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Electrical Hysteresis in Rigid Ferroelectric Bodies

Mawafag F. Alhasadi, Pankaj Ghansela, Qiao Sun, Salvatore Federico*
Department of Mechanical and Manufacturing Engineering, The University of Calgary, Calgary, Canada
* salvatore.federico@ucalgary.ca

ABSTRACT

The early models of rate-independent plasticity (Green and Naghdi, 1965, *Arch. Rat. Mech. Anal.*, 18, 251-281; Kratochvil and Dillon, 1969, *J. Appl. Phys.*, 40, 3207-3218) were based on the formulation of thermodynamics with internal variables (Coleman and Gurtin, 1967, *J. Chemic. Phys.*, 47, 597-613) and the additive decomposition of the Green-Lagrange strain into plastic and elastic parts. Based on an analogy with these pioneering works, we develop a non-linear thermoelectric framework for *rate-independent ferroelectricity*, adequate for capturing the phenomenon of electrical hysteresis in ferroelectric materials. When a large electric field is applied to a ferroelectric material, the orientation of the polarisation field can change or reverse, a phenomenon that is called domain switching, which results in ferroelectric behaviour and ferroelectric hysteresis.

In the theory of plasticity, the additive decomposition of the Green-Lagrange strain has been largely abandoned in favour of the Bilby-Kröner-Lee multiplicative decomposition of the deformation gradient (see Remark 9.2.1.1, page 308, in Simo and Hughes, 1998, *Computational Inelasticity*, Springer). However, it is appropriate to additively decompose the polarisation field, which is a pseudovector field, into a reversible and an irreversible part. In our approach, the rate of the irreversible polarisation is linear in the rate of the electric field and the rate of the temperature, so that the process is independent of the time scale (rate-independent). Evolution laws are also postulated for the isotropic and kinematic electric hardening parameters. The evolution equations of the irreversible polarisation and the electric hardening parameters are governed by the switching surface function (the analogue of the yielding function of plasticity) and an auxiliary scalar function that switches the irreversible loading "on" and "off" (domain switching). We impose thermodynamical restrictions on the constitutive equations, to guarantee positive dissipation during the irreversible domain switching.

We demonstrate the capabilities of the proposed framework by numerically solving a one-dimensional example in which a cyclic electric field is applied to a rigid ferroelectric material. We show that the model reproduces correctly the classical electric hysteresis loop and predicts the behaviour of the temperature as a function of time and of the applied electric field.

We plan to extend this work to the case of a deformable material and to account for the coupling between ferroelectricity and elastoplasticity.