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Magnetostriction of hard magnetic $Nd_{80}Fe_{20}$ mold-cast rod

R. Sato Turtelli[a,*], C. Bormio-Nunes[b], G. Kumar[c], R. Grössinger[a], J. Eckert[d,c], L. Schultz[c]

[a]*Institut f. Festkörperphysik, Technische Universität Wien, Wiedner Hauptsrasse 8-10, 1040 Vienna, Austria*
[b]*FAENQUIL, Depto de Eng. de Materiais, CP 116, 12600-970 Lorena SP, Brasil*
[c]*Institut für Mettalische Werkstoffe, IFW Dresden, Postfach 270016, D-01171 Dresden, Germany*
[d]*Universität Darmstadt, Petersenstr. 23, D-64287 Darmstadt, Germany*

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Abstract

Results of linear magnetostriction measurements on a $Nd_{80}Fe_{20}$ mold-cast rod applying a field up to 9 T parallel and perpendicular to the axis of the rod are presented. At 4.5 K, the parallel and perpendicular magnetostrictions at an applied field of $\mu_0 H = 9\,\mathrm{T}$ are -366×10^{-6} and -180×10^{-6}, respectively, indicating that the pure Nd crystalline phase formed in $Nd_{80}Fe_{20}$ during the solidification exhibits a crystallographic and a magnetic anisotropy. At 280 K, the $Nd_{80}Fe_{20}$ rod is magnetically isotropic and exhibits a positive magnetostriction of 36×10^{-6}, at $\mu_0 H = 9\,\mathrm{T}$. The magnetostrictive properties are discussed based on the temperature dependence of magnetization and thermal expansion in conjunction with the previously reported results about the microstructure of the same specimen.
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1. Introduction

Understanding of correlation between the structural and hard magnetic properties of mold-cast Nd-rich Nd–Fe and Nd–(Fe,Co)–Al alloys has provided a large stimulus for the research into these materials. Mold-cast $Nd_{80}Fe_{20}$, $Nd_{60}Fe_{30}Al_{10}$, and $Nd_{60}Fe_{20}Co_{10}Al_{10}$ specimens show a similar room temperature coercivity of about 0.4 T [1–4]. The Curie temperature of these mold-cast specimens is in the range of 450–525 K [1–5]. Although, the mold-cast $Nd_{60}Fe_{30}Al_{10}$ and $Nd_{60}Fe_{20}Co_{10}Al_{10}$ rods do not display obvious crystalline peaks in the X-ray diffraction patterns but the high resolution transmission electron microscopy studies

*Corresponding author. Tel.: +43-1-58801-13150; fax: +43-1-58801-13199.
E-mail address: reiko.sato@ifp.tuwien.ac.at (R. Sato Turtelli).

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have revealed the presence of Nd-rich nanocrystals embedded in the amorphous matrix [6,7]. On the other hand, recently Kumar et al. [8] showed the formation of multi-phase microstructure in mold-cast $Nd_{80}Fe_{20}$ rod. The phases were identified as, pure Nd phase and Fe–Nd phase that is further composed of Nd-nanocrystallites embedded in an amorphous matrix. Therefore the temperature dependence of the coercive field and the magnetization of mold-cast $Nd_{80}Fe_{20}$ and $Nd_{60}(FeCo)_{30}Al_{10}$ alloys are similar, indicating magnetic ordering of the Nd-rich phases at low temperatures (20–50 K depending on the composition), resulting in two-phase hysteresis loops at temperature lower than 50 K. Additionally, the hysteresis loops are not saturated even at a maximum applied field of 22 T indicating the presence of a large magnetic anisotropy [3,9–11]. So far it has not been possible to make direct measurements of magnetic anisotropy in the mold-cast $Nd_{80}Fe_{20}$ and $Nd_{60}(FeCo)_{30}Al_{10}$ alloys due to the polycrystalline structure, therefore the lack of magnetic anisotropy data has made difficult to understand the large coercivity in mold-cast $Nd_{80}Fe_{20}$ and $Nd_{60}(FeCo)_{30}Al_{10}$ alloys.

Magnetostriction is one of the basic characteristics of a magnetic material, which can be explained on the macroscopic scale in terms of the stress dependence of the magnetic anisotropy. Generally rare-earth compounds like Nd–Fe and Nd–Co exhibit a large magnetic anisotropy [11]. In our previous work, linear magnetostriction measurements on bulk $Nd_{60}Fe_{20}Co_{10}Al_{10}$ alloy were reported [12]. The magnetostriction of this alloy is always positive, and a large value of 260×10^{-6} was measured at 4.5 K with an applied field of 9 T. In contrary to this, the polycrystalline elemental Nd exhibits a large negative magnetostriction of about -640×10^{-6} at similar temperature and applied field [12].

In the present work, linear magnetostriction measurements on a $Nd_{80}Fe_{20}$ mold-cast rod were carried out with increasing and decreasing field. The investigations were made in the temperature range of 4.5–280 K with a maximum applied field, μ_0H of 9 T. Additionally, the thermal expansion was measured from 4.2 to 25 K. The results are compared with that previously reported for pure Nd and mold-cast $Nd_{60}Fe_{20}Co_{10}Al_{10}$ alloy.

2. Experimental procedure

Mold-cast $Nd_{80}Fe_{20}$ and $Nd_{60}Fe_{20}Co_{10}Al_{10}$ rods of 3 mm diameter and 40 mm length were prepared by casting into a copper mold under argon atmosphere. In this preparation method, a radial solidification may occur in the cylindrical material. The temperature dependence of the thermal expansion and magnetostriction of mold-cast $Nd_{80}Fe_{20}$ and $Nd_{60}Fe_{20}Co_{10}Al_{10}$ rods with a length of 3 mm, and a polycrystalline Nd sample in the shape of a cube with a length of 3 mm were measured using a miniature capacitance dilatometer [13]. The magnetostriction measurements were performed at temperatures between 4.5 and 280 K by applying a field parallel and perpendicular to the long axis of the rod specimen. The measurements were performed during increasing as well as decreasing the field from a maximum of 9 T. The temperature dependence of the thermal expansion was measured between 4.2 and 25 K. The magnetization as a function of temperature at an applied field of 4 T was measured by using a vibrating sample magnetometer (VSM). X-ray diffraction measurements were carried out using a Philips PW 1050 diffractometer with CoKα radiation ($\lambda = 1.7889$ Å). Detailed microstructural studies of the mold-cast $Nd_{80}Fe_{20}$ and $Nd_{60}(FeCo)_{30}Al_{10}$ alloys are reported elsewhere [2,8,12].

3. Experimental results

Fig. 1 shows the field dependence of the linear magnetostriction ($\Delta l/l$) of mold-cast $Nd_{80}Fe_{20}$ rod measured by applying a field parallel and perpendicular to the long axis of the rod. At high temperatures, the total $\Delta l/l$ is positive and at temperatures <27 K, the $\Delta l/l$ is negative, which is similar to the behavior of polycrystalline Nd [12]. However, there is significant difference between the parallel (A in Fig. 1) and perpendicular (B in Fig. 1) magnetostriction values. The parallel magnetostriction is much larger than that of the

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