Rapid stress annealing dependence of structural and magnetic properties of Fe$_{75-x}$Co$_x$Cu$_1$Nb$_3$Si$_{15}$B$_6$ alloys

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Abstract Structural and magnetic properties of nanocrystalline Fe$_{75-x}$Co$_x$Cu$_1$Nb$_3$Si$_{15}$B$_6$($x = 0, 2, 5$) alloys are reported using magnetic measurements X-ray diffraction, Mössbauer spectroscopy. Results show that: (1) for the specimens with $x = 0$ reveal that the volume fraction of the nanograins and their grain diameter ranges between 56% and 80% and 10 and 18 nm, (2) annealing above 700°C apart from Fe$_3$Si type nanocrystals, magnetically hard Fe$_3$B, Fe$_{23}$B phases also appear, leading to a sharp increase of the coercive field, (3) Co content and applied stress during annealing has considerable effect on relative permeability and stress induced anisotropy, which is perpendicular to the ribbon axis, Mössbauer spectroscopy also suggests changes in spin texture.

Keywords Mössbauer spectroscopy · Magnetic properties · Rapid stress annealing
Nanocrystalline FINEMET-type alloys [1] exhibiting both reduced squareness ratio, losses and linear permeability are especially attractive for applications. Optimized alloy composition and suitable thermal treatments will have effect on the magnetic properties of the nanocrystalline structure, needed for various applications and Co is found to be effective for this purpose [2]. Rapid stress annealing is a fast and convenient way for the production of wound annealed cores displaying different permeability values, high induced anisotropy [3] and improved ductility, highly desirable for applications. In this work we report the influence of rapid stress annealing on structural and magnetic properties of nanocrystalline Fe$_{75-x}$Co$_x$Cu$_1$Nb$_3$Si$_{15}$B$_6$ ($x = 0, 2, 5$) alloys using magnetic measurements X-ray diffraction (XRD) and Mössbauer spectroscopy.

2 Experimental

Ribbons having composition Fe$_{75-x}$Co$_x$Cu$_1$Nb$_3$Si$_{15}$B$_6$ ($x = 0, 2, 5$; 20 μm thick and 10 mm wide) were prepared using a planar flow casting technique. Samples were annealed with/without stress, between 500 and 800°C for 10 s, and the applied stress ($\sigma$) during annealing was between 0 and 280 MPa. Measured Cu $- K_\alpha$ XRD patterns were analyzed by fitting a crystalline and amorphous component using pseudo-Voigt line profile to obtain the Schereer’s grain diameter ($D$), crystalline volumetric fraction ($V_x$). For amorphous phase, first near-neighbor distance between atoms ($X_m$) was obtained using: $X_m = \frac{1.227 \lambda}{2 \sin \theta}$. Hysteresis loops were measured using a computerized quasi-static hysteresis loop tracer. Induced anisotropy constant $K_{\sigma}$, is derived from hysteresis curves. Permeability was measured using impedance meter. Transmission Mössbauer spectra were recorded at room temperature in a constant acceleration mode, using $^{57}$Co:Rh source; fitted with overlapping of amorphous and crystalline components using NORMOS program [4].

3 Results and discussions

Representative XRD patterns (for specimens with $x = 0$ and $\sigma = 0$) were obtained after annealing at 660°C, 700°C and 750°C reveal that the $V_x$ ranges between 56% and 80% whereas their average grain diameter ranges between 10 and 18 nm. XRD confirms the formation of Fe$_3$Si nanocrystals up to annealing at 700°C, and annealing at 750°C leads to the formation of magnetically hard boride phases (Fe$_3$B, Fe$_{23}$B). Annealing (no stress) temperature dependence of coercive field ‘$H_c$’ is shown in Fig. 1. Annealing up to 700°C the studied alloys exhibit soft magnetic behavior. Annealing temperatures higher than 700°C, a sharp increase of the $H_c$ in all the studied alloys is ascribed to the appearance of hard magnetic Fe–B phase as confirmed by XRD measurements.

Figure 2 depicts the variation of relative permeability after rapid stress annealing as a function of stress and inset of Fig. 2 shows the variation of induced anisotropy as a function of applied stress. Perusal of Fig. 2 shows that, relative permeability monotonically decreases with increase of the stress during annealing treatment. It is