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Fatigue Strength of Aged and Reversion-Treated Al-Zn Alloys

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Abstract

Al-Zn alloy specimens of several compositions, from 2mass% to 20mass% Zn, were aged at 273K or 293K after quenching from 673K. The thickness of the soft layer was negligible for the 2 and 20mass% alloys but reached a maximum of 100μm for the 12mass% alloy. Fatigue tests were carried out on these samples and the results compared with tests made on those in which the soft layer had been removed by electropolishing. It was found that removing the soft layer decreased the fatigue strength. The fatigue strength of the as-heat-treated samples depended on the thickness of the soft surface layer; it increased with Zn concentration up to 12%, and then decreased beyond. The 20%Zn specimen, which had no soft surface layer and a low fatigue strength, showed a higher fatigue strength after a short reversion treatment.

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 superduralumin, which have a high specific strength and are widely used for aircraft industries. When Al-Zn alloys are quenched from high temperature and aged around room temperature, GP zones form and grow and the specimens are age-hardened. It was commonly accepted previously that GP zones were formed uniformly in the specimen except for the regions near the grain boundaries. Ohta et al. [1], however, examined carefully age-hardening at various positions of specimen with microhardness testing, and found that regions near the surface were less hardened relative to the interior of specimen even after a long time of aging. From the results of X-ray small angle scattering experiment and transmission electron microscope observation, the effect was attributed to the suppression of GP zone formation near the surface because the surface is an effective sink for vacancies [2].

It is well known that fatigue cracks start at the free surface. Surface microstructure, therefore, should have significant effect on the fatigue strength and we have studied the effect of the relatively soft surface layer formed by aging on fatigue [3-6]. In this study the fatigue strength of the Al-Zn alloy specimens which were aged and reversion treated is reported.

2. Experimental Procedures

Alloys, Al-2%Zn (mass% hereafter), Al-6%Zn, Al-8%Zn, Al-10%Zn, Al-12%Zn, Al-15%Zn, Al-16%Zn, Al-18%Zn, and Al-20%Zn in nominal composition, were obtained 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 and forged at 723K to plates of 5mm thickness. The plates were cold-rolled, with appropriate intermediate annealings, to strips of 1.1mm thickness. Fatigue specimens, the shape and dimensions of which were reported previously [1,4], were prepared from these strips. Specimens were solutionized at the quenching temperature (T_Q), around 673K, for 3.6ks and then quenched to iced water. Aging was carried out by immersing specimens for various periods of time (t_A) in an ethanol bath kept at the aging temperature (T_A), 273K or 293K.

Fatigue tests of the heat-treated specimens were carried out in a repeated tensile mode at room temperature and the number of cycles at fracture (N) was obtained under various stress amplitudes (σ). Hardness of the aged specimens was measured at room temperature by a microhardness tester with various indentation loads.

3. Results and Discussion

Figure 1 shows variation of hardness of the aged Al-12%Zn specimen with changing indentation load when surface layers, each 25μm in thickness, were successively removed by electropolishing. The load dependence of hardness was no longer observed when the surface layer, 100μm in thickness, was removed. This result is considered to be due to the existence of soft surface layer whose thickness is nearly 100 μm. On the other hand, the aged specimen of Al-20%Zn alloy did not show any dependence of hardness on the load even when surface layer was not removed (Figure 2). In this case soft surface layer was hardly made during aging. GP zones are easily formed in this alloy due to the high concentration of Zn and age-hardening was achieved enough even near the surface. Figure 3 shows the dependence of thickness of soft surface layer on the solute concentration.

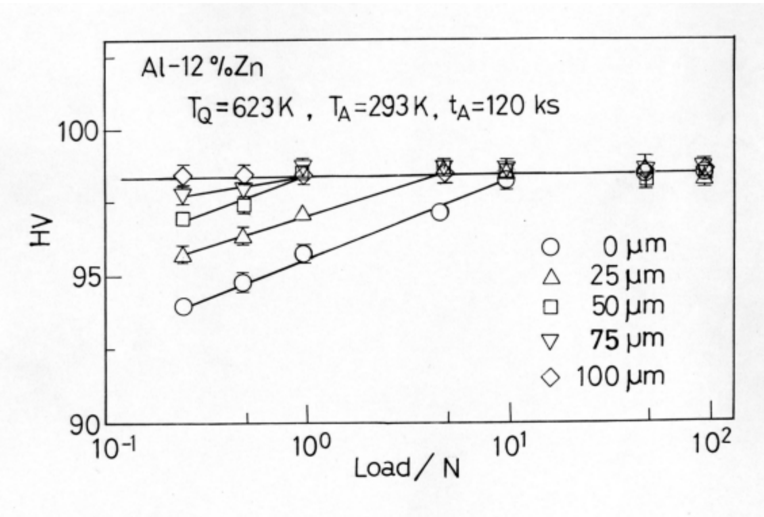

Figure 1: Variation with indentation load of hardness of the Al-12%Zn specimen aged at 293K for 120ks after quenching from 623K. Surface layer was successively removed layer by layer, each 25μm in thickness, and the load dependence was measured after each removal.

