Proceedings of "Applications of Physics in Mechanical and Material Engineering" (APMME 2024)

Research on the Influence of Small Changes in the Chemical Composition on Changes in the Environment of Fe Atoms in Rapid-Quenched Alloys

K. Jeż[a], P. Pietrusiewicz[b,*], A.V. Sandu[c,d], M.A.A.M. Salleh[e], M.M. Nabiałek[b] and T. Jaruga[f]

[a]*Faculty of Civil Engineering, Czestochowa University of Technology, Akademicka 3, 42-200 Częstochowa, Poland*
[b]*Department of Physics, Faculty of Production Engineering and Materials Technology, Czestochowa University of Technology, al. Armii Krajowej 19, 42-200 Częstochowa, Poland*
[c]*Faculty of Material Science and Engineering, Gheorghe Asachi Technical University, 64 Dumitru Mangeron Blvd, 700050 Iasi, Romania*
[d]*Academy of Romanian Scientists, 54 Splaiul Independentei St., Sect. 5, 050094 Bucharest, Romania*
[e]*Center of Excellence Geopolymer and Green Technology, Universiti Malaysia Perlis, Taman Muhibbah, 02600 Arau, Perlis, Malaysia*
[f]*Department of Technology and Automation, Faculty of Mechanical Engineering and Computer Science, Czestochowa University of Technology, al. Armii Krajowej 19c, 42-200 Częstochowa, Poland*

Doi: 10.12693/APhysPolA.147.156 *e-mail: pawel.pietrusiewicz@pcz.pl

Rapid-quenched Fe-based alloys may show hard or soft magnetic properties depending on the chemical composition and structure of the alloy. One of the most sensitive methods of studying the structure and, indirectly, magnetic properties is Mössbauer spectroscopy. Using this method, it is possible to determine the surroundings of Fe atoms and to identify crystalline phases in the volume of the alloy. The distributions of hyperfine field induction supplemented with measurements of saturation magnetization as a function of the external magnetic field allow us to explain significant differences in magnetic properties also within the amorphous structure. The paper presents the results of research on the structure and magnetic properties of rapid-quenched FeNbYHfB alloys. It was found that slight changes in the chemical composition affect the surroundings of Fe atoms and the density of the alloy, which correlates with the change in the value of the coercive field and saturation magnetization of rapid-quenched alloys.

topics: bulk amorphous alloys, Mössbauer spectroscopy, soft magnetic properties

1. Introduction

Amorphous alloys based on iron are characterized by good soft magnetic properties [1–5]. For this reason, they can be used in the power industry, among others, for the construction of low-loss transformer cores or magnetic screens. These properties depend on the chemical composition (the appropriate share of components with ferromagnetic properties) and structure. The lack of long-range atom order facilitates the magnetization process of these materials. As a result of the action of an external magnetic field, domain walls rotate easily, and magnetization increases relatively quickly.

Bulk amorphous alloys based on Fe are an interesting object of research also due to the possibility of describing the real structure as a result of the analysis of magnetic interaction measurements. Using Mössbauer spectroscopy, it is possible to assess changes in the environment of the central atom ^{57}Fe [6–8]. Of course, this measurement is only possible for samples rich in Fe. Based on the obtained results, a precise description of the structure corresponding to the magnetic properties of these materials is possible.

The aim of this work is to describe the influence of variable content of transition metals (Y and Hf) on the magnetic structure and magnetic properties of bulk amorphous alloys based on Fe.

2. Experimental procedure

The samples of the rapid-cooled alloys were produced in a two-stage process. The polycrystalline charge was produced in an arc furnace in an argon protective atmosphere. The samples were melted from components with a purity of over 99.9%. 10-gram samples were weighed to an accuracy of 0.0001 g. The melting process was carried out on a water-cooled copper plate using a non-consumable tungsten electrode. The charge, which had been melted several times, was divided into smaller pieces and cleaned with an ultrasonic cleaner. Approximately 1-gram pieces were used to produce rapid-cooled alloys using the suction method. The charge was placed on copper plates in a working chamber in an argon protective atmosphere. The polycrystalline charge was melted with an electric arc. The liquid alloy was sucked into a water-cooled copper mold. The samples were obtained in the form of 0.5 mm thick plates. The samples were tested using a Mössbauer transmission spectrometer with a ^{57}Co source in an Rh matrix with an activity of 100 mCi. The spectrometer speed calibration was performed on α-Fe foil with a purity of 4N, the hyperfine field of which is B_{hf} = 33.1 T. Measurements were performed for powder samples at room temperature. Mössbauer spectra were fitted using NORMOS software [9, 10]. Static magnetic hysteresis loops were measured using a Lake Shore VSM 7307 vibrating sample magnetometer in the range of external magnetic field strength up to 2 T.

