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Quantification of the effect of texture on the magnetization behavior

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For electrical steels there is a need to describe the intensity of the present texture components in the finally processed material as well as after the various processing steps. Preferable texture components like the cube fibre texture will improve the magnetization behaviour. Furthermore, there is interplay between the various processing steps at fabrication on the resulting final texture in the fully processed material. A texture parameter A can be derived from the orientation distribution function (ODF) for arbitrary texture, which describes the texture for each texture components. Taking into account this fact, we used a so-called A-map. The A-map gives the value of A for each point in the Euler space for two fixed values (constants). This A-map may be used to estimate immediately the effect of a different resulting image of texture due to variation of the technology of fabrication of the material. Any increase of the intensity of texture within the area of the ODF, where the A-values are smaller than a certain value, results in improved magnetization behaviour. Within the paper some examples are given.

K e y w o r d s: electrical steel, magnetization behaviour, effect by crystallographic texture in these polycrystalline material

1 Introduction

The magnetic properties of electrical steels such as magnetization curves, permeability, coercive field intensity and specific magnetic losses are related to the microstructure imperfections and texture of the material. The structural features, which have a strong influence on the magnetic properties, are grain size, precipitates, inclusions, internal stresses and surface defects. Low field magnetizing behaviour is mainly dominated by the intensity and character of the structural features. The existing crystallographic texture determines remanent magnetic induction as well as the B *vs* H curve, especially at high values of applied external magnetic field. The preferable texture components and fibres for non-oriented electrical steels are: cube ($\{100\}\langle 001\rangle$), rotated cube ($\{100\}\langle 011\rangle$) component, the theta ($\{100\}||ND$) and eta ($\{001\}||RD$) fibres. In the case of grain oriented electrical steels the preferable texture is the Goss texture. In real materials there are naturally not only these texture components. A measure, which characterizes the mixture of the different texture components and their intensity on the magnetization behaviour, is required. Such a measure would be also helpful to describe the existing correlation of the texture after the various processing steps: hot rolling, hot band annealing (optional), cold rolling and the texture after final annealing [1-4]. In this paper we will describe the so-called A-map, which may be used for this purpose.

2 A-parameter and A-map and their application

To characterize the quality of the magnetic texture $A_\theta(g)$ can be determined [5]. The parameter $A_\theta(g)$ is defined as the minimum of the cosine of the angle between the direction of the externally applied magnetic field H and the closest $< 100 >$ axis of the cubic crystallographic lattice (3 equivalent directions), see Fig.1. The externally applied magnetic field, which is represented by the magnetization vector $\boldsymbol{M}$ makes an angle θ with respect to the rolling direction (RD) of the sheet. It is supposed that $\boldsymbol{M}$ lies along $\boldsymbol{H}$. Experimental determined orientation distribution function ODF from EBSD measurements gives the intensity of a given orientation $f(g)$. The orientation g is defined by the Euler angle. $A_\theta(g)$ is the texture parameter, as described above, for each orientation g at given angle θ of the applied magnetic field.

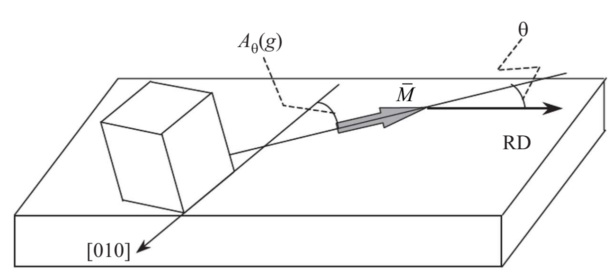

Fig. 1. Definition of $A_\theta(g)$

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A texture parameter A_θ can be defined by

$$A_\theta = \int A_\theta(g)\, f(g) \mathrm{d}g \qquad (1)$$

The value of A_θ gives an orientation averaged measure for the texture for the measured volume of the sample. The value of A_θ correlated clearly with the value of the magnetization B at 2500 A/m, see Fig.2.

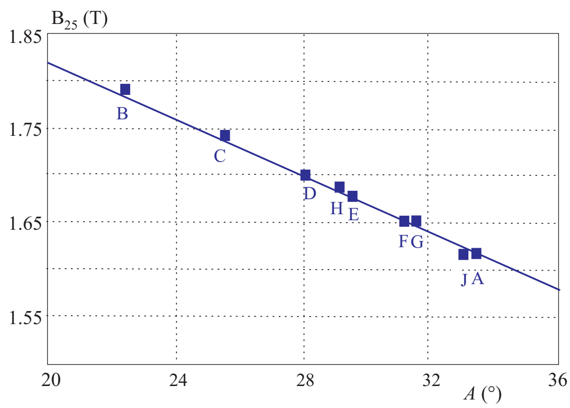

Fig. 2. B_{25} values calculated in [8] for various mixtures of textures in a polycrystalline material *vs*'; the value of A for these texture intensities (see also [1])

