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Stress annealed CoFeNbB alloy : A structural study

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ABSTRACT

Article presents the influence of Nb content on structural properties of stress annealed $Co_{21}Fe_{64-x}Nb_xB_{15}$ (x = 3, 5, 7) alloys has been studied using differential scanning calorimetery, in-situ length change measurements during annealing and x-ray diffraction. Results show that, increase of Nb content in the alloy increases the stability of the alloy against crystallization and is also responsible for higher elongation of the specimens. Crystallization leads to the formation of bcc Fe-Co nano-granular phase containing Co up to 38 % and affects the spin texture.

1. INTRODUCTION

Stress annealing of magnetic materials is known to induce significant uniaxial magnetic anisotropy. In materials consisting of α-Fe type nanoparticles dispersed in an amorphous matrix, this treatment can result in a strong anisotropy. In FINEMET type alloys (FeSiBNbCu), the stress induced anisotropy is perpandicular ($K_U<0$) to tensile stress direction [1] and strong (~10 $J.m^{-3}MPa^{-1}$) whereas Co substitution truns it to longitudinal direction ($K_U>0$) for 20 to 50% Co substituted to Fe [8]. The sign of uniaxial anisotropy coefficient is generally the same as that of the magnetostriction coefficient of the nanograins However, for some alloys (FeZrB NANOPERM or 80% Co substituted FINEMET) the direction of the anosotropy is opposite to expectations [2]. It seems that this phenomenon is linked to the viscous behaviour of the amorphous phase in the supercooled liquid region, i.e., between the glass transion and crystallisation temperatures (T_g and resp. T_X). To go insight this problem, it is necessary to study alloys with different T_X-T_g values. The influence of Nb content on structural properties of stress annealed $Co_{21}Fe_{64-x}Nb_xB_{15}$ (x = 3, 5, 7) alloys has been studied using differential scanning calorimetery (DSC), in-situ length change measurements during annealing and x-ray diffraction (XRD).

2. EXPERIMENTAL DETAILS

Ribbons of nominal composition $Co_{21}Fe_{64-x}Nb_xB_{15}$ with x = 3, 5, 7 (about 20 μm thick and 10 mm wide) were prepared using a planar flow casting technique on copper wheel. First crystallization peak temperature (T_{X1}) was determined using DSC measurements performed at a heating rate of 20 ^oC/min. Specimens were annealed at 450, 500 and 550 ^0C with applied stress of 200 MPa for 1 h in the protective atmosphere of flowing Ar. The elongation (ΔL) of the 1 m long ribbons was measured during annealing by means of a Linear Variable Differential Transformer. Recording of ΔL and temperature was performed using a PC linked GPIB standard card as a function of time at a rate of 1 point/s during the whole thermal treatment (heating at 10 K/min, plateau at T_A, cooling at 10 K/min). Cu-K_α XRD measurements were done at room temperature, and were analyzed using pseudo-Voigt line profile to obtain lattice parameter (a) and average grain size (D) and the volume fraction of the nanograins (V_x). Transmission Mössbauer spectra were recorded at room temperature, using ^{57}Co:Rh source.

3. RESULT AND DISCUSSION

T_{X1} for samples with x = 3, 5 and 7 are respectively 408, 442 and 475 ^{0}C, showing that increase of Nb content increases the stability of the alloy against crystallization. Figure 4 shows the elongation (ΔL) for $Co_{21}Fe_{64-x}Nb_xB_{15}$ during the same annealing cycle. Perusal of figure 4 shows that, higher the Nb content in the alloy higher is the elongation of the alloy.

T_{X1} for samples with x = 3, 5, and 7 are respectively 408, 442 and 475 °C, showing that increase of Nb content increases the stability of the alloy against crystallization. Fig. 1 shows the elongation (Δl) for $Co_{21}Fe_{64-x}Nb_xB_{15}$ during the annealing cycle (mentioned above). Perusal of Fig. 4 shows that, higher the Nb content in the alloy higher is the elongation of the alloy. T_g is deduced from the plot of dl/dt, which is the viscous flow speed. Below T_g, this speed is small and equal for all samples (0.5 mm/min). After correction of the thermal dilatation (~ 5×10^{-6} K^{-1}), the constant viscosity (~ 0.5×10^{-12} Pa.s) is attributed to short range ordering [3].

