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Abnormal near-surface magnetic properties of heterogeneous (amorphous/nanocrystalline) $Fe_{80.5}Nb_7B_{12.5}$ ribbons

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Abstract

The study of near-surface and volume magnetic properties and also near-surface micromagnetic structure (equilibrium distribution magnetization) of the as-cast and annealed for 1 h at T=380–650 °C $Fe_{80.5}Nb_7B_{12.5}$ ribbons was carried out employing magneto-optical micromagnetometer and a vibrating sample magnetometer (VSM). According to VSM data, the annealed at $T \leq 600$ °C samples exhibit a slight in-plane magnetic anisotropy and excellent soft magnetic properties. For the annealed at T=400–550 °C ribbons, inverted near-surface hysteresis loops were discovered that was ascribed to the coexistence of amorphous and nanocrystalline phases. The study of near-surface micromagnetic structure of the ribbons showed that with increasing annealing temperature, the magnetic homogeneity of the examined samples improves.

Keywords: Amorphous ribbons; Hysteresis loops; Kerr measurements

1. Introduction

Recently [1,2], a new class of soft magnetic materials with nanoscale ferromagnetic particles has been developed by controlled crystallization of melt-spun amorphous precursors. The iron-based FeMB alloys with M: Zr, Ta, Mo or Nb (NaNOPERM), are especially interesting because of their unique magnetic, mechanical and kinetic properties [2,3] even in comparison with currently popular alloys such as FINEMET. The study [2–10] of volume magnetic properties of FeNbB systems showed that these alloys, annealed in the temperature range from 300 to 1050 °K, behave as materials containing two (amorphous and nanocrystalline) phases and the volume of the nanocrystalline fraction depends on the annealing temperature. At the same time, near-surface magnetic properties of the above material were practically unexplored. The aim of this work is the comparative study of the near-surface and volume magnetic properties of the as-cast and annealed $Fe_{80.5}Nb_7B_{12.5}$ ribbons.

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2. Experimental

Amorphous $Fe_{80.5}Nb_7B_{12.5}$ ribbon, 15 mm wide and 30 μm thick, has been prepared by a planar flow casting method from the melt. The pieces of the ribbon were annealed in Ar atmosphere for 1 h at temperature T=380–650 °C. The samples under study had the circular form to exclude the influence of a shape anisotropy on the magnetic properties. The microstructure of the samples was examined by X-ray diffraction analysis (XRD). The study of the near-surface magnetic properties of the ribbons was carried out employing the magneto-optical magnetometer (described in [11]) by means of the transverse Kerr effect (TKE). The magnitude of TKE, δ, is determined as $\delta=(I-I_0)/I_0$, where I and I_0 are the intensities of the reflected light from the magnetized and nonmagnetized sample, respectively. Actually, the dependences of $\delta(H)/\delta_S \propto M(H)/M_S$ were measured. Here δ_S is the value of TKE at $M=M_S$ and M_S is the saturations magnetization. The thickness of a probed near-surface layer was equal to 20 nm. The magnetic field was applied parallel to the sample plane and perpendicular to the plane of the light incidence. The near-surface hysteresis loops were measured by detecting the magneto-optical

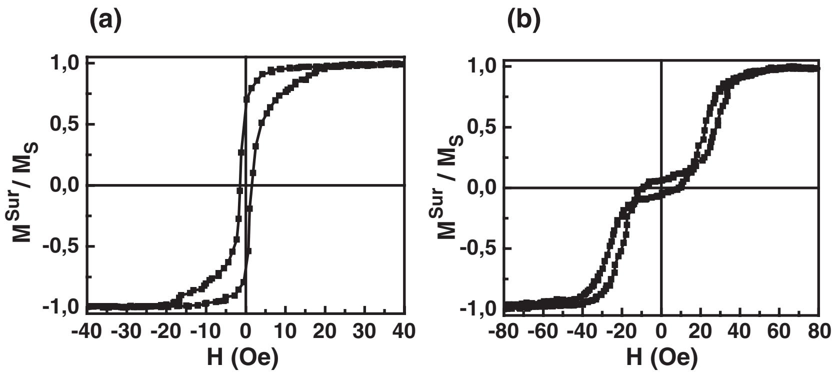

Fig. 1. Near-surface hysteresis loops, observed for the wheel side of the sample annealed at T = 550 °C in the magnetic field, oriented under ϕ = 0 and 90°: (a) and (b), respectively. Magneto-optical signals were detected from the part of 3 mm diameter.