Figure 2 gives calculated values of B_{25} for various mixtures of texture components in a polycrystalline material *vs* the value of A_θ at $\theta = 0$. The starting point are the values of B_{25} for iron crystals in different crystallographic directions Based on this it is possible to calculate the values of B_{25} for different mixture of these crystallographic orientation [6] as well as for different fibers, like $(100) < uvw >, (110) < uvw >, (111) < uvw >$ [1]. If one defines a critical value $A = 30$, all values of smaller than 30 may indicate an improvement of the value of B_{25} . Similar relation can be obtained also for B_8 , B_{50} and so on. Generally also the grain size and the Sicontent may affect to a certain extent the value of B at a given magnetic field [1], [7,8]. As expected, good linear relation between B_{25} and A is found at higher values of the applied magnetic field.

A_θ gives no infromation, which texture components have changed. For that reason,we introduced the so-called A-map, which gives the value of A for a given angle θ of the applied magnetic field with respect to the rolling direction (RD) of the sheet for each point (orientation g) in the $\varphi_2 = 45$øsection of the Euler space, see Fig. 3.

One may compare the obtained ODF by EBSD measurements in the $\varphi_2 = 45$øsection of the Euler space with the A -map. In this way one may immediately see, which texture components give the observed changes in the value of A_θ, see equation (1). Regarding the area, where $A(g) \leq 30$, one obtains a measure for the increase of the value of the magnetic induction B_{25} .ΔB_{25} is proportional to $(-)\Delta A_\theta$

$$\Delta A_\theta = \int A_\theta(g) f(g) \mathrm{d}g \quad \text{for all } g, \text{ where } A(g) \leq 30 \qquad (2)$$

The value of $A(g) \leq 30$ was chosen for the reason that values of B_{25} above 1. 65 T are desirable for most of the applications of non-oriented electrical steels. Any change in the texture, respectively its effect on B_{25}, due to variation of process parameters at the fabrication of the hot band, after cold rolling of the hot band and the final annealing of the cold rolled material can be followed for the regarded process step and finally for the fully processed material. Examples are given in Figure 4 and 5. Details of the regarded materials are given in[4, 9]. Regarding ODF and $A_\theta(g)$ in the $\varphi_2 = 45$øEuler section at $\theta = 0$øand $\theta = 90$øone may also analyse the anisotropy of the magnetization behaviour for the magnetic field applied parallel, respectively perpendicular to the rolling direction of the sheet.

3 Conclusions

An increase of magnetically preferable texture components will give a contribution to the improvement of the magnetization behaviour. A texture parameter A can be defined, which characterize the Magnetic Quality of the material at a given direction of the applied magnetic

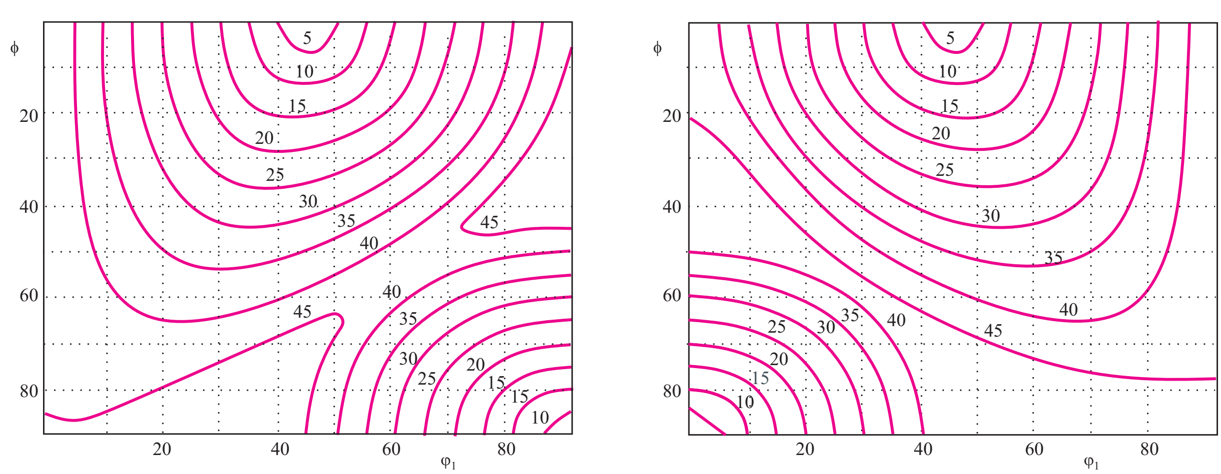

Fig. 3. $A_\theta(g)$ for $\varphi_2 = 45$øEuler section" (a) – $\theta = 0$ø, and (b) – $45 \leq$ and $90 \leq$

