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Temperature dependence of magnetization stability for Nd-Fe-B magnets

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The time dependence of the flux loss $\Delta\Phi$ of Nd-Fe-B sintered and bonded magnets were measured for 1000 h at 297 to 373 K. $\Delta\Phi$ of the sintered magnet varied in accordance with the logarithmic law. During the period in which $\Delta\Phi$ obeyed, the logarithmic law was shorter for the bonded magnets. The initial flux drops increased for the sintered magnet as the sample length was shorter and the temperature became higher. In contrast, the sample lengths did not affect the bonded magnets and the value was reduced by about 40% of the sintered magnet. Permanent flux loss of the sintered magnet was only 1%, but that of the bonded magnets reached to 2–4% at 373 K.

1. INTRODUCTION

Recently, the Nd-Fe-B magnets have been widely used in office automation, audio and video equipment. Research on their magnetization stability at a high temperature is particularly important to secure the high reliability as electronics parts. Mildrum et al. had reported the time dependence of magnetic properties for $SmCo_5$ magnets [1]. The time dependence of magnetization in permanent magnets obeys a logarithmic law and is depend on the aftereffect constant Sv, the irreversible susceptibility X_{irr} and ln t [2].

This paper reports the time dependence of the change in magnetic flux (flux loss $\Delta\Phi$) for 1000 h at 297 to 373 K, for sintered and bonded Nd-Fe-B magnets.

2. EXPERIMENTAL

The compositions of sintered and bonded Nd-Fe-B magnets are $Nd_{14.2}Dy_{0.6}Fe_{77.6}B_{6.6}Al_{1.0}$ and $Nd_{12.2}Fe_{77.0}Co_{5.4}B_{5.4}$ respectively. Two cylindrical specimens (ϕ10 mm × 7 mm : permeance factor P = 2 and ϕ10 × 3 mm: P = 0.8) were prepared. The surface of the magnets was uncoated with rust prevention. Figure 1 shows temperature dependence of demagnetizing curves for spherical magnets measured by VSM.

The time dependence of $\Delta\Phi$ was measured for 1000 h at 297, 326, 348 and 373 K. The specimens were sealed in capsules. A pulse magnetizing field of 5 MA/m was initially applied to the specimen. An electromagnetic induction method was used to measure $\Delta\Phi$ of the magnets. They are pulled out from a search coil with 80 windings at a constant speed of 2.7 mm/s. The magnetic flux was measured using a fluxmeter (4-digit indication, 1 × 10^{-6} Wb sensitivity). After magnetizing, $\Delta\Phi$ was measured and the value of the magnetic flux of 1 h later was taken as the initial reference value.

The flux Φ_0 was measured immediately after magnetizing at 297 K. Flux Φ_1 was measured after preserving specimens at various temperatures for 1 h. The initial flux drop was designated as $(\Phi_0 - \Phi_1)/\Phi_0 \times 100$ (%). The specimens were remagnetized at 297 K after preserving 1000 h at various temperatures and flux Φ_2 was measured after 1 h. The value of $(\Phi_1 - \Phi_2)/\Phi_1 \times 100$ (%) was recorded as a permanent flux loss (deterioration).

3. RESULTS AND DISCUSSIONS

Figure 2 and Table 1 show the time dependence of $\Delta\Phi$, decay of magnetic flux, initial flux drop and permanent flux loss of the sintered magnets. The initial flux drop increased as P was smaller and the preservation temperature was higher. For the ϕ10 × 7 mm specimen rapid increase of $\Delta\Phi$ was observed at the temperature higher than 348 K, while that of the ϕ10 × 3 mm specimen occurred at the temperature higher than 326 K.

The time dependence of $\Delta\Phi$ obeyed a logarithmic law at each temperature. The decay of magnetic flux of the ϕ10 × 7 mm specimen was rapid above 348 K, whereas that of the ϕ10 × 3 mm specimen increased with the increment of preservation temperature. Nd-Fe-B sintered magnets have an excellent rectangularity ratio SQ and a low X_{irr} at near room temperature. The initial flux drop and decay of magnetic flux are small. Temperature coefficient of intrinsic coercive force $\alpha[H_{cJ}]$ is large, about $-0.6\%/K$, [3]. The operating point exists near the knee point of the J-H demagnetizing curve at a temperature higher than the temperature of about 373 K for $\phi 10 \times 7$ mm specimen and of about 326 K for $\phi 10 \times 3$ mm specimen. This results in increasing the initial flux drop and decay of magnetic flux.

