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ELECTROELASTIC FIELDS CONCENTRATIONS AND POLARIZATION SWITCHING BY CIRCULAR ELECTRODES IN PIEZOELECTRIC DISK COMPOSITES

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Summary The linear axisymmetric electroelastic problem for a piezoelectric composite with an electrode was analyzed theoretically. A numerical and experimental investigation of a piezoelectric disk composite with circular electrodes was also conducted. It is found that high values of electroelastic fields arise in the neighborhood of the circular electrode tip. These values are sufficiently high to produce polarization switching, electromechanical failure and dielectric breakdown.

INTRODUCTION

Piezoelectric ceramics play a significant role as active electronic components in many areas of science and technology, such as new biomaterials, smart structures and MEMS. Stress and electric field concentrations in the neighborhood of a crack tip or an electrode tip in piezoelectric ceramics can result in mechanical and electrical degradation. It is therefore important to understand the electroelastic fields in the vicinity of the crack or the electrode in piezoelectric ceramics and to improve the device's design and performance. Work on piezoelectric fracture mechanics has been reported by several research groups [1-4]. Recently, Shindo et al. have performed the indentation fracture [5], single-edge precracked-beam [6], and modified small punch [7] tests, and corresponding finite element analyses on piezoelectric ceramics.

Several theoretical investigations of piezoelectrics with electrodes have been presented. Shindo et al. [8] considered the behavior of the elastic and electric variables in the vicinity of a surface electrode attached to a piezoelectric ceramic, and found that high values of electroelastic fields arise in the neighborhood of the electrode tips. Ye and He [9] analyzed the distribution of the displacement and electric potential near the edges of parallel electrodes in piezoelectric ceramics. Some designs are in existence for piezoelectric MEMS devices with circular electrodes [10,11]. Bonded piezoelectric and elastic disks with a circular electrode embedded at the interface are also used as sounders. The purpose of this paper is to report a theoretical, numerical and experimental evaluation of electroelastic fields in the neighborhood of a circular electrode in a piezoelectric disk composite. A nonlinear finite element model incorporating the polarization switching mechanism is used to predict electroelastic fields concentrations ahead of circular electrodes in piezoelectric disk composites.

A SEMI-INFINITE PIEZOELECTRIC COMPOSITE WITH A CIRCULAR ELECTRODE

The electroelastic response of two-dissimilar piezoelectric half-spaces with an electrode is analyzed based on the linear theory of piezoelectricity. Hankel transforms are employed to reduce the electroelastic problem to the solution of a pair of dual integral equations. Then the closed form solutions of these dual integral equations are obtained.

A PIEZOELECTRIC DISK COMPOSITE WITH CIRCULAR ELECTRODES

Consider the piezoelectric disk I with radius b^{I} and thickness h^{I} as shown in Fig. 1. The piezoelectric disk is bonded to the upper surface of the piezoelectric disk II with radius b^{II} and thickness h^{II}. The origin of the coordinates (r, θ, z) coincides with the center of the interface considered as z=0, $0 \leq r \leq b^{\mathrm{I}}$. Three parallel circular electrodes of radius a lie in the planes z=-h^{II}, 0, h^{I}. Let the voltage applied to the internal electrode surface be denoted by V_0. The surface electrodes are grounded.

The enhanced electroelastic fields level at the electrode tips results in localized domain switching. When the electrical and mechanical work exceeds a critical value, polarization switching occurs [12]. The model is used to predict the

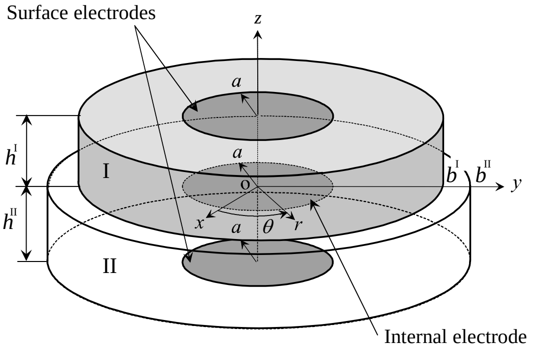

Fig. 1 Piezoelectric disk composite with circular electrodes

macroscopic nonlinear response involving 180° and 90° polarization switching.

The axisymmetric models were generated using the commercial finite element method (FEM) software package ANSYS. The surface electrode layers were not incorporated into the model. Four-node elements PLANE 13 were used in the model.

