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The Influence of Heat Treatment on the Magnetic Properties of the Alloy $Fe_{62}Co_{10}Y_8B_{20}$ Produced by the Injection Suction Casting Method

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The paper presents studies of annealing effect on the magnetic properties of the bulk $Fe_{62}Co_{10}Y_8B_{20}$ alloy in the form of rods. The thermal treatment was performed at the temperature well below the crystallization temperature. Structure, revealed by X-ray diffraction and Mössbauer spectroscopy and magnetic properties in high magnetic fields in the $Fe_{62}Co_{10}Y_8B_{20}$ alloy after fabricated and after the annealing were studied. We have stated that the investigated alloy was fully amorphous. It is due to the stress relieving of the sample. Using a vibrating sample magnetometer the magnetization in high magnetic fields was studied. For both the sample after solidification and after heat treatment, the magnetization process in the area called "the approach to ferromagnetic saturation" is affected by free volumes. In addition, the heat treatment improved the magnetic properties and increased the packing density of atoms.

topics: bulk amorphous alloys, injection suction casting, the approach to ferromagnetic saturation

1. Introduction

The bulk Fe-based amorphous alloys are relatively a new group of materials [1–3]. The properties of these alloys depend mainly on their chemical composition, but also on their structure. There are two types of structure defects in amorphous materials. One-dimensional defects, so-called free volumes or point defects, play a similar role in amorphous materials as vacancies in crystalline materials, while two-dimensional defects (quasidislocational dipoles) can be compared to linear defects present in crystalline materials [4–6]. By using heat treatment, we can change the structure and thus affect the magnetic properties of these materials. Heating the material below its crystallization temperature only causes the structure to relax. As a result of structure relaxation, the atoms are rearranged and the structure is unified [7–9].

In this work, the effect of heat treatment on microstructure and magnetic properties in strong magnetic fields for $Fe_{62}Co_{10}Y_8B_{20}$ alloy was examined.

2. Materials and methods

The amorphous rods have been obtained by an injection suction casting method in a protective argon atmosphere. The structure and microstructure of the samples was studied by X-ray diffractometry and the Mössbauer spectroscopy. The magnetization under the influence of strong magnetic fields was measured using a vibrating sample magnetometer. The results of the magnetic investigations, carried out using strong magnetic fields, were interpreted according to the Kronmüller theorem [10, 11]. All investigations were carried out for the samples in the as-quenched state and after annealing at 700 K for 35 min in vacuum. The aim of the thermal treatment was only to relax the structure, and not to crystallize the sample.

3. Results

Figure 1 shows X-ray diffractograms for the bulk $Fe_{62}Co_{10}Y_8B_{20}$ alloy in as-solidified state (Fig. 1a) and after heat treatment at 700 K/35 min (Fig. 1b).

In the X-ray diffraction patterns narrow maxima characteristic of the crystalline phase did not occur. Only the broad maximum characteristics of the materials with amorphous structure were visible.

The Mössbauer transmission spectra and corresponding hyperfine fields distributions for the tested alloy in solidified state and after heat treatment at 700 K/35 min are presented in Fig. 2.

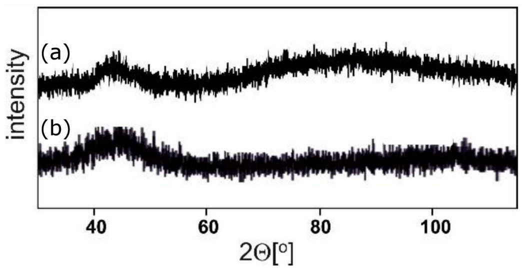

Fig. 1. X-ray diffraction images for the bulk $Fe_{62}Co_{10}Y_8B_{20}$ alloy after solidification (a) and after heat treatment at 700 K/35 min (b) [12].

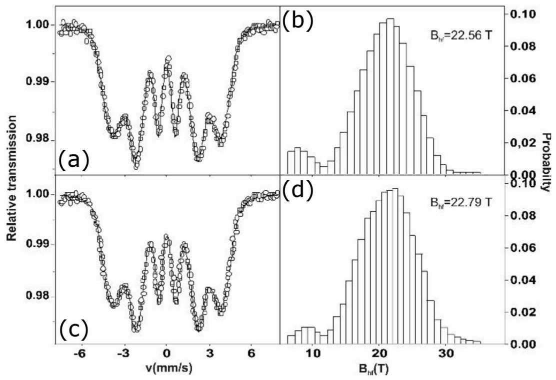

Fig. 2. Mössbauer transmission spectra(a, c) and corresponding hyperfine fields distributions(b, d) for the bulk $Fe_{62}Co_{10}Y_8B_{20}$ alloy after solidification (a, b) [12] and after heat treatment at 700 K/35 min (c, d).