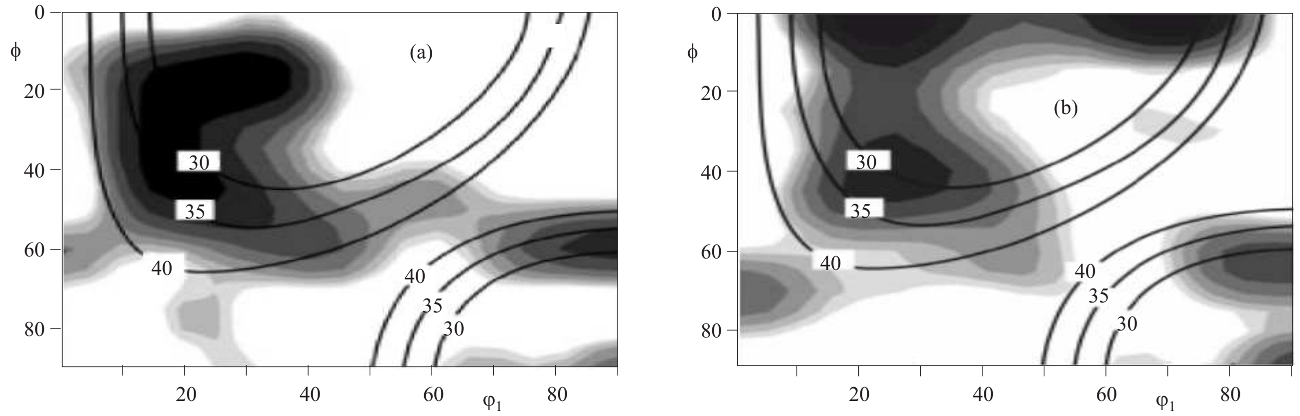

Fig. 4. ODF and $A_{\theta}(g)$ for the $\varphi_2 = 45$øEuler section at $\theta = 0$øafter final annealing at 1000ø/20 s of hot band fabricated in different way

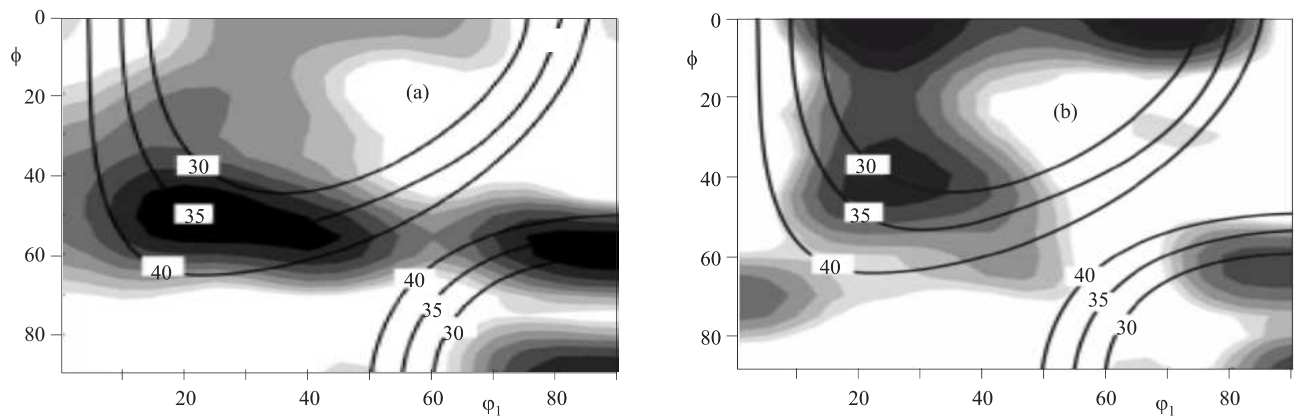

Fig. 5. ODF and $A_{\theta}(g)$ for the $\varphi_2 = 45$øEuler section at $\theta = 0$øafter final annealing at 800ø/20 s (left) and 1000ø/20 s (right) of a given hot band

field in the sheet plane. The value of A depends on the crystallographic orientation of the crystals in the polycrystalline material. Crystallographic orientation of this polycrystalline material can be characterized by the orientation distribution function (ODF) obtained by EBSD. The values of the magnetic induction B_{25} is proportional to A. Introducing an A map, which give the value of A for each orientation in the $\varphi_2 = 45$øEuler section, the experimental obtained intensities of the ODF in the $\varphi_2 = 45$øEuler section may be immediately used to analyse the expected values of B_{25}.

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