Effect of loading frequency on corrosion fatigue crack growth rate of 7N01 aluminum alloy

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Abstract. The fatigue damage of engineering structures is mostly caused by cyclic stress and external environmental factors. Therefore, the study of corrosion fatigue crack propagation is of great significance to the safety and durability of structures. The effects of different loading frequencies (10Hz, 1Hz and 0.1Hz) on fatigue crack growth rate of 7N01 aluminum alloy in humid air were studied by using load control method. The results show that the corrosion fatigue crack growth rate is basically the same at 10Hz and 1Hz, When the loading frequency decreases to 0.1Hz, the corrosion fatigue crack growth rate is slightly higher than 10Hz and 1Hz.

1. Introduction

Most of the fatigue damage of engineering structures is caused by cyclic stress and external factors. Therefore, the study of corrosion fatigue crack propagation is of great significance to the safety and durability of structures.

As a major mechanical influence factor, loading frequency is also a mechanical parameter closely related to time, which has a significant impact on corrosion fatigue. The basic rule is that with the decrease of loading frequency, the crack growth rate (da/dN) have increased. Dill and Saff [1-2] studied the effect of loading frequency under the environment which is NaCl solution at 3.5% on the fatigue crack growth rate of 7075-T6, 7049-T73 aluminum alloy and 300M steel through experiments, and he found in that solution environment, load frequency will have little impact on the aluminum alloy crack propagation rate, which can be ignored, however it has a great influence on the 300 M steel, which must be considered in the process of analysis. Ryder and Pickel[3] studied the corrosion fatigue behavior of 300 M steel and found that the growth rate of fatigue crack have increased significantly with the decrease of the medium ΔK values, while the frequency had little effect at high and low ΔK values. Wei and Landes  [4] also reached a similar conclusion by testing the austenitic stainless steel 0Cr18Ni9 fatigue crack growth in 3.5%NaCl solution. Fujimoto and Gallagher [5] proposed the concept of critical frequency, holding that loading frequency would have an impact on corrosion crack growth only under a certain frequency, and proposed the frequency response function of crack growth rate while the frequency have been lower than the critical one.

Corrosion fatigue crack propagation is a complex phenomenon, and different materials/environmental systems may differ greatly. Different material/environment systems have different effects of loading frequency. The variation of corrosion fatigue crack growth rate with loading frequency of 7N01 aluminum alloy in moist air was studied in detail.
2. Test procedures

2.1. Test method

A compact tensile specimen with prefabricated cracks in Figure 1 was used to conduct the growth tests of fatigue crack under humid air conditions. Three loading frequencies, 10Hz, 1Hz and 0.1Hz, were applied. The effect of loading frequency on corrosion fatigue crack growth rate was studied. P-v curve was recorded in the test, crack length was calculated by the flexibility method, fatigue crack growth rate \( \frac{da}{dN} \) was obtained by the secant method, and the corresponding stress intensity factor \( \Delta K \) of \( \frac{da}{dN} \) was calculated, and finally the \( \frac{da}{dN}-\Delta K \) curve was obtained.

![Figure 1. Compact tensile specimen diagram.](image)

2.2. Test data processing

The crack length was determined by using the flexibility method and visual inspection method to detect whether the crack appeared bifurcation and inclination.

According to GB/T 6398-2000 <Test method for fatigue crack growth rate of metallic materials> [6], for compact tensile samples, the compliance expression is:

\[
\frac{1}{2} \frac{B}{P} \begin{bmatrix} C_0 \oplus V_x \oplus C_1 \oplus C_2 \oplus C_3 \oplus C_4 \oplus C_5 \end{bmatrix} = \begin{bmatrix} 0.0010 \oplus -4.6695 \oplus 18.460 \oplus -236.82 \oplus 1214.9 \oplus -2143.6 \end{bmatrix}
\]

Where:
- \( E \) is elastic modulus,
- \( P \) is the applied load,
- \( V_x \) is the displacement of measuring point opening,
- \( B \) is the thickness of the sample.

The relationship between crack length and flexibility can be normalized as:

\[
a / W = C_0 + C_1 U_x + C_2 U_x^2 + C_3 U_x^3 + C_4 U_x^4 + C_5 U_x^5
\]

Where: \( C_0=1.0010, C_1=-4.6695; C_2=18.460; C_3=-236.82; C_4=1214.9; C_5=-2143.6. \)

The fatigue crack growth rate \( \frac{da}{dN} \) is obtained from the \( a-N \) data obtained from the test by secant method, and its expression is:

\[
\frac{da}{dN} \frac{\Delta a}{\Delta N} = \frac{a_{i+1} - a_i}{N_{i+1} - N_i} \]

where: \( a_i \) is the crack length corresponding to cycle times \( N_i \).

