AGE HARDENING AND FATIGUE STRENGTH OF TWO-STEP QUENCHED Al-Zn ALLOYS

Akira SAKAKIBARA, Faculty of Engineering, Okayama University *
and Teruto KANADANI, Faculty of Engineering, Okayama University of Science **

* Tsushimanaka 3-1-1, Okayama 7008530, Japan
** Ridaicho 1-1, Okayama 7000005, Japan

ABSTRACT Aging behavior of Al-Zn alloys, containing 6 to 15mass%Zn, step-quenched, first from 673K and second from between 373 and 473K, was investigated by hardness test, resistometry and fatigue test. Difference of hardness between the region near the grain boundary and the region apart from the grain boundary was remarkable compared with that of single quenching. Thickness of the soft surface formed in the specimen aged after step quenching was larger than the one aged after single quenching, and fatigue strength of the former specimen was higher than that of the latter.

Keywords: *aluminum zinc alloy, age-hardening, two-step quench, fatigue, hardness*

1. INTRODUCTION

In Al-Zn alloy a lot of spherical GP zones several nm in diameter are formed in the initial stage of aging and are responsible to the hardening of this alloy [1]. The present authors studied in detail the effects of grain boundary and specimen surface on low temperature aging of this alloy [2]. They found that hardening did not necessarily occur homogeneously in the specimen and that depending on the heat treatment surface region was a little softer than interior region. Owing to the presence of this soft surface fatigue strength in the repeated tensile mode became higher [3].

When Al-Zn alloy specimen was aged after two-step quenching, that is, quenched from high temperature to an intermediate temperature between 373K and 473K, kept there for several tens second and quenched again to iced water, large spheroidal GP zones whose diameter came to several tens nm were found, different from the ordinary aged microstructure [4]. In this paper low temperature age hardening at each part of the specimen is examined after various two-step quenching, soft surface regions are evaluated, and fatigue property is tested.

2. EXPERIMENTAL PROCEDURES

2.1. Specimen

Alloys, Al-6, 8, 10, 11, 12 and 15mass%Zn in nominal composition, were made from 99.99%Al and 99.999%Zn by melting in a high-alumina crucible in air. Ingots, 15mm in diameter and 150mm in length, were homogenized for 180ks at 723K, hot forged and cold rolled with intermediate annealing to strips of several thicknesses, 1.1, 0.7 and 0.4mm, from which specimens for hardness test, fatigue test and resistometry were prepared, respectively. Shape and dimension of the specimens were the same as previously reported [2,3]. Grains in the specimens for hardness test were coarsened to about 4mm in diameter by strain annealing.

2.2. Heat Treatment

Quenching procedures were as follows: A specimen was inserted into the slit made in an aluminum block at 773K and kept there for 3.6ks for homogenization. Then it was furnace cooled to the quenching temperature (T_{Q1}), kept there for 3.6ks, and quenched into silicon oil at a temperature (T_{Q2}) between 373K and 473K. After keeping for a period (t_{Q2}) between 30 and 3000s at T_{Q2} it was quenched into iced water. Aging was carried out in an ethanol bath at 273 or 293K.

2.3. Measurements

Hardness was measured with Vickers hardness tester, Vickers microhardness tester and ultramicrohardness tester (MZT-1). Age hardening was followed on three groups of location; just on the grain boundary (GB), near the GB and more than 200μm apart from the GB, at 0.49 or 1.96N of indentation load. In order to investigate the variation of hardness along the depth from surface, surface layer several tens μm thick was removed layer by layer by electropolishing and after each removal hardness was measured at various indentation load between 0.01 and 9.8N on the location far apart from the GB.

Fatigue test was carried out in repeated tensile mode with various loads to obtain cycles to failure.

Electric resistance was measured by a conventional potentiometric method at 77K. Measuring temperature was calibrated by use of dummy specimen.

