MODELLING THE ANISOTROPIC PROPERTIES OF GRAIN-ORIENTED MATERIALS

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Grain oriented material presents highly anisotropic properties involving both the magnetocrystalline anisotropy and shape anisotropy. Whereas the former is generally well known for iron silicon alloys, the later involves a complex domain decomposition. In this paper, we propose to model the anhysteretic vector properties of grain-oriented steel sheet with a multiscale model. The complexity of the domain decomposition is simplified by a simple shape anisotropy term. The general trend of the measured anhysteretic flux density components can be reproduced by the model.

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I Introduction

Grain-oriented materials presents advantageous magnetic properties in large transformer. Thanks to their large grain size, they hysteresis loss are lower than the microscopic grain in non-oriented steel sheets. Furthermore, the magnetizing current of electric application remains very low thanks to the high permeability. The Goss texture aligns the crystal easy axis, <100>, with the rolling direction and the crystal medium axis, <110>, aligns toward the transverse and the normal direction. Whereas the crystal anisotropy is strongly orienting the magnetization, the thin sheet is about ten times smaller than the grain length. This specific shape leads to a significant demagnetization effect due to stray field. The combination of both the crystal anisotropy and the shape anisotropy leads to a very specific pattern of magnetic domains [1]. In Fig. 1, the domain lancets appear near the grain boundary while magnetizing the grain-oriented toward their easy direction [2], the domain branching corresponds to the application of a magnetic field along the transverse direction [1,3,4].

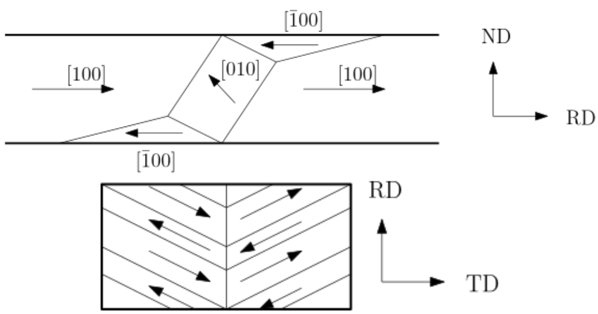

Figure1; Representation of the domain pattern in grain oriented steel sheet in the case of a magnetic field applied along the rolling direction, RD, (left) and the transverse direction, TD, (right). ND stands for the normal direction

The characterization of grain-oriented material requires a precise experimentation. Due to the specific nature of the domain decomposition, a significant magnetization component directed toward the normal direction is measured on a round rotational single sheet tester [5]. Hence, the magnetic model of grain-oriented material should account for a 3D representation of the anisotropy. Whereas the coenergy model developed in [6,7] can properly reproduced the measurements of the anhysteretic property [8], we employ the multiscale model deployed in [2] due to its inherent 3D properties and the explicit description of the grain misalignment. In our method, the demagnetization tensor presents the physical property of a unit trace with cross-coupling effect in the crystal frame.

II Multi-Scale Model for Grain-Oriented Steel Sheet

The multiscale model described in [2] is adjusted to incorporate the shape anisotropy of an oblate ellipsoid in the steel sheet frame [1]. The diagonal demagnetization tensor is rotated into the single crystal frame, leading to symmetric cross-coupling component between the normal and the transverse component when the magnetization of the domain remains along the easy axis of the crystal. Furthermore, the orientation of the magnetic domains are computed by minimizing the energy, the sum of the Zeeman energy, the magnetocrystalline anisotropy energy, and the demagnetization energy. The volume fraction of the six domains is evaluated with a Boltzmann distribution similarly as in [2]. Finally, the magnetization is reconstructed with the weighted vectorial sum of the six magnetic domains.

III Results and Discussion

The Fig.2 presents the simulation results for an ideal grain oriented steel sheet with Bunge-Euler angles (0^o, 45^o, 0^o). The magnetic field is applied in the (RD,TD) plane with three different directions with respect to the rolling direction (RD). The amplitude of the in-plane flux density and the angle of the in-plane flux density are respresented in the left and the middle. Similarly as the experiments conducted by Goričan et al. [5], the out-of plane component of the flux density is significant and can reach more than half of the saturation level (Fig.2, right).

