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Serration and Reversion Treatment in Al-10mass%Zn Alloy

Akira SAKAKIBARA*
Dept. of Mechanical Engineering
Okayama University
3-1-1 Tsushimanaka, Okayama, Japan

Teruto KANADANI
Faculty of Engineering
Okayama University of Science
1-1 Ridaicho, Okayama, Japan

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The relationship between occurrence of serration and reversion heat treatment was studied by tensile test on Al-10mass%Zn alloy. Serration was observed for the furnace cooled specimen, but not for the as-quenched one and the shortly aged one, which result is difficult to be interpreted by the Cottrell theory. The stress amplitude in the serration increased with increasing the time of annealing for reversion up to 10ks and then stayed at a constant value which might be interpreted by the Cottrell theory. The stress amplitude in the serration decreased with increasing the annealing temperature, which is contrary to the prediction by the Cottrell theory. The specimen directly annealed without aging and the one annealed after aging agreed well with each other in the tensile strength and the stress amplitude in the serration, which suggests solute clusters as the cause of serration.

1. Introduction

Appearance of serration in the stress-strain curve of Al-Zn alloys has been studied by Chossat[1)], Price and Kelly[3)] and others. It is widely accepted that the appearance and the range of strain where serration occurs depend on alloy composition, heat treatment and strain rate. Recently Pink and Krol[3)] revealed the relationship between the appearance of serration and the size and amount of the aging products by means of X-ray small angle scattering. According to their results, serration occurs either when GP zones smaller than several nm in diameter are sheared by dislocations or when the dislocations accumulated around GP zones/precipitates as large as several tens nm in diameter suddenly start to move. The present authors, on the other hand, have studied the appearance of serration in Al-6%Zn alloy under various conditions of heat treatments and found that serration occurred in the specimens in their very early stage of aging where spherical GP zones less than 1 nm in diameter or clusters of solute atoms were formed.

In this report the relationship between the appearance of serration and the reversion heat treatment is studied on Al-10%Zn alloy and compared with the result of Pink[3)] et al.

2. Experimental Procedures

Al-12mass%Zn alloy in nominal composition, was prepared by melting pure metals of Al(99.996%) and Zn(99.999%) in a high alumina crucible in air. Ingots, 15mm in diameter and about 150mm in length, were homogenized for 180ks at 723K, pealed by a lathe, and forged at 723K to plates of 5mm in thickness. The plates were cold-rolled, with appropriate intermediate annealings, to strips of about 1mm in thickness. Specimens, shape and dimension of which were reported previously[6,9)], were prepared from these strips.

Specimens solutionized at 723K for 3.6ks were quenched to iced water, aged at 293K for 3.6ks, and kept at the reversion temperature between 353K and 463K for various length of time.

Specimens heat-treated were examined by

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*E-mail: sakaki@mech.okayama-u.ac.jp

tensile test with Instron testing machine, 4505, at room temperature, 293K, strain rate mainly being $2\times10^{-4}s^{-1}$. Aging process was followed by hardness with micro-Vickers hardness tester. Microstructure of the aged specimens was examined by transmission electron microscope.

3. Results and Discussion

Fig.1 shows the stress(σ)–strain(ε) curve of the specimen aged at 293K for 3.6ks after quenching from 723K. The curve is smooth up to the peak and no serration is recognized. Serration was not found on the σ–ε curve of the as-quenched specimen from 723K, either.

Fig.2 shows the σ–ε curve of the specimen furnace-cooled to room temperature. As shown in the inserted figure which magnifies a part of the curve, serration occurs clearly. It seems to be difficult for the Cottrell theory, widely accepted so far, to explain the result that serration occurred in the case of the furnace-cooled specimen where solute concentration was lower in the solid solution than the as-quenched one and the one aged for relatively short time as much as 3.6ks.

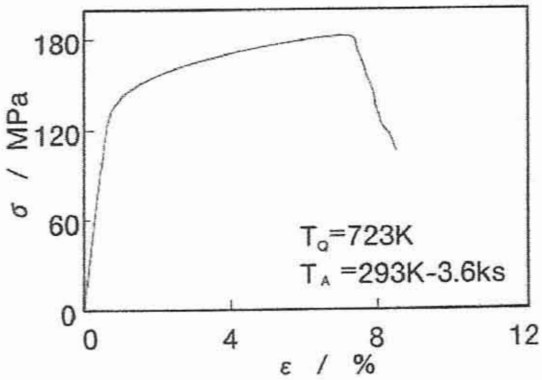

Fig.1 Stress(σ)-strain(ε) curve of the specimen aged at 293K for 3.6ks after quenching from 723K.

