Poling of Ferroelectric Ceramics

E. Bassiouny

Department of Mathematics, Faculty of Science, Cairo University, Fayoum, Egypt

Abstract: In this study, we use the model Basic Equations to deduce a one-dimensional model for the description of the poling of ferroelectrics ceramics. This is built within the scheme of the thermo dynamical theory of internal variables. The model produces both plastic and electric hysteresis effects in the form of "plasticity", i.e., rate-independent evolution equations for the plastic strain and the residual electric polarization and both mechanical and electric hardenings. The influence of stresses on ferroelectrics hysteresis loops through piezoelectricity and electrostriction is a natural outcome of this model. Some simple experimental methods for the determination of the material coefficients of the considered ceramics are suggested.

Key words: Ferroelectrics, phenomenological model, poling of ceramics, constitutive equations, internal variables

INTRODUCTION

It is only recently that general approaches have been presented for the description of coupled electromechanical behaviors of electrically polarized (as also magnetized) deformable solids and, more particularly, crystals. While accounting for some microscopic features, these works offer a fully deductive, phenomenological scheme. Among these, the approach by Collet and Maugin (1974), Maugin and Eringen (1977), Maugin (1980), Maugin and Pouget (1980) and Maugin (1988), following the pioneering works of Toupin, Eringen, Tiersten and others, is based on the fruitful notion of principle of virtual power (for finite velocities and without thermodynamical restrictions). Basing on previous model Bassiouny et al. (1988a, b) and Bassiouny (2005) were a framework for phenomenological constitutive laws capable of handling complex multi-axial electromechanical loading and making use of concepts of phenomenological plasticity theory including yield surfaces and isotropic and kinematic hardening was developed and the polarization response of the material during initial poling is characterized and hysteresis loops during cyclic electrical loading were given. This model presents a study to deduce a one-dimensional thermodynamical model for the description of the poling of ferroelectric ceramics.

A rather complete phenomenological constitutive model for ferroelectric materials subject to switching has been developed by Kamlah and Tsakmakis (1999) and Kamlah and Böhle (2001). This constitutive model is based on a framework akin to that of Bassiouny et al. (1988a, b) and uses a number of non-linear functions to represent behavior during switching.

The essential ferroelectric property is the possibility of reversal, or change in orientation, of the polarization direction by an electric field. The hysteresis loop is a manifestation of this key property. Additionally, ferroelectricity is characterized by a specific property: mechanical and electric loads of sufficient magnitude may change the dipole orientation of unit cells, leading to domain switching and domain wall motion (Kamlah and Liskowsky, 2005).

The key physical phenomena governing the non-linear response of ferroelectrics below the Curie temperature is switching of the remnant electrical polarization of crystalline material between distinct polarization states. When the remnant polarization switches between distinct states, the switch is in some cases accompanied by a change of shape of the unit cell, giving rise to remnant strain. Consequently, switching may be driven by stress ( termed ferroelastic switching) or by electric field (Huber and Fleck, 2001).

The poling process may differ from one substance to another. Mechanical stresses may play a role in the poling. For instance, some Perovskit ferroelectrics such as BaTiO₃, it is often straightforward to obtain a single domain plate by application of electric field alone, while for other, such as PbTiO₃, it is easier to remove a-axis type domain with an applied stress in the plane of the plate while orienting c-axis or 180 domains with a field (Dungan and Storz, 1985).

An alternative procedure for poling ferroelectrics is to switch reverse domains below the Curie temperature with electric fields higher than the coercive field. For several materials high coercivity allows poling in this way only near to Tc, but in most materials electrical poling may be