sensitivity was observed. In the peak and over−aged conditions serrations were not exhibited. In addition, the increase in strain rate suppressed the occurrence of serrated flow. The results were discussed in terms of the interactions of the solute atoms, dislocations and the precipitates with the mobile dislocations.

Introduction

It is well known that many alloy systems exhibit serrations on stress−strain curves in a certain range of temperature and strain rates. This phenomenon has been termed the Portevin−Le Chatelier effect. In general, the occurrence of serrated flow is explained using Cottrell's model of solute atmospheres or modefied models[1−3]. Serrated flow in Al−Li based alloys was also observed during tensile testing. However, the theoretical explanations of this effect in the Al−Li alloys are disputable. For example, Tamura et al reported that in the single crystal of Al−Li alloy the serrated flow was attributed to the work softening associated with dislocation cutting of the δ' particles[4]. Wert and Wycliffe have suggested that the serrated flow at high strains in the underaged Al−Li−Cu−Mg−Zr alloys is primarily a result of copper and magnesium in solid solution[5]. Gregson et al have considered that the serrated flow is attributed to be rapid release of dislocations pinned by an atmosphere of Li, but not Cu and Mg atoms[6]. Recently, Welpmann et al have suggested that the serrated flow is to be associated with the formation of GPB[7]. In additon, during the tensile testing of Al−Li alloys negative strain rate sensitivity was also observed[8,9], which seems to always be a prerequisite condition for serration. In the present work the effect of precipitation hardening on the serrated flow phenomenon in an 8090 type Al−Li alloy was investigated. the strain rate dependence of flow stress at the occurrence of serrated flow was also studied.

Experimental method

The material used in this investigation was an 8090 type Al−Li alloy in the form of 2mm−thick sheet. The chemical compositions were Al−2.70Li−1.20Cu−0.90Mg −0.14Zr(Wt%). The specimens were solution treated in a salt bath at 530 C for 40 minites and quenched into ice−water. After quenching the specimens were aged in an oil bath at 190 C for varying times immediately. The testpieces were machined from the longitudinal direction of the sheet and electropolished after aging. The tensile tests were carried out using an Instron testing machine with nominal strain rate of 4.2x10^{-3}s^{-1}~4.2x10^{-5}s^{-1} at room temperature. The load−displacement curves of the specimens tested were recorded by a x−y recorder. The foils for TEM examination were prepared using a twin−jet electron polishing technique in a solution of 33% HNO_3+67% methanol at −20 C and DC voltage of 12v. TEM observations were carried out using H800 with an accelerating voltage of 200kv.

