Proc. of the International Conference on Mechanochemistry and Mechanical Alloying, Kraków, Poland, June 22–26, 2014

Structure and Magnetic Properties of the Alloys $Fe_{60}Co_{10}W_xMo_2Y_8B_{20-x}$ ($x = 0, 1, 2$)

J. Garus[a,*], S. Garus[a], M. Nabiałek[a] and M. Szota[b]

[a]Częstochowa University of Technology, Faculty of Production Engineering and Materials Technology, Institute of Physics, al. Armii Krajowej 19, 42-200 Częstochowa, Poland

[b]Częstochowa University of Technology, Faculty of Production Engineering and Materials Technology, Institute of Materials Engineering, al. Armii Krajowej 19, 42-200 Częstochowa, Poland

The aim of this paper were studies of the structure and magnetic properties of the bulk $Fe_{60}Co_{10}W_xMo_2Y_8B_{20-x}$ ($x = 0$, 1, 2) alloys. Ingots of the alloys were prepared by arc melting of high purity elements in an argon atmosphere. The samples in the form of plates were obtained by a rapid solidification of liquid metal in a copper mold cooled with water. Topography of produced samples were examined using a ZEISS SUPRA 35 high resolution scanning electron microscope. Furthermore, using a vibrating sample magnetometer the magnetization in high magnetic fields was studied. Moreover, from initial magnetization curves the parameters related with the Holstein–Primakoff paraprocess were determined.

DOI: 10.12693/APhysPolA.126.954

PACS: 75.50.–y, 75.50.Kj, 75.30.Ds, 75.20.En, 75.47.Np, 75.50.Bb, 75.60.Ej

1. Introduction

Occurring in the electromagnets cores and transformers energy losses creates the need to seek new types of materials characterized by a higher saturation magnetization, smaller coercive field, low value of losses and low effective anisotropy. Good responses to the occurring need are based on iron, cobalt, boron and yttrium amorphous alloys [1–4]. Slight changes in the alloy composition in the form of admixtures are able to affect its magnetic properties [5–9]. This fact causes a continuous need to search a material with the best properties.

The aim of the study was to investigate the effect of tungsten dopants on the magnetic properties and structure of bulk amorphous alloys based on FeCoMoYB.

2. Material and experimental procedure

Using the injection casting method, after melting high-purity components by electric arc, samples were obtained in the form of plates with dimensions $10 \times 10 \times 1$ mm^3. Samples of the $Fe_{60}Co_{10}W_xMo_2Y_8B_{20-x}$ (where $x = 0$, 1 lub 2) alloy, used in the investigations, have been prepared using high purity elements: Fe — 99.99%, Co — 99.99%, W — 99.9999%, Mo — 99.9999%. The boron element has been added in a form of the alloy $Fe_{45.4}B_{54.6}$.

The structure was studied in 2θ angle between 30 °C to 100 °C, measuring increments was equal 0.02 °C on Bruker X-ray diffractometer with Cu K_α tube with a wavelength equal to $\lambda = 1.54056$ Å.

Samples breakthroughs were analyzed by using a high resolution scanning electron microscope — ZEISS SUPRA 35.

The magnetization process at high fields was analyzed by research done at the LakeShore vibrating magnetometer in the range of magnetic fields up to 2 T. The VSM studies have been performed on the samples powdered by low-energy milling.

The Kronmüller theory can describe the effect of defects on the initial magnetic polarization curve $\mu_0 M$ as a function of a strong external field H [10–13]:

$$\mu_0 M(H) = \mu_0 M_s \times\left[1-\frac{a_{1/2}}{(\mu_0 H)^{1/2}}-\frac{a_1}{(\mu_0 H)^1}-a_2(\mu_0 H)^2\right]+b(\mu_0 H)^{1/2}, \quad (1)$$

where a_i are coefficients of linear fit describing the influence of defects in the structure of the process of magnetization, and by the b coefficient by which there can be examined the effect of external field on the suppression of thermally excited spin waves, which is so-called Holstein–Primakoff paraprocess [14]. The b coefficient can be described as [15]:

$$b = 3.54 g\mu_0\mu_B\left(\frac{1}{4\pi D_{spf}}\right)^{3/2} kT(g\mu_B)^{1/2}, \quad (2)$$

where: g — gyromagnetic coefficient, k — Boltzmann constant, D_{spf} — spin-wave stiffness parameter, μ_B — Bohr magneton, T — temperature.

