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Effect of Specimen Thickness on Aging and Fatigue Strength of Al-Zn Alloys

Akira SAKAKIBARA*, Tadashi TANIMOTO**, Takahisa MATSUSHIMA***,
Norio HOSOKAWA** and Teruto KANADANI**

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Repeated tensile fatigue strength of the low temperature age-hardened Al-Zn alloys is investigated varying the specimen thickness. Fatigue strength of the age-hardened specimens decreases with the specimen thickness when the specimen is thinner than a certain thickness, whereas fatigue strength of non age-hardened specimens, i.e., pure aluminum and dilute Al-Zn alloy, does not depend the specimen thickness. The dependence of fatigue strength on the thickness of age-hardened specimen is considered to be caused by the decrease of the strength of specimen as a whole, as a result of increase in volume ratio of the soft surface layer formed after age-hardening with decreasing specimen thickness.

1. INTRODUCTION

It was believed that GP zones were formed homogeneously, except for precipitate free zones (PFZ) near the grain boundaries, when thin specimens, less than 1mm in thickness, of Al-Zn alloy were age-hardened at around room temperature(1). According to the study by Ohta et al.(2), however, microstructures were not homogeneous even in those thin plate specimens, after some heat treatment; especially regions in the vicinity of surface were softer than the interior region even after long aging.

Present authors have studied relation of fatigue strength to low temperature age hardening of the various parts of the specimen, particularly paying attention to the effect of heat treatment. It has been found that difference in fatigue strength in the repeated tensile mode is caused by the difference in existence/thickness of soft surface layer formed in the low temperature aging, rather than the difference in the microstructure originated from the different heat treatments(3)~(8). In this paper fatigue strength in the repeated tensile mode of low temperature age-hardened Al-Zn alloy specimens is investigated in detail in relation to specimen thickness.

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* Department of Mechanical Engineering

** Department of Mechanical Engineering, Okayama University of Science

*** Graduate School of Okayama University of Science (Present: Daiwabo Co., Ltd.)

2. EXPERIMENTAL PROCEDURES

2.1. Specimens

Alloys, of which the nominal compositions were Al-2, 6, 8, 10, 12mass%Zn, were obtained by melting pure metals, 99.996%Al and 99.999%Zn, in high alumina crucibles 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 0.3mm and 1.3mm in thickness. Specimens for various measurements were prepared from these strips. Shape and dimension for each measurement were the same as reported previously[(1),(3),(8)]. Method of heat treatment was the same as reported previously[(6),(9)] and aging was performed in an ethanol bath kept at 273K or 293K.

2.2. Measurements

A micro-Vickers hardness tester and an ultramicro-hardness tester (Akashi MZT-1) were used for hardness measurement. Hardness was measured at room temperature with various loads from 0.01N to 9.8N, at various positions, that is, on the grain boundary (GB), on the areas in the vicinity of GB and about 200μm apart from GB, for the specimens aged sufficiently and the ones whose surface layer, several tens μm in thickness, was removed by electropolishing after aging.

Fatigue strength of the specimens with various thicknesses was measured in the repeated tensile mode by a fatigue tester (Shimazu UF-15). Number of cycles to rupture was obtained under various loads.

Electrical resistance was measured by a conventional four lead method, using an automatic resistance measuring instrument (Yokogawa 3802-64). Specimens were soaked in liquid nitrogen during measurement using dummy for temperature calibration. In order to compare the data among various specimens, resistance of each specimen annealed at 473K for 1.8ks after quenching from 613K was obtained for the standard and resistance data during aging was normalized by dividing by this standard value.

