Ferroelastic Domain Switching for Toughening of Ceramics

Mahamudu Mtebwa, Nava Setter, Enrico Colla, Tomas Sluka
Ceramic Laboratory, Swiss Federal Institute of Technology

Introduction
Ferroelastic toughening is considered to be one of the promising mechanisms for the improvement of fracture toughness in ferroelectric-ferroelastic ceramics as it does not deteriorate the functional properties. High stresses developed during crack propagation ahead of the crack tip in a ferroelectric material result into ferroelastic domain switching in the process zone [1].

Number of macroscopic measurements of fracture toughening in ferroelectrics have been assigned to ferroelastic toughening involving x-ray diffraction (XRD) and atomic force microscopy (AFM) [1, 2]. In this work both modeling and experimental work have been done to study the ferroelastic toughening mechanism through local observation of ferroelastic domain switching during crack propagation by using piezoresponse force microscopy (PFM) and phase field simulation.

Phase-Field Modeling

- Time dependent Landau Ginzburg equation gives the evolution of spontaneous polarization of the system with time. Polarization is the primary order parameter and is continuous on domain walls.

\[
\frac{1}{\Gamma} \frac{\partial P_i}{\partial t} = -\frac{\partial \Psi}{\partial E_i} \Rightarrow R \{\text{polarisation}\}
\]

\[
\left( \frac{\partial \Psi}{\partial E_i} \right)_{j} = 0 \Rightarrow u_i \{\text{displacement}\} \left( \frac{\partial \Psi}{\partial E_1} \right)_{j} = 0 \Rightarrow \varphi \{\text{Electric potential}\}
\]

Where: \( \Psi \) : Helmholtz free energy density
\( E_i \) : Electric field
\( u_i \) : Mechanical strain

\[
e_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)
\]

Experimental Technique

- Actuator contracts under voltage
- Actuator with indented sample expands when voltage is released
- Experimental technique developed in this work to control crack propagation. The Crack propagation on half cut sample of commercial soft PZT mounted on AFM stage is controlled by reducing D.C voltage applied on multilayer actuator.

Experimental Results

- Before crack propagation
- After crack propagation
- Domain structure at the crack tip of the PZT sample with controlled crack growth. (a) AFM image, (b) PFM amplitude and (c) PFM phase. Crack path on PFM images indicated by a yellow line. No change in domain structure was observed after crack propagation.

Conclusions

- The experimental method to control crack growth by using piezoelectric multi layer actuator has been developed.
- The AFM-PFM results have shown no significant change in the domain structure in bulk PZT induced by crack propagation. This could be attributed to the surface charge pinning effect.
- In the model, a 23% lower change in the free energy density of the ferroelectric phase under 100 MPa externally applied stress as compared to the paraelectric (cubic) phase suggests that ferroelectric toughening mechanism could be responsible for minimizing the total energy by change in domain structure.
- Further work is planned to involve experimental study of ferroelastic domain switching in single crystals.

References