The Fig.3 presents the measured in-plane component of the flux density for the same condition of the applied magnetic field as in the simulation. The non-monotonous behavior of the in-plane amplitude of the flux density appears for an applied field oriented by 60^o and 75^o with respect to the rolling direction. The multiscale model can reproduce this non-motonous behavior for the former field direction, only. Neverthless, the in-plane angle of the flux density can be properly approached with the multiscale model. The out-of plane component of the flux density was not measured in [8] so we can not properly compared the simulation in this case. In the future, the effect of the grain misalignment will be considered together with a proper fit of the shape anisotropy parameters. Furthermore, the shape anisotropy energy should be evaluated for the various domain configuration represented in Fig. 1.

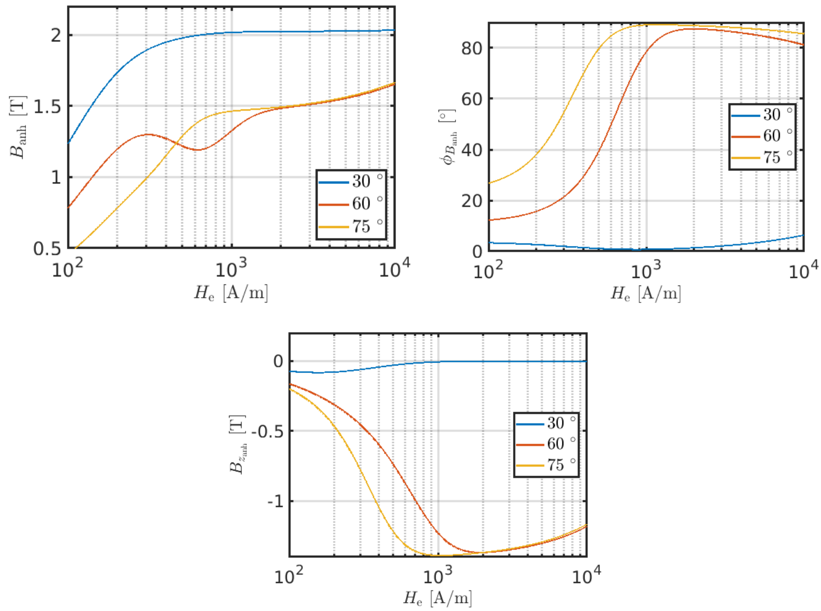

Figure 2: Multiscale simulation results for three orientations of the applied magnetic field. The amplitude of the in-plane flux density, the phase of the in-plane flux density, and the out of-plane component of the flux density are represented from left to right with respect to the amplitude of the applied field.

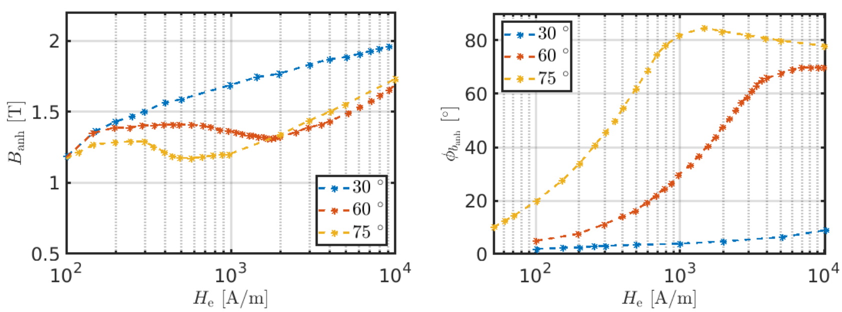

Figure 3: Anhysteretic measurement of the M6H grade of 3% FeSi grain-oriented materials [7,8]. The in-plane flux density amplitude and the in-plane phase of the flux density are represented from left to right with respect to the amplitude of the applied field for three different orientations of the magnetic field.

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