Magnetic and structural study of melt-spun YCo_5 ribbons

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Abstract

Anisotropic YCo_5 ribbons have been obtained by melt spinning arc-cast ingots of the alloy. The surface velocity of the Cu roll was varied between 25 and 48.5 m/s. Magnetic anisotropy was observed, reflecting crystallographic texture associated with the ribbon solidification process, with the c-axis preferentially aligned parallel to the ribbon plane. The crystallographic texture is attributed to directional solidification induced by the thermal gradient. Ribbons obtained with a roll velocity of 48.5 m/s exhibited an intrinsic coercivity of 7.8 kOe, a high M_r=M_s ratio of 0.75 and a $(BH)_{max}$ = 7:11MGOe at room temperature. The high coercivity is attributed to the high anisotropy field of the YCo_5 phase and to its nanoscale grain size.

Introduction

Since their discovery in the late 1960s, rareearth-cobalt-based magnetic materials have attracted considerable attention due to their large anisotropy fields H_A, relatively high saturation magnetizations M_s and high Curie temperatures T_C [1]. Most of the interest in this type of alloy has been focused on $SmCo_5$ due to its exceptionally high H_A that facilitates high coercivity ${}_iH_c$, which is combined with relatively high maximum energy product $(BH)_{max}$, an important figure of merit for permanent magnets [2]. This phase has been processed by melt spinning [3,4], mechanical alloying [5], and mechanical milling [6]. Other compounds in the $RECo_5$ (RE = rare earth) family also have good magnetic properties, including $PrCo_5$ and YCo_5 [7-9]. High coercivities have been obtained for mechanically milled YCo_5 with a nanoscale grain size, stimulating

interest in this material for possible permanent magnet applications [8,9]. In this paper, we report the microstructure and the magnetic properties of YCo_5 ribbons obtained by melt spinning of arc cast ingots of the alloy.

Experimental

The alloy with nominal composition of YCo_5 was prepared by arc melting pure elements in an Ar atmosphere. The ingot was re-melted 3 times to ensure homogeneity. Then, ingot fragments of mass 3 g were inserted into a 15mm diameter quartz tube with a nozzle diameter of ~0.6 mm. The melt spinning chamber was evacuated to $3x10^{-4}$ bar and then filled with high purity argon gas to a pressure slightly lower than atmospheric pressure. The charge was induction melted and ejected through the nozzle using a pressure difference of about 0.6 bar. Surface velocities v_r of the Cu roll between 25 and 48.5 m/s were investigated. The structures of the melt-spun ribbons were studied by X-ray diffraction (XRD) using a Siemens D500 diffractometer with Cu Kα radiation (λ = 1:542 Å). Microstructural and compositional analyses were carried out with a JEOL JSM-5800 LV scanning electron microscope (SEM). Magnetic properties were measured at room temperature with a vibrating sample magnetometer (Oxford Maglab VSM 9100) using a maximum applied field of 50 kOe.

Results and discussion

The X-ray diffraction study of the melt-spun ribbons showed that only the YCo_5 phase was present. All the diffraction peaks could be indexed with the $CaCu_5$ hexagonal structure with lattice parameter values, a = 4.9191Å and c = 3.9584 Å, in good agreement with those reported for stoichiometric YCo_5 [10].

Fig. 1 shows the X-ray diffraction patterns for the melt-spun ribbon spun at different Cu roll velocities and for a randomly oriented powder sample, for comparison. The XRD pattern for the ribbon spun at v_r = 25 m/s shows relatively very strong (1 1 0) and (2 0 0) peaks while the relative intensities of the (1 0 1), (1 1 1) and (0 0 2) peaks are low, which is significantly different from the pattern for isotropic YCo_5 (Fig. 1d), for which the strongest peak is (1 1 1) [9]. This indicates that these samples had a strong crystallographic texture, with a preference for the c-axis of the YCo_5 crystallites to be aligned parallel to the ribbon plane [11]. Fig. 1c shows the XRD pattern for the ribbon obtained at v_r = 48.5 m/s. It has relative peak intensities broadly similar to those of the randomly oriented YCo_5 powder sample (Fig. 1d), particularly with respect to the (2 0 0) and (0 0 2) reflections, indicating that the crystallographic texture tends to diminish with increasing v_r.

