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► To cite this version:

Julien Taurines, Boris Kolev, Rodrigue Desmorat, Olivier Hubert. Modeling of the morphic effect using a 1st-order transitional magneto-elastic energy. 25th Soft Magnetic Materials conference 2022, May 2022, Grenoble, France. hal-03773047

HAL Id: hal-03773047

<https://hal.science/hal-03773047>

Submitted on 8 Sep 2022

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Modeling of the morphic effect using a 1st-order transitional magneto-elastic energy

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The study takes place in the context of magneto-elastic coupling. A new magnetoelastic energy formulation is proposed at the magnetic domain scale in order to account for the non-linear and non-monotonous effect of stress on magnetization and magnetostriction. The model uses 1st order cubic/isotropic invariants and a transition function taking an equivalent stress as argument.

Keywords: magnetostriction, second-order effect, invariants

1 Introduction

Magnetostriction and Villari effect are two consequences of the magneto-elastic coupling [1]. In some materials such as Fe-3%Si, the mechanical loading has a non-monotonous influence on the magnetic behaviour (fig1). This second-order phenomenon is denoted as the morphic effect [2,3,4].

2 Former simulations and drawbacks

This phenomenon can be modeled by adding a quadratic term to the usual Gibbs magneto-elastic energy density $\Psi\mu\sigma$. This term can be formulated via a constitutive 6th order tensor [3] or via an equivalent polynomial formulation using polynomial invariants [4]. The main drawback of this formulation is that both magnetostriction strain and magnetic behaviour are not bounded with respect to the stress leading to strong divergences at high stress.

3 New first order transitional model

One way to avoid this problem is to use a transition function f (eq. 1) in the magnetoelastic free energy density allowing to switch from one linear energy formulation ψ_1 to another ψ'_1 (both functions of local stress σ and magnetization m) This reflects a modification of the material constants c_{210} involved in eq. 2 (where ' indicates the deviatoric part of tensors). f takes as argument a magneto-elastic equivalent stress σ_{eq} (eq. 3 – M_s : saturation magnetization) [5].

$$\Psi\mu\sigma(\sigma, m) = f(\sigma_{eq}) \cdot \psi_1(\sigma, m) + (1 - f(\sigma_{eq})) \cdot \psi'_1(\sigma, m) \quad (1)$$

$$\psi_1(\sigma, m) = c_{210} \cdot [(m \otimes m)'] : \sigma' \quad (2)$$

$$\sigma_{eq} = 3/(2M_s^2) \cdot [(m \otimes m)'] : \sigma' \quad (3)$$

The new formulation is introduced in a multiscale model. Figure 1 illustrates the way the new model respects the non-monotony of the magnetization, the change of sign of the magnetostriction and its saturation at high stress.

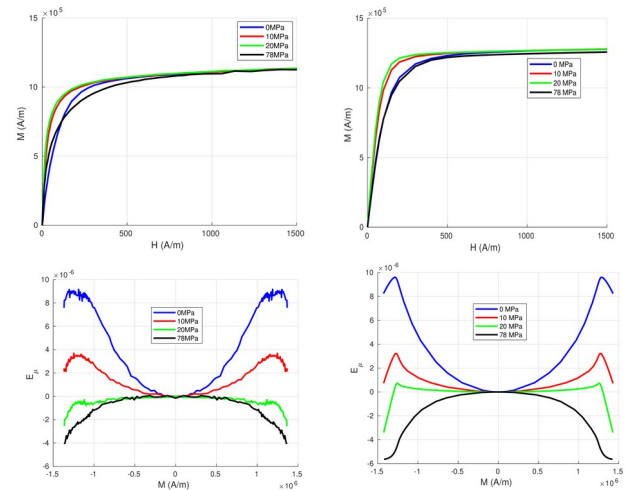


Figure 1 : Comparison between experimental magnetostriction (left) and comparison model (right) for magnetization (up) and magnetostriction (down) as function of stress.

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