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THE ISOTHERMAL REMANENCE OF FINE PARTICLE SYSTEMS

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Abstract. – A numerical model based upon the "Stoner-Wohlfarth theory" has been developed to predict Isothermal Remanent Magnetisation (IRM) curves for a system of fine particles with uniaxial anisotropy. This paper reports the predictions of our model for the effects of easy axes alignment on the IRM curve. We have also investigated the effect of the standard deviation after the application of a non-saturating field to the system.

Introduction

In many applications of fine magnetic particles they are required to possess a high remanence (500-650 Gauss) after the application of a relatively modest field, H_m (1-1.5 kOe), to the system. They can then store information which can be read magnetically.

The variation of remanence with magnetising field is the so-called Isothermal Remanent Magnetisation (IRM) curve. Previous authors predicted IRM curves for a system of fine particles with aligned easy axes [1] and randomly orientated easy axes [2]. We have determined the effects of partial alignment of easy axes. Investigations have also been made into the dependence of the remanence on the standard deviation (σ) of the particle size distribution for the randomly orientated easy axes IRM model.

The numerical model is based upon the Stoner-Wohlfarth theory of fine ferromagnetic particles [3]. This theory assumes that the particles are non-interacting and that the anisotropy is uniaxial. However, our model also contains a particle size distribution. This distribution will affect the properties of the system and will result in a distribution of energy barriers. The behaviour is often characterised by the distribution of switching fields for the assembly of particles. The switching field distribution (SFD) is a measure of the coercivities of the individual particles in the system and can be obtained by differentiation of the IRM curve [4].

Theory

The Stoner-Wohlfarth theory of uniaxial fine magnetic particles gives the criteria for a single domain particle to undergo magnetisation reversal. Reversal takes place for a given critical value of field $h_c (= H_c/H_k)$ where

$$h_c = -\left(1 - t^2 + t^4\right)^{1/2} / 1 + t^2 \qquad (1)$$

where

$$t = \tan\theta_c = \tan^{1/3}\phi \qquad (2)$$

where θ is the angle between the particle easy axis and the direction of the moment vector and ϕ is the angle between the easy axis and the applied field.

We can define a critical volume for superparamagnetic behaviour in zero field, $V_p(0)$, which has a value approximately equal to 25 kT/K [5]. Also there will be a critical volume present in an applied field, $V_p(H_m)$, which will be dependent upon ϕ, h, T and t, the experimental time of measurement. Therefore particles with $V_p(0) < V < V_p(H_m)$ have made the transition into the field direction and will contribute to the remanence of the system. The remanence is then given by

$$\frac{I_r(H_m)}{I_s} = \bar{I}_r(H_m) = \int_0^{\pi/2} d\theta \int_{V_p(0)}^{V_p(H_m)} f(\phi)\, f(V)\, dV \qquad (3)$$

where $f(V)$ is the normalised volume distribution function and $f(\phi)$ is the texture function describing the degree of easy axes alignment in the system ie the texture.

The particle size distribution is characterised by a distribution of volume fraction $f(y)$ where y is the reduced diameter $y = D/D_v$, D_v is the median diameter of the distribution. In our model a lognormal distribution is assumed given by

$$f(y) = \frac{1}{\sqrt{2\pi}\sigma y}\left[\exp - (\mathrm{Ln}\ y)^2 / 2\sigma^{-}\right]. \qquad (4)$$

Alignment of the easy axes is achieved by weighting the integral of equation (3) with the following texture function

$$f(\phi) = \beta \sin\phi \left[\exp(\beta\cos\phi) + \right.$$
$$\left. + \exp(\beta\sin\phi)\right] / \exp(\beta) - 1. \qquad (5)$$

When $\beta > 0$ alignment is in the measurement direction. $\beta = 85.6$ results in the easy axes being fully aligned with the direction of the field.

Results

The remanence has been calculated for a system of fine cobalt particles of anisotropy constant $K = 2 \times$

10^6 erg/cc, I_{sb} = 1 400 emu/cc and T = 300 K. The value of K selected is often observed for fine cobalt particles in the fcc phase.

Figure 1 shows a set of IRM curves for a system of cobalt particles with the median diameter D_v = 120 Å and $\sigma = 0.3$. The three curves generated are for a system of particles with easy axes randomly orientated, partially aligned ($\beta = 5$) and aligned fully with the direction of the applied field. Differentiation of these curves gives us the SFD as shown in figure 2. It is seen that the alignment of the easy axes broadens the SFD and the maximum value of the SFD decreases.

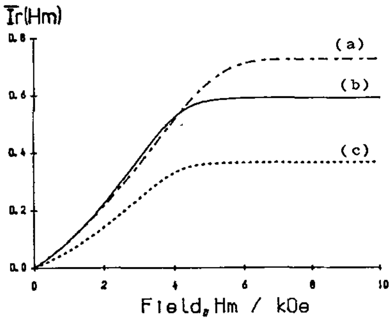

Fig. 1. – IRM curves for easy axes aligned (a), partially (b) and randomly orientated (c).

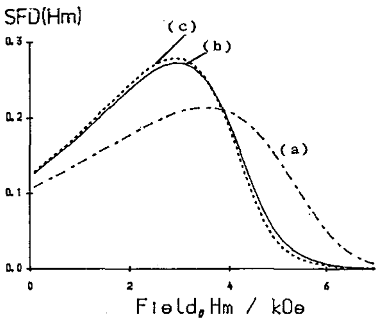

Fig. 2. – SFD curves for easy axes aligned (a), partially (b) and randomly orientated (c).

The relationship between the remanence and the standard deviation, σ, is illustrated in figure 3. The predictions have been made for a system of particles with randomly orientated easy axes. It has been assumed that a field of 1 kOe has been applied to the system of particles at each value of σ. This field is insufficient to saturate the system. It is seen that $\bar{I}_r(H_m)$ depends strongly on σ. It would be expected that at $\sigma = 0$ (i.e. a monodispersed system) the maximum remanence $\left(\bar{I}_r(H_m) = 0.5\right)$ would be achieved. However, for particles with diameters between 94 Å and 98 Å this is not the case since for these particles $V < V_p(0)$ (i.e. superparamagnetic particles). However, for the larger particles with diameters between 100 Å and 120 Å a maximum value of $\bar{I}_r(H_m) = 0.5$ is attained at $\sigma = 0$ since here $V_p(0) < V < V_p(H_m)$.

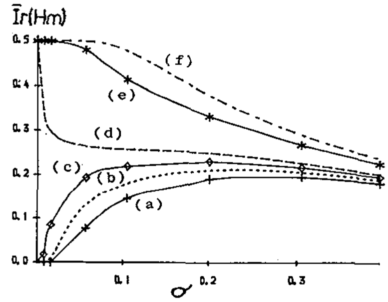

Fig. 3. – $\bar{I}_r(H_m)$ *vs.* σ for a range of values of D_v 94 Å (a), 96 Å (b), 98 Å (c), 100 Å (d), 110 Å (e), 120 Å (f).

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