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Structure and magnetostriction of $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ pseudobinary compounds

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Abstract

The melting behaviour, structure, Curie temperature and magnetostriction of the pseudobinary compounds $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ were investigated. These compounds are essentially single phase with cubic Laves' structure. All these compounds contain a trace of a second phase when $x \leqslant 0.4$. Beyond $x > 0.6$, a non-cubic phase appears. The Curie temperature decreases steadily with increasing x. The maximum magnetostriction exists near $x = 0.1$.

1. Introduction

In general, for industrial application magnetostrictive materials should possess necessarily high strains for a low magnetic field. The pseudobinary cubic Laves' phase compounds have been found frequently with the desired ratio of high magnetostriction to low magnetocrystalline anisotropy required for many practical applications [1]. The magnetostriction of some pseudobinary compounds, *i.e.* $Tb_{1-x}R_xFe_2$ or $Sm_{1-x}R_xFe_2$ ($R \equiv$ Dy, Pr, Ce, Ho), have been investigated [2, 3]. The investigation of the structure and magnetostriction of $R_{1-x-y}R'_xR''_yFe_2$ pseudobinary compounds has not been reported.

In the present investigation, data are presented on the melting behaviour, structure, Curie temperature and magnetostriction of $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ pseudobinary compounds.

2. Experimental procedures

The alloys were prepared initially by melting constituent metals of rare earths and Fe with purities of 99.9% and 99.8%, respectively, in a magneto-controlled arc furnace under a high purity Ar atmosphere. $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ compounds with $x = 0$, 0.1, 0.2, 0.4, 0.6, 0.8 and 0.9 were made. For magnetostriction measurements, the cylindrical polycrystalline samples (Ø10 mm × 20 mm) were made by arc casting in an arc furnace under a high purity Ar atmosphere, and were homogenized at 1150 °C for 5 h under a purified Ar atmosphere.

The phase transition temperatures were determined using the LCP-1 model differential thermal analysis (DTA) apparatus under a purified Ar atmosphere. Alumina crucibles were used. X-ray diffraction analysis and lattice parameter measurements were performed in a D/max-rA X-ray diffractometer with a pyrolytic graphite monochromator. Cu Kα radiation was used. The Curie temperature was assessed in the DSC apparatus.

A narrow, flat surface parallel to the longitudinal axis of the cylindrical specimen was prepared onto which a strain gauge was fixed. The magnetostrictions of the as-cast and annealed specimens parallel and perpendicular to the applied field were measured at room temperature up to 20 kOe.

3. Results and discussion

The melting behaviour of the $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ compounds is shown in Fig. 1. The temperature of complete melting (liquidus) decreases slightly with an increase in the Pr concentration. The melting temperature (solidus) decreases steadily when $x \leqslant 0.4$, dropping drastically and approaching the eutectic temperature at about $x = 0.6$. It then remains practically unchanged with further Pr substitution, implying that some eutectic is formed when $x \geqslant 0.6$. A small amount of eutectic was observed by metallographic examination in these alloys. It was found that, when $x \leqslant 0.4$, annealed

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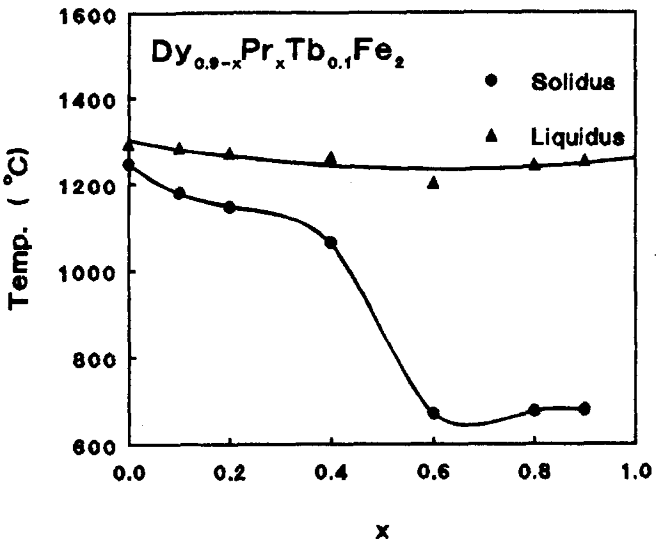

Fig. 1. Melting behaviour of $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$.

