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Dynamic internal crack problem of a functionally graded magneto-electro-elastic strip

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Abstract

In this paper the dynamic anti-plane problem for a functionally graded magneto-electro-elastic strip containing an internal crack perpendicular to the boundary is investigated. The crack is assumed to be either magneto-electrically impermeable or permeable. Integral transforms and dislocation density functions are employed to reduce the problem to Cauchy singular integral equations. Numerical results show the effects of loading combination parameter, material gradient parameter and crack configuration on the dynamic response. With the magneto-electrically permeable assumption, both the magnetical and electrical impacts have no contribution to the crack tip field singularity. However, with the impermeable assumption, both the applied magnetical loads and electrical loads play a dominant role in the dynamic fracture behavior of crack tips. And for the two kinds of crack surface conditions, increasing the graded index can all retard the crack extension.

Keywords: Impact; Magneto-electro-elastic material; Functionally graded material (FGM); Crack; Dynamic energy release rate; Singular integral equation; Integral transform; Strip

1. Introduction

Composite material consisting of a piezoelectric phase and a piezomagnetic phase has drawn significant interest in recent years, due to the rapid development and application of this material in adaptive

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control systems. It shows a remarkably large magnetoelectric coefficient, the coupling coefficient between static electric and magnetic fields, which does not exist in either component. The magnetoelectric coupling is a new product property of the composite, since it is absent in each component. In some cases, the coupling effect of piezoelectric/piezomagnetic composites can be even a hundred times larger than that in a single-phase magnetoelectric material. Consequently, they are extensively used as magnetic field probes, electric packaging, acoustic, hydrophones, medical ultrasonic imaging, sensors, and actuators with the functionality of magneto-electro-mechanical energy conversion (Wu and Huang, 2000). When subjected to mechanical, magnetical and electrical loads in service, these magneto-electro-elastic composites can fail prematurely due to some defects, such as cracks, holes and inclusions arising during their manufacturing process. Therefore, it is of great importance to study the fracture behaviors of piezoelectric/piezomagnetic composites under magneto-electro-elastic interactions (Song and Sih, 2003; Sih and Song, 2003).

The development of piezoelectric-piezomagnetic composites has its root from the early work of Van Suchtelen (1972) who proposed that the combination of piezoelectric-piezomagnetic phases might exhibit a new material property—the magnetoelectric coupling effect. Since then, the magnetoelectric coupling effect of $BaTiO_3$-$CoFe_2O_4$ composites has been measured by many researchers. Much of the theoretical work for the investigation of magneto-electro-elastic coupling effect has only recently been studied (Wu and Huang, 2000; Song and Sih, 2003; Sih and Song, 2003; Harshe et al., 1993; Avellaneda and Harshe, 1994; Nan, 1994; Benveniste, 1995; Wang and Shen, 1996; Huang and Kuo, 1997; Li and Dunn, 1998; Li, 2000; Pan, 2001; Zhou et al., 2004; Lage et al., 2004).

To date, analysis of dynamic fracture problems of magneto-electro-elastic material is very limited. Du et al. (2004) obtained the scattered fields of SH waves by a partially debonded magneto-electro-elastic cylindrical inhomogeneity, and determined the numerical results of crack opening displacement. Hou and Leung (2004) analyzed the plane strain dynamic problem of a magneto-electro-elastic hollow cylinder by virtue of the separation of variables, orthogonal expansion technique and the interpolation method. Buchanan (2003) considered the free vibration problem of an infinite magneto-electro-elastic cylinder. To the best of our knowledge, in all of these studies, the magneto-electro-elastic media are either homogeneous or multi-layered.

On the other hand, although the transient response of piezoelectric material with cracks are widely investigated (Shindo et al., 1996; Chen and Yu, 1997; Wang and Yu, 2000; Kwon and Lee, 2000; Li, 2001; Gu et al., 2002; Chen et al., 2003), to our knowledge, the transient response of cracks in magneto-electro-elastic media has not been studied.

In this paper, the dynamic anti-plane problem of a functionally graded magneto-electro-elastic strip containing an internal crack perpendicular to the boundary is studied. The material properties are assumed to vary exponentially along the x-direction. Two kinds of crack surface conditions, i.e. magneto-electrically impermeable and magneto-electrically permeable, are adopted. Integral transform technique is used to reduce the problem to the solution of singular integral equations. Numerical results are shown graphically to illustrate the effects of loading combination parameter, material gradient parameter and crack configuration on the dynamic responses.

2. Statement of problem

Consider an infinite magneto-electro-elastic strip that contains a Griffith crack with reference to the rectangular coordinate system x, y, z, as shown in Fig. 1. The strip exhibits transversely isotropic behavior and is poled in z-direction. The anti-plane shear impacts and in-plane electric displacement and magnetic induction impacts are suddenly applied on the crack surfaces at $t = 0$, and then maintain constants as imposed loads. In Fig. 1, $H(t)$ denotes the Heaviside unit step function.