MH loop Modeling of NdFeB Anisotropic Bonded Magnet

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1. Introduction

The NdFeB anisotropic bonded magnet is one of the most important permanent magnets. It enables the achievement of complex shapes and is superior in strength to other magnets$^{1)}$. Therefore, it is useful for motors of hybrid vehicles (HV) and electric vehicles (EV), which are in demand because of their smaller size and higher-speed rotation. However, we are concerned about its demagnetization, which is called “magnetic fatigue”$^{2)}$. We expect that the magnetic fatigue is caused by a high frequency field of 0.5 kOe at 10 kHz, a DC reverse field from 3 to 4 kOe, and a high temperature over 400 K. In our previous study, we showed that when the anisotropy field (H_k) of a grain-surface is lower than that of a main phase, the coercivtiy field H_c is much lower than H_k. However, the MH loop did not fit an experimental value.

In this study, the standard deviations of c-axis orientation distribution ($\sigma_{C\text{-}axis}$) and H_k distribution (σ_{Hk}) were investigated to fit the experimental MH loop of an NdFeB anisotropic bonded magnet.

2. Micromagnetic simulator

In this simulation, a one-grain model was assumed for the MH loop modeling of an NdFeB anisotropic bonded magnet$^{1)}$. A dynamic magnetic reversal process was calculated by using the Landau-Lifshitz-Gilbert equation as follows.

$$\frac{\mathrm{d}M}{\mathrm{d}t} = -\gamma(M\times H_{eff}) + \frac{\alpha}{M_s}\left(M\times\frac{\mathrm{d}M}{\mathrm{d}t}\right) \tag{1}$$

M is the magnetization, and M_s is the saturation magnetization. H_{eff} is the effective field, which is summed up as an external field, a static field, an anisotropy field, and an exchange field. γ is the gyromagnetic ratio, and α is the damping factor.

The one-grain model is shown in Fig. 1. The grain was divided into 16×16×16 hexagonal prism cells, and each cell was 2 nm in diameter and 2 nm high. The grain was assumed to have a low H_k surface, which was painted grey in Fig. 1. The surface layer was 2 nm wide. The M_s was 1.61 T, the intercell exchange energy was assumed to be 0.5×11^{-11} J/m, and the damping constant was 1.0 at room temperature. The c-axis represented the perpendicular direction (z-axis direction) and changed from 0 to 3° every 1°, and the anisotropy constant K_u changed from 0.8 to 7.0 MJ/m^3 every 0.2 MJ/m^3 to fit the experimental MH loop of the NdFeB anisotropic bonded magnet. First, MH loops were calculated with every combinations of c-axes and K_u values. Next, each magnetization was multiplied by the constant in accordance with a statistical probability. Last, all magnetizations were summed up, and the MH loop modeling was completed.

3. Results and discussions

Fig. 2 shows the comparison of MH loops between simulations and the experiment. The experimental data was for magnetic particles of the NdFeB bonded magnet$^{3)}$. For the simulation, the $\sigma H_k/<H_k>$ was 10 and 30 % when the $\sigma_{C\text{-}axis}$ was 1°. Here, H_k is defined as $2K_u/M_s$. $<H_k>$ was the average H_k, and the main phase $<H_k>$ was 6077 kA/m. The H_k of the surface layer was 0.135 times lower than the main phase. From this result, the experimental MH loop fit the simulation loop for $\sigma H_k/<H_k>$ of 30 %. Therefore, the NdFeB bonded magnet is predicted to have a large distribution of H_k and a low distribution of c-axes.

Acknowledgments

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References

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3) http://www.magfine.net/magfine/images/MAGFINE%20CATALOG%20A4%20ENG%20BACK.pdf.

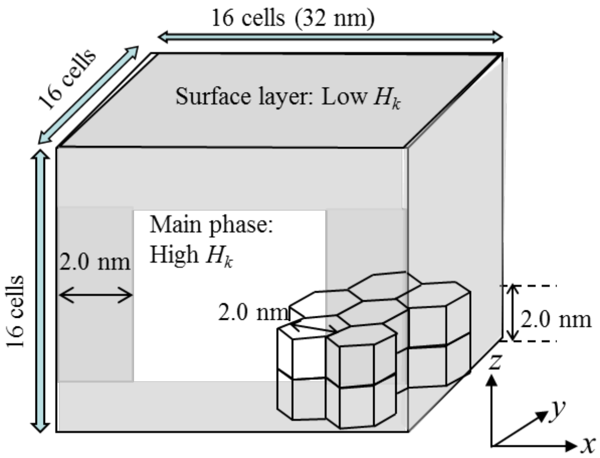

Fig. 1 Structural model of one grain.

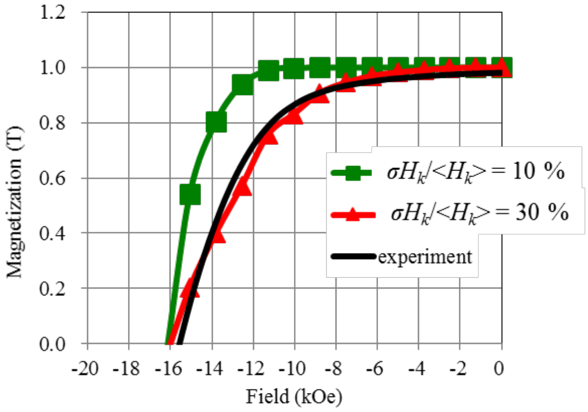

Fig. 2 Comparison of MH loops between experiment and simulations.