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An inclined surface crack subject to biaxial loading

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ABSTRACT

The elastic–plastic stress fields and mode mixity parameters for semi-elliptical surface cracks on biaxial loaded plates have been investigated using detailed three-dimensional finite element calculations. Different degrees of mode mixity are given by combinations of the far-field stress level, biaxial stress ratio and inclined crack angle. These analyses were performed for different surface flaw geometries to study the combined load biaxiality and mode mixity effects on the crack-front stress fields and the size and shape of the plastic zones. It is clear from considering the local stress distributions along the crack front that the elastic crack tip singularities have been derived for several particular cases of mixed mode biaxial loading. By theoretical analysis, the new formulae have been introduced for both the elastic and plastic mode-mixity parameters, accounting for ratios between the I/II, II/III and III/I modes. Particular attention was paid to the strong variations of the mode-mixity parameters along the semi-elliptical surface crack front. The mixed-mode behavior of the crack growth direction angle along the semi-elliptical crack front for different combinations of biaxial loading and inclination crack angles was also determined. It was done using methods based on the maximum tangential stress and the strain energy density criteria.

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1. Introduction

A literature review shows that (Dalle Donne, 1999; Aoki et al., 1987) there are two competing fracture mechanisms in a ductile material under mixed-mode loading that are operative near the sharpened and blunted site of the notch, respectively. Moreover, the mixed-mode ratio will certainly have an effect, and a transition at the site of the crack initiation may be observed with a change of the loading conditions. The dominant mechanism determines the stable crack growth direction. The principal feature of such crack growth is that the stable crack propagates either as being dominated by a tensile crack fracture mechanism in approximately the direction normal to the maximum tangential stresses, or as being dominated by a shear crack fracture mechanism in the maximum strain direction.

The mode mixity has also been proven to be an important parameter in characterizing the near tip elastic–plastic fields of 2D and 3D crack problems. Li et al. (2004) established a criterion to study the competition between the tensile fracture and the shear fracture in the frame of Ritchie–Knott–Rice (RKR) conception (Ritchie et al., 1973). Based on the generalization by Shih (1974), on the HRR-solution and on the knowledge of the mixity parameter M_P, the RKR-based criterion is transformed into a J–M_P criterion. This criterion is given as a function of the mixity parameter M_P and the strain hardening exponent n of the material. When the crack grows in accordance with the cleavage fracture mechanism in elastic solids, the mixed-mode crack behavior can be described by either the elastic stress intensity factors K_I and K_{II} or the elastic-mixity parameters M_E. Moreover, the criteria used to assess the crack growth direction angle for both tensile and shear crack must be also scaled by M_E or M_P.

All of the considered criteria are only applicable when a highly accurate evaluation of the mixity parameters M_E or M_P has been given. Therefore, it is physically more reasonable to establish mixed-mode fracture criteria on the basis of the J–M_E and J–M_P annuli. In these criteria, the elastic M_E and the plastic M_P are both governing parameters of the mixed-mode crack behavior. Even if some attempts have been made recently, there are currently no results available to provide the critical applied mixed-mode ratio characterizing the usual change in the fracture mode.

All of the above-mentioned (both analytical and numerical) analyses of the effects of the dominant fracture mechanism during mixed-mode loading have focused only on through thickness crack type (Shlyannikov, 2010). A similar investigation of inclined surface cracks in elastic–plastic solids has not been carried out. Only a few works related to 3D-analysis of fracture criteria and parameters behavior have been presented in the literature (Ayhan, 2004; English et al., 2010; Miura and Takahashi, 2010; Wang, 2006; Burdekin and Xu, 2003; Zhao et al., 2007).

Surface flaws are typical damage to different types of engineering structures. The assessment of changes in both the form and the size of the surface cracks during propagation is an essential element for the prediction of the structural integrity of biaxially

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