Special Issue of the 8th International Advances in Applied Physics and Materials Science Congress (APMAS 2018)

Influence of Boron Addition on Magnetic Properties of Sm_2Fe_{17} Alloy

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With the boron addition, the Curie temperature of Sm_2Fe_{17} permanent magnet was observed to increase from 130 °C and reach its highest value of 362 °C for the sample at $x = 4$. In the X-ray diffraction measurements, the peaks diffracted from the planes of hard magnetic Sm_2Fe_{17} phase, observed in the sample without boron, disappeared with the boron addition and magnetic $SmFe_3$ and Fe_2B phases were detected. For all samples, the major peaks belong to the α-Fe phase. According to the magnetization measurements, the Ms value of the sample without boron is 155.52 emu/g, it decreased to its lowest value of 97.93 emu/g for the sample at $x = 4$. Boron addition resulted in an evolution of the phase constitution that caused changes in magnetic properties of the alloys.

DOI: 10.12693/APhysPolA.135.687
PACS/topics: arc melting, magnetic properties, Curie temperature, rare-earth permanent magnets

1. Introduction

Sm_2Fe_{17} compound which has a rhombohedral Th_2Zn_{17}-type structure has an easy plane magnetocrystalline anisotropy at room temperature and relatively low Curie temperature. To improve intrinsic magnetic properties, small interstitial atoms such as B, N, and C have been introduced into Sm_2Fe_{17} structure. The Sm_2Fe_{17} phase can absorb appreciable amount of C or N atoms without losing or transformation of its basic structure [1–3]. The interstitial modifications of Sm_2Fe_{17} phase have been initiated by using C atoms. The introduced interstitial C and N atoms expand the lattice and Fe–Fe distance in the structure resulted in the enhancement of the exchange interaction between magnetic moments leading to a high Curie temperature. Among the interstitial modifications, $Sm_2Fe_{17}N_x$ nitride has been found to have the highest solubility in comparison with the $Sm_2Fe_{17}C_x$ carbide and $Sm_2Fe_{17}B$, boride [3, 4]. The purpose of this study is to investigate the effects of boron additions at high ratios on magnetic properties of stoichiometric Sm_2Fe_{17} alloy.

2. Materials and equipments

The alloy ingots with nominal compositions of $Sm_2Fe_{17}B_x$ ($x = 0, 1, 2, 3, 4$) were prepared by arc-melting method under Ar atmosphere followed by heat treatment at 1000 °C for 2 h under vacuum. The samples were remelted three times for the homogeneity of the ingots. The changes in the structures of the samples were measured by X-ray diffraction (XRD) with Cu K_α radiation at room temperature. The microstructures of the materials were characterized by scanning electron microscope (SEM). The Curie temperatures of the samples were determined by AC magnetic susceptibility measurements by heating the samples up to 550 °C. Vibrating sample magnetometer (VSM) was used to measure the magnetic properties of the samples with a maximum magnetizing field of 10 kOe at room temperature.

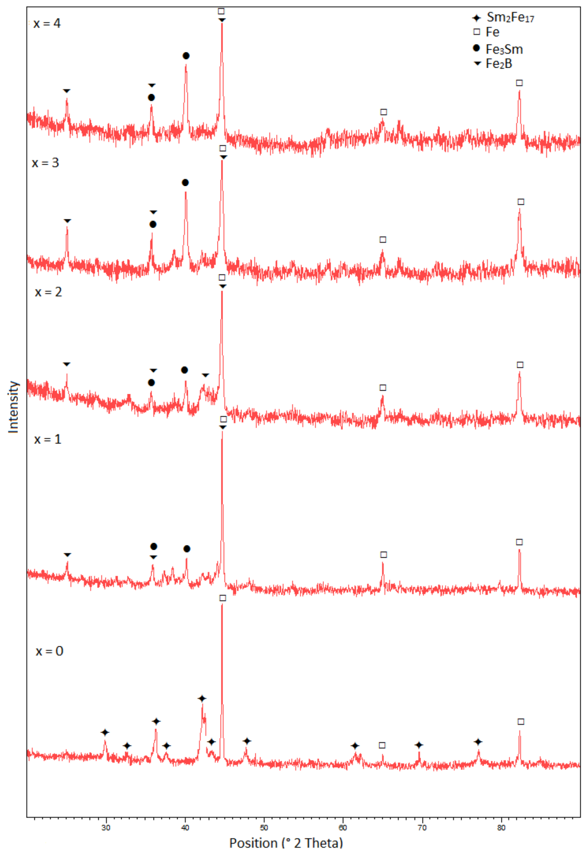

Fig. 1. Effect of boron addition on the crystal structure of $Sm_2Fe_{17}B_x$ alloy.

