Influence of H and N insertion on the magnetostriction and thermal expansion of $YFe_{10}V_2Z_x$ (Z = N, H) compositions

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Abstract

Experimental results on the thermal expansion and magnetostriction of $YFe_{10}V_2$ composites are reported and the influence of H and N interstitial atoms is studied. The anisotropic magnetostriction is about 30% larger in the composite than in the starting alloy. Also, the anisotropic magnetostriction remains positive after insertion of H (N) ion while the sign of volume magnetostriction changes by hydrogenation. The anisotropic magnetoelastic interactions are enhanced by insertion of H and especially N interstitial atoms. The results are discussed considering the effect of H and N, and of temperature on magnetic anisotropy and microstructure.
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1. Introduction

$REFe_{12-y}M_y$ (RE is rare earth element or Y and M is V, Ti, Mo, etc.) compounds with simple tetragonal $ThMn_{12}$-type structure are interesting because of their rather high Curie temperature (for instance, 532 K in $YFe_{10}V_2$) and magnetization level [1]. In addition, it is well known that the magnetic properties of these compounds are considerably affected by insertion of interstitial small atoms (e.g. H, N and C), so that some of them (particularly, $NdFe_{10.5}V_{1.5}$) exhibit intrinsic ferromagnetic properties better than those of $Nd_2Fe_{14}B$, the archetype of permanent magnet materials. In this respect, much attention has been paid on the effect of interstitial atoms on the crystallographic structure and magnetic properties of these compounds [1–13]. The purpose of this research is to study the influence of H and N interstitial atoms on the magnetoelastic properties of $YFe_{10}V_2$ compound, which have been rather less considered until now. We made this by measuring magnetostric-

tion and thermal expansion of the polymer-bonded $YFe_{10}V_2Z_x$ (Z = N, H) powders.

The first effect of the insertion of interstitial atoms into $REFe_{12-y}M_y$ compounds is an expansion of their crystallographic unit cell (about 1% and 3% in volume upon insertion of H and N, respectively) [10,11]. Moreover, previous results show that the interstitial atoms occupy 2b crystallographic sites in the $ThMn_{12}$ structure. From a different viewpoint, the second-order crystal field parameter (A_2^o), and accordingly the magnetic anisotropy, is oppositely influenced by donor and acceptor interstitial elements. For example, insertion of the $H^+(N^-)$ enforces the negative (positive) contributions to A_2^o [4,5], so that the planar (axial) magnetic anisotropy is strengthened in the $REFe_{12-y}M_y$ compounds whenever RE is a rare earth element with negative Stevens factor (i.e. $\alpha_j < 0$), such as Nd. But, in the case of the $YFe_{10}V_2$ compound where the Y^{+3} is non-magnetic and Fe-sublattice anisotropy favors c-axis as easy magnetization direction, insertion of H^+ (C^- or N^-) does not modify the easy axis, but weakens the anisotropy [1,11–13]. Briefly, most of magnetic properties of $REFe_{12-y}M_y$ compounds are affected by insertion of

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interstitial atoms. Hence, we expect sensible changes of the magnetoelastic interactions by introducing the interstitial atoms within the $YFe_{10}V_2$ compound. Considering the non-magnetic nature of Y ions, we may assume their contribution as negligible in the following results and attribute them to the effect of H and N on the magnetostrictive strains of Fe sublattice in this family of compounds.

2. Experimental details

$YFe_{10}V_2$ ingots were prepared by high frequency melting of the constituting elements under purified-argon atmosphere. Then, as-cast ingots were enveloped within tantalum foils and annealed for 24 h at 960 °C in a 133×10^{-9} mbar evacuated furnace. After complete removing of the outer oxidized layers by sand paper, the alloys were crushed into powders in alcohol to a size less than 200 μm. The hydrogenation and nitrogenation treatments of powders have been executed in an autoclave for 48 h duration under $P = 6$ and 20 bar pressures and $T = 250$ and 400 °C temperatures, respectively. Phase purity of the powders was assisted by X-ray diffraction (XRD).

For magnetoelastic effects experiments, the homogeneous and isotropic disk-shaped samples (with 8 mm in diameter, 2 mm thickness) were prepared by embedding powders into epoxy resin with the weight proportion of epoxy with respect to alloy powder of 5:100, and then, the mixtures were compacted using 2 GPa pressure. The epoxy resin was fully dried by post-annealing of the compact mixtures at 150 °C for 2 h. No creep has appeared during magnetostriction measurements.

