Journal of Alloys and Compounds 429 (2007) 56–59

Journal of ALLOYS AND COMPOUNDS

www.elsevier.com/locate/jallcom

The correlation between the first magnetocrystalline anisotropy constant K_1 and the composition of giant magnetostrictive alloy Tb–Dy–Fe

Jianchong Wang *, Maocai Zhang, Xuexu Gao, Shouzeng Zhou, Run Wang

State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing 100083, PR China

Received 13 February 2006; received in revised form 5 April 2006; accepted 6 April 2006
Available online 23 June 2006

Abstract

In this paper five *J–H* curves, the magnetic polarization curves, which are come from five *M–H* curves, have been given. From these curves, by using the approaching saturation law, the anisotropy constants of corresponding alloys have been given. And the curve K_1–x has been got. The variation of the curve K_1–x has been discussed.

Keywords: Giant magnetostriction; Anisotropy constant; Approaching saturation law; Terfenol-D

1. Introduction

For giant magnetostrictive alloy Tb–Dy–Fe, the matrix is Laves phase with the structure of cubic $MgCu_2$ (C_{15}), ⟨1 1 1⟩ is the easy and ⟨1 0 0⟩ is the hard. The magnetostrictive anisotropy of Laves phase is very large, $\lambda_{111} = 16.4\lambda_{100}$ [1]. The first magnetocrystalline anisotropy constant K_1 is related with the composition, and largely contributes to the properties of material.

There are two kinds of commercial directional solidification giant magnetostrictive alloy, one has the axial direction of ⟨1 1 2⟩ with the trade name of Terfenol-D [2] and the other has the axial direction of ⟨1 1 0⟩ with the trade name of TDT-110 [3]. The two alloys mainly are applied in low frequency, for example the large power low frequency underwater acoustic transducer and the large power low frequency hypocenter etc. The electrical resistivity of the two alloys is about 5–6 × 10^{-7} Ω m. It is too low to be applied in the high frequency (≥20 kHz). For this kind of alloy, in order to be applied in the high frequency, one of the useful methods is to be made into bonding anisotropic material with axial orientation. We found that, in the same field and in the same organic glue of definite proportion, the orientation and solidification of single-crystal particles of alloy $Tb_xDy_{1-x}Fe_{1.80–1.84}$ is in difference. The result of axial orientation is bad as $x = 0.27$, is good as $x = 0.33$ and is very good as $x = 0.50$ [4]. It indicates that, in the field, the orientation of the Laves phase particles is related with the composition, and the orientation of the single-crystal particles is tightly related with its magnetocrystalline anisotropy. So, it is necessary to study the correlation between the first magnetocrystalline anisotropy constant K_1 and the composition. For alloy $Tb_xDy_{1-x}Fe_y$, in the range of $0.27 \le x \le 0.50$ and $1.80 \le y \le 2.0$, the study about it is not reported.

For the polycrystalline alloy Tb–Dy–Fe, The K_1 can be gained by using the approaching saturation law [5]. From it there is:

$$\frac{dJ}{dH} = J_s\left(\frac{a}{H^2} + \frac{2b}{H^3} + \cdots\right) + x_0 \quad (1)$$

where the item with a cannot be explained by the homogeneous rotation of magnetization vector. It is related to the stress field rounding dislocation. The item with x_0 is, in the super magnetic field of being largely higher than that of technique saturation, generated from the increase of induced spontaneous magnetization. The item with b is related with the first magnetocrystalline anisotropy constant K_1. In a definite range of super magnetic field the curve dJ/dH–$2b/H^3$ is linear. This is the homogeneous rotational stage of magnetization vector. At this stage both the item with a and the item with x_0 can be ignored. In order to gain K_1, in the process of using the approaching saturation law, it is necessary to obtain each rate of slope k. Here the k is $2bJ_s$ in (1).

* Corresponding author. Tel.: +86 10 62334327; fax: +86 10 62333502.
E-mail address: wjchong@sina.com.cn (J. Wang).

0925-8388/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2006.04.012

So

$$k = 2bJ_s \tag{2}$$

According to the literature [5] and (2), the result is:

$$b = \frac{8K_1^2}{105J_s^2} = \frac{k}{2J_s} \tag{3}$$

From (3) there is:

$$K_1 = -\sqrt{\frac{105}{16}J_s k} \tag{4}$$

In the above equations, J_s is the saturated magnetic polarization (Wb/m^2) and k is the rate of slope of linear part of curve dJ/dH–2b/H^3, $K_1 < 0$.

