Investigation of the Structure and Magnetic Properties of Bulk Amorphous FeCoYB Alloys

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The paper presents the results of structural and microstructural studies for the bulk Fe$_{65}$Co$_{10}$Y$_5$B$_{20}$ *and* Fe$_{63}$Co$_{10}$Y$_7$B$_{20}$ *alloys. All the rods obtained by the injection casting method were fully amorphous. It was found on the basis of analysis of distribution of hyperfine field induction that the samples of* Fe$_{65}$Co$_{10}$Y$_5$B$_{20}$ *alloy are characterised with greater atomic packing density. Addition of Y to the bulk amorphous* Fe$_{65}$Co$_{10}$Y$_5$B$_{20}$ *alloy leads to the decrease of the average induction of hyperfine field value. In a strong magnetic field (i.e. greater than* 0.4H_C*), during the magnetization process of the alloys, where irreversible processes take place, the core losses associated with magnetization and de-magnetization were investigated.*

Keywords: bulk amorphous alloy, Mössbauer spectroscopy, the total power loss, eddy current loss

Since the discovery of amorphous alloys many new multi-component Fe materials have been reported [1-33]. The excellent glass forming ability (GFA) of these alloys and the possibility of production in the form of thick tapes or cores at quite low annealing cooling rates are best examples of their good properties [34-41]. Amorphous alloys in the room temperature state exhibit good thermal stability of their structure and magnetic properties. This is caused mainly due to the irreversible loosening of the structure which occurs during the production process. Many of iron based amorphous alloys can be characterized by excellent soft magnetic properties [42-53]. Those are especially interesting materials from both scientific and application point of view. Amorphous alloys are metastable in their nature and tend to the crystalline state for obtaining their minimum energy. This thermal instability depends both of their chemical composition and on the production parameters as well. It is known that this effect (structural relaxations) is connected with irreversible displacement of atoms near vicinities. The relatively low cooling rate during preparation using the suction/injection casting with radial cooling methods is responsible for their structure relaxations, which often leads to higher atom packing density in respect to the ordinary amorphous alloys.

In amorphous alloys there are structural defects (which can be described using methods and researches presented in [55, 56]) ie free volumes and pseudo-dislocating dipoles, which are the source of internal stresses [57-59]. Structural defects that are the source of long-range stresses are centres that inhibit the motion of the domain walls during magnetisation of amorphous material. Those alloy centres, that block the movement of the domain walls are influencing the parameters of the hysteresis loop. One of such parameters is the loss of demagnetization. Total losses P_t for magnetization in magnetic materials consist of three main components: hysteresis losses (P_{his}), eddy current losses (P_{cl}) and additional losses (P_{exc}) [59-62]:

$$P_t = P_{his} + P_{cl} + P_{exc} \qquad (1).$$

In the amorphous alloys there are also no defects like in crystalline materials, which also leads to small losses of hysteresis. These materials due to the small cross-section of the samples and high electric resistance also show slight losses on the vortex currents. The additional losses that occur in the pattern are primarily associated with migration-type relaxation [59, 61]. Due to the fact that in the amorphous alloys there is a very complex domain structure, the loss analysis only allows to establish the relationship between the alloy microstructure and the core losses on demagnetization.

This paper presents the results of structural, microstructural and magnetic properties studies for bulk Fe$_{65}$Co$_{10}$Y$_5$B$_{20}$ and Fe$_{63}$Co$_{10}$Y$_7$B$_{20}$.

Experimental part

Computational details

Studied alloys Fe$_{65}$Co$_{10}$Y$_5$B$_{20}$ and Fe$_{63}$Co$_{10}$Y$_7$B$_{20}$ were made using injection casting method. Ingots of these alloys were obtained by melting the components of high purity (Fe – 99.99% at, Co – 99.98% at, Y – 99.98% at., boron was added as a Fe$_{56.4}$B$_{43.6}$ compound) using arc melting, in the argon atmosphere. The obtained alloy samples were subjected to X-ray diffraction using BRUKER's ADVANCE 8 diffractometer. The apparatus was equipped with a cobalt X-ray lamp. The study was conducted in the 2θ angle ranking from 30 to 120° with measurement step 0.02° and one step time of 5s.

Microstructure of alloys was investigated using the POLON mössbauer spectrometer. Source of ã radiation was cobalt isotope ^{57}Co In the Rh matrix of activity 50 mCi and half-life time 270 days. The NORMOS program was used for analysis of transmission Mössbauer spectra. This software (made by R. A. Brand) enables the decomposition of experimental spectra into component spectra and determines the distribution of induction of superfine fields P(B). Distribution of induction of hyperfine fields on the ^{57}Fe was determined according to the Hesse-Rübatsch method, treating the experimental spectrum as the sum of elemental sextets:

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$$T(v) = \int_0^\infty P(B) L_6(B, v) dB \qquad (2)$$

where:

P(B)is a distribution of induction of the hyperfine field,

L_6(B,v) - is elementary Zeeman sextet,

v - is the relative velocity of the source to the absorbent.

