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Modelling magnetic polarisation J_{50} by different methods

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Abstract

Two different methods for modelling the angular behaviour of magnetic polarisation at 5000 A/m (J_{50}) of electrical steels were evaluated and compared. Both methods are based upon crystallographic texture data. The texture of non-oriented electrical steels with silicon content ranging from 0.11 to 3%Si was determined by X-ray diffraction. In the first method, J_{50} was correlated to the calculated value of the average anisotropy energy in each direction, using texture data. In the second method, the first three coefficients of the spherical harmonic series of the ODF and two experimental points were used to estimate the angular variation of J_{50}. The first method allows the estimation of J_{50} for samples with different textures and Si contents using only the texture data, with no need of magnetic measurement, and this is advantageous, because texture data can be acquired with less than 2 g of material. The second method may give better adjust in some situations but besides the texture data, it requests magnetic measurements in at least two directions, for example, rolling and transverse directions.

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

1. Introduction

The manufacturing process of commercial non-oriented electrical steels originates the anisotropy of magnetic properties [1]. A method to correlate the polarisation measured at 5000 A/m (J_{50}) to the crystallographic texture of non-oriented electrical steels was recently described [2]. In this method the average magnetocrystalline energy $\bar{E}a$ [3], used to correlate magnetic properties to texture, is calculated from texture measurements determined by X-ray diffraction [2]. The $\bar{E}a$ can be calculated from numerical values of orientation distribution function density $f(g)$:

$$\bar{E}a = \sum_{\varphi_1=0}^{90^\circ} \sum_{\phi=0}^{90^\circ} \sum_{\varphi_2=0}^{90^\circ} Ea(g) f(g) \Delta g. \quad (1)$$

As the main result a very simple equation was obtained by fitting [2] (here, possible effects of demagnetizating field are considered as negligible):

$$J_{50}/J_s = 1.0 - 0.19\, \bar{E}a. \quad (2)$$

In this paper, two different methods for modelling the angular behaviour of magnetic polarisation J_{50} are compared. Both methods are based upon texture data of the studied steels. The first method [2] (Eq. (2)) will be improved in order to get better-estimated values of J_{50}. A sample with 2.2% Si was included in the analysis and, in order to improve the method, small differences observed between the linear fits of all samples were took into account. In the second method [4–6] the first three coefficients of the spherical harmonic series of the orientation distribution functions (ODF) and two experimental points were used to estimate the angular variation of J_{50}.

2. Experimental

Magnetic characterisation was performed in Epstein strips of commercial silicon steel cut in different directions

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with respect to rolling direction (RD). In this manner 0° corresponds to the RD and 90° corresponds to the transverse direction (Figs. 1 and 3). Saturation polarisation J_s and anisotropy constant K_1 [2] are shown in Table 1.

The ODF were calculated from incomplete pole figures {1 1 0}, {2 0 0} and {2 1 1} measured in a Shimadzu Difractometer XRD6000. The first three coefficients of the spherical harmonic series of the ODF are shown in Table 2.

3. Results and discussion

The angular behaviour of calculated $\bar{E}a$ is opposite to experimental J_{50} (Fig. 1), the minimum of $\bar{E}a$ corresponds to the maximum of J_{50}.

From the J_{50} versus $\bar{E}a$ curve (Fig. 2) we extracted linear relations of type:

$$J_{50} = c_1 - c_2\,\bar{E}a, \tag{3}$$

where c_1 and c_2 depend, in principle, on the sample composition (see Fig. 2).

In order to generalise Eq. (3) to be valid for any chemical composition, a quadratic fitting of c_1 and c_2 as function of J_s was done, resulting Eqs. (4) and (5):

$$c_1 = 19.1706 - 17.08346J_s + 4.24696J_s^2, \tag{4}$$

$$c_2 = 22.20874 - 20.27905J_s + 4.70645J_s^2. \tag{5}$$

In the second method [4–6], the first three coefficients of the spherical harmonic series of the ODF (Table 2) and two experimental points ($J_{50}(0°)$ and $J_{50}(90°)$) were used to estimate the angular variation of J_{50}, according the Eq. (6):

$$J_{50}(\beta) = A + B[-1.091C_4^{11} + 1.6266C_4^{12}\cos(2\beta) - 2.1516C_4^{13}\cos(4\beta)], \tag{6}$$

where A and B are adjustable parameters determined from experimental data, $C_l^{\mu\nu}$ are ODF coefficients according to Bunge [4] notation and β is the angle to RD.

