

Time-dependent magnetization in co-precipitated cobalt ferrite

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Abstract

A study of the magnetic aftereffect in co-precipitated cobalt ferrite is presented. Measurements of the magnetic viscosity S were performed at room temperature along the demagnetization curve for different applied fields H_{ap} over a wide range of fields ($0 \text{ kOe} < H_{ap} < 7 \text{ kOe}$). The interrelation function $n = \frac{1}{4} \frac{\partial M_{rev}}{\partial M_{irr}} \frac{\partial M_{irr}}{\partial H_i}$ between the DCD reversible M_{rev} and irreversible M_{irr} magnetization components was determined as well. The experimental results for $S_n(H_i)$ where H_i is the internal field, showed a broad distribution with a maximum at $H_i = 2.7 \text{ kOe}$. However, the irreversible susceptibility X_{irr} displays a maximum at $H_c = 0.75 \text{ kOe}$, the coercivity of the material. The experimental behavior of n and the non-proportionality between S_n and X_{irr} suggest that the magnetic viscosity in this material is principally supplied by events of nucleation of inverse domains and the depinning of domain walls. When the main mechanism of reversal magnetization changes to rotation of magnetic moments for all the grains, the magnetic viscosity decreases.

Keywords: Magnetic viscosity, Magnetic aftereffect, Cobalt ferrite, Reversal magnetization

Introduction

Cobalt ferrite is a cubic spinel ferrite with interesting magnetic properties useful in many technological applications. However, few studies about the magnetization reversal process have been developed so far and there are many nonunderstanding aspects about this problem.

It is well known that the time-dependent magnetization is a process connected with the thermal activation phenomena. Essentially, the presence of many metastable states in the material free energy is the source for the so-called magnetic aftereffect. In many materials, over restricted ranges of elapsed time and appropriate conditions, the magnetization M of a previously saturated sample in a positive field, decreases in a negative constant applied field H_{ap} ; following a logarithmic time law:

$$M(t) = M_0 - S \ln(1 + t/t_0). \quad (1)$$

Here, M_0 and t_0 are constants and S is the so-called magnetic viscosity. However, it must be taken into account that reversible and irreversible changes of the magnetization occur together during the relaxation process. It means that any variation dM of the magnetization can actually involve reversible (dM_{rev}) and irreversible (dM_{irr}) parts. These components are usually correlated by the phenomenological equation [1] $dM_{rev} = \chi_{rev}^i dH_i + n M_{irr}$. Here, $H_i = H_{ap} - DM$ is the internal magnetic field, D is the sample demagnetization factor and χ_{rev}^i and n are given by

$$\chi_{rev}^i = (\partial M_{rev} / \partial H_i)_{M_{irr}}, \quad \eta = (\partial M_{rev} / \partial M_{irr})_{H_i}. \quad (2)$$

Then, during a magnetic viscosity experiment, the irreversible changes of the magnetization can be expressed by the relation $dM_{irr} = S_n d(\ln(1+t/t_0))$, where

$$S_n = S(1 + D\chi_{rev}^i)/(1 + \eta). \quad (3)$$

From S_n and the irreversible susceptibility χ_{irr} it is possible to obtain the fluctuation field $H_f = S_n/\chi_{irr}$ and the activation volume $v_{ac} = (k_B T)/(M_s H_f)$ [2–4] (M_s is the spontaneous magnetization). In general, $v_{ac}^{1/3}$ gives a measure of the characteristic

length of the magnetization inhomogeneity which is involved in each thermally activated process.

In a previous work [5], it was shown that the behavior of the DCD reversible magnetization in cobalt ferrite was compatible with the nucleation of reverse domains subject to pinning during the demagnetization process. In this work, measurements of the magnetic aftereffect are presented and its behavior is interpreted in relation to the mentioned reversal magnetization mechanism.

Experimental

Cobalt ferrite powder was prepared as indicated in Ref.[6]. The particles present polyhedral geometry 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 for protection. Magnetic aftereffect tests at 300K were performed using a vibrating sample magnetometer with a 20 kOe electromagnet. In each test, the sample was previously saturated at 15 kOe. Later on, the magnetic field was suddenly changed to a negative value. $M(t)$ data for times between 10 and 300 s (i.e. 10 s of waiting period) were fitted to Eq. (1), in order to determine the magnetic viscosity S . Following each viscosity test, the magnetic field was returned to zero internal field in order to obtain the DCD M_{irr} component. DCD $M_{rev}(M_{irr})$ curves at a constant internal field were built as explained in Ref.[5] and the n function was calculated from Eq.(2). Finally, S_n was obtained from Eq.(3).

Results and discussion

The remanent magnetization $4\pi M_R=1950G$ and a saturation magnetization $4\pi M_S=4200G$ were determined from the major hysteresis loop for the sample. The DCD

irreversible susceptibility and the S and S_n viscosity parameters are shown in Fig.1 as functions of the internal field. The maximum of X_{irr} occurs at $H_c = 0.75$ kOe. It is important to note that the material presents a very broad switching field distribution reflected in the width of X_{irr} . It is seen that S_n displays a broad distribution centered in a maximum at $H_i = 2.7$ kOe. This value is quite different from the coercivity of the sample and reflects an unusual nonproportionality between X_{irr} and S_n . As was discussed by Street and Brown [4], the fluctuation field H_f is a measure of $\partial E/\partial H$, the variation in the field of the activation energy of the irreversible metastable processes which are active at each point on a magnetization curve. Our experimental results suggest a complex dependence of the activation energy with the magnetic field for this material. A posterior study of this interesting feature will be presented elsewhere.