From the distribution of induction of hyperfine fields, the mean value of induction of the hyperfine field was determined. When matching these Mössbauer spectra of amorphous alloys, a linear relationship between the isomeric shift and induction of the hyperfine field (B_{hf}) [63].

$$IS(B_{hf}) = IS(B^0_{hf}) - \alpha(B_{hf} - B^0_{hf}) \qquad (3)$$

where:

(B^o_{hf}) - minimal value of induction of superfine field

α - linear fitting factor.

Total losses are determined from the hysteresis loop without separation for hysteresis losses, vortex currents and additional losses. The obtained results of the loss measurements were presented as a function of the maximum logarithmic induction and as a function of the frequency of the magnetizing field

Results and discussionsa

Figure 1 shows the X-ray diffraction images of the samples in the form of a rod in a state after solidification.

The X-ray diffraction patterns for investigated samples are typical for amorphous materials; consist only of a broad peak at an angle $2\theta \approx 45^o$.

In order to prove amorphous structure additionally were done Mössbauer effect studies. The transmission Mossbauer spectra and corresponding hyperfine field induction distributions for investigated alloys are presented in figure 2.

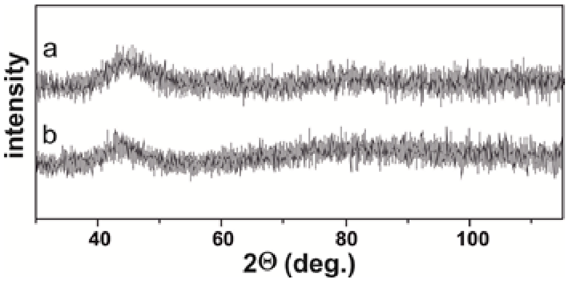

Fig. 1. X-ray patterns obtained for investigated samples: a) $Fe_{65}Co_{10}Y_5B_{20}$, b) $Fe_{63}Co_{10}Y_7B_{20}$ in the as- quenched state

The Mossbauer transmission spectrum consists of Zeeman sextets with wide overlapping lines. This is due to structural fluctuations occurring in the amorphous state. In addition, there is a slight asymmetry of the line in these sextets, depending on the chemical composition of the alloy. According to Le Caer and Dubois'a [64] This asymmetry is mainly due to anisotropy of the hyperfine field in the material. The superfine induction distributions obtained from the Mossbauer spectra for the alloys studied are not symmetric, indicating the presence in the sample of areas with different concentrations of iron atoms. For the alloys studied, the value of the mean hyperfine field was determined to 22.79 T for $Fe_{65}Co_{10}Y_5B_{20}$ alloy and 22.08 T for sample $Fe_{63}Co_{10}Y_7B_{20}$. A slightly higher value of the mean induction of the hyperfine field indicates a higher packing density of the atoms due to the reduction of free volumes for the sample with less yttrium content.

In figure 3 the dependence of magnetic susceptibility on amplitude of the magnetizing field (a, c) and total loss on demagnetization as a function of maximum induction (b, d) for amorphous massive amorphous was presented.

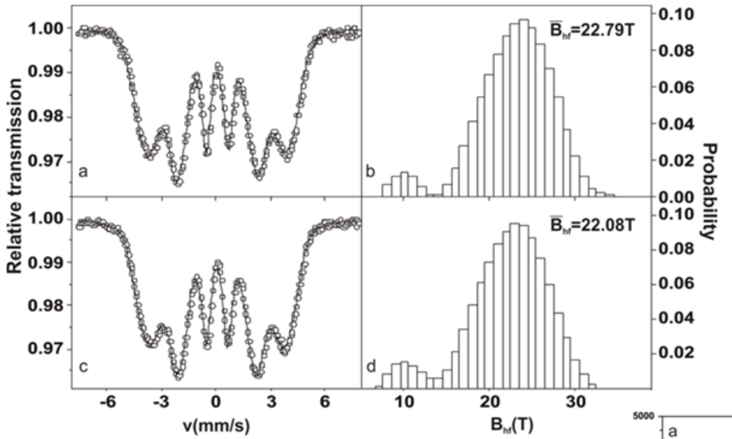

Fig. 2. Mössbauer spectra (a, c) and corresponding hyperfine field induction distributions (b, d) for $Fe_{65}Co_{10}Y_5B_{20}$ (a, c), $Fe_{63}Co_{10}Y_7B_{20}$ (b, d) alloys after solidification