The expression of stress intensity factor amplitude \( \Delta K \) at the crack tip of the compact tensile sample is:
2.3. Analysis of test results

In humid air, corrosion crack growth da/dN-ΔK curves at three loading frequencies of 10Hz, 1Hz and 0.1Hz are shown in Figure 2(a), Figure 2(b) and Figure 2(c) respectively. Under the circumstance of sinusoidal wave loading in humid air, curves under different loading frequencies (10Hz, 1Hz and 0.1Hz) are shown in Figure 2(d).

It can be seen from Figure 2.(d) that, in a humid air environment, when the loading frequency is 0.1Hz, the growth rate of fatigue crack is the fastest, and the growth rate of 1Hz and 10Hz with high loading frequency is basically the same. However, in the view of engineering application, the crack growth rate under three loading frequencies can be considered to be basically the same in humid air environment. In this way, the test cost can be greatly reduced. In other words, the crack growth curve at low frequency can be obtained from high frequency data.

Corrosion fatigue damage is controlled by mechanical damage and corrosion damage. At the beginning of the alternating stress stage, internal grain metal materials can form massive slip band, and the static load is different, slip band will not across the whole grain, can lead to more concentrated in the early years of the alternating stress plastic deformation, in this slip band metal resistance to deformation is reduced, the activity of the metal atoms increases, make the metal surface has a bigger electrochemical inhomogeneity. The formation of fatigue crack is related to the alternating stress level. The cyclic strain may lead to cyclic hardening or softening of materials. For example, if the material is relatively hard, the cyclic strain will be rearranged with high dislocation density structure, resulting in material softening, which depends on material properties, loading conditions, strain rate, etc. When the corrosive medium subjected the material to cyclic loading, the slip bands formation was accelerated, and a large number of active slip surfaces were formed at the earlytime of loading.

The fatigue crack growth rate under corrosion condition is related to loading conditions. The lower the loading frequency, the longer the opening time of crack, and the longer the acting time of crack tip and crack surface with moist air. At the same time, the plasticity of crack tip leads to crack growth. The plasticity of crack tip is a process that increases continuously at the stage when the load begins to rise until it reaches the maximum value. Many literatures indicate that the loading ascending stage is the main action stage in the corrosion fatigue process.

During the period from load to maximum load, the depolymerization of corrosive medium intensifies, thus promoting crack growth.

The strain rate of crack tip has great influence on the crack growth rate of corrosion fatigue. The lower the loading frequency, the slower the strain rate of crack tip, and the longer the time of environmental factors on crack tip. When the loading frequency is higher, the strain rate at the crack tip also increases, but when the loading frequency reaches more than 1Hz, the loading frequency increases, and the environmental factors have little influence on the crack growth rate, mainly mechanical fatigue.
Figure 2. da/dN data of 7N01 aluminum alloy under different loading frequencies in humid air.

3. Conclusion

Through the influence of different loading frequencies (10Hz, 1Hz and 0.1Hz) on the fatigue crack growth rate of 7N01 aluminum alloy in humid air environment, the study shows that the corrosion fatigue crack growth rate is basically the same in the case of 10Hz and 1Hz. When the frequency decreases to 0.1Hz, the corrosion fatigue crack growth rate is slightly higher than that of 10Hz and 1Hz.

4. Acknowledgments

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References
[1] Dill, H.D., and Saff, C.R., Spectrum Crack Growth Prediction Method Based on Crack Surface Displacement and Contact Analyses, Fatigue Crack Growth Under Spectrum Loads, ASTM STP 595, American Society for Testing and Materials, 1976, 306-319.
[2] Dill, H.D., and Saff, C.R., Effect of Fighter Attack Spectrum on Crack Growth, AFFDL-TR-76-112, March 1977.
[3] Ryder, J.T., and Pickel, F.M., Effect of Temperature on Stress Corrosion Cracking of 300M Steel, Journal of Testing and Evaluation, Vol. 6, No. 2, March 1978, 129-133.
[4] Wei, R.P., and Landes, J.D., Correlation Between Sustained-Load and Fatigue Crack Growth in High Strength Steels, Materials Research and Standards, Vol.9, No. 7, July 1969, 25-28.
[5] Fujimoto, W.T., and Gallagher, J.P., Summary of Landing Gear Initial Flaws, AFFDL-TR-77-125, Decemeber 1977.
[6] GB/T 6398-2000, Standard Test Method for Fatigue Crack Growth Rates of Metallic Materials.