DETERMINATION OF THE SECOND ORDER ANISOTROPY CONSTANT K1 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 $Y(Fe_{11}Ti)$ 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 $\mathbf{B}_a$. 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 [5] problem which gives accurate values of $\mathbf{B}_a$ from magnetization measurements on partialy-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

$$E(\theta, \theta_B) = K_1 \sin^2 \theta - M_S\, B \cos(\theta - \theta_B) \qquad (1)$$

where K_1 is second order anisotropy constant and $\mathbf{B}$ is internal field, θ and θ_B are respectively the angle from the **c**-axis for $\mathbf{M}_S$ and $\mathbf{B}$. By minimizing equation (1) with respect to θ we obtain:

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

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 coworkers [6, 7] to solve equation (2) for the lag-angle δ. Due to the oscillatory behaviour near $\gamma \cong 1$ 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 θ_0 is the degree of misalignment, the value of magnetization at a fixed reduced internal field γ is given by

$$\langle M \rangle = \int M_S \cos \delta(\gamma, \theta_B)\; P(\theta_B)\; d\Omega. \qquad (3)$$

Again we employ numerical integration with $\Delta\theta_B = 0.1°$ to simulate the theoretical magnetization curves for different given value of θ_0. In order to deduce the anisotropy field $\mathbf{B}_a$ (or K_1) from these curves, we have made Sucksmith-Thompson plots [8] of γ / σ *versus* σ^2 where $\sigma = \langle M \rangle / M_S$ is the reduced magnetization. Examples are shown in figure 1. It can been seen that

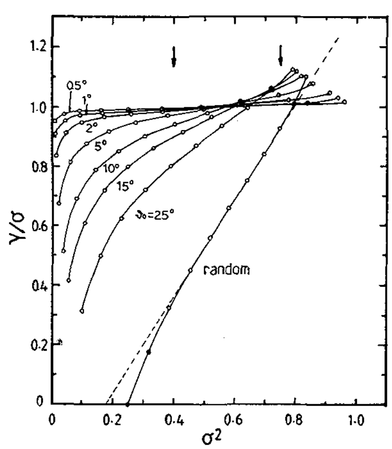

Fig. 1. – Sucksmith-Thompson plots for different fixed values of the degree of misalignment θ_0.

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

$$\gamma / \sigma = a(\theta_0) + b(\theta_0)\,\sigma^2 \tag{4}$$

where $a(\theta_0)$ and $b(\theta_0)$ are constants depending only θ_0. We find by interpolation in the range $\theta_0 = 0° - 30°$, that the θ_0 dependence of a and b is given by

$$a(\theta_0) = 1.000 - 0.01933\,\theta_0 \tag{5a}$$

$$b(\theta_0) = (0.0400 - 0.000435\,\theta_0)\,\theta_0 \tag{5b}$$

where θ_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 θ_0, is the essential feature of the proposed model. Transforming equation (4) into a more familiar form gives:

$$B_{\mathrm{app}} / \langle M \rangle = (\mu_0 D + aB_{\mathrm{a}} / M_{\mathrm{S}}) + \\ + \left(bB_{\mathrm{a}} / M_{\mathrm{S}}^3\right) \langle M \rangle^2 \tag{6}$$

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 θ_0 (as well as a and b) can be directly deduced from the slope and intercept of a plot of $B_{\mathrm{app}} / \langle M \rangle$ *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 $Y_2Fe_{14}B$. 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 $\theta_0 = 27°$ 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 θ_0 was confirmed by Mössbauer spectroscopy [12]. Furthermore the value of K_1 at 4.2 K deduced for an oriented $Y_2Fe_{14}B$ 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 $Y_2Fe_{14}B$ justifies the validity of the proposed approach.

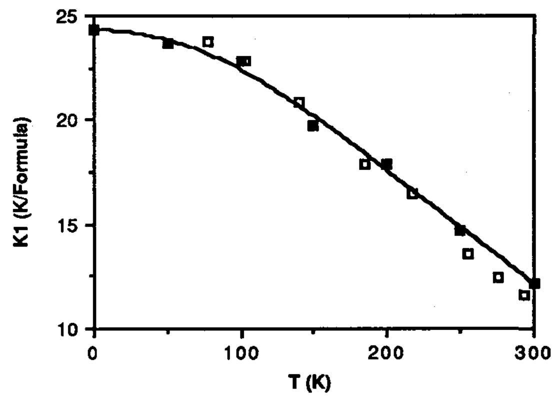

Fig. 2. – Comparison of the values of K_1 for $Y(Fe_{11}Ti)$ obtained from equations (5) and (6) of the model (full squares) with those from SPD measurements [12] (open squares).

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