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Microstructure and some magnetic properties of bulk amorphous $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{100-x}Y_x$ ($x=0$, 2, 3 or 4) alloys

K. Sobczyk [a], J. Świerczek [a,*], J. Gondro [a], J. Zbroszczyk [a], W.H. Ciurzyńska [a], J. Olszewski [a], P. Brągiel [b], A. Łukiewska [a], J. Rzącki [a], M. Nabiałek [a]

[a] Institute of Physics, Częstochowa University of Technology, al. Armii Krajowej 19, 42-200 Częstochowa, Poland
[b] Institute of Physics, Jan Długosz University, al. Armii Krajowej 13/15, 42-200 Częstochowa, Poland

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ABSTRACT

Microstructure, revealed by X-ray diffraction, transmission electron microscopy and Mössbauer spectroscopy, and magnetic properties such as magnetic susceptibility, its disaccommodation, core losses and approach to magnetic saturation in bulk amorphous $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{100-x}Y_x$ ($x=0$, 2, 3 or 4) alloys in the as-cast state and after the annealing in vacuum at 720 K for 15 min. are studied. The investigated alloys are ferromagnetic at room temperature. The average hyperfine field induction decreases with Y concentration. Due to annealing out of free volumes its value increases after the heat treatment of the samples. The magnetic susceptibility and core losses point out that the best thermal stability by the amorphous $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{97}Y_3$ alloy is exhibited. Moreover, from Mössbauer spectroscopy investigations it is shown that the mentioned above alloy is the most homogeneous. The atom packing density increases with Y concentration, which is proved by the magnetic susceptibility disaccommodation and approach to magnetic saturation studies.

1. Introduction

Amorphous alloys are usually prepared by a rapid quenching method in the form of ribbons with the thickness limited to several dozen micrometers [1,2]. This method requires the cooling rate higher than 10^5 K/s. Multicomponent systems characterized by significant atomic mismatches (above 12%) and negative heat of mixing of the main constituent elements exhibit excellent glass forming ability [3,4]. Large pieces of the amorphous alloys in the form of rods, tubes and plates can be obtained at cooling rate as low as 1–100 K/s by the suction or injecting methods of a liquid alloy into a copper mold cooled with water [5,6]. It is commonly known that the amorphous alloys are metastable and tend to the crystalline state by other metastable states [7,8]. Thermal instability of the amorphous alloys depends not only on their chemical composition but on the preparation conditions as well [9,10]. This effect is connected with structure relaxation, i.e. irreversible displacement of atoms. The relatively low cooling rate during preparation of bulk amorphous alloys enables the structure relaxations which in turn involve higher atom packing density than in the ordinary amorphous alloys and their good thermal stability [11,12]. An effective method to improve the glass forming ability of the alloys is the increase of the number of components or the small addition of proper elements [13,14].

In this paper we report the microstructure, thermal stability and some magnetic properties (susceptibility, its disaccommodation, core losses and approach to magnetic saturation) studies of the bulk amorphous $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{100-x}Y_x$ ($x=0$, 2, 3 or 4) alloys.

2. Experimental procedure

Ingots of the alloys with the nominal compositions $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{100-x}Y_x$ ($x=0$, 2, 3 or 4) were prepared by the arc melting of the high purity elements in Ti-gettered argon atmosphere. In order to obtain homogenous materials the ingots were re-melted four times. The bulk amorphous alloys in the form of rods 1 mm in diameter and 2 cm long were produced by a suction casting method [5] in a protective argon atmosphere.

The microstructure of the samples was investigated by the X-ray diffractometer (Bruker—AXS, type D8 Advanced), high resolution electron microscope (JEM 3010) and Mössbauer spectrometer. X-ray diffraction patterns and transmission Mössbauer spectra were recorded for the powdered samples at room temperature. The Mössbauer spectra were measured using a conventional Mössbauer spectrometer working at a constant acceleration

* Corresponding author. Tel./fax: +48 34 3250795.
E-mail address: swiercz@wip.pcz.pl (J. Świerczek).

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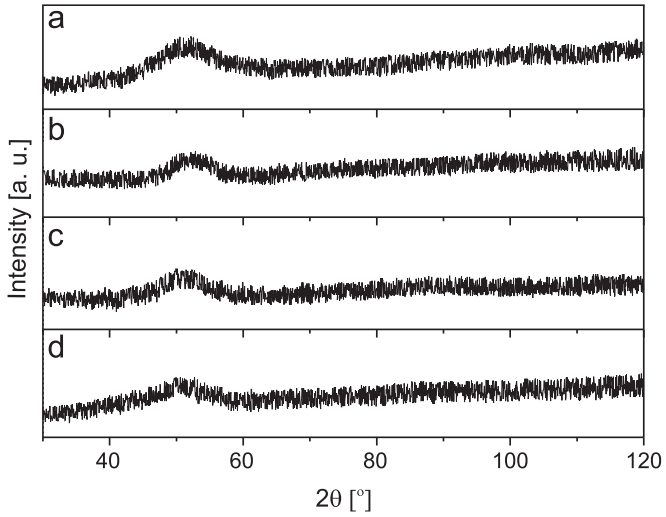

Fig. 1. X-ray diffraction patterns for the powdered samples of the as-quenched bulk amorphous $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{100-x}Y_x$ alloys: $x=0$ (a), $x=2$ (b), $x=3$ (c) and $x=4$ (d).

