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The effect of compound addition Dy_2O_3 and Sn on the structure and properties of NdFeNbB magnets

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Abstract

NdFeNbB with the additions of Dy_2O_3 and Sn permanent magnets have been attained by means of powder-blending technique, and their magnetic properties, temperature performance and microstructure were studied in this paper. The addition of just 2.0 wt% Dy_2O_3 or 0.3 wt% Sn proved to be very effective in improving the permanent magnetic properties of NdFeNbB magnets. Dy_2O_3 additions result in the increase in the H_{ci} and temperature dependence due to the increase of T_c, formation of (NdDy)-rich phase and grain refinement of Φ phase. This improvement of the coercivity stability of the magnets from the addition of Sn is attributed to the smoothing effect of the Sn addition at the grain boundaries. The magnetic properties, the temperature dependence and Curie temperature of NdFeNbB with Dy_2O_3 and Sn combined addition were found to be considerably improved. From the X-ray diffraction, SEM-EDAX studies and the thermo-magnetic study, the improved properties due to the solution of Dy and Sn to the Φ phase, the reduced N_{eff} and the smaller Φ phase.

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1. Introduction

NdFeB permanent magnetic materials have enjoyed considerable attention high magnetic properties and do not include precious metals such as Co and Ni [1]. Although NdFeB magnet exhibits a record high-energy product, the fairly low Curie temperature (312 °C) and high-temperature coefficient of B_r and H_{ci} will restrict its utility, especially in the field of motors and precision instruments [2].

NdFeB permanent magnets mainly consists of $Nd_2Fe_{14}B$ matrix phase (Φ phase), the minority of Nd-rich phase and B-rich phase [3]. The temperature performance of the magnets depends on the component design and microstructure. The hard magnetic properties of NdFeB magnets can be influenced by adding small amounts of further elements. Low-melting metals, such as Al, Ga, Cu, Sn or Zn, may form new intergranular phases with an improved wettability behavior during liquid sintering [4,5]. High-melting refractory metals, such as Nb, V, Mo and Ti, may form precipitates and high-melting borides [6–8]. The other additives, such as Co, Dy and Pr, substitute the magnetic elements in the hard magnetic phase [9–11]. A research conducted so far has identified that substitution of Nd by heavy rare-earth elements (i.e. Dy, Tb) and Fe by low melting elements and high melting points provokes effects mentioned earlier [12].

In this paper, we have investigated the NdFeB magnets with Nb, Dy_2O_3 and Sn additives by means of powder-blending technique, and also their structure, magnetic properties and temperature stability.

2. Experimental

The NdFeNbB alloy was melted in vacuum-induced furnace in the high-purity Ar atmosphere. The alloy ingot

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was broken and Dy_2O_3 and Sn was added before ball milling with gasoline to particle size of 3–5 μm. The powders were pressed in the 1.8 T magnetic field. After isotropic pressing, the green compacts were then sintered at 1115 °C for 1 h in vacuum and subsequently heat treated at 580 °C for 1 h.

Magnetic properties were measured using a vibrating sample magnetometer with a maximum applied field of 2 T. The backscattering electronic image (BEI) and secondary electronic image (SEI) were investigated using a JCX-733 electron microprobe microanalyzer. The microstructure was investigated using scanning electron microscope (SEM). The phase-make-up of the samples was analyzed by means of Japnese Theoreitical 3014 X-ray diffraction analysis machine.

3. Results and discussion

Fig. 1 demonstrates the dependence of B_r, H_{ci} and $(BH)_{max}$ on the Dy_2O_3-content in the magnet. The additions of Dy_2O_3 can be seen to result in a considerable increase of H_{ci} and H_{cb}. On the other hand, B_r slightly decreases with the addition of Dy_2O_3. The $(BH)_{max}$ slightly increases up to $x = 1.5$ wt% and then decreases with subsequent addition of Dy_2O_3 content. The main disadvantage of the addition of Dy or any other heavy rare earth to NdFeB arises from the unfavorable magnetic coupling between the 4f and 3d magnetic moments. Since the maximum value of remanence (B_r) is determined by the saturation magnetization (J_s) of the alloy, the addition of Dy results in a reduction in B_r and consequently the energy density $(BH)_{max}$ as shown in Fig. 1.

