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Transient response of interface cracks between dissimilar magneto-electro-elastic strips under out-of-plane mechanical and in-plane magneto-electrical impact loads

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Abstract

Using the integral transform and the Cauchy singular integral equation methods, the problem of interface cracks between dissimilar magneto-electro-elastic strips under out-of-plane mechanical and in-plane magneto-electrical impacts is investigated. The magneto-electric permeable boundary condition on the crack surfaces is adopted. The number of the interface cracks is arbitrary. The field intensity factors and energy release rates are derived and discussed. The effects of the crack configuration and the main constitutive parameters of the magneto-electro-elastic materials on the dynamic response are examined. Results show that the dynamic energy release rates (DERRs) as the crack extension force are quite equivalent to the dynamic stress intensity factors (DSIFs) for magneto-electric permeable interface cracks. The DERRs may be retarded or accelerated by specifying different combinations of material parameters. In addition, the parameters of the crack configuration, including the ratio of the strip width to the crack length, the ratio of the widths for different strips, and the distances between two cracks, exert a considerable influence on the DERRs. The results seem useful for design of the magneto-electro-elastic composite structures and devices of high performance.

Keywords: Impact; Dynamic energy release rate; Interface cracks; Magneto-electro-elastic strips; Singular integral equations; Integral transform

1. Introduction

It is well known that the coupling nature of piezoelectric materials has led to their wide applications. When subjected to mechanical and electrical loads in service, these piezoelectric materials can fail prematurely owing to defects, e.g. cracks, holes, inclusions, etc. arising in the manufacturing process.

The dynamic response problem of mechanical and electrical behaviors in a piezoelectric material under various time-dependent loads is of great importance in some practical applications and great progress in this area has been made. For example, Dascalu and Maugin [1] investigated the dynamic fracture of piezoelectric materials by the quasielectrostatic approximation. Li and Mataga [2,3] studied a pair of concentrated longitudinal shear loads that suddenly act on the crack surfaces and move at a constant velocity along the crack surface far away from the crack tip, and derived the dependence of the field intensity factors and the energy release rate on the moving velocity for an electrode crack and a vacuum crack, respectively. Chen et al. [4,5] investigated an impermeable finite crack situated in a piezoelectric medium and two coplanar cracks situated in a piezoelectric strip subjected to impact loads, where numerical stress intensity factors have been determined by the numerical solution of a Fredholm integral equation. Wang and Yu [6] studied the mode-III problem of a crack in piezoelectric strip subjected to the mechanical and electrical impacts by solving numerically resulting Cauchy

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integral equations. Wang et al. [7] investigated the multiple impermeable crack problem for multilayered piezoelectric materials. Kwon and Lee [8] analyzed the transient response of a rectangular piezoelectric body with a center crack. Li [9] and Li and Fan [10] investigated the transient response of a piezoelectric material with a semi-infinite impermeable mode-III crack under impact loads and the problem of a through permeable crack situated in the mid-plane of a piezoelectric strip under anti-plane impact loads, respectively. Feng et al. [11] studied the transient response of multiple electric permeable coplanar interface cracks between dissimilar piezoelectric materials. Gu et al. [12,13] respectively studied the mode-III and mode-I problems of an interface crack between dissimilar piezoelectric layers under the mechanical and/or electrical impacts.

Recently, more advances are the smart or intelligent materials where piezoelectric and piezomagnetic materials are involved, and the magneto-electric effect in composite materials consisting of a piezoelectric phase and a piezomagnetic phase has drawn attention. In 1981, Bracke and Van Vliet [14] reported a broadband magneto-electric transducer with a flat frequency response. Since then, numerous researchers have investigated the magneto-electric coupling in piezoelectric/piezomagnetic composites both theoretically and experimentally [15–18]. Li and Dunn solved inhomogeneity problems in an infinite magneto-electro-elastic medium [19], and analyzed the average fields and effective moduli of heterogeneous media that exhibit full coupling between stationary elastic, electric, and magnetic fields [20]. Wang and Shen [21] deduced the conservation laws and the path-independent integrals based on the concept of the energy-momentum. Huang and Kuo [22] investigated the inhomogeneity-related problem in the magneto-electro-elastic medium by means of the three-dimensional Green function. Pan [23] derived the exact solutions for three-dimensional, anisotropic magneto-electro-elastic, simply supported and multilayered rectangular plates under both surface and internal loads. Wang and Shen [24] gained the general solution to the three-dimensional problems of the magneto-electro-elastic materials. Du et al. [25] obtained the scattered fields of SH waves by a partially debonded magneto-electro-elastic cylindrical inhomogeneity, and gave the numerical results of the crack opening displacement.

In this paper, we study the transient response of multiple coplanar interface cracks between dissimilar magneto-electro-elastic strips subjected to out-of-plane mechanical and in-plane magneto-electrical impacts. The magneto-electric permeable boundary condition on the crack surfaces is adopted. Integral transforms and dislocation density functions are used to reduce the problem to Cauchy singular integral equations. The dynamic energy release rate of crack tips are obtained and numerically solved. It is shown that the crack tip behaviors depend strongly upon the material properties, strip widths and crack size, which could be of particular interest to the analysis and design of smart sensors/actuators constructed from magneto-electro-elastic composite laminates. The present work, in fact, include both the previous dynamic crack problems of piezoelectric, piezomagnetic, or purely elastic materials and the previous dynamic interface crack problems of different material combinations, such as piezoelectric piezoelectric combination, piezoelectric elastic combination and so on. Therefore, the present results can serve as benchmarks to impact theories of layered magneto-electro-elastic composite structures.

2. Statement of the problem

Consider n mode-III Griffith interface cracks between two bonded magneto-electro-elastic strips occupying $0 < y < h_1$ and $-h_2 < y < 0$, respectively, with their basal planes perpendicular to the z-axis as shown in Fig. 1. The x coordinates of the kth crack tips are set to be a_k and b_k $(k = 1 - n)$. The out-of-plane shear impacts and the in-plane electric displacement and magnetic induction impacts are imposed on the crack surfaces at $t = 0$.

For the anti-plane problem considered here, the out-of-plane elastic displacements w_i, in-plane electric potentials ϕ_i and magnetic potentials ψ_i satisfy the following governing equations:

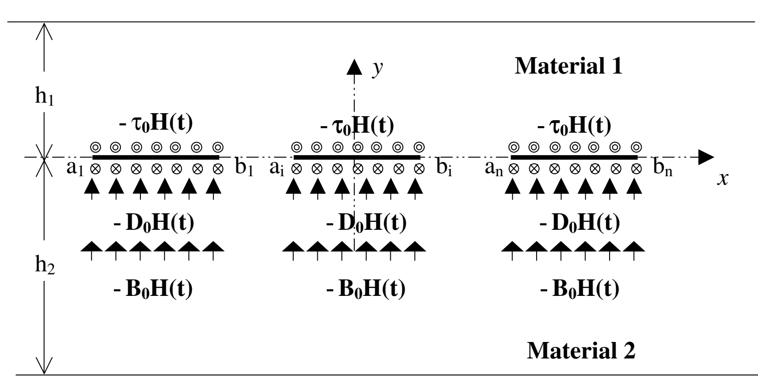

Fig. 1. Two dissimilar bonded magneto-electro-elastic strips with multiple interface cracks under anti-plane mechanical and in-plane magneto-electrical impacts.