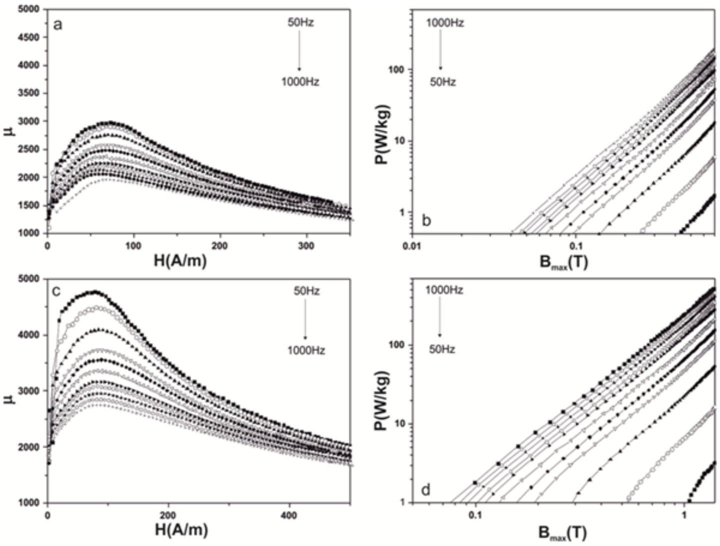

Fig. 3. Dependence of the magnetic susceptibility on the amplitude of the magnetic field (a, c) and core losses in function of maximum induction (b, d), for bulk amorphous alloys: $Fe_{65}Co_{10}Y_5B_{20}$ (a, b), $Fe_{63}Co_{10}Y_7B_{20}$ (c, d)

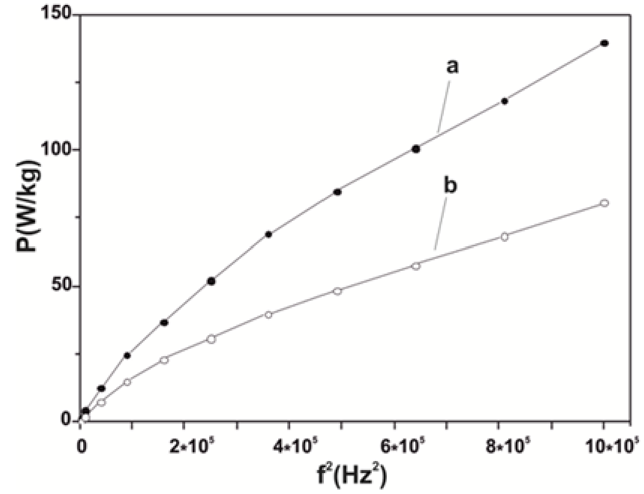

Fig. 4. Core losses in function of frequency squared for: a) $Fe_{65}Co_{10}Y_5B_{20}$ and b) $Fe_{63}Co_{10}Y_7B_{20}$

At a frequency of 50Hz the permeability of the alloy sample $Fe_{65}Co_{10}Y_5B_{20}$ is about 3000, while for the alloy $Fe_{63}Co_{10}Y_7B_{20}$ it is about 4800. With a further increase in the amplitude of the magnetizing field the magnetic susceptibility decreases. The value of the total loss of magnetization for the investigated alloys is comparable to that of classical Fe-Si alloys. Core losses for demagnetization in a function of squared magnetizing field are show in figure 4.

In the figure shown we see an increase in total losses along with the square of the frequency of the magnetizing field. Nonlinear dependence $P(f^2)$ indicates that there are additional losses in the sample [65]. These losses may result from one or more processes and are related to magnetic delays. The magnetic delay can be caused by, among others. with diffusion of interstitial atoms or caused by thermal fluctuations. In soft magnetic materials, these fluctuations may allow the wall of the domain to pass through the energy barrier.

Conclusions

The structure of the alloys in the as-quenched state was investigated by means of X-ray diffractometry. It was confirmed that the samples were amorphous. The Mössbauer transmission spectra of the examined specimens consist of broad asymmetric overlapping lines, what is typical for spectra achieved for amorphous materials. It was found on the basis of analysis of distribution of hyperfine field induction (B_{hf}) that the samples of $Fe_{65}Co_{10}Y_5B_{20}$ alloy are characterised with greater atomic packing density as compared with $Fe_{63}Co_{10}Y_7B_{20}$ specimens. This is confirmed by greater value of the average induction of hyperfine fields (average B_{hf} = 22.79 T for $Fe_{65}Co_{10}Y_5B_{20}$ alloy, and average B_{hf} = 22.08 T for $Fe_{63}Co_{10}Y_7B_{20}$ alloy). The increase in B_{hf} value can be related to the topological ordering of structure.

Stronger magnetic fields (>0.4Hc) cause the irreversible magnetizing processes and the magnetic hysteresis loop is observed, its area being the measure of loses due to reorientation of magnetization. These loses are related to the irreversible processes of magnetization reorientation, which are influenced by centres retarding movement of domain walls. It was concluded on the basis of the carried out examinations that the investigated amorphous rods exhibit larger losses due to reorientation than thin amorphous ribbons, what is related to their lower electric resistance due to their significant thickness. This involves larger losses resulting from eddy currents. It was found that beside the losses due to magnetic hysteresis and eddy currents, also additional losses occur during magnetization of alloys, being related mainly to the relaxations due to atomic migration. It should be stressed that the mechanism of magnetization reorientation is more complex in amorphous alloys than in magnetically soft Fe-Si alloys, and the strict relation between the magnetization losses and the domain structure is difficult to establish. Creation of additional domain walls or annihilation of some existing ones can occur during the magnetization reorientation

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