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MAGNETIC PROPERTIES OF THE Fe-BASED AMORPHOUS ALLOYS

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The labile amorphous phase in Fe-based amorphous alloys passes to a metastable equilibrium state through a series of transformations, which are realized, in the first place, due to a change in the compositional (chemical) and topological (geometrical) short-range order of stacking of atoms and a decrease in the free redundant volume. Compositional ordering is connected with the possibility of rearrangement of the nearest neighboring atoms. Its characteristic feature consists of thermal reversibility, which manifests itself in the restoration of values of the Curie points under conditions of a cyclic change in the annealing temperature. Topological changes in the structure of amorphous alloys induce irreversibility of the magnetic properties of specimens, which is connected with a decrease in the fluctuations of local density in the course of annealing.

Keywords: magnetic properties, amorphous alloys based on Fe.

1. Introduction

Since the synthesis of a ferromagnetic Fe–P–C amprphous alloy in 1967, it has ben found that some ferromagnetic Fe- and Co-based amorphous alloys exhibit good soft magnetic properties.

Metalloid atoms form strong bonds with metal atoms and so they should have a considerable influence on the properties of amorphous ferromagnetic alloys. For metallic glasses it was found that the magnetic properties such as saturation magnetization (and magnetic moment), Curie temperature [1] and also mechanical properties such as for example density, microhardness [2] change significantly with metalloids content.

Young's modulus for example for the $Co_xSi_5B_{95-x}$ system increases linearly with the increase of metalloid (B+Si) content [3, 4]. It has been also found that changes of Young's modulus are nearly twice as large when metalloid elements are replaced in the alloys with fixed metal concentration ($Co_{70}Si_yB_{30-y}$) than during replacing metallic element with fixed concentration of one metalloid ($Co_xSi_5B_{95-x}$). It is worth stating that for low Si contents value of Young's modulus change slower than for higher Si contents.

Probably for low Si content silicon atoms fit better into the Co–B amorphous structure (higher density) than for higher Si content (lower density). Young's modulus is a very sensitive parameter to the compositional short range order which probably changes from Co_3B to $Co_3(Si, B)$ type. Linear saturation magnetostriction decreases with higher Si content. Also magnetic moment and Curie temperature have the same and all these parameters are lower for Co–Si–B than for Co–B alloys [5, 6]. This can be explained assuming that the presence of Si atoms which have larger size than B atoms increases the inter-atomic distance of Co-Co pairs.

Magnetic properties of amorphous alloys yield to changes during heating below the recrystallization temperature due to instability of their structure. One of research methods used for investigations of these instabilities is the measuring of magnetic permeability and permeability disaccommodation of amorphous ribbons because these quantities are sensitive to structural changes, too.

For example, magnetic permeability of $Co_{70.3}Fe_{4.7}Si_{15}B_{10}$ alloys and its disaccommodation in weak magnetic fields depend on the kind of heat treatment applied [7, 8]. Magnetic permeability of specimens heated at 580 K for 1 h without external magnetic field increases 6 times with respect to the specimens in as-quenched state. Heating in magnetic field parallel to the specimen axis almost does not change the permeability of specimens, where as heating at 680 K improves the permeability only 2 times.

For specimens tested there occurs the disaccommodation band of magnetic permeability within the temperature range 280–480 K that consists of two parts at least which maxima are at temperatures 350 K and 420 K. The intensity of this band maximum depends on the kind of heat treatment applied.

Two models of structure relaxators responsible for the magnetic after-effects in amorphous alloys are discussed at least [9–14]. However, the precise description of the relaxation mechanism responsible for the observed phenomenon requires further investigations.

All this results are presented for Co-based alloys, but in this article are showen investigation of the magnetic properties of the Fe-based amorphous alloys.