3. Results

Figure 1 shows the transmission Mössbauer spectra measured for the samples produced.

These spectra are typical for amorphous ferromagnetic alloys with a relatively low hyperfine field. After appropriate magnification of the graph, distinct Zeeman sextets are visible. On this basis, the distributions of hyperfine field induction on ^{57}Fe nuclei were developed (Fig. 2).

In the hyperfine field induction distributions on ^{57}Fe nuclei, it can be seen that these distributions are multimodal, which is related to the different Fe environments around the central ^{57}Fe atom. Two components can be distinguished, i.e., low field (red) and high field (green). This indicates the inhomogeneity of the samples produced — in the alloy volume, there are different environments of the central ^{57}Fe atom, which should be explained by the occurrence of two different amorphous matrices. In other words, these distributions indicate the existence of areas in which the distances between iron atoms are smaller (green) or larger (red). The presence of such areas is associated with the occurrence of topological and chemical disorders in amorphous materials. Based on the measurements, the values of the average hyperfine field on ^{57}Fe nuclei and the dispersion of the distribution were determined. The results are presented in Table I.

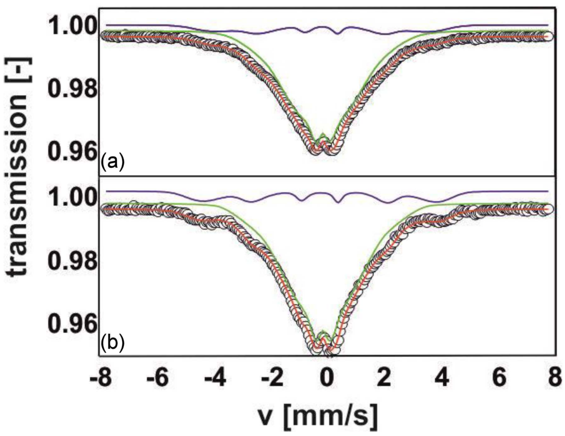

Fig. 1. Mössbauer transmission spectra obtained for the tested alloys: (a) $Fe_{65}Nb_5Y_5Hf_5B_{20}$, (b) $Fe_{65}Nb_5Y_6Hf_4B_{20}$.

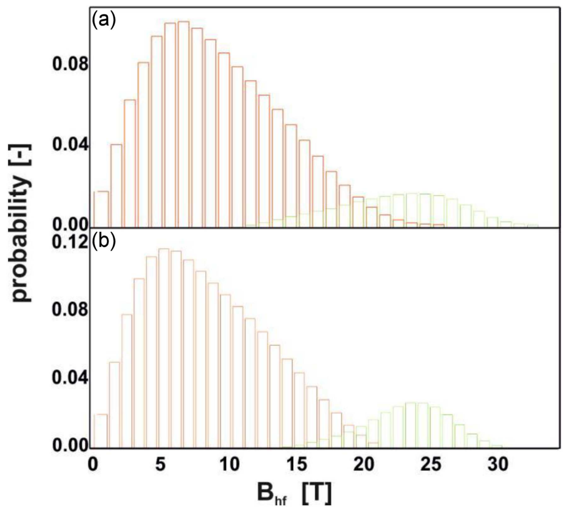

Fig. 2. Distributions of hyperfine field induction obtained based on the analysis of Mössbauer transmission spectra for the tested alloys: (a) $Fe_{65}Nb_5Y_5Hf_5B_{20}$, (b) $Fe_{65}Nb_5Y_6Hf_4B_{20}$.

Figure 3 shows static magnetic hysteresis loops. These loops are typical for materials exhibiting soft magnetic properties. They are characterized by an almost rectangular shape. There are no visible loop extensions which could indicate areas that impede the magnetization process. Based on the loop analysis, magnetic properties were determined, namely the value of the coercive field (H_C) and the saturation magnetization (M_S). The results are presented in Table I.

Interestingly, for the first distinguished distribution (red in Fig. 3), the mean hyperfine field values and the dispersion of its distribution are identical.

