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Fatigue Strength of Al-evaporated Al-Zn Alloys with High Zn Concentration

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Abstract. Authors have studied relation of fatigue strength to low temperature age-hardening of the various parts of the Al-Zn alloy specimen. 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. In this study, the effect of Al evaporation on the fatigue strength is investigated for the Al-20mass%Zn alloy specimen, which hardly had soft surface layer after the aging and showed low fatigue strength. As a result, the fatigue strength of Al-evaporated specimens is remarkably higher than the non-evaporated ones. Variation of Zn concentration on the cross-section of the Al-evaporated specimen after the fatigue test revealed considerable diffusion of Zn from the alloy to the evaporated Al layer, so that the soft surface layer with concentration gradient was formed. It is considered that fatigue strength of this alloy is able to be improved by Al-evaporation. As for this method, an application to the practical use materials that generation is difficult of the soft surface layer will be promising.

1. Introduction

There have been lots of works on Al-Zn alloys about the variation of mechanical properties with heat treatment and its relationship with the microstructure because they are basic alloys of 7000 series Al alloys, such as extra super duralumin, which have a high specific strength and are widely used for aircraft and automobiles. Al-Zn alloys are hardened by the formation and growth of GP zones when aged at low temperature, but the hardening, in some case, is not uniform across the specimen depending on the heat treatment. Even in a specimen as thin as 1mm or less and after a long aging, regions near the surface and regions near the grain boundaries were not hardened remarkably relative to the interior of the specimen [1]. From the results of X-ray small angle scattering experiment and transmission electron microscope observation, this result was explained by the decrease of vacancy concentration near the surface and grain boundaries, which act as sinks for quenched excess vacancies [2]. In the reversion of age-hardened Al-Zn alloys, on the other hand, the softening of the surface layer preceded that of the interior, which was considered to be caused by the effect of surface as vacancy sources [3]. Generally, micro-cracks occur in the vicinity of surface and propagate into the specimen [4], therefore, various methods to harden the surface of metal, such as shot-peening [5], are employed to prevent the micro crack initiation. Soft surface layer formed in the aging or reversion, however, was found to increase the fatigue strength of Al-Zn and Al-Cu alloys in the repeated tensile mode [6, 7].

In this report the effect of Al evaporation on the fatigue strength is investigated for the Al-20 and 22mass%Zn alloy specimen, which hardly had soft surface layer after the aging and showed low fatigue strength.

2. Experimental procedure

Alloys of nominal composition Al-12, 16, 20 and 22mass%Zn were prepared by melting 99.996%Al and 99.999%Zn in a high alumina crucible in air. The ingots were hot forged after homogenization and cold rolled to sheets of about 1mm thickness, then cut out to specimens for the measurements. The shape and the dimension of the specimens are as previously reported [2, 6, 7]. The surface of the specimen was rinsed in an ultrasonic bath and coated with pure aluminum (99.99% purity) by vacuum evaporation. Specimens, either evaporated or non-evaporated, were solutionized at 773K, furnace-cooled to 673K, kept there for 3.6ks, and quenched to iced water. Each specimen was aged for 90ks in an ethanol bath at 273K. The specimen heat-treated was fatigue tested at various stress amplitude with the stress ratio of 0 and the frequency of 30Hz. Number of repetition to rupture, N, was measured under various stress amplitude, σ. Tensile test was carried out with Instron universal testing machine (model 5500R) at room temperature mainly at the strain rate of 2×10^{-4} s^{-1} and the stress-strain curve was obtained. Vickers micro hardness was measured to follow the age hardening at various positions of the specimen.

3. Results and Discussions

Figure 1 shows variation of hardness of the aged Al-12%Zn specimen with changing indentation load when surface layers, each 25 m in thickness, were successively removed by electro polishing. The load dependence of hardness was no longer observed when the surface layer, 100 m in thickness, was removed. This result is considered to be due to the existence of soft surface layer whose thickness is nearly 100 m.

