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Effect of Moisture on Fatigue Crack Growth of Age-Hardened Al Alloy

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ABSTRACT: The effect of moisture on the growth behavior of a fatigue crack was investigated for an extruded bar of age-hardened Al-Zn-Mg-Cu alloy (7075-T6) in relative humidity of 25% and 85% at frequencies of 50 Hz and 6 Hz under rotating bending. Fracture in high humidity was a shear mode in short life region and a tensile one in long life region at 50 Hz, though all the fractures were a tensile one in low humidity. Fracture surface was covered with many slip planes and voids in the shear mode fracture, while a few brittle facets were observed in addition to striations in high humidity. On the other hand, at 6 Hz in high humidity, fracture occurred in the tensile mode with striations and brittle facets even in short life region. The difference in fracture mechanism depending on the fatigue life and frequency was explained from the difference in amount of hydrogen generated by the reaction of aluminum with water vapor.

Keywords: Extruded 7075-T6, Moisture, Shear mode crack, Tensile mode crack

1. INTRODUCTION

High strength Al alloys have no definite fatigue limit and their fatigue strengths are very low in comparison with their high static strengths [1]. In addition, their fatigue strength are largely influenced by ambient air, even though the humidity is mild for low and medium strength metals [2]. Therefore it is important to know the effect of humidity on fatigue properties.

In the present study, rotating bending fatigue tests were carried out in relative humidity of 25% and 85% at frequency of 50 Hz and 6 Hz for an extruded bar of age-hardened Al-Zn-Mg-Cu alloy to investigate the effect of moisture on the growth behavior of a fatigue crack.

2. MATERIAL AND EXPERIMENTAL PROCEDURE

Material used was an extruded bar of age-hardened Al-Zn-Mg-Cu alloy, 7075-T6. The chemical composition (mass %) of the alloy was 0.09 Si, 1.47 Cu, 0.25 Fe, 0.03 Mn, 2.56 Mg, 0.19 Cr, 5.46 Zn, 0.03 Zr, 0.03 Ti, and the remainder Al. The mean grain size was about 13 μm. The alloy had a marked texture of a (111) plane at the cross section of the bar. The mechanical properties were 527 MPa of 0.2% proof stress, 673 MPa of tensile strength, 712 MPa of true fracture strength and 11.3% of reduction of area, respectively.

Fatigue specimen was a smooth one with 8 mm in diameter. The observation of fatigue damage and the measurement of crack length were conducted under a scanning electron microscope (SEM) or under an optical microscope by using the plastic-replica technique. Surface crack length, ℓ, was measured in the circumferential direction of the specimen in both propagations of a tensile mode and a shear one. Fatigue tests were carried out using a rotating bending fatigue testing machine operated at 50 Hz and 6 Hz repetitions in relative humidity (RH) of 25% and 85%. The deviation of humidity was RH±5% and temperature in ambient air was not controlled but was 25±3°C.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1 shows *S-N* curves in constant humidity of 25% and 85% at 60 Hz. In the figure, typical crack morphologies at low and high stress levels are also shown. Fatigue strength was decreased by high humidity. Fatigue strength at 10^7 in 85% decreased to about 70% in comparison with that in 25%.

