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Stress intensity factors for penny-shaped cracks perpendicular to graded interfacial zone of bonded bi-materials

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Abstract

This paper examines the stress intensity factors that are associated with a penny-shaped crack perpendicular to the interface of a bi-material bonded with a graded interfacial zone. Elastic modulus of the graded interfacial zone is assumed to be an exponential function of the depth. The stress intensity factors are calculated numerically using a so-called generalized Kelvin solution based boundary element method. Three cases of normal or shear tractions acting on the crack surfaces are examined. Values of the stress intensity factors are examined by taking into account the effects of the following four parameters: (a) the crack front position; (b) the non-homogeneity parameter of the graded interfacial zone; (c) the crack distance to the graded interfacial zone; and (d) the graded interfacial zone thickness. The numerical results are compared well with existing solutions under some degenerated conditions. These results are useful to furthering our knowledge on fracture behavior of bi-material systems with or without a graded interfacial zone.

Keywords: Boundary element method; Generalized Kelvin solution; Bi-materials; Functionally graded materials; Interface; Penny-shaped crack; Stress intensity factors

1. Introduction

It has been well recognized that spatial discontinuity or sharp change in the properties of a solid material would disrupt the bi-harmonic distribution of stress and displacement fields, cause stress concentrations or singularities and eventually lead to damage or failures in the material. Functionally graded materials (FGMs), also termed as graded materials, are new composite materials to overcome the intrinsic problem

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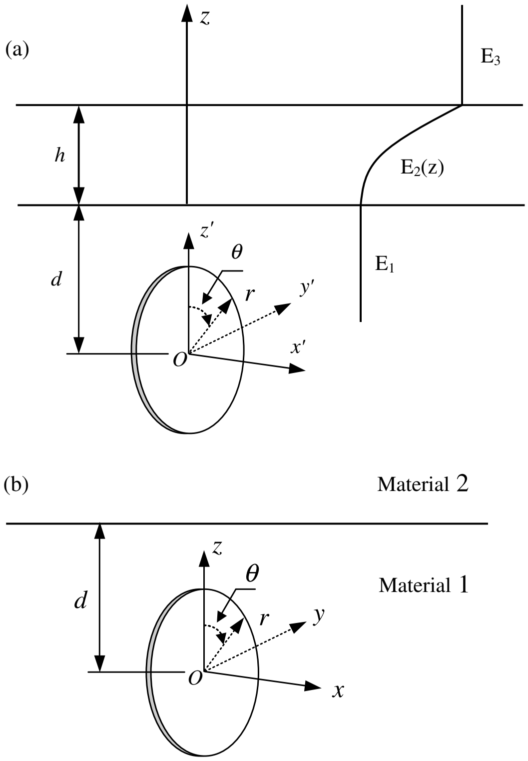

Fig. 1. Penny-shaped crack perpendicular to the interface of a bonded bi-material system with a graded interfacial zone (a) or without a graded interfacial zone (b).

associated with conventional composite materials whose properties have discontinuous interfaces. The FGMs are fabricated in such a way that their material properties are continuous functions of the spatial position along the depth direction and have no change along the lateral directions. One of the applications of the FGMs is to form a bi-material system bonded with a graded material. Such bi-material system will have its property values continuously changing from those of the first homogeneous material to those of the third homogeneous material (Fig. 1a). As a result, the bi-material system will not have any sharp or discontinuous spatial changes in its material properties, which eliminates the possibility of stress concentrations or singularities due to the presence of spatial discontinuities in material properties (Fig. 1b). In recent years, investigations of the mechanics of FGMs have been growing rapidly around the world. In particular, a special issue of the Engineering Fracture Mechanics, An International Journal was devoted to the fracture mechanics of FGMs in March 2002 [1]. Results of such investigations can be used to predict initiations and growths of cracks in the new materials.

The fracture mechanics dealing with cracks in or near a graded interfacial zone in the new bi-material system have been investigated by a number of researchers using analytical methods. Erdogan and his co-researchers presented a series of solutions for crack problems in the FGMs. These solutions include a crack either perpendicular or parallel to a FGM interface zone [2–7]. Dag and Erdogan [8,9] further investigated the crack problems involving a surface crack in a semi-infinite elastic graded solid under either a general loading condition or a smooth rigid punch. Schovanec and Walton [10] and Gao and Kuang [11] examined the singular behavior of the anti-plane shear stress field for cracks perpendicular to