Results

Effect of Aging on the Serrated Flow

Fig. 1 shows the stress−strain curves of the specimens aged at 190 C for various

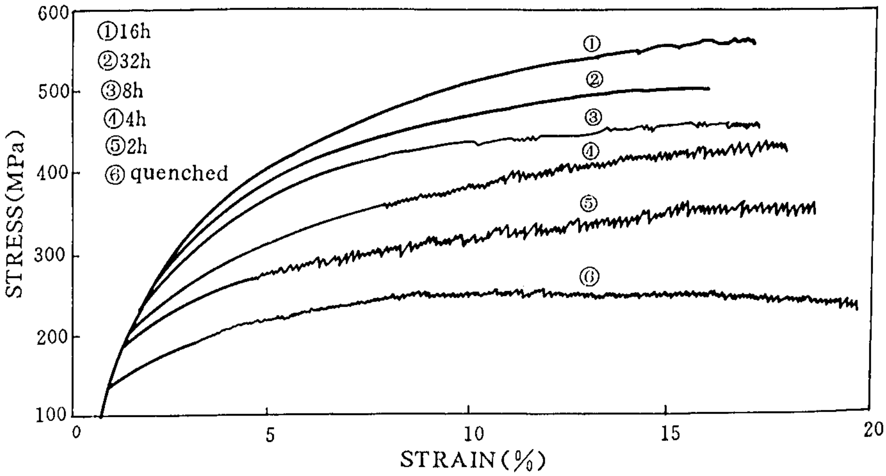


Fig. 1 The stress−strain curves of the specimens aged at 190 C for various times

times at a strain rate of 4.2x10^{-4}s^{-1}. It can be seen that the as−quenched specimen exhibited the fine serrations. The stress drop of serrations (e.g. serration amplitude $\triangle\sigma$) was smaller, but the frequency of serrated flow was higher. With increasing aging times up to 4 hours, the serrated flow became more severe, the serration amplitude $\triangle\sigma$ increased, and the frequency slightly decreased. More long aging times resulted in serrations to become less severe. At the peak aged condition (aged for 16h) the serrations disappeared. The stress—strain curves of the over—aged specimens did not exhibit any serrations. From stress—strain curves it is also seen that the critical strain ε_c at the onset of serrated flow increased with increasing aging.

The serration amplitude was smaller and the frequency was larger at the initial stages of the serrated flow, with increasing strain the serration amplitude increased at first and then became constant. The effect of aging on the critical strain ε_c for the onset of serrated flow and the serration amplitude $\triangle\sigma$ at the constant stages of serrated flow are shown in Fig. 2.

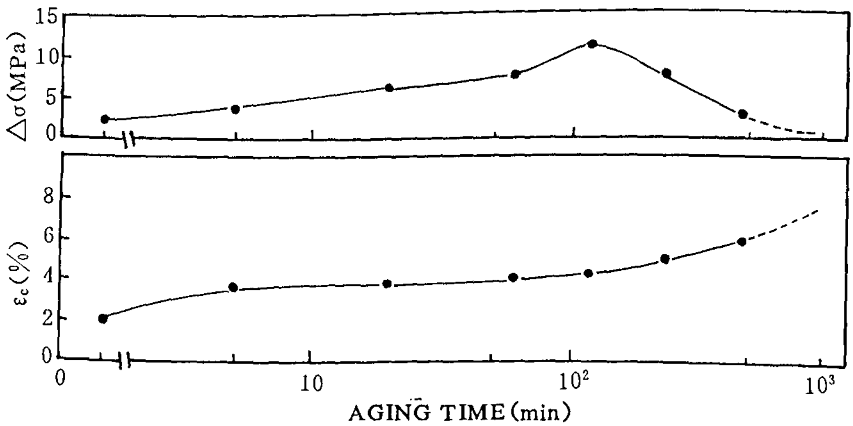


Fig. 2 The variation of the critical strain εc and the serration amplitude $\triangle\sigma$ with aging times

Effect of Strain Rate on the Serrated Flow

Fig. 3 shows the stress—strain curves of the specimens aged at 190 C for 2 hours at different strain rates. From this it can be seen that at a slow strain rate the serrations were very obvious, the critical strain for the onset of serrated flow was smaller and the serration amplitude was larger. With increasing strain rate the critical strain was increased and the serration amplitude was also decreased. At a high strain rate (4.2x$10^{-3}s^{-1}$) the stress—strain curve was almost smooth, only a few serrations were visible. This indicates that the increase in strain rate suppresses the occurrence of serrated flow. These results are agreement with the results observed in the some Li—free alloys[10. 11].

Deformation Structure

Dislocation configurations of the specimens during serrated flow were examined by TEM observations. Fig. 4 shows the dislocation structure developed in a specimen

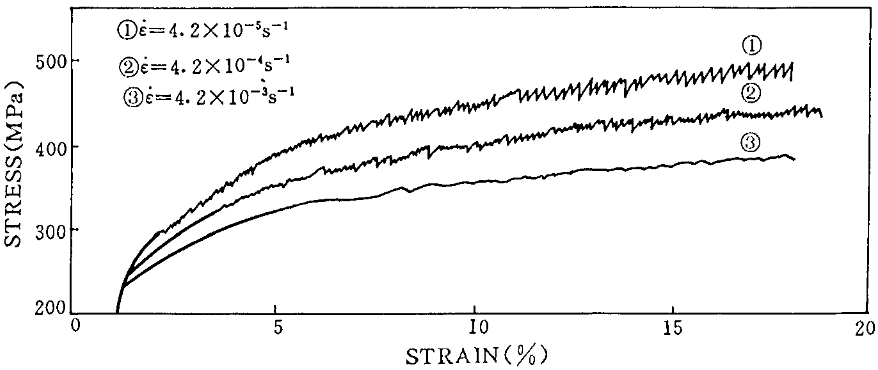
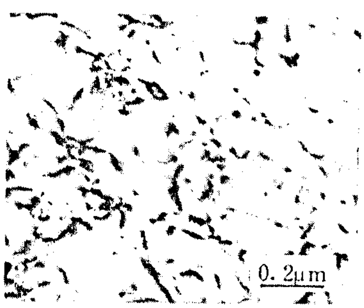


