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Fatigue Strength of Age-Hardened Al-Zn Alloys under Repeated Tensile Loading

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SYNOPSIS

Effect of the soft surface layer that was formed on low temperature aging of Al-Zn alloy on fatigue strength was studied under repeated tensile loading. Vickers microhardness test revealed that there existed less hardened region in the vicinity of grain boundary and surface, and that the region extends 50 to 100 μm from the surface inward. From the plot of the stress amplitude against the number of cycles to failure, it is concluded that the presence of less hardened surface layer strengthens fatigue resistance of the age hardened Al-Zn alloys containing 8 to 16mass%Zn under the repeated tensile loading.

1. INTRODUCTION

Aging phenomena of Al-Zn alloys have been studied in many works. Particularly when these alloys are aged around 273K after quenching from high temperature, many GP zones enriched in solute Zn atoms are formed, which is thought to be the cause of low temperature age-hardening.(1) GP zones, spherical in the initial stage, are sometimes grown to be several tens nm in size and become ellipsoidal in shape depending on the heat treatment condition.(2,3) It had been considered in most works that GP zones were formed homogeneously through the specimen except for the vicinity of, less than 1 μm from, the grain boundary

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(PFZ). In the beginning of eighties, however, Ohta et al.(4-6) studied the dependence of hardening on the distance from the surface and from the grain boundary in Al-Zn alloys and found inhomogeneity of the rate and the extent of age-hardening in the specimen heat-treated under a certain condition; age-hardening was less advanced in their vicinity, especially in the vicinity of surface, than in the regions distant from them. Later, Ohta et al.(7,8) gave interpretation to the phenomenon, based on the study of electrical resistivity (ρ) and X-ray small-angle scattering, that surface and grain boundary played a role of effective sinks of excess quenched vacancies and accordingly the aging in their vicinity was retarded or virtually ceased on account of the depletion of vacancies.

Ultra-super Duralmin based on Al-Zn binary system has been used as structural members of aircraft because of its strength per weight. Fatigue failure of the member is often taken to be one of the main causes of aircraft accident these days. In many cases of fatigue failure micro-cracks generated at the surface propagate into the specimen, and therefore the surface characteristics are important when it is used under repeated loading. In this paper, the effect of the less hardened surface layer on the fatigue strength of aged specimen is studied using Al-Zn alloys of various compositions.

2. EXPERIMENTAL PROCEDURES

2.1 Specimen

Specimens, Al-2, 8, 10, 12 and 16mass%Zn in nominal composition, were prepared by melting high purity materials, 99.99% aluminum and 99.999% zinc, together in a high-alumina crucible in the air and by casting. Ingots were homogenized at 723K for about 180ks in the air after peeling. They were worked to strips, 20mm in width and 1.1mm in thickness, with over ten times of alternate hot-forging and intermediate annealing at 723K for 0.9ks. Specimens for fatigue test and hardness test, whose shape and size are the same as reported previously,(9,10) were made from these strips.

2.2 Heat Treatment

Specimens were solutionized at 773K for 3.6ks by holding between aluminum blocks in an electric furnace, then furnace-cooled to 673K, held there for 3.6ks and quenched into iced water. Aging was carried out in an ethanol bath at 273K or 293K.

2.3 Fatigue Test

Aged specimens, some of which were electropolished to remove the surface layer, were attached to the repeated tensile loading apparatus of Shimazu fatigue machine (UF-15). Number of cycles to failure was measured under various tensile loads.

2.4 Hardness Test

Akashi micro-Vickers-hardness tester (MVK-E) and Akashi ultra-microhardness tester (MZT-1) were used. Hardness test was carried out at various loads from 0.001 to 9.8N to the specimen lightly electropolished and aged.