2. Experimental processes

The feed of the experiment is 99.99%Fe, 99.9%Tb and 99.9%Dy. The samples are batched according to the definite composition of $Tb_xDy_{1-x}Fe_y$. In argon atmosphere, the sample is smelted in vacuum non-consumable electric-arc furnace. A sample is repeatedly smelted three in order to homogenize the composition. At 1323 K and with argon atmosphere, the alloy pigs are placed in the vacuum demagnetization furnace for a uniform heat treatment of 12 h. In the furnace the samples are cooled to room temperature. All the samples are analyzed by spectrofluorimetry. The compositions are indicated in the Table 1. Form all of the samples, individually fetching a block with mass between 60 and 90 mg, at the temperature of 300 K and the H range of 0–3979 kA/m (0–5 T), the five initial magnetization curves M–H can be obtained by measuring. The equipment is superconducting quantum interference device (SQUID) magnetometer. The curves M–H have been turned into the curves J–H in Fig. 1. Using the curve J–H and the approaching saturation law, the curve dJ/dH–1/H^3 of each corresponding x has been gained. And each rate of linear part of every curve has been gained. The K_1 has been derived from Eq. (4). Then the correlation curve K_1–x has been gained too.

Table 1
The value of x and y of alloy $Tb_xDy_{1-x}Fe_y$

Number of the alloys	Analytical composition of alloy $Tb_xDy_{1-x}Fe_y$		
	x	$1-x$	y
1	0.269	0.731	1.834
2	0.294	0.706	1.817
3	0.328	0.672	1.837
4	0.365	0.635	1.836
5	0.496	0.504	1.808

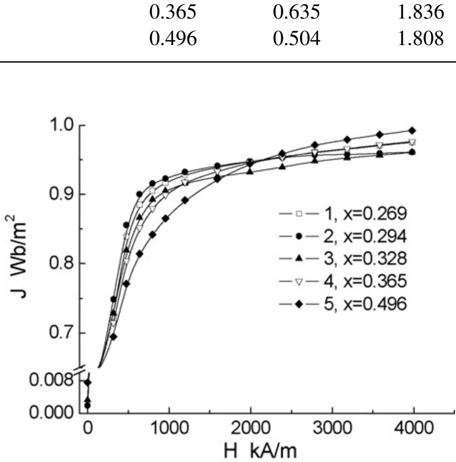

Fig. 1. The magnetization curves of five x.

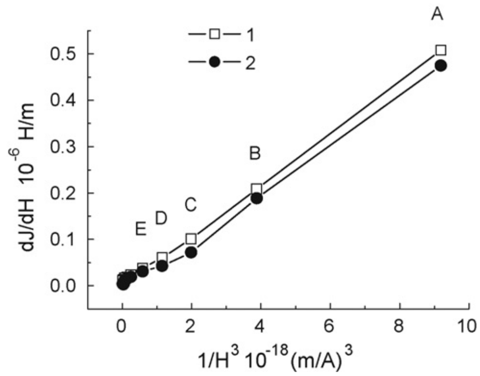

Fig. 2. $x = 0.269$, $x = 0.294$, dJ/dH–1/H^3.

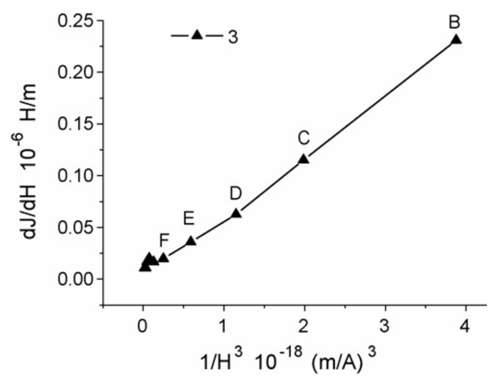

Fig. 3. $x = 0.328$, dJ/dH–1/H^3.

3. Results and discussion

Fig. 1 indicates that, for the five curves, the order of reaching to the saturated state is curve 2, curve 1, curve 3, curve 4, and curve 5. It means near $x = 0.294$, existing a point ε, within $0.269 < x < \varepsilon$, with the increasing of x, the alloy is easier to be magnetized. And within $\varepsilon < x < 0.50$, with the increasing of x, the alloy is more difficult to be magnetized. From Fig. 1, each curve dJ/dH–1/H^3 of alloy $Tb_xDy_{1-x}Fe_{1.80-1.84}$ can be obtained, and each linear part of the curve dJ/dH–1/H^3 located in the high magnetic field also can be obtained individually in Figs. 2–5. The linear part of the curve dJ/dH–1/H^3 of alloys 1 or 2 is part AC in Fig. 2. For the alloy 3 the linear part is BD in Fig. 3. For the alloy 4 the linear part is DF in Fig. 4. For the alloy 5 the

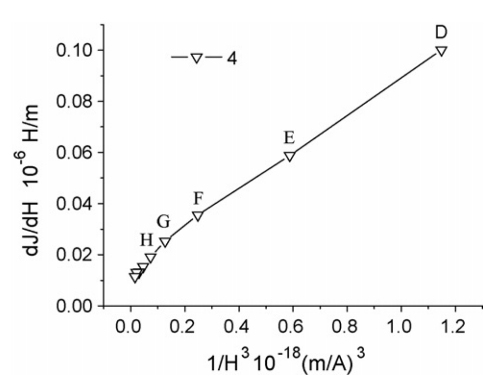

Fig. 4. $x = 0.365$, dJ/dH–1/H^3.