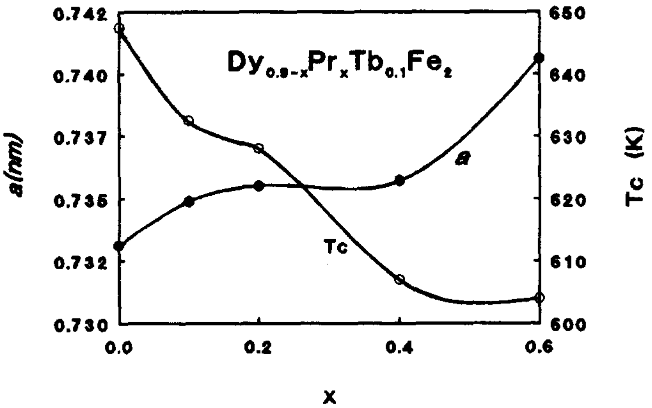

Fig. 2. Lattice parameter a and Curie temperature $vs.$ Pr content of $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$.

$Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ samples are almost a single phase of cubic Laves' structure [(Dy, Tb, Pr)Fe_2] with a trace of $DyFe_3$ or (Dy, Pr, Tb)Fe_3. The lattice parameter and Curie temperature of the (Dy, Tb, Pr)Fe_2 phase as functions of the Pr content are shown in Fig. 2. The lattice parameter a increases appreciably when $x \leqslant 0.1$ and increases slightly in the range $0.1 \leqslant x \leqslant 0.4$; beyond $x > 0.4$ it increases drastically. It seems that the Laves' phase RFe_2 becomes unstable when the substitution of Pr exceeds this concentration. The Curie temperature decreases steadily with increasing Pr substitution (Fig. 2).

The magnetostriction was expressed as the difference between the strains parallel and perpendicular to the applied magnetic field, *i.e.* $\lambda = (\lambda_{\parallel} - \lambda_{\perp})$. The Pr dependences of the magnetostriction λ at room temperature in different applied magnetic fields for four as-cast and annealed $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ polycrystalline specimens are shown in Figs. 3 and 4 respectively. The magnetic field dependences of the magnetostriction λ

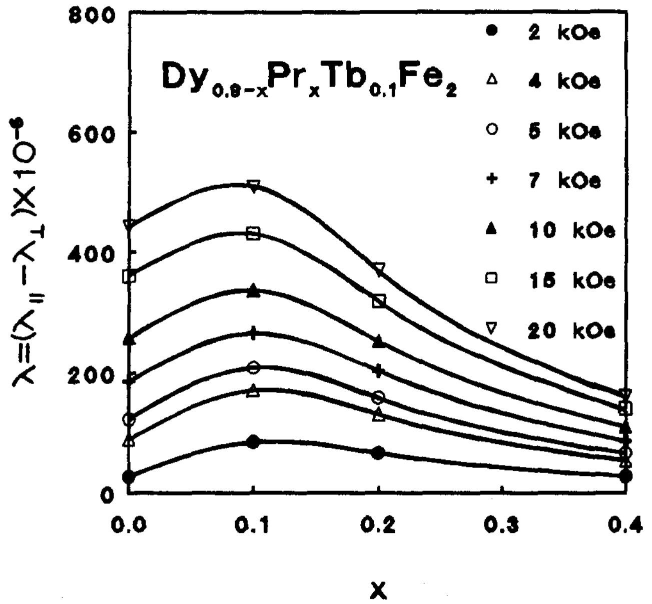

Fig. 3. Pr dependence of magnetostriction λ for as-cast polycrystalline $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ compounds at room temperature ($x = 0$, 0.1, 0.2, 0.4).

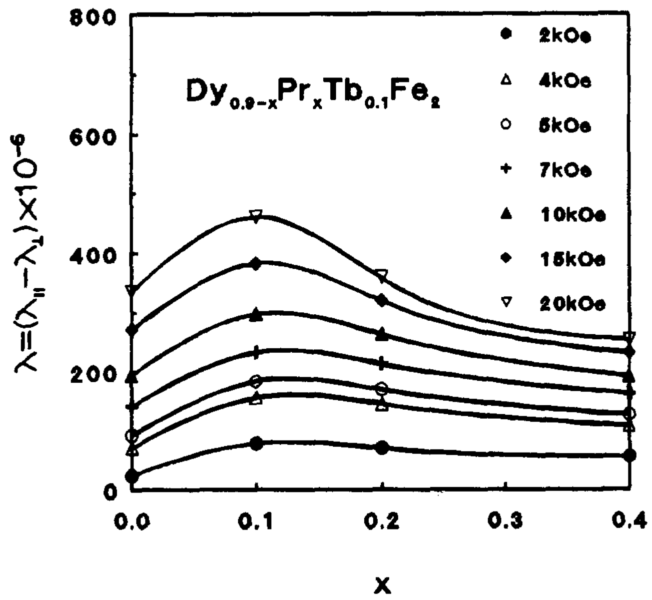

Fig. 4. Pr dependence of magnetostriction λ for annealed polycrystalline $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ compounds at room temperature ($x = 0$, 0.1, 0.2, 0.4).

for these specimens are shown in Figs. 5 and 6 respectively.