3. RESULTS AND DISCUSSION

Figure 1 shows variation of isothermal aging curve at 293K in resistance of the 10% alloy for T_{Q1}=673K and T_{Q2}=433K, when t_{Q2} was changed. Shape of the curve is similar to each other, showing maximum of resistance characteristic to formation and growth of GP zones. Rate of the process decreased monotonically with t_{Q2}. The maximum resistance, however, decreased at first, then increased and finally became constant as t_{Q2} increased. Figure 2 shows isothermal age hardening curves at 293K after the same step quenching as Fig.1. Indentation was made on the location more than 200μm apart from the GB. Shape of the curve was similar for all t_{Q2}, hardness increasing at first and saturating at last. The rate of change and the saturated hardness value decreased with t_{Q2}. These behaviors with t_{Q2} in resistance and hardness were obtained in common for different T_{Q1} and T_{Q2} and also for different alloy composition. These results were interpreted as

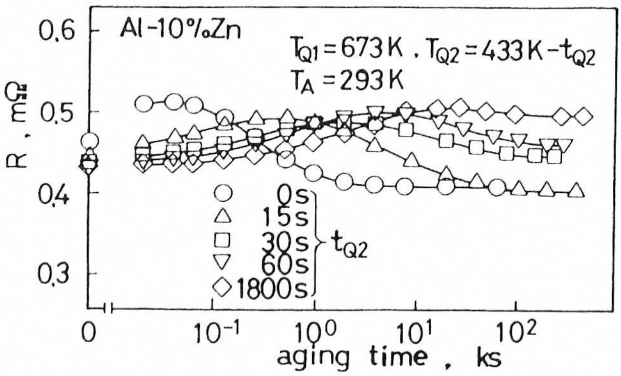


Fig.1 Variation of isothermal aging curves in resistance with t_{Q2} when the 10% alloy specimen was aged at 293K after step quenching (673K→433K × t_{Q2}→273K).

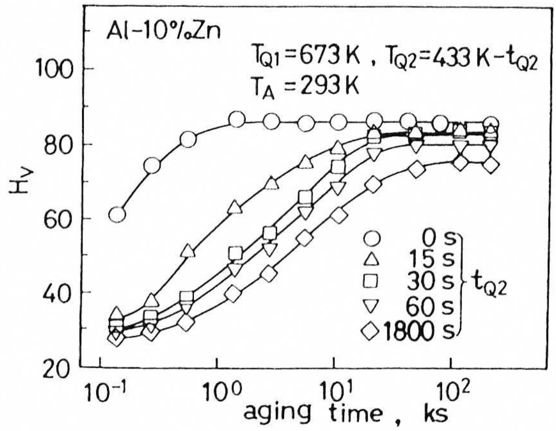


Fig.2 Variation of isothermal age hardening curves with t_{Q2} when the 10% alloy specimen was aged at 293K after step quenching

the effects of the formation of inhomogeneity of solute concentration and the decay of vacancies occurred at T_{Q2} on the low temperature aging thereafter [4].

Figure 3 shows an example of aging curves at 293K in hardness on various locations of the

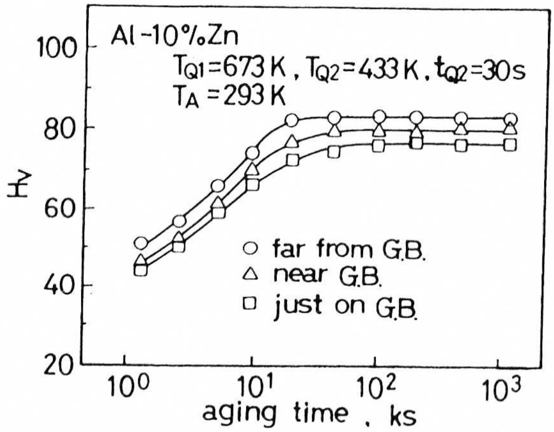


Fig.3 Location dependence of age hardening curves of the 10% alloy aged at 293K after step quenching when t_{Q2}=30s.

