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Magnetostriction Measurements of (Fe–Co)–Mo–Cu–B Alloys with Varying Atomic Fe/Co Ratio

G. Vlasák, D. Janičkovič and P. Švec

Institute of Physics, SAS, 845 11 Bratislava, Slovakia

Amorphous rapidly quenched ribbons of $(Fe–Co)_{76}Mo_8Cu_1B_{15}$ with the ratio Co/Fe = 0, 1/9, 1/6, 1/4, 1/3, 1/2, 1/1 and 2/1 were prepared by planar flow casting. The dependence of the Curie temperature T_C on Co/Fe ratio was determined. Due to the presence of the invar effect it was possible to measure the spontaneous volume magnetostriction in the temperature interval between 300 K and T_C. Field dependences of magnetostriction in parallel and perpendicular directions of applied magnetic field were obtained by direct measurement method. Subsequently, saturation magnetostriction and volume magnetostriction as well as forced magnetostriction were computed. Saturation magnetostriction increases with increasing Co/Fe ratio from 0 up to 17 ppm, depending both on the Co/Fe ratio and on the shift of T_C with composition. The alloy with ratio Co/Fe = 0 exhibits T_C near room temperature, thus field dependences of magnetostriction, corresponding to the dependences of a paramagnetic system are practically linear functions of applied field, corresponding to paramagnetic state.

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1. Introduction

Rapid solidification of some alloys with quenching rates up to 10^6 K/s can improve their physical properties or lead to new and unusual ones. This is the case of e.g. ferromagnetic rapidly quenched alloys with soft magnetic properties. Phenomenological description of the magnetoelastic coupling yields the relation for linear magnetostriction $\lambda(H) = \Delta l/l = (1/3)\omega(H)+(2/3)\lambda_S(H)(\cos^2 \Theta-1/3)+\lambda^F$ with λ_S being the saturation magnetostriction, $\omega(H) = \Delta V/V$ is the volume magnetostriction, λ^F is the bipolar magnetostriction (form effect) and Θ is the angle between the direction of deformation measurement and the direction of the applied magnetic field [1], where $\lambda_S(H) = (2/3)[\lambda_{par}(H) - \lambda_{perp}(H)]$, $\omega(H) = \Delta V/V = \lambda_{par}(H)+2\lambda_{perp}(H)$. The quantities $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ in saturation as well as λ_S can be determined as in [2]. Due to the quantity ω being often not well defined, in technological applications the quantity $\partial\omega/\partial H$ is used instead, denoted as isotropic forced volume magnetostriction.

The present work investigates the effect of composition on magnetostriction of rapidly quenched amorphous $(Fe_xCo_y)_{76}Mo_8Cu_1B_{15}$ alloys. Compositions, where interesting values of linear, saturation and volume magnetostrictions and of forced volume and spontaneous volume magnetostrictions were expected, are reflected in the choice of $y/x = 0$, 1/9, 1/6, 1/4, 1/3, 1/2, 1/1 and 2/1.

2. Experimental

Samples for investigation were prepared in form of 6 mm wide amorphous ribbons by planar flow casting. X-ray diffraction and transmission electron microscopy were used to check the amorphous state of the samples. Measurements of field dependences of linear magnetostrictions λ_{par} and λ_{perp} were performed on discs with 6 mm diameter electrochemically etched from the ribbons using a special device [2].

The dependences λ_{par} and λ_{perp} (external magnetic field applied in the plane of the ribbon along the ribbon axis and in perpendicular orientation, respectively), measured on the Fe–Co–Mo–Cu–B system (Fig. 1) were used to compute the values of linear saturation magnetostriction λ_{S}, the dependence $\omega(H)$ as well as that of forced volume magnetostriction $\partial\omega(H)/\partial H$ (Fig. 2).

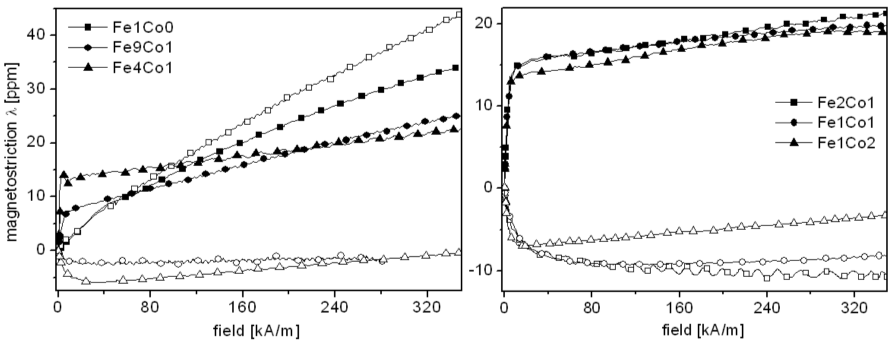

Fig. 1. Field dependence of magnetostrictions $\lambda_{\mathrm{par}}(H)$ and $\lambda_{\mathrm{perp}}(H)$ (full and open symbols, respectively) of $(Fe_xCo_y)_{76}Mo_8Cu_1B_{15}$ for $y/x = 0$, 1/9, 1/4 (left) and for $y/x = 1/2$, 1/1 and 2/1 (right).