It is found that the magnetostriction is affected markedly by the substitution of Pr for Dy. Near $x = 0.1$, the magnetostriction in various applied fields exhibits a peak. It is thought that, because the magnetocrystalline anisotropy is affected strongly by the substitution of Pr for Dy, the domain wall and domain will be much easier to move and/or rotate at this concentration. Clark [2] has come across a similar situation in the $Tb_{1-x}Dy_xFe_2$

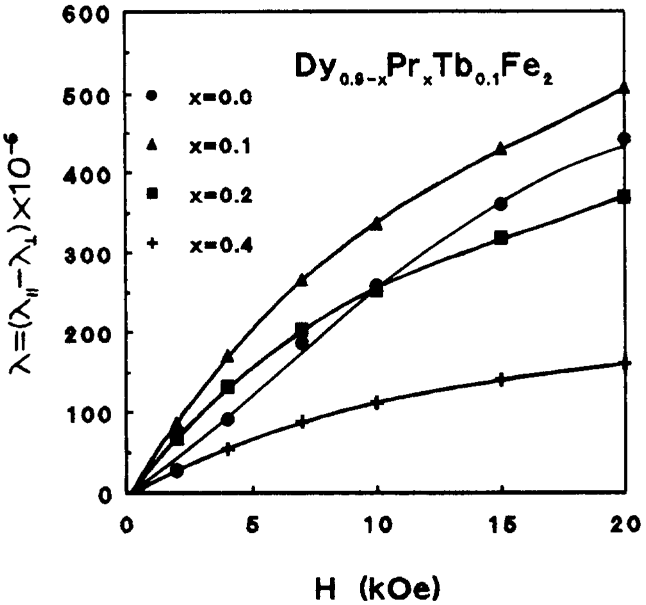

Fig. 5. Magnetic field dependence of magnetostriction λ for as-cast polycrystalline $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ compounds at room temperature ($x=0$, 0.1, 0.2, 0.4).

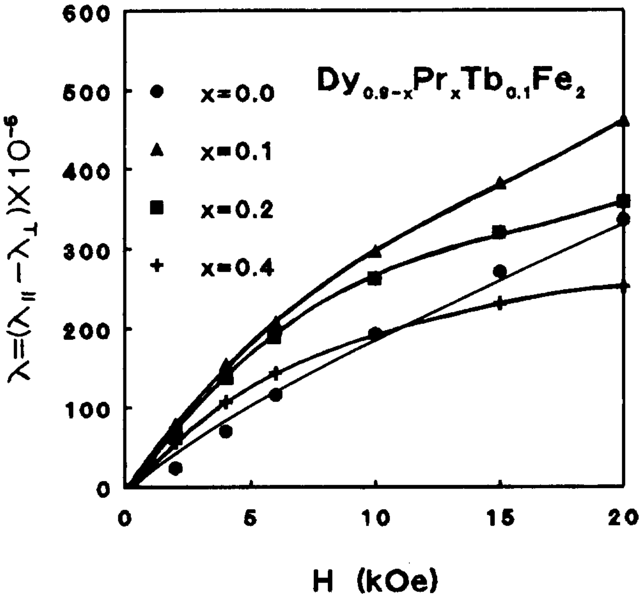

Fig. 6. Magnetic field dependence of magnetostriction λ for annealed polycrystalline $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ compounds at room temperature ($x=0$, 0.1, 0.2, 0.4).

system. The magnetostriction at room temperature in different applied fields of polycrystalline samples of $Tb_{1-x}Dy_xFe_2$ decreases steadily with increasing Dy substitution; however, it increases again at approximately $x=0.6$ and exhibits a peak near $x=0.7$. He argued that the magnetic anisotropy is nearly zero at this concentration. In the present investigation it is found that the magnetostriction of the annealed specimen is smaller than that of the as-cast specimen. X-ray diffraction analysis indicated that the grains of the as-cast sample were oriented preferentially along the [511] and/or [333] directions, as a result of solidification in the cylindrical copper mould 10 mm thick. This preferred orientation was lost after annealing.

4. Concluding remarks

The $Dy_{0.9-x}Pr_xTb_{0.1}Fe_2$ compound series is essentially single phase with cubic Laves' structure when $x \leqslant 0.4$. The cubic Laves' phase structure becomes unstable when $x > 0.4$. The lattice parameter a increases and the Curie temperature decreases with increasing Pr substitution. The magnetostriction is affected markedly by the substitution of Pr for Dy. Arc casting induced a substantial degree of preferred orientation in the cylindrical samples.

Acknowledgments

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