# Effect of the Surface Layer on the Fatigue Strength of an Al-3mass%Mg Alloy

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ABSTRACT Al-3mass%Mg alloy specimen which had been held at 823K for 7.2ks and aged after quenching was studied by hardness test. Surface layer about 50 $\mu$m thick was a little softer than the interior and the thickness decreased when the quenching temperature was lowered to 773K. The annealing curves in resistivity at various temperatures were not ascribed to GP zone formation but to solute clustering. These results suggest that the soft surface was not caused by the difference in microstructure but by magnesium demetallification due to oxide formation. Fatigue strength of the specimen with the soft surface layer was higher than that without soft surface layer.

Keywords: *aluminum magnesium alloy, clustering, fatigue strength, surface, demetallification*

## 1. INTRODUCTION

Al-Mg alloys are vastly used as wrought aluminum alloy because of their solution and work hardenability, good weldability, corrosion resistance, etc., in spite of the difficulty in hot work due to the grain boundary cracking at temperatures between about 473K and 673K. Precipitation hardening is clearly recognized for the alloys containing high Mg, but for the alloy containing Mg less than about 7% it has hardly been recognized under the conventional heat treatment conditions. Partly for this reason precipitation process of Al-Mg alloys has not been studied much. It was previously considered that β'($Al_3Mg_2$) phase alone formed before stable β($Al_3Mg_2$) phase finally precipitated, but according to the recent work GP zone formation has been found [1,2]. The present authors found anomalous increase of electrical resistivity at temperatures higher than the solvus of GP zone and suggested the existence of some kind of Mg cluster [3].

The present authors studied in detail the low temperature age hardening at various positions of the Al-Zn and Al-Cu specimens which are to be hardened by GP zones. The results showed that regions near the surface were a little softer than the interior of the specimen even after a long aging [4,5]. And the specimen with a soft surface layer had a higher fatigue strength in the repeated tensile mode[6-8].

It has been known that magnesium is oxidized on the surface and the concentration of magnesium is lowered near the surface[9]. In this paper the state of the surface of the Al-Mg specimen with about 3% Mg content kept at high temperatures around 823K and the effect of the surface condition to the fatigue strength are reported.

## 2. EXPERIMENTAL PROCEDURES

Al-3mass%Mg alloy in nominal composition were made from 99.99% aluminum and 99.99% magnesium by melting in a high-alumina crucible in air. Chemical composition of the alloy is in Table 1. Ingots were homogenized at 723K for 180h and hot-forged to plates of 5mm in thickness. These plates were cold-rolled to strips 1.1mm thick with intermediate annealings at about 623K, because this alloy apt to make double sheets if annealed at temperatures higher than 673K [10,11]. Specimens for hardness test, 50mmx10mmx0.1mm, were strain annealed for the grains to grow to about 5mm in average diameter.

Specimens were quenched from a temperature ($T_Q$) between 623K and 823K into iced water and annealed at a temperature ($T_A$) between 273K and 463K. Mg concentration on the specimen surface was controlled by use of a hot press furnace.

Table 1 Chemical composition (mass%) of the alloy

| Alloy | Mg | Cu | Si | Fe | Al |
|---|---|---|---|---|---|
| Al-3%Mg | 2.92 | 0.001 | 0.002 | 0.002 | bal |

Hardness test was conducted at room temperature using a Vickers microhardness tester and an ultramicrohardness tester (MZT-1) to estimate the formation of soft surface layer. Tensile strength and fatigue strength were measured with the specimens after various heat treatments and the ones after electropolishing to remove the soft surface layer. Tensile test was carried out using Instron type universal tester at the strain rate $10^{-3}$ $s^{-1}$. Fatigue test was carried out to obtain the number of cycles up to fracture at various stress amplitudes in the repeated tensile mode. Fracture surface and microstructure after annealing were observed by SEM and TEM, respectively. Electrical resistance was measured at 77K, calibrated with a dummy specimen, using a conventional potentiometric method.

## 3. RESULTS AND DISCUSSION

Variation with indentation load of hardness, $H_V$, of the specimen quenched into iced water after holding for 7.2ks at 823K is shown in Fig.1 by open circles. Surface layer about 10μm were removed by electropolishing slightly before the hardness test so that magnesium oxide layer formed on the surface at higher temperatures might not hinder accurate measurement. Each circle represents the average of eight values measured for a load and the standard deviation is within the mark. Hardness decreases with decreasing load less than 1N, which indicates that surface layer is a little softer than interior. On the other hand, constant hardness obtained at 1N and larger load indicates that hardness of the interior beyond some depth from the surface is constant. In order to evaluate the thickness of the surface layer which is a little softer than the interior, one side of the surface was removed layer by layer, each several tens μm thick, and hardness test was carried out after each removal. After removing the surface 20μm thick (open triangle), hardness was identical at 0.49N and larger load but lower hardness was obtained at smaller load. Further removal of the surface by 20μm gave hardness independent of the load (open square). From this result thickness of the soft surface layer was evaluated to be between 40 and 50μm. Result of the similar experiment with lower quenching temperature, 723K, is shown in Fig.2, where soft surface layer was observed but was about 20μm thick, less than that of the higher quenching temperature.