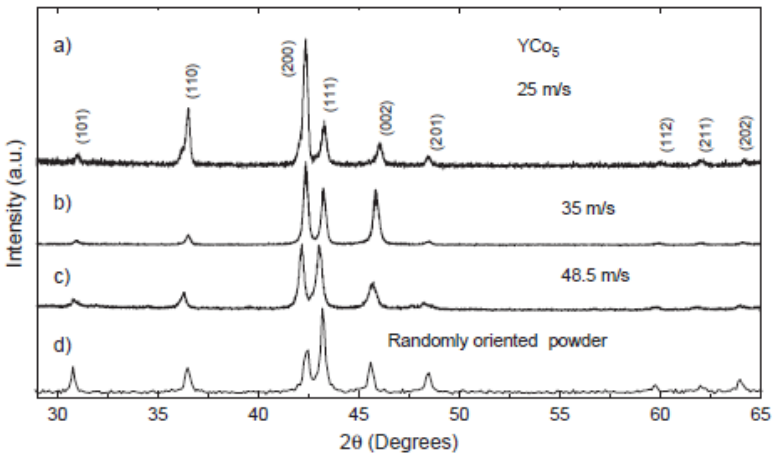

Fig. 1. X-ray diffraction patterns of the melt-spun ribbons obtained with different Cu roll velocities and a randomly oriented powder sample.

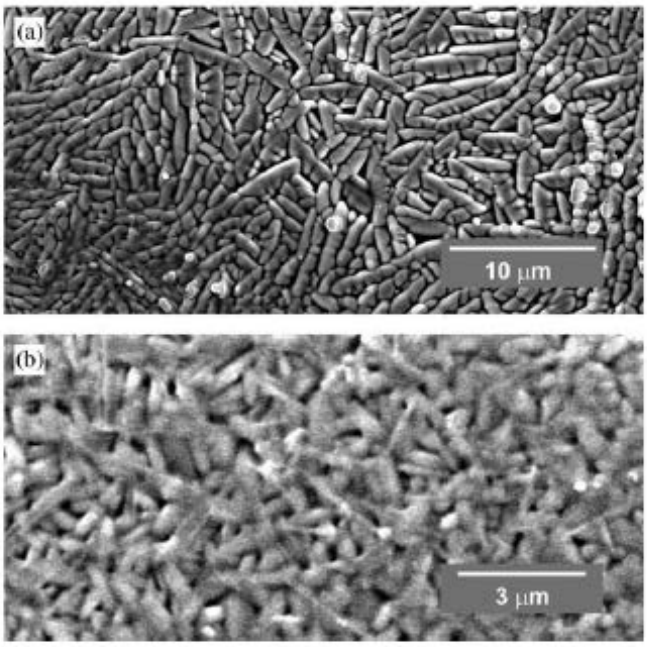

Fig. 2. SEM micrograph of longitudinal plane surface of the ribbon obtained with: (a) 25m/s Cu roll velocity; (b) 48.5m/s Cu roll velocity.

Fig. 2 shows scanning electron micrographs for the non-contact surfaces of ribbons spun at different v_r. The microstructure of the ribbon processed with v_r = 25m/s is shown in Fig. 2a; it consists of dendrites with their long axes parallel to the plane of the ribbon, consistent with the crystallographic texture evident in the XRD pattern's comparison (Fig. 1a and d). The typical dendrite size measured for this sample was between 4 and 9 μm. Fig. 2b shows the surface microstructure for the ribbon spun at v_r = 48:5m=s. The dendrites are finer than those in Fig. 2a, at between 1 and 4 mm; they also appear to be less aligned with the ribbon plane. The latter is consistent with the weaker crystallographic texture shown in the XRD pattern for this sample. Evidently, the crystallographic texture is associated with the dendritic structure, where the c axis of the hexagonal YCo_5 phase is aligned with the long axis of the dendrite growing directions.

High roll velocities resulted in reduction of ribbon thickness, with a finer, more randomly oriented dendritic structure due to the higher solidification rate [3].