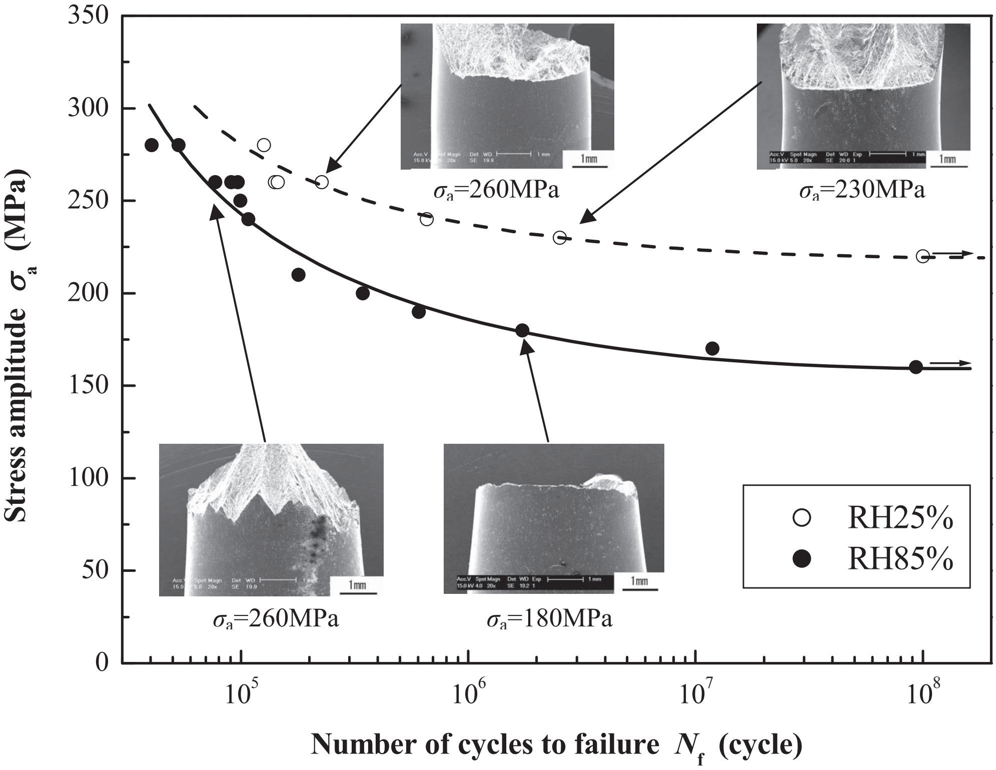
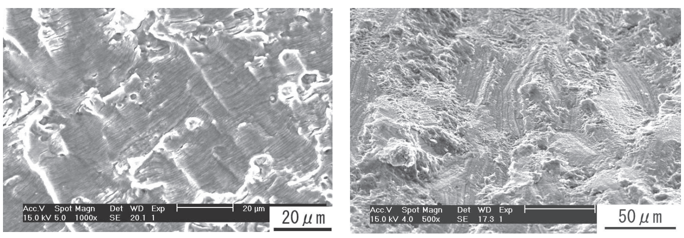
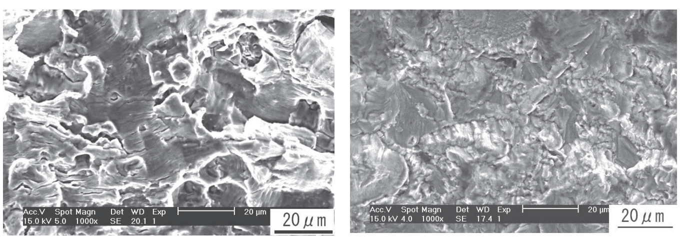


Fig. 1: *S*-*N* curves and macroscopic appearance of fracture at 50 Hz



(a) In 25%
(σ_a=240MPa, striations)

(b-1) At high stress level
(σ_a=260MPa, striations)

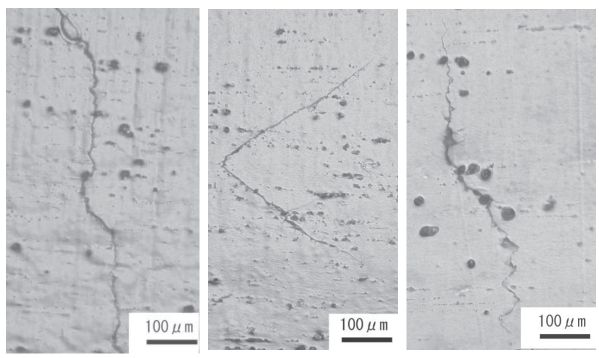


(b-2) At low stress level
(σ_a=200MPa, striations)

(b-3) At low stress level
(σ_a=180MPa, brittle facets)

(b) In 85%

Fig. 2: Fracture surfaces



(a) In 25%
(σ_a=240MPa)

(b-1) At high stress level
(σ_a=260MPa)

(b-2) At low stress level
(σ_a=200MPa)

