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A Numerical Simulation of Probability Study on Fatigue Fracture of Heavy Machinery

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Abstract

The construction of heavy machinery is giant, of which the propagation process of fatigue crack is complex, there is big difference when different model of fatigue crack growth was selected in estimating its residual life. For this problem, a three stages method of assessment for crack propagation process is divided which include surface cracks, center penetrate cracks and edge through crack. and the characteristics what the stress intensity factor is changing with crack size is considered, based on probability fracture theory, the model in three stages fatigue crack growth which is used to estimate remaining life is established under constant amplitude loading. By the numerical simulations of Monte-Carlo, the survival line of 50-97% probability or P-S-N curve were obtained, also the sensitivity analysis about which the initial size of surface crack effects to the total life was given. It was shown that the time of surface crack propagation which has a closer relationship with the thickness of the plate occupies a large proportion of the total life, and the effect of the center and edge cracks can be ignored when the thickness of the plate is more than 12×10^{-3} m finally, the experience range of the stress correction factor was given. the results can be regarded as theoretical foundation for estimation of fatigue residual life under about heavy machinery in amplitude and random load.

Keywords: Heavy machinery; Fatigue fracture; Crack growth; Probability analysis; Fatigue Life; Simulation.

1. Introduction

More and more accidents and serious economic loss were caused by the fatigue fracture of heavy machinery. It is need a more accurately method to estimate the residual fatigue of metal structure, providing special inspection agencies a theoretical support at the next step after obtaining testing results (fatigue crack size). To reach this goal, the residual life was always predicted by using the method of fracture mechanics and fatigue cumulative damage

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theory, and probability modeling and reliability analysis by combining the uncertainty of loading and responding0. The fracture mechanics can more accurately estimate the fatigue life, so obtained widespread recognition, and Paris formula is also widely used in the estimate of fatigue life in heavy machineries0. But the evaluation results are always different from the experimental measurements because of that the metal structures of heavy machineries are always relatively large weldments, stress condition is difficult to measure accurately and crack extension is very complex. On one hand, it caused by the different model selections of crack extension, single crack extension model is difficult to describe the complex extension progress completely. On the other hand, it was caused by the different values of model parameters0.

2. Heavy machinery fatigue crack growth mechanism

2.1. Crack location and growth process

According to the existing crane box beam fatigue test, it can be see that there are two key positions of destructions caused by crack growth: Crack growth originated from the weld toe defects of diaphragm plate -- web, and the continuous fillet welds drawback of weld plate -- underneath cover plate0. This paper only studied the first situation. The origin and extension trajectory of crack are shown in Figure 1.

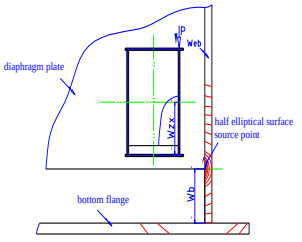

Figure 1. crack growth for the defects originate from the weld toe of diaphragm plate web

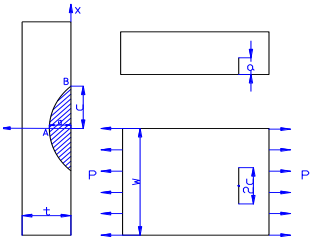

Figure 2. diagram of semi-elliptical crack in two DOF

2.2. The model of crack growth

The construction of heavy machinery is giant and the process of crack growth is complex, as the crack growth process in web, so this paper believe that web crack growth process may experience in three stages: surface cracks, center penetrate cracks and edge through cracks0.

The first stage is surface crack growth, namely growth before strike. The crack growth along two direction include depth and length, according to the two-dimensional crack model of semielliptical to carry on the analysis, and the limit of crack depth is the web thickness.

3. The theoretical foundation and calculation modal

The growth rate of initial crack $\mathrm{d}a/\mathrm{d}N$ and the stress intensity factor ΔK are the functions that related to the stress ratio R, and increased following with the decrease of R. But in the subsequent stable stage of crack extension, no matter the average stress is big or small, same stress amplitude is along with the similar stress fatigue life. So stress ratio of 0 is used to calculate in this paper.

3.1. Surface crack

When it occurs in a certain range, under constant amplitude loading, the model of fatigue crack growth with the semielliptical crack of two DOF (Figure 2) can be built by Paris – Erdogan formula.

$$\mathrm{d}a/\mathrm{d}N = C\left(\Delta K_A\right)^m \quad \Delta K_{thr} < \Delta K_A \le \Delta K_{tr} \tag{1}$$

$$\mathrm{d}c/\mathrm{d}N = C\left(\Delta K_B\right)^m \quad \Delta K_{thr} < \Delta K_B \le \Delta K_{tr} \tag{2}$$