3. RESULTS AND DISCUSSION

In an ordinary hardness test grain size of the specimen is usually reduced as much as possible and special attention is not paid to the position of indentation. An example of age-hardening curves thus obtained is shown in Fig.1, when a 10%Zn alloy was aged at 293K after quenching from 673K and tested at 0.49N. Measured hardness numbers scattered rather vastly at each aging time (t_A) in this case, standard deviation being up to ± 6. Next, variation of hardness with location of indentation was taken care of and the data were classified into three groups, that is, positions (1) more than 200μm distant from, (2) about 70μm distant from, and (3) just on, the grain boundary. These aging curves of 10%Zn alloy under the same heat treatment and the same load as in Fig.1 were shown in Fig.2, where the average values and the standard deviations are written. It is noticed that the standard deviations are not so large in all these curves, and that the nearer the location to the grain boundary, the smaller the hardness becomes. Comparing Figs.1 and 2, one can regard the scat-

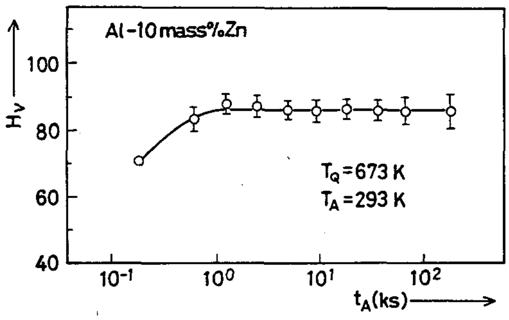


Fig.1 Age-hardening curve of the 10%Zn alloy at 293K after quenching from 673K.

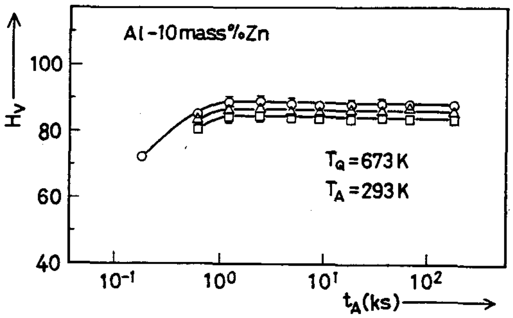


Fig.2 Position dependence of the age-hardening curve. ○ far from the grain boundary(GB), △ near the GB, □ on the GB.

tering of hardness numbers observed in Fig.1 as mainly depending on the location of penetration relative to the grain boundary.

Variation of hardness (H_V) with depth from the specimen surface was also examined. Fig.3 shows plots of hardness against the load, of the 12%Zn alloy aged at 273K for 120s after quenching from 673K, the surface of which was removed layer by layer, each 50μm in thickness, by electropolishing. For non-electropolished state (○), hardness was small at smaller loads, which suggests softness of the surface layer. With increasing thickness removed, hardness became independent of the load and increased up to 97 of H_V when 100μm thickness was removed. Particularly when the surface layer thicker than 100μm was removed, ultra-microhardness measurement using the load from 0.1 down to 0.001N showed constant hardness irrespective of the load. It is therefore considered that the thickness of less hardened surface layer was not more than 100μm and hardness in the more distant interior from the surface was constant under the present conditions of heat treatment. Thus age hardening in the Al-Zn alloys progresses inhomogeneously in the specimen, more slowly near the vacancy sinks, especially near the specimen surface.

Effect of the soft surface layer on fatigue strength was investigated. Fig.4 shows plots of stress amplitude (σ) against number of cycles to failure (N) from repeated tensile fatigue test for the specimen of 12%Zn alloy which was heat treated in the same manner as Fig.3 followed by the removal of surface layer, 0 to 100μm in thickness by electropolishing. Curves of the specimen whose surface was removed are lower as a whole than that not electropolished (○). Fatigue strength of the specimens whose thickness of removed layer was

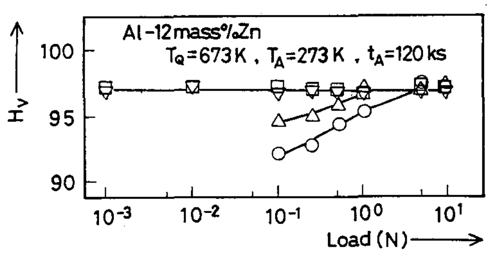


Fig.3 Hardness vs. load plot of the 12%Zn alloy aged at 273K for 120ks after quenching from 673K. Thickness of the surface layer removed by electropolishing is ○ 0μm, △ 50μm, □ 100μm, ▽ 150μm.