Maximum flow speed was 60 mm/min for x=7% and the viscosity felt down to 4·10-9 Pa.s at 500 °C. The higher elongation is observed for the same sample due to the increase of crystallization temperature, enhancing the super cooled liquid region. It is important to note that application of stress modifies the total free energy of the metastable amorphous phase resulting in a lower Tg compared to measurements performed by DSC.

XRD data shows that the crystallization of the specimens starts after annealing at 450 ^{o}C with 200 MPa stress (except for the specimen with x= 7, where crystallization starts after annealing of the specimen after 500 ^{o}C) showing a co-existence of the crystalline phase and the residual amorphous matrix.

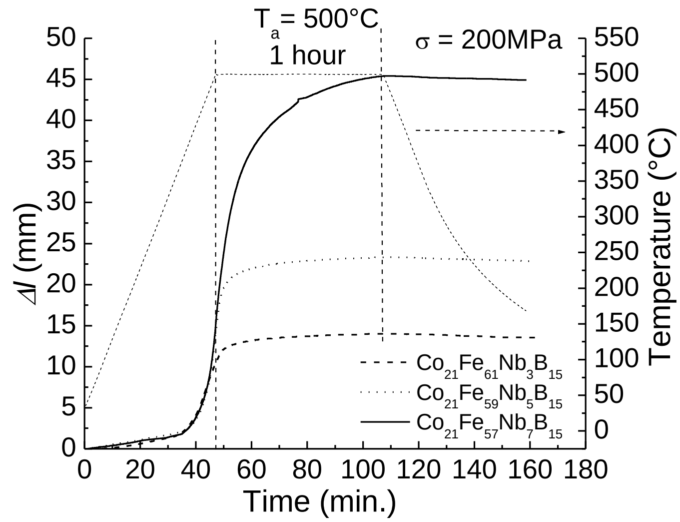

Figure 1: Elongation (ΔL) for $Co_{21}Fe_{64-x}Nb_xB_{15}$ alloys after annealing at 500 ^{o}C

Table 1 depicts the Scherrer's crystallite size (D), lattice parameter (a) and volume fraction of the nano-grains (V_x) obtained by fitting the XRD data. In the early stage of crystallisation (450°C), lattice parameters are rather high which suggests the precipitation of bcc Fe nano-granular phase with rather low Co content (15%) and a substantial lattice expansion that can be due to the presence of Nb solute atoms. As the annealing temperature increases, lattice parameters become consistent with bulk values and indicate a Co content of 15 - 20%, 30%, and 35% for x=3, 5, and 7 respectively. As Nb content in the specimen increases, for same annealing temperature 'D' is systematically smaller for the sample containing higher Nb content. Vx shows similar behavior for the studied samples. Behavior of D and Vx can be understood in terms of increase of T_{X1} values with increase of Nb content in the alloy.

Table 1: Thermodynamical (T_X, T_g) and structural (*a*, *D* and V_x) parameters for stress annealed $Co_{21}Fe_{64-x}Nb_xB_{15}$ specimens.

Nb (at.%)	T_X/T_g (°C)	Ann. Temp (°C)	ΔL (mm)	a (nm) ± 0.0001	*D* (nm) ± 2	V_x (%) ± 2
3	408 342	450	10.4	0.2869	30	45
		500	14.1	0.2867	35	55
		550	17.9	0.2867	38	55
5	442 384	450	12.9	0.2870	15	15
		500	13.4	0.2869	16	45
		550	27.2	0.2864	15	60
7	475 397	450	10.7	-	-	-
		500	45.4	0.2862	10	25
		550	>50	0.2862	15	55

4. CONCLUSION

In conclusion, higher Nb content in the alloy increases the stability of the alloy against crystallization and is also responsible for the obtained higher elongation of the alloy through the enhancement of the super cooled liquid region. Crystallization of the studied alloys affects their spin texture in the amorphous matrix showing that higher the elongation, the more spin texture is out of plane.

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