Reversible processes in magnetization reversal of co-precipitated cobalt ferrite

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

Abstract

A study of the magnetization reversal process in a co-precipitated cobalt ferrite material at 300K was carried out. The evolution of the reversible M_{rev} and irreversible M_{irr} magnetization components were determined by measuring sets of recoil curves from different points on the initial magnetization curve and demagnetization curve. From these data, $M_{rev}(M_{irr})H_i$ curves were built, being H_i the internal field of the sample. The interrelation function $n = (M_{rev}/M_{irr})H_i$ was determined as well. The results suggest that domain wall movement subject to pinning is the dominant mechanism for the reversal magnetization process in this material.

Cobalt ferrite is a cubic spinel ferrite that exhibits interesting magnetic properties useful in many technological applications [1]. However, studies about its internal mechanisms in the magnetization reversal process, have not been well developed yet. In order to study this problem, the DC demagnetization method was used for separating the total magnetization M into reversible M_{rev} and irreversible M_{irr} components. The experimental procedure followed to determine this components has been published elsewhere [2].

Recent studies of demagnetization processes in permanent magnets have shown that the behavior of $M_{rev}(M_{irr})H_i$ curves can be used as an indicator of the mechanism in the magnetization reversal process [3,4]. The dependence between M_{rev} and M_{irr} was expressed in Ref. [2] as $dM_{rev} = X^{i}_{rev}dH_i + ndM_{irr}$: Here n is the interrelation function given by n = $(M_{rev}/M_{irr})H_i$; X^i_{rev} is the reversible susceptibility and Hi is the internal field defined as $H_i = H_{ap}$-DM; where H_{ap} is the applied field and D is the demagnetization factor of the sample. In systems where the magnetization reversal occurs by coherent rotation of non-interacting single domains, linear $M_{rev}(M_{irr})H_i$ curves are expected. If the nucleation and unpinning of inverse domains are the basis of the mechanism in magnetization reversal, the $M_{rev}(M_{irr})H_i$ curves exhibit a minimum during the demagnetization process [3,4]. In this work, a study of the experimental behavior of Mrev; as indicator of the mechanism during the reversal magnetization in $CoFe_2O_4$, is presented.

Ref. [5]. The particles present polyhedral geometry with grain sizes around 300 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. Measurements of $M(H_i)$ were made at 300K using a vibrating sample magnetometer with a 20 kOe electromagnet. The H_i fields were calculated using the demagnetization factor appropriate for the geometry of the sample. From the demagnetized state, a set of 64 recoil curves to $H_i = 0$ for progressively increasing positive peak fields was obtained. Afterwards, starting with the sample saturated at 15 kOe, a set of 65 recoil curves with negative peak fields was measured.

The remanent magnetization $4\pi M_R$ measured for the sample was 1800 G. In Fig. 1, representative sets of M_{rev}/MR versus $M_{irr}=M_R$ curves at different fixed H_i are shown, for the initial magnetization process (Fig. 1a) and for the demagnetization process (Fig. 1b). It is seen from these figures that the general behavior of M_{rev} is similar in both cases. During the initial magnetization process and for values of H_i up to the coercivity (H_c = 396 Oe), M_{rev} increases to a maximum and then decreases. On the other hand, during the demagnetization, M_{rev} exhibits a well-defined minimum. In both processes, when $H_i > H_c$; M_{rev} shows a predominantly monotonic behavior, which is particularly evident in the case of the demagnetization process. The magnitudes of M_{rev} during the demagnetization process are slightly larger than the corresponding to the initial magnetization process for similar Hi values. Crew et al. [3] associated these shapes of the $M_{rev}(M_{irr})H_i$ curves to an increasing of the total domain wall area. Our material is an isotropic system of magnetic particles with mean grain size expressively larger than the domain wall width (25 nm). Then, it is expected a multidomain state in each grain for the demagnetized state. In this case M_{rev} would have three principal contributions described as follows. The first one is the rotation of the magnetic moments in single domain grains. This contribution becomes important at high internal fields, when M_{irr} is close to M_R.

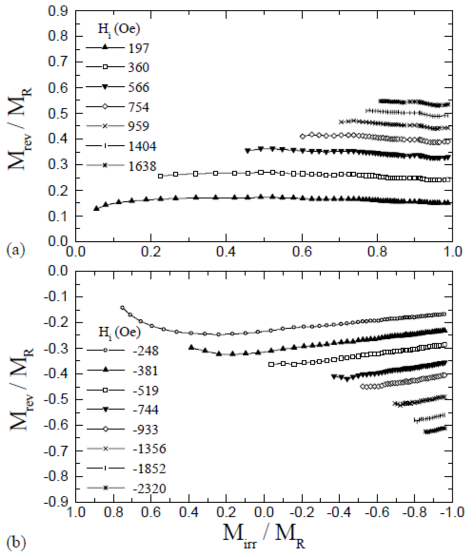

Fig. 1. M_{rev} as a function of M_{irr} at different fixed H_i for (a) the initial magnetization and (b) demagnetization curve.