(b) In 85%

Fig. 3: Fracture surfaces

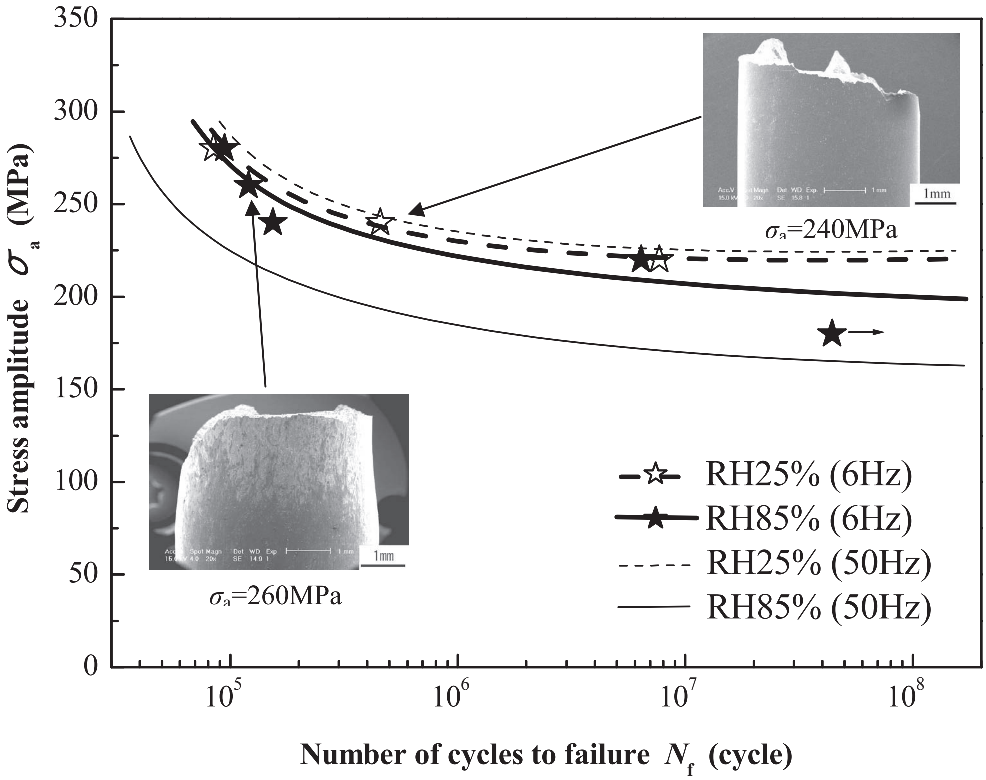


Fig. 4: *S*-*N* curves and macroscopic appearance of fracture at 6 Hz

Macroscopic appearances of fractures are a shear mode at high stress levels in high humidity, though those are a tensile mode in other conditions of humidity and stress level.

Figure 2 shows fracture surfaces yielded by the shear mode crack and the tensile one. Fracture surface was covered with many slip planes and voids in the shear mode fracture, while it was with striations in the tensile mode fracture. In addition, a few brittle facets are also observed at low stress levels in high humidity. The fracture surface yielded by the shear mode crack was a (100) plane which was confirmed by etch pit method.

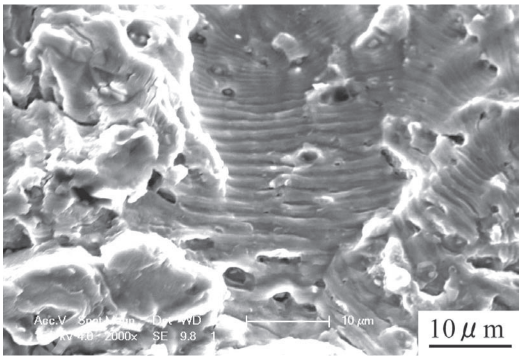
Figure 3 shows morphologies of the tensile crack mode and the shear mode one. The macroscopic growth direction of the shear mode crack is about 35° to the specimen axis and the shear mode crack is straighter than the tensile mode crack, meaning that the deformation of the shear mode crack are localized at the crack tip.

Figure 4 shows *S*-*N* curves and typical fracture morphologies at 6 Hz. In the figure, *S*-*N* curves at 50 Hz are also indicated by lines only. The tests at low frequency were carried out to investigate the effect of exposure time in high humidity. As well known, there is no or little influence of frequency on fatigue life in low humidity. While, in high humidity, fatigue life at low frequency was larger than that at high frequency in spite of decrease in crack initiation life due to longer exposure in high humidity, i.e. promotion of crack initiation by anodic dissolution. In addition, the specimen fractured in the tensile mode.

