V-NOTCHED COMPONENTS UNDER TORSIONAL FATIGUE LOADING

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Abstract
Finite Fracture Mechanics (FFM) is applied to assess the brittle or quasi-brittle failure initiation at sharp V-notches under torsional loading. By assuming that failure is shear stress governed, the approach is developed in the fatigue framework. The analysis includes a discussion on the calibration of the material properties, and the comparison with experimental data available in the literature.

1. Introduction

The FFM coupled criterion [1] has been recently applied to predict the fatigue limit of mechanical components subjected to mode I loading conditions and weakened by cracks, sharp V- or U-notches [2]. In the present work, the approach is extended to assess the fatigue limit of V-notched structures subjected to torsional loading. By referring to a cylindrical geometry (Fig. 1a), FFM can be written as:

$$\begin{cases} \Delta\tau_{yz}(r = l_c) = \Delta\tau_0 \\ \int_0^{l_c} \Delta K_{III}^2(c) 2\pi(R-c)\,\mathrm{d}c = \Delta K_{III,th}^2\, \pi\left[R^2 - \left(R - l_c\right)^2\right] \end{cases} \tag{1}$$

where $\Delta\tau_0$ represents the fatigue limit or the high-cycle fatigue strength of the material under torsion loading, and $\Delta K_{III,th}$ is the threshold value of the mode III SIF range, above which propagation of long cracks occurs according to Paris' law. The FFM approach is thus described by a system of two equations: a stress requirement and the energy balance. The two unknowns are represented by the critical crack advance l_c and the fatigue limit $\Delta\tau_f$.

Introducing the asymptotic expressions for the stress field and the stress intensity factor in Eq. (1), simple analytical manipulations lead to:

$$l_c = 2\lambda_{III}^2 l_{th,III} / \pi \tag{2}$$

and

$$\frac{\Delta\tau_f}{\Delta\tau_0} = \frac{\varsigma}{k_3\,\bar{R}^{1-\lambda_{III}}} \tag{3}$$

where $\bar{R} = R / l_{th,III}$, $\varsigma(\omega) = \left(2\lambda_{III}\right)^{2(1-\lambda_{III})}$ and $\lambda_{III} = \pi / (2\pi - \omega)$. The shape function $k_3 = k_3(\omega, a/R)$ can be evalutated, for each geometry, through a simple finite element analysis [3]. The parameter $l_{th,III}$ generalizes the classical Irwin's length to mode III loading conditions in the fatigue regime..

2. Results

FFM predictions according to Eq. (3) are compared with experimental data available in the literature [4] obtained by testing V-notched bars with $\omega = 55°$ and being made of several steel categories (518 MPa $\leq$ $\sigma_{UTS} \leq$ 883 MPa). The high cycle fatigue strengths of plain and notched bars were defined at 10^7 cycles. The threshold values of the mode III SIF range were not experimentally derived. Consequently, they were estimated based on the relationship proposed in [5]. Results are presented in Fig. 1b.

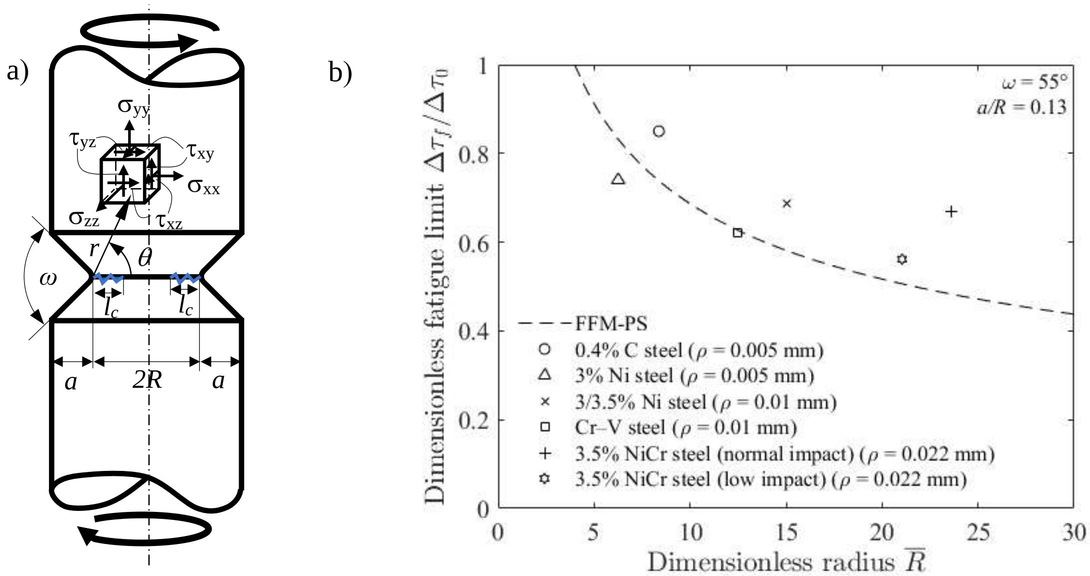

Fig. 1 – (a) V-notched bar under torsion (b) FFM predictions vs. experimental data [4].

3. Conclusions

By supposing that failure is shear-stress governed and that fracture propagates along the notch bisector plane, the FFM approach was extended to assess the fatigue limit of sharply V-notched elements under torsional loading. Theoretical predictions were compared with experimental results on cylindrical bars, confirming the soundness of the present approach.

References

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