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Separation of Magnetization Loop in Domain Wall Movement and Domain Rotation Contributions for Soft Magnetic Materials

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The domain wall movement and magnetization rotations processes are separated experimentally in quasi-static magnetization process of a Finemet type ultrasoft magnetic material. The reversible domain rotations contribution is obtained from the integration of the reversible permeability, μ_{DR}, as a function of biasing DC field, measured with very small alternative field amplitude, less than $0.05H_{\mathrm{c}}$. The domain wall movement component is obtained by the integration of the permeability obtained by extraction of μ_{DR} from the differential permeability derived from one branch of the quasi-static major loop.

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1. Introduction

The quasi-static magnetization process is considered to be composed of reversible and irreversible terms. The reversible domain wall bowing and domain rotation (DR) are represented by the reversible component M_{rev}. The energy loss in the hysteretic material is represented by the irreversible component M_{irr}, as the irreversible domain and domain wall processes. This type of separation is mainly theoretical; there are no clear experimental techniques to measure them separately. It is more appropriate for an experimentalist to divide the quasi-static magnetization process in low field ($H < H_{\mathrm{c}}$, Rayleigh) and high field ($H \gg H_{\mathrm{c}}$) regions, where the magnetization takes place by domain wall movement (DWM) and by DR, respectively, as it is asserted in all the textbooks. These two magnetization processes however are overlapping in ultrasoft magnetic materials (amorphous and nanocrystalline), especially in low and medium field region. The differentiation of DWM and DR processes is rather difficult in the case of round type hysteresis loop where no induced anisotropy is present and the local crystalline anisotropy is averaged out ($K_{\text{eff}} \approx 1{-}5$ J/m^3) by the exchange interaction. In such a soft magnetic material the domain and the domain wall width are large and as a result, the local rotation of the spin cannot be attributed solely to either the DR or DWM processes and their interplay is an important aspect of hysteretic behavior. Both processes have irreversible and reversible parts although their relative weight is different and depend on the applied field in quasi-static conditions. Thus, both magnetization mechanisms show hysteretic behavior; therefore they contribute to the overall character of the composite hysteresis loops.

In this work we propose an experimental technique for separation of these two magnetization mechanisms in the whole excitation range and linearly superimposed in the $H{-}M$ plane. We suppose that at very small AC field excitation and enough high frequencies the rotational mechanism (DR) prevail and the contribution from damped and wide domain walls can be neglected. Consequently, the separation of the two contributions can be done step by step in the following manner:

1. By measuring the permeability at different DC biasing field with a very small AC exciting field (reversible permeability). Following that, by integrating the measured $\mu_{\text{R}}(H)$ for a whole cycle of magnetization, one can obtain the rotational contribution to the hysteresis loop ($\mu_{\text{rev}} \sim \mu_{\text{rot}}$).

2. By differentiating the quasi-static hysteresis loop, the so-called differential permeability, $\mu_{\text{diff}}(H)$, can be obtained. The contribution from DWM and so the dominant irreversible contribution can be obtained by integrating: $\mu_{\text{DW}}(H) = \mu_{\text{diff}}(H) - \mu_{\text{R}}(H)$.

2. Experimental

As an example for the ultrasoft magnetic material, an optimally heat treated Finemet ($Fe_{73.5}Si_{15.5}B_7Nb_3Cu_1$) nanocrystalline toroid was selected with a characteristic round type hysteresis curve. It was obtained from amorphous precursor ribbon of 10 mm wide and 22 μm thick produced by planar flow annealed at 550°C for 1 h, without applying magnetic field therefore letting its inner structure to reach its natural random state after cooling.

3. Results

The quasistatic hysteresis loop was measured by applying a triangular shape exciting field at $f = 0.001$ Hz and integrated with a Walker integrator. The descending and ascending branches of the hysteresis loop were differentiated numerically to obtain $\mu_{\text{diff}}(H)$ for each branch. The reversible permeability was determined by using a Hewlett Packard 4274 A LCR instrument, running at 100 Hz and at an AC field amplitude of 0.05 A/m. The biasing DC field was created by a linear conductor passing through the center of the toroid. The field was varied slowly between the two saturating values, one cycle taking 5000 seconds. The measured $\mu_{\rm diff}, \mu_{\rm R}$ and the calculated $\mu_{\rm DW}$ are depicted in Fig. 1a and b for the descending and ascending branches, respectively.

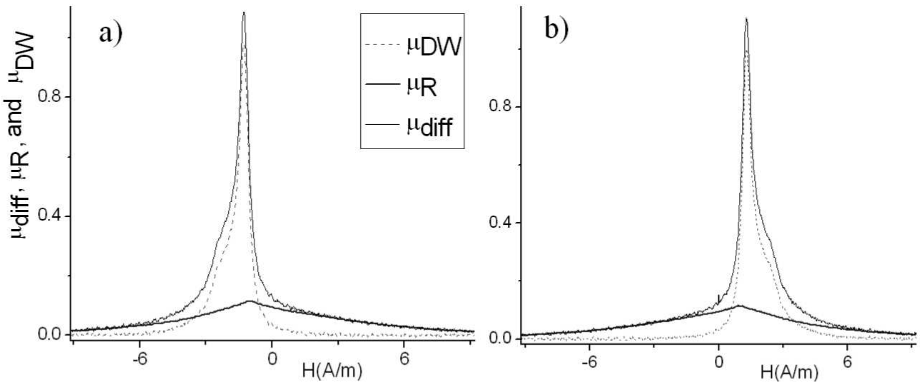

Fig. 1. The measured $\mu_{\rm diff}$ and $\mu_{\rm R}$ and the calculated $\mu_{\rm DW} = \mu_{\rm diff} - \mu_{\rm R}$ as a function of the biasing DC field for descending (a) and ascending branches (b), respectively. The absolute values of permeabilities are shown in V s/(A m) units.

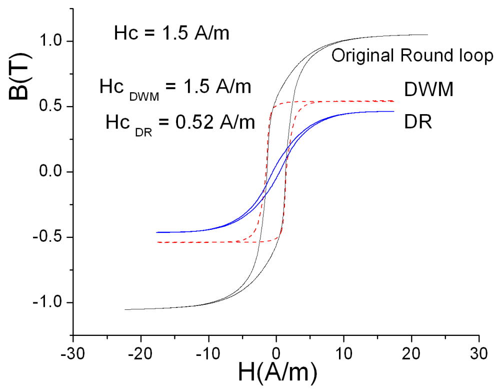

Fig. 2. The measured major and experimental decomposed (DWM, DR) loops.

The DR and DWM contributions can be obtained by integrating the corresponding permeabilities $\mu_{\rm DW}(H)$ and $\mu_{\rm R}(H)$. The sum of these will make up the original round loop measured with a quasi-static inductive method (see Fig. 2).

4. Conclusion

It is shown in the paper that the DWM and the DR can be treated as separate but overlapping processes in quasistatic magnetization process. The DWM process gives a square-like loop as wide as the original major loop whereas the DR process shows a flat loop with much smaller coercivity (0.52 A/m instead of 1.5 A/m). This type of separation of the quasistatic hysteresis loop into DR and DWM components seems to be general applicable to all the ferromagnetic materials. The unique feature of the ultrasoft magnetic materials consists in the fact that the saturation magnetizations of these two parts are comparable.

Similar decomposition of the magnetization processes in DWM and DR components have been published so far for AC magnetization only [1, 2]. The results presented here could be of a great value as a nondestructive testing method correlating the hysteretic behavior with the mechanical properties.

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