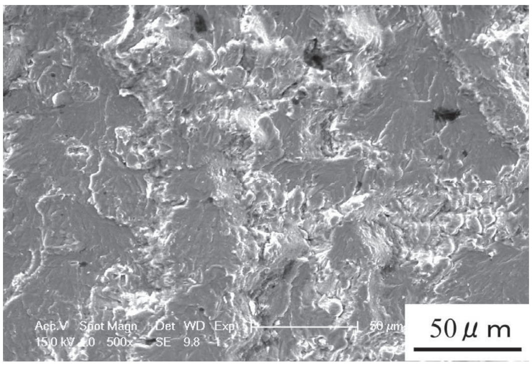
Figures 5 and 6 show morphologies of cracks and fracture surfaces in high humidity at stress level where the shear mode fracture occurred at high frequency. In case of the low frequency test, a crack propagates in a zigzag manner and a few brittle facets are observed in addition to striations at fracture surface similar to the results at low stress levels in high humidity at 50 Hz as shown in Fig.2 (b-3).

From the results mentioned above, the difference in fracture mechanism depending on fatigue life and frequency in high humidity may be explained as follows. High humidity is a sever environment more than in hydrogen gas. Moreover, in high humidity, hydrogen atoms are generated by the reaction of aluminum with water vapor [3] and diffuse into the matrix through the transportation of hydrogen atoms by dislocations [4].

Fig. 5: Crack morphology in high humidity (6 Hz, σ_a=220MPa)



(a) Striations



(b) Brittle facets

Fig. 6: Fracture surfaces in high humidity (6 Hz, σ_a=280MPa)

In short life region, ductile fracture occurred and the crack growth was accelerated in high humidity. In addition, the deformation around a crack was localized. These properties are explained by Hydrogen enhanced localized plasticity (HELP) mechanism [4]. Moreover, in the growth process, a crack propagated to the specified direction, 35° inclined to the specimen axis, because the alloy had a marked texture. That is, the growth direction of crack is corresponding to the angle composed by the fracture surface, (100) plane, and the texture, (111) plane. This is a reason for the growth of macroscopic shear mode crack. On the other hand, the tensile mode crack in long life region may be explained as follow. Fatigue life at 6 Hz was hardly decreased by high humidity, meaning that the crack growth rate was lower in high humidity than that in low humidity, because the crack initiation was accelerated by high humidity due to anodic dissolution [5], [6]. In addition, a crack propagated in the tensile mode and a zigzag manner. These results suggest that the shear mode crack to the specified direction was suppressed. Longer exposure in high humidity at low frequency may supply many hydrogen atoms. It is reported that the interaction of hydrogen atoms with dislocations has not only a strengthening effect but also a weakening effect inversely depending on the hydrogen content [4], [7]. Consequently, a crack causing by multiple slips propagates because of the suppression of slip to the one direction due to many hydrogen atoms. Moreover, the growth of a zigzag crack is suppressed by roughness induced crack closure. These may be reasons for that fracture occurred by the tensile mode and fatigue life was not reduced in high humidity at low frequency in spite of reduction of the crack initiation life.

4. CONCLUSIONS

In the present study, rotating bending fatigue tests were carried out in relative humidity of 25% and 85% and at frequencies of 50 Hz and 6 Hz for an extruded bar of age-hardened Al-Zn-Mg-Cu alloy (7075-T6) to investigate the effects of moisture and stress level on the propagation behaviour of a fatigue crack. Macroscopic appearances of fractures are a shear mode at high stress levels in high humidity at high frequency, though those are the tensile mode in other conditions of humidity, stress levels and frequency. The macroscopic growth direction of the shear mode crack was about 35° to the specimen axis and the shear mode crack in high humidity was straighter than the tensile mode crack in low humidity. In high humidity, fatigue life at low frequency was larger than that at high frequency in spite of decrease in crack initiation life due to longer exposure time in high humidity, though there is no or little influence of frequency on fatigue life in low humidity.

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