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Experimental analysis of the magnetoelastic anisotropy of a non-oriented silicon iron alloy

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Abstract

This paper deals with experimental measurements of the mechanical, magnetic and magnetostrictive behaviours of a non-oriented 3%SiFe alloy. The results show that the low crystallographic texture of the material brings important anisotropic effects and that the coupled magnetomechanical properties are much more sensitive than uncoupled ones.

Keywords: Silicon steels; Magnetic measurements; Magnetostriction; Magnetoelastic anisotropy

1. Introduction

Non-oriented (NO) silicon iron laminations are widely used in the electric construction for their isotropic magnetic behaviour in the sheet plane. Anisotropy nevertheless exists and could explain an important part of noise linked to the magnetostriction in the electromagnetic devices, like for grain-oriented materials [1]. An experimental analysis of the influence of the texture for an NO material on the magnetic, mechanical and coupled properties is proposed.

2. Experimental procedure and results

A commercial 0.5 mm thick Fe–3%Si NO alloy has been employed, indicating no morphologic texture of the grains. Electron back-scattered diffraction measurements (EBSD) show that the forming process brought about a $\{1\,1\,1\}\langle 1\,1\,\bar{2}\rangle$ type crystallographic texture (Fig. 1). Samples for all experiments consist of 250 mm long and 12.5 mm wide bands. They were cut by electroerosion machining in the lamination each 10° from the rolling direction (RD). Standard tensile tests have been carried out to measure the Young's modulus and Poisson's ratio thanks to usual strain gauges. Magnetic measurements were implemented using a non-standard experimental frame [2]. The magnetisation characteristics have been investigated under quasistatic excitation conditions (0.1 Hz), and a special procedure allowed to build the anhysteretic curve ($M_{\mathrm{an}}(H_{\mathrm{an}})$) [2]. The magnetostriction characteristics have been measured simultaneously. The samples have been instrumented with longitudinal and transverse constantan strain gauges (low magnetoresistive sensitivity [3], gauge factor $K = 2.07 \pm 0.5\%$). Different configurations of measurements have been tested: quarter or half bridge systems (using a free gauge put on the other side of the sample and submitted to the same level of magnetic field), with temperature compensation. They give rise to similar results. The highest problem is the non-negligible level of the electromagnetic noise compared to the very low level of e.m.f. signal in the bridge. An efficient low pass filtering is consequently necessary (LP frequency less than 10 Hz) that implies the excitation system to work at very low frequency to avoid any distortion ($f = 0.1$ Hz). The measurement of the anhysteretic magnetostriction is another efficient solution, even if the duration of measurement is much longer.

Fig. 2a shows the main measured magnetic characteristics of the material (first magnetisation, anhysteretic and hysteretic curves) for a 70° oriented sample in sheet plane. Fig. 2b allows to compare the anhysteretic curves for all directions. A strong anisotropic magnetic

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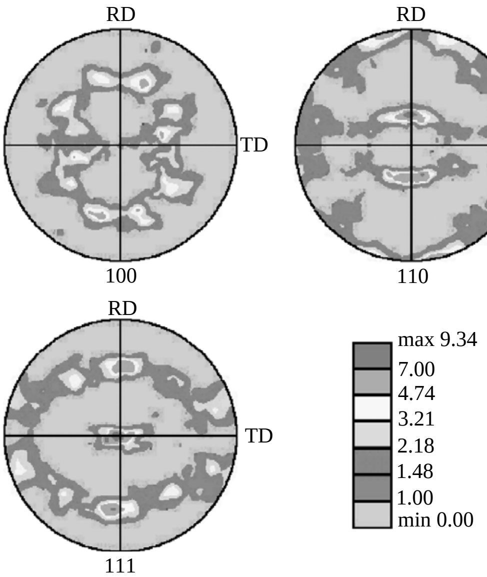

Fig. 1. Poles figure of a NO 3%SiFe alloy (EBSD method).

