DYNAMIC ANALYSIS OF INTERFACE CRACKS IN LAYERED PIEZOELECTRIC MATERIALS WITH NON-LINEAR CRACK-FACE BOUNDARY CONDITIONS UNDER IMPACT LOADING

Michael Wünsche*, Chuanzeng Zhang*
*Faculty of Science and Technology, Chair of Structural Mechanics, University of Siegen, D-57068 Siegen, Germany

Summary This paper presents a transient dynamic crack analysis in two-dimensional (2D), layered and linear piezoelectric solids. For this purpose a time-domain boundary element method (TDBEM) in conjunction with a multi-domain technique is developed. The time-domain dynamic fundamental solutions for homogenous and linear piezoelectric solids are applied in the present time-domain BEM. The spatial discretization of the boundary integral equations is performed by a symmetric Galerkin-method, while a collocation method is adopted for the temporal discretization of the arising convolution integrals. An iterative solution algorithm is developed to solve the non-linear semi-permeable electrical crack-face boundary conditions. An additional iteration scheme for crack-face contact analysis is implemented at time-steps when a physically unacceptable crack-face intersection occurs. Numerical examples are presented to show the influences of the different crack-face boundary conditions and the layer combination on the dynamic intensity factors.

INTRODUCTION

Piezoelectric materials offer many possibilities in advanced engineering structures due to their inherent coupling effects between mechanical and electrical fields and are widely applied in smart devices and structures like transducers, actuators and sensors. An important application of piezoelectric materials is related to layered or laminated composites because they can be optimized to satisfy the high-performance requirements according to different in-service conditions. Beside cracks inside homogeneous domains, one of the most dominant failure mechanisms in layered or laminated composites is the interface failure. Interface crack problems are in general much more complex than the corresponding crack problems in homogeneous piezoelectric materials. The asymptotic crack-tip field shows different kinds of oscillating and non-oscillating singularities in the stress and electrical displacement components near the crack-tips [1], which gives rise to some analytical and numerical difficulties in defining and computing the field intensity factors. An important role in the analysis of interface cracks in piezoelectric materials plays the formulation of the mechanical and electrical crack-face boundary conditions [2]. Since analytical solutions are available only for very simple crack geometries and loading conditions, efficient numerical methods are needed to solve more general crack problems.

PROBLEM STATEMENT AND NUMERICAL SOLUTION ALGORITHM

Dynamic analysis of interface cracks in layered piezoelectric materials with non-linear crack-face boundary conditions under impact loading is investigated. A time-domain boundary element method (TDBEM) in conjunction with a multi-domain technique is developed in order to solve the corresponding initial-boundary value problem. The temporal discretization is performed by the collocation method, while the spatial discretization is carried out by the symmetric Galerkin-method. The 2D time-domain piezoelectric fundamental solutions [3] are implemented in the present time-domain BEM. The intensity factors for the interface crack between two dissimilar piezoelectric materials are obtained from the crack-tip field of the generalized displacements [1]. Two different non-linear crack-face boundary conditions have to be considered in the investigated initial-boundary value problem. At each time instant where positive crack-opening displacements are obtained the Newton-Raphson scheme with backward difference quotients is used to solve the semi-permeable electrical crack-face boundary conditions. In contrast, at time instants where a physically unacceptable crack-face intersection occurs, an iterative crack-face contact analysis is applied to satisfy the mechanical constraint condition. It should be mentioned, that the solution of non-linear crack-face boundary conditions is an application field where the BEM is very attractive and efficient since both, the generalized displacements and the generalized tractions are primary variables in the boundary integral equations.

NUMERICAL EXAMPLE

In the numerical example, we consider a layered, rectangular plate with a central interface crack of $2a$ and the geometrical data $h = 20mm$, $2w = h$ and $2a = 4.8mm$ under impact electromechanical loading as shown in Fig. 1. PTZ-5H is chosen as the material for the domain I while $\mathrm{BaTiO_3}$ is used for the domain II. The normalized dynamic intensity factors $K_1^*(t) = K_1(t)/K_0$, $K_2^*(t) = K_2(t)/K_0$ and $K_4^*(t) = e_{22}^I K_4(t)/(\varepsilon_{22}^I K_0)$, with $K_0 = \sigma\sqrt{\pi a}$ and a being the half-length of the internal crack, are presented in Fig. 2 for the impermeable (imp.) and the permeable (p.) electrical crack-face boundary conditions without and with contact solution (cont.).