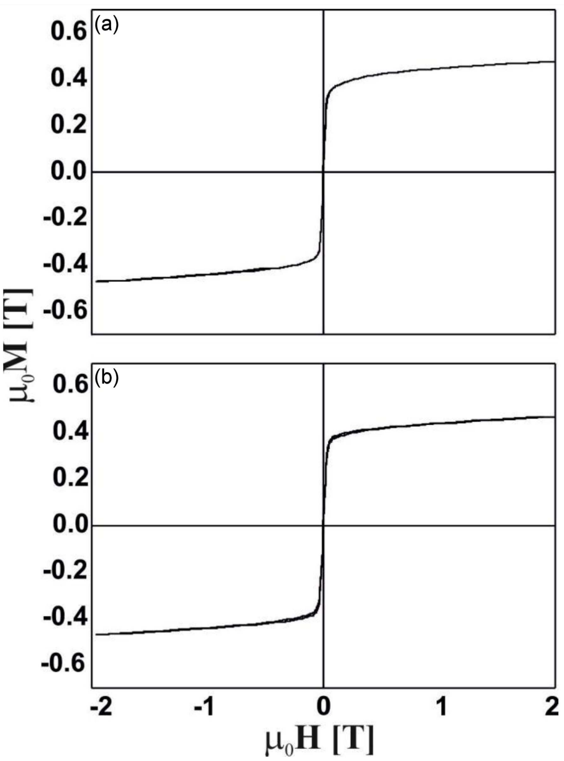

Fig. 3. Static hysteresis magnetic loops for the tested alloys: (a) $Fe_{65}Nb_5Y_5Hf_5B_{20}$, (b) $Fe_{65}Nb_5Y_6Hf_4B_{20}$.

TABLE I

Values of $\mu_0 M_S$ — saturation magnetization [T], H_C — coercivity field [A/m], B_{hf} — average value of the hyperfine magnetic field induction [T], and ΔB_{hf} — decomposition dispersion [T] of the tested alloys.

Parameter	$Fe_{65}Nb_5Y_5Hf_5B_{20}$	$Fe_{65}Nb_5Y_6Hf_4B_{20}$
$\mu_0 M_S$	0.47	0.47
H_C	36	70
B_{hf1}	8.54	8.53
ΔB_{hf1}	4.92	4.92
B_{hf2}	21.78	24.64
ΔB_{hf2}	4.50	3.41

In the case of the second distribution, the addition of Y at the expense of Hf increases the value of B_{hf} while reducing the dispersion of the distribution.

4. Conclusions

The paper investigates the effect of variable Hf and Y content on the structure and magnetic properties of bulk amorphous alloys based on Fe. The alloys produced are characterized by soft magnetic properties, as indicated by the coercive field value below 100 A/m. An interesting result of the research is the practically identical value of the mean hyperfine field for the low-field component of the hyperfine field distribution. This means that in specific areas of both samples, there are almost identical environments of the ^{57}Fe central atom. In the case of the high-field component, the addition of Y increases the B_{hf} value while reducing the dispersion of the distribution. This can be explained by a slight change in the environments of the ^{57}Fe central atom in these areas. These areas are probably richer in Y (which is a logical consequence of the greater addition of Y). Taking into account the fact that in this type of alloys, the crystallization products are phases rich in Fe and Y with magnetically semi-hard (Fe_5Y) or hard ($Y_2Fe_{14}B$) properties, it can be concluded that the formation of atomic configurations similar to these phases occurred. This is indicated by both the increase in the B_{hf} value with a simultaneous decrease in the distribution dispersion and the twofold increase in the coercive field value.

References

[1] W. Maziarz, A. Kolano-Burian, M. Kowalczyk, P. Błyskun, R. Chulist, P. Czaja, M. Szlezynger, A. Wójcik, *Arch. Metall. Mater.* **68**, 1165 (2023).

[2] Y. Han, C.T. Chang, S.L. Zhu, A. Inoue, D.V. Louzguine-Luzgin, E. Shalaan, F. Al-Marzouki, *Intermetallics* **54**, 169 (2014).

[3] M.E. McHenry, M.A. Willard, D.E. Laughlin, *Prog. Mater. Sci.* **44**, 291 (1999).

[4] B. Jeż, *Arch. Metall. Mater.* **69**, 231 (2024).

[5] G. Herzer, *Acta Mater.* **61**, 718 (2013).

[6] N. Randrianantoandro, A.D. Crisan, O. Crisan, J. Marcin, J. Kovac, J. Hanko, J.M. Grenèche, P. Svec, A. Chrobak, I. Skorvanek, *J. Appl. Phys.* **108**, 093910 (2010).

[7] B. Jeż, J. Wysłocki, S. Walters, P. Postawa, M. Nabiałek, *Materials* **13**, 1367 (2020).

[8] M.B. Miglierini, J. Dekan, M. Cesnek, I. Janotová, P. Švec, M. Bujdoš, J. Kohout, *J. Magn. Magn. Mater.* **500**, 166417 (2020).

[9] R.A. Brand, *Nucl. Instrum. Methods Phys. Res. B* **28**, 398 (1987).

[10] J. Hesse, A. Rubartsch, *J. Phys. E Sci. Instrum.* **7**, 526 (1974).