10% alloy when T_{Q1}=673K, T_{Q2}=433K and t_{Q2}=30s. Curves are separated clearly with the location; the nearer is the location to the GB, the lower is the hardness. This tendency has been observed in the ordinary age hardening after a direct quenching but difference in hardness between different locations is larger in this case of step quenching. This may be caused by the decay of vacancies during t_{Q2} at T_{Q2} particularly near the GB, suppressing GP zone growth in this region.

Figure 4 shows variation with t_{Q2} of fatigue strength, stress amplitude(σ) vs. cycles to failure (N), of the 10% alloy specimen aged for 180ks at 273K when T_{Q1}=673K and T_{Q2}=403K. Fatigue strengths of the specimen for t_{Q2} 30 to 300s are almost identical and are higher than that of ordinary single quenching. Microstructure of GP zones, however, was very different each other depending on t_{Q2} according to the transmission electron microscopic observation of the specimen with the same composition and under the same conditions of heat treatment as this [6]. Therefore microstructure is not considered to be responsible to that increase of fatigue strength. Figure 5 shows variation with t_{Q2} of the thickness of soft surface layer in the 10% alloy specimen aged for 180ks at 273K

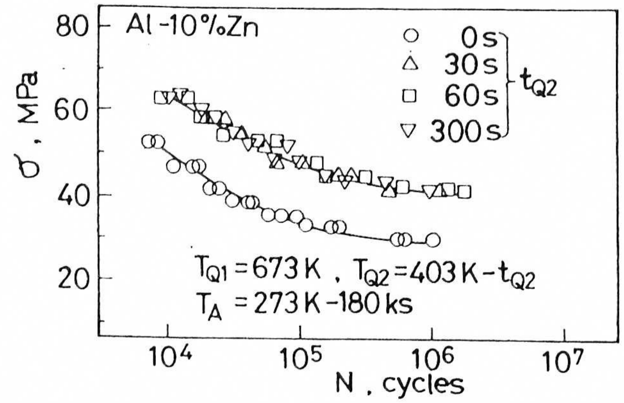


Fig.4 Stress amplitude (σ) versus number of cycles to failure (N) plots of the age hardened specimens of 10% alloy aged for 180ks at 273K when t_{Q2} was varied.

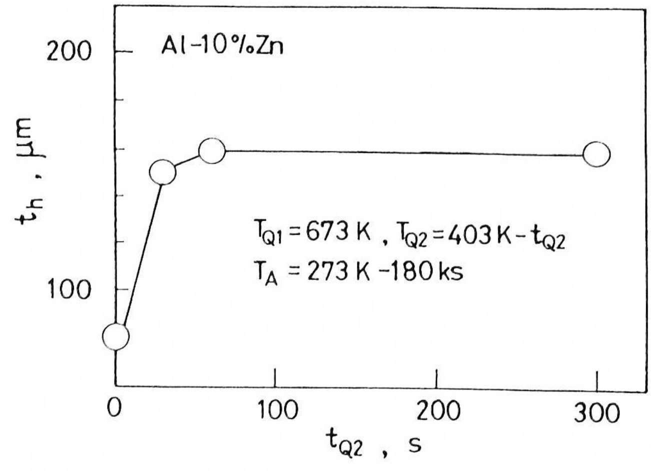


Fig.5 Dependence of thickness of the soft surface layer (t_h) on t_{Q2} for the age hardened specimens of 10% alloy.

