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Influence of bimaterial interface on kinking behaviour of a crack growth emanating from notch

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Abstract

The mechanism of crack deviation by an interface modifies considerably the behaviour of bimaterials fracture. Their fracture resistance is highly affected by the difference of the elastic properties of the bonded materials. In this work, the finite element method is applied to analyze the behaviour of a crack emanating from semicircular notch root growing in interface ceramic/metal composites and perpendicularly to this interface. The obtained results showed that the crack grew to interface from harder material, its energy decreased at the approach of the interface, in this case was retarded; an inverse phenomenon occurs if the crack is propagated towards a lower strength material and its energy increases, it has tendency to accelerate. The effects of geometry on the crack deflection near the interface are also discussed.

Keywords: Notch; Crack deviation; Interfacial crack; Bimaterial; Stress intensity factor (SIF); Energy release rate; Fracture mechanics

1. Introduction

The interface between two dissimilar solids represents a weak point for many applications of structures composed of different materials. The presence of regions with different mechanical properties and the existence of an interface between them have a pronounced influence on the stress distribution of composite bodies. The characteristics of fracture in the vicinity and through the interface are strongly influenced by the properties of the interface and of the materials on either side of the interface. Fracture usually starts at a defect in the interface, especially at an interface microcrack, or at the free edge of the interface. Another important problem is the influence of the interface on the advance throughout this. The concentration of stress due to interface defects has recently been studied extensively, and basic ideas of the fracture mechanics have been developed, but many questions still must be answered [1–6]. The propagation of cracks which approach and intersect the interfaces between dissimilar solids is a topic of considerable academic and practical interest. In the past, the most of investigations dealt with crack growth near interfaces [7–9].

When material contains macroscopic geometrical defect, its tensile strength decreases considerably. These defects constitute privileged zones where the value of the local stress can reach the tensile strength [10].

The objective of this work is to study by finite elements using FRANC 2D/L code, the effect of interaction of a crack emanating from a semicircular notch oriented perpendicularly to an interface within a ceramic/metal couple. The approach of the energy release rate is used as a fracture criterion. The effects of the elastic properties of the two constituents, the widths of two couples and the distance between the crack tip and the interface are highlighted. The propagation of a crack emanating from a notch

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situated in the interface of the material couple of different elastic properties is analyzed by an approach based on the SIF. The study is restricted to the case of an elastic behaviour of the two constituents and to a perfect junction.

2. Interaction crack interface

The characteristic oscillating stress singularity for the elastic interface crack problem was first determined by Williams [11], and solutions to specific problems were presented by England [12], Erdogan [13] and Rice and Sih [14]. The complete form of the near tip field was derived by Rice [15] following Hutchinson et al. [16] and may be written in the following form:

$$(\sigma_{yy} + i\tau_{xy})_{\varphi=0} = \frac{Kr^{i\zeta}}{\sqrt{2\pi r}} \qquad (1)$$

where K is a complex stress intensity factor with real and imaginary components k_1 and k_2, respectively, which uniquely characterizes the singular field, and r and φ are polar coordinates originating at the crack tip, as shown in Fig. 1. The bi-elastic constant ζ is defined as

$$\zeta = \frac{1}{2\pi} \ln\left[\frac{1-\beta}{1+\beta}\right] \qquad (2)$$

where β is one of the two Dundurs' parameters [17] defined by

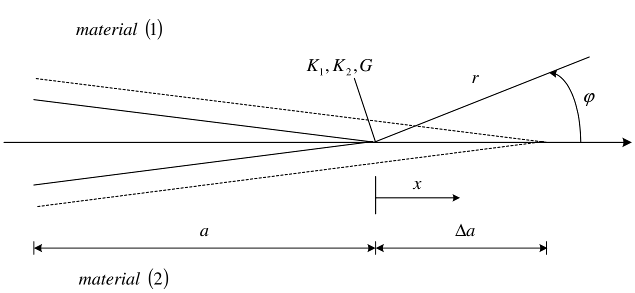

Fig. 1. Geometry of an interfacial crack of a bimaterial.

$$\alpha = \frac{G_1(\kappa_2+1) - G_2(\kappa_1+1)}{G_1(\kappa_2+1) + G_2(\kappa_1+1)} \quad \text{and}$$
$$\beta = \frac{G_1(\kappa_2-1) - G_2(\kappa_1-1)}{G_1(\kappa_2+1) + G_2(\kappa_1+1)} \qquad (3)$$

where G and v are the shear modulus (not energy release rate) and Poisson's ratio, respectively, and the subscripts denote the materials on the different sides of the interface. For a homogenous material, α and β are both zero, in which case ζ is also zero and the real and imaginary parts of the complex interface stress intensity factor become the standard definitions of the stress intensity factor: $k_1 = K_\mathrm{I}$ and $k_2 = K_2$.

The Dundurs' parameters express the difference between the elastic characteristics of bimaterial. When parameters α and β are null that means the material is homogeneous while the condition $\alpha = \pm 1$ corresponds to the presence of an infinitely rigid constituent. If the two constituents of the bimaterial are reversed, two parameters α and β change sign by preserving their absolute value.

The local representation of stress in case of a crack oriented perpendicularly in the interface of a bimaterial [18,19] has the following form:

$$\sigma_{ij} = \frac{K}{r^{1-\lambda}} f_{ij}(\varphi) \qquad (4)$$

being σ_{ij} is the stress field; K is the SIF; f_{ij} is a function depending only on the polar angle φ and λ is the power of the singularity at the crack tip which depends only on the elastic characteristics of the materials. Its value is the solution of the following characteristic equation [20]:

$$\cos \lambda\pi - \frac{2(\beta-\alpha)}{1+\beta}(1-\lambda)^2 + \frac{\alpha+\beta^2}{1-\beta^2} = 0 \qquad (5)$$

The calculation of the value λ shows that a strong ($\alpha < 1/2$) or a weak ($\alpha > 1/2$) singularity is obtained according to the nature of the two connected materials: $\alpha < 0$ or $\alpha > 0$ [21]. The energy release rate is obtained by the calculation of the displacement of crack lips [22] or by the calculation of the variation of the potential energy for two crack lengths a and $a + \Delta a$.

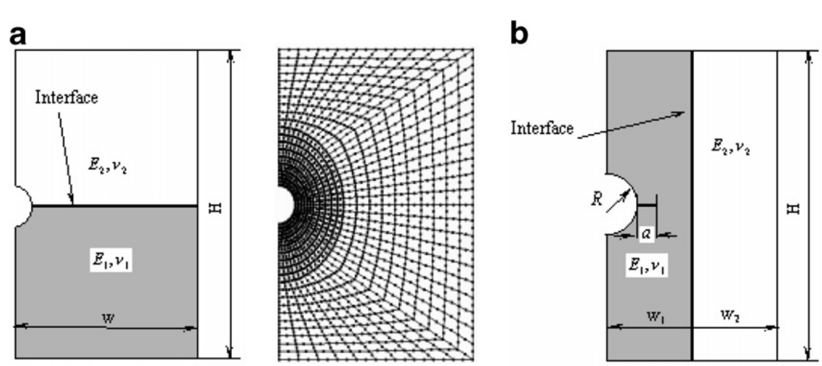

Fig. 2. Geometrical model and typical FE mesh of bimaterial plate with notch: (a) interface perpendicular to the applied load and (b) interface parallel to the applied load.