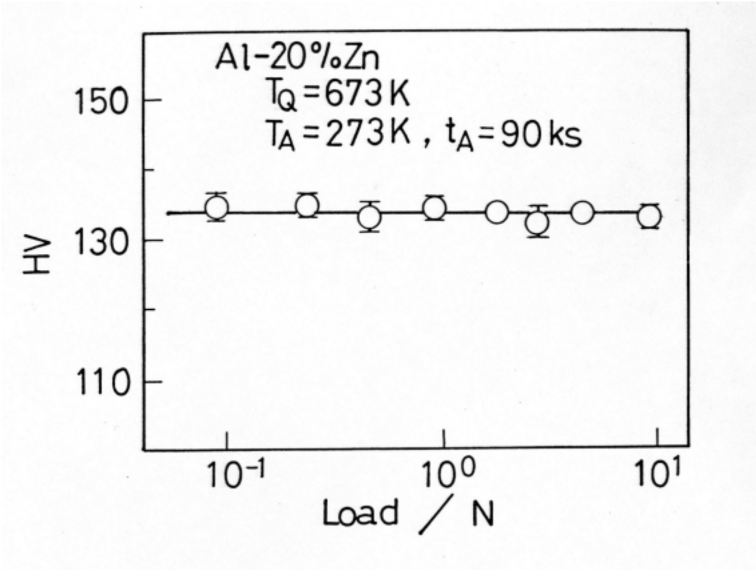

Figure 2: Variation with indentation load of hardness of the Al-20%Zn specimen aged at 273K for 90ks after quenching from 673K.

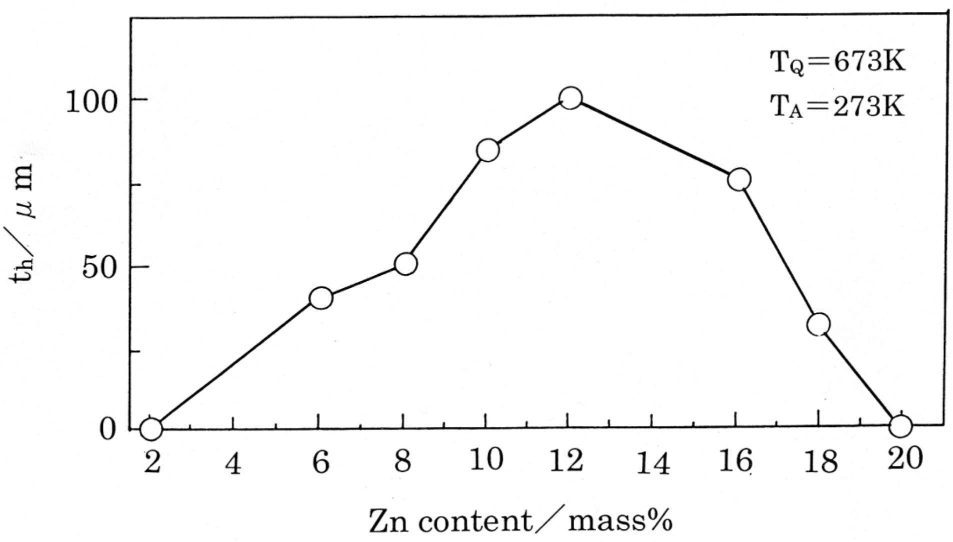

Figure 3: Variation of the thickness of soft surface layer with alloy composition for the specimens aged at 273K for more than 90ks after quenching from 673K.

Figure 4 shows an example of fatigue strength depending on whether the soft surface layer exists or not. The thickness of the soft surface layer evaluated by hardness measurement was about 50μm for this specimen. Fatigue strength was significantly lowered when soft surface layer, 50μm in thickness, was removed by electropolishing. Such a result was observed in many other alloys. Figure 5 shows σ-N curves of Al-2%Zn alloy which was heat treated in the same way as above. It is known that GP zones are not formed in this alloy at 273K; therefore, there was formed no soft surface layer. Removal of surface layer did not affect the fatigue strength in this case, which indicates that the electropolishing itself was not the cause of the change in fatigue strength.