The difference between experimental and calculated values using Eq. (3) was in the worst case 0.016 T (0.9%) and in the best case no differences could be detected. According to Table 3 only four values in 25 presented differences higher than 0.01 T (0.6%).

The advantage of the first method is the possibility to estimate J_{50} for samples with different textures and Si contents using only the texture data. For magnetic measurement in Epstein frames, at least 0.5 kg of material, in each direction, are necessary. This means that 5 kg was

Table 1
Chemical composition of samples (wt%)

Sample	Si	Al	J_s (T)	K_1 (10^4J/m^3)
1	3.00	0.58	1.991	3.758
2	2.20	0.19	2.05	4.045
3	0.30	0.21	2.13	4.690
4	0.11	0.12	2.144	4.758

Table 2
First three coefficients of the ODFs

Sample	c_4^{11}	c_4^{12}	c_4^{13}
1	−0.3650	−1.3812	0.7138
2	0.4088	−1.2098	1.2727
3	−0.2660	−0.8664	0.1377
4	1.1588	−0.9635	−2.0847

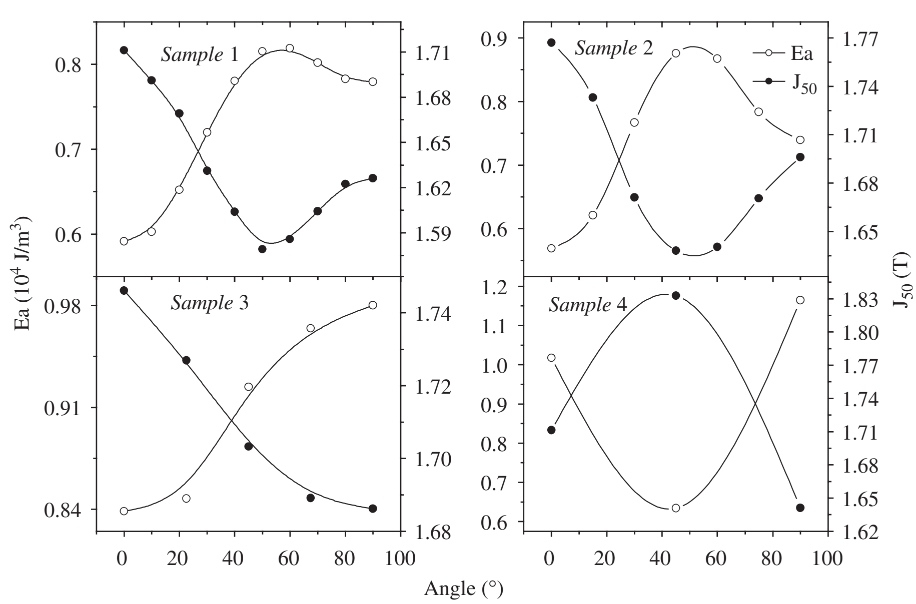

Fig. 1. Angular variation of J_{50} and $\bar{E}a$.

