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Influence of Low Temperature Annealing on the Magnetic and Structural Properties of $\mathrm{Fe}_{61}\mathrm{Co}_{10}\mathrm{Y}_8\mathrm{W}_1\mathrm{B}_{20}$ Alloy

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In alloy materials, the onset of crystallization temperature (T_x) is treated as the threshold of structural stability. In amorphous materials, this threshold is the temperature above which heterogeneous crystalline grains begin to appear. However, in amorphous materials, frozen nuclei of the crystalline grains also come into existence during the production process. These nuclei have a strong influence on the properties of the amorphous materials. The growth of the nuclei of the crystalline grains is possible even below the crystallization temperature, and maintaining control over their size allows the application properties, for example the magnetic properties, to be controlled. In this paper, the influence of two-stage isothermal annealing (below the crystallization temperature) on the structure and magnetic properties of $\mathrm{Fe}_{61}\mathrm{Co}_{10}Y_8W_1B_{20}$ alloy was investigated. Samples of the material were prepared in the form of plates, and subjected to thermal treatment at temperatures of 700 K and 770 K, for 1 and 3.5 hours, respectively.

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1. Introduction

At present, various industries are conducting searches for new functional materials which possess specific parameters and properties. One of these classes of materials is that of ‘amorphous alloys’, which exhibit structures completely different from those of commonly used crystalline materials [1]. The single-phase structure, with short-range interactions, is responsible for the excellent properties exhibited by these materials [1-4]. In addition to the very promising values of their mechanical parameters, exceeding those observed for crystalline materials, amorphous materials with the specific chemical composition possess good magnetic properties: ‘soft’ or ‘hard’. The amorphous materials based on FeCoB alloy (with soft magnetic properties) form a group of alloys intensively investigated for potential applications in the energy industry [2-4]. It has to be mentioned that, in these materials, improvement of the soft magnetic properties may be achieved by thermal treatment, leading to structural relaxation [4-6].

In this paper, the results are presented for the investigation of the microstructure and magnetic properties of the $\mathrm{Fe}_{61}\mathrm{Co}_{10}Y_8W_1B_{20}$ alloy. This alloy was subjected to thermal treatment at temperatures of 700 K and 770 K for 1 and 3.5 hours, respectively.

2. Experimental details

Samples of the investigated $\mathrm{Fe}_{61}\mathrm{Co}_{10}Y_8W_1B_{20}$ alloy were made in the form of plates of thickness 0.5 mm; the injection casting method was used for this process. The components used for production had following purities: Fe – 99.99 at.%; Co – 99.99 at.%; Y – 99.99 at.%; W – 99.999 at%. The boron content was introduced to the alloy in the form of $\mathrm{Fe}_{45.4}B_{54.6}$ alloy. The obtained samples were investigated by the means of the X-ray "Bruker Advance D8" diffractometer with (CuKα) lamp and "S/TEM TYTAN 80-300 FEI" electron scanning microscope. The prepared samples were scanned in a 2θ scattering angle range from 30° to 100° with step of 0.002° and exposure time of 5 s. Images of the structure obtained from the HREM were taken after ion polishing of the laminated structure. The magnetic properties of the investigated alloys were measured using a "LakeShore" vibrating sample magnetometer (VSM). The samples used during X-ray and VSM measurements were in the powder form, obtained by a low-energy milling process. In the case of the VSM measurements, this allowed the elimination of effects related to the sample shape; for XRD measurements, information from the whole volume of the sample was obtained.

3. Results and discussion

The X-ray diffractometry patterns obtained for the investigated samples (in the as-cast state and after isothermal annealing at the temperatures of 700 K for 1 h and 770 K for 3.5 h) are presented in Fig. 1a; these patterns were found to consist of only wide, broad maxima, typical for amorphous materials [1, 4]. The amorphicity of the investigated samples of $\mathrm{Fe}_{61}\mathrm{Co}_{10}Y_8W_1B_{20}$ alloy (after isothermal annealing) was confirmed by HRTEM imaging (Fig. 1b), which showed short-range ordering between atoms.

Thermal stability of the alloy was determined using differential scanning calorimetry (DSC). DSC measurements confirmed the good glass-forming ability (GFA) of the alloy (Table I).