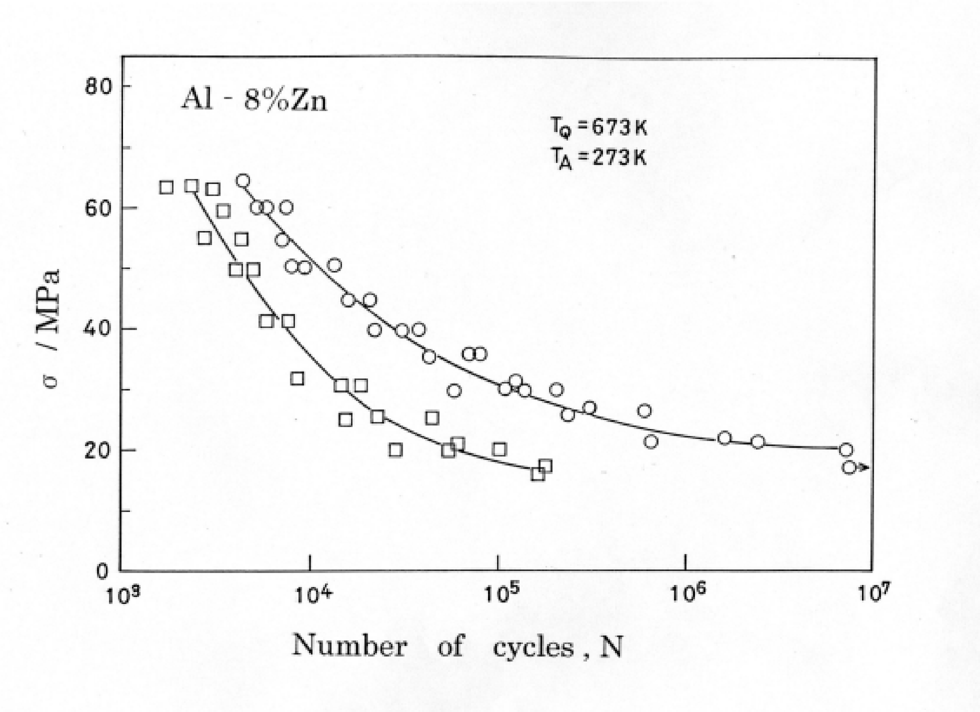

Figure 4: σ-*N* curves of the Al-8%Zn alloy aged at 273K for 60ks after quenching from 673K. Thickness of the surface layer removed: ○ 0μm, □ 50μm.

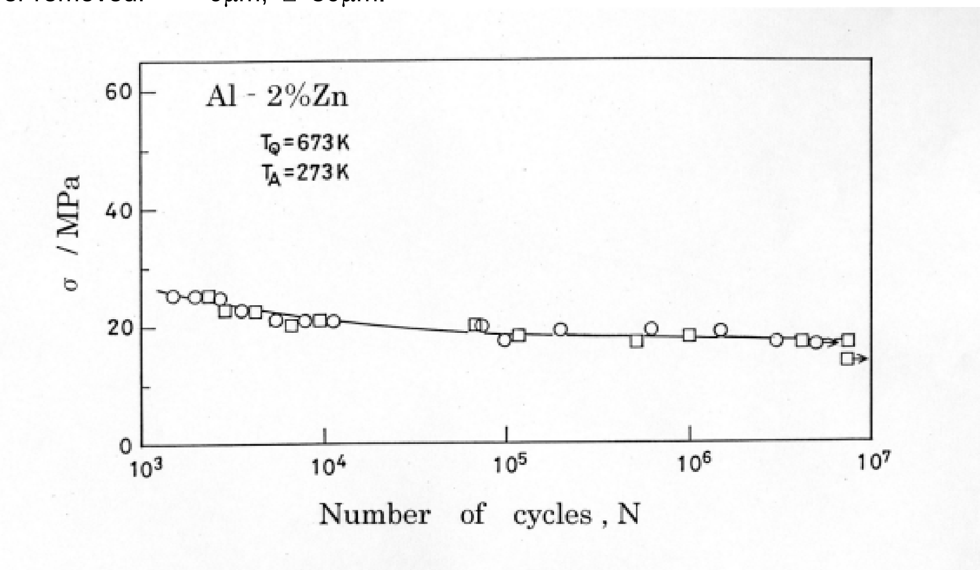

Figure 5: σ-*N* curves of the Al-2%Zn alloy aged at 273K for 60ks after quenching from 673K. Thickness of the surface layer removed: ○ 0μm, □ 50μm.

Figure 6 shows the dependence of fatigue strength on the solute concentration for Al-12, 16 and 20%Zn alloy fully aged at 273K after quenching from 673K. Fatigue strength increased with increasing Zn concentration up to 12%Zn (figure omitted) but decreased beyond that concentration, which has the same relationship with the result in Figure 3. It should be noticed that fatigue strength was fairly low for the Al-20%Zn alloy specimen where soft surface layer was not formed.

