



Magnetic properties of $\text{SmCo}_{5-x}\text{Fe}_x$ ($x = 0-4$) melt-spun ribbon



Tetsuji Saito^{a,*}, Daisuke Nishio-Hamane^b

^a Department of Mechanical Science and Engineering, Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino, Chiba 275-0016, Japan

^b Institute for Solid State Physics, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8581, Japan

ARTICLE INFO

Article history:

Received 26 August 2013

Received in revised form 25 September 2013

Accepted 26 September 2013

Available online 9 October 2013

Keywords:

Sm–Co magnets

Melt-spinning

Nanocomposite

TEM

ABSTRACT

$\text{SmCo}_{5-x}\text{Fe}_x$ ($x = 0-4$) alloys were produced by melt-spinning and subsequent annealing. It was found that the small substitution of Fe for Co in the SmCo_5 alloy results in the formation of the $\text{Sm}(\text{Co,Fe})_5$ phase, but that the large substitution of Fe for Co results in the formation of other phases such as the $\text{Sm}(\text{Co,Fe})_7$ and $\text{Sm}_2(\text{Co,Fe})_7$ phases. The remanence of the annealed $\text{SmCo}_{5-x}\text{Fe}_x$ melt-spun ribbons increased from $x = 0$ to $x = 3$ then decreased with increasing Fe content, while their coercivity decreased as the Fe content increased. Transmission electron microscope (TEM) studies revealed that the annealed SmCo_4Fe melt-spun ribbon consisted of relatively coarse $\text{Sm}(\text{Co,Fe})_5$ grains, whereas the annealed SmCo_2Fe_3 melt-spun ribbon consisted of a mixture of extremely fine grains of the $\text{Sm}(\text{Co,Fe})_7$ and Fe phases. The annealed SmCo_4Fe alloy with the $\text{Sm}(\text{Co,Fe})_5$ phase showed a high coercivity of 10.2 kOe with a remanence of 60 emu/g, while the annealed SmCo_2Fe_3 alloy formed a nanocomposite magnet with a high remanence of 100 emu/g and a coercivity of 2.9 kOe.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Since it was found that Nd–Fe–B permanent magnets exhibit excellent hard magnetic properties, research and development of new permanent magnetic materials has largely concentrated on rare-earth-containing alloys [1,2]. As a result of intensive research on such alloys, various new rare-earth intermetallic compounds have been produced such as the RFe_{12} , R_3Fe_{29} , and R_5Fe_{17} phases [3–5]. Because the binary RFe_{12} and R_3Fe_{29} phases are metastable, the formation of these phases is rather difficult. It has been found that the small substitution of Fe for M (M: transition metal) in the RFe_{12} and R_3Fe_{29} phases results in the formation of the $\text{R}(\text{Fe,M})_{12}$ and $\text{R}_3(\text{Fe,M})_{29}$ phases [6–11]. However, the magnetic properties of these compounds are inferior to those of Nd–Fe–B magnets. In the case of the R_5Fe_{17} phase, the binary $\text{Sm}_5\text{Fe}_{17}$ phase has been produced by melt-spinning. The coercivity of the $\text{Sm}_5\text{Fe}_{17}$ phase is much larger than that of Nd–Fe–B magnets, but its remanence is much lower [12,13]. The outlook for the discovery of new magnetic phases with magnetic properties comparable to those of Nd–Fe–B magnets is therefore not promising.

Another approach is to improve the magnetic properties of nanocomposite magnets, one of the new types of permanent magnets [14]. Nanocomposite magnets are composed of a mixture of nanosize soft magnetic and hard magnetic phases. It is known that the existence of the soft magnetic phase in a permanent magnet weakens the remanence and maximum energy product. Due to

exchange coupling of the nanosize soft magnetic and hard magnetic phases, nanocomposite magnets exhibit a higher remanence than conventional magnets. Anisotropic nanocomposite magnets are expected to show giant maximum energy products as high as 1 MJ/m^3 when the soft magnetic and hard magnetic phases are arranged in the optimal manner [15]. Since the coercivity of nanocomposite magnets is highly dependent on the coercivity of the hard magnetic phase, a hard magnetic phase with high coercivity such as the SmCo_5 phase is desirable as the hard magnetic phase in these magnets. Thus, the production of SmCo_5 -based nanocomposite magnets by mechanical alloying has been studied [16–19].

