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REMANENCE RELATIONSHIPS AND DOMAIN WALL PINNING IN FERROMAGNETS

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Comparisons with a relationship between initial and demagnetizing remanence are made for PtCo and MnAlC magnets. They yield information about microscopic domain wall pinning. For PtCo the same pin site distribution is active for forward and reverse fields. For MnAlC a higher pin density is active for reverse fields.

1. Introduction

Sub-microscopic information about coercive field mechanisms can sometimes be deduced from macroscopic magnetic measurements on thermally demagnetized samples. A good example is the initial magnetization curves of sintered Sm_2TM_{17} [1] and $SmCo_5$ [2] materials which appear almost ideally soft with coercive fields of only a few Oe. The material becomes almost fully magnetized in applied fields of less than 1 kOe as domain walls move freely within the alloy grains. These walls become trapped however by a high density of localized inhomogeneities (pins) at the grain boundaries. These pins give rise to much higher coercive fields than any random inhomogeneities inside a grain, with the result that large kOe fields are needed to demagnetize the samples after initial saturation. This reverse demagnetization process has sometimes been called "domain wall nucleation" but in principle there is no essential difference between "unpinning" of a domain wall from randomly distributed pins within a grain and "nucleation-unpinning" from a high localized pin density.

Less extreme contrasts between the initial and demagnetizing loops occur in other materials. In order to concentrate on the irreversible component of magnetization, following unpinning, it is more convenient to analyse the remanent magnetization loops after application and removal of forward and reverse fields rather than the ordinary loop with the field left on.

2. Remanent magnetization

The remanence relationship

$$M_D(H) = M_R(H_{max}) - 2M_R(H) \tag{1}$$

was first derived by Wohlfarth [3] for an array of non-interacting single domain particles, where $M_R(H)$ was the initial remanent magnetization after application of a forward field H to the initially zero magnetization array, H_{max} was the maximum value of H used and $M_D(H)$ was the demagnetizing remanence after application of the maximum forward field H_{max} followed by a reverse field of magnitude H. Any deviations from the relationship were taken as implying either interaction between the single domain particles or multidomain particles. The relationship is also valid however for multi-domain uniaxial ferromagnets if the walls interact with the same density and distribution of pinning sites on both the initial and demagnetizing branches of the magnetization curve [4]. The derivation assumes that the coercive force associated with a grain is higher than the field required to sweep a domain wall through the grain in the absence of pins and that pins are distributed throughout the grains. Deviations from the relationship will occur if the reversing domain walls do not interact with the same density and distribution of pin sites as on the forward trip.

2.1. Demagnetizing corrections

A rough value of the remanent moment of a ferromagnet is given by the measured moment in zero applied field. The "true remanence" is however the magnetization in a zero effective field, whereas the magnetization in zero applied field is in fact the magnetization in an effective field of $-NM$ where N is the demagnetizing factor and M is the magnetization of the material. The remanence in zero effective field on the demagnetizing branch, $M_D(0)$, can be obtained from the ordinary magnetization against effective field curve. The effective fields applied to establish remanence can also be read from the same curve. For the initial loop an effective forward field, H, is applied and then removed leaving a moment $M'_R(H)$ in an effective field $H_D = -NM'_R(H)$, so that $M'_R(H)$ is less than the "true remanence" $M_R(H)$.

The amount of reduction ΔM is found from the demagnetizing branch of the ordinary magnetization loop at the effective field $-NM'_R(H)$ so that:

$$M_R(H) - M'_R(H) = M_D(0) - M(H_D) = \Delta M, \tag{2}$$

where $M(H)$ is the magnetization at effective field H with the field on. After application of the maximum forward field, the application of a small negative effective field will cause some low coercivity regions to reverse reducing the magnetization. On removing the

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field therefore the demagnetizing field will be lower in magnitude than the small negative effective field and no further reversals take place so that $M'_D(H) = M_D(H)$ and no corrections are necessary. Higher effective reverse fields will reduce the magnetization to negative values which will give rise to a positive "remagnetizing" field and again a correction has to be applied such that

$$M_D(H) - M'_D(H) = M_D(0) - M(H_D), \tag{3}$$

where $H_D = -NM'_D(H)$.

3. Application to PtCo and MnAlC magnets

Corrected values of $M_R(H)$ and $M_D(H)$ have been measured for a $Pt_{52}Co_{48}$ magnet with a room temperature coercive field of 3200 Oe and for a Matshushita Co. MnAlC magnet of coercive field 2900 Oe. In fig. 1 $M_R(H)/M_R(H_{max})$ is plotted against $M_D(H)/M_R(H_{max})$ for the two alloys. If eq. (1) is obeyed the points should fall on the straight line joining $M_D(H)/M_D(H_{max}) = -1$, $M_R(H)/M_R(H_{max}) = 1$ to $M_D(H)/M_R(H_{max}) = 1$, $M_R(H)/M_R(H_{max}) = 0$. As can be seen the PtCo alloy is close to the ideal which indicates that the domain walls interact with a similar density and distribution of pinning sites during initial and reverse magnetization. The pinning sites in this alloy are thought to be the junctions between retragonal lamellae whose c axes are mutually at 90° to one another and are randomly distributed within the crystallographic grains [5].

The MnAlC alloy shows marked deviations from the ideal relation. The initial remanence curve indicated a forward coercive field of 1800 Oe, due to random pinning sites within the thermally demagnetized grains, but as the remanence approached saturation in the maximum forward field the walls became pinned, at localized higher density pinning sites associated with a demagnetizing coercivity of 2900 Oe. As this field is greater than the initial 1800 Oe, the original random pinning sites are inactive during demagnetization.

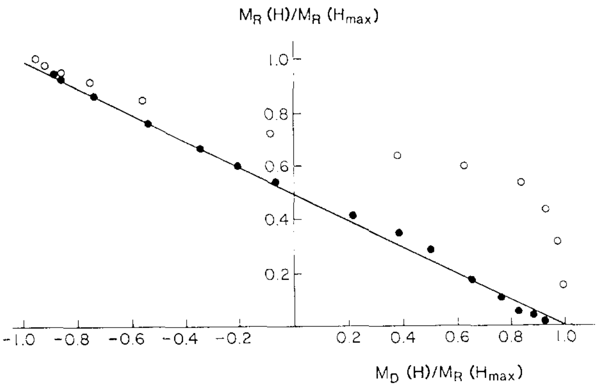

Fig. 1. $M_R(H)/M_R(H_{max})$ against $M_D(H)/M_R(H_{max})$ for PtCo (solid circles), and MnAlC (open circles).

We recently arrived at similar conclusions for these alloys, based on magnetic viscosity measurements over a range of temperature. The measurements suggested that "localized weak pinning" was active for the demagnetizing curve but clear electron microscope evidence of such pinning has not so far been found [6].

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