

# Electric and Mechanic Fracture Toughness for Conductive Cracks in PZT 8 Ceramics

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Metal electrodes embedded in ferroelectric ceramics may function as conductive cracks. In this paper, we report the experimental results on the fracture behavior of conductive cracks in poled lead zirconate titanate PZT 8 ceramics (Morgan Electro Ceramics) under purely mechanical or electrical loading.

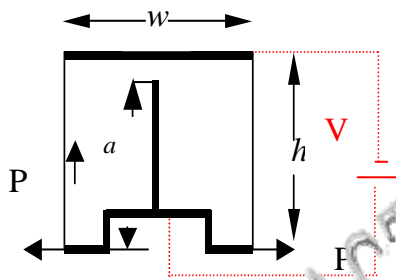


Fig. 1 Schematic of the sample and loading condition.

Fig. 1 shows the used compact tension (CT) samples with a width of  $w=9\text{mm}$ , a length of  $h=10\text{mm}$  and a thickness of about  $B=3\text{mm}$ . The notch ( $a$ ) tip curvature was around  $1\text{mm}$ . The arrow in Fig. 1 on the left side of the sample represents the poling direction. Silver paint was filled into the notch (crack) to make it function as an electrode. Finite element analysis (FEA) was carried out to obtain the stress intensity factor ( $K_M$ ) and the intensity factor of electric field ( $K_E$ ), which were defined by

$$K_M = \sigma_x(s)\sqrt{2\pi s}, \quad K_E = E_y(s)\sqrt{2\pi s} \quad (1)$$

where  $s$  is the distance from crack tip along the crack propagation direction,  $\sigma_x$  is the stress normal to the crack direction and  $E_y$  denotes the electric field along the crack direction. The numerical results of  $K_M$  and  $K_E$  versus the normalized effective crack length,  $t=a/h$ , which was  $t=0.45$  in the experimental tests, are given respectively by

$$K_M(t) = \frac{P}{E\sqrt{w}} (-33.03294 + 231.74762 t - 459.75758 t^2 + 339.39394 t^3), \quad (2)$$

$$K_E(t) = \frac{V}{\sqrt{h}} (-3326.69 + 23678.57 t - 44885.71 t^2 + 32000 t^3). \quad (3)$$

where  $P$  is the mechanical force in Newton,  $V$  is the electrical voltage in kV and the length dimensions in meter. The electric and mechanical energy release rates,  $G_E$  and  $G_M$ , in units of  $\text{J/m}^2$  are given by

$$G_M = (0.26834 - 3.12789 t + 13.34729 t^2 - 24.69638 t^3 + 16.97133 t^4) P^2, \quad (4a)$$

$$G_E = (-14.98088 + 146.98518 t - 541.45124 t^2 + 902.97243 t^3 - 558.60534 t^4) V^2. \quad (4b)$$

The experimental data of  $G_M$  and  $G_E$  under purely mechanic and electric loading follow Weibull

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distributions. For the PZT 8 ceramics, the averaged values of  $G_{IC}^M$  and  $G_{IC}^E$  are  $11.0 \text{ J/m}^2$  and  $194.27 \text{ J/m}^2$ , respectively, indicating that  $G_{IC}^E$  is about 20 times higher than  $G_{IC}^M$ . Both the mechanical toughness and electric fracture toughness are close to the corresponding values of poled PZT 4 ceramics [1], but much lower than the corresponding values of depoled PZT 4 ceramics [2].

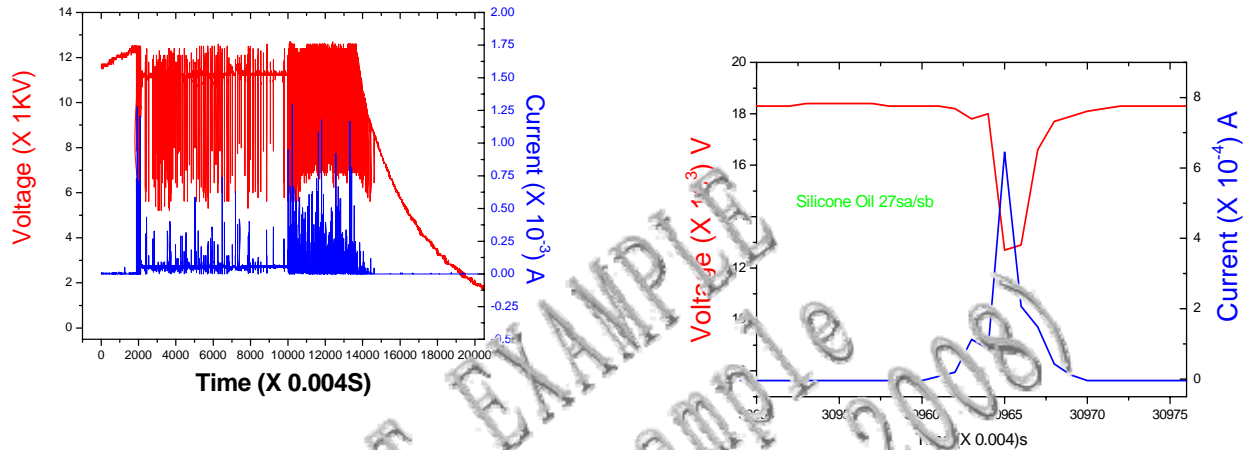


Fig. 2(a) Voltage and current during the failure.

Fig. 2(b) Voltage drop and current pulse.

Fig. 2(a) shows the voltage and current recorded by a digital oscilloscope during the electrically fracturing process, while Fig. 2(b) illustrates a typical current pulse and the associated voltage drop. The magnitude of the current pulse is at the order of  $10^{-6} \text{ A}$ . With the results, we calculated the work done by the electric field. The average work done by electric field on the specimen under the purely electric loading is  $20.77 \text{ J}$ , which is much higher than the value,  $0.003 \text{ J}$  estimated by multiplying the electric fracture toughness with the area created during fracture. The large amount of energy dissipation was mainly caused by electric discharge, as shown in Fig. 3.

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Fig. 3 Electric discharge.

## Reference

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