Engineering Fracture Mechanics xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Neuber fictitious notch rounding approach reformulated for orthotropic materials

Michele Zappalorto*, Paolo Andrea Carraro

Department of Management and Engineering, University of Padova, Vicenza, Italy

ARTICLE INFO

Keywords:
Fictitious notch rounding
mode I loading
Orthotropic materials

ABSTRACT

In this short contribution, the fictitious notch rounding concept is applied to U-shaped notches in orthotropic bodies. Using the normal stress criterion, the fictitious notch radius is determined in closed form. It is found that the fictitious radius strictly depends on the actual notch radius, the microstructural support length and the elastic properties of the material, the latter playing a crucial role.

1. Introduction

Geometrical variations such as holes, notches, fillets are unavoidably present in mechanical components, reducing their static and fatigue strength. As widely debated in the previous literature, the maximum notch tip stress can be directly used (in the sake of safeness) as a strength-effective parameter only in the case of blunt notches (full notch sensitivity). Differently, reminiscent of Neuber's idea of "elementary particle", in the presence of notches with a small notch tip radius, an averaged stress value, as evaluated over a short distance close to the notch tip and normal to the notch contour, is a more appropriate parameter to be used. Such a length, referred to as microstructural length, is a material-dependent parameter [1].

In the Neuber fictitious rounding approach, the basic idea is to determine the effective notch stress without notch stress averaging, but instead, carrying out the notch stress analysis with a fictitiously enlarged notch radius $\rho_f = \rho + s\rho^*$ (Neuber [1]), where ρ is the actual notch radius, s is a factor dependent on the failure hypothesis used, and ρ^* is the microstructural support length.

Following Neuber's concept, Radaj [2,3] proposed to predict the high-cycle fatigue strength of welded joints made of structural steels and aluminium alloys based on the fictitious notch rounding approach and this proposal became a standardised procedure within the IIW design recommendations [4].

In the recent years, Neuber fictitious rounding approach was comprehensively reconsider by Berto and co-workers, showing the considerable effect exerted by the notch geometry and the loading conditions [5–14], also discussing some applications [15].

In this short contribution, the fictitious notch rounding concept is applied to U-shaped notched orthotropic bodies. Using the normal stress criterion, a new explicit expression is obtained for the fictitious notch radius ρ_f which makes it explicit the crucial role played by the elastic properties of the material.

2. Normal stress distribution due to a blunt crack in an orthotropic body under tension

Consider an orthotropic plate with a blunt crack (parabolic or U-shaped notch) under tension (see Fig. 1).

The normal stress along the notch bisector line, in the highly stressed zones, can be determined according to the following

* Corresponding author.
E-mail address: michele.zappalorto@unipd.it (M. Zappalorto).

https://doi.org/10.1016/j.engfracmech.2018.01.006
Received 20 November 2017; Accepted 12 January 2018

Please cite this article as: Zappalorto, M., Engineering Fracture Mechanics (2018), https://doi.org/10.1016/j.engfracmech.2018.01.006

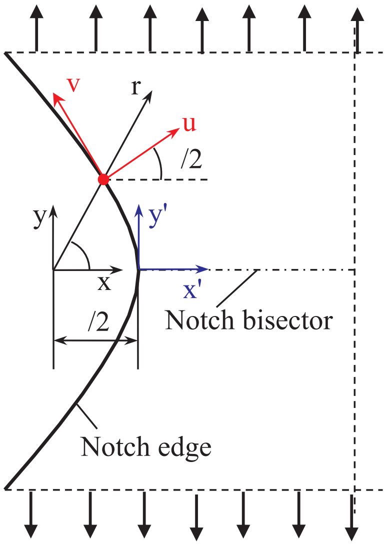

Fig. 1. Plate with a blunt crack under tension.

expression [16]:

$$\sigma_{yy} = \frac{A}{\sqrt{\rho}}\left[\frac{\beta_1}{\sqrt{2x'/\rho + \beta_2^2}} - \frac{\beta_2}{\sqrt{2x'/\rho + \beta_1^2}}\right] \tag{1}$$

where A is a constant depending on the notch geometry, the far applied tension and the material's elastic constants, x′ is the distance from the notch tip, ρ is the notch root radius and $\mu_{1,3} = \pm i\beta_1$ and $\mu_{2,4} = \pm i\beta_2$ are the conjugate roots of the following equation [17,18]:

$$T_{11}\mu^4 + (2T_{12} + T_{66})\mu^2 + T_{22} = 0 \tag{2}$$

namely:

$$\beta_{1,2} = \sqrt{\frac{2T_{12} + T_{66} \pm \sqrt{(2T_{12} + T_{66})^2 - 4T_{11}T_{22}}}{2T_{11}}} \tag{3}$$

In Eqs. (2) and (3) T_{ij} equate the terms of the compliance matrix, S_{ij}, for plane stress. In this case, invoking the engineering elastic constants:

$$S_{11} = 1/E_x \quad S_{22} = 1/E_y \quad S_{12} = -\nu_{xy}/E_x \quad S_{66} = 1/G_{xy} \tag{4a}$$

so that:

$$\beta_{1,2} = \sqrt{-\nu_{xy} + \frac{E_x}{2G_{xy}} \pm \sqrt{\left(-\nu_{xy} + \frac{E_x}{2G_{xy}}\right)^2 - \left(\frac{E_x}{E_y}\right)}} \tag{4b}$$

Different, in the case of plane strain conditions, T_{ij} equates B_{ij}, defined as [18]:

$$B_{11} = \frac{S_{11}S_{33} - S_{13}^2}{S_{33}} \quad B_{12} = \frac{S_{12}S_{33} - S_{13}S_{23}}{S_{33}}$$
$$B_{22} = \frac{S_{22}S_{33} - S_{23}^2}{S_{33}} \quad B_{66} = S_{66} \tag{5}$$

3. Exact solution for the fictitious notch radius for orthotropic materials

3.1. Complete solution

By using Eq. (1) for σ_{yy} and considering the normal stress criterion, the effective normal stress can be evaluated as the average value over the microstructural support length in front of the notch tip:

$$\sigma_{eff} = \frac{1}{\rho^*}\int_0^{\rho^*} \sigma_{yy}\,dx' = \frac{A}{\sqrt{\rho}}\frac{\rho}{\rho^*}\left[\beta_1\sqrt{\frac{2\rho^*}{\rho} + \beta_2^2} - \beta_2\sqrt{\frac{2\rho^*}{\rho} + \beta_1^2}\right] \tag{6}$$