The other two contributions are the free motion of the domain wall in the grain, between two positions stabilized by dipolar fields, and the bowing of the domain wall in pinning sites. These contributions were associated to the total domain wall area in the sample [3]. During the demagnetization process, the increase in magnitude of M_{rev} when M_{irr} decreases from M_R (Fig. 1b), is associated to a fast increase of the total domain wall area, due to the formation of inverse domains and subsequently free displacement of the wall up to a stable position or a pinning site. The following decrease of M_{rev} can be associated to the decrease of total domain wall area due to unpinning of the domain wall and the subsequent occupation in the whole grain of the reversal domain [3]. There are evidences that in cobalt ferrite the pinning centers are associated with stacking foils defects [6].

The $M_{rev}(H_i)$ and $M_{irr}(H_i)$ curves during the initial magnetization process, are shown in Fig. 2. It is seen that initially Mrev increases faster and remains greater than M_{irr} up to H_c. This initial increase of M_{rev} at low H_i can be attributed to the increase of the total domain wall area arisen by bowing. This is possible if the pinning in the grains is sufficiently strong to prevent the easy displacement of the domain walls. Afterwards, when the domain walls in the majority of the particles have been driven to the grain boundaries, the rotation of magnetic moments becomes the main contribution to M_{rev} and the curves show an approximately linear behavior.

Fig. 3 shows the values of $n(H_i)$ calculated on the initial curve (Fig. 3a) and the demagnetization curve (Fig. 3b). It is seen in both cases that n is initially positive and shows a rapid decrease when H_i approaches to H_c: This is consistent with a decrease of the total domain wall area available for the bowing process, when H_i is increased. Furthermore, in the initial magnetization curve, the n values are almost two times greater than the corresponding to the demagnetization curve. This can be associated to the fact that initially, the grains of the sample are in multidomain state.

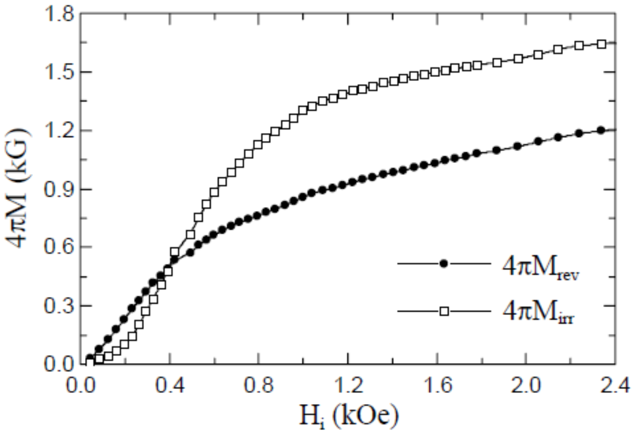

Fig. 2. Components of the magnetization during the initial magnetization process.

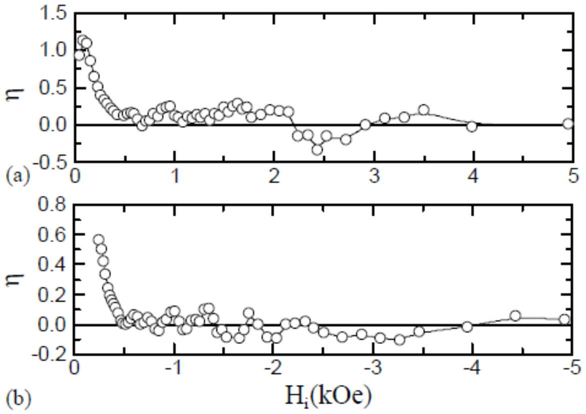

Fig. 3. η values as a function of H_i in (a) the initial magnetization and (b) demagnetization curve.

This state can supply more reversible magnetization available, in comparison with the remanence, the initial state in the demagnetization process. For values of $H_i \gtrsim H_c$, the behavior of n is more complex. On the initial curve, and H_i up to 2 kOe approximately, n remains positive. This suggests that there are a certain percent of strong pinning sites in the sample. This agrees with the fact that stronger internal fields compared to H_c; are necessary to approach M_{irr} to M_R: During the demagnetization process, n becomes oscillating when $H_i<H_c$; with a tendency towards to negative values. This is consistent with the rotation of the magnetization in single domain particles [3].

In conclusion, a study of the experimental behavior of $M_{rev}(M_{irr})H_i$ curves was done. The general behavior of these curves is similar during the initial magnetization and the demagnetization. Our results suggest that the domain wall movement subject to pinning is the dominant mechanism for the reversal magnetization in this material.

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

References

[1] M. Grigorova, H.J. Blythe, V. Blaskov, V. Rusanov, V. Petkov, V. Masheva, D. Nihtianova, Ll.M. Martinez, J.S. Muñoz, M. Mikhov, J. Magn. Magn. Mater. 183 (1998) 163.

[2] R. Cammarano, P.G. McCormick, R. Street, J. Phys. D: Appl. Phys. 29 (1996) 2327.

[3] D.C. Crew, P.G. McCormick, R. Street, J. Appl. Phys. 86 (6) (1999) 3278.

[4] D.C. Crew, L.H. Lewis, J. Appl. Phys. 87 (9) (2000) 4783.

[5] A. Medina Boudri, D. Bueno-B!aques, L. Fuentes-Cobas, M. Miki-Yoshida, J. Matutes-Aquino, J. Appl. Phys. 87 (9) (2000) 6235.

[6] R.C. O’Handley, Modern Magnetic Materials: Principles and Applications, Wiley, New York, 2000, p. 512.