

FRACTURE IN PIEZOELECTRIC CERAMICS AND PZT/ELECTRODE INTERFACES

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The fracture behavior of piezoelectric ceramic (PZT) as well as metal/PZT interfaces under mechanical and electric loading is examined in four and three point bending under conditions of controlled crack growth (see Fig. 1). The experiments are performed in a custom made very stiff testing machine. A special modulation technique, i.e. a small signal compliance method, allows in situ determination of the mechanical compliance C_m , the capacitance C_e , and the piezoelectric compliance C_p as a function of the crack length. By calculating the derivatives of these generalized compliances with respect to the crack surface area we get the total linear energy release rate.

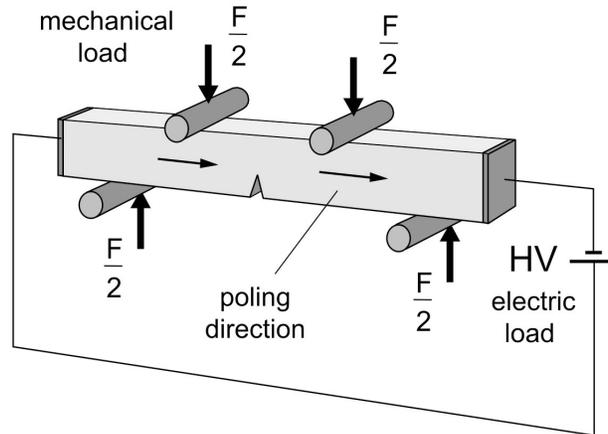


FIGURE 1. Schematic four point bending set-up.

The energy release rate is given in eq. (1) representing a generalized Irwin-Kies-Relation (Z. Suo [1]). The superscript ' V ' stands for constant voltage and ' F ' for constant force. We have

$$G_{tot} = \frac{F^2}{2} \frac{\partial C_m^V}{\partial A} + \frac{V^2}{2} \frac{\partial C_e^F}{\partial A} + FV \frac{\partial C_p}{\partial A} \quad (1)$$

$$\text{with } C_e^F = \left(\frac{\partial Q}{\partial V} \right)_F, \quad C_m^V = \left(\frac{\partial \Delta}{\partial F} \right)_V, \quad \text{and} \quad C_p = \left(\frac{\partial Q}{\partial F} \right)_V = \left(\frac{\partial \Delta}{\partial V} \right)_F \quad (2)$$

Scrutinizing the modulation technique and the results we found that the small displacement modulation with an amplitude of about 30 nm yields pure linear elastic response of the material. Thus, we measure solely the intrinsic toughness due to the creation of new crack surface. It follows that the linear elastic energy is separated from inelastic and other dissipative processes.

This method was applied for ferroelectric bulk material (PZT PIC151) as well as for metal ceramic interfaces in commercial piezoelectric actuators. In the case of PZT bulk material measurements with insulating and conducting cracks were performed. The effect of an external electric field is quite different. In the case of the insulating crack an electric field of 500 V/mm yields a toughness change of the order of 10 %. This is much less than theoretically predicted for an impermeable crack, implying that the interior of the crack is highly permeable to electric fields. In the case of a conducting crack (see also Heyer et al. [2]), realized with a NaCl-solution in the crack interior, the effect of a corresponding electric field is of the order of 100 %. For example, with the appropriate field direction the crack grows by its own without any mechanical loading, which is in agreement with theoretical predictions.

For PZT bulk material as well as for metal ceramic interfaces in multilayer actuators the experimental data are compared with FEM-calculations, taking into account the piezoelectric coupling and the layout of the inner metal electrodes of the actuators. Technically it is more difficult to achieve stable crack growth in metal ceramic interfaces than in PZT-bulk material. The fracture toughness was measured for different poling configurations.

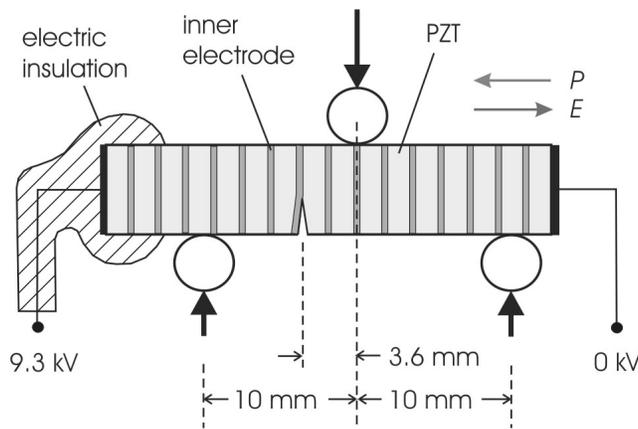


FIGURE 2. Schematic 3-point-bending arrangement of a multilayer actuator specimen for mixed mode loading and external electric field E (P = polarization).

In order to investigate mixed mode loading we performed an experiment in symmetric three point bending with stable crack growth. The notch is shifted away from the middle position between the lower support rollers (see Fig. 2), which yields a combination of the stress intensity factors K_I and K_{II} . During the measurement the crack does not bend off but stays in the interface. Thus, a new method is presented which allows for the determination of the total linear energy release rate including the mechanical, the electric and the piezoelectric contribution. A paper [3] has been submitted and two others are in preparation.

References

1. Suo, Z., *ASME 1991*, AD-Vol. **24**/AMD-Vol. **123**, 1-6
2. Heyer, V., Schneider, G.A., Balke, H., Drescher, J., and Bahr, H.-A., *Acta Mater.*, vol. **46**(18), 6615-6622, 1998
3. Jelitto, H., Felten, F., Swain M.V., and Schneider G.A., *J. Appl. Mech.*, submitted