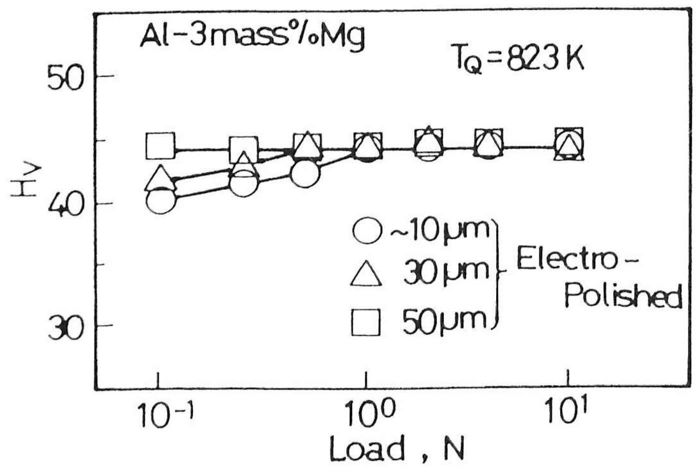


Fig.1 Variation of the dependence of $H_V$ on the load with the thickness of surface layer removed of the specimen quenched from 823K.

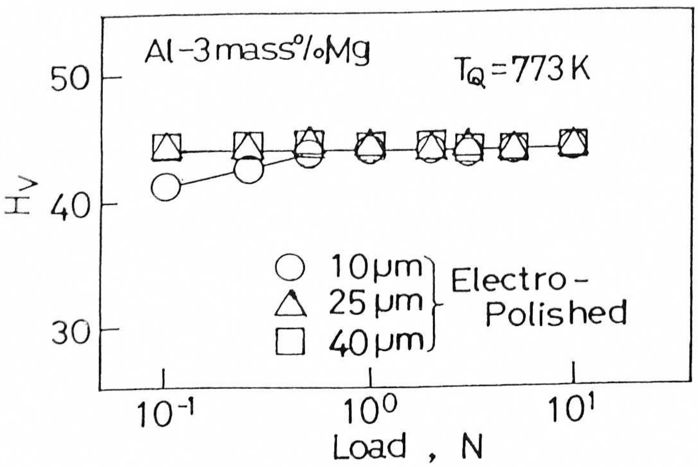


Fig.2 Variation of the dependence of $H_V$ on the load with the thickness of surface layer removed of the specimen quenched from 773K.

Figure 3 shows isothermal annealing curves in resistivity at various temperatures between 373K and 463K after quenching from 623K. Resistivity, $\rho$, changes monotonically at first with annealing time and stays constant later. This constant resistivity depends on the annealing temperature; the lower the annealing temperature the larger the resistivity. Such a tendency agrees

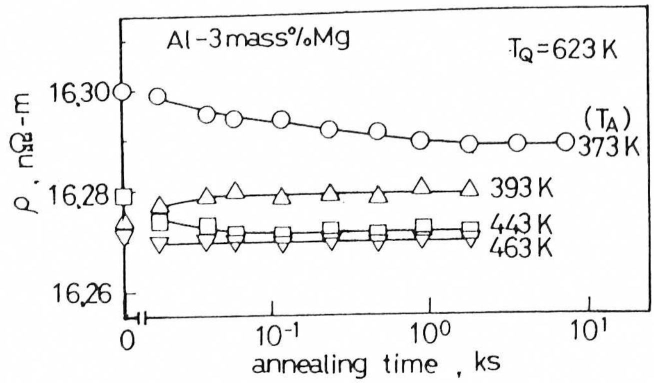


Fig.3 Variation of the isothermal annealing curve in resistivity with annealing temperature for the specimen quenched from 623K.

well with the case where small clusters of solute atoms are supposed to be formed in Al-Zn alloy *etc.* [12-14]. According to Osamura *et al.*, the solubility limit temperature of GP zone for this alloy composition is below 273K [1]. And no precipitates were observed in the transmission electron microstructure. Therefore the formation of the soft surface layer observed in Figs. 1 and 2 is considered to be due to demetallification of magnesium from the surface. Higher temperature promotes demetallification so that the soft surface layer was thicker for the higher quenching temperature (823K) than that of 723K.

