POWER LOSS AND MICROSTRUCTURE IN NON-ORIENTED SiFe LAMINATIONS

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POWER LOSS AND MICROSTRUCTURE IN NON-ORIENTED SiFe LAMINATIONS

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Abstract. – Results are reported about the power loss dependence on microstructural parameters in SiFe non-oriented laminations. In particular, the direct influence of grain size and crystallographic texture on hysteresis losses is investigated. A general phenomenological law is provided, by which we are able to enucleate the individual effects of impurity content, average grain size and texture on losses.

1. Introduction

Optimization of the quality of non-oriented electrical steel relies to a large extent on a good knowledge of the role played on loss and permeability by microstructural parameters: precipitated impurities, crystallographic texture and grain size (minor emphasis should be placed on residual stresses in well annealed laminations). While the qualitative aspects of this problem are fairly well known and discusses in the literature [1-4], little has been done so far to assess the general phenomenology of power loss *vs.* microstructure from a quantitative, predictive point of view.

Recently, in a drive to improve the quality of non-oriented alloys, special efforts have been devoted to a better control of microstructure [5], in particular of crystallographic texture [1, 6]. But the extent to which the loss figure is benefited by improved texture is, at best, only approximately known. In the present paper we have therefore tried to produce a quantitative formulation for the joint effects of grain size and texture on hysteresis loss, the largely predominant, microstructure sensitive loss component [7]. Results concerning two different SiFe alloys are reported in the following.

2. Results and discussion

Hysteresis loss has been measured by standard methods at a peak induction of 1.5 T in: 1) 0.65 mm thick FeSi laminations (Si 0.50 % , Al 0.25 % , Mn 0.51 %) and 2) 0.50 mm thick FeSi laminations (Si 1.1 % , Al 0.32 % , Mn 0.27 %), obtained through a single stage cold reduction. One batch of type 2) lamination underwent a special treatment at the hot rolling stage, in order to obtain textural improvement. Final decarburized specimens ($C < 50$ ppm) were subjected to sequential heat treatments, in order to progressively increase grain size. Treatments were restricted to the temperature region below the $\alpha \rightarrow \gamma$ phase transition. In some cases, to enlarge grains, the method of critical deformation was applied. Final values of average grain size $\langle s \rangle$ ranged in lamination 1) from 25 μm to 275 μm, while in lamination 2) they covered the interval 32 μm-82 μm. Evolution of crystallographic texture upon increase of grain size was monitored by measuring the magnetic anisotropy couple, in the lamination plane. To widen the spectrum of textural conditions to be sensed by magnetization, longitudinally and transversally cut laminations were separately investigated. For each sample and at each stage of grain growth, the initial magnetization curve, up to 10^4 A/m, was also determined, with the ballistic method. This offered an interesting tool for texture characterization, in that a suitable parameter, the magnetization at high fields, could be found to closely follow textural evolution, quite independently on actual grain size and/or impurity content. In the present case, magnetization at 5×10^3 A/m, I_5, seemed to represent the appropriate texture indicator. I_5 shall therefore be taken in the following as the parameter encompassing all the ensemble of textural situations leading to the same final effect on magnetic properties. A further more refined step could possibly envisage some form of relationship between I_5 and prominent crystallographic orientations. In the present experiments I_5 was found to vary between 1.72 T and 1.82 T in lamination 1) and between 1.65 T and 1.78 T in lamination 2).

We have experimentally determined an ensemble of 50 Hz hysteresis loss values $P_{\mathrm{h}}\left\{\langle s \rangle, I_5\right\}$ that we postulate to be in agreement with a general law of dependence of loss on microstructure of the type

$$P_{\mathrm{h}} = P_0 + (A_0 - kI_5) / \sqrt{\langle s \rangle}, \tag{1}$$

with P_0 a background contribution exclusively due to precipitated impurities, A_0 and k two parameters characterizing the dependence on texture. For each lamination, the best set of fitting values P_0^*, A_0^*, k^* has been determined, by means of a least squares procedure. By finding P_0^*, the specific, impurity related loss contribution, we get a first valuable information about the quality of the material. We obtain $P_0^* = 0.42$ W/kg in lamination 1) and $P_0^* = 0.9$ W/kg and 1.1 W/kg in the two different batches of lamination 2) (see also Fig. 2).

