Magnetization reversal in co-precipitated cobalt ferrite

D.R. Cornejo, A. Medina-Boudri, H.R. Bertorello, J. Matutes-Aquino

Abstract

A study about the magnetic viscosity and magnetization reversal in co-precipitated cobalt ferrite was carried out. Measurements of direct current demagnetization reversible M_{rev} and irreversible M_{irr} magnetization as well as magnetic viscosity S_n were performed at room temperature along the demagnetization curve for different applied fields H_{ap}($0 > H_{ap} > - 7$ kOe). From these data $M_{rev}(M_{irr})_{Hi}$ curves were built. The experimental results show a minimum in the $M_{rev}(M_{irr})_{Hi}$ curves and a non-proportionality between S_n and X_{irr}; suggesting two different contributions to the reversal magnetization during the demagnetization process.

Keywords: Magnetization reversal; Magnetic viscosity; Cobalt ferrite

Cobalt ferrite is a cubic spinel ferrite with interesting magnetic properties useful in many technological applications [1]. However, no study about its magnetic viscosity involving reversal process has been developed yet. It is well known that the time dependence magnetization is a process connected with the thermal activation phenomena. In many materials the total magnetization M of a previously saturated sample in a positive field, decreases in a negative constant applied field Hap; following a logarithmic time law [2]

$$M(t) = M_0 - S \ln(1 + t/t_0), \qquad (1)$$

where M_0 and t_0 are constants and S is the magnetic viscosity. However, reversible (dM_{rev}) and irreversible (dM_{irr}) changes of the magnetization (dM) occur together during the relaxation process, this means

$$\mathrm{d}M = \mathrm{d}M_{\mathrm{rev}} + \mathrm{d}M_{\mathrm{irr}}. \qquad (2)$$

These components are correlated by the phenomenological equation [3]

$$\mathrm{d}M_{\mathrm{rev}} = \chi^{\mathrm{i}}_{\mathrm{rev}}\,\mathrm{d}H_{\mathrm{i}} + \eta\,\mathrm{d}M_{\mathrm{irr}}. \qquad (3)$$

Here, $H_i = H_{ap}$ - DM is the internal magnetic field, D being the demagnetization factor appropriate to the geometry of the sample. The parameters X^i_{rev} and *n* are given by [3] $X^i_{rev} = (\partial M_{rev}/\partial H_i)M_{irr}$ and $n = (\partial M_{rev}/\partial M_{irr})._{Hi}$

Differentiating $H_i = H_{ap} – DM$ we get $dH_i = - DdM$ and replacing into Eq. (3) we obtain

$$\mathrm{d}M = [(1+\eta)/(1+D\chi^{\mathrm{i}}_{\mathrm{rev}})]\,\mathrm{d}M_{\mathrm{irr}}. \qquad (4)$$

Differentiating Eq. (1) and replacing into Eq. (4) at constant magnetic field, we obtain

$dM_{irr} = S_n\, d(\ln+t/t_0))$,

where

$Sn = S(1+DX^i_{rev})/(1+n)$. (5)

The magnetic field at which reversal takes place is called fluctuation field $H_f = S_n/X_{irr}$ [4], where X_{irr} is the irreversible susceptibility. Considering that the magnetic energy involved in the reversal process is $E_m = (V_{ac}M_s)\ H_f$ (M_s is the spontaneous magnetization), the activation volume V_{ac}, which is the volume associated with the magnetic reversal, results $V_{ac} = K_bT/M_sH_f$ (K_b is the boltzman constant) [4]. In this work, it is shown that the magnetic viscosity and direct current demagnetization (DCD) M_{rev} behavior in this material are consistent with the nucleation of reverse domains and a later unpinning of the respective domain walls.

Co-precipitated cobalt ferrite powder was prepared as indicated in Ref. [5]. The material is a conglomerate of polyhedral-shape particles with a relatively wide grain size distribution, between 200 and 500 nm. The powder was cold-pressed with a 10-ton press into 5mm diameter cylinder. An ellipsoidal shape sample was cut and covered with resin. Magnetization measurements were performed using a vibrating sample magnetometer with a 20 kOe electromagnet. Viscosity tests at room temperature were performed at intervals of H_{ap} = 50 Oe along the demagnetization curve. Magnetization measurements for times between 10 and 300 s were fitted to Eq. (1) to determine the magnetic viscosity S. After this measurement, the magnetic field was returned to $H_i = 0$ in order to obtain the DCD M_{irr} and M_{rev} components [3,6]. From these, $M_{rev}(M_{irr})_{Hi}$ curves were built and the $n(H_i)$ function was calculated [6].

The remanent magnetization measured for the sample was $4\pi M_R$ = 1800G and the intrinsic coercive field was H_c = 0:75 kOe (value comparable to those presented in Ref. [7]). In Fig. 1a representative sets of M_{rev}=M_R versus M_{irr}=M_R curves are shown. The single domain size observed for this ferrite is 70nm [8], this means that the particles are a multidomain system at the demagnetized state. The minimum in these curves arises because M_{rev} is proportional to the total domain wall area [6,9]. When M_{irr} is at remanence (positive or negative), the total domain wall area will be zero. But somewhere between these two extremes in M_{irr}, there must be a maximum in the total domain wall area, giving rise to a maximum in M_{rev}.