2. Experimental details

In the form of a tape amorphous alloys $Fe_{73,1}Cu_{1,0}Nb_{3,0}Si_{15,5}B_{7,4}$; $Fe_{78,5}Ni_{1,0}Mo_{0,5}Si_{6,0}B_{14,0}$ was obtained by melt-spinning method (10^6 K/s) on a copper cooling rotating drum. For such amorphous metallic ribbons identify contact (c) and external (e) sides, which are characterized by different physico-chemical properties. Some samples were dispersed in a powder.

The phase magnetic analysis of the alloys was carried out using a vibration magnetometer, which provided the recording of the specific saturation magnetization (σ_s) in the temperature range from 77 K to 1000 K at the magnetic field strength of 800 $kA \cdot m^{-1}$.

3. Results and discussion

As a result of the comparison temperature dependence of the relative saturation magnetization of the amorphous alloy $Fe_{73,1}Cu_{1,0}Nb_{3,0}Si_{15,5}B_{7,4}$ in the form of a tape and a similar powder composition (l<0,1μm), it was found that when heated with a rate of 10 K/min in the case of a tape material, a bimodal peak appears within the range (806÷838) K with a total area of 22 r.un. This testifies to the initial formation of an unstable magnetic phase $(FeNb)_3B$ (σ_T/σ_0 = 0,22, T_n = 806 K), which, with further heating, passes into $(FeNb)_{23}B6$ (σ_T/σ_0 = 0,29, Tn = 838 K). On magnetograms of a powder-like amorphous alloys, only one peak in the region of lower temperatures (726÷843) K appears (Fig. 1), and the course of the dependence $\sigma_s = f(T)$ until the paramagnetic zone is achieved in both cases is similar (Fig. 1).

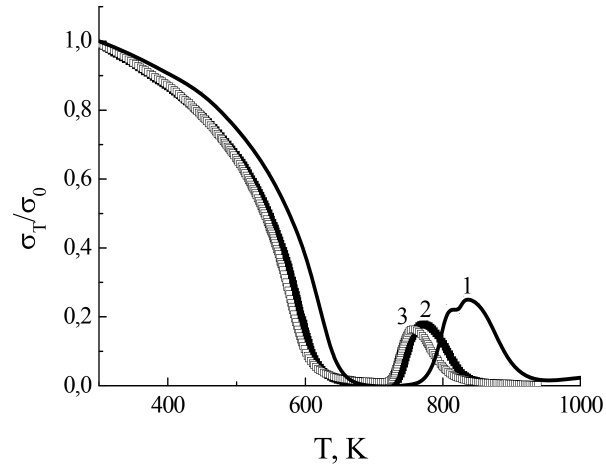

Fig. 1. Temperature dependence σ_T/σ_0 of $Fe_{73,1}Cu_{1,0}Nb_{3,0}Si_{15,5}B_{7,4}$ at v = 10 K/min: 1 – ribbon; 2 – powder, 3 – powder at v = 30 K/min.

The increase of the heating rate of the powdered alloy to 30 K/min does not make a significant change in the dependence of $\sigma_s = f(T)$ in general, except that the peak area of the ferromagnetic phase increases. Due to the previous annealing of amorphous powder to 940 K in a magnetic field the ferromagnetic phases are not recorded on a thermomagnetic graph (Fig. 2). Consequently, the milling of the alloying tape to particles of less than 0,1 μm, as well as the local half-width of the temperature, obviously somewhat limits the domain space and their three-dimensional motion. The initial value of the specific magnetization (σ_0) for almost all forms of the AMS varies around 138±1 $A \cdot m^2 \cdot kg^{-1}$. However, as a result of the heating with a constant magnetic field (H = 800 kA/m), the formation of the magnetic phase in the powder is already observed in the lower temperature interval (ΔT_l) than in the amorphous metallic alloys tape.

It was found (Fig. 3) that freezing the amorphous metallic alloys sample at the temperature of the liquid nitrogen (T = 77 K) does not affect its magnetic properties.

The presence of microscopic regions, whose sizes are measured in nanometers, and the probability of the formation of intermediate states of the same size at the change in temperature allow reducing the magnetization processes up to microscopic regions regardless of the ambient magnetic matrix. As a result of such properties of the amorphous alloy its magnetic susceptibility is stabilized.