Let us now examine the separate dependence of P_h on I_5 and $\langle s \rangle$. In figure 1 we report for each lamination the experimental values $(P_h - P_0^*) . \sqrt{\langle s \rangle}$vs. I_5, together with the associated best fitting lines $A_0^* - k^* I_5$. Such lines can be used to normalize the hysteresis loss data to a given value of I_5. In this way wa are able to single out the dependence of P_h on $\langle s \rangle$ at a fixed texture. In figure 2, the results obtained in longitudinally and transversally cut sheets are separately presented, in the plane $\left(P_h,\ 1/\sqrt{\langle s \rangle}\right)$. We can notice how the straight fitting lines progressively decrease their slope upon a progressive texture improvement (i.e. increase of I_5). To stress also that such a slope decreases with an increase of Si content (at a same value of I_5).

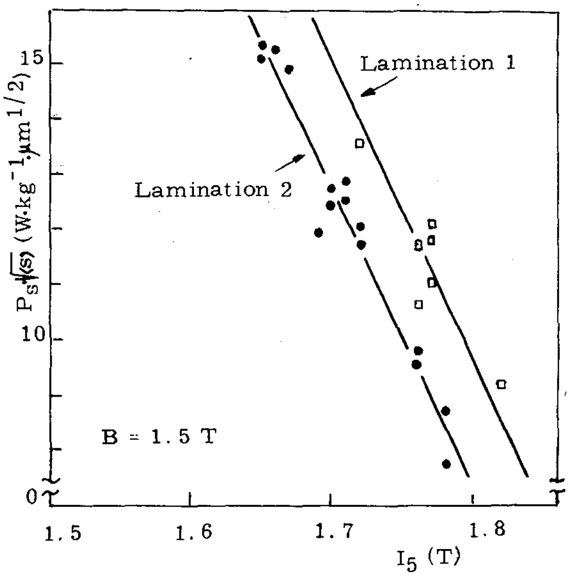

Fig. 1. – Experimental values of $P_s = (P_h - P_0^*) . \sqrt{\langle s \rangle}$ as a function of magnetization at 5×10^3 A/m, I_5, against best fitting lines $A_0^* - k^* I_5$ (see text and Eq. (1)).

These measurements, which still need to be suitably extended to further compositions, offer a novel phenomenological assessment of the microstructure related loss properties in non-oriented laminations. Besides their intrinsic physical value, they appear to provide a practical method of material quality evaluation. For one thing, we expect to associate to any composition a single couple of parameters (A_0, k). A unique determination of P_h and I_5 at a given grain size will then

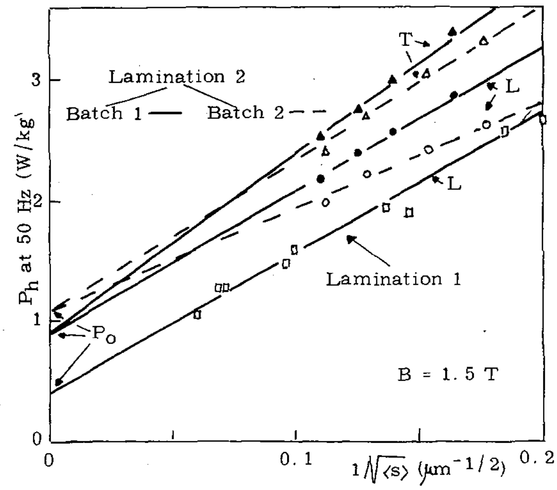

Fig. 2. – Hysteresis loss at 50 Hz and 1.5 T *vs.* $1/\sqrt{\langle s \rangle}$, with $\langle s \rangle$ average grain size. The experimental points have all been normalized to a given value of I_5, through the linear equations displayed in figure 1. The background impurity contribution P_0 is given by intercepts of fitting lines given by equation (1) with the y-axis. L = longitudinal sheets, T = transverse sheets. Each line pertains to a different value of I_5 (in sequence 1.65, 1.70, 1.72, 1.78 T for lamination 2 and 1.77 T for lamination 1). The lines slope decreases with increasing I_5.

suffice to recognize, through equation (1), the general contribution of the different microstructural parameters to hysteresis loss and possibly lead the way to a better control of material processing variables.

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