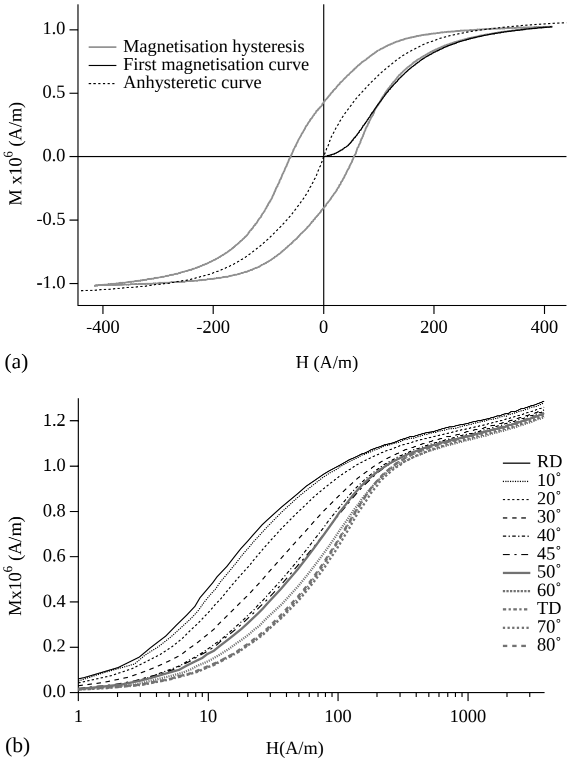

Fig. 2. (a) First magnetisation, hysteresis and anhysteretic curve for a 70° specimen; (b) anhysteretic curve $M_{\mathrm{anh}}(H_{\mathrm{anh}})$ of the material in the sheet plane.

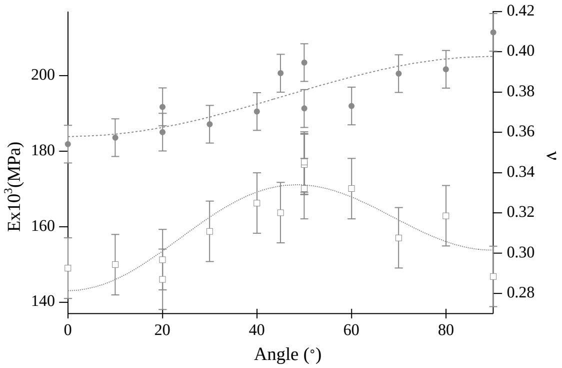

Fig. 3. Young's modulus and Poisson's ratio of the material in the sheet plane.

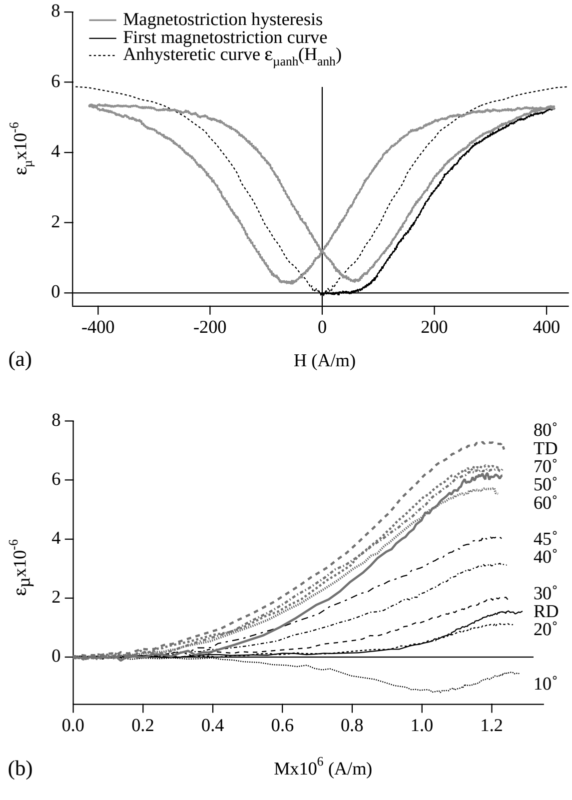

Fig. 4. (a) First longitudinal magnetostriction, hysteresis and anhysteretic magnetostriction curve for a 70° specimen; (b) longitudinal anhysteretic magnetostriction curve $\varepsilon_{\mu\mathrm{anh}}$ (M_{anh}) in the sheet plane.

behaviour is clearly shown especially for low magnetic field strengths ($H < 200$ A/m): the magnetic permeability is decreasing between the rolling (RD) and transverse (TD) directions. At higher levels the differences are not exceeding 15%. The same variations are roughly obtained for the other uncoupled magnetic characteristics. Young's modulus and Poisson's ratio evolution in the sheet plane are shown in Fig. 3. The highest stiffness is for TD and it roughly decreases monotonously to RD, highlighting a similar level of anisotropy than for uncoupled magnetic characteristics. Poisson's ratio is very sensitive to the crystallographic texture considering the non-monotonous variations and amplitudes between RD and TD.