a) Corresponding author. E-mail: wuensche@bauwesen.uni-siegen.de

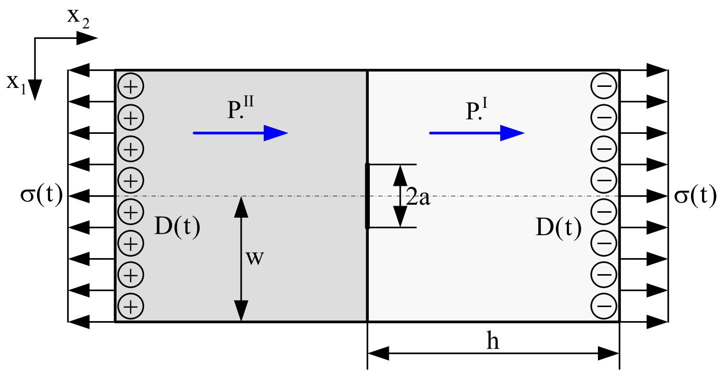

Figure 1. A rectangular plate with a central interface crack

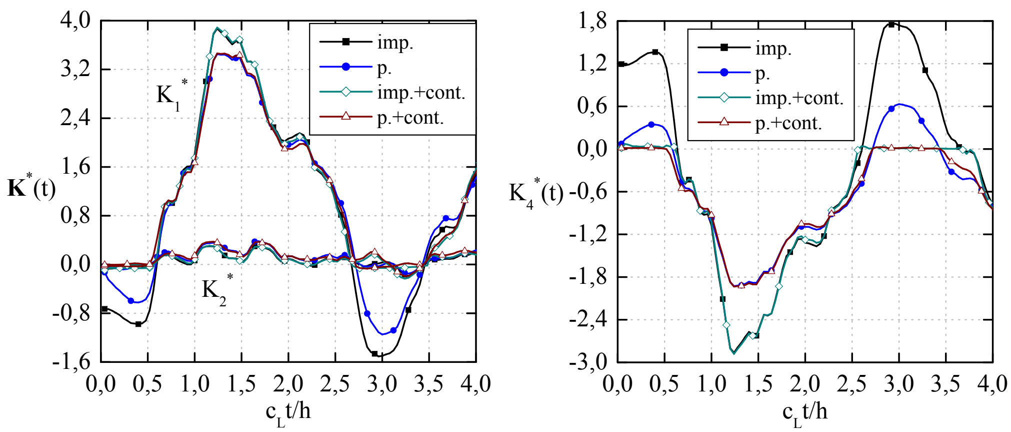

Figure 2. Normalized dynamic IFs for different crack-face boundary conditions

Since a combined electrical and mechanical impact loading is applied the normalized dynamic intensity factors start from a non-zero value due to the quasi-electrostatic assumption for the electrical field. This implies that the cracked plate is immediately subjected to the electrical impact. As clearly observed, the applied electrical crack-face boundary conditions have a significant influence on the normalized dynamic intensity factors. It can be further seen, that the investigated impact loading leads to a physically unacceptable crack-face intersection in different time intervals and therefore a contact solution is required for more realistic crack simulations.

CONCLUSIONS

Dynamic analysis of interface cracks in layered piezoelectric materials with non-linear crack-face boundary conditions under impact loading is considered in this paper. The numerical example indicates a significant influence of the electrical crack-face boundary conditions on the normalized dynamic intensity factors for an interface crack. It can be further observed that the crack-face intersection, mainly induced by the dynamic loading and the scattered wave fields, plays an important role in the dynamic fracture mechanics of layered piezoelectric solids and therefore a contact analysis is necessary in advanced realistic crack simulations. The developed time-domain BEM is very attractive and efficient for the dynamic crack analysis in layered linear piezoelectric solids.

References

[1] Suo Z., Kuo C-M., Barnett D.M., Willis J.R.: Fracture mechanics for piezoelectric ceramics. *Journal of the Mechanics and Physics of Solids* **40**: 739–765, 1992.

[2] Hao T.H., Shen Z.Y.: A new electric boundary condition of electric fracture mechanics and its applications. *Engineering Fracture Mechanics* **47**: 793–802, 1994.

[3] Wang C.-Y., Zhang Ch.: 3-D and 2-D dynamic Green's functions and time-domain BIEs for piezoelectric solids. *Engineering Analysis with Boundary Elements* **29**: 454–465, 2005.