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Statistical analysis of fatigue crack growth behavior for grade B cast steel

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Tests for fatigue crack growth rate (FCGR) and crack-tip opening displacement (CTOD) were performed to clarify the fatigue crack growth behavior of a railway grade B cast steel. The threshold values of this steel with specific survival probabilities are evaluated, in which the mean value is 8.3516 MPa m$^{1/2}$, very similar to the experimental value, about 8.7279 MPa m$^{1/2}$. Under the conditions of plane strain and small-scale yielding, the values of fracture toughness for this steel with specific survival probabilities are converted from the corresponding critical CTOD values, in which the mean value is about 138.4256 MPa m$^{1/2}$. In consideration of the inherent variability of crack growth rates, six statistical models are proposed to represent the probabilistic FCGR curves of this steel in entire crack propagation region from the viewpoints of statistical evaluation on the number of cycles at a given crack size and the crack growth rate at a given stress intensity factor range, stochastic characteristic of crack growth as well as statistical analysis of coefficient and exponent in FCGR power law equation. Based on the model adequacy checking, result shows that all models are basically in good agreement with test data. Although the probabilistic damage-tolerant design based on some models may involve a certain amount of risk in stable crack propagation region, they just accord with the fact that the dispersion degree of test data in this region is relatively smaller.

1. Introduction

Up to now, study on fatigue crack growth rate (FCGR) expressed as a function of crack-tip stress intensity factor range, da/dN versus ΔK, has been a conventional means to carry out the damage tolerance design, mostly used to assess the useful fatigue lives of key mechanical components [1]. Generally, the FCGR curve represented by the logarithmic plot of da/dN versus ΔK exhibits a sigmoidal variation. In this plot, three distinct crack propagation regions can be identified: (I) near-threshold region controlled by threshold stress intensity factor range, ΔK_{th}, (II) stable crack propagation region characterized by well-known Paris–Erdogan power law and (III) unstable crack propagation region controlled by plane-strain fracture toughness, K_c. Some developed FCGR models based on Paris–Erdogan power law, such as the Collipriest model [2], Priddle model [3], and several modified Forman models [4,5], have been proposed to describe the entire crack growth curve by taking account of the effects of ΔK_{th}, K_c and R-ratio. However, it is inevitable that a considerable amount of scatter for FCGR can be observed even under the same loading condition, especially in the regions I and III, which may be mainly attributed to the inhomogeneous material properties [6]. Furthermore, studies have proved that the dispersion degree of FCGR is significantly affected by some special factors such as the aggressive environment [7], stress ratio [8], and loading history [9], in which the dispersion degree of FCGR in region II is relatively smaller than that in regions I and III. Therefore, from the viewpoint of reliability, it is not enough to make more reliable prediction of fatigue crack growth only based on the conventional deterministic equations.

In order to overcome this difficulty, a number of probabilistic and statistical approaches have been proposed to evaluate the variability in fatigue crack growth. For instance, some evolutionary probabilistic models such as the Markov chain model [10,11], exponential model [12,13] and polynomial model [11], were developed to model fatigue crack growth. However, the intrinsic characteristics of these models are considered to be more partial to the statistical analysis of test data, lacking in physical meaning [4]. Furthermore, from the viewpoint of linear-elastic fracture mechanics (LEFM), some newly developed stochastic models [14–16] based on the assumption that the material's resistance to fatigue crack growth is regarded as s random variable, or a random process of time, or a random process of space can effectively investigate the stochastic nature in fatigue crack growth. Nevertheless, for a

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