Abstract

Sm-Co-based magnets are commercially available magnets for dynamic and high-temperature applications. Examples of applications that require high-energy density permanent magnets with stable magnetic fields over various environmental conditions and vast temperature ranges include microwave tubes, gyroscopes and accelerometers, reaction and momentum wheels to control and stabilize spacecraft, magnetic bearings, sensors, and actuators. Sm-Co-based magnets, which have high intrinsic magnetic characteristics, are considered as high-energy density permanent magnets and can make excellent candidates for further research and development.

In the present work, three different series of Sm-Co-based ribbons were synthesized using melt-spinning method as follows: $(Sm_{0.12}Co_{0.88})_{95}Hf_{5-x}C_x$ (considering 1:7H structure), $(Sm_{0.12}Co_{0.88})_{95}Hf_{5-x}B_x$ (considering 1:7H structure) and $Sm_{(1-x)}RE_xCo_5$ (considering 1:5H structure). The correlations between microstructure, structural and magnetic properties have been reported.

The $(Sm_{0.12}Co_{0.88})_{95}Hf_{5-x}C_x$ (x=0, 1, 2, 3, 4, and 5) alloys were melt spun at 30 m/s and 40 m/s to explore the effect of cooling rate on the structure and the properties of the alloys. Experimental results have displayed that the combined or individual addition of Hf and C stabilized the 1:7H crystal structure, promoted the uniform nanoscale grain structure, and caused significant improvements in the magnetic characteristics. The coercivity (H_c) of the ribbons melt spun at higher wheel speed (40 m/s) increased systematically from approximately ~8 kOe (x=0) to ~22 kOe (x=2). The remanence magnetization (M_r) increased from ~42 emu/g (x=0) to 62 emu/g (x=4) with a maximum reduced remanence (M_r/M_s) value of 0.79 (x=1). The APT analysis revealed the carbide precipitate in the nanoscale range, prohibiting the domain wall motion to improve the coercivity. The TEM analysis disclosed the *fcc*-Co precipitate (10-100 nm) at higher wheel speed, which helped to improve the remanence. Interestingly, the ribbon (x=5) melt spun at 40 m/s showed a dendritic structure with a very high coercivity value (~41 kOe).

The $(Sm_{0.12}Co_{0.88})_{95}Hf_{5-x}B_x$ (x=0, 1, 2, 3, 4, and 5) alloys were melt spun at 40 m/s and annealed at various temperatures (700 °C, 800 °C, and 900 °C) in order to further optimize the magnetic characteristics of the ribbons. As-spun ribbons were studied to observe significant changes in magnetic properties. The stability of metastable 1:7H phase has been studied using DFT (density functional theory) calculations and experimental measurements. The secondary phase, boride, was also observed, which acts as a pinning center to enhance the coercivity. The maximum coercivity (H_c) of the as-spun ribbon varied between ~7 kOe (x=5) and ~12 kOe (x=2). The $(Sm_{0.12}Co_{0.88})_{95}Hf_3B_2$ ribbons showed the maximum magnetic anisotropy energy (MAE) value of 9.86 MJ/m^3. On the other hand, the remanence magnetization (M_r) increased from ~43 emu/g (x=0) to ~55 emu/g (x=5). The disorder-order transformation was observed in the case of annealed ribbons. The ribbon (x=4) annealed at 700 °C showed improved magnetic properties, especially coercivity ($H_c \approx$ 8.6 kOe), as compared to the as-spun ribbon ($H_c \approx$ 8.2 kOe).

The $Sm_{(1-x)}RE_xCo_5$ (RE= Gd and/or Dy) ribbons were synthesized at 40 m/s. The phase analysis confirmed the presence of 1:5H crystal structure, which was prevalent along with a fraction of 2:17R structure in all the ribbons. H_c and M_r values for Dy added ribbon was 13.3 kOe and 37.17 emu/g, respectively. The as-spun ribbons were analyzed to understand the high-temperature magnetic behaviour. And α and β (300 K-600 K) of $Sm_{0.6}Gd_{0.3}Dy_{0.1}Co_5$ ribbon were about -0.0017 %/K and -0.0011 %/K, respectively.

Keywords: Permanent magnets, Sm-Co-based magnets, LRE, HRE, Rapid solidification, Wheel speed, Annealing, Microstructure, Disorded structure, Ordered structure, Disorder-order transformation, Coercivity, Remanence magnetization, Temperature Co-efficient, DFT.