THE JUMPING DIELECTRIC BREAKDOWN BEHAVIOR INDUCED BY CRACK PROPAGATION IN FERROELECTRIC MATERIALS: A PHASE FIELD STUDY

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Abstract
Ferroelectric materials often experience fracture and dielectric breakdown under large mechanical and/or electrical loadings. These two failure behaviours can affect each other and may lead to new phenomena. In the present study, a new type of jumping dielectric breakdown are predicted during the crack propagation in ferroelectric materials by using a phase field model with multiple order parameters. The driving force for the jumping dielectric breakdown induced by crack propagation is analysed based on the concept of configurational force. It is found that the jumping dielectric breakdown is attributed to the competition between the crack propagation and the breakdown initiation at the moving crack tip. The breakdown pattern is related to the polarization domain structure and thus greatly influenced by the applied electric field and the crack boundary conditions. Further, the jumping breakdown associated with possible mechanical degradation on the material can change the driving and resistant forces for the crack propagation. The present work not only suggests a novel dielectric breakdown behaviour during crack propagation but also provides new insights into the coupling failure of ferroelectric materials.

1. Introduction
Ferroelectric materials have excellent electromechanical coupling properties and have been widely used in various electromechanical devices. The materials are usually subjected to large mechanical loads and high electric fields in extreme working environments. Consequently, fracture and dielectric breakdown may occur in ferroelectric materials, which limits their applications in devices. Recently, the authors developed a multiple-order-parameter phase field model for the coupling evolution of polarization, fracture and dielectric breakdown in ferroelectric (Zhang et al., 2022). In this study, the developed model is reconsidered in a thermodynamically consistent manner. The configurational forces (Gurtin, 2000) corresponding to polarization, fracture and dielectric breakdown are derived from the multiple-order-parameter phase field model to analysis the driving force of their evolution. Based on the model, a jumping dielectric breakdown around the moving crack is predicted in ferroelectric materials. The influences of the mobility parameters, applied electric field, crack boundary conditions and the mechanical degradation on the overall evolution process are investigated. The present work not only suggests a novel dielectric breakdown behaviour during crack propagation but also provides new insights into the coupling failure of ferroelectric materials.

2. Results
Taking advantage of the configurational-force-based driving force analysis and systematic parametric study, it is found that the dielectric breakdown along the propagating crack path results from the concentration of the electric field around the impermeable crack tip and the crack-induced breakdown channels will inhibit movement of the domain walls. A faster crack propagation resulting in sparser breakdown points along the crack path shown in the simulations implies that breakdown jumping behavior is induced by the competition between the moving of the crack tip and the initiation of the breakdown. The crack-induced breakdown pattern can be greatly influence by the external applied electric field and the crack boundary conditions for electric displacement and polarization because the polarization domain structure and the internal local electric field is sensitive to them. Besides, the breakdown points can influence both the driving and resistant forces for the crack propagation. In particular, the breakdown can decrease the crack driving force and the decrease is heavier if the breakdown cause degradation on the elastic properties. While only the breakdown with degradation on the fracture toughness can change the crack resistant force. Moreover, the dynamically

evolving breakdown with fracture toughness degradation shows dramatic effects on the crack resistant forces depending on the relative evolution rate of the crack and breakdown.

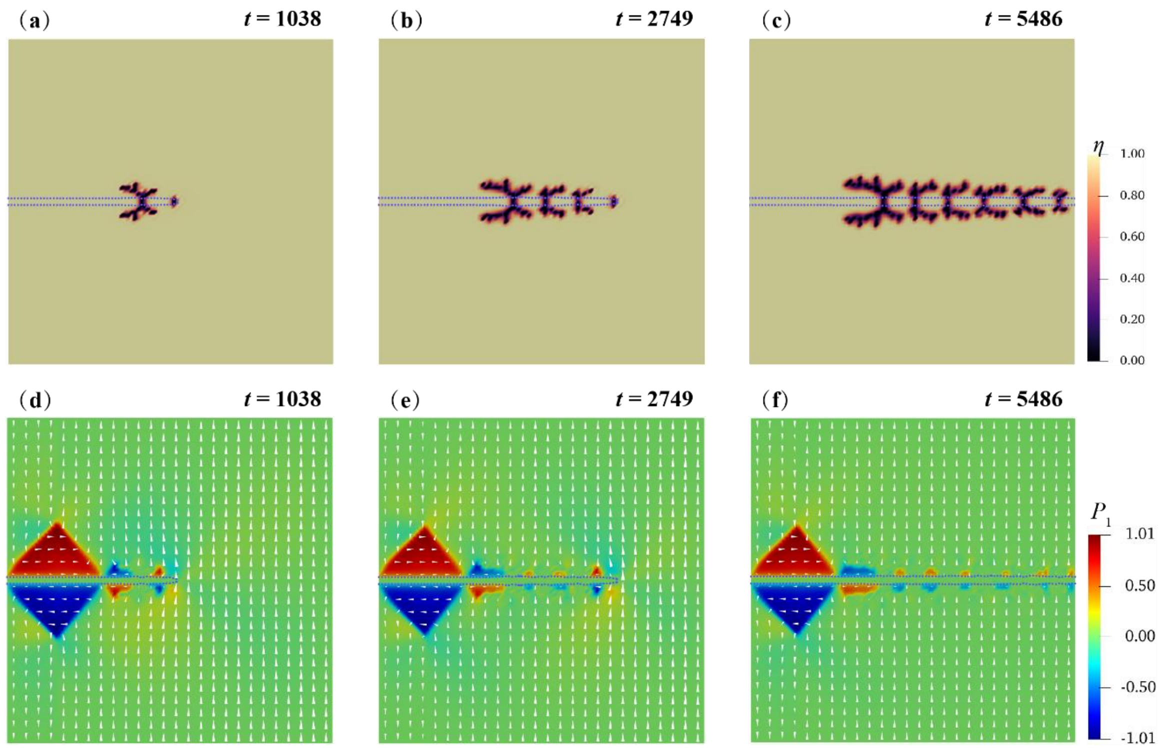

Fig.1 Temporal evolution of dielectric breakdown and spontaneous polarization during crack propagation, in which the dotted lines denote the cracks. (a)-(c) dielectric breakdown, (d)-(f) polarization component P_1 and polarization vectors.

3. Conclusions

Analogous to the competition between the crack propagation and the crack-tip dislocation emission predicted by Liang et al. (2019), the predicted jumping crack-tip dielectric breakdown may bring new behavior mechanism around the crack tip in the crystal. It provides new insights into the coupling failure of ferroelectric materials.

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