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Acoustic emission study of fatigue crack closure of physical short and long cracks for aluminum alloy LY12CZ

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ABSTRACT

Crack closure of physical short and long cracks of LY12CZ aluminum alloy during fatigue process was investigated using acoustic emission (AE) technique. Results showed that the effective fatigue crack growth curve (da/dN vs. ΔK_{eff}) of physical short and long cracks obtained by the AE technique was consistent with the effective fatigue crack growth curve at high stress ratio (R = 0.8), which implied that the AE technique could measure the crack closure level, especially for physical short crack. The growth rate of physical short crack was much higher than that of long crack at the same ΔK, and the lower crack closure level of short crack was the main reason.

1. Introduction

The crack closure phenomenon is important during fatigue crack growth and it can be used to evaluate the effective driving force for crack growth. The crack closure concept, first introduced by Elber [1], has been considered important in assessing the fatigue life of structural materials under cyclic loading. During the past three decades many investigations have focused on studying the various mechanisms and the measurement methods of crack closure. When a fatigue crack grows, the two crack surfaces can contact each other during the unloading process due to a variety of mechanisms including general plastic deformation, sliding of the crack surface with respect to the other, or the collection of debris such as oxide particles [2-5]. This is so-called "crack closure". The influences of crack closure on the fatigue crack growth have been well documented [6-8]. In the past decade years, there was also some reports about which the importance of closure had been doubted. It was considered that the action of crack closure on crack growth was magnified [9-10]. But some researchers still were at work on crack closure study on mechanisms, action on crack propagation and measurements [11-13]. As to the measurement methods, many different techniques such as the crack opening displacement (COD) gauge method [14], the strain gauge method [15], the ultrasonic method [16], the potential drop method [17] and the interferometry method [18] have been established. However, these techniques frequently give inconsistent results for closure loads due to the measurement location and the data interpretation method [19]. The acoustic emission technique [20] has been used to measure the closure loads during the fatigue of Al alloys. Compared the results obtained by AE with those obtained by the conventional COD method, the back face strain (BFS) gauge method and the surface strain (SS) gauge method [21], the AE technique is considered to be a reliable method for measure crack closure.

In this paper, the AE technique was used to measure the closure level during the fatigue process of physical short and long cracks of LY12CZ alloy. Fatigue tests at high stress ratio (R = 0.8) were conducted to approve the accuracy of the measurement, then to show that the different of crack closure level induced the different growth rate of fatigue physical short and long cracks.

2. Experimental procedures

Aluminum alloy LY12CZ was used and its chemical composition (wt.%) is as follows: Cu/4.36, Mg/1.49, Mn/0.46, Fe/0.25, Si/0.14, Zn/0.07, Ti/0.01, Cr <0.01 and Al/Balance. The specimens for physical short and long crack tests were single edge notched plate specimens with 250 mm long, 36 mm wide and 2 mm thick.

A notch with 5 mm depth, 0.2 mm width and 0.1 mm root radius was wire cut perpendicular to the loading direction. The notched specimens were pre-cracked to obtain short cracks with sinusoidal waveform loading at stress ratio R of 0 and frequency of 30 Hz in air. In order to reduce the size of plastic zone at the pre-crack tip, the load was gradually decreased. When the crack propagated every 250 μm, the load would be decreased by 5%, which would ensure the length of crack growth was at least four

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Table 1
Parameters setting of AE testing

Parameter type	Hardware setup values
Threshold value	30 dB
Preamplifier	40 dB
Peak definition time (PDT)	300 μs
Hit lock time (HLT)	1000 μs
Hit definition time (HDT)	600 μs
Sample rate	5MSPS
Pre-trigger	100 μs
Hit length	2 km
Filter on board (low)	20 kHz
Filter on board (high)	2 MHz
Front end filter	No

times bigger than the size of plastic zone at the every load level. The load was repeatedly decreased till the crack growth rate reached about 10^{-7} mm/cyc. The length of pre-crack initiated from the notch root was about 3 mm. Then the crack wake was wire cut along the loading direction to remove the most length of the crack and leave a physical short crack of about 150–350 μm. The size of physical short crack was more than that of material microstructure or local plastic zone, but less than 1–2 mm length [22]. Now the samples were ready for fatigue test.

Fatigue test was carried out using an INSTRON servo-mechanical fatigue testing machine with sinusoidal load at stress ratio R of 0.1 and 0.8 and frequency of 1 Hz in ambient laboratory air (temperature:20–25 °C). The σ_{max} was 180 MPa. The crack length was measured at one side of the specimen using a traveling microscope with a magnification of 30 and accuracy of 0.01 mm.