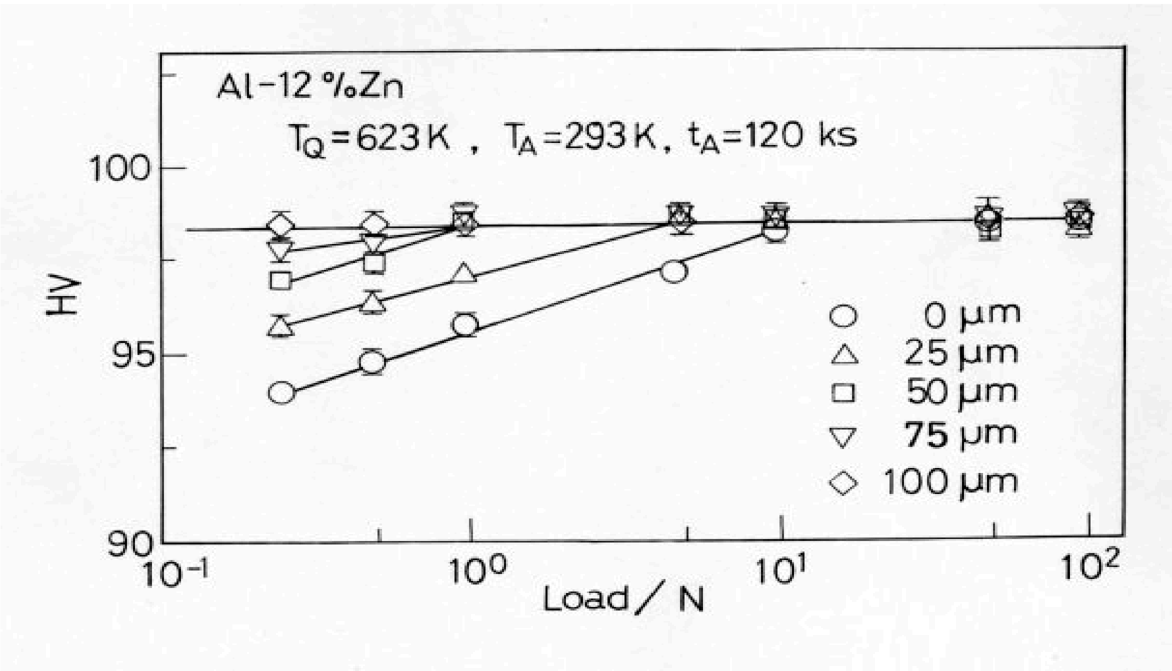

Fig.1 Variation with indentation load of hardness of the Al-12%Zn specimen aged at 293K for 120ks after quenching from 623K. Surface layer was successively removed layer by layer, each 25 m in thickness, and the load dependence was measured after each removal.

On the other hand, Figure 2 shows variation of hardness of the aged Al-20%Zn specimen with changing indentation load. Dependence of hardness on the indentation load was not recognized in this specimen, therefore the soft surface layer is considered to be very thin. Formation and growth of the GP zones were so rapid in this high concentrated alloy that the formation of the soft surface layer could be suppressed.

