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A statistical approach for predicting the crack retardation due to a single tensile overload

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Abstract

In this study, in order to investigate crack retardation behavior and the variability of retardation cycles, crack growth tests are conducted on 7075-T6 aluminum alloy under a single tensile overload. A retardation coefficient D is introduced herein as the ratio of the crack growth rate under constant amplitude loading and the crack growth rate after an overload. This coefficient D is separately formulated according to the retardation behavior composed of the delayed retardation part and the retardation part. To describe the variability of crack growth, the statistical crack growth equation was developed by modifying the Forman equation and adding a random variable Z to it in a previous study. By using the definition of the retardation coefficient and the statistical crack growth law, retardation cycles after an overload are predicted. The prediction by this method presents the representative retardation behavior and agrees with the experimental data. Especially, this method predicts the distribution of retardation cycles very well.

Keywords: Single tensile overload; Crack retardation; Delayed retardation part; Retardation part; Retardation coefficient; Retardation cycles; Variability

1. Introduction

Many mechanical components and structures are usually operated under variable amplitude loading rather than constant amplitude loading. Under variable amplitude loading, fatigue behavior considerably differs from that under constant amplitude loading. A tensile overload occurring in the variable amplitude loading condition retards crack growth and decreases crack growth rate, which consequently increases fatigue life. Many researchers, thus, have proposed various retardation models to describe retardation behavior and to predict fatigue life under variable amplitude loading.

Generally, retardation models have been developed on the basis of ‘crack closure’ or ‘crack-tip plasticity’. The crack closure model was first proposed by Elber [1]. He postulated that crack closure decreased the crack growth rate by reducing the effective stress intensity range. By directly measuring the opening stress from stress–displacement curves at the crack tip, he proved that the crack closure phenomenon could account for the retardation effects in crack propagation. However, measuring the opening stress under variable amplitude loading is very difficult and determining the opening stress level is not clear.

The crack-tip plasticity model is based on the assumption that crack growth retardation occurs due to the large plastic zone developed during overloading. The representative models were developed by Willenborg et al. [2] and Wheeler [3]. Willenborg et al. [2] proposed that the retardation was caused by compressive residual stresses acting on the crack tip, and computed the effective stress intensity factor being reduced by the compressive residual stress. To describe the reduction of the crack growth rate after overloading, Wheeler [3] introduced a retardation parameter, which was assumed to be a power function of the ratio of the present plastic zone size and the distance from the crack tip to the border of the overload plastic zone. These models have a signifi-

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Table 1
Mechanical properties for 7075-T6 aluminum alloy

Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
461.9	524	12.9

cant defect that the delayed retardation phenomenon cannot be predicted. In addition, if the load spectrum is changed, this retardation parameter should be newly determined by experimentation.

Lu and Li [4] newly proposed a semi-empirical model to predict the retardation behavior including the delayed retardation. They described the retardation behavior after overloading based on three parameters. These were the lowest fatigue crack growth rate, the crack growth increment at which the crack growth rate reaches its minimum, and the overload affected zone size. This model can describe the delayed retardation and present a better expression of the macro-mechanism of the retardation.

Although experiments are performed under the same loading condition, crack growth rates fluctuate remarkably. Many researchers have investigated these fluctuations. In a recent work [5], we also studied the variability of fatigue crack growth rates under constant amplitude loading and proposed a statistical crack growth model. However, studies on the variability of crack growth retardation have scarcely been reported. Thus, the purpose of this paper is to propose a statistical approach for predicting crack growth retardation. To analyze and investigate retardation behavior, a single tensile overload is applied at various crack lengths while fatigue crack growth tests are performed under constant amplitude loading. The results are predicted by a statistical method.

2. Experiment

The material used in this study was 7075-T6 aluminum alloy. The chemical composition and the mechanical properties are summarized in Tables 1 and 2, respectively. The specimen configuration was compact tension (CT) type and its width *W* was 50.8 mm. The thicknesses *B* were 1.6 and 9.8 mm. The tensile axis was parallel to the rolling direction (*L–T*).

Table 2
Chemical composition (mass %)

Designation	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Al 7075-T6	0.10	0.38	1.25	0.14	9.15	0.22	7.30	Re

Table 3
Loading condition

Thickness, *B* (mm)	1.6	9.8
Maximum load, $P_{\max}$ (kN)	0.3	1.8
Stress ratio, *R*	0	
Frequency, *f* (Hz)	5	
Wave form	Sine	

The crack growth tests were performed in air at room temperature on an MTS material test machine. All tests were performed at 5 Hz under zero-tension condition. The maximum load on each specimen was chosen so that the stress intensity factor had the same value at the same crack length in all thicknesses. The loading conditions are shown in Table 3. A single overload was applied manually when the crack length reached a_o = 24, 26, 28 and 30 mm. The overload ratio is defined as shown in Fig. 1(a).

$$\%\mathrm{OL} = \frac{P_{2\max} - P_{1\max}}{P_{1\max}} \times 100, \tag{1}$$

where $P_{2\max}$ is the maximum tensile overload and $P_{1\max}$ is the maximum constant load. The percent overload

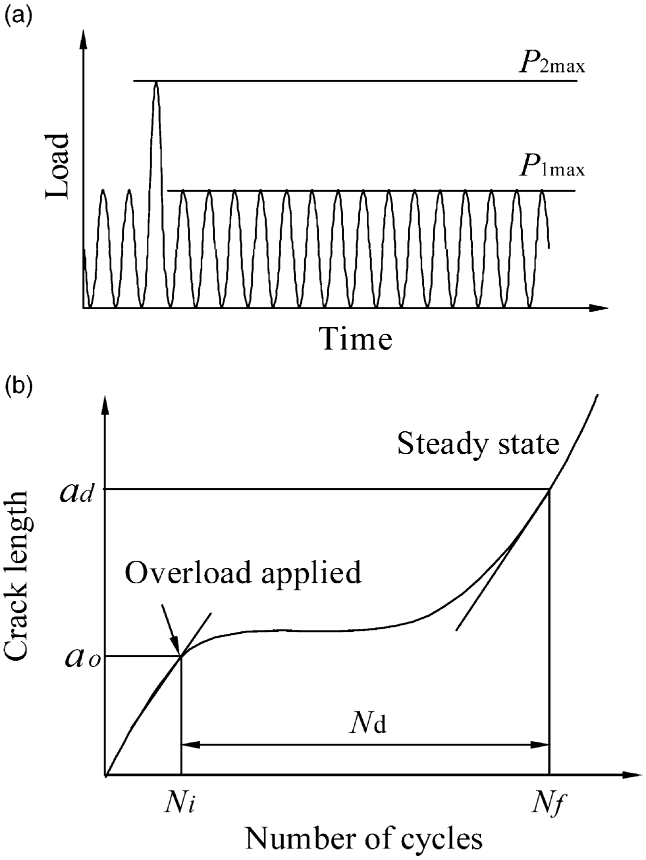

Fig. 1. Schematic illustration of crack retardation after a tensile overload.