Transmission Mössbauer spectra (Fig. 2a,c) consist of the Zeeman sextets with wide overlapping lines, which is caused by structural fluctuations occurring in the amorphous state. In the Mössbauer spectrum (Fig. 2b) of the heat-treated sample, no additional narrow lines indicating the presence of the crystalline phase were observed. Distribution of the hyperfine fields induction obtained from the Mössbauer spectra (Fig. 2b,d) was asymmetrical, which indicates the presence in the sample of areas with different iron concentrations. In the case of alloy after heat treatment, a slight increase in the average hyperfine field induction is visible. This indicates an increase in the packing density of atoms due to a decrease in free volumes.

Figure 3 presents static hysteresis loops measured for the examined alloy after solidification (a) and after heat treatment (b).

For both samples, the shape of the static hysteresis loop is typical for ferromagnetic materials with soft magnetic properties. The alloy after annealing exhibits the higher value of saturation magnetization and lower values coercivity: 1.25 T and 38.20 A/m for sample in the as-quenched state and 1.34 T and 22.71 A/m for the sample after annealing. We can conclude that the heat treatment

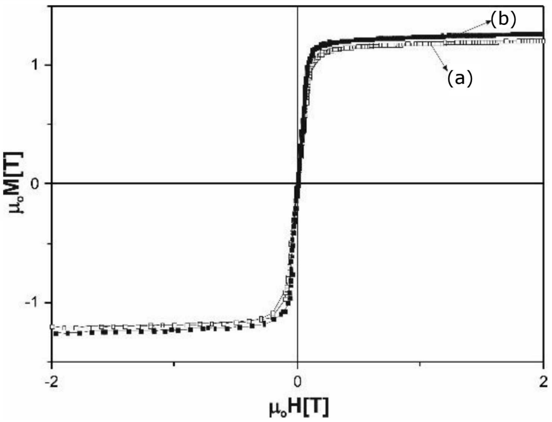

Fig. 3. Static hysteresis loops pertaining to the investigated alloys: in the as-quenched state (a) [12], and after annealing (b).

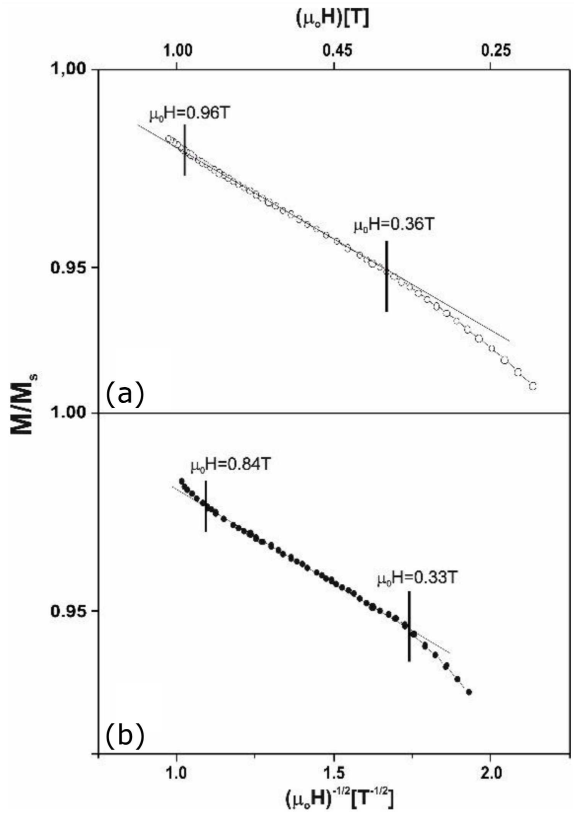

Fig. 4. The high-field magnetization curves $\mu_0 M((\mu_0 H)^{-1/2})$ for the investigated alloys: in the as-quenched state (a) [12], and after annealing (b).

caused homogeneity and relaxation of the structure. In the case of the amorphous materials, the dominant mechanism in the magnetic hysteresis is the pinning of the domain wall at local stress centres.

