Available online at www.sciencedirect.com
ScienceDirect
Engineering Fracture Mechanics 75 (2008) 1854–1863
Engineering Fracture Mechanics
www.elsevier.com/locate/engfracmech

Fatigue assessment using an integrated threshold curve method – applications ☆

Mirco D. Chapetti *

INTEMA – Research Institute for Material Science and Technology, CONICET – University of Mar del Plata, J.B. Justo 4302, (B7608FDQ) Mar del Plata, Argentina

Received 4 August 2006; received in revised form 1 November 2006; accepted 16 November 2006
Available online 29 December 2006

Abstract

This paper deals with the analysis and prediction of a high-cycle fatigue behaviour in notched and damaged specimens, as well as butt-welded joints by using a threshold curve for fatigue crack propagation that includes the short crack regime (a function of crack length, a). The approach regards the effective driving force applied to the crack as the difference between the total applied driving force defined by the applied stress distribution corresponding to a given geometrical and loading configuration, $\Delta K(a)$, and the threshold for crack propagation, $\Delta K_{\mathrm{th}}(a)$. Chapetti's model is used to estimate the threshold for crack propagation by using the plain fatigue limit, $\Delta\sigma_{\mathrm{e}R}$, the threshold for long cracks, $\Delta K_{\mathrm{th}R}$, and the microstructural characteristic dimension (e.g. grain size). Applications, predictions and results, in good agreement with experimental results from the literature, demonstrate the ability of the method to carry out quantitative analyses of the high cycle fatigue propagation behavior (near threshold) of short cracks in different geometrical, mechanical and microstructural configurations.

Keywords: Short cracks; Fatigue crack propagation threshold; Non-propagating cracks

1. Introduction

The problem of the fatigue strength estimation of materials or components that contain natural defects, inclusions or inhomogeneities is of great importance from both a scientific and industrial point of view. Fatigue damage is one of the major life limiting factors in most structural components subjected to variable loading during service. Hence, the containment of this damage is essential for an intelligent design and selection of materials to minimize the total life-cycle costs. Fatigue damage can be estimated by using the safe-life philosophy, i.e. by controlling fatigue damage through the use of safety factors in the structure design or by using

☆ This article appeared in its original form in *Fracture of Nano and Engineering Structures: Proceedings of the 16th European Conference of Fracture, Alexandroupolis, Greece, July 3–7, 2006* (Edited by E.E. Gdoutos, 2006). Springer, Dordrecht, The Netherlands. ISBN 1-4020-4971-4.

* Tel.: +54 2234816600; fax: +54 2234810046.
E-mail address: mchapetti@fi.mdp.edu.ar

0013-7944/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engfracmech.2006.11.005

the damage tolerant mechanism based on fracture mechanics, where a given structure should be periodically examined at specific critical locations by non-destructive inspection (NDI) methods to quantify the nature of the imperfections.

The natural tendency in the implementation of a "damage tolerant" approach to fatigue is to relate the remaining life based on the predictions of the crack propagation rate to inspectable flaw size. In low cycle fatigue (LCF), this has proved to be a suitable approach. For high cycle fatigue (HCF), the direct application of such approach cannot work for "pure" fatigue, since the required inspection sizes are well below the state of the art in non-destructive inspections (NDI). The underlying problem is that LCF involves early crack initiation and long propagation life as a fraction of total life. On the whole, LCF cracks are typically of an inspectable size early enough in total life, so that there is a considerable fraction of remaining life during which an inspection can be made. HCF, however, requires a relatively large fraction of life to initiate an inspectable size crack, which should be in the order of 1 mm, the minimum size for a crack to be considered long (a crack whose length is greater than that at which crack closure is fully developed), and for which the threshold for crack propagation in terms of ΔK is independent of crack length for a given load ratio. This results in a very small fraction of remaining life for macro-crack propagation. It can be generally observed that a component in service spends about 80% of its life-time in the region of short crack growth (crack length <1 mm) [1–12]. Consequently, further research to understand, identify, detect, and estimate HCF damage in the early stages of total fatigue life becomes of vital importance. To do so, it is necessary to deal with complex processes in the early stages of crack nucleation, initiation and early propagation, and to understand how this behaviour might be influenced by the presence of defects, stress concentrations, residual stresses, and other features related with processing and surface treatment.

This work presents examples of the application of an integrated threshold curve method that includes the short crack regime to analyze and estimate the high cycle fatigue behaviour of notched and damaged metallic components.

1.1. Threshold for short crack propagation

The effect of crack size on the fatigue crack propagation threshold of many metals can be described conveniently by means of the Kitagawa–Takahashi diagram, which relates the threshold stress with the crack size, as shown in Fig. 1a. If the strongest microstructural barrier for fatigue crack propagation is placed at a given distance d from the material surface, the crack is non-damaging with respect to the fatigue limit up to a crack size $a = d$ [1–4]. For a microstructurally small crack initiated from a smooth surface, the fatigue limit at a given stress ratio R, $\Delta\sigma_{eR}$, defines the critical nominal stress range needed for a continued crack growth (microstructural threshold). On the other hand, for long or large cracks the threshold stress for propagation is given by the threshold for a long cracks (ΔK_{thR}) and decreases with an increasing crack size [1–9]. In the physically small crack regime, which corresponds to the transition between the microstructurally small and long crack regimes, the threshold is below $\Delta\sigma_{eR}$ and the $\Delta\sigma_{th}$ is given by ΔK_{thR}.

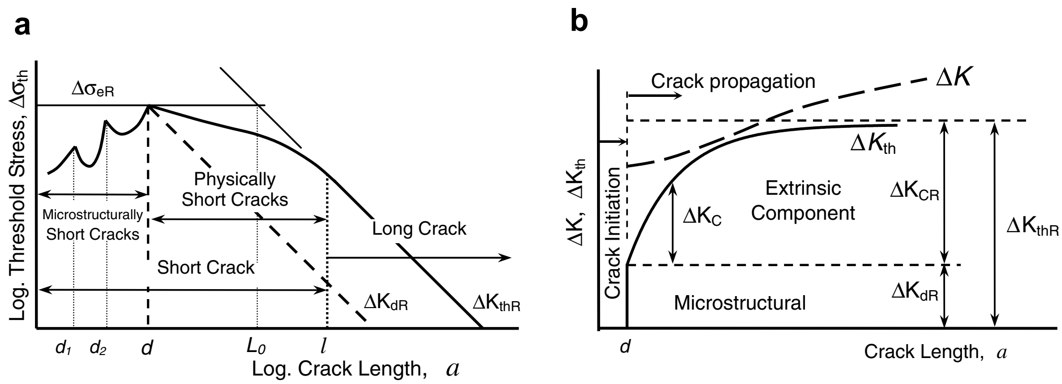

Fig. 1. Threshold curves given by: (a) expression (2) and (b) expression (1).