In order to determine spontaneous volume magnetostrictions, dilatation as function of temperature was measured on a dilatometer designed for measurements on thin ribbons [3, 4]; sample length was 30 mm. To eliminate the effect of relaxation processes, taking place in certain temperature interval below crystallization, on temperature dependences of dilatation, all samples were subjected to prior relaxation heat-treatment (Fig. 3). The Curie temperature T_{C} was determined from turning point of the temperature coefficient of thermal dilatation, well visible in

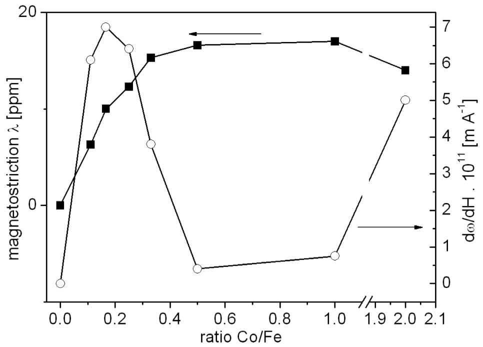

Fig. 2. Compositional dependence of saturation magnetostriction λ_S and forced volume magnetostriction $\partial\omega(H)/\partial H$ of $(Fe_xCo_y)_{76}Mo_8Cu_1B_{15}$ for $y/x = 0$, 1/9, 1/4, 1/2, 1, and 2.

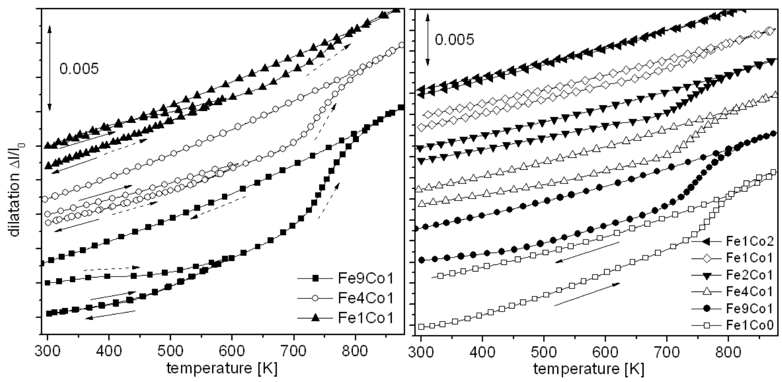

Fig. 3. Left: temperature dependences of dilatation of $(Fe_xCo_y)_{76}Mo_8Cu_1B_{15}$ during cyclic heating-cooling-heating runs (rate 5 K/min, two cycles); first cycle — relaxation annealing (solid arrows), second cycle — crystallization (dashed arrows). Right: temperature dependences of dilatation of relaxed samples (after the first heating-cooling cycle). The curves are shifted vertically for clarity.

ferromagnetic materials with invar effect. Spontaneous volume magnetostriction was determined from these dependences.

3. Results and discussion

The values of λ_S obtained from $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ increase with increasing Co/Fe ratio from 0 to 17×10^{-6}. The values obtained, measured at 300 K, are influenced also by the value of T_C; it can be expected that for the ratio of Co/Fe > 1 the values of the magnetostriction λ_S would exhibit a decreasing character, similarly as in the case of Finemets or Hitperms with higher Co content [5, 6].

Sample with the composition $Fe_{79}Mo_8Cu_1B_{15}$, the T_C of which lies close to room temperature, was measured in this region. At low fields the dependences

$\lambda_{\rm par}(H)$ and $\lambda_{\rm perp}(H)$ are not linear, indicating that the relation $J = \kappa H$ is not fulfilled, i.e. κ (magnetic susceptibility) is not constant; linearity and the validity of the relation is observed for higher H.

Forced magnetostriction $\partial\omega(H)/\partial H$ exhibits a maximum at Co/Fe = 1/9 and a minimum for Co/Fe concentration ratio of 0.3–0.5, indicating a decrease in internal stresses in the amorphous phase. The magnitude of spontaneous volume magnetostriction $\omega_{\rm spon}$ increases with decreasing temperature from $T_{\rm C}$ down to 300 K and probably also further down. Relaxation processes change the bonding between magnetic dipoles. The magnitude of this magnetostriction also increases with increasing Co/Fe ratio, as shown in Fig. 2.

The Curie temperature $T_{\rm C}$ increases with increasing content of Co from $\approx$ 305 K for Co-free alloy up to $\approx$ 525 K for Co/Fe = 0.25. For alloys with higher Co content it is not possible to determine $T_{\rm C}$ by the method used. The process of relaxation and viscous flow of the sample in the vicinity of the glass transition smears out the turning point of the coefficient of thermal dilatation α; furthermore, relaxation processes can lead to formation of different short-range ordered amorphous clusters enhancing the mentioned smearing effect.

4. Conclusions

Magnetostriction measurements show clearly that the ratio of concentrations of Co to Fe in Fe–Co–Mo–Cu–B alloys determines the concentration dependences and values of $T_{\rm C}$, $\lambda_{\rm S}$, $\partial\omega(H)/\partial H$ as well as of the spontaneous volume magnetostriction. The values of $T_{\rm C}$ and $\partial\omega(H)/\partial H$ were determined advantageously from temperature dependences of dilatation.

Acknowledgments

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