AE measurements were performed using AE equipment (Digital Signal Process (DiSP) system) manufactured by the Physical Acoustic Corporation. Two wideband transducers (WB) at a distance of 80 mm from the crack were symmetrically mounted on both sides of the pre-crack so that AE signal from the crack could be differentiated from the grip noise. AE signals from the two transducers were amplified by preamplifiers (40 dB), and then sent to the DiSP microprocessor. The WB transducers were broadband, high-fidelity and high sensitivity. These preamplifier outputs were bandpassed filtered from 20 kHz to 2 MHz. All the signals exceeding the threshold of 30 dB were transferred to a computer which could acquire and count characteristic parameters of AE signals and analyze frequency spectrum by special software. The setting of AE parameters is listed in Table 1. The crack closure load (P_{cl}) for short and long cracks was detected during the unloading process of one fatigue cycle by AE. P_{cl} was the load at which the two crack surfaces firstly contacted during the unloading cycle. The first AE signal detected in the unloading cycle was due to the crack closure, therefore, the load related to the first AE signal was P_{cl}. For determining P_{cl} accurately, P_{cl} was measured within the continuous five unloading cycles by AE, which could assure that the measurement of P_{cl} was at the same ΔK. And AE signals were recorded in the range of 2 mm growth length for the physical short crack.

3. Results and discussion

3.1. Crack growth detected by AE

Fig. 1 shows the relationship between the crack propagation rate (da/dN) and the stress intensity factor range (ΔK) for long and physical short cracks of LY12CZ aluminum alloy at $R = 0.1$ and 1 Hz. It could be seen that the growth rates of both long and physical short cracks were linear with ΔK on logarithmic axes and physical short crack propagated much faster than long crack at the same ΔK. This indicated that the physical short crack was easier to propagate than the long crack at the same driving force.

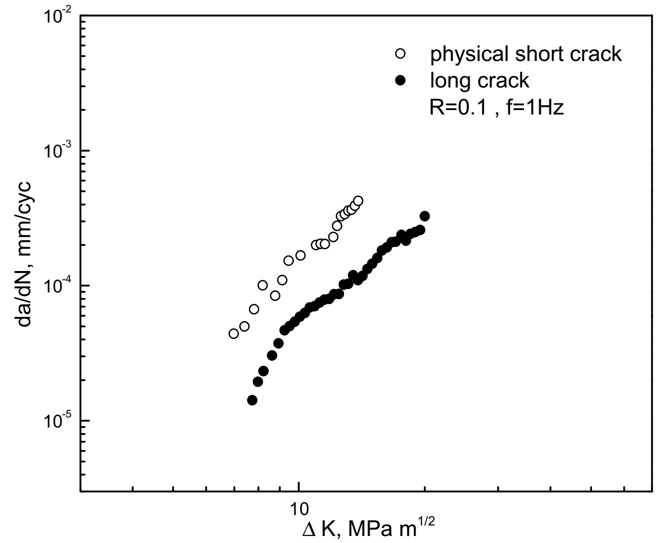

Fig. 1. The relationship of crack growth rates da/dN and ΔK of long and physical short cracks of LY12CZ aluminum alloy at $R = 0.1$ and 1 Hz.

The AE count rate(dc/dN) increased almost linearly with ΔK on logarithmic axes for both physical short and long cracks at $R = 0.1$ and 1 Hz as shown in Fig. 2. The AE count rate of the physical short crack was higher than that of the long crack, which was consistent with the crack growth rate. The relationship between da/dN and ΔK was similar to that between dc/dN and ΔK. Fig. 3 shows the relationship between da/dN and dc/dN. The AE count rate increased almost linearly with the crack growth rate on logarithmic axes for both physical short and long cracks. The results showed that AE parameters such as the AE count rate (dc/dN) could describe the law of crack growth of physical short and long cracks very well, especially when the crack was too short to detect by other methods.

3.2. Crack closure detected by AE

During unloading of a fatigue cycle, the closure load P_{cl} was the load at which the first AE event generated by the contact of the two

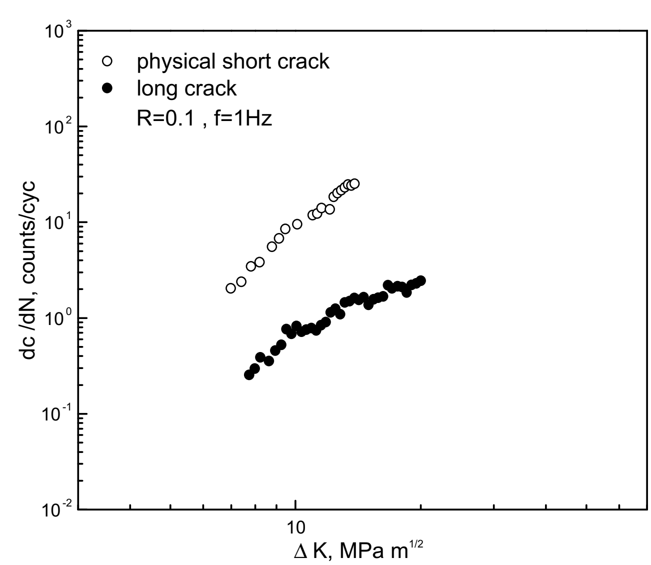

Fig. 2. The relationship of AE count rates dc/dN and ΔK of physical short and long cracks of LY12CZ aluminum alloy at $R = 0.1$ and 1 Hz.