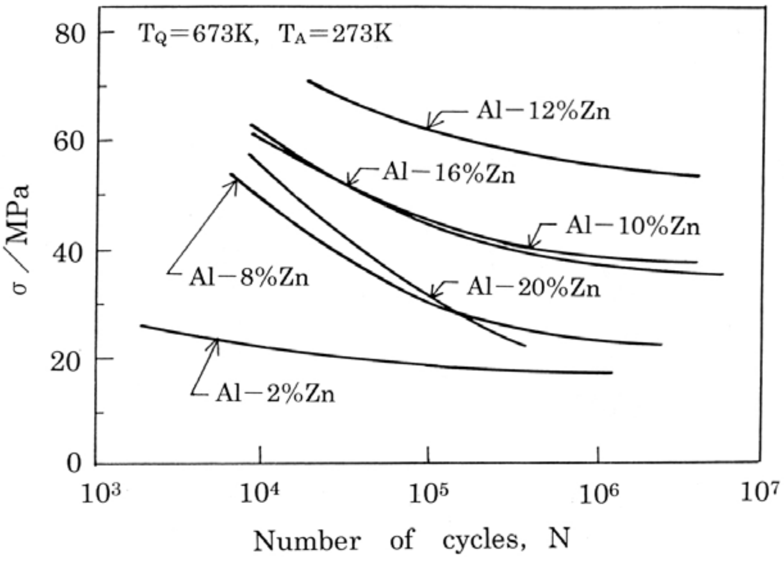

Figure 6: σ-*N* curves of various alloys aged at 273K for more than 90ks after quenching from 673K.

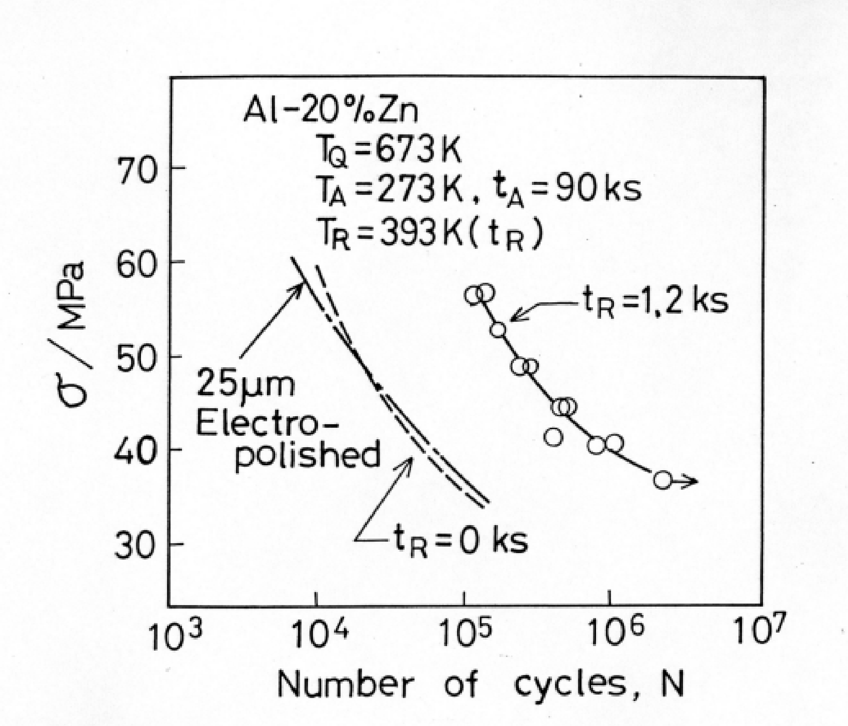

Figure 7: σ-*N* curves of the Al-20%Zn alloy, aged at 273K for 90ks after quenching from 673K (dashed line), aged at 273K and then annealed at 393K for 1.2ks (solid line), and electropolished after aging and annealing (chain line).

In the short reversion treatment, where aged specimen is kept at a higher temperature for a short time, GP zones are partially dissolved near the surface because of the effect of surface as a source of vacancies and soft surface layer is formed [7]. Figure 7 shows σ-*N* curves of Al-20%Zn alloy kept at 393K for 1.2ks after aging, where no soft surface layer was made (Figure 3). The fatigue strength was remarkably improved by the reversion treatment. By removing the surface layer, 25μm in thickness, fatigue strength was lowered again, and became almost the same value as that before the reversion treatment.

It is possible to say from above results that the soft surface layer formed by aging/reversion treatment contributes to the increase of fatigue strength. It was observed (figures omitted) that the soft surface layer became hardened gradually during the fatigue test and that the spacing of slip band was narrow and uniform in the soft surface layer compared with that in the specimen without the surface layer. These results suggest that the soft surface layer played a role of buffer against the nucleation of persistent slip band or the generation/propagation of fatigue cracks .

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