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A piezoelectric-inhomogeneity system with imperfect interface

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Abstract

This paper examines the electro-mechanical fields for a circular anisotropic piezoelectric fiber sensor inside an anisotropic piezoelectric or non-piezoelectric elastic matrix with imperfect interface under remote in-plane uniform tension. The interface imperfection is posed on the mechanical fields only. The present formulation admits different boundary value problems in a unified manner, so various fiber–matrix interface conditions are considered: (1) perfect bonding; (2) pure debonding; (3) in-plane pure sliding; (4) out-of-plane pure sliding; (5) full debonding; and (6) partial debonding. An interface condition is modeled by a specific layer of mechanical springs with vanishing thickness, namely k_{sd} for normal debonding, k_{st} for in-plane sliding, and k_{sv} for out-of-plane sliding. Partial debonding is the one that allows to represent intermediate states between cases (1)–(5) above, for which the spring constants can take on any arbitrary values. An accurate three-dimensional approach in conjunction with an energy formulation based on linear theory of piezoelectricity is presented. The generalized displacement field is expressed in terms of series involving some appropriate amending functions. In the context of the present study the nature of the solution satisfies the necessary continuity in the electric potential across the fiber–matrix interface, while accounting for possible discontinuity in its derivative at the interface. This consideration accelerates the convergence rate significantly.

Keywords: Piezoelectric; Imperfect interface; Three-dimensional solution; Generalized plane strain; Spring stiffness; Debonding

1. Introduction

The attractive property of piezoelectric materials, that become electrically polarized when strained, and that become strained when subjected to an electric field is the underlying foundation for achieving numerous types of smart structures. Nowadays, piezoelectric materials have a key role in manufacturing of sensors and actuators, which may be used for active control of elastic deformations and vibrations of the structures. These

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materials have a wide range of applications in science and technology such as in ultrasonic transducers, sonar projects, and under water acoustic.

In order to successfully integrate piezoelectric actuators into structures, the physical nature of the interface condition between the actuators and the base structure, and its effect on the induced electro-mechanical field must be fully understood.

Based on the three-dimensional formulation of linear piezoelectricity that was presented by Tiersten [1], a number of two and three-dimensional problems have been examined in the literature. Sosa [2] solved the problem of a PZT-4 containing a cylindrical cavity under remote electro-mechanical loading. Pak [3] presented a closed-form solution for a circular piezoelectric inclusion embedded in an infinite piezoelectric matrix under far-field antiplane mechanical load and an in-plane electrical load. Xiao and Bai [4] considered a circular piezoelectric fiber sensor embedded in a non-piezoelectric elastic material. In their problem the fiber sensor is assumed to be transversely isotropic and is perfectly bonded to its surrounding matrix. There are a considerable number of publications devoted to the analysis of piezoelectric plates, Ray et al. [5,6], Heyliger [7], Ruan et al. [8], Bisegna and Maceri [9], Vel and Batra [10], and Reddy and Cheng [11]. On piezoelectric structures with arbitrary geometries and interfaces the work of Shodja and Kamali [12] and Kamali and Shodja [13] should be mentioned.

To date, to the best of the authors knowledge, the problems associated with piezoelectric materials and inhomogeneities with imperfect interface conditions have not been proposed in the literature. However, the case of pure elastic matrix and inhomogeneity with imperfect interface has been addressed by many investigators, Achenbach and Zhu [14], Hashin [15], Huang et al. [16], and Gao [17]. The idea is that, across the matrix–inhomogeneity interface, the traction stresses are continuous, while depending on the type of the imperfection some components of the displacement field are discontinuous. The present work considers different types of piezoelectric systems, and examines the effects of interface conditions: perfect bonding, partial debonding, and full debonding on the induced electro-mechanical fields. When one of the matrix or inhomogeneity phases is made of lithium tantalate or lithium niobate, the phenomenon of generalized plane strain will prevail. These crystals are found to have unique properties, which are quite suitable for electro-optical and acousto-optical devices.

2. The governing equations for a piezoelectric sensor with perfect/imperfect interface

Consider a thick plate occupying space Ψ, containing a circular cylindrical inhomogeneity Ω with imperfect interface. The radius of the cylinder is a, the dimensions of the plate and the Cartesian coordinate system is

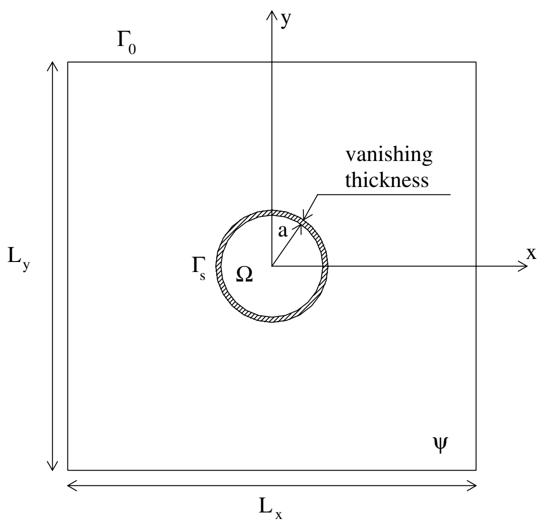

Fig. 1. The geometry of a circular cylindrical inhomogeneity embedded in a thick plate.