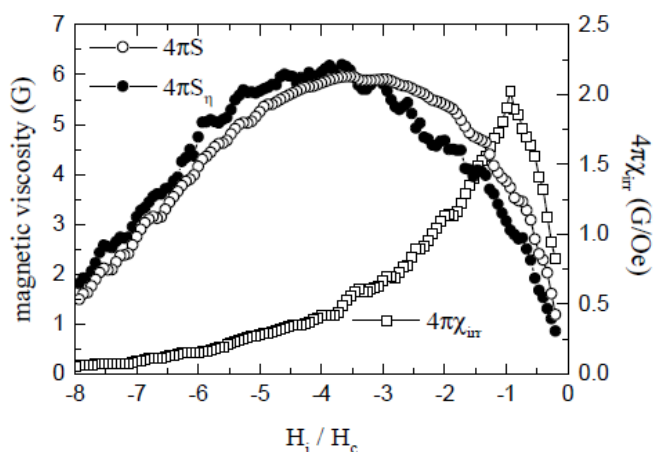


Fig. 1. DCD irreversible susceptibility, and the S and S_n viscosity parameters as a functions of the normalized internal field for the sample.

The interrelation between DCD M_{rev} and M_{irr} components is displayed by the Z function in Fig.2. It is seen that n is initially positive and has a maximum prior to the coercive field. Later on, n decreases when the internal field increases in magnitude. For

values of $H_i/H_c < -3.5$, n becomes negative. As it was discussed in Ref. [5], increasing values of n are consistent with an increase in the total domain wall area in the sample by nucleation of inverse domains and subsequent trapping of the respective walls in the pinning sites. When the inverse field is increased in magnitude, the nucleation of new domains is held but the depinning and subsequent shift of the domain walls to the grain boundaries, produces the decrease in n : Finally, when the rotation of magnetic moments in the whole grains becomes the main contribution to the reversible magnetization, n becomes negative [7,8].

The analysis of Figs.1 and 2 shows that the magnetic aftereffect is maximum when the n function changes its sign. It suggests that the magnetic viscosity in this material is principally supplied by events of nucleation of inverse domains and later by the depinning of domain walls. When the main mechanism of reversal magnetization changes to rotation of magnetic moments in the whole grains, the magnetic viscosity decreases. The width of the switching field distribution in the material suggests that high inverse fields, in comparison to coercive field, are necessary in order to overcome the trapping of all the domain walls in the grains. This behavior results in comparatively important values of viscosity at internal fields greater than the coercivity.

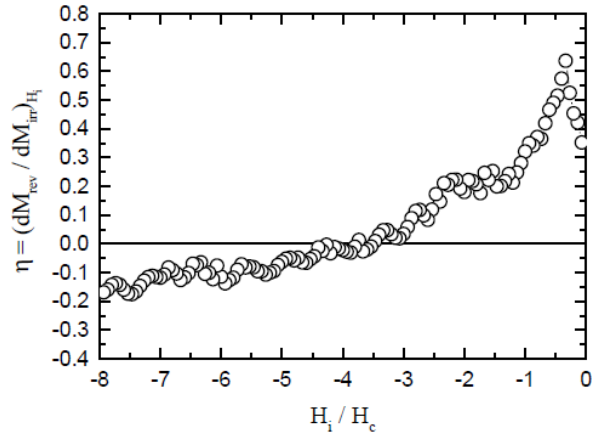


Fig. 2. η Values as a function of the normalized internal field in the demagnetization curve.

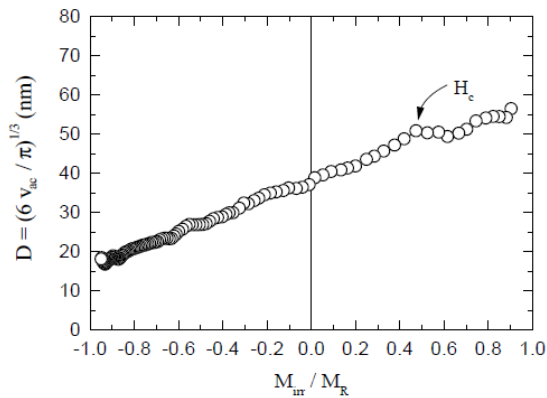


Fig. 3. Diameter of the activation volume as a function of the normalized DCD irreversible magnetization during the demagnetization in cobalt ferrite.

The dependence of the characteristic length associated to the activation volume with the irreversible magnetization component is shown in Fig.3. Clearly, the diameter D of the activation volume is lower than the average sample particle size for all values of $M_{irr}=M_R$. It indicates an incoherent reversal magnetization mechanism, in accordance with the n behavior. Initially, when the nucleation is the main mechanism for reversal magnetization, this diameter is similar to the single domain size observed for this ferrite, 70nm [9]. For internal fields lower than H_c ; approximately, the diameter D decreases

linearly with M_{irr} . This behavior suggests that when the depinning of domain walls becomes more active, the activation volume in each thermally activated event decreases, probably limited by the average separation between pinning sites.

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