Magnetostriction and thermal expansion are measured by standard strain gage in applied fields up to 1.5 T, and in the temperature range of 77–320 K. The accuracy of these measurements is better than 2×10^{-6}. By measuring magnetostriction parallel (λ_t) and normal (λ_n) to the field direction, the anisotropic ($\Delta\lambda = \lambda_t - \lambda_n$), and volume ($\Delta V/V = \lambda_t + 2\lambda_n$) magnetostrictions were deduced. Thermal expansion coefficients (α) and their average in 80–300 K temperature interval were obtained by calculating slopes of the experimental curves and the corresponding linear fits.

3. Results and discussion

XRD patterns of the prepared samples confirm the tetragonal structure for $YFe_{10}V_2$ with $ThMn_{12}$ symmetry as major phase beside tiny traces of α-Fe as a minor phase. After nitrogenation, increase of the percentage of minor phase is negligible which was expected from low temperature of nitrogenation (400 °C) [6]. But, the XRD pattern shows that the crystallites are partially decomposes after nitrogenation so that only three broadened peaks of the major phase have been appeared in the XRD pattern of the nitrogenated compound. As shown in Table 1, refined lattice parameters of the major phase are consistent with the literature [10–12]. Also, it is clearly seen that the lattice

Table 1
Lattice parameters of $YFe_{10}V_2Z_x$ (Z = N, H) and expansion of the unit cell volume after hydrogenation and nitrogenation

Compound	a (Å)	c (Å)	V (Å^3)	$\Delta V/V$ (%)	α (10^{-5} K^{-1})	
					80 K	300 K
$YFe_{10}V_2$	8.4953	4.7734	344.490	–	1.39	2.96
$YFe_{10}V_2N_x$	8.5543	4.7733	349.291	1.4	1.03	2.91
$YFe_{10}V_2H_x$	8.5097	4.7800	346.143	0.48	1.14	2.69

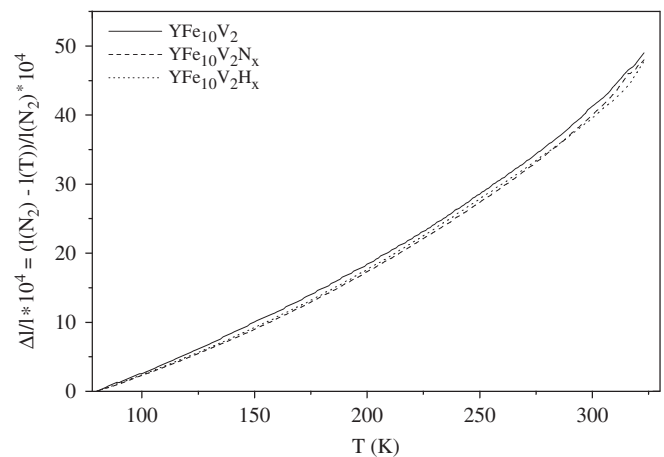Thermal expansion coefficients at 80 and 300 K have also been given.

Fig. 1. Thermal expansion of $YFe_{10}V_2Z_x$ (Z = N, H) composites.

parameters, and accordingly the unit cell volume, increase after insertion of the interstitial H and N atoms. It should be noticed that the lattice parameter refinements of the nitrogenated compound are not so accurate due to low number of the Brag's peaks. From comparison of the volume expansion with the literature and by weighting the samples before and after the gas–solid reactions, the amount of absorbed interstitial elements by metal matrix was estimated to be $x(H) = 1.0$ and $x(N) = 2.1$.

The magnitude of the thermal expansion coefficients (α), deduced from slopes of the experimental curves of the thermal expansion at typical temperatures of 80 and 300 K, is given in Table 1. Experimental curves of the thermal expansion are shown in Fig. 1. As clearly seen from this figure, thermal expansion curves of the Y-based compounds exhibit similar thermal variations, although their average thermal expansion coefficients changes about 10% upon insertion of interstitial atoms. Considering that the magnetic contribution to the thermal expansion of a polycrystalline sample originates from isotropic strictions, this similarity indicates that the H and N insertions do not affect considerably the isotropic magnetoelastic interactions in the $YFe_{10}V_2$ compound.

Fig. 2 shows typical isothermal curves of the anisotropic magnetostriction of the studied samples. It is clear that the anisotropic magnetostriction of all samples is positive.