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Dynamic fracture behavior of functionally graded magnetoelectroelastic solids by BIEM

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ABSTRACT

Dynamic anti-plane fracture problem of an exponentially graded linear magnetoelectroelastic plane with a finite impermeable crack subjected to time-harmonic SH-waves is solved. Directions of wave propagation and material inhomogeneity are chosen in an arbitrary way. The fundamental solution for the coupled system of partial differential equations with variable coefficients is derived in a closed form by the hybrid usage of both an appropriate algebraic transformation for the displacement vector and the Radon transform. The formulated boundary-value problem is solved by a nonhypersingular traction boundary integral equation method (BIEM). The collocation method and parabolic approximation for the unknown generalized crack opening displacements are used for the numerical solution of the posed problem. Quarter point elements placed next to the crack-tips ensure properly modeling the singular behavior of the field variables around the crack tip. Fracture parameters as stress intensity factor, electric field intensity factor and magnetic field intensity factor are computed. Intensive simulations reveal the sensitivity of the generalized intensity factors (GIF) at the crack-tips to the material inhomogeneity, characteristics of the incident wave, coupling effects, wave-material and wave-crack interaction phenomena.

1. Introduction

A wide class of single crystals, see Sirotin and Shaskolskaya (1982), and new composite materials, see Nan et al. (2008), possess simultaneously piezoelectric, piezomagnetic and magneto-electric effects and they are classified as magnetoelectroelastic (MEE) materials. These multifunctional materials, known also as multiferroic ones, see Erenstein et al. (2006), can produce direct and inverse magnetoelectric (ME) effect first reported by Suchtelen (1972). The direct effect is the appearance of an electric polarization upon applied magnetic load, while the converse one reveals the magnetic properties of the material subjected to an electric field. Usually these materials are multiphasic and have piezoelectric and piezomagnetic phase, see Nan et al. (2008), Liu and Huang (2005), Chue and Hsu (2008). The ME effect results from the elastic interaction between two phases. The following mechanism for this interaction exists: (a) when a magnetic field is applied, the piezomagnetic phase changes its shape and provokes mechanical strain, which passes through the piezoelectric phase and results in an electrical polarization; (b) when electric load is applied, the piezoelectric phase transforms it to an elastic strain passing through the piezomagnetic phase which converts the mechanical energy into magnetic one. There exist natural single-phase multiferroic materials, but their magnetoelectric responses are either relatively weak or occur at very low temperature. In contrast, man-made multiferroic composites based on piezoelectric and magnetic oxide ceramics typically yield giant magnetoelectric coupling above room temperature. This fact makes these composites ready for new technological applications as electric packaging components, sensors and actuators, acoustic/ultrasonic devices, hydrophones, and transducers.

The composites are highly sensitive to the presence of manufacturing and service-related defects (microcracks, voids, impurities, etc.) that can reach a critical size during service and thus compromise the structure safety. Also when the MEE material is performed by a laminate structure, see Nan et al. (2008), internal stress is accumulated between layers and delamination failure can occurs, see Chue and Hsu (2008), due to incompatible structural and thermal properties. To overcome the sharp interface and reduce stress concentration between layers, the concept for functionally graded materials (FGM) was proposed in the last years, see Ma and Lee (2009). To enhance the promising applications, it is necessary to better understanding this new class of multifunctional intelligent composite materials in the context of their fracture state evaluation.

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