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Serration in Al-Zn Alloys Containing a Small Amount of Fe

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Effect of addition of Fe on the occurrence of serration in Al-12mass%Zn alloys was investigated. Specimens aged at 293K for various periods after quenching from various temperatures (T_Q), 398K to 823K, were tensile-tested at room temperature. Serration occurred more easily and more remarkably with decreasing T_Q for as-quenched specimens: in the case that T_Q=448K serration was observed both for the binary and Fe added alloys, while in the case that T_Q=573K none of the three alloys showed serration. For the binary alloy serration was observed only when the aging period was short enough, but addition of Fe to the binary alloy prolonged the aging period where serration could be recognized. Aging rate measured by hardness was remarkably retarded with the increase of Fe addition. These results confirm the interpretation that the serration in Al-Zn alloy occurs in the early stage of aging where small GP zones or solute clusters are formed.

1. Introduction

Appearance of serration in the stress-strain curve of Al-Zn alloys has been studied since the work by Chossat[1]. Saito et al.[2] studied the mechanism of serration and explained the appearance of serration in terms of the Cottrell effect[3] involving interaction between solute atoms and dislocations. Besides that, explanations in terms of the interaction of dislocations with super-jogs, which were made from lattice defects and dislocations[4], or in terms of the interaction of dislocations with coherent particles such as GP zones[5] were presented. Recently the present authors studied systematically the relation between the appearance of serration and the heat treatment, and found that in this alloy serration appeared at the initial stage of aging where GP zones with several nm in size or clusters of solute atoms were formed[6,7].

Aging process of Al-Zn alloys is remarkably changed with a small addition of some kind of third element. Addition of Ag, for example, elevates dissolution temperature of GP zones and addition of Fe slows down aging rate due to refinement of grains[8,9]. Fatigue strength is likely to be fairly increased with addition of Fe[10].

In this report effect of addition of Fe on the appearance of serration is investigated.

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2. Experimental Procedures

Alloys, Al-12mass%Zn, Al-12mass%Zn-0.1-mass%Fe and Al-12mass%Zn-0.5mass%Fe in nominal composition, were obtained by melting pure metals of Al and Zn and a mother alloy of Al-5mass%Fe 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 were solutionized at 823K for

Table 1 Chemical composition (mass%) of alloys used.

Alloys	Zn	Fe	Cu	Si	Al
Al-12%Zn	11.6	0.001	0.002	0.002	bal.
Al-12%Zn-0.1%Fe	11.8	0.107	0.001	0.001	bal.
Al-12%Zn-0.5%Fe	11.5	0.509	0.003	0.002	bal.

3.6ks, furnace-cooled to the quenching temperature (T_Q), 823K to 398K, kept there for 3.6ks and then quenched into iced water. Aging was carried out by immersing specimens for various periods in an ethanol bath kept at the aging temperature (T_A), 293K. Accuracy of the T_A measurement was within 0.5K.

Specimens heat-treated were examined by tensile test with Instron testing machine, 4505, at room temperature, 293K, strain rate being $2\times10^{-4}s^{-1}$. Aging process was followed by hardness with micro-Vickers hardness tester. Details of the measurement were described in the previous papers[6,9]. Average grain sizes of the binary alloy, 0.1%Fe added alloy and 0.5%Fe added alloy are 120μm, 70μm and 30μm, respectively.

3. Results and Discussion

Fig.1 shows the stress(σ)-strain(ε) curves of the specimens as-quenched from 473K. As is shown in Fig.2, serration observed in these curves fluctuates; therefore it is classified into so-called A-type serration[11]. A smooth curve without serration was obtained for the binary alloy. In the case of 0.5%Fe added alloy, on the other hand, serration appeared in the strain range between about 1% and 8.5%. In the case of 0.1%Fe added alloy serration is also observed but the range of its occurrence is limited between 2% and 4% strain.

When the quenching temperature, T_Q, was 573K or above, serration did not appear irrespective of the addition of Fe. When $T_Q \leqq$ 448K, serration could be observed in all specimens. As the quenching temperature decreased, the range of strain where the serration was observed widened and the serration amplitude increased. Serration observed in the Fe added alloy specimen was more remarkable than that of the binary alloy for the same quenching temperature.