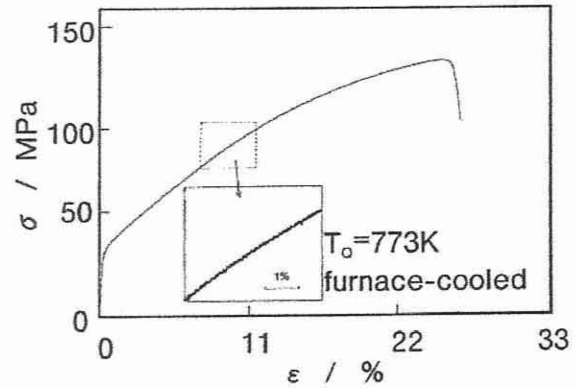

Fig.2 Stress(σ)-strain(ε) curve of the specimen furnace cooled from 773K to room temperature.

Fig.3 shows dependence of the tensile strength (σ_b) and the maximum stress amplitude of the serration ($\Delta\sigma_{max}$) on the reversion time (t_R) when the specimens were quenched from 723K, aged at 293K for 3.6ks and reversion heat-treated at 423K. Solid circles in the figure represent occurrence of serration. The value of σ_b decreases with increasing t_R and becomes constant beyond 10ks of reversion time. The value of $\Delta\sigma_{max}$ increases with t_R and becomes constant also beyond 10ks. Serration was not recognized in the as-aged specimen, t_R=0, but appeared in every specimen which was reversion heat-treated.

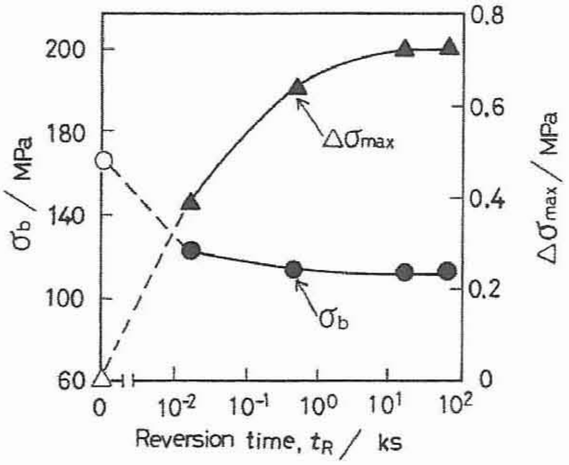

Fig.3 Effect of reversion time (t_R) on the occurrence of serration, tensile strength (σ_b) and the maximum stress amplitude ($\Delta\sigma_{max}$) in the serrated flow. Solid and open symbols correspond whether serration occurred or not, respectively.

Figs.4 and 5 show the σ–ε curves of the specimens aged at 293K for 3.6ks and then annealed for 21.6ks at 353K and 403K, respectively, for reversion treatment. The value of σ_b is smaller and the elongation is larger for the specimen annealed at 403K than the one annealed at 353K, which indicates further progress of reversion in the former. Serration is recognized for the former whereas it is not for the latter.

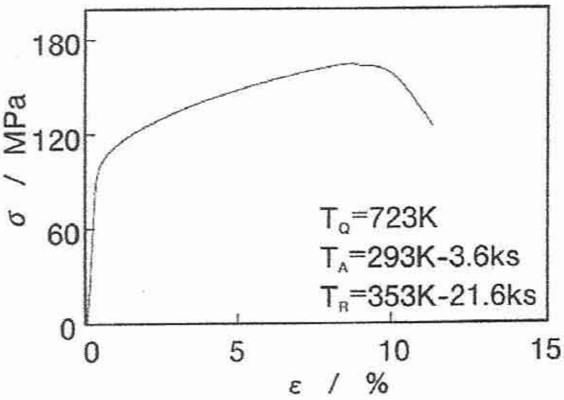

Fig. 4 Stress(σ)-strain(ε) curve of the specimen aged at 293K for 3.6ks after quenching from 723K and then annealed at 353K for 21.6ks.