3. RESULTS AND DISCUSSION

Figure 1 shows variation of the aging behavior in resistivity with the specimen thickness (t_h) for

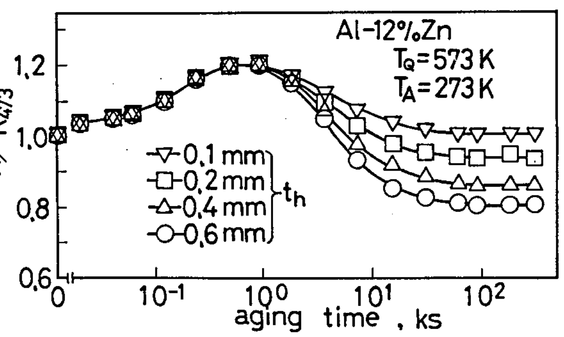

Fig.1 Variation of isothermal aging curves in resistance with thickness when 12%Zn alloy specimens were quenched from 573K and aged at 273K.

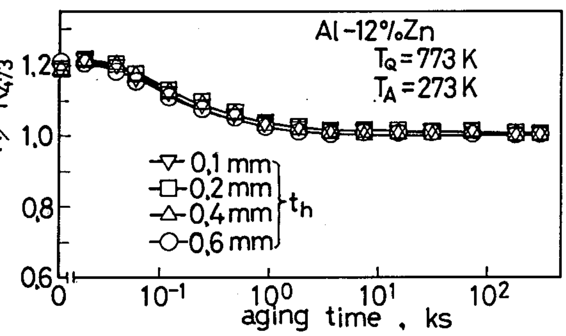

Fig.2 Variation of isothermal aging curves in resistance with thickness when 12%Zn alloy specimens were quenched from 773K and aged at 273K.

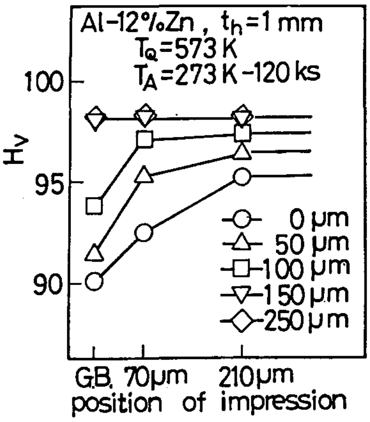

Fig.3 Variation of HV at different positions with successive removal of surface layers of the specimen with original thickness of 1mm which was aged for 120ks at 273K after quenching from 573K.

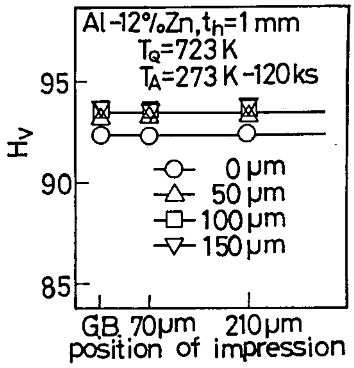

Fig.4 Variation of HV at different positions with successive removal of surface layers of the specimen with original thickness of 1mm which was aged for 120ks at 273K after quenching from 723K.

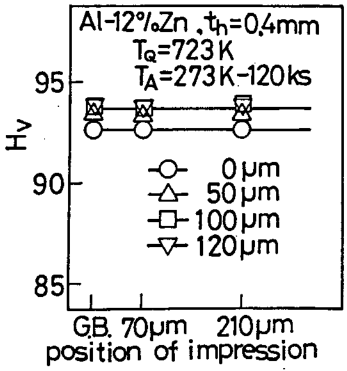

Fig.5 Variation of HV at different positions with successive removal of surface layers of the specimen with original thickness of 0.4mm which was aged for 120ks at 273K after quenching from 723K.

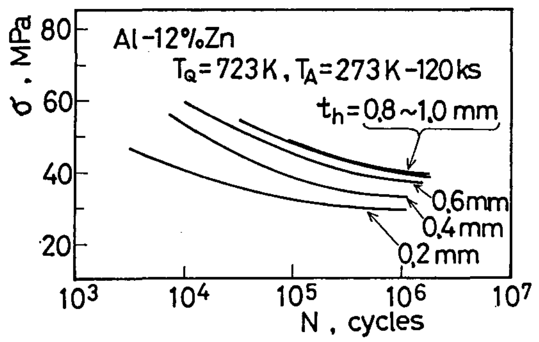

Fig.6 Variation of s-N curves with specimen thickness when 12%Zn alloy specimens were quenched from 723K and aged for 120ks at 273K.