Determination of the b coefficient allows to estimate the exchange constant A_{ex} and the exchange distance l_h [13, 16–20]:

$$A_{ex} = \frac{M_s D_{spf}}{2g\mu_B}, l_h = \left(\frac{2A_{sx}}{\mu_0 H M_s}\right)^{1/2}. \quad (3)$$

*corresponding author; e-mail: jg@wip.pcz.pl

3. Research

Single broad peaks of low intensity at diffraction patterns obtained for the tested alloys (Fig. 1) provide a sufficient rate of cooling during the production of these materials necessary to produce the metallic glass structure.

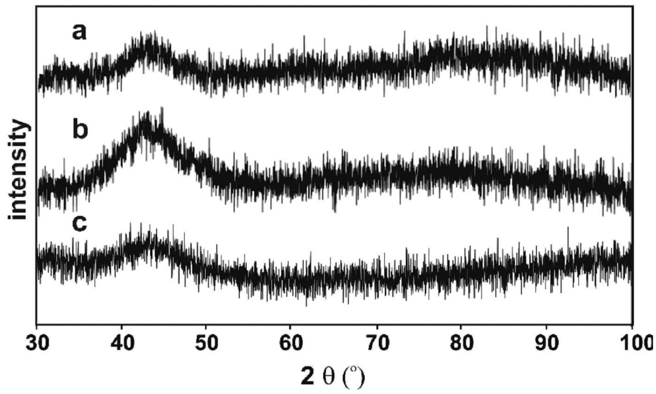

Fig. 1. X-ray diffractions.

Figure 2 shows the breakthroughs images of test materials obtained with a scanning electron microscope. Observation of the surface structure allows for a relative assessment of the ductility of the sample.

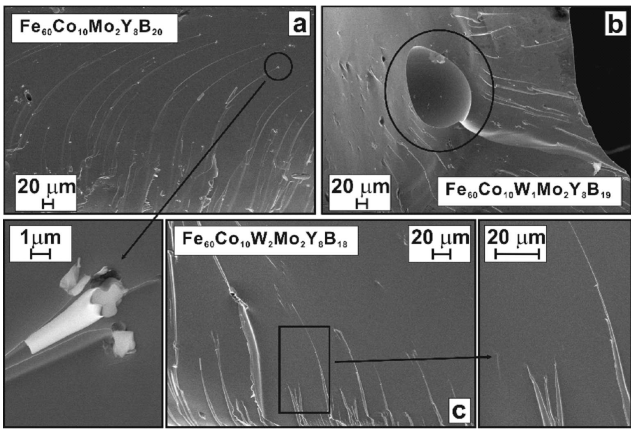

Fig. 2. Samples breakthroughs obtained by SEM for (a) $Fe_{60}Co_{10}Mo_2Y_8B_20$, (b) $Fe_{60}Co_{10}W_1Mo_2Y_8B_{19}$, (c) $Fe_{60}Co_{10}W_2Mo_2Y_8B_{18}$ alloys.

Breakthroughs tiles were smooth, but there were many imperfections of visible structure in the form of gas bladder. An example of such bladder is shown in Fig. 2b. It should be also noted the occurrence of fibrous and conchoidal fractures around the edges, indicating greater outer plates ductility than in the interior, which are associated with non-uniform cooling rate inside the material. Bladder smooth internal structure indicates a high degree of relaxation. This is caused by the lowest cooling rate near the gas filled space.

