FATIGUE LIFE PREDICTIONS OF NOTCHED COMPONENTS BASED ON FINITE FRACTURE MECHANICS

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Abstract

A new fatigue criterion is proposed to assess the lifetime of notched components by developing Finite Fracture Mechanics (FFM). Wohler's curves for a plain and a notched sample are used for the calibration of the model parameters, and theoretical predictions are validated against experimental data taken from the literature.

1. Introduction

FFM is a failure criterion that assumes a discrete crack extension of amount, L by coupling the stress and energy conditions. The distance L is not only a material property but also a function of the structure. In the static framework, the FFM approach writes as follows:

$$\begin{cases} \dfrac{1}{L}\displaystyle\int_0^L \sigma dx = \sigma_u \\ \dfrac{1}{L}\displaystyle\int_0^L K_I^2 da = K_{Ic}^2 \end{cases} \tag{1}$$

The first equation consists of a stress criterion, which states that failure occurs when the (average) stress ahead of the notch tip over L achieves the critical value of the strength, namely the ultimate tensile stress σ_u. The second condition represents the energy balance: failure happens when the available energy for a discrete crack extension L reaches the critical energy release rate $\mathcal{G}_c$. In Eq. 1, this condition is rewritten in terms of the stress intensity factor (SIF) and fracture toughness K_{Ic} by means of Irwin's relationship.

The FFM generalization to the fatigue regime can be expressed as follows:

$$\begin{cases} \dfrac{1}{L}\displaystyle\int_0^L \Delta\sigma dx = \Delta\sigma_0 \\ \dfrac{1}{L}\displaystyle\int_0^L \Delta K_I^2 da = \Delta K_{th}^2 \end{cases} \tag{2}$$

where $\Delta\sigma_0$ represents the fatigue limit or the high-cycle fatigue strength of the material, and ΔK_{th} is the threshold value of the SIF range. On the other hand, as finite fatigue life lies in between static and fatigue limits, the idea for FFM extension to fatigue life estimation consists of varying the strength and the critical value of the stress intensity factor based on their cyclic behaviors. For this purpose, Basquin's equation can be used to determine the dependence on the number of cycles, using both plain and cracked or notched geometries, respectively.

2. Results

The set of experiments we use to validate the model is related to single edge notch tension (SENT) samples made by a commercial steel called EN3B. The specimens had 6 mm thickness and presented different features: a V-notch with an opening angle α= 60° and notch tip radius ρ= 0.12 mm; a hole with two different radii R= 1.75, 2 mm; a U-notch with ρ= 1.5 mm. The tests were performed under tension-compression loading (R_L=–1). The number of cycles N_f to failure corresponded to a stiffness decay of 50% with respect to the intial value.

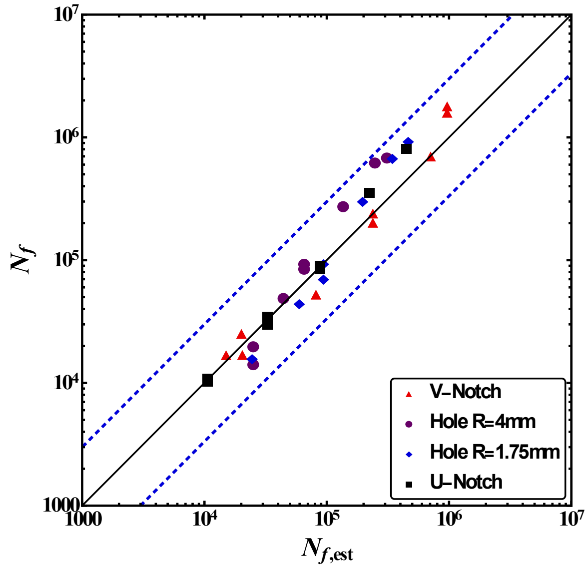

Fig.1 – Estimated fatigue lives vs experimental results.

Fig.1 illustrates the accuracy of the proposed model for the four notched geometries. As the blunt V-notch geometry is used for the calibration of free parameters, it is expected that the model has the best accuracy for this type of notch. Indeed, the model can easily predict the results for other types of features, since all FFM predictions lay in the scatter band defined by a factor three.

Conclusions

This paper investigated the accuracy of a new fatigue criterion for notched specimens based on FFM. After calibration of free parameters of the model based on Wohler's curve for a plain and a notched geometry, it was demonstrated that the approach is able to estimate finite fatigue life for different notch geometries. Results confirmed that the model works very well: its advantage is not only the simplicity. but also the high accuracy via 2D linear elastic analyses.

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