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DEVELOPMENT OF A COHESIVE MODEL FOR DAMAGE SIMULATION IN FERROELECTRIC MATERIALS SUBJECTED TO ELECTROMECHANICAL LOADING

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Piezoelectric materials have widespread applications in modern technical areas such as mechatronics, micro system technology or smart structures, serving as sensors, actuators, transducers, but are brittle and sensitive to fracture. The application of a high electric field or mechanical stresses can cause failure of such devices. Defects may originate from the process of initial polarization during manufacturing or from cyclic electric loading during exploitation. The problem of fracture in piezoelectric ceramics is quite complex and far from exhaustive understanding. Therefore, the creation of an appropriate model to assess fracture behavior is very important for increasing reliability of piezoelectric devices.

A phenomenological model of electromechanical ferroelectric fatigue based on a ferroelectric cohesive law was proposed in [1]. Micro-crack based damage effects in piezoelectric materials are numerically investigated by utilization of a cohesive-type approach [2]. A cohesive zone finite element model for quasi-static fracture of piezoelectric polycrystals was developed in [3].

Many currently presented models are quite complex but still not exhaustive since the microstructural behavior is not realistically formulated. In the presented publication, fracture of ferroelectric materials is studied numerically using an advanced exponential cyclic cohesive zone model together with the ferroelectric bulk material properties. The implemented irreversible cohesive law allows damage accumulation during (re)loading (Fig.1). Change in polarization direction (as a result of possible switching of ferroelectric domains) around cracks due to applied electromechanical loading and its influence on the cohesive element behavior is considered (Figs.1, 2). In order to represent the permittivity of grain boundaries or crack faces a parallel plate capacitor model is implemented into cohesive law. Results plotted in Fig. 1 and 2 are calculated for the PZT-5H test specimen subjected to the uniaxial mechanical preloading followed by the electrical cycling. It is worth to note that damage in the cohesive element is accumulated merely due to the cyclic electric loading. It could be concluded that neglect of the possible domain switching might lead to the incorrect results in cohesive elements behavior.

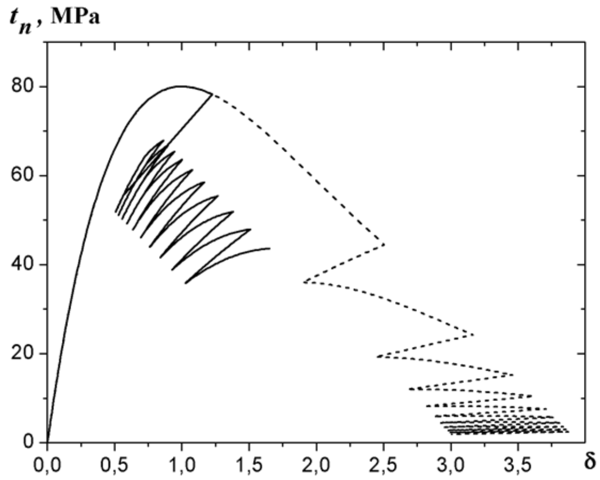

Figure 1. Response of the CZE to the electric cyclic loading in cases when domain switching is considered (solid line) or neglected (dashed line).

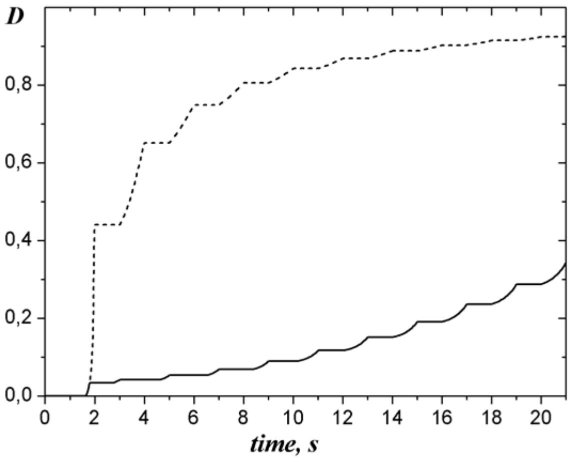

Figure 2. Difference in damage accumulation patterns when taking into account domain switching.

As an example of possible model applications the numerical simulations are also performed for a crack in ferroelectric bulk material. The results show realistic electric field influence on the damage initiation and accumulation near the crack tip due to cyclic electric loading.

The implemented electromechanical cohesive zone model forms a solid basis for simulations of fatigue and damage occurring in the microstructure of smart ceramics as well as in smart devices.

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