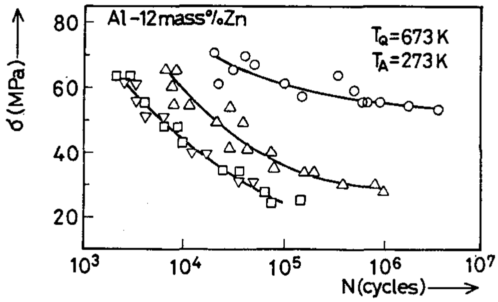


Fig.4 S-N curves of the aged 12%Zn alloy. Thickness of the surface layer removed: ○ 0μm, △ 10μm, □ 50μm, ▽ 100μm.

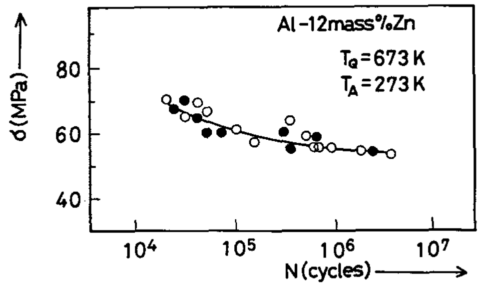


Fig.5 Effect of the surface polishing on the S-N curve of the aged 12% alloy. ○ non-electropolished, ● electropolished before aging.

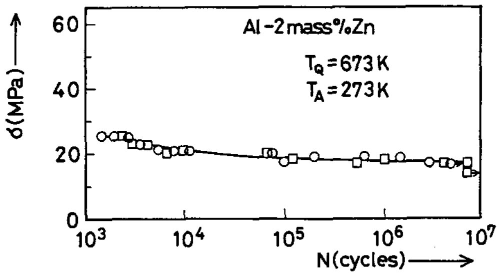


Fig.6 S-N curve of the annealed 2%Zn alloy. Thickness of the surface layer removed: ○ 0μm, □ 50μm.

50μm and 100μm coincide with each other. Together with the result in Fig.3 that the soft surface layer was less than 100μm in thickness, this suggests that the soft layer had an effect of increasing fatigue strength.

In order to examine the dependence of the fatigue strength on whether the surface was polished or not, the specimen electropolished beforehand was aged and fatigue tested. Fig.5 shows that its fatigue strength (●) was almost the same as that of the specimen non-electropolished (○), indicating no effect of polished surface. Furthermore, 2%Zn alloy heat treated in the same way as above, in which the same hardness (H_V=20) was observed both at the surface and the interior because of the absence of GP zones,(11) shows constant fatigue strength irrespective as to whether or not the surface layer was removed by electropolishing (see Fig.6).

Effect of the alloy composition was also examined. Figs.7 and 8 show the

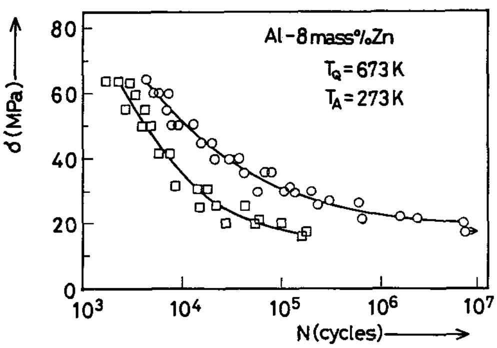


Fig.7 S-N curves of the 8%Zn alloy aged at 273K after quenching from 673K. Thickness of the surface layer removed: ○ 0μm, □ 50μm.