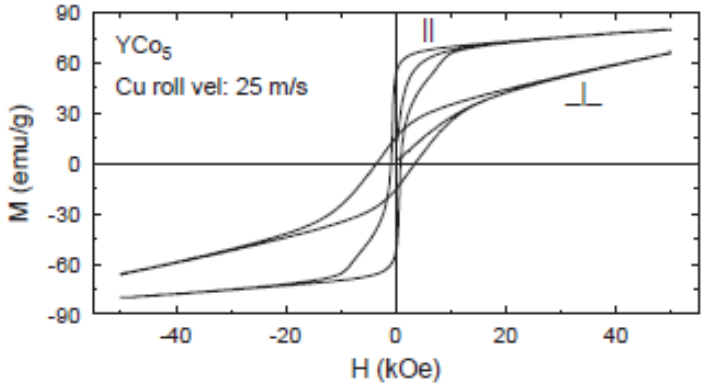

Fig. 3. Hysteresis loops measured with the magnetic field applied parallel and perpendicular to the plane of a ribbon melt-spun with $v = 25\,\mathrm{m/s}$.

Fig. 3 shows the hysteresis loops measured with the magnetic field applied parallel and perpendicular to the plane of a ribbon melt-spun at v_r = 25m/s. The maximum magnetization measured parallel to the ribbon plane at a field of 50 kOe was 80.2 emu/g while that with the applied field perpendicular to the ribbon was 66.0 emu/g. This difference is in agreement with the fact that the hard axis (i.e. the crystallographic a axis) of the hexagonal YCo_5 phase had a preference for alignment perpendicular to the ribbon plane and consistent with the direction of fastest crystallographic growth rate during solidification being the closer packed a direction. In addition, the value of ${}_iH_c$ measured perpendicular to the ribbon plane is about double that measured in the longitudinal direction, again confirming that a substantial texture is present in the ribbons spun at lower velocities.

Fig. 4 shows the dependences of M_r and ${}_iH_c$, measured in the longitudinal and transverse directions, on v_r. M_r measured with the applied field parallel to the ribbon

plane (II) was consistently larger than that perpendicular to the ribbon plane ($\perp$), as shown in Fig. 4a, though there was a tendency for the two to converge at the highest v_r. M_r increases with increasing v_r, due to the fact that the texture decreases for higher roll velocities.

Values of $_iH_c$ measured in the two orthogonal directions increase with v_r, as shown in Fig. 4b. For low and intermediate v_r, p40 m/s, $_iH_c$ measured perpendicular to the ribbon plane was consistently larger than that measured in the ribbon plane, though the difference decreases with increasing v_r and rapid convergence occurs for v_r>45m=s. For v_r = 48.5m/s, they have the same value (7.8 kOe). The coercivity increase probably reflects a reduction of crystallite size with increasing v_r, while the corresponding convergence of the values can be related to the reduction in crystallographic texture, in agreement with the XRD patterns. Using the theoretical density of 7.56 g/ cm^3, calculated with the POWDERCELL programme (W. Kraus and G. Nolze, FIMRT), a $(BH)_{max}$, value of 7.11MGOe was calculated for the sample spun at 48.5 m/s. $(BH)_{max}$ increased progressively with v_r and can be ascribed to the increases in both M_r and $_iH_c$.

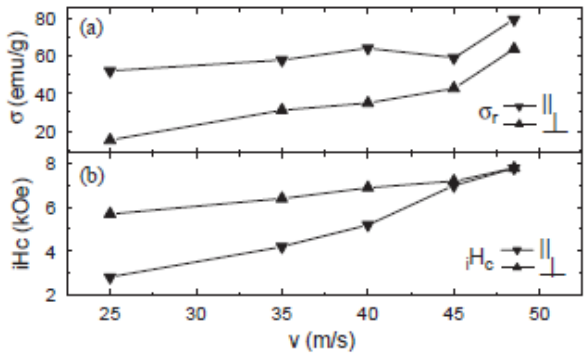

Fig. 4. (a) Remanence magnetization and (b) coercivity dependence with the Cu roll velocity and the applied field direction.

Conclusions

Anisotropic magnetic properties and a dendritic-like microstructure were obtained for YCo_5 alloy ribbons, especially those spun at lower roll velocities v_r. The dendritic microstructure, which was clearly visible by SEM on the ribbon surface, was aligned such that the crystallographic c-axis (easy axis), corresponding to the dendrite long axes, tended to lie in the plane of the ribbon, particularly at lower and intermediate roll velocities. This preferred orientation, however, diminished at higher v_r and, for the highest v_r investigated (48.5 m/s), the differences in the measured coercivities and remanences for the two orthogonal directions were rather small. The highest maximum energy product of 7.11MGOe was obtained for v_r = 48:5m/s.

Acknowledgements

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