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Journal of Alloys and Compounds 228 (1995) 102–104

Journal of ALLOYS AND COMPOUNDS

A study of melt-spun $SmCo_5$ ribbons

J. Ding, P. G. McCormick, R. Street

Research Centre for Advanced Mineral and Materials Processing, The University of Western Australia, Perth, WA 6009, Australia

Received 15 March 1995

Abstract

Anisotropic $SmCo_5$ ribbons have been prepared by melt-spinning using low wheel velocity. Dendritic structure was observed, with needle-like crystallites having their long axis preferentially aligned in the ribbon plane. Ribbon prepared with a wheel velocity of 6 m s^{-1} exhibited a remanence of 80 emu g^{-1} (about 80% of the saturation magnetisation) and a coercive force of 9.6 kOe.

Keywords: Melt spinning; Low wheel velocity; Ribbons

1. Introduction

$SmCo_5$ is a widely used rare-earth magnet because of its high Curie temperature and high anisotropy field [1]. High maximum energy products exceeding 20 MGOe have been achieved in anisotropic magnets prepared by conventional sintering techniques after alignment under magnetic field [1–3].

High coercivities have been reported for $SmCo_5$ with nanocrystalline structure prepared using different methods, such as sputtering [4] and mechanical alloying [5]. The measurements of Cadieu et al. [4] have shown that sputtered films are anisotropic, exhibiting a high maximum energy product of 18 MGOe with a coercivity of 23 kOe [4]. Such properties are certainly useful for application as permanent magnets.

Materials prepared using melt-spinning can have a structure similar to that in mechanically alloyed and sputtered material and, therefore, high coercivities, as found for $Nd_2Fe_{14}B$ [6,7], $SmFe_{12-x}M_x$ [8]. In addition $Nd_2Fe_{14}B$ ribbons prepared using low wheel velocity exhibit anisotropy, where the easy magnetisation direction is oriented normal to the ribbon plane [6]. Such anisotropic materials are suitable for fabrication of bonded magnets, provided they possess the necessary coercivity. In the present paper, we report the structure and magnetic properties of $SmCo_5$ ribbons prepared by melt-spinning.

2. Experimental

Arc-melted ingots having a $Sm_{17}Co_{83}$ starting composition were used for melt-spinning, which was performed with a standard melt-spinner having a single 200 mm diameter copper wheel. Small pieces of ingot (2–3 g) were inserted into a 10 mm diameter quartz tube with a nozzle of ~0.6 mm in diameter. The chamber was evacuated to a vacuum of $2–3 \times 10^{-4}$ mbar and then filled with high purity Argon gas with a pressure of 1 atmosphere. The sample was induction melted and ejected through the nozzle using a pressure difference of about 0.6 atmosphere. The surface velocity of the Cu wheel was varied between 6 and 37 m s^{-1}.

The structure was determined by X-ray diffraction using a Siemens D5000 diffractometer with Cu Kα radiation. Microstructure and composition distributions were studied by scanning electron microscopy using Philips 305 SEM and Joel 6400 SEMs fitted with energy dispersive analysers. Magnetic properties were measured on ribbons at room temperature using a vibrating sample magnetometer (VSM 3001 Oxford Instrument Company) with a maximum applied field of 120 kOe.

3. Results and discussion

X-ray diffraction measurements showed that melt-spun ribbons were single $SmCo_5$ phase with the $CaCu_5$ structure [1]. The values of lattice parameters, a and c, determined from the X-ray spectra were 5.01 and 3.98 nm, respectively, in good agreement with the lattice constants reported for stoichiometric $SmCo_5$ [1,4].

SSDI 0925-8388(95)01653-8

Anisotropic ribbons were obtained by melt-spinning with lower Cu wheel velocities. As shown in Fig. 1, the intensities of (200) and (110) reflection lines were significantly higher than expected for isotropic $SmCo_5$, where the highest intensity reflection should be (111) [9], indicating that the c axis of crystallites lies primarily in the plane of the ribbon. With the increasing Cu wheel velocity, the relative intensity of (200) and (110) decreased and the (101) reflection appeared (Fig. 1). X-ray diffraction patterns of ribbons melt-spun with velocities greater than 30 m s^{-1} were close to that expected for isotropic materials [9]. Similar results have been reported in melt-spun RE–Fe [10] and $N_2Fe_{14}B$ [7] ribbons using low velocities, also indicating the development of a preferred crystallite orientation during solidification.