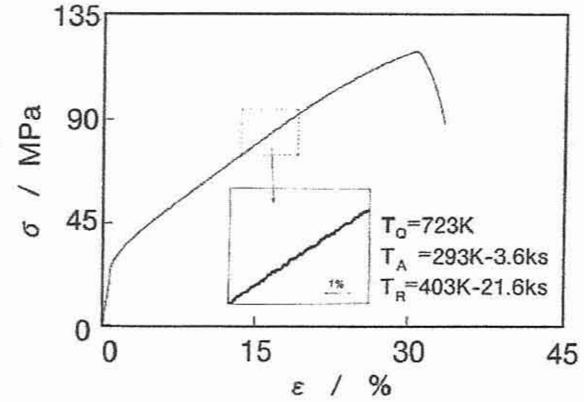

Fig. 5 Stress(σ)-strain(ε) curve of the specimen aged at 293K for 3.6ks after quenching from 723K and then annealed at 403K for 21.6ks.

Fig.6 shows variation of the tensile strength (σ_b) and the maximum stress amplitude of the serration ($\Delta\sigma_{max}$) with reversion temperature (T_R) when the specimens were quenched and aged in the same way as above and annealed at T_R for 21.6ks. Serration was recognized for all T_R except for 353K, which is lower than the solubility limit for GP zones in this alloy. It is found from the variation of $\Delta\sigma_{max}$ that the lower is the reversion temperature, the more significant is the extent of serration.

The result of Fig.3 could be explained if the appearance of serration is assumed, according to Cottrell[6], to be caused by the interaction between dislocations and solute atoms; serration appeared according as the solute concentration became higher, because GP zones were dissolved by the reversion treatment. The result that $\Delta\sigma_{max}$ increases with t_R might be compatible with this explanation. This interpretation, however, predicts larger $\Delta\sigma_{max}$ for higher T_R because the solute concentration should be higher, which is contradictory with the result in Fig.6. Pink and Krol[3] suggested that serration occurs due to coarsening of the GP zones during reversion treatment which was formed in the room-temperature aging.

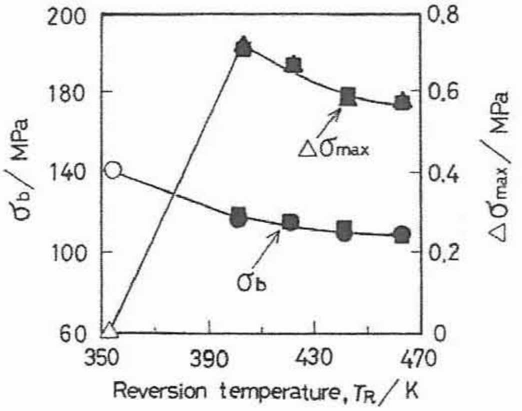

Fig.6 Effect of the reversion temperature (T_R) on the occurrence of serration, tensile strength (σ_b) and the maximum stress amplitude ($\Delta\sigma_{max}$) in the serrated flow. Solid and open symbols correspond whether serration occurred or not, respectively. Solid squares represent the annealed specimen.

The specimen quenched directly to the oil bath at the reversion temperature (T_R) from 723K was kept at T_R for more than 10ks. This specimen, which was annealed at T_R without aging, also showed serration and the values of σ_b and $\Delta\sigma_{max}$ (solid squares in Fig.6) agreed well with those annealed at T_R after aging. Neither coarse ellipsoidal GP zones nor precipitates were observed in that specimen. Ohta and Hashimoto[8] found an increase of electrical resistivity in this alloy at the temperature higher than the GP zone solvus and suggested the formation of spatial fluctuation of solute concentration or solute atom clusters. It is noted that the dependence of $\Delta\sigma_{max}$ on the temperature (T_R) shown in Fig.6 coincides with that of the resistivity[8]. From this result it seems to be more reasonable to ascribe the serration to the formation of solute cluster rather than to the coarsening of GP zones³⁾, but the relationship to microstructure change during deformation should be further investigated.

4.CONCLUSIONS

The relationship between occurrence of serration and reversion heat treatment was studied by tensile test on Al-10mass%Zn alloy and the results obtained are as follows:

(1) Serration was observed for the furnace cooled specimen, but not for the as-quenched one and the shortly aged one, which result is difficult to be interpreted by the Cottrell theory.

(2) The stress amplitude in the serration increased with increasing the time of annealing for reversion up to 10ks and then stayed at a constant value which might be interpreted by the Cottrell theory.

(3) The stress amplitude in the serration decreased with increasing the annealing temperature, which is contrary to the prediction by the Cottrell theory.

(4) The specimen directly annealed without aging and the one annealed after aging agreed well with each other in the tensile strength and the stress amplitude in the serration, which suggests solute clusters as the cause of serration.

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