# CHARGE-FREE ZONE MODEL AND FAILURE CRITERION FOR CONDUCTIVE CRACKS IN DIELECTRIC AND PIEZOELECTRIC CERAMICS*

Tong-Yi Zhang
Department of Mechanical Engineering
Hong Kong University of Science and Technology
Clear Water Bay, Kowloon, Hong Kong, China

## Abstract

Analogous to the dislocation-free zone (DFZ) model, we propose a charge-free zone (CFZ) model to understand the failure behavior of conductive cracks in dielectric and piezoelectric ceramics under combined electrical and mechanical loading. The CFZ model treats dielectric and piezoelectric ceramics as mechanically brittle and electrically ductile. Charge emission and charge trapping consume more energy and thus lead to electric ductility. In the CFZ model, the local electric intensity factor has a non-zero value and consequently there is a non-zero local electric energy release rate, which contributes to the driving force to propagate the conductive crack. The merit of the CFZ model, similar to the DFZ model, lies in the ability to apply the Griffith criterion directly to link the local energy release rate to the fracture toughness in a completely brittle manner. As a direct consequence, an explicit failure criterion results from the CFZ model, which is able to predict the failure behavior of conductive cracks in dielectric and piezoelectric ceramics under combined electrical and mechanical loading. When the critical stress intensity factor is normalized by the critical stress intensity factor under purely mechanical loading and the critical electric intensity factor is normalized by the critical electric intensity factor under purely electric loading, the failure criterion for conductive cracks in dielectric and piezoelectric ceramics is described by a quadratic function of the normalized electric intensity factor versus the normalized stress intensity factor. The theoretical predictions have been verified by experimental observations. The significance of the failure criterion is that it provides designers of electronic and electromechanical devices with information on the electrical fracture toughness and the mechanical fracture toughness. The advantage of applying the failure criterion lies in the ability to predict the critical electric field and the critical mechanical load at which a dielectric or piezoelectric ceramic material containing a conductive crack or an internal electrode fails under combined electrical and mechanical loading. The critical electric field and the critical mechanical load are functions of the crack dimensions or the length of the electrode, while the electrical fracture toughness and the mechanical fracture toughness are both material properties. Thus, one can predict the critical electric field and the critical mechanical load when information on the sample geometry and on the electrical and mechanical fracture toughness is available.

* This work was supported by a grant (N_HKUST602/01) from the Research Grants Council of the Hong Kong Special Administrative Region, China. Drs. M.H. Zhao, T.H. Wang, Y. Wang and R. Fu and Mr. G.N. Liu participated in this study. TY Zhang thanks the Croucher Foundation for the Croucher Senior Research Fellowship Award, which gave him more research time by releasing him from teaching duties.