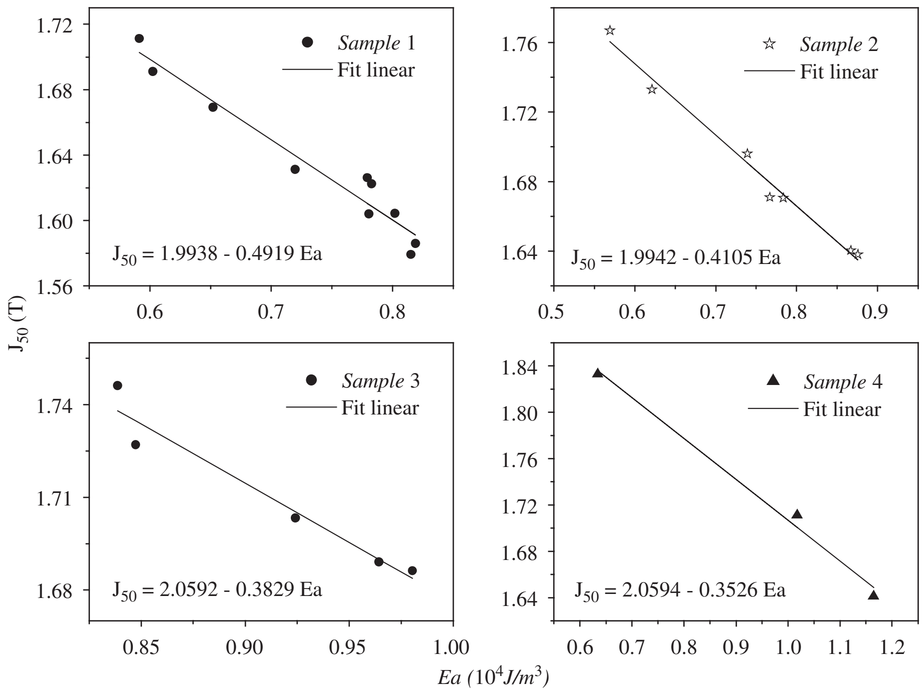

Fig. 2. J_{50} in function of $\bar{E}a$.

Table 3
Angular variation of J_{50} (T)

Sample	Angle (°)	J_{50} exper.	J_{50} Equ(3)	J_{50} Equ(6)
1	0	1.711	1.703	1.711
	10	1.691	1.698	1.702
	20	1.669	1.673	1.677
	30	1.631	1.640	1.646
	40	1.604	1.610	1.620
	50	1.579	1.593	1.605
	60	1.586	1.592	1.604
	70	1.604	1.600	1.612
	80	1.622	1.609	1.622
	90	1.626	1.611	1.626
2	0	1.767	1.760	1.767
	15	1.733	1.739	1.738
	30	1.671	1.678	1.675
	45	1.638	1.633	1.633
	60	1.640	1.637	1.640
	75	1.671	1.671	1.676
	90	1.696	1.690	1.696
3	0	1.746	1.743	1.746
	22.5	1.727	1.740	1.731
	45	1.703	1.712	1.704
	67.5	1.689	1.697	1.689
	90	1.686	1.691	1.686
4	0	1.711	1.695	1.711
	45	1.833	1.834	1.877
	90	1.641	1.641	1.641

needed to perform all magnetic measurements of sample 1. On the other hand, it is possible to perform texture measurements using less than 2 g of material. The second method gave a better adjust in the case of samples 2 and 3 (Fig. 3) but magnetic measurements are needed. It is important to emphasise that when there is no available material for any magnetic measurement, J_{50} can be estimated using Eq. (3).

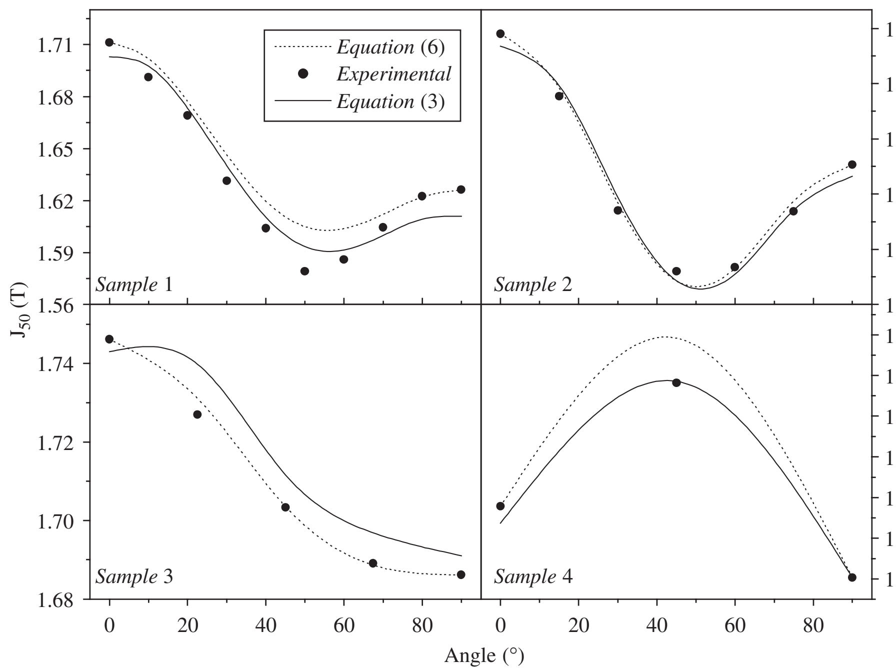

Fig. 3. Calculated angular variation of J_{50}.

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