Nanocomposite magnets can be produced not only by mechanically alloying but also by melt-spun spinning [20–24]. In the present study, $\text{SmCo}_{5-x}\text{Fe}_x$ ($x = 0-4$) alloys were produced by the melt-spinning technique. The purpose of this study was to seek the possibility of producing SmCo_5 -based nanocomposite magnets by melt-spinning and subsequent annealing. The structures and magnetic properties of the resultant Sm–Co–Fe melt-spun ribbons are discussed here.

2. Experimental

$\text{SmCo}_{5-x}\text{Fe}_x$ ($x = 0-4$) alloy ingots were prepared by induction melting of Sm (99.9 wt%), iron (99.9 wt%), and cobalt (99.9 wt%) under an argon atmosphere. An alloy ingot of 20 g was induction melted under an argon atmosphere in a quartz crucible having an orifice of 0.6 mm in diameter at the bottom. The molten metal was ejected through the orifice with argon onto a chromium-plated copper wheel rotating at a surface velocity of 50 ms^{-1} . The resultant melt-spun ribbons were obtained as fragmented pieces (thickness: 10 μm ; width: 1 mm). In spite of the high oxidation tendency of Sm-containing alloys, the melt-spun ribbons had a smooth

* Corresponding author.

E-mail address: tetsuji.saito@it-chiba.ac.jp (T. Saito).

metallic surface. The melt-spun ribbons were wrapped with tantalum foil and annealed under an argon atmosphere for 5 min at temperatures between 673 K and 1073 K. The phases in the specimens were examined by X-ray diffraction (XRD) using Cu K α radiation. The microstructures of the specimens were examined using a transmission electron microscope (TEM) after ion-beam thinning. The thermomagnetic curves of the specimens were examined by heating them at a rate of 0.16 K/s in a vacuum using a vibrating sample magnetometer (VSM) with an applied field of 500 Oe. The VSM was calibrated with a pure nickel sphere. The slope of the thermomagnetic curve near the Curie temperature was determined by curve fitting and the Curie temperature was determined by extrapolation. The magnetic properties of the specimens were measured at room temperature by the VSM with a maximum applied field of 25 kOe.

3. Results and discussion

Fig. 1 shows the dependence of the remanence and coercivity of the $\text{SmCo}_{5-x}\text{Fe}_x$ ($x = 0-4$) melt-spun ribbons on the Fe content. The SmCo_5 alloy melt-spun ribbon exhibited a high coercivity of 11.2 kOe and a remanence of 42 emu/g. As can be seen in the figure, the remanence of the $\text{SmCo}_{5-x}\text{Fe}_x$ ($x = 0-4$) melt-spun ribbons increases up to $x = 2$ then gradually decreases as the Fe content increases. However, the coercivity monotonically decreases with increasing Fe content. It was found that the substitution of Fe for Co in the SmCo_5 alloy increased the remanence but resulted in a significant decrease in coercivity.

The structures of the Sm–Fe–Co melt-spun ribbons were examined by XRD and thermomagnetic studies to evaluate the differences in remanence and coercivity. The results are shown in Figs. 2 and 3, respectively. The SmCo_5 alloy shows diffraction peaks assigned to the SmCo_5 phase and its thermomagnetic curve shows one magnetic transition at around 1010 K, which corresponds to the Curie temperature of the SmCo_5 phase [25]. This confirms that the SmCo_5 alloy consists of the SmCo_5 phase. The XRD patterns of the SmCo_4Fe and SmCo_3Fe_2 alloys are somewhat similar in appearance to that of the SmCo_5 alloy, and their thermomagnetic curves are also similar, confirming that these alloys consist of a SmCo_5 -type phase such as the $\text{Sm}(\text{Co,Fe})_5$ phase. On the other hand, the XRD patterns of the SmCo_2Fe_3 and SmCoFe_4 alloys differ from that of the SmCo_5 alloy. This suggests that the large substitution of Fe for Co in the SmCo_5 alloy resulted in the formation of a different phase, not the SmCo_5 -type phase. The XRD pattern of the SmCo_2Fe_3 alloy was somewhat indexed to a SmCo_7 -type phase; in this case, the $\text{Sm}(\text{Co,Fe})_7$ phase. The Curie temperature of the $\text{Sm}(\text{Co,Fe})_7$