In Table 2 is shown the tensile strength with various surface layer thicknesses removed by electropolishing for the specimen held for 86ks at 273K after quenching from 823K. Difference in tensile strength seems not to be large. The specimen of which the surface layer 40μm thick was removed, however, shows a little higher tensile strength, which may be caused by the complete removal of soft surface layer.

Table 2 Dependence of tensile strength on the thickness of the layer removed from the surface of the specimen annealed for 86ks at 273K after quenching from 823K.

| thickness removed (μm) | tensile strength |
|---|---|
| 0 | 171±4 |
| 10 | 169±3 |
| 40 | 175±3 |

Dependence of fatigue strength on the presence of soft surface layer was investigated. In Fig.4 plots of stress amplitude, σ, against number of cycles to fracture (N) are shown for the specimen as-annealed for 86ks at 273K (open circles) and the one whose soft surface layer was removed after the same annealing (open triangle). The σ-N curve of the specimen with soft surface layer is higher as a whole than that of the specimen without it, having a higher fatigue strength.

Figure 5 shows the dependence of fatigue strength on the presence of the surface layer when the quenching temperature was lowered to 623K. As is clearly seen in the figure, both σ-N curves, with and without the surface layer, coincide each other, showing no difference in fatigue strength. In similar experiment to that of Figs.1 and 2, existence of soft surface layer, therefore demetallification of Mg, was hardly recognized when the quenching temperature was 623K. These results indicate that the decrease of fatigue strength of the specimen whose surface layer was removed by 40μm compared with the specimen with the surface layer is not only due to removal of oxide surface but due to removal of the soft surface layer. Presence of soft surface layer makes this alloy stronger in fatigue in the repeated tensile mode as is the case in Al-Zn alloy etc. age hardened by forming GP zones.

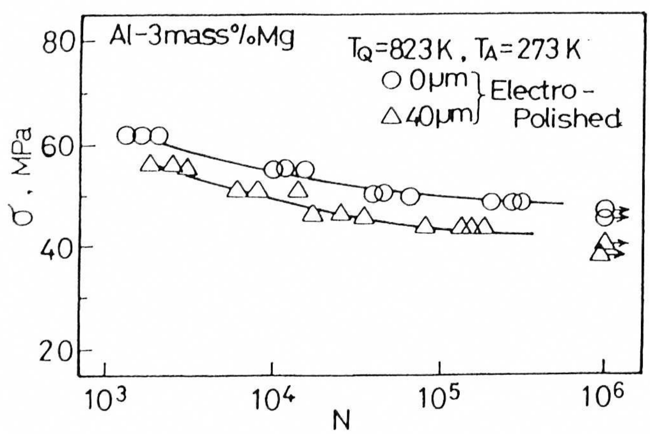


Fig.4 Variation of σ-N curve with the thickness of surface layer removed for the specimen annealed enough after quenching from 823K.

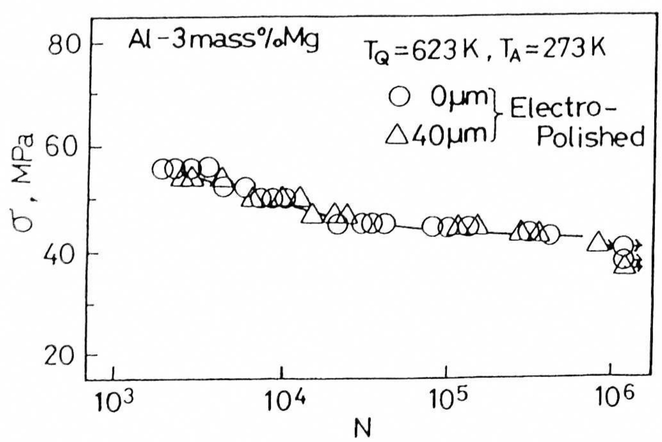


Fig.5 Variation of σ-N curve with the thickness of surface layer removed for the specimen annealed enough after quenching from 623K.

## 4 CONCLUSION

Al-3mass%Mg alloy held at temperatures as high as 823K was examined by microhardness test on the change of hardness along the depth. It has been found that surface region is a little softer than the interior region and that thickness of the soft surface layer is about 50μm. Neither GP zones nor precipitates were found in this specimen; therefore the soft surface layer is considered to be due to demetallification of Mg. Presence of this soft surface layer makes fatigue strength higher at least in the repeated tensile mode.

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