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Correlation between magnetic properties and crystallographic texture of silicon steel

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Abstract

A quantitative way to correlate magnetic property to texture is by means of average magnetocrystalline energy $\overline{E}_a$. In the present work, $\overline{E}_a$ was calculated from texture measurements determined by X-ray diffraction. It was observed the presence of texture gradient in the sample thickness direction. In order to determine the average texture, the measurements were performed on RD section and two computer programs were developed to analyze the X-ray texture data. The relation between J_{50} and $\overline{E}_a$ is a first degree equation.

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Keywords: Silicon steel; Non-oriented steels; Magnetic anisotropy; Average texture; J_{50}

The polarization measured at 5000 A/m (J_{50}) varies according to crystallographic texture. Due to the production process, the commercial non-oriented electrical steels present magnetic property anisotropy. A quantitative way to correlate magnetic property to texture is by means of average magnetocrystalline energy $\overline{E}_a$. In recent papers [1,2], $\overline{E}_a$ was calculated from individual orientations obtained by EBSD. In the present work, it was calculated from texture measurements determined by X-ray diffraction. From X-ray measurements it was possible to verify the texture gradient in sample thickness direction. In order to determine the average texture, the samples were prepared to allow measurements on RD section (section perpendicular to rolling direction). Usually the texture measurement is done on ND section (section perpendicular to normal direction). Two computer programs were developed to analyze the X-ray texture data: one for texture transformation [3] and the second for $\overline{E}_a$ calculation. The $\overline{E}_a$ can be calculated from numerical values of orientation distribution function density $f(g)$:

$$\overline{E}_a = \sum_{\varphi_1=0}^{90^\circ} \sum_{\phi=0}^{90^\circ} \sum_{\varphi_2=0}^{90^\circ} E_a(g) f(g)\,\Delta g. \quad (1)$$

Magnetic characterization was performed in Epstein strips of silicon steel that were cut in different directions, from 0° to 90° with respect to rolling direction.

Saturation polarization J_s and anisotropy constant K_1 depend strongly on Si and Al content, as shown in Table 1. Based on literature [4,5], the following relations are proposed:

$$K_1 = 4.77 - 0.21256{*}\%\text{Si} - 0.03816{*}\%\text{Al}, \quad (2)$$

$$J_s = 2.162 - 0.043{*}\%\text{Si} - 0.0625{*}\%\text{Al}. \quad (3)$$

The orientation distribution functions (ODF) were calculated from three measured incomplete pole figures {1 1 0}, {2 0 0} and {2 1 1} and represented in the Euler space. Fig. 1 shows $\varphi_2 = 45^\circ$ sections of ODFs for three thicknesses (surface, $\frac{1}{4}$ and $\frac{1}{2}$ thickness from surface) of samples 3 and 1. The presence of texture gradient in thickness direction was observed for the three samples. As J_{50} is a volumetric property the correlation between magnetic property and texture must be done using the average texture. In order to determine the average

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Table 1
Chemical composition of samples (wt%)

	Si	Al	J_s (T)	K_1 (10^4 J/m^3)
Sample 1	3.00	0.58	1.99	4.110
Sample 2	0.30	0.21	2.13	4.698
Sample 3	0.11	0.12	2.15	4.738

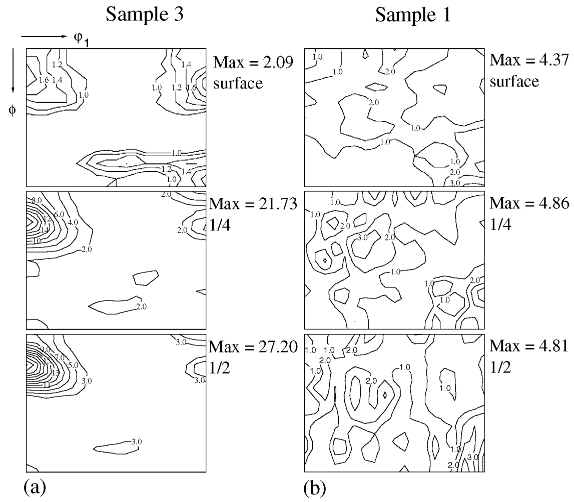

Fig. 1. $\varphi_2 = 45^\circ$ section of ODF for three thicknesses.

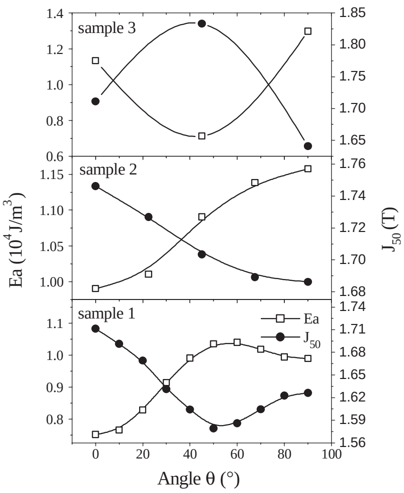

Fig. 2. Angular variation of J_{50} and $\overline{E}_a$.

texture, X-ray measurements were performed on RD section.

Despite the difference of J_{50} angular behavior for the three samples (Fig. 2), they show a good relation to $\overline{E}_a$, calculated from average texture. The relation between J_{50} and $\overline{E}_a$ (Fig. 3) is a first degree equation. The normalization by J_s (Fig. 4) brings all experimental data

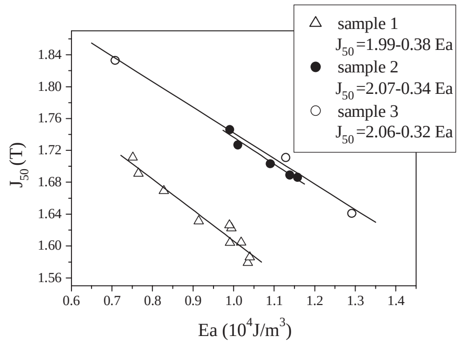

Fig. 3. J_{50} in function of $\overline{E}_a$.

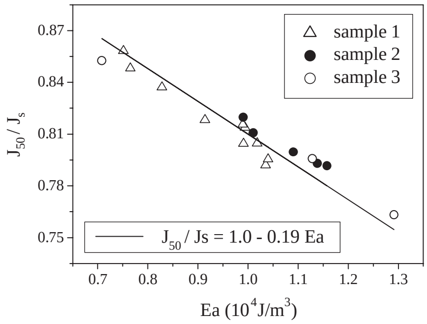

Fig. 4. (J_{50}/J_s) in function of $\overline{E}_a$.

close to the same linear fit, given by the equation

$$J_{50}/J_s = 1.0 - 0.19 * \overline{E}_a. \tag{4}$$

The equation obtained from Fig. 4 can be used to estimate J_{50} for samples with different textures and Si and Al contents.

It is important to emphasize that this kind of analysis, when using EBSD data, is only possible if the sample does not present strong texture gradient, as in sample 1. In the case of samples 2 and 3 the only way to correlate magnetic property to texture is by the average texture.

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References

[1] M.A. Cunha, P.C. Luna, Acta Microsc. 8 (Suppl.A) (1999) 289.
[2] F.J.G. Landgraf, T. Yonamine, M. Emura, M.A. Cunha, J. Magn. Magn. Mater. 254–255 (2003) 328.
[3] H. Inoue, N. Inakazu, ICOTOM 12, International Academic Publishers, Montreal, 1999, p. 168.
[4] R.C. Hall, J. Appl. Phys. 31 (1960) 1037.
[5] R.M. Bozorth, Ferromagnetism, D. Van Nostrand Company, Inc., Princeton, NJ, 1955.