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DEFORMATION OF ELECTROELASTIC MATERIALS WITH DISPERSED MICRODAMAGEABILITY

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Piezoelectric ceramics has been indispensable for electromechanical transducers, sensors, actuators. When subjected to loading, these materials can fail prematurely due to the propagation of flaws or defects induced during manufacturing process and by the in-service electromechanical loading. There is therefore a need for models that describe the deformation process and predict the electroelastic properties of such piezoelectric materials.

We consider transversally isotropic piezoelectric material. To describe progressive accumulation of microdamages, the Daniels structural model is used. The microdamageability is considered as a process of origin of a system of flat elliptic or circular microcracks randomly dispersed over volume, the concentration of which increases with a load. The general procedure of the model construction taking into account the coupled process of damageability and deformation of a material consists of two stages. At the first stage we derive constitutive equations for a damaged material, choose the fracture criterion and low of microdamage distribution. With respect to transversally isotropic material, which is simulating pre-polarized piezoceramic, the Mises–Hill strength criterion can be used.

The main point of this model is outlined in detail in references [1].At the second stage, the method for determining effective electroelastic properties of the damaged medium and the model of accumulation of microdamages are employed. In accordance with the generalized Eshelby principle, fractured electroelastic materials can be simulated by a continuous anisotropic medium. The energy method is based on the principle of equivalence of the deformation energy of fractured piezoelectric materials and the energy of medium, which is modeling these materials as a continuous medium. The key point of this approach is to determine the densities of the released elastic and electric energy. With regard to inhomogeneous electroelastic materials, the Eshelby principle is modified due to the need to take into account the electric component in the overall energy balance of the body. For this purpose, a local criterion of microfracture for electroelastic materials is used. Under condition of jump of the electric field on the crack faces i.e. crack opening, there is the electrical component of the released energy. The change of density of electrical energy in the material does not exist under sliding mode and tearing mode because of preservation of contacts between the faces of crack. It will be noted that such phenomenon for the elastic energy does not occur. To determine the released energy $\bar{W}$ it is necessary to have the solution for individual crack i. e. to have solution about the distribution of displacements on the surface of crack. Another way could be one of the two equivalent tasks: determining the intensity of released energy G_i^n $(i = 1,2,3)$ or stress intensity factors K_i^n $(i = 1,2,3)$ at the crack under these basic types of deformation caused by loading at infinity. If such solutions are known, the density determination of the released mechanical energy during the formation of the *n*-individual crack could be expressed in the form

$$\overline{W}_m^n = \int_{s_n} \sum_{i=1}^{3} G_i^n \left(a_{klmn}^{(0)}, \sigma_{i3}^n, \theta^n, \psi^n, \varphi^n\right) ds_n . \quad (1)$$

$$\overline{W}_m^n = \frac{1}{3} \oint_{c_n} \sum_{i=1}^{3} r\, S_i \left(a_{klmn}^{(0)}, \theta^n, \psi^n, \phi^n\right) \left(K_i^n\right)^2 dc_n . \quad (2)$$

where G_i^n, K_i^n, S_i $(i = 1,2,3)$ are the intensity of released energy, stress intensity factors and the compliance of the material in the plane of the crack accordingly, the definition of which is an independent problem for individual cracks in anisotropic material; $r -$ distance from the local coordinate system associated with a crack to the tangent at the current point of the cracks contour $c_n, a_{klmn}^0, \vartheta^n, \psi^n, \varphi^n$ are compliances in a continuous orthotropic medium and angles of the crack orientation in the main coordinate system.

We suppose that microdamages in form of flat circular cracks appear in piezoelectric materials under loading. This type of microfracture most unfavorable to the material because of the degree of influence of microcracks on the stiffness of the material is mainly related to the area and volume of cracks opening. Besides, that in during deformation, cracks do not grow, do not interact. The volume density (concentration) of microdefects varies with increase in the level of average stresses due to feature of orientation anisotropic materials. Destruction of the structural elements occurs at the different levels of the stress due to random nature of the orientation and differences of the values of ultimate strength of the structural elements in different directions. It will be noted that for cracks located in an anisotropic plane $(\vartheta = 0)$ containing the axis of polarization $0x_3$, there is no the analytical solution to determine the stress intensity factor for circular cracks in closed form. Therefore, the released energy for a circular crack in an orthotropic plane is approximately determined by using the relations for the intensity of released energy in the tunnel crack under normal rupture, longitudinal and lateral shifts

As an example that illustrates the approach presented to describing the coupled process of deformation and dispersion fracture, we consider the transversely isotropic piezoelectric ceramics under uniaxial tension in direction of polarization and with given the component of electrical field E_3^0. We consider circular microcracks in the plane of isotropy. It is assumed that the density of microcracks is described by two-parameter distribution function of the ultimate strength of the material of the structural elements. We assume that the amount of crack opening for a particular case is the volume of the circular crack perturbation region. It is shown that the discontinuity of this kind leads to a significant decrease in the values of the dielectric constant and piezoelectric coefficients. Decrease in the absolute values of these parameters is directly proportional to the volume concentration of microdefects. The results obtained are in a good agreement with the experimental data of the developer and manufacturer of "ELPA" piezoceramic materials, as well as with the results of theoretical and experimental studies devoted to determining the electroelastic characteristics of piezoelectric ceramics with different porosity.

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3.V.T. Grinchenko, A.F.Ulitko, N.A.Shulga, Electroelastcity, Kyiv Sciences Dumka, 1989, 279 p. (In Russian)

ДЕФОРМИРОВАНИЕ ЭЛЕКТРОУПРУГИХ МАТЕРИАЛОВ С РАССЕЯННОЙ МИКРОПОВРЕЖДАЕМОСТЬЮ

Предложена методика построения уравнений состояния для повреждающихся путем растрескивания электроупругих материалов, обладающих пьезоэффектом. В основу методики положен принцип эквивалентности энергии деформирования микронеоднородной трещиноватой и моделирующей ее континуальной среды в сочетании с модифицированным вариантом принципа Эшелби для определения энергии освобождения при образовании микротрещин.

На примере предварительно поляризованной керамики, ослабленной системой круговых трещин, нормальных к оси поляризации, показано, что нарушение сплошности такого вида приводит к понижению значений модулей упругости, пьезомодулей и диэлектрической проницаемости. Снижения последних двух физических величин по абсолютным зачениям прямо пропорциональны объемной концентрации микродефектов. Понижение значений упругих параметров в зависимости от увеличения концентрации микродефектов носит нелинейный характер.