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Magnetocrystalline anisotropy in $Y(Co_{0.85}Al_{0.15})_2$ with the C15 cubic Laves phase structure

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Abstract. The temperature dependence of the first magnetocrystalline anisotropy constant K_1 has been deduced from the analysis of isothermal magnetization curves $I(H)$ for polycrystalline $Y(Co_{0.85}Al_{0.15})_2$ samples with the C15 cubic Laves phase structure. The magnitude of K_1 is equal to 7.6×10^4 erg cm^{-3} at $T = 7$ K and falls rapidly with increasing temperature. K_1 has a negative sign over the temperature range investigated from 7 to 20 K, i.e. below $T_C = 25$ K. The results of the anisotropy study are used to explain the low-field magnetic behaviour of the $Y(Co_{0.85}Al_{0.15})_2$ alloy.

1. Introduction

For the last two decades, many of the magnetic properties of weak ferromagnetic metals have been extensively studied and analysed in terms of various magnetism models [1–4]. Despite the considerable and growing body of information a number of basic questions concerning both the ground state and the thermal properties remain poorly resolved. One of these is the nature of magnetic anisotropy and its influence on magnetization curves in some crystals of weak itinerant ferromagnets.

In this article we report a study of the anisotropic part of the free energy for $Y(Co_{0.85}Al_{0.15})_2$ with the C15 Laves phase structure. On the assumption of a strictly cubic lattice, the free energy can be expressed in terms of the anisotropy constants $\{K_n\}$ [5]:

$$F = K_0 + K_1 s + K_2 p + \dots \tag{1}$$

where $s = \alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2$, $p = \alpha_1^2\alpha_2^2\alpha_3^2$, and α_1, α_2 and α_3 are the direction cosines of spontaneous magnetization along the cube axes. For $Y(Co_{0.85}Al_{0.15})_2$ we assume that constants beyond the first are much smaller in magnitude than K_1 and that K_n for $n > 1$ can be neglected. Under these conditions we focus our attention on the first anisotropy constant K_1.

The saturation magnetization curve for polycrystalline ferromagnets with cubic symmetry can be well described by the following expression [5, 6]:

$$I = I_0(1 - a/H - b/H^2 - c/H^3) + \chi_p H \tag{2}$$

where I_0 is the saturation magnetization, χ_p is the susceptibility of the paramagnetic process and H is the magnetic field strength. The term a/H is thought to be associated with the local magnetic anisotropy caused by the deformation of the crystal or by the presence of non-magnetic inclusions [5]. On the assumption that in ferromagnetic crystals

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the internal stresses are absent, the parameters b and c are fully determined by the first magnetocrystalline anisotropy constant and saturation magnetization [5, 6]:

$$b = 0.0762 K_1^2 / I_0^2 \tag{3}$$

$$c = 0.0383 K_1^3 / I_0^3. \tag{4}$$

Thus equations (2) and (3) allow us to calculate the magnitude of K_1, which is one of the most important characteristics of ferromagnetic crystals. The sign of K_1 can be determined from equations (2) and (4).

2. Experimental details

Polycrystalline samples of $Y(Co_{0.85}Al_{0.15})_2$ with the C15 Laves phase structure were prepared by arc furnace melting, followed by homogenization annealing at 850 °C for 200 h in an evacuated quartz tube. To avoid the appearance of foreign phases, a 4 wt% excess of Y over the stoichiometric composition was necessary. The phase purity was checked by x-ray and metallographic analyses. No evidence for precipitates of other phases were found in the samples used in the present study.

Magnetic measurements were performed using a vibrating-sample magnetometer in fields of up to 25 kOe. The low-field behaviour of $Y(Co_{0.85}Al_{0.15})_2$ was studied using a SQUID magnetometer at temperatures below 70 K.

3. Results and discussion

To determine the Curie temperature T_C we plot $I(H, T)$ in the form of an Arrott plot (I^2 versus H/I). A characteristic feature of this plot for $Y(Co_{0.85}Al_{0.15})_2$ is that the magnetic isotherms are slightly concave rather than linear although they are almost parallel to each other. The value of T_C determined is 25 K, which agrees with the previously published data [7].