Relative magnetization is close to unity, the Curie temperature, to 400 K. The formation of the magnetic phase occurs in the interval 500–700 K, regardless of prior exposure at T = 77 K. The temperature dependence of the ordering and magnetization showed that in the precooled samples an inhibition of crystallization occurred at the subsequent heat treatment.

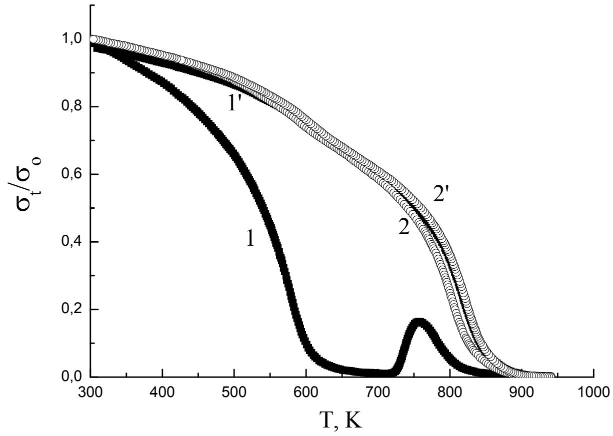

Fig. 2. Temperature dependences of relative saturation magnetization of alloy $Fe_{73,1}Cu_{1,0}Nb_{3,0}Si_{15,5}B_{7,4}$, measured at heating (1, 2) and cooling (1', 2') initial (1, 1') and preliminary annealed to 940 K (2, 2'). Speed of heating and cooling 30 K/min.

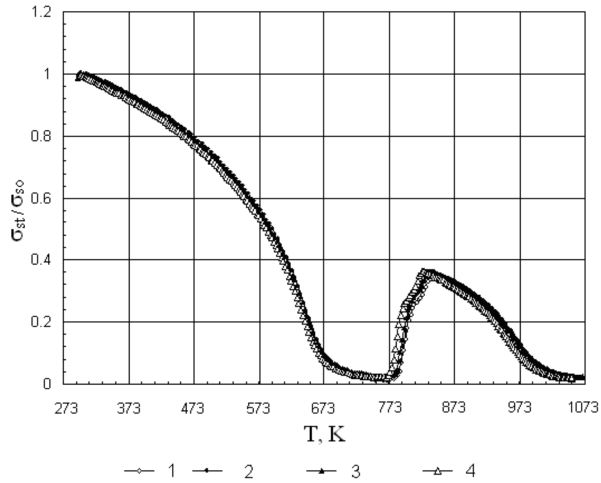

Fig. 3. Thermomagnetograms (H = 800 $kA \cdot m^{-1}$) of (1) the initial amorphous alloy $Fe_{78,5}Ni_{1,0}Mo_{0,5}Si_{6,0}B_{14,0}$ and (2–4) prior exposured samples (2–4) at T = 77 K. (T) Temperature (K). Preincubation time (hours): (2) 0,5; (3) 2,0; (4) 3,0.

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РЕЗЮМЕ

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МАГНІТНІ ВЛАСТИВОСТІ АМОРФНИХ МЕТАЛЕВИХ СПЛАВІВ

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Лабільна аморфна фаза у Fe-вмісних аморфних сплавах переходить до мета-стабільного рівноважного стану через серію перетворень, які реалізуються, в першу чергу, внаслідок зміни композиційного (хімічного) та топологічного (геометричного) ближнього упорядкування атомів і зменшення вільного простору. Композиційне упорядкування пов'язане з можливістю перестановки найближчих сусідніх атомів. Його характерною особливістю є теплова оборотність, що проявляється у відновленні значень точок Кюрі за умов циклічної зміни температури відпалу. Топологічні зміни в структурі аморфних сплавів викликають незворотність магнітних властивостей зразків, що пов'язано зі зменшенням коливань локальної щільності в процесі відпалу.

Ключові слова: магнітні властивості, аморфні сплави на основі Феруму.

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