Engineering Fracture Mechanics 191 (2018) 143–152

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

A polling direction influence on fracture parameters of a limited permeable interface crack in a piezoelectric bi-material

O. Viun[a,*], A. Komarov[a], Y. Lapusta[b], V. Loboda[a]

[a] Department of Theoretical and Computational Mechanics, Oles Honchar Dnipro National University, 49010 Dnipro, Ukraine
[b] Université Clermont Auvergne, CNRS, SIGMA Clermont (ex- French Institute of Advanced Mechanics – IFMA), Institut Pascal, F-63000 Clermont-Ferrand, France

ARTICLE INFO

Keywords:
Piezoelectric material
Interface crack
Analytical solutions
Polling direction
Finite Element Method

ABSTRACT

An arbitrary polling direction of the upper material is considered for a plane-strain problem of a crack between two different piezoelectric materials subject to a tensile mechanical stress and an electrical displacement that are applied at infinity. Limited permeable electrical conditions at the crack faces are considered.

The problem is reduced to the problem of linear relationship by use of complex function theory. Formulas for stresses at the interface as well as the intensity factors at the crack tips are presented in the form of simple analytical formulas.

A finite-sized piezoelectric bi-material plate with interface crack, which length is substantially less than the plate dimension, was analysed by the finite elements method. The influence of the polling direction on the fracture parameters is studied. The results are presented for different polarisation angles and for different combinations of the materials. A good agreement between analytical and numerical results is shown.

1. Introduction

Active materials used in smart structures are often brittle and predisposed to occurrence of defects during their manufacturing and service life. Their premature failure can be caused by strong mechanical stresses, high electrical or magnetic fields. Appearing and growth of cracks can take place due to an initial imperfect bonding or during the service life. Therefore, studies of the electro-mechanical or magneto-electro-mechanical behaviours and fracture of active components with cracks have a great practical importance. Analyses of such problems were carried out in many papers (e.g. [1–7], etc.).

Correct formulation of the boundary conditions on the crack faces plays an important role in analysis of piezoelectric devices with cracks. One idealized case was proposed in [8] and assumed that the crack is fully permeable and does not obstruct any electric field. The electrically permeable crack assumption simply treats the crack as completely penetrable for an electric field. This condition for piezoelectric materials has attracted considerable attention in the literature (e.g. [9,10]).

However, cracks are usually filled by some medium (water, air, etc.). Therefore the properties of this medium should be taken into consideration. The crack face conditions which take into account the property of the crack medium were suggested in [11,12] and they are called limited permeable conditions. These conditions were analysed and further developed in papers [13–15]. The work [16] performed the modelling of electromechanical pre-fracture zones for a crack with limited electric permeability in a homogeneous piezoelectric material. A semi-permeable mode-III crack in piezoelectric strip was studied in [17]. It is noted in this paper

* Corresponding author.
E-mail addresses: Viun.Alexei@gmail.com (O. Viun), lapusta@sigma-clermont.fr (Y. Lapusta), loboda@dnu.dp.ua (V. Loboda).

https://doi.org/10.1016/j.engfracmech.2018.01.024
Received 31 October 2017; Received in revised form 15 January 2018; Accepted 24 January 2018

that increasing crack medium permittivity leads to decreasing of the relative crack sliding. The limited permeable boundary conditions were used in the work [18] for studying of the Maxwell stresses influence on fracture parameters. In the work [19] the effect of distance between cracks with different types of crack-face boundary conditions was studied for mono-ceramics. The problem of two equal collinear cracks weakening a piezo-electro-magnetic material was solved in the work [20]. The semi-permeable crack face boundary conditions were adopted.

