Vol. **113** (2008) *ACTA PHYSICA POLONICA A* No. 1

Proceedings of the CSMAG'07 Conference, Košice, July 9–12, 2007

Influence of V and Cr Substitutions on Magnetic Properties of FeCoNbB Hitperms

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FeCoNbB Hitperm, where 4 at% of Fe are substituted by V or Cr show expected reduction of saturation, slightly lowered magnetostriction and slightly higher coercivity. Despite of significantly larger grain caused by Cr, the coercivity does not increase sharply. Detrimental ambient influences at non-vacuum annealing are not appreciably blocked by V or Cr.

PACS numbers: 75.50.Tt, 75.60.Ej

1. Introduction

The Hitperms present a promising type of rapidly quenched soft magnetic materials to be used at higher induction and working temperature than Finemets [1, 2]. If crystallized to attain the higher saturation, the Hitperms show fine (< 20 nm) grain with bcc structure. Several compositions and substitutions for Fe or Co have been searched [3]. Cr has been reported to lower coercivity in Finemets [4], V is used in crystalline CoFe to improve ductility [1]. Cr and V bind well to oxygen and can thus modify the "native oxide layer" [5] frequently found on air-cast Fe-based ribbons. Various influences of this layer, which transforms at the nanocrystallization annealing, result often in macroscopic heterogeneity (MH) [6]. Generally undesired hard-ribbon-axis anisotropy is the benchmark of the MH in positively magnetostrictive materials whose thermal expansion increases at the structural transformation.

2. Experimental

$Fe_{61}Co_{20}Nb_7B_{12}$ (HP-0) Hitperm was chosen as the base to compare to alloys with V and Cr substituted for 4 at.% of Fe. Thus the composition is

$Fe_{57}Co_{20}M_4Nb_7B_{12}$ (M = V, Cr) labeled here as HP-V and HP-Cr. The amorphous ribbons have been prepared by planar-flow casting method. Strips of 10 cm length, 6–10 mm width and 17–21 μm thickness (calculated from strip dimensions, mass and the as-cast density — 7.82, 7.83, and 7.84 g/cm^3 for the above compositions, respectively) were annealed in vacuum or in Ar at 500°C, 540°C and 580°C for 1 hour. Hysteresis loops were recorded at ac (21 Hz) sinusoidal H excitation in Helmholtz drive coils. Magnetostriction coefficient λ_s was determined from magnetostrictive strain using a capacitive sensor. The longitudinal dilatation measurements were performed at a heating rate 5 K/min under the tension of 3 and 5 MPa (the larger stress for the narrower HP-0 ribbon). The crystalline share A_{cr} and the grain size of the annealed alloys were calculated from X-ray diffraction (XRD) spectra.

3. Results

The most marked difference between the vacuum annealed Cr and V containing Hitperms is the different rate of the increase of saturation (see Table) and coercivity at increasing annealing temperature. If plotted as the variation with the annealing temperature, the basic FeCoNbB alloy shows a convex increase of the saturation and a concave increase of the coercivity, whereas the Cr substituted alloy shows just the opposite — Fig. 1a. The increase of J_s and H_c of the HP-V alloy fits in between the behavior of the other two materials. The HP-V shows the rise of J_s with the annealing temperature quite equivalent to the basic alloy HP-0 whereas the saturation of HP-Cr remains to lag behind despite the largest crystalline share of this material. The behavior of all the three materials annealed in Ar is governed by the MH which brings the hard-ribbon-axis anisotropy — Fig. 1b. Indeed, all the hysteresis loops are more or less slant if compared to the corresponding loops after the vacuum annealing. The reduction of MH as expected of the minor Fe substitution by V and Cr is seen, if at all, on the loops after the 500°C annealing. The

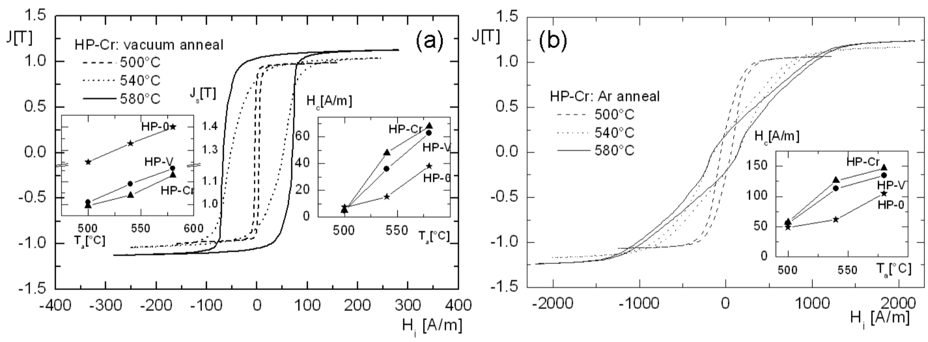

Fig. 1. Hysteresis loops of HP-Cr after the indicated annealing. The different concave and convex variations with annealing temperature T_a are visualized by the left inset for J_s and the right insets for H_c.