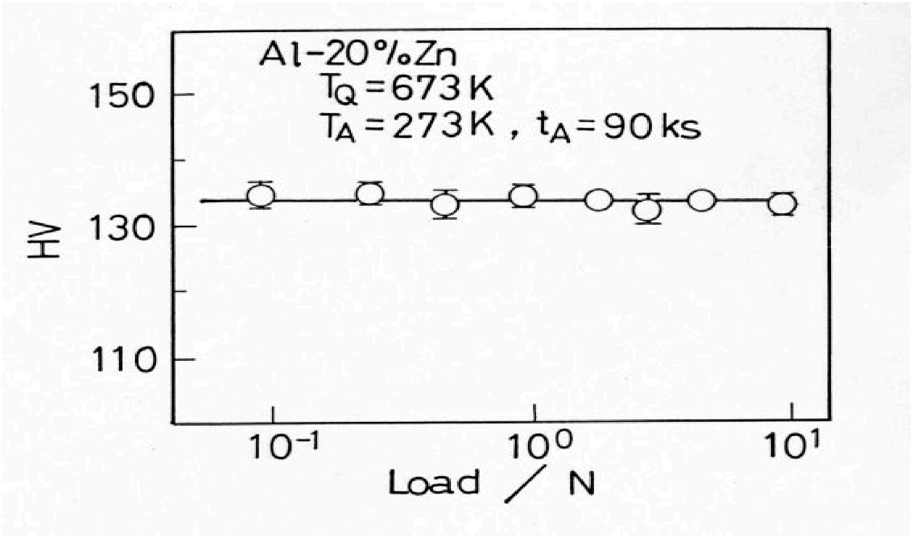

Fig. 2 Dependence of hardness number on the load for the Al-20%Zn alloy aged at 273K for 90ks after quenching from 673K.

Figure 3 shows the σ - N curves of Al-12, 16 and 20%Zn alloy fully aged at 273K after quenching from 673K. The relation of N to σ showed remarkably lower fatigue strength of the aged Al-20%Zn specimen than the aged Al-12 and 16%Zn one. Taking account of the fact that the grain size of Al-20%Zn specimen was smaller than that of Al-12 and 16%Zn specimen and that the soft surface layer as thick as 100 or 75 m was formed in Al-12 and 16%Zn specimen, it was considered that lower fatigue strength of Al-20%Zn specimen was mainly due to suppression of the soft surface layer.

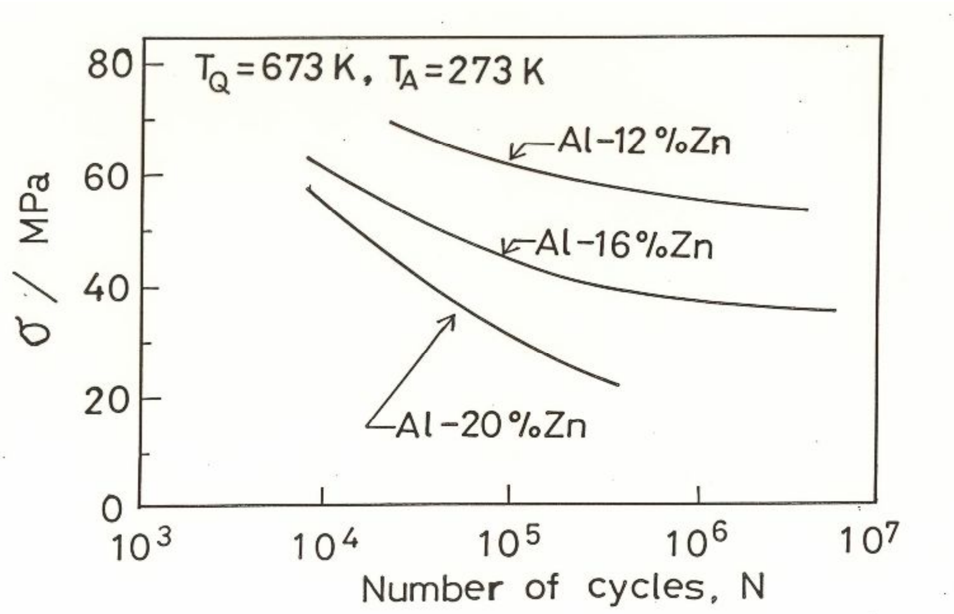

Fig.3 Plot of stress amplitude against number of stress cycles for alloys aged at 273K after quenching from 673K.