As it was mentioned above, smart structures are mostly used as actuators and therefore they may contain piezoelectric multilayer with different polling directions: the S-morph actuator ([21]), piezoelectric stack actuator. From this point of view, it is important to study the interface cracks between two piezoelectric materials with different polling directions. An arbitrarily oriented limited-permeable crack in a piezoelectric medium was studied in [22]. The influence of the crack orientation and the applied loads on the fracture parameters of crack in piezoelectric materials is studied. Two cases of polling direction in piezoelectric bi-material system were considered in [23] for a penny-shaped crack. It was found, that a system with opposite polling directions has a higher chance for dielectric breakdown under both positive and negative charge loading. Mode 1 stress intensity factor of a bi-material system with identical materials and the same or opposite polling directions is independent of the material type, polling orientation and magnitude of electric charge. The influence of electric boundary conditions, polling direction and electric field on fracture parameters were investigated in [24] for electrically permeable and impermeable crack. The XFEM method was applied to numerical analysis of sub-interface crack in transversely isotropic piezoelectric bi-materials in the work [25]. In the work [26] the influence of polling direction on two equal collinear semi-permeable cracks in the framework of mechanical and electric strip-yield model for a transversely isotropic piezoelectric plate was studied. It is shown that polling direction perpendicular to the crack plane leads to the maximum this opening, and the rotation of the polling direction axis toward the x_1-axis leads to the reducing of this opening.

The cracks in homogeneous piezoelectric materials were studied earlier for arbitrary polarisation directions. However interface crack problem for the case of different polling directions in upper and lower materials has not been studied yet for the limited permeable boundary conditions. Therefore, in the present paper, a plane-strain problem is studied for a crack between two different piezoelectric materials with two different polling directions. The influence of the polling direction of the upper material on the fracture parameters is presented. The crack opening maximum position is found for different polling directions of the upper material. Also, for comparison purposes, a similar problem is solved by finite element method for the case of a finite size cracked body for the different polling direction of the upper and lower materials. Also, calculations for different crack filler were presented. The importance of accounting for the polling direction is demonstrated. It is shown that the electric permeability has a small influence on the crack opening for same interval of the polling direction. The limited permeable boundary conditions on the crack faces are adopted. The effects of the polling direction, the electrical permeability of the crack medium and the mechanical and electrical loading upon the crack opening displacement and electric potential jump are studied. Within the framework of these boundary conditions, it is obtained that an increasing electric field leads to decreasing of the crack opening for strong electric field and it has an opposite effect for weak electric flux.

2. Problem formulation and derivation of the basic relations

2.1. Constitutive relations and interface conditions

Consider a plane strain problem in x_1Ox_3 plane for two piezoelectric spaces $x_3 > 0$ and $x_3 < 0$ partially adhered along the interface $x_3 = 0$. The directions of polarization of both materials lie in plane x_1Ox_3. For the lower material it coincides with axis Ox_3 and for the toper one the polarization direction is determined by angle β with Ox_3 axis. A tunnel interface crack $-a < x_1 < a$ (Fig. 1) is situated between the mentioned ceramic spaces, at $x_3 = 0$ and the remaining part of the interface is bonded. The semi-infinite spaces are subjected at infinity by in-plane uniform constant tension $\sigma_{33} = \sigma^\infty$ and electrical displacement $D_3 = D^\infty$.

The constitutive relations for a linear piezoelectric material in the absence of body forces and free charges for plane-strain state

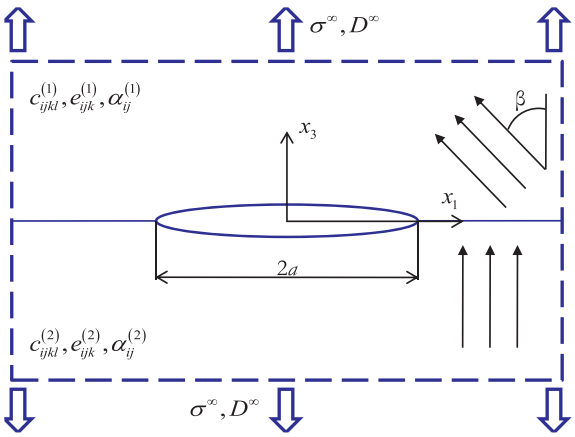

Fig. 1. Crack between two semi-infinite piezoelectric spaces.