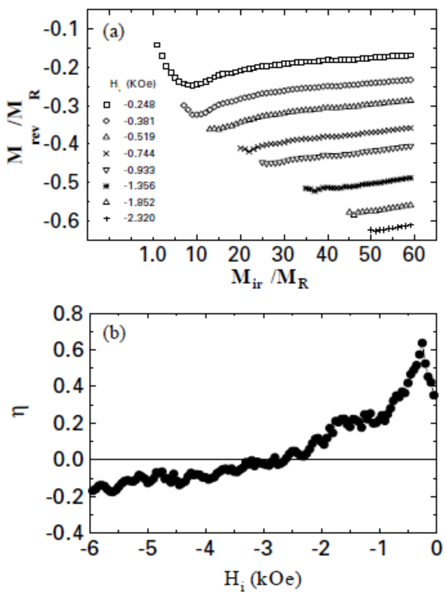

Fig. 1. (a) DCD M_{rev} as a function of M_{irr} at different fixed H_i. (b) η values as a function of the internal field in the demagnetization curve.

In this case the nucleation field is smaller than the pinning field and M_{rev} will arise from domain wall bowing and movement [6,9]. Fig. 1b shows the curve n(H_i). *n* is initially positive and have a maximum prior to H_c. Later on, n(H_i) decreases as H_i increases. For H_i< 2.5 kOe, n becomes negative. Crew et al. associated these shapes of n(H_i) to the following mechanism. When H_i exceeds the nucleation field, a domain wall is nucleated being free to displace along the grain until is pinned at spaced strong pins which lets the wall to bow. This stage is indicated by n > 0 at low H_i and by an increase in magnitude of M_{rev} as M_{irr} decreases from positive remanence, due to the increase in domain wall area. After this, when H_i exceeds the unpinning field and the domain walls are driven into the grain boundary, there is no more reversible motion of the domain wall leading to n<0 in higher fields, and the rotation of the magnetic moments in the grains becomes the main contribution to M_{rev}.

The DCD irreversible susceptibility as a function of H_i is shown in Fig. 2a. The X_{irr} maximum occurs at H_c = 0.75 kOe. It is seen that the material presents a very broad switching field distribution reflected in the width of wirr(H_i). Fig. 2b shows the behavior of the magnetic viscosity parameters, S and S_n obtained from Eqs. (1) and (5). It is seen that the existence of an interrelation between both components of magnetization altered up to 60% the relative values of the viscosity in this material. On the other hand, S_n displays a broad distribution centered in a maximum at H_i = -2.7 kOe. This value is very different from H_c = 0.75 kOe and reflects the non-proportionality between X_{irr} and S_n.

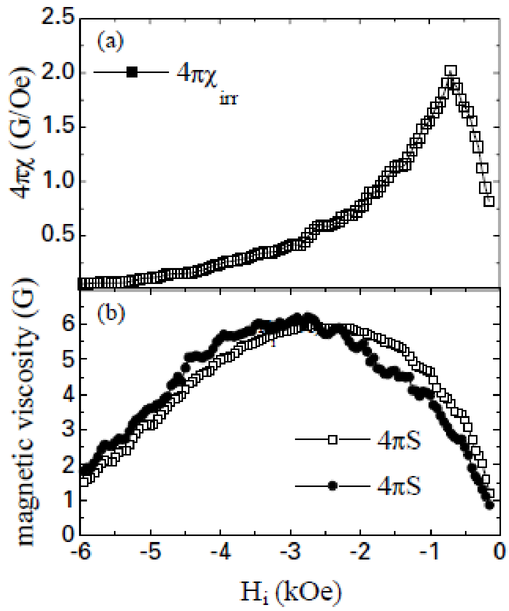

Fig. 2. (a) DCD irreversible susceptibility and (b) magnetic viscosity S and S_η, as a function of the internal field during the demagnetization.

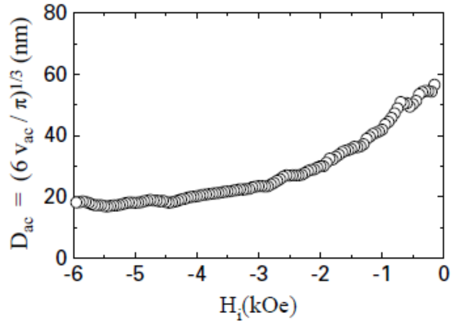

Fig. 3. Diameter of the activation volume as a function of the internal field during the demagnetization in cobalt ferrite.

In fact, the maximum of S*n* occurs when *n*(H_i) changes sign (see Fig. 1b). This suggests that the magnetic viscosity in this material is principally supplied by events of nucleation of inverse domains and for the unpinning of domain walls. When the main mechanism of reversal magnetization becomes the rotation of magnetic moments into grains, S_n decreases. The width of the switching field distribution in this material indicates that higher inverse fields, in comparison to H_c; are necessary in order to overcome the trapping of all domain walls in the grains. This behavior results in comparatively important values of viscosity at internal fields greater than the coercivity.

The diameter D_{ac} of the activation volume as a function of H_i is shown in Fig. 3. Clearly, D_{ac} is lower than the average size of the particles in the sample at all range of H_i. Initially, when the nucleation is the main mechanism of reversal magnetization, this diameter is close to the single domain size observed for this ferrite, 70 nm. This diameter decreases when H_i increases. For $H_i < -4$ kOe; approximately, D_{ac} attained a plateau close to 20 nm. This behavior suggests that when the unpinning of domain walls becomes more active, the activation volume in each thermally activated event decreases, probably limited by the average separation between pinning sites.

The corresponding author wishes to thank SECYTUNC for the partial financial support of this work.

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