Increasing the amount of tungsten impurities instead of boron in the alloy resulted an increase in alloys ductility, as evidenced by the increased participation of conchoidal fracture in the studied fractures.

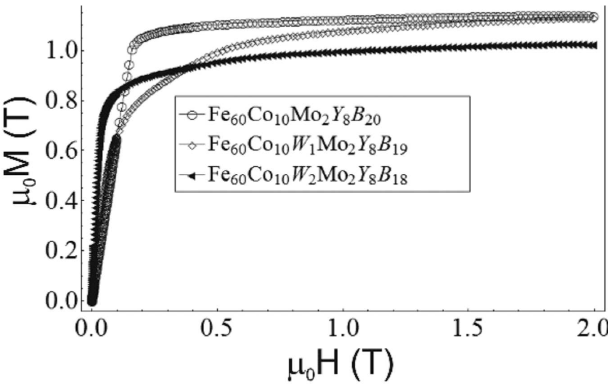

Fig. 3. Initial magnetization curves.

Figure 3 shows the initial magnetization curves as a function of the external field. Introduction to tungsten alloy with a much larger atomic radius compared to the atomic radius of boron affects weakens the ferromagnetic interaction between the magnetic moments occurring in the studied alloys.

The polarization saturation of the sample, wherein the tungsten did not occur was 1.14 T. After adding one percent tungsten dopant polarization saturation decreased slightly to 1.13 T. Further increase in the amount of tungsten in place of the boron to two percent in the melt resulted in a significant reduction in the polarization saturation to 1.03 T.

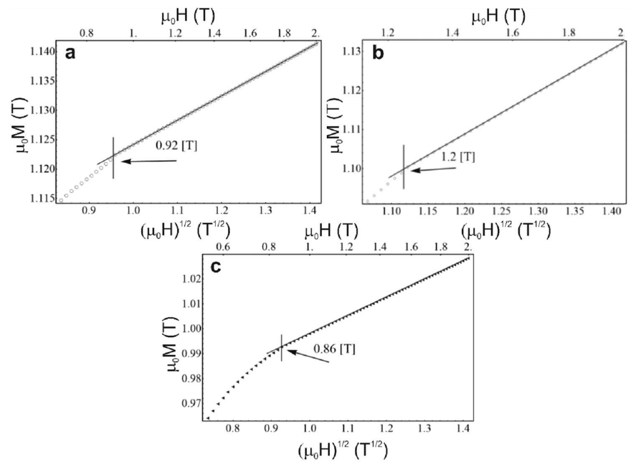

Fig. 4. High-field magnetization curves as a function of $(\mu_0 H)^{1/2}$ for investigation alloy.

Figures 4 a-c show high-field polarization curves as a function of $(\mu_0 H)^{1/2}$. The linear increase in magnetization above the $\mu_0 H_p$ to the Holstein–Primakoff paraprocess is associated with suppression of thermally excited spin waves. For the sample without the addition of tungsten field transition was 0.92 T (Fig. 4a). The one percent by mass addition of tungsten instead of boron resulted in an increase in the transition of paraprocess field value to 1.2 T (Fig. 4b). Further increasing the tungsten admixture in the alloy decreased the transition field value to 0.86 T (Fig. 4c).

Table I shows the results of magnetic properties of the studied alloys.

TABLE I

The results obtained from the analysis of magnetization studies.

	$Fe_{60}Co_{10}W_xMo_2Y_8B_{20-x}$		
	$x = 0$	$x = 1$	$x = 2$
$\mu_0 M_s$ (T)	1.14	1.13	1.03
$\mu_0 H_p$ (T)	0.92	1.24	0.86
b $[10^{-2}\ T^{1/2}]$	4.15	10.82	8.51
D_{spf} (10^{-2} meV nm^2)	55.45	29.25	34.34

4. Conclusions

In this paper effect of the tungsten addition instead of boron on the magnetic properties and structure of the $Fe_{60}Co_{10}W_xMo_2Y_8B_{20-x}$, (where $x = 0$, 1 or 2) alloys was investigated.