signals from the part of 3 mm diameter. By scanning the light spot of 20 μm diameter along the surfaces of the examined samples, the near-surface local magnetization curves and the distributions of the in-plane magnetization components both on the free and wheel ribbon sides were measured. The volume magnetic characteristics of the samples were examined by using a vibrating sample micromagnetometer (VSM). The anisotropy of the magnetic properties was studied by rotating a sample around the normal to its surface. The angle between the as-cast ribbon axis and the orientation of the magnetic field, H, was marked as ϕ.

3. Results and discussion

According to VSM data, all samples exhibit a low strength of an in-plane magnetic anisotropy. With increasing annealing temperature up to 550 °C, the values of the coercivity H_C of the samples were found to decrease from 3.6 Oe to 0.1 Oe. An analysis of the X-ray diffraction patterns showed that the as-cast $Fe_{80.5}Nb_7B_{12.5}$ ribbon is amorphous while in the annealed samples, there are amorphous and nanocrystalline phases. The volume of the nanocrystalline fraction was found to increase from 14.2% to 62.4% with the annealing temperature changing from 400 to 600 °C. In agreement with the random anisotropy model [12], generalised to the two-phase magnetic systems [13], the increase of the volume of the nanocrystalline fraction leads to a more effective intergranular interaction that causes the decrease of the coercivity. For the annealed at T = 650 °C sample, the magnitude of H_C increases strongly that can be explained by its complete crystallization. The saturation field, H_S, has the same temperature behaviour.

The near-surface magnetic properties of the samples differ essentially from the volume characteristics. It was established that both on the free and on wheel sides of the ribbons, the shape of hysteresis loops, observed at ϕ = 0 and 90°, is different showing the presence of the near-surface magnetic anisotropy in the samples (see Fig. 1 for illustration). It was found also that the near-surface values of H_C are larger (up to 10 times) than the volume ones. This experimental result can be ascribed to the strong inhomogeneities in the structure and chemical composition near the ribbon surfaces. According to data, obtained by using a transmission electron microscope, there is a significant difference in microstructure of the volume and the near-surface regions. In particular, it was found that the concentration of nonmagnetic ions increases within a surface layer of 0.4 μm thick. Moreover, it was revealed that the values of the coercivity H_C and the saturation field H_S for the free sides are lower than those for the wheel ones. This result can be explained by different residual stresses, induced at the wheel and free sides during

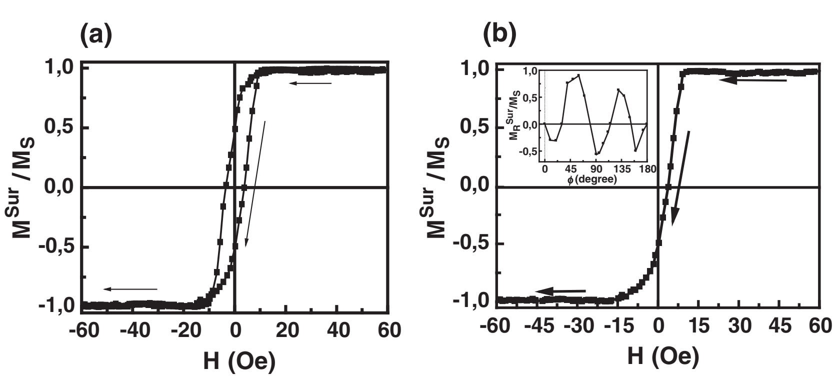

Fig. 2. Near-surface hysteresis loops, observed for the free side of the sample annealed at T = 500 °C in the magnetic field, oriented under ϕ = 90°, and the forward hysteresis branch: (a) and (b), respectively. The insertion in (b) displays the dependence of the reduced remanent magnetization M_R/M_S on the angle ϕ observed for the free side of the sample annealed at T = 500 °C.