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DETERMINATION OF THE SECOND ORDER ANISOTROPY CONSTANT $K_1$
FROM THE MAGNETIZATION CURVES OF POLYCRYSTALLINE SAMPLES:
APPLICATION TO Y-Fe RICH COMPOUNDS

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Abstract. – A new approach to the determination of the second order anisotropy constant $K_1$ for either random or partially oriented polycrystalline samples is described. Good agreement with the results of Singular Point Detection measurements on Y(Fe11Ti) and measurements on an $Y_2Fe_{14}B$ single crystal, justifies the proposed approach.

1. Introduction

The determination of anisotropy constants $\{K_i\}$ from measurements on polycrystalline samples is a well known problem. Czerlinsky [1], Akurov [2] and Néel [3] have proposed the approach to saturation law:

$$M = M_s - a_1/H - a_2/H^2 - a_3/H^3.$$  

The use of this model for the determination of anisotropy constants is quite difficult due to the lack of an explicit relationship between $\{a_i\}$ and $\{K_i\}$. Usually one uses the perpendicular magnetization curves of an aligned polycrystalline sample to estimate the anisotropy field $B_a$. However, imperfect alignment always leads to erroneous values even when making some nontrivial corrections [4]. Here, we describe a new approach based on numerical solutions of the Stoner-Wohlfarth problem which gives accurate values of $B_a$ from magnetization measurements on partially-oriented or random polycrystalline samples.

2. Model

As a first approximation, the oriented polycrystalline sample is considered as a collection of monodomain particles with a certain distribution of c-axes around the aligning direction. The magnetization process as a function of applied field in a uniaxial monodomain particle was first solved by Stoner and Wohlfarth using iterative numerical methods. The free energy for a such system is given by

$$E(\theta, \theta_B) = K_1 \sin^2 \theta - M_S \cos (\theta - \theta_B)$$  

where $K_1$ is second order anisotropy constant and $B$ is internal field, $\theta$ and $\theta_B$ are respectively the angle from the c-axis for $M_S$ and $B$. By minimizing equation (1) with respect to $\theta$ we obtain:

$$2\gamma \sin \delta = \sin 2(\theta_B - \delta)$$  

where $\delta = \theta_B - \theta$ and $\gamma = B / B_a (B_a = 2K_1 / M_S)$ are respectively the lag-angle and the reduced internal field. Recently, a new analytical approach based on Fourier analysis has been used by Pastor and co-workers [6, 7] to solve equation (2) for the lag-angle $\delta$. Due to the oscillatory behaviour near $\gamma \approx 1$ and $\theta_B < \pi / 2$, we have chosen the numerical solutions rather than the analytical ones. Assuming the distribution of c-axes around the aligning direction is described by a Gaussian,

$$P(\theta_B) = A \exp \left( -\theta_B^2 / \theta_0^2 \right)$$  

($P(\theta_B) \equiv 1$ for random sample) where $A^{-1} = \int d\Omega P(\theta_B)$ is a normalization constant and $\theta_0$ is the degree of misalignment, the value of magnetization at a fixed reduced internal field $\gamma$ is given by

$$\langle M \rangle = \int M_S \cos (\gamma, \theta_B) P(\theta_B) \, d\Omega.$$  

Again we employ numerical integration with $\Delta\theta_B = 0.1^\circ$ to simulate the theoretical magnetization curves for different given value of $\theta_0$. In order to deduce the anisotropy field $B_a$ (or $K_1$) from these curves, we have made Sucksmith-Thompson plots [8] of $\gamma / \sigma$ versus $\sigma^2$ where $\sigma = \langle M \rangle / M_S$ is the reduced magnetization. Examples are shown in figure 1. It can been seen that

Fig. 1. – Sucksmith-Thompson plots for different fixed values of the degree of misalignment $\theta_0$. 

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in the range $0.35 < \sigma^2 < 0.75$, $\gamma / \sigma$ varies quite linearly with $\sigma^2$. Such variation is described by

$$\gamma / \sigma = a(\theta_0) + b(\theta_0) \sigma^2$$

where $a(\theta_0)$ and $b(\theta_0)$ are constants depending only on $\theta_0$. We find by interpolation in the range $\theta_0 = 0^\circ - 30^\circ$, that the $\theta_0$ dependence of $a$ and $b$ is given by

$$a(\theta_0) = 1.000 - 0.01933 \theta_0$$

$$b(\theta_0) = (0.0400 - 0.000435 \theta_0) \theta_0$$

where $\theta_0$ is in degrees. A random sample is a special case where $a = -0.2835$ and $b = 1.6235$. This dependence of the parameters $a$ and $b$ on a single parameter $\theta_0$, is the essential feature of the proposed model.

Transforming equation (4) into a more familiar form gives:

$$B_{app} / \langle M \rangle = (\mu_0 D + aB_a / M_S) + (bB_a / M_S^2) \langle M \rangle^2$$

where $\mu_0 = 4 \pi \times 10^{-7}$, $B_{app}$ and $D$ are respectively the applied field and demagnetizing factor. It is now clear that the anisotropy field and $\theta_0$ (as well as $a$ and $b$) can be directly deduced from the slope and intercept of a plot of $B_{app} / \langle M \rangle$ versus $\langle M \rangle^2$ using equations (5) and (6) and assuming a knowledge of the spontaneous magnetization $M_S$.

3. Application

The model described above is valid for uniaxial systems where only the second order anisotropy constant $K_1$ is important. Yttrium-iron compounds are examples of such systems [9, 10]. We have used the model to deduce the values of $K_1$ from equations (5) and (6) for Y(Fe$_{11}$Ti) and Y$_2$Fe$_{14}$B. To avoid the complication of magnetic interactions between grains, all samples were prepared by mixing finely-ground alloy powder with epoxy resin and aligning in a field of 1.5 T. The value of $D$ is always taken as $1/3$ in the analysis. Results for $K_1$ obtained with $\theta_0 = 27^\circ$ for Y(Fe$_{11}$Ti) are compared in figure 2 with those obtained in pulsed field by singular point detection (SPD) [11], the value of $\theta_0$ was confirmed by Mössbauer spectroscopy [12]. Furthermore the value of $K_1$ at 4.2 K deduced for an oriented Y$_2$Fe$_{14}$B sample is 0.664 MJm$^{-3}$, close to the value of 0.705 MJm$^{-3}$ [10] obtained from single crystal measurements. The excellent agreement between results deduced from the model and those from SPD or single crystal measurements for Y(Fe$_{11}$Ti) and Y$_2$Fe$_{14}$B justifies the validity of the proposed approach.

Fig. 2. – Comparison of the values of $K_1$ for Y(Fe$_{11}$Ti) obtained from equations (5) and (6) of the model (full squares) with those from SPD measurements [12] (open squares).

References

[12] Hu Bo-Ping, Li Hong-Shuo and Coey, J. M. D., Hyperfine Interactions, in press.