Fig. 4a shows the main measured magnetostriction characteristics of the material (first magnetostriction, anhysteretic and hysteretic curves) for the previous 70° oriented sample. Longitudinal anhysteretic magnetostriction evolution in the sheet plane is drawn as a function of the magnetisation level in Fig. 4b. Only the relative variations have to be taken into account because the elastic deformations ($\approx 1\times10^{-6}$) due to the magnetic forces [4] have not been removed. The amplitude of variations of $\varepsilon_{\mu\mathrm{an}}(M_{\mathrm{an}})$ reaches a maximum of about 8×10^{-6} ($H < 4000$ A/m). The anisotropy of the magnetostrictive behaviour in the sheet plane is much stronger than for uncoupled behaviours. The observed anisotropy and variations for the transverse magnetostriction are of same order than the longitudinal one (Fig. 5a).

3. Discussion and conclusion

The magnetostriction through the thickness has been calculated (Fig. 5b) using the hypothesis that magnetostriction is an isochore deformation for this material [2]. This strain is highly non-monotonous facing to either the magnetisation orientation, or the magnetisation level. The associated high frequency deformation harmonics could be an important source of noise in a rotating field machine. Let us finally consider the observed various anisotropies facing the crystallographic texture. A simple treatment of the previous orientation data file is proposed: a triplet of Euler's angles $\{\phi_1, \theta, \phi_2\}$ corresponds to six $\langle 100\rangle$ orientations. The closest $\langle 100\rangle$ direction is projected along each orientation of the previous measurements between RD and TD (Fig. 5c). A good agreement appears between the variations of uncoupled properties and this projection: the $\langle 100\rangle$ direction is first an easy magnetic direction and second a "soft" mechanical direction [5]. The tendency for magnetostriction is correct considering that the motion of 180° magnetic walls at low field occurs easily for $\langle 100\rangle$ oriented crystals without magnetostriction [5]. The higher density of $\langle 100\rangle$ directions corresponds to the lower magnetostriction amplitude. Anisotropy is just highly amplified.

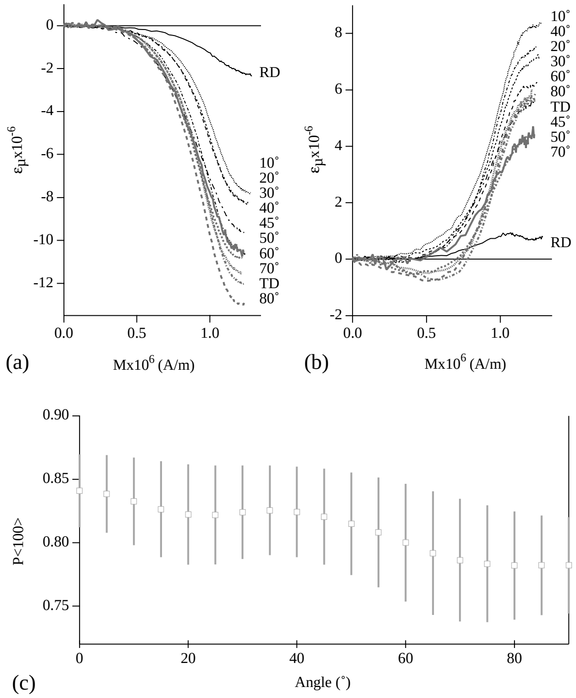

Fig. 5. (a) Transverse anhysteretic magnetostriction curve $\varepsilon_{\mu\mathrm{anh}}$ (M_{anh}) in the sheet plane; (b) calculated anhysteretic magnetostriction through the thickness; (c) $\langle 100\rangle$ direction projection in the sheet plane.

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