All samples had an amorphous structure. The increase in tungsten content caused an increase in the ductility of the alloy, and simultaneously reducing the value of the saturation magnetization.

The smallest value of the spin wave stiffness parameter for a sample of one percent share of tungsten in the alloy indicates a small number of nearest magnetic atoms and reduce the short-range order. The admixture of tungsten with a large (135 pm) relative to boron (85 pm) atomic radius reduced interaction of Fe–Co, Fe–Fe, and Co–Co atoms pairs.

References

[1] K. Błoch, M. Nabiałek, P. Pietrusiewicz, J. Gondro, M. Dośpiał, M. Szota, K. Gruszka, *Acta Phys. Pol. A* **126**, 108 (2014).

[2] K. Takenaka, T. Sugimoto, N. Nishiyama, A. Makino, Y. Saotome, Y. Hirotsu, A. Inoue, *Mater. Lett.*, **63**, 1895 (2009).

[3] P. Sharma, H. Kimura, A. Inoue, *J. Appl. Phys.* **100**, 083902 (2006).

[4] K. Błoch, *Arch. Mater. Sci. Eng.* **64**, 97 (2013).

[5] J. Olszewski, J. Zbroszczyk, K. Sobczyk, W. Ciurzyńska, P. Brągiel, M. Nabiałek, J. Świerczek, M. Hasiak, A. Łukiewska, *Acta Phys. Pol. A* **114**, 1659 (2008).

[6] H.J. Sun, Q. Man, Y.Q. Dong, B. Shen, H. Kimura, A. Makino, A. Inoue, *J. Alloys Comp.* **504**, s31 (2010).

[7] H.Y. Jung, S. Yi, *Intermetallics*, **18**, 1936 (2010).

[8] J. Gondro, J. Świerczek, J. Rzącki, W. Ciurzyńska, J. Olszewski, J. Zbroszczyk, K. Błoch, M. Osyra, A. Łukiewska, *J. Magn. Magn. Mater.* **341**, 100 (2013).

[9] M. Nabiałek, J. Zbroszczyk, J. Olszewski, M. Hasiak, W. Ciurzyńska, K. Sobczyk, J. Świerczek, J. Kaleta, A. Łukiewska, *J. Magn. Magn. Mater.* **320**, e787 (2008).

[10] H. Kronmüller, *J. Appl. Phys.* **52**, 1859 (1981).

[11] H. Kronmüller, M. Fahnle, *Micromagnetism and the Microstructure of Ferromagnetic Solids, Cambridge University Press, Cambridge 2003.*

[12] H. Kronmüller, M. Fahnle, H. Grimm, R. Grimm, B. Groger, *J. Magn. Magn. Mater.* **13**, 53 (1979).

[13] H. Kronmüller, *IEEE Trans. Magn.* **15**, 1218 (1979).

[14] H. Kronmüller, S. Parkin, *Handbook of Magnetism and Advanced Magnetic Materials*, Vol. 2, Wiley, Hoboken 2007.

[15] J. Zbroszczyk, *Phys. Status Solidi A* **136**, 545 (1993).

[16] M. Vázquez, W. Fernengel, H. Kronmüller, *Phys. Status Solidi* **115**, 547 (1989).

[17] J. Zbroszczyk, J. Świerczek, W. Ciurzyńska, M. Baran, B. Wysłocki, S. Szymura, *J. Magn. Magn. Mater.* **109**, 221 (1992).

[18] M. Hischer, R. Reisser, R. Würschum, H.E. Schaefer, H. Kronmüller, *J. Magn. Magn. Mater.* **146**, 117 (1995).

[19] N. Lenge, H. Kronmüller, *Phys. Status Solidi A* **95**, 621 (1986).

[20] M. Nabiałek, M. Szota, M. Dośpiał, P. Pietrusiewicz, S. Walters, *J. Magn. Magn. Mater.* **322**, 3377 (2010).