The specimens were remagnetized and their permanent flux losses were measured. The measured values slightly increased as the temperature increased, and were independent of P. They were small, at about 0.8 to 1.1%, even after preserving for 1000 h at 373 K.

Figures 3, 4 and Tables 2, 3 show the time dependence of $\Delta\Phi$, decay of magnetic flux, initial flux drop and permanent flux loss of the bonded magnets. The initial flux drop of compression bonded magnets were slightly lower than those of injection bonded magnets. Those of all the bonded magnets slightly increased as P became smaller, but their increases were specially small compared with those of the sintered magnet. It increased when the preservation temperature was higher.

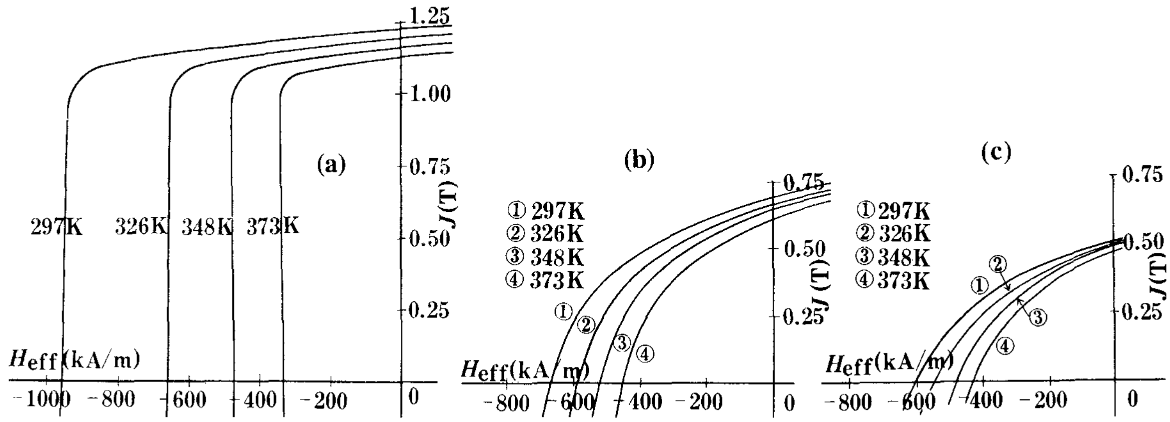

Figure 1. Temperature dependence of demagnetizing curves for $Nd_{14.2}Dy_{0.6}Fe_{77.6}B_{6.6}Al_{1.0}$ sintered (a), $Nd_{12.2}Fe_{77.0}Co_{5.4}B_{5.4}$ compression (b) and injection (c) bonded magnets at various temperatures.

