PROPAGATION BEHAVIOR OF A FATIGUE CRACK OF HIGH STRENGTH AI ALLOY

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In order to investigate the effect of humidity change on growth behavior of a fatigue crack of an extruded and age-hardened Al alloy 7075-T6, rotating bending fatigue tests were carried out using plain specimens in relative humidity of 25% and 85%. In constant humidity, a crack propagated in a tensile mode macroscopically in low humidity and in a shear mode in high humidity. The crack growth rate was accelerated by high humidity. By changing humidity, the growth rate and the growth mode of a crack were changed to those corresponding to the changed humidity. That is, cumulative fatigue life in humidity change may be estimated by the fatigue life in constant humidity.

Keywords: Fatigue; Extruded 7075-T6; Rotating bending; Humidity; Crack propagation.

1. Introduction

Application of high strength metals for materials of machines and structures are effective to reduce the environment load because of their high specific strengths. However their fatigue properties are very complex, e.g. change in fracture mechanism in long life region¹, high notch sensitivity² and so on. Moreover fatigue strength of high strength metals are largely influenced by ambient air, even though the humidity is mild for low

and medium strength metals³. Therefore it is important to know the effects of humidity and its change on fatigue properties, because the humidity usually changes.

In the present study, rotating bending fatigue tests were carried out in controlled relative humidity of 25% and 85% for an extruded bar of an age-hardened Al-Zn-Mg-Cu alloy (7075-T6) to investigate the effects of humidity and its change on the propagation behavior of a fatigue crack.

2. Material and Experimental Procedure

Material used was an age-hardened bar of an extruded Al-Zn-Mg-Cu alloy, 7075-T6. The chemical composition (mass%) of the alloy was 0.09Si, 1.47Cu, 0.25Fe, 0.03Mn, 2.56Mg, 0.19Cr, 5.46Zn, 0.03Zr, 0.03Ti, and the remainder Al. The mean grain size was about 13 μm .

The mechanical properties were 527MPa of 0.2% proof stress, 673 MPa of tensile strength, 712 MPa of true fracture strength and 11.3% of reduction of area, respectively.

Figure 1 shows shape and dimensions of specimen. Prior to fatigue testing, all of the specimens were slightly electro-polished by 40 μm to secure the direct surface observation. 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 and a shear modes. The orientation of grain was measured by Electron Back Scatter Diffraction Pattern (EBSD) method. Fatigue tests were carried out using an Ono-type rotating bending fatigue testing machine operated at 50 Hz repetition in relative humidity (RH) of 25% and 85%. The deviation of humidity was $\text{RH} \pm 5\%$ and temperature in ambient air was not controlled but was $25 \pm 5^\circ\text{C}$. The change in humidity was performed after 30min when the humidity reached to the next one.

Fig. 1. Shape and dimension of specimen.

3. Experimental Results and Discussion

3.1. Fatigue strength and propagation behavior of a fatigue crack in constant humidity

Figure 2 shows $S-N$ curves in constant humidity of 25% and 85%. 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.2. S - N curves.

Figure 3 shows crack growth curves in each humidity at the stress of $\sigma_a=260$ MPa. A crack initiated at the early stage of stress repetitions in both humidity, and the crack growth was accelerated by high humidity. That is, the decrease in fatigue strength by high humidity was mainly caused by the acceleration of the crack growth. As seen from Fig. 3(b), the crack length in high humidity is larger than that in low humidity at the same N/N_f .

(a) l - N relation. (b) l - N/N_f relation.

Fig.3. Crack growth curves at the stress of $\sigma_a=260$ MPa.

