



Coercivity mechanism in nanophase (Nd–Pr)–Fe–B melt spun alloys

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Abstract

The nucleation mechanism to predict coercivity values in melt-spun exchange-coupled (Nd_{1-x}Pr_x)_yFe_{94-y}B₆ alloys for various Nd:Pr ratios x , and Fe:RE ratios y , was tested using the dependence of the anisotropy constant K_1 on Pr content x for the minimum nucleation field H_N^{\min} in the modified Brown's equation. Very good agreement was found between experimental data and theoretical values, confirming the predominance of the nucleation of reverse domains over the wall pinning process in the coercivity mechanism of melt spun REFeB alloys. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Coercivity mechanism; Micromagnetic model

1. Introduction

Coercivity is one of the most important extrinsic parameters that characterise permanent magnets since it reflects the ability of the magnet to resist magnetisation reversal under the application of an external field. In principle, it can be assumed that the magnetisation reverses uniformly and coherently under the application of an external reversing field. For this case, coercivity, H_c equals the nucleation field H_N for reverse domains, which is given by Brown's equation [1]:

$$\mu_0 H_N = \frac{2K_1}{M_s} - (N - N_{\perp})J_s, \quad (1)$$

where K_1 is the first anisotropy constant, $J_s = \mu_0 M_s$ the spontaneous polarisation and N_{\parallel} , N_{\perp}

the demagnetisation factors parallel and perpendicular to the rotational symmetry axis of an ellipsoidal particle. The dominant process for magnetisation reversal in melt spun nanophase REFeB alloys has been proposed as nucleation of reverse domains [2–5], using a modification of Brown's equation, which, for nanocrystalline alloys with non-interacting decoupled grains, has the following form:

$$\mu_0 H_C = \alpha_K \mu_0 H_N^{\min} - N_{\text{eff}} J_s, \quad (2)$$

where the microstructural parameters α_K and N_{eff} are associated with the non-perfect microstructure of real magnets [6]. α_K describes the reduced anisotropy of non-perfect grains and N_{eff} corresponds to an effective demagnetisation factor describing the internal stray fields acting on the grains. The minimum nucleation field H_N^{\min} denotes the value for the nucleation field of the most unfavourably aligned grains having a

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misalignment angle of 45° . For nanocrystalline alloys, Eq. (2) should be modified in order to incorporate the detrimental effect of the ferromagnetic exchange coupling between neighbouring grains on H_c . This can be realised by introducing another microstructural parameter α_{ex} , leading to [7]

$$\mu_0 H_c = \alpha_K \alpha_{ex} \mu_0 H_N^{\min} - N_{eff} J_s, \quad (3)$$

where H_N^{\min} is a function of the anisotropy constant K_1 [8].

In the present paper, Eqs. (2) and (3) are used to calculate H_c values for three types of melt spun RE–Fe–B ribbon alloys: (i) exchange-coupled stoichiometric *single phase* nanocrystalline alloys [9] (12 at% RE content with various Nd:Pr ratios [10]); (ii) exchange-coupled *nanocomposite* 8% and 10% RE alloys [9,10] and (iii) RE-rich 14% RE alloy ribbons with grains *largely decoupled* by a paramagnetic RE-rich phase at the grain boundaries [10]. The predicted H_c values are compared with experimental data.

2. Results and discussion

Experimental processing conditions for the alloys in the compositional series $(Nd_{1-x}Pr_x)_y Fe_{94-y}B_6$ ($y = 12$ and $x = 0-1$; $x = 0.75$ and $y = 8-14$) are described elsewhere [10]. H_c values for *stoichiometric* exchange-coupled $(Nd_{1-x}Pr_x)_{12}Fe_{82}B_6$ ($x = 0-1$) nanocrystalline alloy ribbons, were calculated using Eq. (3) with the minimum nucleation field H_N^{\min} as a function of the Pr content x . The dependence of K_1 on x , $K_1(x)$, was reported by Kim et al. [11] at low temperatures (0–250 K) for the same stoichiometric $(Nd_{1-x}Pr_x)_{12}Fe_{82}B_6$ system. For the present study, we extrapolated the K_1 values of Kim et al. for various Pr contents x to room temperature. Then, the $H_N^{\min}(K_1(x))$ term was inserted in Eq. (3), using the microstructural parameters $\alpha_K \alpha_{ex}$, and N_{eff} for 12% RE alloys reported by Bauer et al. [7]. The predicted $H_c(x)$ based on these calculations are given in Fig. 1. They are in very good agreement with an experimentally measured values which are also plotted.

