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Precipitation Hardening and Effect of Surface Layer on the Fatigue Strength of an Al-1.2mass%Si Alloy

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Dependence of precipitation hardening on the distance from specimen surface and effect of the surface layer on the fatigue strength of an Al-1.2mass%Si alloy were studied by microhardness test, transmission electron microscopy and repeated tension fatigue test. Rate of age-hardening was slower in the vicinity of surface than in the interior of the specimen aged at 423K after quenching from 853K. The result of the electron microscopy was that the size of Si precipitates formed in the vicinity of surface was smaller than that in the interior of specimen aged for 6ks at 423K. This difference was considered to be caused by the effect of the surface as vacancy sinks which slowed down the growth of Si precipitates in the vicinity of the specimen surface. A specimen surface layer whose hardness was different from that of the specimen interior was formed at the vicinity of the surface when the specimen was aged at relatively low temperature such as 423K. The fatigue strength in repeated tensile test of the specimen did not depend on whether the specimen surface layer was present or not.

1. INTRODUCTION

Al-Si alloys have superior castibility and are very often used as molding and die casting alloys. Moreover, they have superior abrasion-resistivity and heat-resistivity and are used as a forging alloy in many abrasion- resisting parts. In research on the precipitation process of Al-Si alloys, it has only been possible to precipitate stable silicon phase with diamond structure without forming GP zones, which are formed in, for example, Al-Cu and Al-Zn alloys. Previous investigations have shown that the Si precipitates form uniformly in the specimen except for the proximity to grain boundaries and dislocations(1). By the way, according to the detailed examination of the age hardening process at various regions in the specimen of Al-Zn alloys, regions near the specimen surface and near the grain boundary at the vicinity of the specimen surface remained, even after a long aging, soft compared with the other hardened regions(2),(3). The result was explained to mean that specimen surface and grain boundaries behave as sinks for quenched excess vacancies and the vacancy concentration in the vicinity of them decreases more rapidly than in the other region, which retards or virtually stops the GP zone growth in the region(4). The difference in the hardness among various regions in the specimen had a serious effect on the mechanical properties of the specimen, for example, fatigue strength(5),(6).

The objective of this research is to clarify the state of precipitation hardening and microstructures at various regions in the specimen. In addition, the relation between the surface layer of specimen and fatigue strength is researched.

2. EXPERIMENTAL PROCEDURES

2.1. Specimens

Alloy, nominal composition of which was Al-1.2mass%Si was made by melting 99.99% Al and 99.999% Si in the alumina crucible in atmosphere. Ingots obtained were homogenized by annealing at 823K for 180ks, peeled mechanically and then hot forged and cold rolled with intermediate annealing procedures to a strip of 1.1mm in thickness, a strip of 0.7mm in thickness and a strip of 0.2mm in thickness, from which were prepared the specimen for hardness test, the ones for fatigue test and the ones for electron microscopy, respectively. Shapes and dimensions of the specimens were the same as reported previously(2)~(6). Crystal grains of the specimen for hardness test were coarsened to about 5mm in diameter by the strain annealing method. The specimens whose surface layer was removed for fatigue test were prepared

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by electropolishing. Thin foils for the transmission electron microscopy were prepared by jet-electropolishing the specimens. The foils for observation at the vicinity of the specimen surface were prepared by polishing only one side and the foils for observation at the specimen interior were prepared by polishing both sides.

2.2. Heat Treatments

The sequence of quenching was as follows : The specimen was inserted into the slit of an aluminum block in an electric furnace and was held at a temperature ranging from 833K to 853K for 3.6ks for solution treatment. Then it was quenched into iced water held there for 60 seconds, and finally aged in a silicon-oil bath at various temperatures ranging from 373K to 423K. The sequence of the heat treatment is schematically shown in Fig. 1.

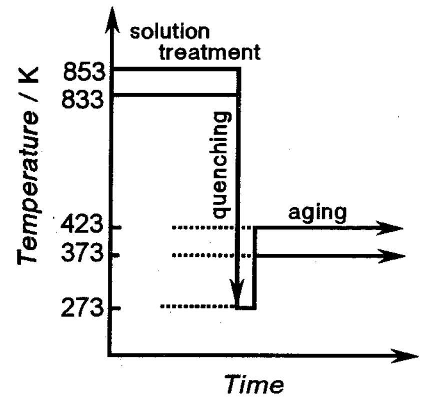

Fig. 1 Schematic diagram of the sequence of heat treatment.

2.3. Measurements

Hardness was tested at room temperature using a Vickers microhardness tester (Akashi Co. Ltd.). Age-hardening process was followed at the load of 0.25N and 1.96N, and fully aged state was examined at various penetration loads, 0.10 to 4.9N, at the position more than 200μm apart from the grain boundary.

Fatigue strength was examined by the repeated tension fatigue test at room temperature. Microstructure of the aged specimen was observed with a transmission microscope, JEM-2000EX, operated at 200kV.

3. RESULTS AND DISCUSSION

Figure 2 shows the variation along the depth from the surface of the hardness of the fully aged specimen. Open circles represent the result of the hardness test carried out at various penetration loads, 0.10 to 4.9N, of the specimen aged at 373K for 80ks after quenching from 833K. The fact that hardness decreases with increase of the load indicates that hardness at the vicinity of the specimen surface is higher than that of the specimen interior. This displays the tendency opposite to that of Al-Zn alloy. The fact that hardness reaches a stationary value above the load 2.94N indicates the uniform hardness at the specimen interior. Figure 3 shows isothermal age-hardening curves of the specimen aged at 423K after quenching from 853K. Open circles show the hardness at the vicinity of the specimen surface and triangles show the hardness at the specimen interior. Both curves initially increase with aging time and have peaks. It is considered that the hardness increased at first because the size and number of Si precipitates increased with increase of aging time, and that as the size of Si precipitates increased further and the number decreased by the competitive growth, the hardnesses decreased, i.e. over-aged. The time for the hardness to reach the maximum at the vicinity of the specimen surface is longer than that at the specimen interior. This means that the rate of age-hardening at the vicinity of the specimen surface is slower than that at the specimen interior.

