Improved coercivity and squareness in bulk hot-deformed magnets by two-step grain boundary diffusion process

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In order to use Nd-Fe-B based permanent magnets for the traction motor of hybrid (electric) vehicles, a coercivity of 0.8 T is required at 160 °C to avoid their thermal demagnetization during operation. To meet this requirement, grain boundary diffusion of RE-based eutectic alloys is employed to improve the coercivity in the hot-deformed magnets. 1) Recently, Li et al. reported a coercivity of ~2.57 T with remanence of 1.38 T in a 2-mm-thick hot-deformed magnet by the grain boundary diffusion of Tb-Nd-Cu alloy. 2) However, such high performance was demonstrated only using a small piece of samples with a thickness of ~2 mm and a question is whether or not we can apply the process to large bulk samples. Previous reports on conventional Dy-vapor diffusion process in micron-grain sized Nd-Fe-B sintered magnets has shown that the limited diffusion depth results in a poor squareness of demagnetization curves. 3) In this work, we investigated the method to improve the squareness of demagnetization curves of Nd-HRE-Cu eutectic-diffusion processed 5.6-mm-thick hot-deformed magnets.

The hot-deformed Nd-Fe-B-based magnets with composition of Fe$_{67.1}$Pr$_{6.7}$Nd$_{21.2}$Co$_{3.5}$Ga$_{0.5}$B$_{1}$ (wt.%) were used as starting materials. The samples of $\times$ 7 x 5.6 (c-axis) mm$^3$ in size were covered by the 12 wt.% Tb$_{20}$Dy$_{10}$Nd$_{40}$Cu$_{30}$ ribbons (with respect to mass of hot-deformed magnet) followed by annealing at 750°C for 1.5 h and post-annealing at 650°C for 9h, which is called as “one-step diffusion process”. In comparison, the two-step diffusion process was carried out as follows: the initial samples were covered by the 10 wt.% Tb$_{20}$Dy$_{10}$Nd$_{40}$Cu$_{30}$ ribbons (with respect to the mass of hot-deformed magnet) followed by annealing at 750°C for 1.5 h. Thereafter, the surface of the magnet was polished and the magnet was again covered by 6 wt.% of Nd$_{80}$Cu$_{20}$ alloy ribbons followed by heat-treatment at 650°C for 9 h. The magnetic properties were studied by pulse BH-tracer.

Fig. 1 shows the demagnetization curves of the one-step and the two-step diffusion processed samples. The coercivity is improved from ~1.14 T in the as-deformed sample to ~2.38 T while remanence degrades from ~1.49 T to ~1.28 T after one-step diffusion process. In contrast, the coercivity is enhanced to 2.43 T with remanent magnetization reduction to ~1.29 T by the two-step diffusion process. The squareness factor of demagnetization curve is defined as $\mu_0H_k/\mu_0H_c$, where $\mu_0H_k$ is the absolute value of external field when the magnetization equals to 90% of remanent magnetization ($\mu_0M_r$) and $\mu_0H_c$ is the coercivity of the sample. The squareness factor was calculated to be ~0.83 for the one-step diffusion processed sample, which is improved to ~0.91 after the two-step diffusion. The origin of the obtained magnetic properties will be discussed based on detailed microstructure characterization.

Reference

Fig. 1 Demagnetization curves of hot-deformed magnets and diffusion-processed magnets