An SEM micrograph of the polished and etched ribbon surface after melt-spinning with a wheel velocity of $v = 6$ m s^{-1} is shown in Fig. 2. The structure consists of dendrites with their long axes parallel to the plane of the ribbon. A similar dendritic structure was also observed on transverse sections of ribbons. No evidence of any spatial variation of compositions could be detected by microprobe analysis. Ribbons prepared using higher wheel velocities ($v \geq 20$ m s^{-1}) exhibited much smaller crystallite sizes and the dendritic structure did not form. Therefore, it is clear that the crystallographic texture in samples melt spun at low wheel velocities is associated with a dendritic structure, where the c-axis (the magnetic easy direction) is parallel to the dendrite growing directions [13] in the ribbon plane. Higher wheel velocities resulted in reduction of ribbon thickness and fine randomly oriented grain structure owing to the high rate of solidification.

Hysteresis loops measured parallel and perpendicular to the plane of a ribbon melt spun with $v = 6$ m s^{-1} are shown in Fig. 3. The remanence measured perpendicular to the ribbon plane was about 18 emu g^{-1},

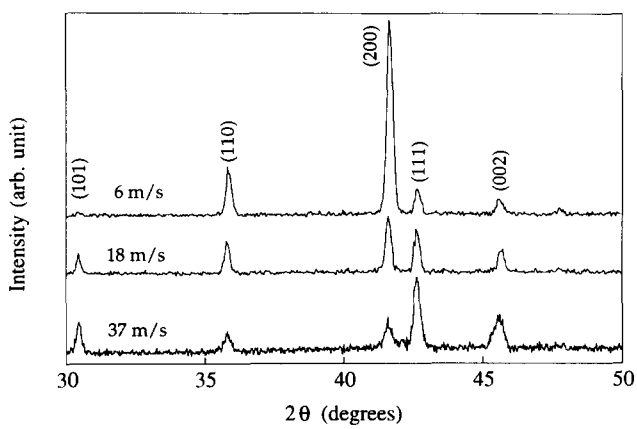

Fig. 1. X-ray diffraction patterns of melt-spun ribbons prepared using different Cu wheel velocities of 6, 18 and 37 m s^{-1}.

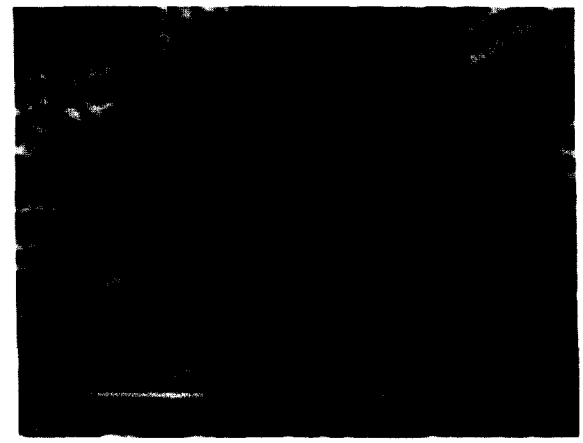

Fig. 2. SEM micrograph of the polished and subsequently etched ribbon surface (wheel speed = 6 m s^{-1}).

while much higher values were obtained with the field parallel to the ribbon plane (Fig. 3). The remanence measured with the field parallel to the ribbon plane and in the wheel rotation direction was 80 emu g^{-1}. This value was about 20% higher than for the field aligned perpendicular to the direction of wheel rotation. These measurements indicate that the texture of ribbons solidified at low wheel speeds is characterised by preferential alignment of the c axis along the longitudinal axis of the ribbons.

Remanence measured with the magnetic field was aligned parallel to the ribbon plane and the wheel rotation direction ($M_{r,\parallel}$) and perpendicularly to the ribbon plane ($M_{r,\perp}$) are plotted as function as the wheel velocity v in Fig. 4. $M_{r,\parallel}$ decreased with the increasing wheel velocity, while $M_{r,\perp}$ increased. The measurements show that the anisotropy associated with crystallographic texture decreased with increasing wheel speed in agreement with the X-ray diffraction