Fig. 3 Effect of strain rate on the serrated flow



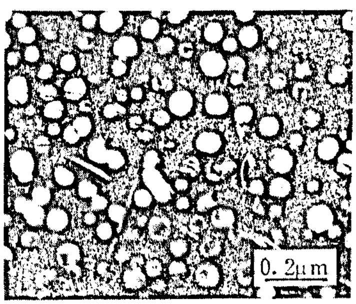


Fig. 4 The dislocation structure of the specimen when the serrated flow was present

Fig. 5 Showing the δ′ praticles cut by dislocations for the over — aged specimen without serrated flow

during tensile deformation within the region of serrated flow. From this it can be seen that except some superdislocations, wavy single dislocations were present. The bowing of dislocations around the precipitates were also observed. This indicates that during serrated flow the dislocations move in the two ways. Some dislocations move in pairs by cutting througt coherent LI_2—type δ′ precipitates, others move bypassing the δ′ precipitates by the Orowan mechanism. TEM observations also indicated that δ′ particles cut by superdislocations were present in the over—aged specimens which did not exhibit any serrated flow during tensile testing. These results indicated that the occurrence of serrated flow in the Al—Li alloys tested appeared not to be the results of the work softening caused by cutting of δ′ particles by superdislocations.

The Strain Rate Dependence of Flow Stress During Serrated Flow

In order to determine the strain rate dependence of flow stress during serrated flow, the strain—rate change tests were carried out. During testing the strain rate was cycled between $4.2\mathrm{x}10^{-4}\mathrm{s}^{-1}$ and $4.2\mathrm{x}10^{-5}\mathrm{s}^{-1}$. Fig. 6 shows the results of strain—rate change tests for the specimens aged for various times at 190℃. From this it can be seen that when the strain rate was increased the sudden load drops were observed and then deformation was continued at a smaller stress level accompanying the decrease in serration amplitude. In contrast, when the strain rate was decreased, the increase in the flow stress and a more large working hardening rate were observed. Here the serration amplitude increased and the frequency decreased. In addition, with increasing aging times these variations became smaller. In the over — aged condition at which serrated flow was not occurred these variations were almost zero, the stress—strain curves became smooth during strain — rate change testing. These results indicated that negative strain—rate sensitivity is a characteristic feature of the alloy tested under the conditions producing sereated flow. This is agreement with the results reported by others[8,9].

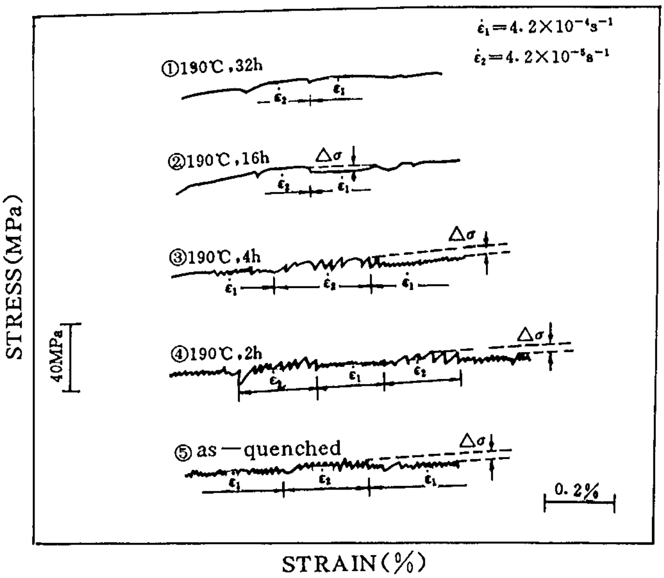


Fig. 6 The characteristics of the stress—strain curves of the specimens aged for various times during strain—rate change testing

