

The thermal expansion coefficient of Nd-Fe-B and Sm-Co permanent magnets in the region of the Curie point

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Abstract. A dilatometric study results on the linear thermal expansion coefficient (LTEC) of Nd-Fe-B and Sm-Co permanent magnets are presented. The experimental data in the temperature range 200–750 K and 293–1163 K, respectively, are obtained. The measurements were made with an error 3%. The character of the change of the linear thermal expansion coefficient in the vicinity of the Curie point is established. The critical exponents of the LTEC for magnetic phase transitions are defined.

1 Introduction

A large number of experimental studies are devoted to measuring the thermophysical properties of substances in a magnetic field. It is known that under its influence curious thermal effects are observed in the magnetic materials. In particular there are magnetostrictive and magnetocaloric effects. The aim of the present work was to measure the linear thermal expansion coefficient (LTEC) of some technically important compounds of Nd-Fe-B and Sm-Co systems, as well as to clarify the question about the influence of the residual magnetization by density and thermal expansion of the samples. The materials which are used to create advanced permanent magnets with record values of the maximum magnetic product were investigated. Literature search revealed that the magnetic and structural properties of compounds with neodymium and samarium were studied in sufficient detail, which is impossible to tell of their thermal characteristics [1–5]. The results presented in this paper allow to partially fill the gap.

2 Material, method, and experimental equipment

The experiments were performed on samples of brands N35M, N35H and N35SH for Nd-Fe-B system and YX-18, YX-24, YXG-22, YXG-30 for Sm-Co system. This is hard magnetic materials containing as a main component the crystalline phase of $\text{Nd}_2\text{Fe}_{14}\text{B}$ type and SmCo_5 and $\text{Sm}_2\text{Co}_{17}$ type, respectively. Their technical characteristics are listed in [6, 7]. The specimens of different grades distinguish range of the operating temperatures and the value of the coercive force. The specimens were the shape of cylinders 25 mm long

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and 6 mm diameter with plane base, their protective coating of zinc was mechanically removed before the beginning of the experiments.

The thermal expansion of permanent magnets was investigated using a DIL-402C horizontal dilatometer [8] with holder and pushrod made of fused silica or sintered alumina. The elongation was measured by an inductive linear variable displacement transducer (LVDT) with a resolution better than 1 nm. Two series of experiments for each brand of investigated alloys were carried out in the temperature range 200–750 K for Nd-Fe-B samples and 293–1163 K for Sm-Co samples during heating and cooling at a rate of 2 K/min. The experiments were carried out in helium (99.995 vol. % pure) which was additionally purified by special device of cleaning and drying of inert gases — EPISHUR-A 11 SL [9]. A detailed description of the experimental technique was given in the previous paper [10].

The instrumental error was determined on standard samples of fused silica (for low temperatures) and sintered alumina (for high temperatures). The results were reproduced within 0.2 μm . The systematic error of the LTEC was determined in experiments with samples of high-purity aluminum, copper (99.99 mass % pure) and platinum (99.93 mass % pure). The results showed that the difference between the data obtained in the present work and the reference data of the LTEC [12, 13] doesn't exceed 3%. All experiments were under conditions identical to those of the main experiments with permanent magnets.

Measurement results was given as the temperature dependence of the relative elongation ε of the sample under heating or cooling. The temperature dependence of the LTEC α , and the true LTEC α^* was found by direct numerical differentiation of the raw experimental data on relative elongation [11].

3 Results and Discussion

The experiments were carried out in two stages for each brand: at low and high temperatures. The obtained data were «sewed together» in overlapping regions. The temperatures of the boundaries of the regions were determined from the condition of equality of the LTEC.

Initially for the samples of each brand experiments to determine the temperature dependence of the residual magnetization and finding of maximum working temperature T_{max} were performed. The maximum working temperature was selected so that irreversible change of residual magnetization was not occurred after heating to this temperature and subsequent cooling down to 293 K. The experiments consisted of successive cycles of heating, isothermal holding and cooling of the initially magnetized sample in the dilatometer furnace. The maximum heating temperature was increased for each subsequent cycle, and the magnetic field of the sample was measured in gaps between cycles. Dilatometric experiments with the magnetized samples were carried out at temperatures that did not exceed the maximum working temperature. Thereafter the samples were demagnetized by heating above the Curie temperature (T_C), and measurements of thermal expansion were made in the entire temperature range.

The experiments to determine the maximum working temperature showed a good agreement of this parameter with values declared by the manufacturer [6, 7]. As shown by experiments, the residual magnetization has no effect on the temperature dependence of the thermal expansion. The measurement results are practically identical and at the higher temperatures for magnetized and demagnetized samples. A similar pattern is typical for the experiments with all samples of Nd-Fe-B and Sm-Co brands. Thus it can be concluded, that the magnetostrictive effect is negligibly small for test materials at a temperature to T_{max} .