TABLE

The parameters of the annealed alloys. λ_s is the saturation magnetostriction coefficient, J_s is the value of magnetization polarization acquired from hysteresis loops at estimated saturation, A_{cr} and D represent the crystalline share and average grain diameter as determined from XRD, respectively.

Alloy	λ_s $\times 10^6$	J_s [T]						A_{cr} [%]	D [nm]
	540°C	500°C		540°C		580°C		580°C	
	Ar	vac	Ar	vac	Ar	vac	Ar	vac	vac
HP-V	13.3	1.01	1.11	1.09	1.18	1.16	1.26	48	20
HP-Cr	11.3	0.98	1.07	1.04	1.17	1.13	1.25	69	50
HP-0	15.3	1.25	1.41	1.33	1.41	1.40	1.42	65	13

loop tilt is clearly less than for the basic HP-0 alloy. However, only minor traces of a crystalline phase are detected after the 500°C annealing in the substituted materials whereas the basic alloy shows already more than 40% crystalline share. The substituting elements, at least Cr, seem to promote a slight increase in the density by the annealing. Vanadium does not prevent the (similarly slight) density decrease at Ar annealing as observed for the basic alloy ($\approx 0.2\%$). However, unlike the most Finemets, all the density changes due to annealing of these Hitperms are very small — below or just about the experimental uncertainty. The longitudinal dilatation curves displayed in Fig. 2 show some minor but interesting differences. HP-0 and HP-V remain slightly elongated when cooled back to room temperature, which could readily be expected as a consequence of the measuring tension and an ensuing modest viscous flow. HP-Cr clearly shrinks. This comes not from a hindered viscous flow (both the substituted alloys are seen to flow somewhat even

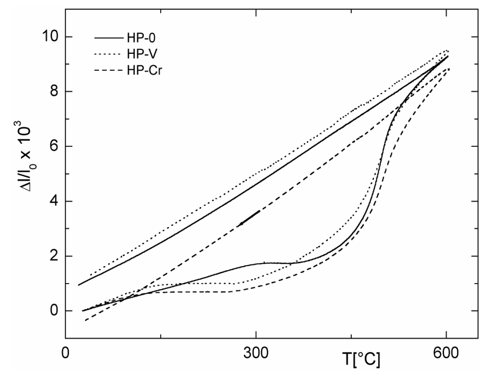

Fig. 2. Longitudinal dilatation measurements for the indicated alloys.

at 600°C) but from significantly larger cool-down shrinkage after crystallization, if compared to the other two alloys. The largest shrinkage of HP-Cr corresponds with the observed largest density rise (0.5% in vacuum, 0.3% in Ar) and also happens together with the largest crystalline share and grain size. The increased thermal expansion (thus shrinkage when cooling down) due to crystallization is essential for MH magnetostrictive effects.

4. Discussion and conclusion

The concave variation of coercivity with the annealing temperature is expected as a consequence of rising grain size D and the frequently quoted D^6 variation [7] after the grain separation decreased enough to enable the intergrain exchange interaction (e.g. [2]). The steadily rising saturation implies that the crystalline share with its high Curie temperature is progressively increasing. The behavior of the HP-V alloy could also be understood in this context — compared to HP-0, it shows larger grain and higher crystallization temperature (thus lower crystalline share, more distant grains). However, the coercivity of HP-Cr with several times the grain diameter of HP-V or HP-0 shows no signs of joining the expected D^6 upswing, rather the contrary. No data now available suggest that this behavior is caused by rising exchange correlation length.

- The grain size is significantly increased, whereas the magnetostriction of partially crystalline alloy is slightly reduced by Cr.
- Although the soft-magnetic properties are not improved by the substituting V and Cr, at least the slightness of the coercivity increase with rapidly growing grain size in HP-Cr deserves further investigation.
- Neither V nor Cr with 4 at.% share help to suppress the MH appreciably.

Acknowledgments

The authors are grateful for partial support by the national grant agency VEGA under grants No. 2/5099/27, 2/5096/27.

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