Figure 4 is photographs showing the feature of a crack and change in the crack length of the specimen observed the growth behavior shown in Fig. 3(a). A crack propagates in a tensile mode in low humidity and a shear mode in high humidity, macroscopically at this stress level. The growth direction of a shear mode crack to the extruded one (i.e. specimen axis) is nearly 35° . These differences in the crack growth mode may relate to those in the $l - N/N_f$ relation in both humidity shown in Fig. 3(b). That is, in the shear mode crack, the load may be partially supported by the crack faces under bending and the load supporting effect may increase with an increasing crack length, yielding the significant growth suppression for a longer crack. As the results, the growth life of a larger crack occupied the fatigue life. The shear mode fracture was related to the texture

of the alloy and hydrogen yielded by the reaction of water vapor and the aluminum⁴. By fractographic observation, striations were observed on the fracture surface in the tensile mode crack in 25%, while fracture surface was covered with many glide planes and voids in the shear mode crack in 85%, and there were no brittle facts which are usually observed on fracture surfaces of high strength Al alloys in high humidity⁵.

Fig.4. Feature of a crack and change in crack length.
($\sigma_a=260\text{MPa}$, $\blacktriangleleft$: crack tip, $\longleftrightarrow$: axial direction)

3.2. Effect of humidity change on fatigue strength and propagation behavior of a fatigue crack

Humidity change tests were carried out at the constant stress of $\sigma_a=260\text{ MPa}$, where the effect of humidity on the growth mode of a crack was observed obviously as stated above. Mean fatigue lives obtained by 3 specimens in each humidity of 25% and 85% were $N_f=1.71\times 10^5$ cycles and $N_f=8.81\times 10^4$ cycles, respectively.

3.2.1. In case of change from low humidity to high humidity (RH25%→RH85%)

Figure 5 shows cumulative cycle ratio $\sum N/N_f$ which is sum of the relative fatigue life of

Fig.5. Cumulative cycle ratio $\sum N/N_f$
(25%→85%, 85%→25%).

Fig.6. Crack growth curves
(25%→85%, 85%→25%).

the first and second humidity ($N_1/N_{f1} + N_2/N_{f2}$). The value of $\sum N/N_f$ is nearly unity and the value is relatively smaller than the estimated one by Fig. 3(b).

Figure 6 shows crack growth curves under humidity change. In the figure, arrow mark $\uparrow$ means the number of cycles of humidity change and the results in constant humidity are also indicated by lines only. By changing humidity, crack growth rate was immediately accelerated and changed to the growth rate in constant humidity of 85%. Figure 7 shows change in crack morphology due to humidity change. The growth mode changes from the tensile mode to the shear one by humidity change. Therefore, the load supporting effect in this case is smaller than that in constant humidity of 85%. This is main reason for that cumulative cycle ratio is smaller than that estimated by Fig. 3(b).

3.2.2. In case of change from high humidity to low humidity (RH85%→RH25%)

Cumulative cycle ratio $\sum N/N_f$ is shown in Fig. 5. The value of $\sum N/N_f$ is nearly unity and the value is relatively larger than the estimated one by Fig. 3(b).

Crack growth curves under humidity change are shown in Fig. 6. By changing humidity, crack growth rate was immediately decreased and changed to the growth rate in constant humidity of 25%.

Figure 8 shows change in crack morphology due to humidity change. The growth mode changes from the shear mode to the tensile one by humidity change. Therefore, the reason for the larger cumulative cycle ratio than unity may be explained from the

suppression of crack growth rate by the load supporting effect due to the shear mode crack in 85%.

As mentioned above, the growth rate and the growth mode of a crack change to those corresponding to the changed humidity. Therefore, the growth behavior of a crack in humidity change may be estimated by the one in constant humidity, meaning that the cumulative cycle ratio is nearly unity.

4. Conclusions

In the present study, rotating bending fatigue tests were carried out in relative humidity of 25% and 85% for an extruded bar of an age-hardened Al-Zn-Mg-Cu alloy (7075-T6) to investigate the effects of humidity and its change on the propagation behavior of a fatigue crack. Fatigue strength at 10^7 in 85% decreased to about 70% in comparison with that in 25%. The main reason for the decrease in fatigue strength was the acceleration of a crack growth by high humidity. A crack propagated in a shear mode macroscopically in high humidity at high stress levels, though the propagation of a crack was a tensile mode in low humidity. By changing humidity from low to high or reverse, both of the growth rate and the growth mode of a crack changed immediately to those corresponding to humidity after change. That is, the growth rate and the growth mode of a crack in humidity change can be evaluated from those in constant humidity.

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