During the heat treatment in the sample, there is a rearrangement of atoms and more atoms are able to take their locally ordered positions. This leads to higher atomic packing density in the structure and this is consistent with the results of microstructure tests (higher B_{hf} value).

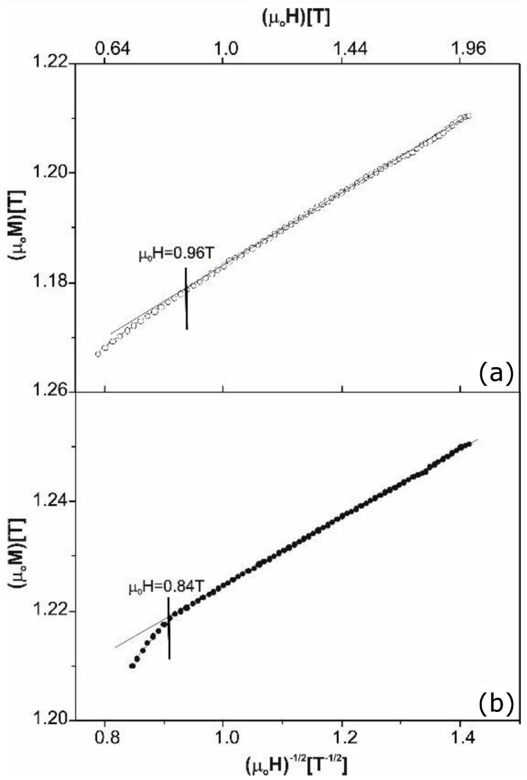

Fig. 5. The high-field magnetization curves $\mu_0 M((\mu_0 H)^{1/2})$ measured for the following bulk amorphous alloys [12].

Using the Kronmüller theory [9, 10], the type of defects occurring in the tested samples in the area called "the approach to ferromagnetic saturation" was determined.

In Fig. 4, the high-field magnetization curves M/M_S in the magnetic field induction function are presented.

In Fig. 4a and b the curves of relative magnetization M/M_s versus induction of magnetizing field $(\mu_0 H)^{-1/2}$ for investigated alloy are shown. For both investigated samples the linear dependence of M/M_s versus $(\mu_0 H)^{-1/2}$ in magnetic field induction range from 0.36 T to 0.96 T and 0.33 T to 0.84 T for as-quenched sample and after annealing was found. We may state that in these magnetic fields ranges the magnetization process in this alloy is dominated by rotation of magnetic moments near point-like defects. At higher magnetizing fields ($\mu_0 H > 0.96$ T for sample after solidification (Fig. 5a) and $\mu_0 H > 0.96$ T for sample after annealing (Fig. 5b)) a good linear dependence of $\mu_0 M$ on $(\mu_0 H)^{1/2}$ was observed. This linear relationships confirm that the magnetization process is connected with dumping of the thermally-induced spin waves: the so-called Holstein–Primakoff paraprocess [13] (Fig. 5).

Analysis of the initial magnetization curve in the Holstein–Primakoff paraprocess region allows the determination of a parameter describing the stiffness of the spin wave (D_{sp}).

Higher value of the spin wave stiffness parameter was obtained for sample after annealing ($D_{sp} = 5.1\times10^{-1}$ eV nm^2 for sample after solidification and $D_{sp} = 5.4 \times 10^{-1}$ eV nm^2 for sample after annealing). A higher value of the spin wave stiffness parameter indicates an increase in the number of magnetic atoms in the nearest neighbourhood, which is connected to the creation of short-range chemical ordering [14]. This is consistent with the Mössbauer and magnetic investigations.

4. Conclusions

- The XRD and Mössbauer investigations confirm that the injection-suction method allows to obtain rod-shaped bulk amorphous $Fe_{62}Co_{10}Y_8B_{20}$ alloy samples
- The enhancement of the mean value of the magnetic hyperfine field induction after the heat treatment was observed.
- In addition, the sample after heat treatment has a higher saturation magnetization value and lower coercivity.
- Approach to magnetic saturation for investigated alloys is achieved by the microscopic rotations of magnetic moments near the point-like defects.
- Additionally, sample after annealing has higher value of spin wave stiffness parameter.
- On the basis of the performed investigations it can be stated that heat treatment carried out at 750 K/35 min (significantly below the crystallization temperature of the alloy) leads to an improvement in soft magnetic properties, as well as to an increase in packing density of atoms.

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