Harnesses of the Al-12%Zn alloy specimen with soft surface layer measured before and after the fatigue test, both decreased with decreasing load below 0.98N, but the specimen after the test was a little more hardened than before. Above 0.98N the hardness was independent of the load and any change was not found after the test. On the other hand, the specimen without soft surface layer showed constant hardness irrespective of the load and no influence of the fatigue test at all. Pahl et al. [8] studied by X-ray small-angle scattering the effect of the repeated tensile loading on the growth of GP zones in Al-Zn alloy and found that small zones with Guinier radius less than about 2nm could grow during the loading but larger zones could hardly grow. The results of the transmission electron microscopy [1] showed that the radius of the GP zones near the surface of the aged specimen was larger than 3nm in the Al-Zn alloy. The hardening near the surface observed after the fatigue test of the specimen with soft surface layer is, therefore, considered to be caused by the work hardening rather than the growth of GP zones. The increase of fatigue strength owing to the soft surface layer may be tentatively explained by the suppression of formation and propagation of the micro cracks at the surface due to the plastic deformation of the soft layer. But details should be investigated further by the observation of microstructure with transmission electron microscope and by the fractography with scanning electron microscope.

Figure 4 shows σ-N curves of the Al-evaporated and non-evaporated Al-20%Zn specimens aged at 273K for 90ks after quenching from 673K. Fatigue strength of the Al-evaporated specimens is remarkably higher than the non-evaporated ones. The same fact is realized as for the Al-22%Zn specimen.

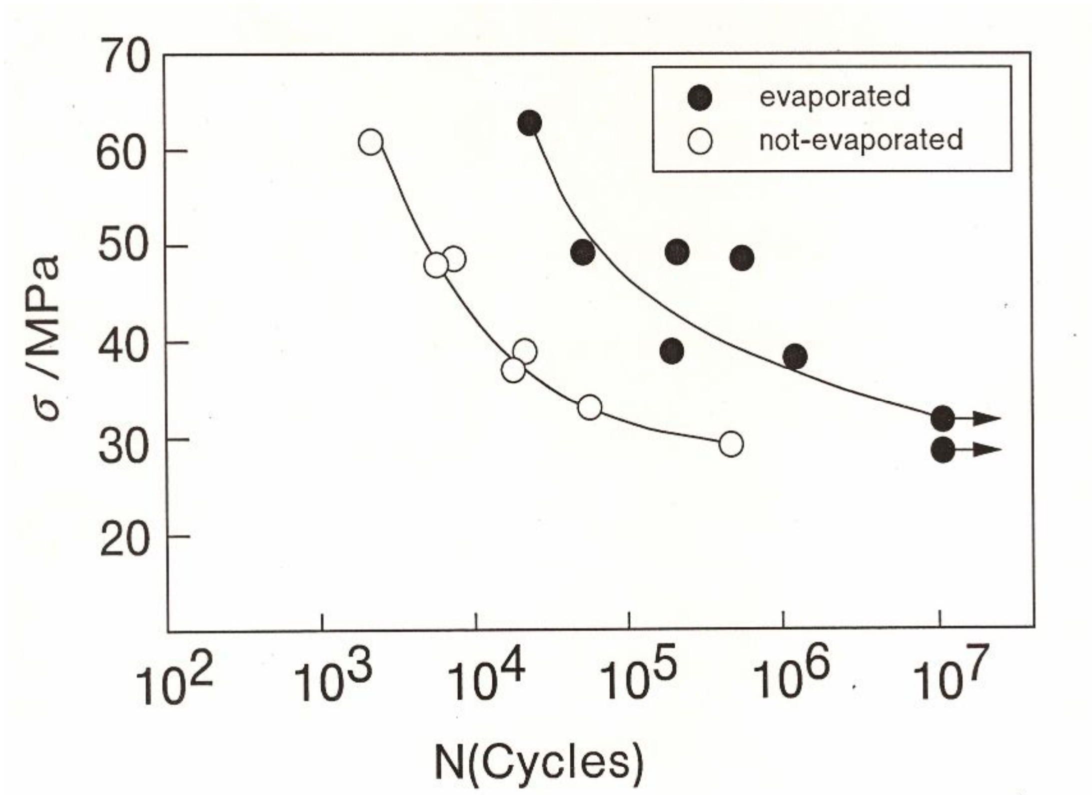

Fig.4 Effect of evaporated Al layer on σ - N curve of Al-20%Zn alloy aged at 273K for 90ks after quenching from 673K.

