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Interaction of a screw dislocation with a semi-infinite interfacial crack in a magneto-electro-elastic bi-material

R.J. Hao, J.X. Liu *

Department of Engineering Mechanics, Shijiazhuang Railway Institute, Shijiazhuang 050043, China

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Abstract

The interaction between a screw dislocation and a semi-infinite interfacial crack in a transversely isotropic magneto-electro-elastic bi-material is investigated. The dislocation line is perpendicular to the isotropic basal plane of the bi-material. The elastic and electromagnetic fields induced by the dislocation are obtained through the use of the complex variable method together with the superposition scheme. The stress, electric displacement and magnetic intensity factors as well as the image exerted on the dislocation are given explicitly. We find that the intensity factors are expressed in terms of the so-called effective materials and the radial component of the image force is only dependent on the elastic modulus of the material with the dislocation. As an illustrative example, the bi-material that consists of piezoelectric and piezomagnetic phases is analyzed.

Keywords: Magneto-electro-elasticity; Bi-material; Piezoelectric; Piezomagnetic; Screw dislocation; Interfacial crack; Image force

1. Introduction

In the recent years, many researchers have used a new terminology, magneto-electro-elastic solid, to describe a class of materials exhibiting full coupling between mechanical, electric and magnetic fields. Few natural materials possess simultaneously the aforesaid coupling properties. However, composite materials composed of a piezoelectric and piezomagnetic phase not only have original piezoelectric and piezomagnetic properties but also exhibit a remarkable magneto-electric coupling effect that is not present in the constituents. Such composites are potential candidates for use as magneto-electric memory elements, smart sensors and transducers because they can facilitate the conversion of energies between electric and magnetic fields.

* Corresponding author. Tel.: +86 311 7936682; fax: +86 311 7935136.
E-mail address: liujx@sjzri.edu.cn (J.X. Liu).

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van Suchtelen (1972) was the first to report that the piezoelectric–piezomagnetic composites may exhibit a new material property—the magneto-electric coupling effect. This magneto-electric effect is a product property that results from the interaction between different properties of the two phases in composites. Later, van den Boomgaard et al. (1974) and van Run et al. (1974) studied the magneto-electric effect of $BaTiO_3$–$CoFe_2O_4$ composites. In the past decade, considerable studies have focused on micromechanical modelling of piezoelectric–piezomagnetic composite materials and the determination of their effective properties, especially magneto-electric coupling effect. A brief review on this subject can be found in recent two papers by Li (2002) and Soh et al. (2003).

The developments of magneto-electro-elastic materials have recently stimulated interest in crack problems. Gao et al. (2003a,b) first investigated a single crack and collinear cracks in an infinite anisotropic magneto-electro-elastic medium and derived exact solutions of elastic and electromagnetic fields. In their work, the normal components of electric displacement and magnetic induction and the tangential components of electric field and magnetic field across the crack are assumed to be continuous. Later, Gao et al. (2003c) solved the interfacial crack problem in bonded dissimilar magneto-electro-elastic materials and found that the stress intensity factors are independent of the remote electromagnetic loads. Song and Sih (2003) and Spyropoulos et al. (2003), respectively, studied the plane and anti-plane deformations of a transversely isotropic piezoelectric–piezomagnetic composite containing one Griffth crack, where the normal components of electric displacement and magnetic induction on the crack surfaces were taken as zero. Extending the strain energy density theory for classical elasticity to magneto-electro-elasticity, they examined the crack initiation and growth behavior under combined mechanical and electromagnetic loads. It is worth mentioning that the magneto-electric constants vanish in the work of Song and Sih (2003) and Spyropoulos et al., which is inexplicable. Using the same electromagnetic boundaries on the crack surfaces as those adopted by Song and Sih (2003), Wang and Mai (2004) analyzed the crack tip fields in an infinite homogeneous magneto-electro-elastic solid. They derived the path-independent conservative integral and also provided the energy release rate expressed in terms of the intensity factors of stress, electric displacement and magnetic induction. The aforementioned investigations are confined to crack problems of magneto-electro-elastic solids subjected to uniformly mechanical and electromagnetic loading at infinity. As well known, dislocations are an important defect in solid materials. The study on the interaction of dislocations with cracks plays an important role in understanding the physical behaviors of materials. This is due to the fact that even if external stress is not applied, cracks in materials may also provide certain preferred places where dislocations accumulate. Furthermore, accumulation of such dislocations leads to crack initiation at these places. On the other hand, dislocations in the vicinity of a crack can retard or enhance crack propagation (Weertman, 1996). To the best of the authors' knowledge, the crack-dislocation interaction in purely elastic materials has been widely investigated. However, the study on this topic in magneto-electro-elastic materials has not been reported yet.

This paper analyzes the interaction of a screw dislocation with a semi-infinite interfacial crack in two bonded dissimilar magneto-electro-elastic materials. The main purpose is to reveal fundamental features of coupled fields and dislocation-crack interaction. Following the introduction, the problem is stated and the basic equations are formulated in Section 2. The solution to the problem is derived explicitly in Section 3. Based on the obtained solution, the expressions for the intensity factors and image force on a screw dislocation are given in Section 4, and as application, a screw dislocation interacting with a crack in piezoelectric–piezomagnetic bi-materials is examined. In the end, the paper is concluded in Section 5.

2. Statement of the problem and basic equations

Considered is the problem shown in Fig. 1. An infinite magneto-electro-elastic bi-material contains a semi-infinite interfacial crack and is subjected to a straight screw dislocation with the Burgers vector b_3