The result given in Fig. 1 indicates that the effect of the substitution of Nd by Pr in the 2/14/1 unit

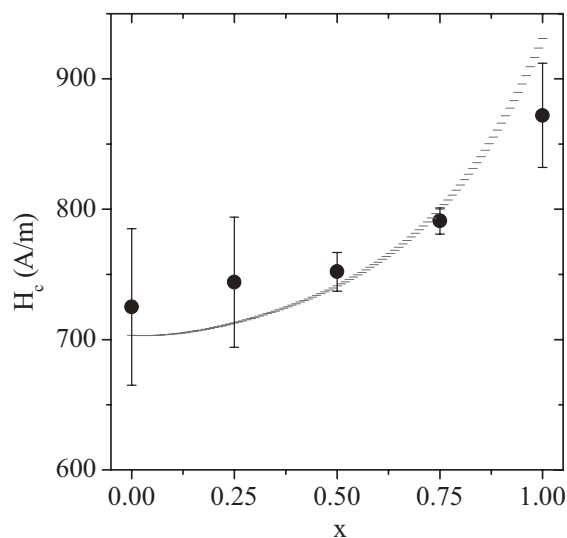


Fig. 1. Comparison between predicted H_c (—), using the functional dependence $H_N^{\min}(K_1(x))$, and experimental data (●) for the melt-spun exchange-coupled $(Nd_{1-x}Pr_x)_{12}Fe_{82}B_6$ ($x = 0-1$) alloy series.

cell does not follow a simple linear rule, since there is a shallow effect on the coercivity up to concentrations of $x \sim 0.50$ whereas, beyond this Pr content, H_c increases much more rapidly. This reflects the experimentally observed non-linear dependence of K_1 on x [11].

For the *nanocomposite* exchange-coupled $(Nd_{0.75}Pr_{0.25})_y Fe_{94-y}B_6$ ($y = 8, 10$) alloys, i.e. with various Fe:RE ratios but fixed Nd:Pr ratio, Eq. (3) was used again to calculate H_c . In this case, instead of employing K_1 as a function of the Pr concentration x , a fixed $H_N^{\min}(K_1(x))$ is calculated for $x = 0.25$. The microstructural parameters $\alpha_K \alpha_{ex}$ were taken from Ref. [7]. For the $(Nd_{0.75}Pr_{0.25})_{14}Fe_{80}B_6$ alloy ribbon with at least partly decoupled grains, Eq. (2) was used, which describes the coercivity for non-interacting particles. Again, a fixed $H_N^{\min}(K_1(x))$ is calculated for $x = 0.25$. The value of $\alpha_K \alpha_{min}$ was taken from Ref. [12].

The comparison between the predicted coercivity based on Eqs. (2) and (3) and the experimental data for nanophase $(Nd_{0.75}Pr_{0.25})_y Fe_{94-y}B_6$ ($y = 8-14$) alloy ribbons is shown in Fig. 2. Excellent agreement is observed between the predicted and experimental points, lending strong

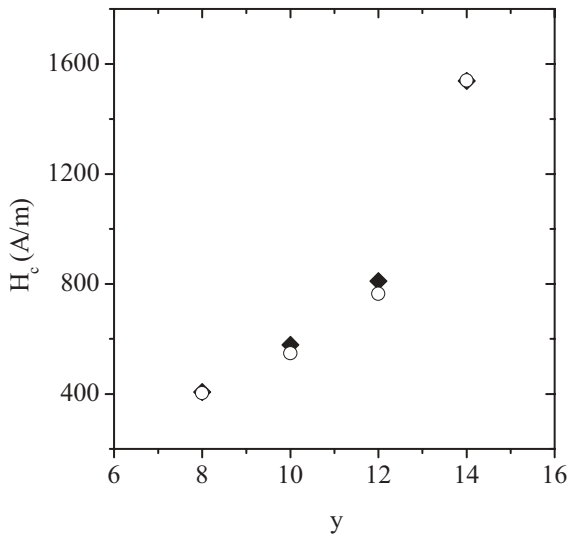


Fig. 2. Comparison between predicted H_c (◆) and experimental data (○) for melt spun $(\text{Nd}_{0.75}\text{Pr}_{0.25})_y\text{Fe}_{94-y}\text{B}_6$ ribbons with (i) exchange-coupled (8–12% RE) grains and partly decoupled non-interacting grains (14% RE).

support to the applicability of Eqs. (2) and (3) for exchange-coupled ribbons (including exchange spring low RE variants) and for ribbons based on at least partly decoupled grains, respectively.

3. Conclusion

Excellent agreement between experimental and predicted H_c was obtained using the modified domain nucleation control model based on Brown's equation for stoichiometric nanocrystalline $(\text{Nd}_{1-x}\text{Pr}_x)_{12}\text{Fe}_{82}\text{B}_6$ ($x = 0-1$) and nanophase off-stoichiometric alloys in the series $(\text{Nd}_{0.75}\text{Pr}_{0.25})_y\text{Fe}_{94-y}\text{B}_6$ ($y = 8-14$). The

results for the stoichiometric alloys indicate that the substitution of Nd by Pr in the $(\text{Nd}_{1-x}\text{Pr}_x)_{12}\text{Fe}_{82}\text{B}_6$ ribbons leads to a non-linear dependence of H_c on Pr content, closely reflecting the effect of the anisotropy constant K_1 .

Acknowledgements

IJBR acknowledges financial support for research to DGAPA, UNAM, Mexico. The financial support for research on nanophase magnetic alloys at Sheffield University by the UK EPSRC, through the AMP, is gratefully acknowledged.

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