Accepted Manuscript

Experimental and numerical evaluation of fatigue crack growth rate based on critical plastically dissipated energy

Jie Wang, Wei Jiang, Qi Wang

PII: S0142-1123(18)30516-4
DOI: https://doi.org/10.1016/j.ijfatigue.2018.09.003
Reference: JIJF 4838

To appear in: *International Journal of Fatigue*

Received Date: 6 May 2018
Revised Date: 17 August 2018
Accepted Date: 11 September 2018

Please cite this article as: Wang, J., Jiang, W., Wang, Q., Experimental and numerical evaluation of fatigue crack growth rate based on critical plastically dissipated energy, *International Journal of Fatigue* (2018), doi: https://doi.org/10.1016/j.ijfatigue.2018.09.003

Experimental and numerical evaluation of fatigue crack growth rate based on critical plastically dissipated energy

Jie Wang[1], Wei Jiang[1*], Qi Wang

1. *School of Mechanical Engineering, Dalian University of Technology, Dalian, 116024, P. R. China*

Abstract: A numerical model based on plastically dissipated energy is suitable for predicting crack growth rate in ductile metal under cyclic loading. The critical plastically dissipated energy is a material dependent constant, which are obtained through the inversion by using the numerical model and crack growth experiment of compact tension (CT) specimen. The predictions of this numerical model with crack propagation criterion based on obtained critical plastically dissipated energy are in good agreement with the results of crack propagation experiment of 304 stainless steel CT specimen. The criterion for crack propagation is in accordance with the theory of fatigue cumulative damage of material. By analyzing the influence of constitutive model of material on the accumulation of plastically dissipated energy, it was found that the ideal elastic plastic material has definite threshold load amplitude for crack propagation and the plastic hardening of materials has a great influence on the crack closure effect.

Keywords: Plastically dissipated energy, Crack growth rate, Fatigue cumulative damage, Constitutive model

1. Introduce

Fatigue is possibly one of the most common failure forms in mechanical components. In the field of fatigue life prediction, accurate description of crack growth rate has always been a great interest in the research field. In 1963, Paris[1] first proposed the fatigue crack growth expression formulated in terms of stress intensity factor. Subsequently, many scholars revised the fatigue damage accumulation model by considering the effect of mean stress which is represented by mean stress intensity factor [2-4]. However, most of these fatigue damage accumulation model involving stress intensity factors are established based on linear elastic fracture mechanics (LEFM) or the empirical formula obtained by fitting experimental data, which has a very limited scope of application. Moreover, there are still many imperfections in the theory of linear elastic fracture mechanics, such as the singularity of stress field at crack tip cannot be explained reasonably. Experimental and theoretical studies have made clear that there is obvious plastic deformation in the vicinity of crack tip within the process of crack propagation, especially for many ductile metals, for instance, aluminum alloy, low carbon steel, etc. Plastic deformation will consume a certain amount of mechanical energy, which is usually referred to as plastically dissipated energy. Plastically dissipated energy is irreversible, and it will accumulate with the plastic deformation of materials. C.E. Feltner et al. [5] point out that strain hysteresis energy can be considered as an index for fatigue damage, and a relation has been developed between stress amplitude and the number of cycles to failure which utilizes only material properties obtained from the static true stress-strain tension test. The extension of crack can also be regarded as the failure of materials at the crack tip due to the accumulation of plastic dissipation energy under cyclic loading. So far, many scholars have established a crack propagation model based on plastic dissipation energy. J. Weertman [6] first proposed the approach based on energy to fatigue crack growth. This original approach was later modified to take into account the plastic energy dissipated or deformation work at the crack tip [7-9]. Some studies suggest that the specific plastically dissipated energy is a constant and equivalent to the static energy release rate at rupture, and the plastically dissipated energy can be used as a criterion for researching fatigue crack growth rates under both constant amplitude and variable amplitude cyclic loading [10-13]. R.P. Skelton et al. [14] developed a simple expression for LEFM/EPFM crack growth on the basis of energy criteria and cumulative damage, and the process zone just ahead of the crack tip will fail when the accumulated energy density reaches a critical value after a certain number of load cycles. N.W. Klingbeil [15] proposed a new theory for predicting fatigue crack growth in ductile solids based on the accumulation of total plastic energy dissipation per cycle ahead of the crack, which unified the criterion for crack extension under monotonic and fatigue loading. The expression for fatigue crack growth rate is given explicitly in terms of the total plastic dissipation per cycle, and the total plastic dissipation is obtained by finite element analysis method. K.N. Pandey and S. Chand [16] developed a theoretical model of fatigue crack growth rate under constant amplitude loading by considering energy balance of process zone during crack growth. The process zone is the vicinity of crack tip, in which the damage of material takes place during crack propagation. J.Z. Zuo et al. [17] proposed a strain energy density crack growth model to predict the lifetime of fatigue crack growth for mixed mode cracks and established an equation for mode I crack. P.J. Huffman [18] proposed a strain energy based fatigue damage model which uses the strain energy from applied loads and the strain energy of dislocations to calculate stress-life, strain-life and fatigue crack growth rates, and the calculation results are in good agreement with the experimental results of various metals. Due to the rapid development of computer and numerical method for the solid mechanics, more and more scholars have studied the relationship between crack propagation and plastically dissipated energy through numerical method. Guoliang Ding et al. [19] simulated Paris-regime fatigue crack growth in polymers through a numerical procedure based on the assumption that crack extension is controlled by the plastically dissipated energy in

[*] Corresponding author. E-mail: jiangwei@dlut.edu.cn, Tel.: +86 15927759473