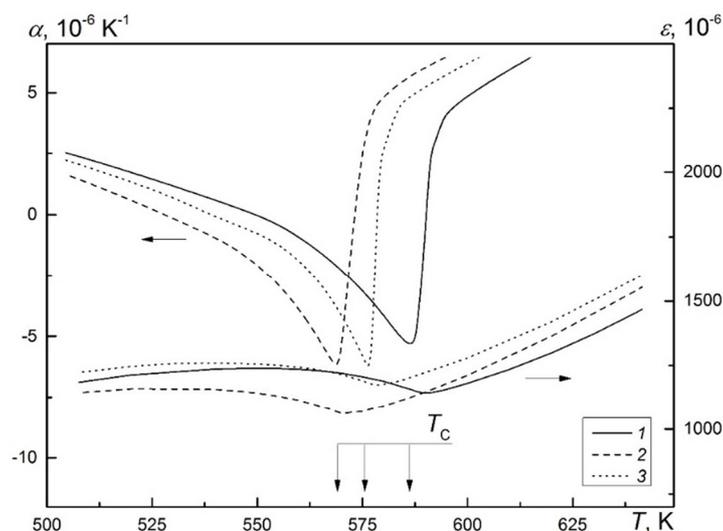


Fig. 1. The linear thermal expansion and the relative elongation of Nd-Fe-B brands in the region of the Curie point. 1 — N35M; 2 — N35H; 3 — N35SH.

Figure 1 shows the thermal expansion results of Nd-Fe-B samples. As can be seen on the dependences $\alpha(T)$, anomalies are observed. Jump is associated with paramagnet-ferromagnet phase transition at the Curie temperature (T_C). The minimum of the LTEC was observed at 586.3, 569.4 and 576.4 K for the brands N35M, N35H and N35SH, respectively.

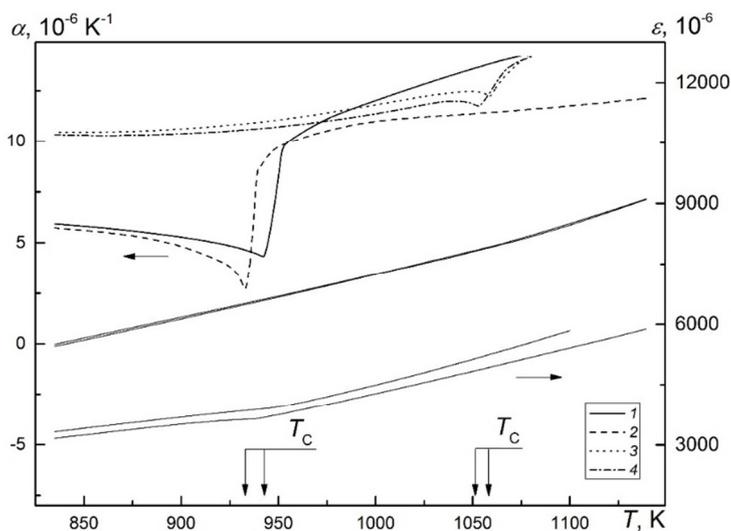


Fig. 2. The linear thermal expansion and the relative elongation of Sm-Co brands in the region of the Curie point. 1 — YX-18; 2 — YX-24; 3 — YXG-22; 4 — YXG-30.

As well as Nd-Fe-B samples, magnetic phase transition for Sm-Co samples at the Curie temperature (T_C) are observed (figure 2). The minimum of the LTEC was observed at 942.4, 932.8, 1059.4 and 1052.6 K for the brands YX-18, YX-24, YXG-22 and YXG-30, respectively.

The data outside the temperature intervals immediately adjacent to the Curie point were fitted by the least-squares method. The treatment in the region of magnetic phase transition was performed by using scaling dependences [14]. A detailed description of the treatment method is given in the work [11]. Table 1 shows the obtained values of the critical exponents α calculated for all investigated samples.

Table 1. The critical exponents of the LTEC for Nd-Fe-B and Sm-Co samples in the region of the Curie point.

Brand	Below the Curie point	Above the Curie point
	α	α
Nd-Fe-B		
N35M	0.5	0.1
N35H	0.5	0.1
N35SH	0.5	0.1
Sm-Co		
YX-18	0.79	1.38
YX-24	0.41	1.61
YXG-22	0.47	0.56
YXG-30	0.53	1.36

4 Conclusion

The experimental data on the linear thermal expansion coefficient of permanent magnets are obtained with high accuracy for the first time. The regions of magnetic phase transitions in detail are studied and the critical exponents at the Curie point are defined. All critical exponents are positive and substantially exceed the critical exponent -0.12 for the specific heat in absolute value. The paper presents recommended data of the thermal expansion, the relative elongation and the critical exponents of the LTEC for Nd-Fe-B and Sm-Co permanent magnets in the region of the Curie point.

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