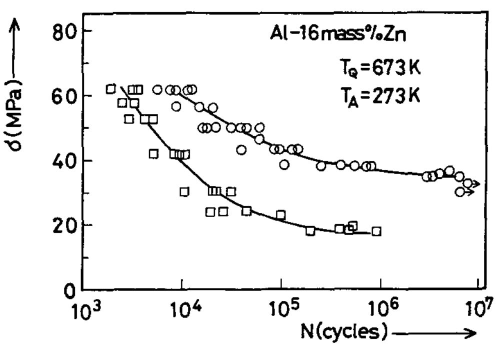


Fig.8 S-N curves of the 16%Zn alloy aged at 273K after quenching from 673K. Thickness of the surface layer removed: ○ 0μm, □ 50μm.

fatigue strength of 8% and 16%Zn alloy heat-treated as above, of which one group was aged only and the other aged and electropolished to remove surface layer 50 μm in thickness. For both alloys the latter, surface removed, clearly showed lower fatigue strength. Since thickness of the soft surface layer examined by harness test was less than 50 μm and less than 100 μm for the 8% and 16%Zn alloy, respectively, presence of the soft layer is considered to increase fatigue strength of the aged alloys of these compositions, too. A specimen of 20%Zn alloy showed the same result as these.(12)

σ-N curves of the specimens aged only, of which the surface was not removed, are collected from Figs.4, 7 and 8, and are shown in Fig.9. Fatigue strength increases with increasing solute concentration from 8 to 12%Zn, but to the contrary that of 16%Zn alloy decreases a little. SEM fractographs of fatigue failure for the 8 and 16%Zn alloy are shown in Photo 1(a) and (b), respectively. Fracture surface of the 8%Zn alloy consists mainly of intragranular fracture, while that of the 16%Zn alloy mainly of intergranular fracture. Thus lower fatigue strength of the 16%Zn alloy may be due to the brittleness of the alloy, but it is worth further investigation because the thickness of the soft layer may vary with composition.

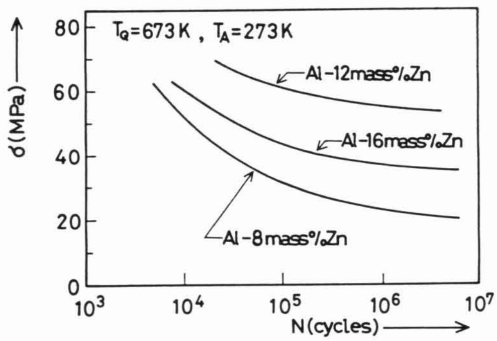
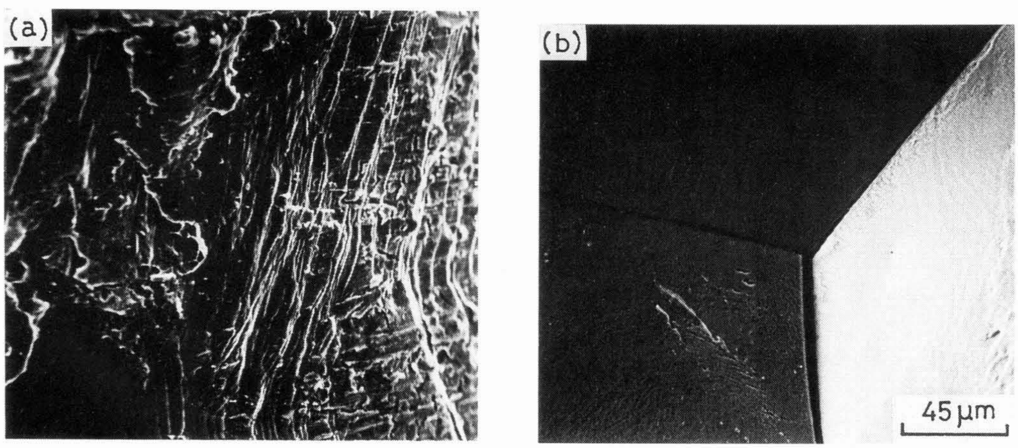


Fig.9 Variation of the S-N curves of the aged Al-Zn alloy with composition.



SEM fractographs of fatigue failure: (a) 8%Zn alloy, (b) 16%Zn alloy.

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