EXPERIMENTAL PROCEDURE

Strain measurements were performed on soft PZT piezoelectric ceramic disks (h^{II}=0 mm), C-91 (Fuji Ceramics Co., Ltd., Japan).The coercive field was approximately E_c = 0.35 MV/m. Disk-shaped specimens of dimensions 30 mm diameter by 5.0 or 1.0 mm thickness were prepared, and nickel-based electrodes with 20 mm diameter were deposited onto the top and bottom faces. The high-voltage amplifier used for the study was limited to 1.25 kV so that a 1.25 MV/m field corresponded to a sample thickness of 1.0 mm. Six strain gauges (KFL-02-120-C1-16 from Kyowa Electronic Instruments Co., Ltd., Japan) were placed at 60° increments around the circular electrode tip region. The centers of the strain gages were at approximately 0.05, 0.1, 1.5, 2.5, 3.0 and 4.0 from the electrode tip. The sensors have an active length of 0.2 mm.

RESULTS AND DISCUSSION

Semi-infinite piezoelectric composite

Consider the problem of an infinite piezoelectric composite ($h^{\mathrm{I}} \to \infty$, $h^{\mathrm{II}} \to \infty$, $b^{\mathrm{I}} \to \infty$, $b^{\mathrm{II}} \to \infty$). It is found that high values of electroelastic fields arise in the neighborhood of the circular electrode tip.

Circular piezoelectric disk composite

For the purpose of comparing the numerical simulations directly with measured strain, the radial strains ε_{rr} of nodes placed at 0.05, 0.1, 1.5, 2.5, 3.0 and 4.0 mm from the electrode-tip (corresponding to the strain gage location) in the finite element model are extracted. The computed strains on the lower surface of the specimen of h^{I}=5 mm (h^{II}=0 mm) under various values of electric field E_0=V_0 / h^{I} are compared with the measured data in Fig. 2.

Fig. 3 displays the computed radial strain ε_{rr} on the interface of bonded C-91 and brass [13] disk of a=10 mm against the electric field E_0 for r-a=1.5 mm and variaus values of h^{II}, while letting b^{I}=15 mm, b^{II} =25 mm and h^{I}=1 mm. The experimental data for C-91 disk (h^{II}=0 mm) are also plotted. The increase of the negative electric field causes the polarization switching, and the strain vs. electric field curves show the nonlinear behavior. The results for two bonded C-91 composite disk are also obtained.

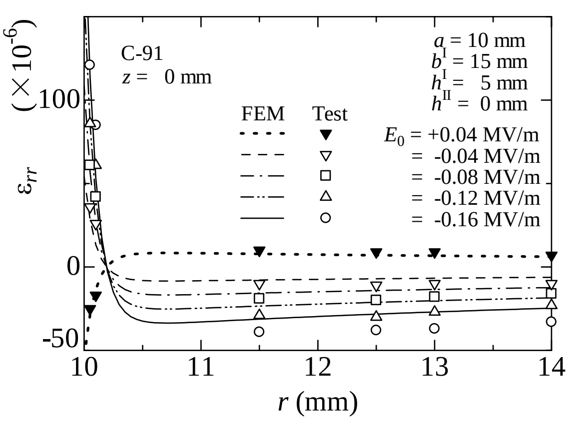

Fig.2 Radial strain ε_{rr} vs r: h^{I}=5mm, h^{II}=0mm

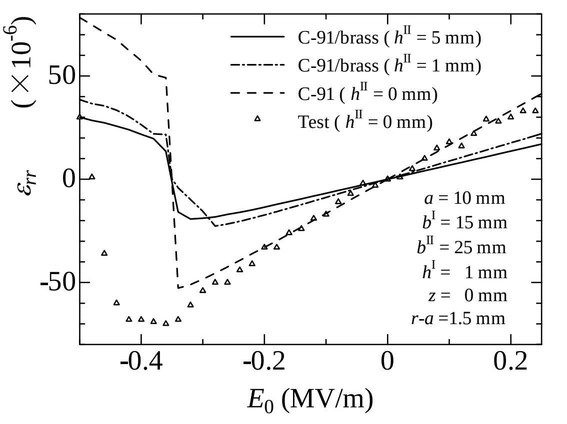

Fig.3 Radial strain ε_{rr} vs electric field E_0

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