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Sensibility analysis of the fatigue critical distance values assessed by combining plain and notched cylindrical specimens

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Abstract

The material critical distance is often deduced from plain and notched specimens, instead of experimentally measuring the (long) crack threshold, which is a challenging task and not adequate in some cases. A dedicated V-notched specimen was proposed along with a dimensionless numerical procedure to derive the critical distance from the fatigue stress concentration factor, by implementing both the line and the point methods. An experimental validation activity is provided here on 42CrMo4+QT steel, focusing on how the critical distance result is sensitive to the actual local radius, the specimen sharpness, and the choice between the line or the point method. The determination of the critical distance with the point method systematically provides higher values than the line method. However, these length discrepancies do not produce large effects in terms of the component strength assessment if the same method for the fatigue limit evaluation is used. By alternatively considering the specimen not involved in the critical distance determination, as a potential design component, the prediction accuracy was evaluated. This analysis confirmed that a small notch radius is recommended for the fatigue strength assessment of larger radius notches or even of a crack, whereas by deducing the critical distance from a blunt notch, a noticeable inaccuracy can be found on smaller radius and crack threshold.

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Keywords: Critical distance determination; Line and point methods; 42CrMo4+QT steel; Rounded V-notched specimen; Sharp and blunt notches

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Nomenclature

ΔK_{th}	Threshold stress intensity factor, full range.
$\Delta\sigma_{fl}$	Plain specimen fatigue limit, full range.
L	Fatigue critical distance.
$\Delta\sigma_{N,fl}$	Notched specimen fatigue limit, nominal stress, full range.
K_f	Fatigue stress concentration factor.
D	Specimen external diameter.
R	Notch radius.
A	Notch depth.
ρ	R/A notch radius ratio.
α	Notch angle.
l_{min}, l_{max}	Minimum and maximum critical distance accuracy range limits.
R	Fatigue load ratio
L_{-1}, $L_{0.1}$	Experimental critical distances for the load ratios -1 and 0.1.

1. Introduction

The strength of notched components, both under fatigue loading and monotonic brittle fracture, can be evaluated with the Theory of Critical Distances (Taylor (2007), Taylor (2008)) and different methods can be formalized within the framework of this theory. Among them, the Line Method and the Point Method are the simplest and most commonly used, assuming the maximum principal stress as criterion. When multiaxial fatigue is involved, the Point method may be preferential, such as for the fretting application (Araújo et al. (2007), Bertini and Santus (2015)), while the Line method can better consider the residual stress field (Benedetti et al. (2010), Benedetti et al. (2016)).

According the its basic definition, the Critical Distance length is obtained by combining the threshold stress intensity factor full range ΔK_{th} and the plain specimen fatigue limit full range $\Delta\sigma_{fl}$:

$$L = \frac{1}{\pi}\left(\frac{\Delta K_{th}}{\Delta\sigma_{fl}}\right)^2 \quad (1)$$

However, an accurate measurement of the threshold may be a challenging experiment, moreover, the status of the material at the crack tip is different from the machined condition typical of any component notch and, for some materials, this may cause inaccuracy in terms of strength assessment. For these reasons, any sharply notched specimen can be considered as an alternative of the fracture mechanics testing to evaluate the L value (Taylor (2011)), or ultimately to obtain the threshold after Eq. 1 inversion. This approach has been emphasized by Susmel and Taylor (2010) finding both the threshold and the fracture toughness for a large variety of materials and fatigue load ratios.

The use of a sharp V-notched specimen has been recently proposed by Santus et al. (2017), providing a formulation to straightforwardly calculate the critical distance. After briefly presenting this procedure, experimental fatigue limits and thresholds are provided for 42CrMo4+QT steel under load ratios -1 and 0.1, then assessment analyses are performed and results discussed.

2. Critical distance determination

Two similar procedures were proposed by implementing both the Line and the Point methods, as summarized in Fig. 1. The analysis is expressed in dimensionless form, and a first length is analytically obtained just by assuming the singularity term solution. This length is calculated introducing the unitary N-SIF ($K_{N,UU}$) and the fatigue stress