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3. Results and discussion

Figure 1 shows the effect of the B addition on the Sm_2Fe_{17} composition, where the B concentration was increased from $x = 0$ to $x = 4$ in $Sm_2Fe_{17}B_x$. Diffraction peaks of the Sm_2Fe_{17} were determined to be soft magnetic cubic Fe and hard magnetic rombohedral Sm_2Fe_{17} phases. With the addition of boron at $x = 1$, the diffraction peaks belonging to Sm_2Fe_{17} phase disappeared and the presence of the magnetic rhombohedral $SmFe_3$ phase and tetragonal Fe_2B phase were observed. The peak intensity of the $SmFe_3$ and Fe_2B phases increased significantly at $x = 3$ and $x = 4$.

In SEM micrographs (Fig. 2), large grain size of about 20 μm was observed for the samples of Sm_2Fe_{17} and $Sm_2Fe_{17}B$ showed in Fig. 2a and b. With the increase of boron ratio at $x = 2$, in some parts of the microstructure, there are lamellar formation exhibited in Fig. 2c. The amount of lamellar structure increased significantly in the microstructure with the further addition of boron at $x = 3$ and $x = 4$

In Fig. 3, the measured Curie temperature (T_c) of the alloy at $x = 0$ is about 130 °C, corresponding to the Curie temperature of hard magnetic Sm_2Fe_{17} phase. With the addition of boron, the Curie temperature of the alloys increased to about 361 °C at x = 1–4 because of disappearance of the Sm_2Fe_{17} phase and formation of the ferromagnetic Fe_3Sm and Fe_2B phases detected in XRD measurement. The Curie temperatures of Fe_3Sm and Fe_2B phases are 367 °C and 742 °C, respectively [5, 6].