Variation of Zn concentration measured with EPMA on the cross-section of the Al-evaporated specimen after the fatigue test, shown in Fig.5, revealed considerable diffusion of Zn from the alloy to the evaporated Al layer, so that the soft surface layer with concentration gradient was formed.

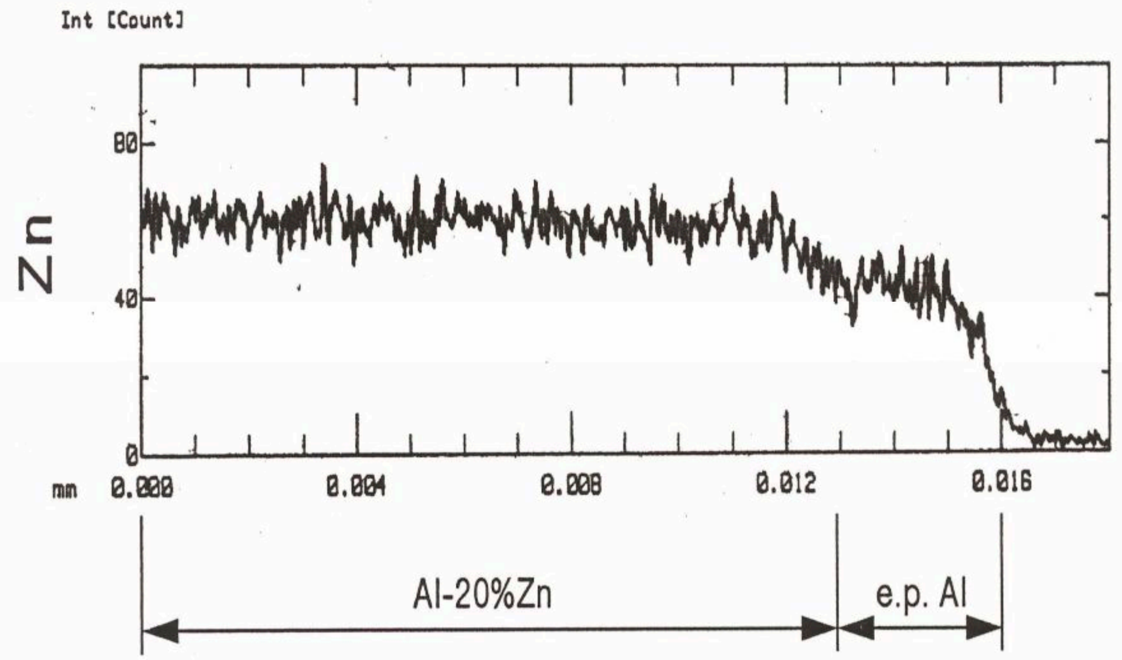

Fig. 5 Variation of Zn concentration with the distance from surface of Al evaporated and heat treated Al-20%Zn alloy specimen.

Furthermore, hardness of the neighborhood of surface and a center was each about HV80, 130, and the surface neighborhood surely softened when we measured micro-hardness to reach from the surface of this sample inside. In addition, the thickness of this soft surface layer was about 20 m. Good joint between the alloy and the evaporated layer was confirmed by the SEM observation of the fracture surface. From these results it is considered that fatigue strength of this alloy is able to be improved by Al-evaporation. As for this method, an application to the practical use materials that generation is difficult of the soft surface layer will be promising.

4. Summary

In this research, the effect of Al-evaporation on the fatigue strength is investigated for the Al-20 and 22%Zn alloy specimen, which hardly had soft surface layer after the aging and showed low fatigue strength. As a result, the fatigue strength of Al-evaporated specimens is remarkably higher than the non-evaporated ones. Variation of Zn concentration on the cross-section of the Al-evaporated specimen after the fatigue test revealed considerable diffusion of Zn from the alloy to the evaporated Al layer, so that the soft surface layer with concentration gradient was formed. It is considered that fatigue strength under the repeated tensile loading of this alloy is able to be improved by Al-evaporation.

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