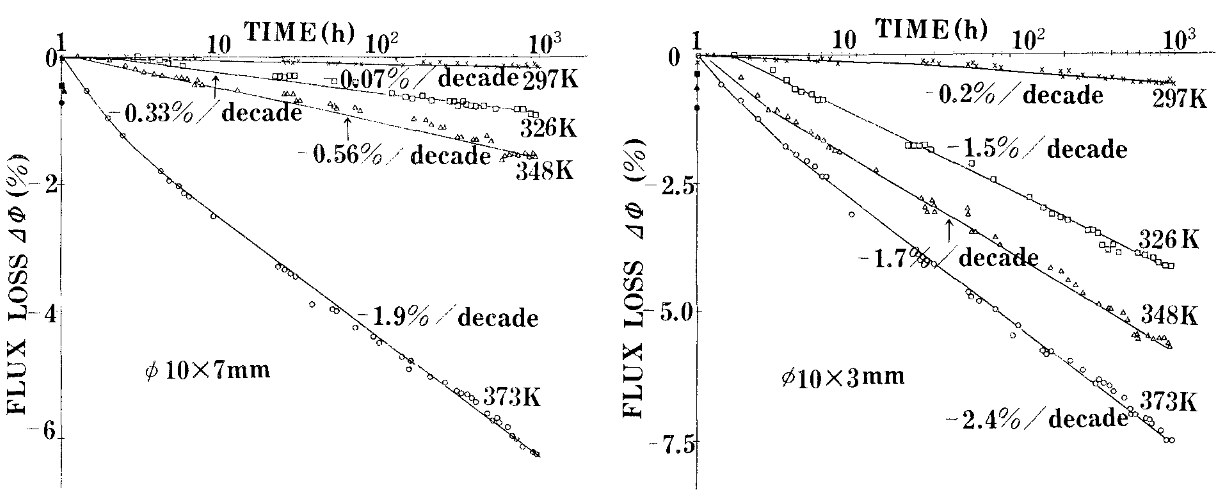

Figure 2. Time dependence of $\Delta\Phi$ for $Nd_{14.2}Dy_{0.6}Fe_{77.6}B_{6.6}Al_{1.0}$ sintered magnet ($\phi 10 \times 7$ mm : P = 2 and $\phi 10 \times 3$ mm : P = 0.8) at various temperatures.

The time dependence of the bonded magnets obeyed a logarithmic law at 297 K. The logarithmic law established 175 h at 326 K, 125 h at 348 K and 50 h at 373 K. The periods in which the law established shortened with increasing the preservation temperature. The decay of magnetic flux rapidly increased when preservation temperatures was higher than 326 K where the logarithmic law no longer established. This trend was specially prominent with the $\phi 10 \times 3$ mm ($P = 0.8$) injection bonded magnet, which showed −6.1%/decade at 400 to 1000 h. The bonded magnets were isotopic and showed poor SQ in J-H demagnetizing curves. The value of, $\alpha[H_{cJ}]$ was about −0.4%/K and was not as large as those of the sintered magnet [4]. Therefore, the initial flux drop and the decay of magnetic flux were lowered in small increments during the period where the logarithmic law established. Those of the sintered magnets lowered rapidly in increasing the preservation temperature during the same period.

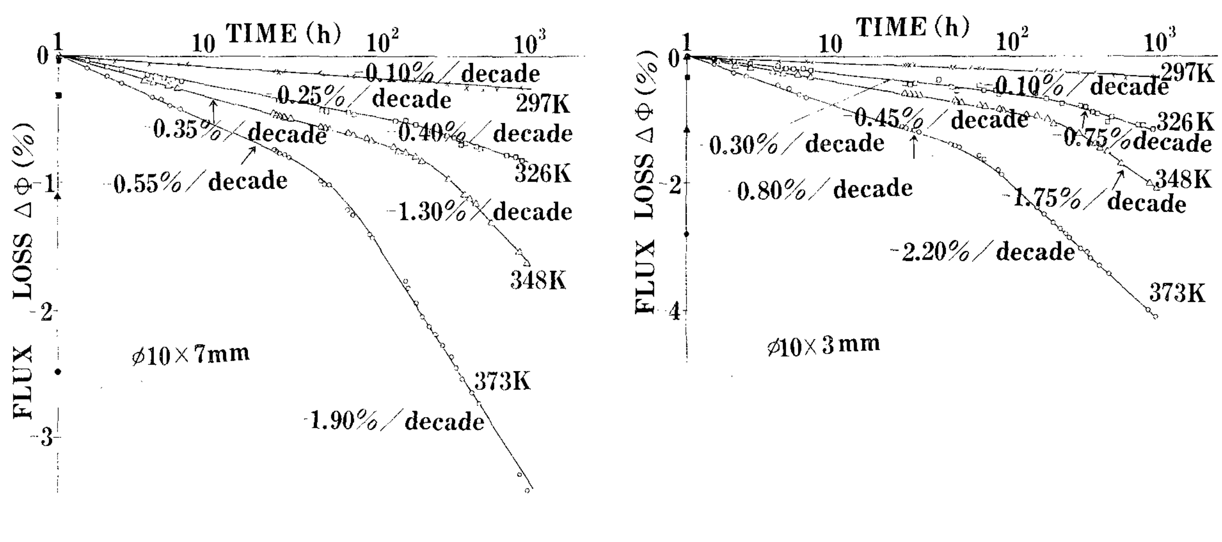

Figure 3. Time dependence of $\Delta\Phi$ for $Nd_{12.2}Fe_{77.0}Co_{5.4}B_{5.4}$ compression bonded magnet ($\phi 10 \times 7$ mm : $P = 2$ and $\phi 10 \times 3$ mm : $P = 0.8$) at various temperatures.