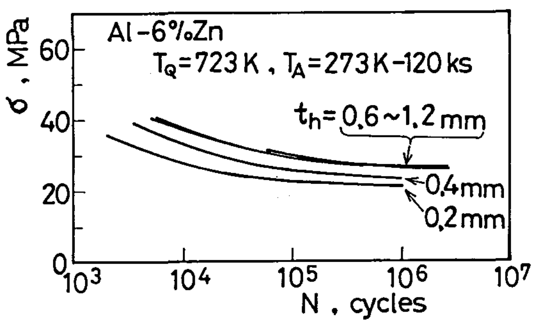

Fig.7 Variation of s-N curves with specimen thickness when 6%Zn alloy specimens were quenched from 723K and aged for 120ks at 273K.

the Al-12%Zn alloy specimens with 0.1, 0.2, 0.4, 0.6mm thickness which were aged isothermally at 273K after quenching from 573K. These curves have resistivity maximum characteristic of the formation and growth of GP zones. After passing the maximum difference appears; according as the thickness decreases, the amount of decrease of resistivity from the maximum becomes smaller and the stationary resistivity, which corresponds to the extent of aging, i.e. growth of GP zones, before aging virtually ceases, becomes higher. Figure 2 shows the behavior of the specimens aged after quenching from a higher temperature, 773K. In this case the difference in the behavior among the specimens of different thickness is hardly found through the aging process. This result that the extent of aging depends on the specimen thickness for a lower quenching temperature is considered to be caused by the less proceeding aging near the surface due to migration and annihilation of vacancies to the surface during aging.

Figure 3 shows variation of hardness with the position of indentation for the aged-hardened specimen with 1mm in thickness after removing surface layer successively, 50mm thick in each, by electropolishing. Age-hardening was carried out for 120ks at 273K after quenching from 573K.

Hardness of the as-aged surface (○), not electropolished, decreases remarkably with decreasing distance from GB. Hardness in the central region of grains was constant at positions 200μm or more apart from GB. According as the surface is removed layer by layer, hardness increases as a whole, remaining the dependence on the distance from GB at first, but finally ceases to change and becomes independent of the position when more than 150μm of thickness is removed. Figure 4 shows the results for a higher quenching temperature, 723K. In this case the dependence of hardness on the distance from GB is not recognized, but hardness as a whole increases from that of the as-aged surface with the thickness removed from surface, reaching a constant value when the thickness removed is about 50μm. From these results the thickness of soft surface layer formed in those specimens aged after quenching from 573K and 723K can be evaluated to be 150μm or less and about 50μm, respectively. Figure 5 shows the results of the same experiment for the specimen with thickness of 0.4mm aged after quenching from 723K. Behavior of this thin specimen is almost the same as that of the thick (1mm) specimen quenched from the same temperature, 723K; the constant value of hardness reached after removing sufficient thickness is 93.5HV and the thickness evaluated for the soft surface layer is about 50μm. Specimens with the thickness other than 1mm and 0.4mm showed almost the same result.

Relation between the specimen thickness and the fatigue strength was studied by fatigue test in repeated tensile mode. Figure 6 shows variation of σ-N curve, plot of cycles to failure (N) with stress amplitude (σ), with thickness of the Al-12%Zn specimen aged for 120ks at 273K after quenching from 723K. σ-N curves of the specimen 0.8mm or more in thickness agree with each other, but for the specimen thickness less than 0.8mm the curve becomes lower as a whole, showing lower fatigue strength with decreasing the thickness. Figure 7 shows the result for the Al-6%Zn specimen, where the thickness of soft surface layer after aging was about 40μm, a little thinner than that of 12%Zn alloy. The same behavior as in Fig.6 is observed, but the thickness where the curves begin to agree with each other is 0.6mm, a little less than that of 12%Zn alloy. These results indicate that fatigue strength decreases with increasing volume ratio of soft surface layer when the ratio becomes greater than a certain value. This may be due essentially to the decrease of strength of the whole specimen with increase of the volume ratio of the soft region. In the case of Al-2%Zn and pure aluminum specimens, where no age-hardening is observed and, therefore no soft surface layer is formed, σ-N curves agree with each other for all specimens with different thickness, shown in Figs.8 and 9.

