Magnetic Viscosity and Magnetization Reversal of Acicular Barium Ferrite Particles

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Abstract—The magnetic viscosity coefficient (S_v), the activation volume (V_{act}), the rotational hysteresis integral (R_h) and the average anisotropy field ($H_{A,ave}$) were examined for acicular $BaCo_xTi_xFe_{12-2x}O_{19}$ ($x=0-1.0$) particles prepared by a conventional sintering method. Acicular hexagonal Ba-ferrite particles with different coercive force ($H_{cj}=35-310$ MA/m) were prepared, and the dependence of V_{act} , R_h and $H_{A,ave}$ on H_{cj} was investigated. The results show that H_{cj} is proportional to $V_{act}^{-2.2}$, as in the case of the platelet Ba-ferrite particles, SrM particles, SrW and $Sm_2Fe_{17}N_x$ magnets, which all have a similar mechanism of magnetization reversal. Also, $H_{A,ave}$ increases with increasing H_{cj} and V_{act} is inversely proportion to the average anisotropy constant. It was found that R_h and V_{act} both decrease, as H_{cj} increases, to approach the coherent rotation mode.

I. INTRODUCTION

Many report on magnetization reversal of hexagonal platelet Ba-ferrite particles have been published [1-4]. Recently, there has been much interest in acicular hexagonal Ba-ferrite particles prepared by a conventional sintering method [5], though studies on their magnetic viscosity and on the mechanism of magnetization reversal are few [6]. The magnetic viscosity in fine particles used for recording media belongs to the Jordan-type aftereffect and is caused by thermal fluctuations [4,7]. It is known to depend on the magnetic viscosity coefficient (S_v), the irreversible susceptibility (X_{irr}) and the logarithm of time ($\ln t$) [8-10]. When the change in magnetization (ΔJ) from time t_1 to t_2 is considered, S_v can be expressed as: $S_v = \Delta J / X_{irr} (\ln t_1 - \ln t_2) = kT / (V_{act} Js)$, where k is Boltzmann constant, V_{act} is the activation volume and Js is the saturation magnetization [8-10].

This paper reports on the dependence of S_v , V_{act} , the rotational hysteresis integral (R_h) and the average anisotropy field ($H_{A,ave}$) on coercive force (H_{cj}) for acicular Ba-ferrite particles prepared by a conventional sintering method.

II. EXPERIMENTAL

Acicular α -FeOOH, $Ba(OH)_2 \cdot 8H_2O$, $C_{10}H_{14}O_4Co \cdot 2H_2O$ and $C_{10}H_{14}O_4TiO$ were previously weighed for the formation of $BaCo_xTi_xFe_{12-2x}O_{19}$ with the doping

rate X ranging from 0 to 1.0 [5]. The starting material for the acicular α -FeOOH particles had a long axis of about $1.3 \mu m$ and an aspect ratio of about 33. The $Ba(OH)_2 \cdot 8H_2O$ was dissolved in warm water and the acicular α -FeOOH particles, $C_{10}H_{14}O_4Co \cdot 2H_2O$ and $C_{10}H_{14}O_4TiO$ were added. The liquid mixture was coated on a stainless steel plate which was heated to about $150^\circ C$ to be dried. The dried mixtures were sintered at $900^\circ C$ for 3 h in air and then quenched.

Table 1 shows the magnetic properties measured using a vibrating sample magnetometer (VSM) for the acicular $BaCo_xTi_xFe_{12-2x}O_{19}$ particles so produced, with X ranging from 0 to 1.0. These particles consisted of hexagonal grains (6-10 in number), whose easy axis was in the c -direction, perpendicular to that in acicular particles (a -direction) [6]. The mean diameter and length of the particles (obtained by a TEM) were $0.07 \times 0.8 \mu m$ respectively (the mean particle volume, $V \sim 30 \times 10^{-22} m^3$).

After the application of 1.6 MA/m, the samples were subjected to a constant magnetic field (H) for 1000 s and ΔJ measured using a VSM [7]. The reversible susceptibility (X_{rev}) and the total differential susceptibility (X_{tot}) were also measured using a VSM.

Table 1. Magnetic properties of acicular $BaCo_xTi_xFe_{12-2x}O_{19}$ particles with X ranging from 0 to 1.0.

X	$Js (\times 10^{-6} Wb \cdot m/kg)$	$H_{cj} (kA/m)$
0	45.2	308
0.5	43.5	137
0.7	42.7	86
1.0	39.7	34

Xirr can be expressed as $X_{tot} - X_{rev}$.