Two methods used to estimate K_1 (a least-squares fitting technique and graphic analysis) led to identical results. The experimental $I(H)$-dependences are expressed very well in the form of (2) in fields of up to 6 kOe. At these fields the effects caused by itinerant metamagnetism [8] in $Y(Co_{0.85}Al_{0.15})_2$ can be neglected. Now we consider the results of a graphic analysis of the isothermal magnetization curve $I(H)$ at $T = 7$ K.

After some algebraic manipulations, equation (2) can be rewritten in the form

$$(1 - I/I_0 + \chi_p H/I_0)H^3 - aH^2 = bH + c. \tag{5}$$

Designating the left-hand side of equation (5) as γ and plotting γ against H, we can calculate the value of b from the slope of the straight part of the $\gamma(H)$ curve (figure 1). The value of c can be determined from the extrapolation of $\gamma(H)$ to zero H. At $T = 7$ K we obtained the following values of the parameters in equation (2):

$$I_0 = 40\ \mathrm{G} \qquad \chi_p = 1.3 \times 10^{-3} \qquad a = 356\ \mathrm{Oe} \qquad b = 2.8 \times 10^5\ \mathrm{Oe}^2. \tag{6}$$

The magnitude of K_1, determined from equation (3), is equal to 7.6×10^4 erg cm^{-3}. As is evident from figure 1, c has a negative sign. This means that the preferred orientation of the

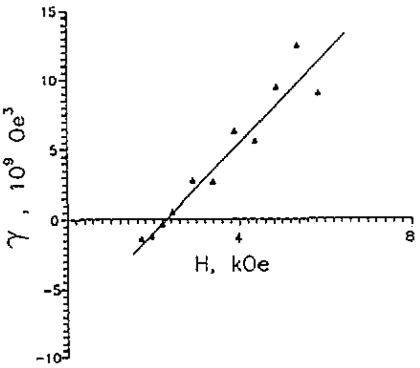

Figure 1. Magnetic field dependence of γ (see text) for a polycrystalline sample of Y(Co$_{0.85}$Al$_{0.15}$)$_2$.

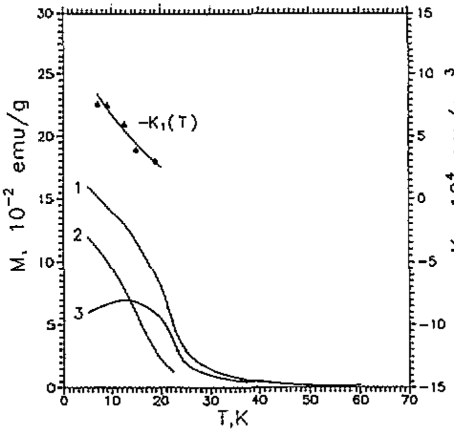

Figure 2. Temperature dependence of the first anisotropy constant K_1 and variation in the field-cooled magnetization M_{FC} (curve 1), zero-field-cooled magnetization M_{ZFC} (curve 3) and thermoremanent magnetization M_{TR} (curve 2) with temperature.

magnetization (in a single domain and in the absence of applied or demagnetizing fields) is for Y(Co$_{0.85}$Al$_{0.15}$)$_2$, as for Ni$_3$Al [9], in the [111] crystallographic direction. Figure 2 shows that the magnitude of $K_1(T)$ falls rapidly with increasing temperature, but K_1 has the same sign over the temperature range investigated from 7 to 20 K.

Now we attempt to use the results obtained to explain the low-field magnetic behaviour of the Y(Co$_{0.85}$Al$_{0.15}$)$_2$ alloy. The lower part of figure 2 presents the results of magnetization measurements at temperatures below 70 K. After preliminary cooling of the sample from 70 to 5 K in a zero field and subsequent measurement in a constant applied field of 20 Oe, a maximum in the $M_{ZFC}(T)$-dependence appears at $T = 10$ K. By cooling the sample in the same measurement field, a maximum does not appear but at 5 K a higher value of magnetization is obtained than in the former case. These differences become less noticeable with increasing field strength. The thermoremanent magnetization $M_{TR}(T)$ falls monotonically with increasing temperature. This is also evidence of a monotonic change in $K_1(T)$. Thus the results obtained allow us to conclude that the presence of a maximum in the $M_{ZFC}(T)$-dependence is caused by a rapid change in the magnitude of K_1, as was observed previously for (Ho,Y)Co$_2$ [10].

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