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Some recent criteria for brittle fracture prediction under in-plane shear loading

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Abstract

Different criteria are available in the literature to assess the fracture behaviour of sharp V-notches. A typical and well-known criterion is based on the application of the notch stress intensity factors (NSIFs), which are able to quantify the intensity of the stress fields ahead of the notch tip.

This work considers two recent energy-based criteria applied here to sharp V-notches. The first criterion is based on the averaged value of the strain energy density (SED), while the second one called Finite Fracture Mechanics (FFM) criterion is available under two different formulations: that by Leguillon et al. and that by Carpinteri et al.

Considering the averaged SED criterion, a new expression for estimating the control radius R_c under pure Mode II loading is proposed and compared with the sound expression valid under pure Mode I loading. With reference to pure Mode II loading the critical NSIF at failure can be expressed as a function of the V-notch opening angle. By adopting the three criteria considered here the expressions for the NSIFs are derived and compared.

After all, the approaches are employed considering sharp V-notched brittle components under in-plane shear loading, in order to investigate the capability of each approach for the fracture assessment. With this aim a bulk of experimental data taken from the literature is used for the comparison.

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Keywords: sharp V-notch; brittle failure; in-plane shear loading; notch stress intensity factor; strain energy density.

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1. Introduction

Dealing with sharp V-notches, several fracture criteria have been proposed in the literature by many researchers. Under linear elastic hypotheses, stresses are singular at the notch tip, the stress components tending to infinity. For this reason, the introduction of a stress field parameter is surely very useful. In the Linear Elastic Notch Mechanics, notch stress intensity factors (NSIFs) are successfully employed for the fracture assessment of brittle materials when weakened by sharp V-notches (Knesl, 1991; Seweryn, 1994).

In a recent contribution (Lazzarin et al., 2014), two widely employed criteria based on energy calculations have been discussed and compared considering V-notched components under pure Mode I loading: the first one is based on the local strain energy density (SED) (Lazzarin and Zambardi, 2001) while the second one is the so-called Finite Fracture Mechanics (FFM) approach. The latter criterion is available in the literature according to two different formulations, the first initially proposed by Leguillon (2002, 2001), the second one due to Carpinteri et al. (2008).

The present contribution is aimed to extend the previous comparison to the case of in-plane shear loading (Mode II). In fact, FFM criteria have been recently extended to in-plane mixed mode and prevalent Mode II loading conditions (Sapora et al., 2014, 2013; Yosibash et al., 2006). Instead, with reference to the SED criterion, a new expression for estimating the control radius under pure Mode II loading will be proposed here and discussed in comparison with the expression valid for pure Mode I.

The local SED criterion (Lazzarin and Zambardi, 2001) is based on the strain energy density averaged over a control volume embracing the notch tip. The control volume size is a parameter dependent on the material and on the loading conditions. The advantage of the local SED approach with respect to the stress-based criteria and point-wise strain energy based criteria is the fact that it is not sensitive to the FE mesh size and it can be applied also with coarse meshes (Lazzarin et al., 2010). Moreover, a method to rapidly calculate the averaged SED for cracks under mixed mode I+II loading by adopting very coarse meshes has been recently proposed (Campagnolo et al., 2016b; Meneghetti et al., 2015): it is based on the peak stresses evaluated from FE analyses, according to the peak stress method (PSM).

In the framework of FFM, the criteria by Leguillon et al. (Leguillon, 2002; Yosibash et al., 2006) and Carpinteri et al. (Carpinteri et al., 2008; Sapora et al., 2014, 2013) require the fulfilment of two independent conditions, the former based on local stresses, the latter on an energy balance. Each condition is separately necessary but not sufficient to provoke the fracture. When both conditions are simultaneously fulfilled, a sufficient condition for fracture is achieved. The basic idea is that a finite incremental crack (or a finite crack advance) should occur at the notch tip. The criteria developed by Leguillon et al. and Carpinteri et al. are based on the same energy equilibrium imposed by considering a finite incremental crack, while the main difference is in the stress calculation: the first approach is based on a point-wise stress condition while the second one considers the stress averaged along the line of previsional crack propagation.

Dealing with mixed mode I+II loading conditions, it is very complex to provide a suitable criterion because the crack path is usually out of the notch bisector line. The critical direction varies as a function of the Mode I to Mode II stress intensity ratio in the vicinity of the notch tip. Another important reason for investigating this topic is the scarcity of experimental data available in the literature. Dealing with sharp V-notches under prevalent Mode II loading limited sets of data are available. The first available criterion applicable under mixed mode I+II loading has been proposed by Erdogan and Sih dealing with cracked plates (Erdogan and Sih, 1963). Several criteria have been also proposed for pointed V-notches and blunt notches under mixed mode I+II loading (Gómez et al., 2007; Lazzarin and Zambardi, 2001; Priel et al., 2008; Sapora et al., 2014, 2013; Yosibash et al., 2006). Different degrees of accuracy in the fracture assessment have been documented with respect to experimental data.

In the first part of the present paper the analytical frame of the three compared criteria (Lazzarin and Zambardi, 2001; Sapora et al., 2014, 2013; Yosibash et al., 2006) is introduced. The critical Mode II Notch Stress Intensity Factor is derived according to the different approaches. This allows a very easy and direct analytical comparison between the three considered approaches. After all, the criteria under consideration are applied to sharp V-notched plates subjected to in-plane shear loading, in order to investigate the capability of each approach to assess the fracture behaviour of brittle materials. The comparison considers a set of experimental data available in the literature.

An extended version of the present manuscript can be found in (Campagnolo et al., 2016a).