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Multiple interfacial cracks in a bi-layered multiferroic composite under magnetostriction or electrostriction

Yong-Dong Li *, Fei-Xiang Feng, Hao Zhao

Academy of Armored Force Engineering, No. 21, Du Jia Kan, Feng Tai District, Beijing 100072, PR China

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ABSTRACT

The purpose of the present paper is to investigate the problem of interfacial fracture in a multiferroic composite under magnetostriction or electrostriction. Methods of distributed interfacial dislocations, Green's function and Cauchy singular integral equations are employed to solve the problem of multiple cracks on the interface. Numerical results of the fracture parameter are discussed, and the magnetostrictive or electrostrictive interfacial fracture is explained via the physical phenomena of "active/passive deformation", "magneto/electro-mechanical coupling" and "piezomagnetic/piezoelectric stiffening".

1. Introduction

With the fast development of modern high-tech fields such as aeronautics, astronautics, energy industry and national defense, there are higher and higher requirements on the performances of smart devices. In many cases, they should have not only piezoelectric and piezomagnetic functions but also magneto-electric coupling capability [1,2]. Due to their low magneto-electric coupling effect at room temperature, it is more and more difficult for the single-phase piezoelectric or piezomagnetic ceramics to meet the needs of high technology. Huang and Kuo [3] revealed that multiferroic composites composed of both piezoelectric and piezomagnetic phases might have magneto-electric coupling effect at room temperature. It was further found that multiferroic composites consisting of alternate piezoelectric and piezomagnetic layers generally have much stronger magneto-electric coupling performance than sintered bulk multiferroic composites do [4,5]. Therefore, investigation on the former gradually became a focus in this field.

There are a number of scientific and technological problems in the research and manufacture of layered multiferroic composites. For example, their mechanical behavior under the action of magneto-electro-mechanical loading is such a problem of significance to their optimal design. With the rise of investigation on layered multiferroic composites, more and more attention has been paid on the related mechanical problems in recent years. Du et al. [6,7] investigated the propagation of Love wave and SH surface wave in layered multiferroic plates and cylinders, respectively. Wang et al. [8] established the two-dimensional Green's functions in anisotropic multiferroic bimaterials with a viscous interface. Zhang et al. [9,10] studied the vibration problems of laminated multiferroic shells and plates, respectively. Liu et al. [11,12] analyzed the propagation of SH wave in periodically layered multiferroic structures. Huang and Li [13] surveyed the effects of interfacial damages on the frequency dispersion behavior of SH wave in a bi-layered multiferroic composite. Compared with the sintered bulk multiferroic composites, the investigation on the fracture problems of layered multiferroic composites have been

* Corresponding author. Tel.: +86 10 6671 9083.
E-mail address: LYDbeijing@163.com (Y.-D. Li).

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Nomenclature

w, φ and ϕ mechanical displacement, magnetic potential andelectric potential
τ, B and D stress, magnetic induction and electric displacement
c_{44}, h_{15}, μ_{11}, e_{15} and ε_{11} elastic constant, piezomagnetic coefficient, magnetic permeability, piezoelectric coefficient and dielectric coefficient
h_1 and h_2 thickness of piezomagnetic layer and piezoelectric strip
H_0 and E_0 applied magnetic field and applied electric field
τ_e equivalent traction on the crack surfaces
q_m and q_e dimensionless constants
k_e and k_m piezoelectric stiffening factor and piezomagnetic stiffening factor
$g_j(x)$ $(j = 1,2,\ldots,n)$ dislocation density functions
δ Dirac delta function
$A_j(\xi)$ $(j = 1,2,\ldots,16)$ are undetermined coefficient functions
$Q_1(\xi)$ and $Q_2(\xi)$ known functions
$G_{yz}(x,s)$ Green's function
$f_j(\tilde{s}_j)$ $(j = 1,2,\ldots,n)$ undetermined dimensionless non-singular functions
K_{ak} and K_{bk} $(k = 1,2,\ldots,n)$ stress intensity factors

scarcely performed. The research team of the present paper [14–17] studied the effects of magneto-electric loading and piezoelectric/piezomagnetic stiffening on the fracture behavior of the interface and piezoelectric/piezomagnetic layer in laminated multiferroic plates and cylinders. Wan et al. [18] studied the multilayered multiferroic composite containing periodic interface cracks and subjected to in-plane magnetic or electric fields.

Among the fracture problems of layered multiferroic composites, interfacial fracture deserves special attention due to the special magneto-electric coupling mechanism [14]. As mentioned above, this kind of composites are composed of alternate piezoelectric and piezomagnetic layers. The two-way magneto-electric coupling effect between the neighboring piezoelectric and piezomagnetic layers are in fact a strain mediated product effect achieved via the interfaces [14]. Therefore, interfaces are significant regions to realize and improve the magneto-electric coupling performance of layered multiferroic composites. In our preceding work [14–16], we only analyzed the idealized problem of a single interfacial crack. However, in engineering, multiple cracks may simultaneously exist on the interface, which would affect the magneto-electric coupling behavior more seriously. Therefore, it is necessary to investigate the problem of multiple interfacial cracks in layered multiferroic composites and find the optimal way to improve their ability against interfacial fracture. In the present paper, we continue to study the more general problem of multiple interfacial cracks in a bi-laminated multiferroic plate containing a piezoelectric strip and a piezomagnetic layer. The methods of dislocation simulation, Green's function and singular integral equation are employed to solve the problem, and the effects of physical parameters on the stress intensity factor are revealed, yielding the theoretical explanation on the magnetostrictive or electrostrictive interfacial fracture.

2. Problem formulation

Consider a bi-layered multiferroic composite consisting of a piezomagnetic layer and piezoelectric strip, as shown in Fig. 1. The thickness of the former is h_1, and that of the latter is h_2. There are a series of interfacial cracks occupying the

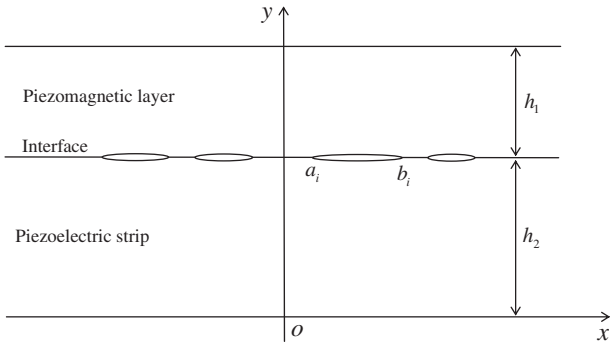

Fig. 1. Multiple interfacial cracks in a bi-layered multiferroic composite.