Discussion

The theoretical explanation for the phenomenon of serrated flow is based on the interaction between moving dislocations and diffusing solute atoms. In terms of the model developed by McCormick[12,13], it is assumes that the onset of serrated flow is attributed to the interaction of solute atoms and mobile dislocations temporarily arrested at obstacles in their slip path. And during deformation a mobile dislocation spends most of its time trying to surpass obstacles. The interaction between mobile dislocations and diffusing solute atoms mainly occurs duing the time the dislocation is waiting in front of the obstacles. When the average dislocation arrest time is equal to the time required to lock the arrested dislocation, aging of the dislocation occurs.

On the basis of McCormick's critical strain equations, the effect of aging on the critical strain ε_c, at the onset of serrated flow appears to be primarily due to changes in matrix solute concentration Co, average distance between obstacles L and mobile dislocation density ρ accompanying precipitation [12,13]. For the as-quenched specimens, solute concentration Co in the matrix is larger compared to the aged specimens, thus from McCormick's equation it can be seen that ε_c will be smaller. During aging δ' particles were precipitated from the matrix. This resulted in the decrease in Co, so, ε_c increased with increasing aging. In the over-aged condition due to accompanying the growth of δ' particles and the formation of the equilibrium phase sufficiently large decrease in Co would cause ε_c to increase to beyond the fracture strain, thus serrated flow could not observed.

Serration amplitude $\triangle\sigma$ is proportional to the number of solute atoms which diffuse to a dislocation and the density of the aged dislocations[14,15]. The increase in vacancy concentration and mobile dislocation density with increasing strain results in the mobile dislocations becoming effectively strain aged. During the initial stages of serrated flow the concentration of the vacancies produced by deformation is lower, the solute atoms to diffuse to the dislocation and the aged dislocation density would be smaller, so, serration amplitude is smaller. With increasing strain, it would be expected that the diffusion of solute atoms becomes accelerated due to increasing vacancy concentration. This would result in the formation of a sufficiently strenthening atmosphere and large aged dislocation density, therefor a sufficiently large external stress is requred to surpass obstacle. Once the obstacle is surpassed, the dislocation jumps at a high velocity to the next obstacle under a smaller level of flow stress. This implies that a large stress drop is present, e. g. $\triangle\sigma$ increases with increasing strain. However, with further increasing strain as a result of the competition between the increase in vacancy concentration and the depletion of solute atoms for locking dislocation the value of $\triangle\sigma$ becomes constant.

The fact that during the initial stages of aging (2 to 4 hours) the serration amplitude was larger than that of the as-quenched specimens could not be explained using the changes in solute concentration because any age hardening always leads to the decrease in solute concentration Co in the matrix. The changes in the obstacles controlling dislocation motion would be considered. Riley et al suggested that the obstacles of dislocation motion on initial aging is changed from dislocation to precipitate particles. [12,13]. In addition, the obstacle strength is increased by aging[16]. During aging the strength of the δ' particles which act as the obstacles to dislocation motion increases due to the precipitation and growth of the δ' particles, the precipitate particles become more effective obstacles to dislocation motion. thus the stress must be increased to keep the dislocation moving., On further aging the decrease in solute concentration accompanying precipitation will result in an increase in the aging time required to lock the arrested dislocation. This decreases the dislocation density becoming effectively strain aged at waiting time, thus, long aging times cause serrarion amplitude again to decrease up to zero.

Conclusions

In the as—quenched and under—aged conditions the 8090 Al—Li alloy exhibites the serrated flow during tensile testing, and, negative strain rate sensitivity of flow stress is present when the serrated flow occurs. The increase in strain rate suppress the occurrence of serrations. The serrated flow behaviour is influenced by the changes in the matrix solute concentration, the obstacles controlling dislocation motion and the obstacle spacing duing aging prosess.

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