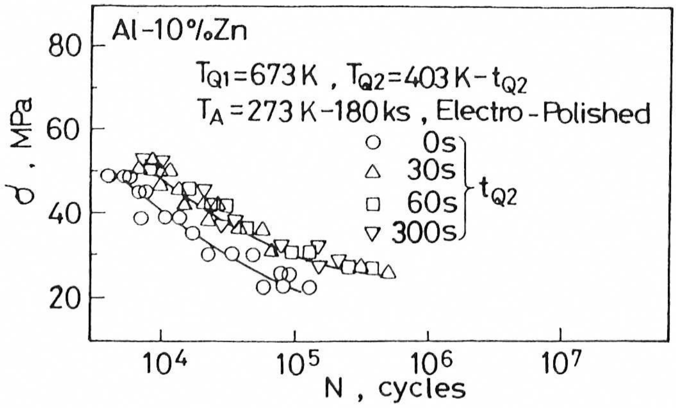
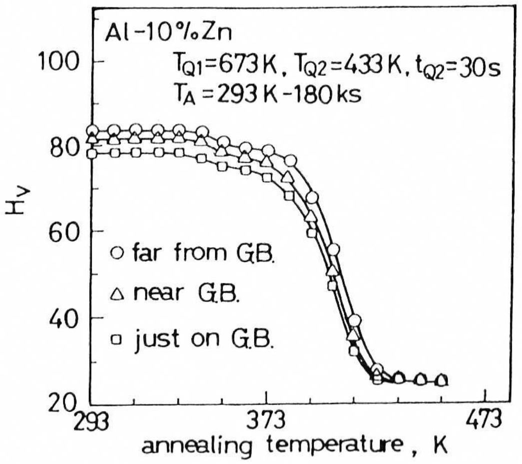


Fig.6 Stress amplitude (σ) versus number of cycles to failure (N) plots when the soft surface layer of the age hardened specimens of 10% alloy was removed by electropolishing.

when T_{Q1}=673K and T_{Q2}=403K. The thickness (t_h) in the step quenched specimens is larger than that of the ordinary single quenched one and almost identical for t_{Q2} 30 to 300s. This is well corresponding to that behavior of the fatigue strength. Figure 6 shows fatigue strength of the specimens whose soft surface layer was removed by electropolishing after the same heat treatments as in Fig.4. Fatigue strength decreases compared with that before the removal of the soft surface layer in each quenching condition and the difference between the strengths for step quenching and single quenching becomes smaller. Figures 7 and 8 show isochronal annealing curves in hardness of the specimen aged for 180ks at 293K after step quenching and ordinary single quenching, respectively, measured on various locations relative to the GB. While hardness decreases



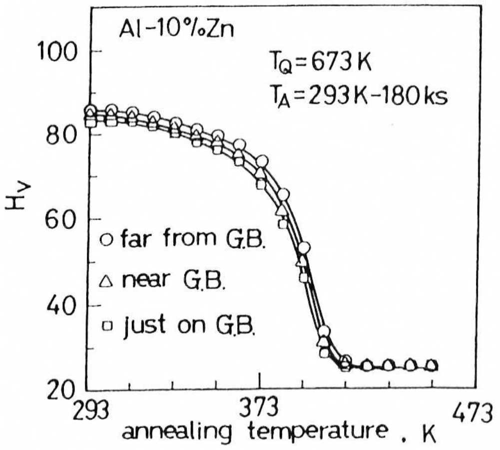


Fig.7 Variation of isochronal annealing curves of the 10% alloy specimen aged for 180ks at 293K after step quenching (673K→433K×30s →273K) with location of impression.

Fig.8 Variation of isochronal annealing curves of the 10% alloy specimen aged for 180ks at 293K after single quenching from 673K with location of impression.

continuously with increasing annealing temperature in the case of ordinary single quenching, two stage decrease of hardness is observed in the case of step quenching. This result indicates that two populations of GP zones different in the thermal stability were formed in the specimen aged after step quenching, which may be the cause of the difference in fatigue strength shown in Fig.6 and of the behavior of the maximum resistance in aging curves in Fig.1.

4. CONCLUSION

Low temperature age hardening and fatigue strength were examined for Al-Zn alloys with various composition which was aged after step quenching.

(1) Isothermal aging curves in resistance and hardness change remarkably with time of holding (t_{Q2}) at the second quenching temperature (T_{Q2}). Isochronal annealing curves show two population of GP zones formed in the specimen aged after step quenching.

(2) Age hardening in the vicinity of grain boundary on the surface is suppressed. This suppression is more noticeable for a certain range of t_{Q2} than that of the specimen aged after ordinary single quenching.

(3) Fatigue strength in the repeated tensile mode becomes higher for a certain range of t_{Q2} than that with ordinary quenching, which is thought to be caused by the thicker soft surface layer.

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