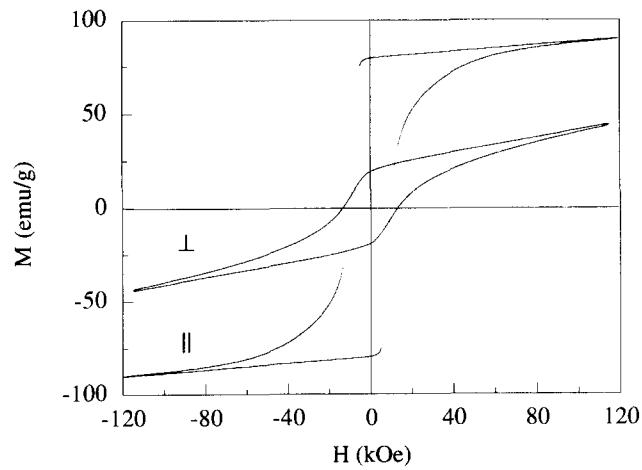

Fig. 3. Hysteresis loops taken for $SmCo_5$ ribbon prepared using Cu wheel velocity of 6 m s^{-1}, while the magnetic field applied perpendicularly (⊥) to the ribbon plain and parallel (∥) to the ribbon plain and wheel rotation direction.

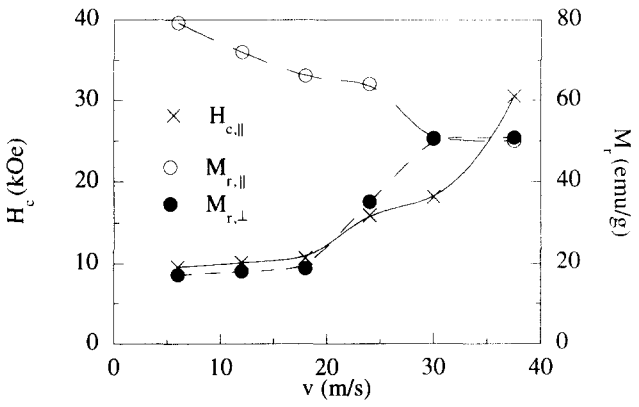

Fig. 4. The coercive force $H_{c,\parallel}$ and the remanence $M_{r,\parallel}$ measured when the magnetic field applied parallel to the ribbon plain and wheel rotation direction, and the remanence $M_{r,\perp}$ measured when the field was perpendicular to the ribbon plain as function of the wheel speed v.

results. For high velocity of $v \geq 30$ m s^{-1}, no significant difference between $M_{r,\parallel}$ and $M_{r,\perp}$ was found (Fig. 4). The measured remanence of about 50 emu g^{-1} is very close to 50% of the saturation magnetisation [1,3], as expected for isotropic materials with uniaxial magnetocrystalline anisotropy.

The coercive force $H_{c,\parallel}$ measured parallel to the ribbon plane and the wheel rotation direction increased with increasing wheel velocity (Fig. 4), from 9.6 kOe at $v = 6$ m s^{-1} to 30.5 kOe at $v = 37$ m s^{-1}. This increase is due to decrease in crystallite size with increasing wheel speed. The coercive force $H_{c,\perp}$ measured perpendicularly to the plane also increased with increasing wheel velocity. As shown in Fig. 3, the value of $H_{c,\perp}$ was always slightly higher than $H_{c,\parallel}$ for anisotropic ribbons.

The highest remanence measured in this study was 80 emu g^{-1}, which corresponds to about 80% of the saturation magnetisation [1,3]. Using the theoretical density of 8.7 g cm^{-3} [1,3], the calculated value of the maximum energy product, $(BH)_{max}$, was 18 MGOe. The value of $(BH)_{max}$ decreased with increasing wheel velocity, owing to the decrease in remanence. The value of $(BH)_{max}$ was estimated to be about 8 MGOe for the ribbon melt-spun with $v = 30$ m s^{-1}, which is very close to that expected for isotropic $SmCo_5$ [1].

4. Conclusion

Melt-spun ribbons prepared using low wheel velocities were anisotropic, with the c axis preferentially aligned in the ribbon plane and parallel to the longitudinal direction. This was associated with a dendritic structure, with needle-like crystallites having their long axis parallel to the ribbon plane. The degree of preferential alignment decreased with increasing wheel velocity and no significant anisotropy was observed for wheel velocities higher than 30 m s^{-1}.

High values of longitudinal remanence were measured in ribbons prepared using low wheel velocities. The highest value of $(BH)_{max}$, 18 MGOe, for the ribbon prepared using 6 m s^{-1} approaches that achieved in sintered $SmCo_5$ magnets [1,3]. Therefore, melt-spun $SmCo_5$ ribbons possess suitable properties for application as permanent magnets in bounded or in flake form.

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