The rotational hysteresis loss (W_r) was measured using a torque magnetometer. R_h , which corresponds to the mechanism of magnetization reversal, is given by the equation $R_h = \int W_r / J_s d(1/H)$ [11]. $H_{A,ave}$ was calculated from the remanent magnetization (J_i) which was measured using a previous described method employing a VSM at increment of 40 kA/m for angles between 0° and 5° [4,12]. The average anisotropy constant ($K_{A,ave}$) is calculated from the equation $K_{A,ave} = 1/2 H_{A,ave} \times J_s$.

III. RESULTS AND DISCUSSION

Fig. 1 shows the magnetic field dependence of S_v obtained from the values of $\Delta J / (\ln t_1 - \ln t_2)$ and Xirr. The value of S_v , obtained around H_{cj} point for all samples, is almost independent of the magnetic field. In this experiment, the logarithm of S_v varies in proportion to $\ln H_{cj}$ as given in the generally accepted Barbier's relationship [7,13].

The author had reported that the relation of $H_{cj} \propto V_{act}^{0.67}$ was obtained for acicular γ - Fe_2O_3 , $Co \gamma$ - Fe_2O_3 and metal particles used for recording media [7]. For acicular Ba-ferrite particles, H_{cj} is proportional to $V_{act}^{2.2}$ as shown in Fig. 2, nearly the same as in the case of the platelet Ba-ferrite particles ($H_{cj} \propto V_{act}^{1.9}$) used for recording media [7], SrM particles ($H_{cj} \propto V_{act}^{2.0}$) used in permanent magnets [14], SrW magnets ($H_{cj} \propto V_{act}^{2.1}$) [15] and $Sm_2Fe_{17}N_x$ compacted powder magnets ($H_{cj} \propto V_{act}^{2.0}$) [16]. It is thus believed that they all have a similar mechanism of magnetization reversal. In the case of the platelet Ba-ferrite particles, V/V_{act} was approximately 1.4 to 2.3 at 293 K [4]. However, for acicular Ba-ferrite particles, V/V_{act} is approximately 90.

Fig. 1 Magnetic field dependence of the magnetic viscosity coefficient S_v for acicular $BaCo_xTi_xFe_{12-2x}O_{19}$ particles.

Fig. 2 Plots of the activation volume V_{act} against coercive force H_{cj} for acicular and platelet Ba-ferrite, acicular γ - Fe_2O_3 , $Co \gamma$ - Fe_2O_3 and metal particles.

Fig. 3 Rotational hysteresis integral R_h against coercive force H_{cj} for acicular and platelet Ba-ferrite particles.

Fig. 4 Anisotropy field H_A distribution of acicular $BaCo_xTi_xFe_{12-2x}O_{19}$ particles.

Fig. 3 plots the relationship between H_{cj} and R_h calculated using the W_r/J_s versus $1/H$ curves for the acicular and platelet Ba-ferrite particles. The R_h value decreases as H_{cj} increases. This suggests that the mechanism of magnetization reversal approaches coherent rotation, namely, the coherency increases as H_{cj} increases. The R_h value for $X=0$ ($BaFe_{12}O_{19}$) is closer to the value calculated from the coherent rotation mode ($R_h=0.4$).

Fig. 5 Plots of the activation volume V_{act} against the average anisotropy constant $K_{A,ave}$ for acicular Ba-ferrite particles.

Fig. 4 shows the H_A distribution of acicular Ba-ferrite particles. Comparing the H_A distribution of $X=0$ with that of $X=0.5 - 1.0$, the $\Delta J_i/J_s$ versus H curve of $X=0$ is more sharply peaked. In acicular Ba-ferrite particles, $H_{A,ave}$ increases with increasing H_{cj} and the value of V_{act} is inversely proportional to $K_{A,ave}$, which was calculated using the value of $H_{A,ave}$ as shown in Fig. 5.

IV. CONCLUSIONS

This paper reports on the dependence of S_v , V_{act} , R_h and $H_{A,ave}$ on H_{cj} for acicular Ba-ferrite particles prepared by a conventional sintering method. The results are summarized as follows:

1) H_{cj} is proportional to $V_{act}^{-2.2}$, as in the case of the platelet Ba-ferrite and SrM particles (used in magnets), and SrW and $Sm_2Fe_{17}N_x$ magnets. They all have a similar mechanism of magnetization reversal.

2) $H_{A,ave}$ increases with increasing H_{cj} and V_{act} is inversely proportional to $K_{A,ave}$. R_h and V_{act} both decrease, as H_{cj} increases, to approach the coherent rotation mode.

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