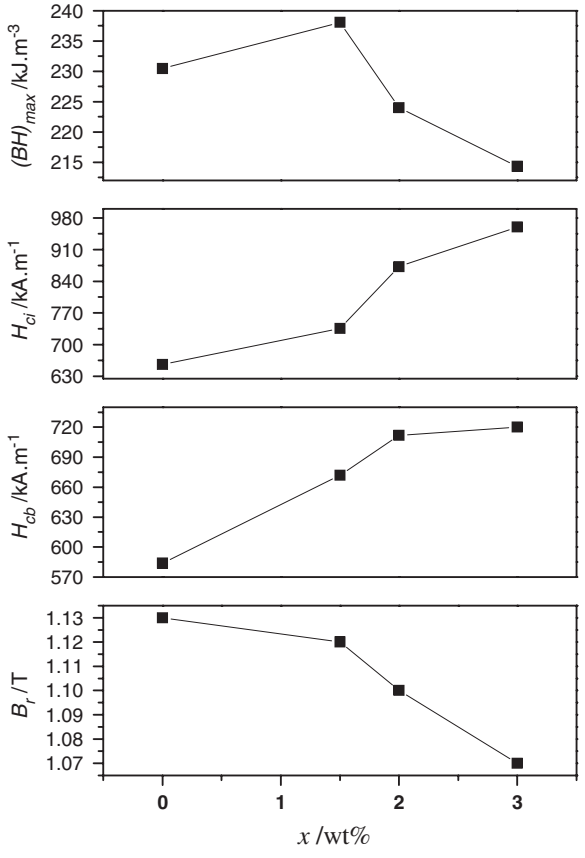

Fig. 1. Variations in B_r, H_{ci} and $(BH)_{max}$ of NdFeNbB + xDy_2O_3 samples as a function of Dy_2O_3 concentration, x.

The alloys of NdFeNbB + xSn in the range $x = 0$–0.6 have been investigated and their magnetic properties are shown in Fig. 2. The addition of Sn up to 0.3 wt% causes the value of H_{ci} to increase, and further addition of Sn results in the decrease of said value. On the other hand, B_r and $(BH)_{max}$ slightly decrease with the addition of Sn.

Table 1 shows the magnetic properties of NdFeNbB with Dy_2O_3 and Sn additions. The simultaneous addition of Dy_2O_3 and Sn considerably increases the magnetic properties of NdFeNbB. Fig. 3 shows the magnetic flux

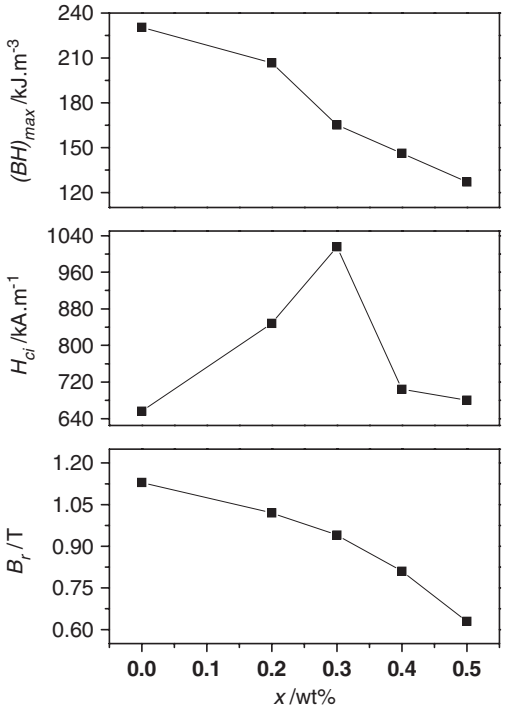

Fig. 2. Variations in B_r H_{ci} and (BH)max of NdFeNbB + xSn samples as a function of Sn concentration, x.

Table 1
The magnetic properties of the magnets at room temperature

Samples	B_r(T)	H_{ci}(kA m^{-1})	$(BH)_{max}$ (kJ m^{-3})
NdFeNbB (A)	1.13	656.0	230.5
NdFeNbB + 2%Dy_2O_3 (B)	1.11	824.0	221.8
NdFeNbB + 0.3%Sn (C)	0.94	1016.0	165.1
NdFeNbB + 2%Dy_2O_3 + 0.3%Sn (D)	1.09	1024.0	214.4