Dependence of the appearance of serration on the aging time (t_A) was examined. Fig.3 shows age hardening curves at 293K of the three specimens quenched from 398K. Solid marks represent the state which showed serration in the tensile test. Rate of hardening is markedly reduced by the addition of Fe to the binary alloy. Retarding of age hardening is considered to be due to the refinement of grains caused by the addition of

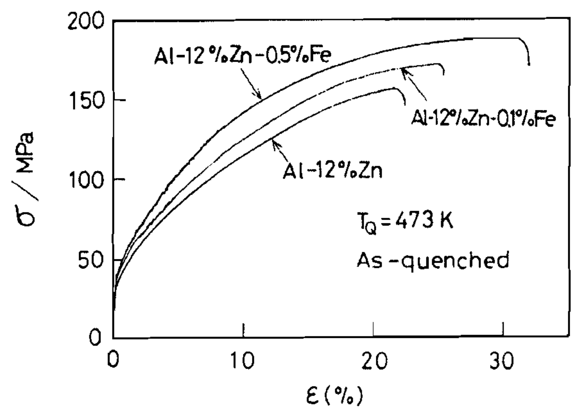

Fig.1 stress(σ)-strain(ε) curves of the binary and Fe-added alloy specimens as-quenched from 473K and tensile-tested at room temperature at a strain rate of $2\times10^{-4}s^{-1}$.

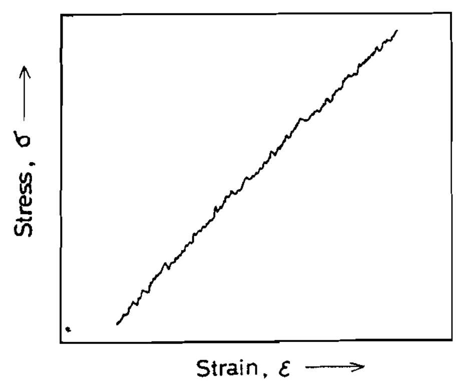

Fig.2 Schematic diagram of the typical serration observed in the Al-Zn alloys.

Fe, and/or to the increase of vacancy sinks, such as dislocations involved with the formation of intermetallic compounds like Al_3Fe. Serration was observed even at the state aged for 480ks in the 0.5%Fe added alloy specimen, while serration could be recognized only within 7.2ks of aging time (t_A) in the binary alloy.

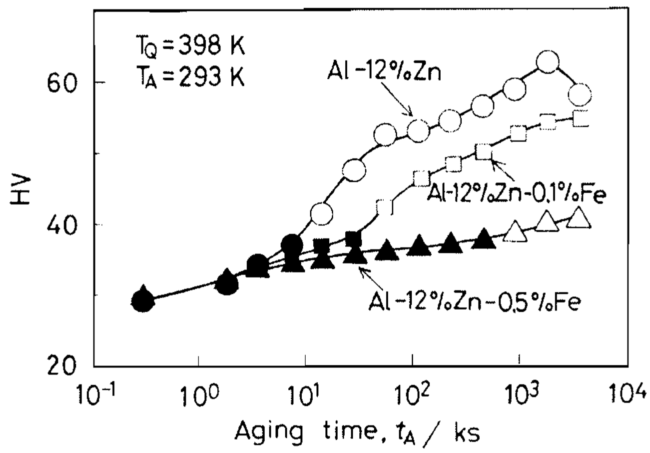

Fig.3 Variation of isothermal age-hardening curve of the binary and Fe-added specimen aged at 293K after quenching from 398K. Solid and open symbols indicate whether the stress-strain curve showed serration or not.

It might be thought that grain refinement and/or intermetallic compound formation themselves promote the appearance of serration, but the grain size and the state of intermetallic compound did not alter during the aging. It should be noted that the maximum hardness of the specimen which showed serration coincided each other. This suggests that serration essentially occurs in the same stage of aging and that addition of Fe increased vacancy sinks and slowed down the aging rate; therefore serration appeared even in longer aging time. In the case of the as-quenched specimens (Fig.1), the result that serration could be observed only in the Fe added alloys for the intermediate quenching temperature may be due to the retardation of growth of GP zones or solute atom clusters during the quench, caused by the addition of Fe. Lowering the quenching temperature had the same effect of retardation as Fe addition and made the serration occur even in the binary alloy.

4. Conclusions

Effect of addition of a small amount of Fe on the appearance of serration in tensile deformation was examined for Al-12mass%Zn, Al-12mass%Zn-0.1mass%Fe and Al-12mass%Zn-0.5mass%Fe alloy specimens aged at 293K after quenching from various temperatures between 398 and 823K.

(1) Serration was not observed for the specimens quenched from high temperatures, $T_Q \geqq 573K$, irrespective of the addition of Fe. On the other hand, when $T_Q \leqq 448K$ serration occurred and became pronounced with decreasing T_Q.

(2) Addition of Fe to the binary alloy promoted the serration.

(3) Lowering T_Q and/or addition of Fe made the aging rate slower, which caused serration to occur easily because serration was allowed to occur in the early stage of aging, where small GP zones or solute clusters existed.

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