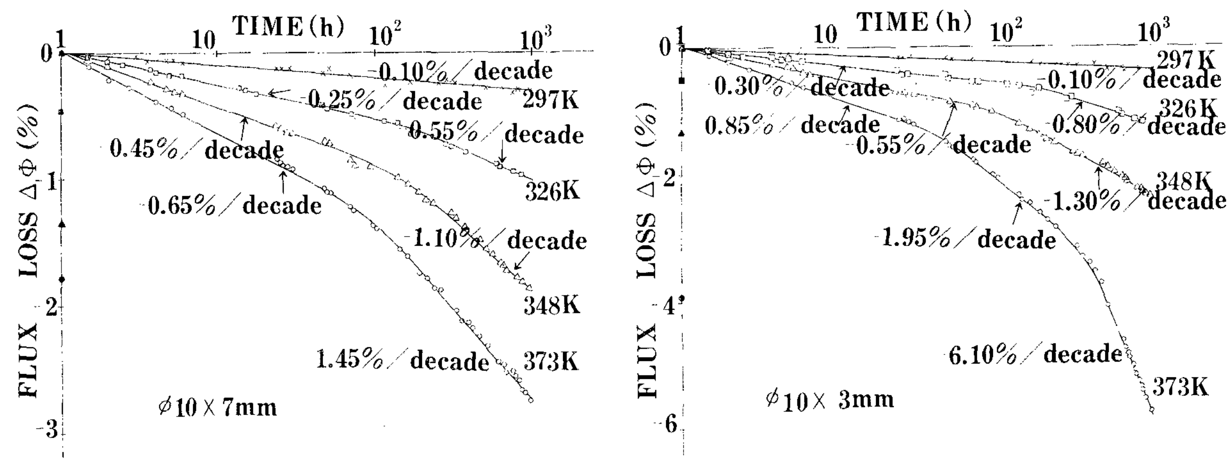

Figure 4. Time dependence of $\Delta\Phi$ for $Nd_{12.2}Fe_{77.0}Co_{5.4}B_{5.4}$ injection bonded magnet ($\phi 10 \times 7$ mm : $P = 2$ and $\phi 10 \times 3$ mm : $P = 0.8$) at various temperatures.

Table 1 Initial flux drop and permanent flux loss of $Nd_{14.2}Dy_{0.6}Fe_{77.6}B_{6.6}Al_{1.0}$ sintered magnet at various temperatures.

Preservation temperature (K)	$\phi 10 \times 7$ mm (P = 2)		$\phi 10 \times 3$ mm (P = 0.8)	
	Initial flux drop (%)	Permanent flux loss (%)	Initial flux drop (%)	Permanent flux loss (%)
297	0	0.1	0	0.1
326	3.2	0.5	12.8	0.4
348	7.1	0.6	21.4	0.6
373	20.8	0.8	39.4	1.1

Table 2 Initial flux drop and permanent flux loss of $Nd_{12.2}Fe_{77.0}Co_{5.4}B_{5.4}$ compression bonded magnets at varios temperatures.

Preservation temperature (K)	$\phi 10 \times 7$ mm (P = 2)		$\phi 10 \times 3$ mm (P = 0.8)	
	Initial flux drop (%)	Permanent flux loss (%)	Initial flux drop (%)	Permanent flux loss (%)
297	0	0	0	0
326	3.7	0.3	4.5	0.3
348	6.9	1.1	8.4	1.2
373	10.9	2.5	13.0	2.8

Table 3 Initial flux drop and permanent flux loss of $Nd_{12.2}Fe_{77.0}Co_{5.4}B_{5.4}$ injection bonded magnets at various temperatures.

Preservation temperature (K)	$\phi 10 \times 7$ mm (P = 2)		$\phi 10 \times 3$ mm (P = 0.8)	
	Initial flux drop (%)	Permanent flux loss (%)	Initial flux drop (%)	Permanent flux loss (%)
297	0	0	0	0
326	4.1	0.5	5.1	0.5
348	7.7	1.3	9.5	1.4
373	12.1	1.8	14.5	3.9

The permanent flux losses were not related to P and the molding methods of bonded magnets from 297 to 348 K. They gradually increased as the preservation temperature increased and were about 1.1 to 1.4% at 348 K. However, at 373 K, they were 2.5 to 2.8% with the compression bonded magnets and 1.8 to 3.9% with the injection bonded magnets. They were no longer negligible.

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