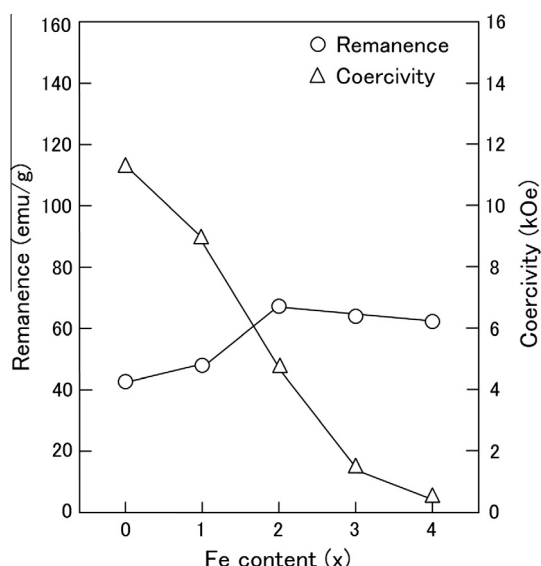


Fig. 1. Dependence of the remanence and coercivity of the $\text{SmCo}_{5-x}\text{Fe}_x$ ($x = 0-4$) melt-spun ribbons on the Fe content.

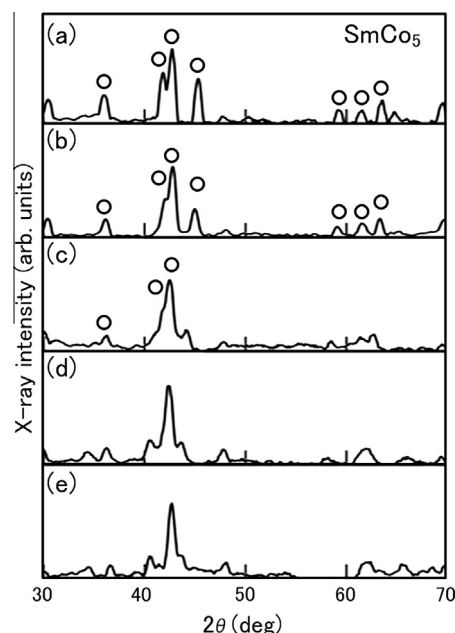


Fig. 2. XRD patterns of the Sm–Co–Fe melt-spun ribbons: (a) SmCo_5 , (b) SmCo_4Fe , (c) SmCo_3Fe_2 , (d) SmCo_2Fe_3 and (e) SmCoFe_4 alloys.

phase is around 910 K, which is much lower than the reported Curie temperature of the SmCo_7 phase is of around 1050 K [26]. It has been reported that the substitution of Ni for Co in SmCo_7 alloy leads to a significant decrease in the Curie temperature of the $\text{Sm}(\text{Co,Ni})_7$ phase [27]. The observed lower Curie temperature of the $\text{Sm}(\text{Co,Fe})_7$ phase is believed to be due to the substitution of Fe for Co in the SmCo_7 alloy. The XRD pattern of the SmCoFe_4 alloy is similar to that of the SmCo_2Fe_3 alloy, but the thermomagnetic curve is quite different. The magnetic transition at 730 K in the thermomagnetic curve of the SmCoFe_4 alloy corresponds to the

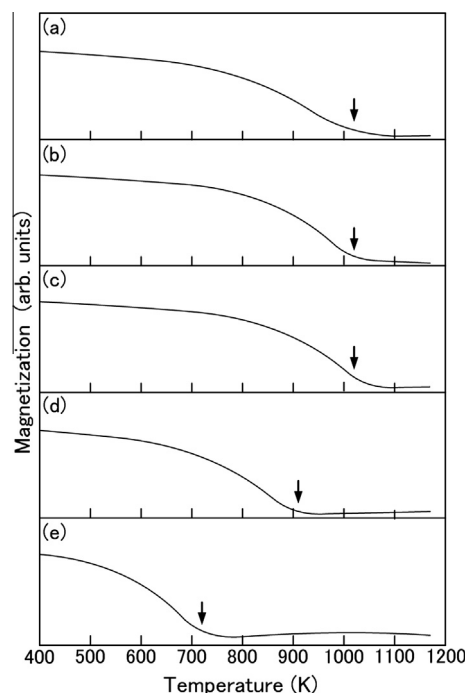


Fig. 3. Thermomagnetic curves of the Sm–Co–Fe melt-spun ribbons: (a) SmCo_5 , (b) SmCo_4Fe , (c) SmCo_3Fe_2 , (d) SmCo_2Fe_3 and (e) SmCoFe_4 alloys.

Download English Version:

<https://daneshyari.com/en/article/1612998>

Download Persian Version:

<https://daneshyari.com/article/1612998>

[Daneshyari.com](https://daneshyari.com)