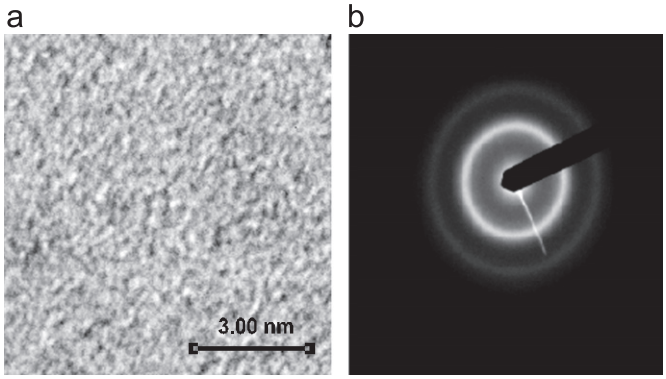

Fig. 2. High resolution transmission electron microscope image (a) and selected area electron diffraction pattern (b) for the as-quenched bulk amorphous $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{98}Y_2$ alloy.

with the ^{57}Co(Rh) radioactive source of the 70 mCi in activity. The spectra were fitted by Normos package [15]. From the spectra the magnetic hyperfine field induction distributions were obtained using the Hesse–Rübartsch method [16]. In this procedure the linear dependence of the isomer shift on the hyperfine field was assumed.

The thermal stability of the amorphous alloys after solidification was studied by differential scanning calorimetry [17]. The DSC traces were measured at the heating rate of 10 K/min. in an argon atmosphere.

Low field magnetic susceptibility was studied using a completely automated setup by a transformer method. The amplitude and frequency of the magnetizing field were 0.16 A/m and 2 kHz, respectively. Before the measurements the samples were demagnetized in an alternating magnetic field with the amplitude decreasing from 800 A/m to zero during 1.1 s. From the results obtained during measurements of low field magnetic susceptibility the isochronal disaccommodation curves were constructed according to the following expression:

$$\Delta\left(\frac{1}{\chi}\right)=\frac{1}{\chi_2}-\frac{1}{\chi_1}=f(T) \quad (1)$$

where χ_2 and χ_1 are magnetic susceptibility measured at $t_2=120$ s and $t_1=2$ s after demagnetization of the sample.

The transformer method was also used during investigations of core losses and magnetic susceptibility as a function of the magnetizing field amplitude for the frequency up to 1 kHz. Moreover, the approach to ferromagnetic saturation was studied by means of a vibrating sample magnetometer (VSM Lake Shore).

The investigations were carried out for the as-quenched and annealed in vacuum at 720 K for 15 min samples.

3. Results and discussion

3.1. Microstructure and thermal stability

In Fig. 1 X-ray diffraction patterns for $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{100-x}Y_x$ ($x=0$, 2, 3 or 4) alloys after solidification are depicted. The patterns are typical of amorphous

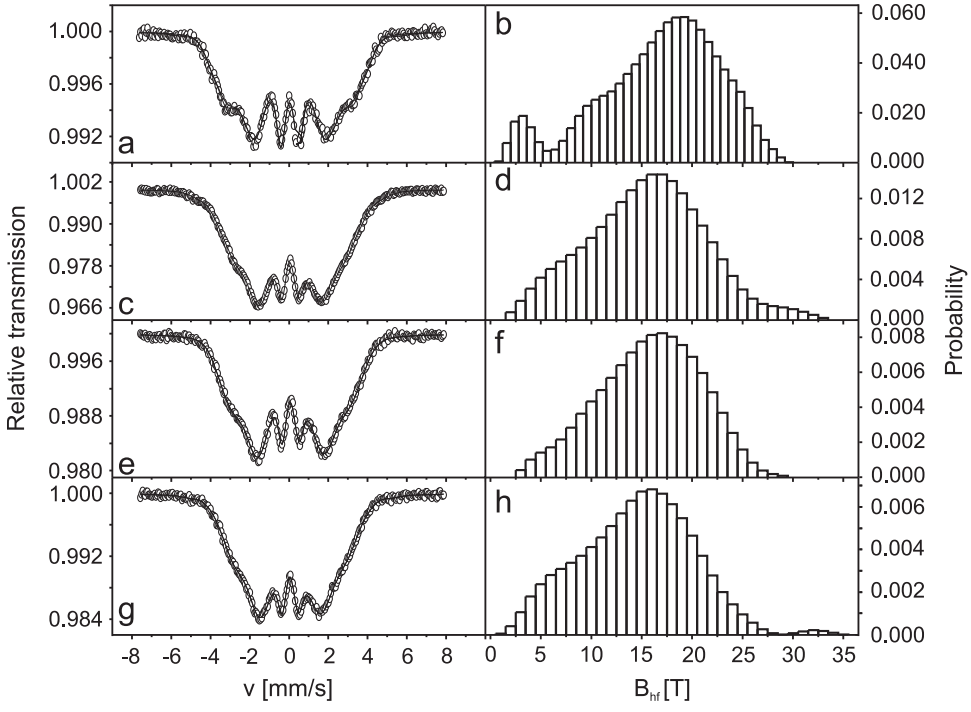

Fig. 3. Transmission Mössbauer spectra (a, c, e and g) and corresponding hyperfine magnetic field induction distributions (b, d, f and h) for powdered as-quenched $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.02}W_{0.02}B_{0.20})_{100-x}Y_x$ rods: $x=0$ (a, b), $x=2$ (c, d), $x=3$ (e, f) and $x=4$ (g, h).