Static hysteresis loops obtained for the investigated samples in the as-cast state and after isothermal annealing are shown in Fig. 2. The magnetic parameters: satu-

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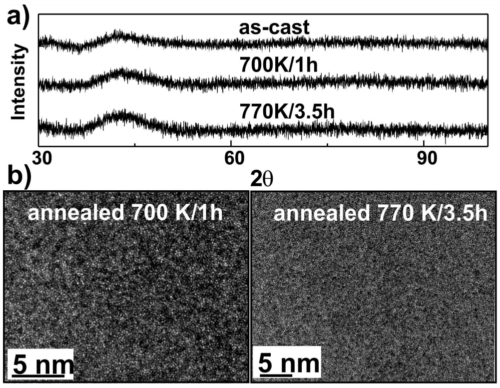

Fig. 1. (a) X-ray diffractometry patterns and (b) images obtained by HRTEM for the samples of the investigated alloy.

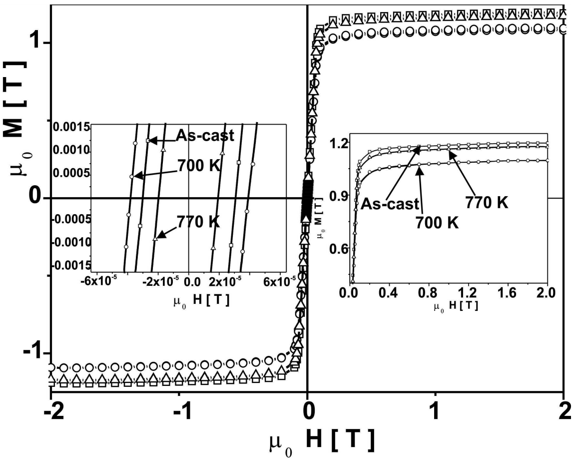

Fig. 2. Static hysteresis loops.

ration magnetization ($\mu_0 M_S$) and coercive field (H_c), are assembled in Table II.

Deterioration of the soft magnetic properties after the first stage of the thermal treatment could be connected with creation of conglomerates of point defects such as quasidislocational dipoles (D_{dip}) [7, 8]. The larger defects present in the material, obstruct the movement of domain walls under the influence of an external magnetic field, which is associated with the increase in coercive field H_c [9, 10]. After annealing at the temperature of 770 K for 3.5 h, these defects, due to their unstable nature, started to separate into a number of smaller defects. Simultaneously with the decrease in the size of the defects, the magnetic properties of the alloy started to improve. In this case, the distances between the atoms are decreasing, and longer annealing time supports migration processes. This leads to re-grouping of atoms towards configuration of the basic elementary cell of the initially-appearing crystalline phases, which in the case of the investigated amorphous alloy are α-Fe or α-FeCo. This state is related with structural relaxation of the alloy and improvement in the interactions between pairs of atoms Fe-Fe and Fe-Co, and, as a result, with increasing $\mu_0 M_s$ and decreasing H_c.

TABLE I

T_g – the glass transition temperature, T_x – crystallization onset temperature, ΔT_x – supercooled liquid range, T_{rg} – reduced glass transition temperature, γ – glass-forming ability parameter.

Composition	T_g (K)	T_x (K)	ΔT_x (K)	T_{rg}	γ
$Fe_{61}Co_{10}Y_8W_1B_{20}$	929	972	43	0.78	0.41

TABLE II

Magnetic parameters obtained from the analysis of the static hysteresis loops.

Composition	Sample	$\mu_0 M_S$ (T)	H$_c$ (A/m)
$Fe_{61}Co_{10}Y_8W_1B_{20}$	As-cast	1.19	24
	700 K / 1 h	1.09	31
	770 K / 3.5 h	1.17	19

4. Conclusions

The injection casting method allowed the production of amorphous samples in the form of plates of thickness 0.5 mm. Isothermal annealing at temperatures below the crystallization temperature of the alloy has not created crystalline grain nuclei. The first stage of the annealing process, at the temperature of 700 K for 1 h, has not produced an improvement of the soft magnetic properties of the alloy. The second stage of the thermal treatment at the temperature of 770 K for a longer time of 3.5 h, resulted in an increase in the $\mu_0 M_s$ value and decreases in the values of the coercivity.

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