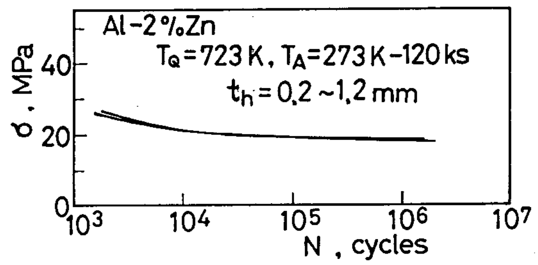

Fig.8 Variation of s-N curves with specimen thickness when 2%Zn alloy specimens were quenched from 723K and aged for 120ks at 273K.

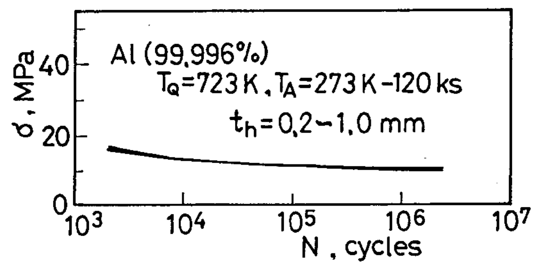

Fig.9 Variation of s-N curves with specimen thickness when pure Al (99.996%) specimens were quenched from 723K and aged for 120ks at 273K.

3. CONCLUSION

Effect of soft surface layer formed after low temperature aging of Al-Zn alloys on their aging and fatigue behavior was investigated by resistometry, hardness test and fatigue test in repeated tensile mode.

(1) Thickness of the soft surface layer is almost the same regardless of the specimen thickness when the specimens with the same composition are heat-treated in the same way.

(2) Isothermal aging curve in resistivity after quenching from low temperature varies with specimen thickness; decrease of resistivity after the maximum becomes smaller as the specimen becomes thinner, corresponding to the increase of volume ratio of the soft surface layer.

(3) Fatigue strength of the aged specimens decreases with thickness of specimen when the thickness is less than a certain value, while fatigue strength of non age-hardened specimens, that is, pure aluminum and dilute Al-Zn alloy, does not depend the specimen thickness.

(4) The dependence of fatigue strength of age-hardened specimen on the specimen thickness is considered to be caused by the decrease of the strength of specimen as a whole, as a result of increase in volume ratio of the soft surface layer formed after age-hardening with decreasing specimen thickness.

REFERENCES

1. H. Kimura, "Precipitation in Alloys" ed. S. Koda, Maruzen, Tokyo (1972), 165.
2. M. Ohta, H. Yamada, T. Kanadani, A. Sakakibara and M. Yamada, Light Metals, **33**(1983), 212.
3. T. Kanadani, Phys. Stat. Sol.(a), **115**(1989), K147.
4. T. Kanadani, "Proc.106th Conf. JIM, Tokyo"(1990), 252.
5. T. Kanadani and A. Sakakibara, Phys. Stat. Sol.(a), **117**(1990), K19.
6. T. Kanadani, T. Matsushima, N. Hosokawa, T. Kaneeda and A. Sakakibara, Phys. Stat. Sol.(a), **124**(1991), K97.
7. T. Kanadani, A. Sakakibara, N. Hosokawa and T. Kaneeda, Phys. Stat. Sol.(a), **129**(1992), K1.
8. T. Kanadani, A. Sakakibara and K. Nakagawa, Light Metals, **45**(1995), 649.
9. M. Ohta, T. Kanadani, M. Yamada and A. Sakakibara, J. Japan Inst. Metals, **50**(1987), 887.