Easy measurement of anisotropy constants for Nd-Fe-B sintered magnet

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1. Introduction To reduce the irreversible demagnetization of Nd–Fe–B sintered magnets at elevated temperatures, it is necessary to significantly improve coercivity (H_{cJ}) which is related to the quadratic (first, K_1) anisotropy constant. Recently easy measurements of anisotropy constants [K_1 and quartic (second, K_2)] have received considerable interest in connection with related fields of applications. We have newly developed useful and simplified torque measurement that efficiently operates in high fields (H) using a superconducting magnet (SCM) in the temperature range of 298-473 K.[1)]

2. Experiment The composition of the sintered magnet used was $Nd_{13.6}Fe_{bal}Co_{1.1}Al_{0.3}B_{5.7}$ with H_{cJ} of 0.99 MA/m and saturation magnetization (J_s) of 1.51 T at 298 K. The composition of the magnet with excellent orientation is considerably close to the $Nd_2Fe_{14}B$ single crystal**,** so that it can be considered as K_1 value makes no great difference. To obtain anisotropy constants, we made use of a new torque magnetometer mounted strain gauges on a rigid pipe (made of Ti) to sense the force (F) in a highly uniform H (0.02%/10 mm cube).[1)] Sample is mounted on the free end of the rigid pipe in the center of SCM. It is only in the case of an ellipsoid that the demagnetizing field becomes uniform for a uniform distribution of magnetization. Thus we chose a sphere (diameter of 7.0 mm) for the shape of sample. To measure the K_1 and K_2 from the results of F obtained from the strain output (ε) using Wheatstone bridge circuit, we ensured angles of inclination (φ) of 45° and 20° to the perpendicular unidirectional H. The torque $L(\varphi)$ obtained from F is equivalent to the values of magnetic torque [$L(\theta)$] curve at θ of 45° and 20°, where θ is the angle between the easy axis and J_s. $L(\theta)$ exerted by the magnetic anisotropy energy of sample can be measured by the mechanical torque [L (= $F \times l_s$)] acting on the rigid pipe, where l_s is the length of the rigid pipe. In highly uniform H, the force (= $M \times \partial H_z/\partial z$) based on magnetic moment (M) does not act on the rigid pipe, because a gradient of H ($\partial H_z/\partial z$) can be disregarded. Therefore, L acting on the rigid pipe is the only $L(\theta)$. $L(\theta)$ of a tetragonal symmetry is generally expressed: $L(\theta) = -(K_1 + K_2)\sin(2\theta) + (K_2/2)\sin(4\theta)$. F was loaded the outside of the SCM by the weight in free end of the rigid pipe mounted horizontally on a vice. The torque proofs were corrected using the product of mass of the weight (10-300 g) and l_s.

3. Results and discussion The large L was almost proportional to ε: $L = 3.839 \times \varepsilon - 0.003$. Fig. 1 shows the strain output for the magnet at φ of 45° and 20°, and the blank sample. The measured values of ε are necessary to make the correction using the values of the blank sample in these respective H (4.8, 5.6, 6.4, and 7.2 MA/m). Fig. 2 shows K_1 of the magnet, which was extrapolated to the infinite H at various temperatures. K_1 and K_2 of the magnet were 4.6 and 0.37 MJ/m^3 at 298 K, respectively. K_1 was in substantially agreement with the published values for the $Nd_2Fe_{14}B$ single crystal.[2)] As the temperature rose to 473 K, these deteriorated remarkably to 1.0 and 0.23 MJ/m^3, respectively. Both K_1 and K_2 decreased as the temperature increased. Anisotropy field of magnet at 298 K was 6.09 MA/m. A significantly higher H than H_A was necessary to obtain H_A for the Nd-Fe-B sintered magnet. Despite the very simple mechanism, this method can measure the large K_1 and K_2 of Nd–Fe–B sintered magnet at elevated temperatures in high H.

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References 1) H. Nishio and K. Machida, IEEE Trans. Magn., **54** (2018) 6000904. 2) D. Givord et al., Solid State Commun., **51** (1984) 857.

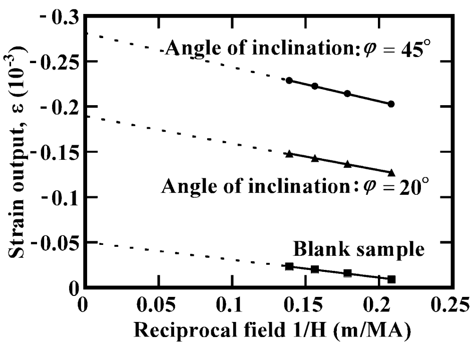

Fig. 1 Plots of strain output versus the reciprocal field at 298 K.

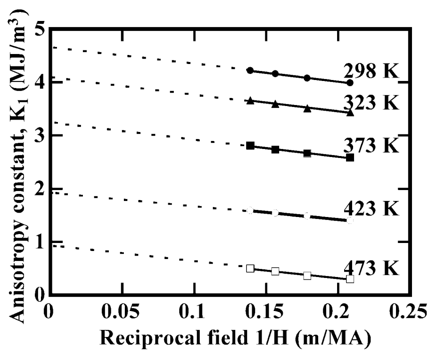

Fig. 2 Plots of the K_1 versus the reciprocal field at 298-473 K.