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CS-01. On the homogeneity and isotropy of non-grain oriented electrical steel sheets for the modeling of basic magnetic properties from microstructure and texture.

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Abstract Laminations of non-grain oriented (NO) electrical steel grades for magnetic cores of electrical machines should feature homogenous magnetic properties within the entire sheet plane. Basic empirical models have been introduced to estimate and correlate magnetic properties with microstructural material parameters. In these considerations the steel sheets are generally considered being homogenous, i.e., orientation dependence and variations across the sheet thickness are often disregarded. Whether or not, these simplifications are justified and how grain size and texture are described most suitable for correlations with magnetic properties, is the focus of this study on four industrial NO steel grades. **Introduction** Electromagnetic properties of non-grain oriented electrical steel directly stem from elemental material properties. Characteristic magnetic values such as permeability, coercivity, losses or saturation polarization depend on, e.g., alloying content, grain size or crystal orientation. Subject of various research is the modeling of distinct magnetic values from empirical correlations between for example Si-equivalent, grain size or texture factors with losses or saturation magnetization [1-3]. However, these equations require explicit values that actually describe the microstructure and texture. Thus, two main factors become of significant importance; isotropy and homogeneity. Even though non-oriented electrical steel refers to the non-grain oriented modification of these materials and thus, indicates isotropic behavior and statistically distributed crystal orientations, distinct deviation from this ideal properties can be observed. Due to the production and processing NO steel actually has a texture that is not random as well as anisotropic magnetic properties. In order to obtain credible values of elemental material properties which affect the magnetic properties the homogeneity and anisotropy of NO steel grade is studied on four different industrial materials. Microstructure and texture are evaluated and correlated to the magnetic properties. **Experimental** Four different industrial NO are studied corresponding to two different M330-50A, a M270-50A and a M300-35A. For texture and microstructure measurements, samples were prepared in different layers of the RD-TD sheet plane. The value of 0% refers to the surface of the sample, whereas 25% and 50% mark ¼ and ½ of the height of the sheet plane. This is sufficient due to the mirror geometry of the sheet thickness along the ½ height. For texture measurements an X-ray goniometer is used. From the ODF measurements the *A*-parameter is calculated according to the parameter introduced by Kestens et al [4]. Samples are then etched and observed under a light optical microscope. The determination of grain size is performed analogous to the line intercept method and carried out along different directions of the RD-TD samples. For the magnetic characterization a 120 mm x 120 mm Single-Sheet-Tester is used. Due to the uniaxial flux in this setup, samples are cut in 5° steps between RD and TD to determine magnetic properties in the different orientations of the sheet plane. **Results & Discussion** For all material under study, texture varies along the sheet thickness, i.e., in different layers. In Fig.1 the *A*-parameter over the range between 0° (RD) and 90° (TD) is depicted. For all layers the mean angle between the directional vector and easy magnetization axis is smaller in RD when compared with TD. If the *A*-parameter is averaged over the sheet plane it is apparent that the *A*-parameter considerately changes. The surface exhibits a mean value of 35 whereas the ½ of the sheet has a value of 31.5. Considering that the ideal orientation for NO is a ND-rotated cube fiber a value of 22.5 and a statistically random texture has an *A*-parameter of approx. 31 it is highlighted that the desired cube texture for NO steel grades is not evident in industrial NO. Grain size can also vary within the cross section of the steel sheets. Different models [1-5], e.g., eq. (1) [4] describe the correlation between magnetic properties and microstructural features. The results of the performed experimental series are applied to some of these models and analyzed in respect to their sensitivity to inhomogeneity and anisotropy of NO. $P\mathrm{h} = (-3.9)d + (0.15)A - 0.869$ (1) **Conclusions** For materials with inconstant microstructural features over the sheet thickness and along different orientations it is necessary to consider the inhomogeneity, when modeling magnetic properties. The studied industrial grades showed distinct differences considering homogeneity and anisotropy with some grades being very isotropic and some being inhomogeneous. Correlations between microstructure, texture and magnetic properties demonstrate that a differentiated consideration leads to good accordance even for inhomogeneous grades. Thus, an initial evaluation of isotropy is important. **Acknowledgement** The work of N. Leuning and S. Steentjes is supported by the DFG and performed in the research group project "FOR 1897 - Low-Loss Electrical Steel for Energy-Efficient Electrical Drives" and as part of the DFG research project "Improved modeling and characterization of ferromagnetic materials and their Losses". The authors thank S. Roggenbuck from the Institute of Physical Metallurgy and Metal Physics of RWTH Aachen University for the texture measurements.

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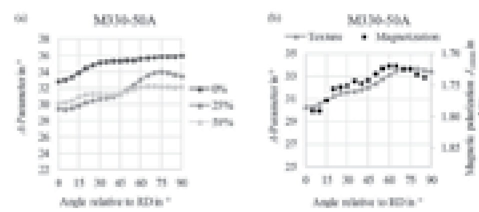

(a) texture in different layers of sheet thickness 0% surface, 25% ¼ height, 50% middle of sheet, (b) correlation between weighted *A*-parameter and magnetic polarization.