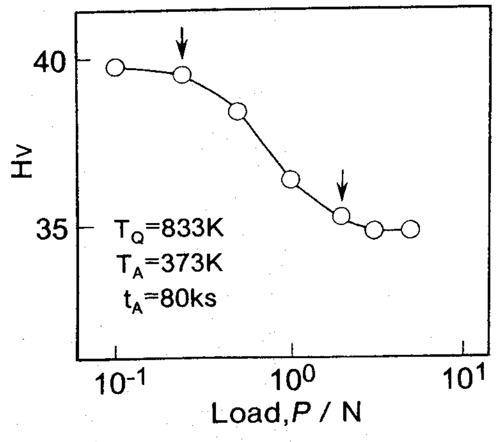

Fig. 2 Dependence of hardness on the indentation load. The specimen was aged for 80ks at 373K after quenching from 833K.

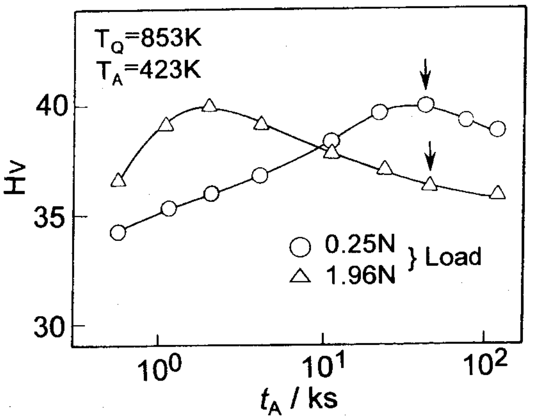

Fig. 3 Isothermal aging curves of the specimen aged at 423K after quenching from 853K by hardness test at different loads : (i) ○ 0.25N, (ii) △ 1.96N. Position of impression was far from grain boundary. Arrows correspond to the ones in Fig. 2.

Figure 4 shows the transmission electron micrograph at the vicinity of the surface and the one at the interior of the specimen aged for 6ks at 423K after quenching from 853K. The interior has many plate-like Si precipitates, the size of which varying from approximately 7 to 10nm ; however the vicinity of the surface has many Si precipitates varying from approximately 2 to 4nm in size. That is, the size of Si precipitates at the vicinity of the specimen surface is smaller than at the specimen interior. This fact agrees well with the age-hardening behavior in Fig.3, indicating that the age-hardening rate at the vicinity of the specimen surface is slower than that at the specimen interior. From the result, it is thought that also in this alloy as in Al-Zn alloy the surface acts as a vacancy sink, and that the growth of Si precipitates at the vicinity of the surface is slower than at the interior, because the vacancy concentration decreases. Figure 5 shows the relation between the surface layer and the fatigue strength for the specimen treated in the same way as in Figure 3. Open circles show the fatigue strength of the specimen aged only and closed circles show the fatigue strength of the specimen whose surface layer, approximately 10μm thick, was removed by electropolishing after the aging. These curves were almost the same, which indicates that the surface layer of the specimen of Al-Si alloy has no effect on the fatigue strength under repeated tensile loading. This may be because the degree of hardening of the surface layer of Al-Si alloy was higher only by ten percent than that of the interior, while the surface layer of the steel is much hardened by, for example, shot peening to improve fatigue property. The present result is different from that of the Al-Zn alloy(5),(6) ; the fatigue strength of the aged specimen of Al-Zn alloy whose surface layer, approximately 10μm thick, was removed by electropolishing was remarkably lower than that of the specimen as-aged.

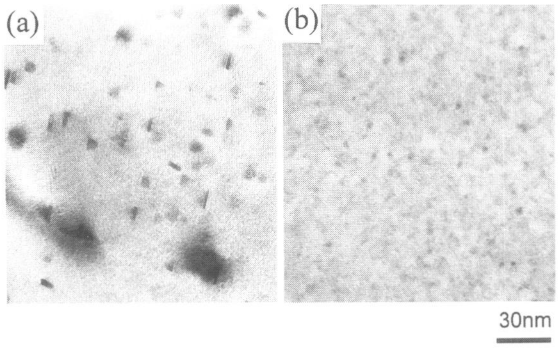

Fig. 4 Transmission electron micrographs of different position of the specimen aged for 6ks at 423K after quenching from 853K. : (a) interior (b) vicinity of surface

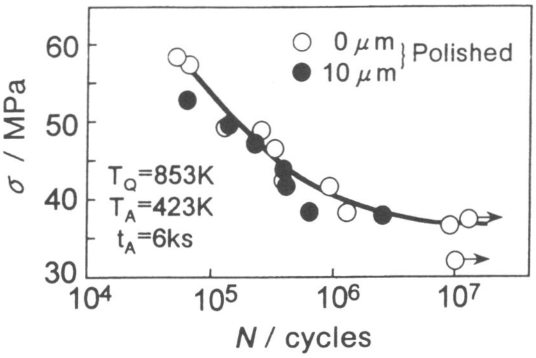

Fig. 5 Variation of σ -*N* curve with the thickness of surface layers removed. : (i) ○ no removed (ii) ● 10 μ m removed

4. ACKNOWLEDGMENT

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