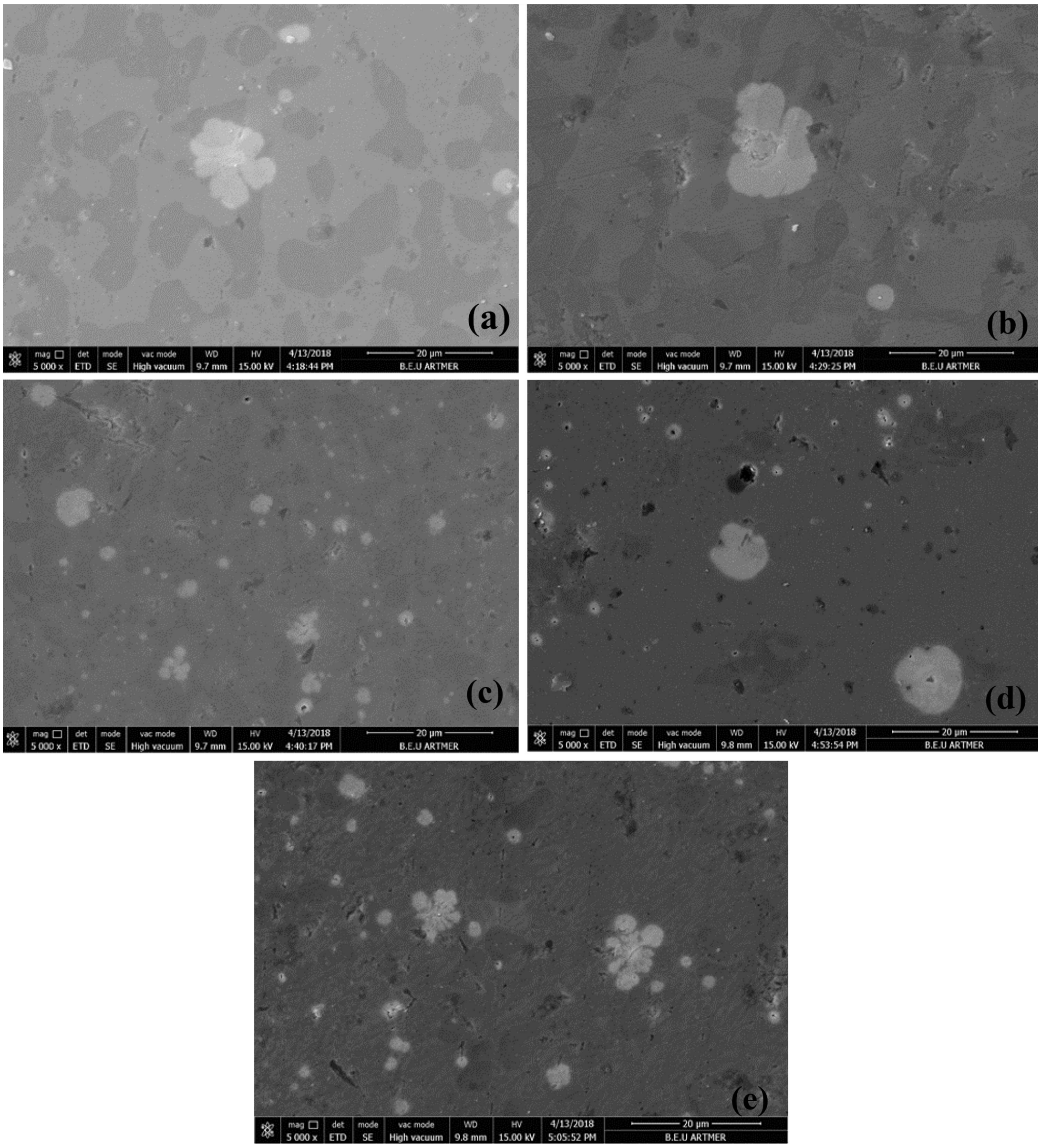

Fig. 2. SEM micrographs of the arc melted Sm_2Fe_{17} (a), $Sm_2Fe_{17}B$ (b), $Sm_2Fe_{17}B_2$ (c), $Sm_2Fe_{17}B_3$ (d), and $Sm_2Fe_{17}B_4$ (e) samples heat treated at 1000 °C for 2 h.

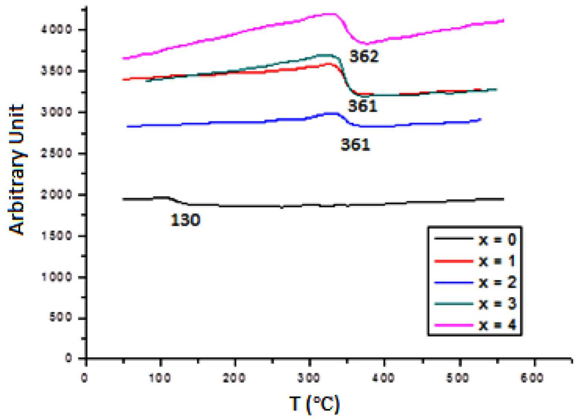

Fig. 3. The Curie temperature measurements of the samples with different boron concentrations.

Figure 4 indicates the hysteresis curves of the $Sm_2Fe_{17}B_x$ (x = 0–4). Although Sm_2Fe_{17} is hard magnetic, the shape of the curve for the sample at $x = 0$ shows soft magnetic behaviour due to the considerable amount of iron (Fe) in the microstructure. For the boron added samples, the hysteresis curves are similar to that without boron but the saturation magnetizations decreased with the increase of boron ratio.

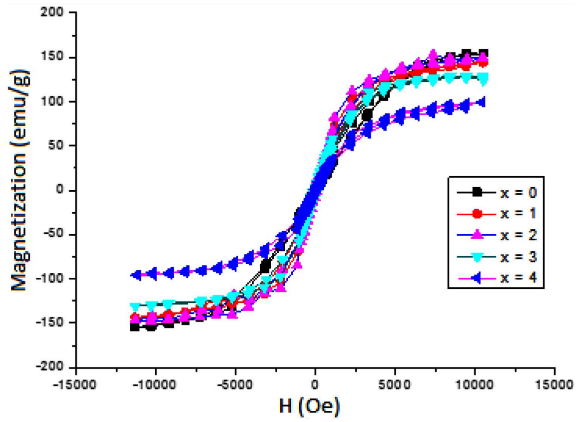

Fig. 4. Hysteresis curves of the samples.

In Table I the saturation magnetization M_s of the Sm_2Fe_{17} alloy has the highest value of 155.5 emu/g. With the addition of boron, the saturation magnetization decreased to its lowest value of 97.9 emu/g for the sample at $x = 4$. This may be due to the decrease in the amount of Fe in the microstructure and also due to the fact that Sm_2Fe_{17} has the higher saturation magnetization (117 emu/g) than that of $SmFe_3$ phase (80.7 emu/g) [5].

TABLE I

Saturation magnetizations of the samples.

Alloy	M_s [emu/g]
Sm_2Fe_{17}	155.5
$Sm_2Fe_{17}B$	145.4
$Sm_2Fe_{17}B_2$	150.9
$Sm_2Fe_{17}B_3$	127.8
$Sm_2Fe_{17}B_4$	97.9

4. Conclusion

In XRD analysis, Sm_2Fe_{17} phase decompose to magnetic $SmFe_3$ and Fe_2B phases, with the increase in boron ratio at $x = 3$ and $x = 4$ the intensity of the peaks diffracted from $SmFe_3$ phase increased. The Curie temperature of the samples increased from 130 °C to 361 °C with the boron addition to the alloy, due to the existence of $SmFe_3$ phase in the microstructure. The saturation magnetization has the highest value of 155.5 emu/g and decreases to its lowest value of 97.9 emu/g for the sample at $x = 4$ because Sm_2Fe_{17} has the higher saturation magnetization (117 emu/g) than that of $SmFe_3$ phase (80.7 emu/g) [5]. In the study, boron addition and heat treatment at 1000 °C resulted in an evolution of the phase constitution that caused changes in magnetic properties of the alloy instead of occupation of boron atoms in the interstitial sites of Sm_2Fe_{17} structure such as C and N.

References

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