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Investigation of the structure and properties of Fe-Co-B-Si-Nb bulk amorphous alloy obtained by pressure die casting method

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Properties

ABSTRACT

Purpose: The main aim of this paper is investigation of the microstructure and thermal properties of selected Fe-Co-B-Si-Nb bulk amorphous alloy.

Design/methodology/approach: The studies were performed on Fe-Co-B-Si-Nb alloy in form of rods with diameter of ø=1.5 and ø=2 mm. Master alloy ingot with compositions of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ was prepared by induction melting of pure Fe, Co, B, Si and Nb elements in argon atmosphere. The structure analysis of the studied materials in as-cast state was carried out using X-ray diffraction (XRD). The thermal properties: glass transition temperature (Tg), onset crystallization temperature (Tx) and peak crystallization temperature (Tp) of the as-cast alloys were examined by differential scanning calorimetry (DSC) method. The microscopic observation of the fracture morphology of studied amorphous materials in rods form with different diameter was carried out by means of scanning electron microscope (SEM), within different magnification.

Findings: The Fe-based bulk metallic glasses in form of rod were successfully produced by die pressure casting method. The investigation revealed that the studied rods are amorphous. These materials exhibit good glass-forming ability. These tested rods with diameter of 1.5 and 2 mm exhibit similar characteristic temperatures (Tg, Tx, Tp). The exothermic peaks describing crystallization process of studied bulk metallic glasses are observed Morphology of cross section rods is changing having contact with copper mould during casting from smooth fracture inside rod to fine narrow dense veins pattern near to rod surface. These rods have smooth surface and metallic luster. The presented fractures are characteristic for metallic glasses.

Practical implications: The success of production of studied Fe-based bulk metallic glasses is important for future practical application of those materials as elements of magnetic circuits, sensors and precise current transformers.

Originality/value: The success formation and investigation of the casted Fe-based bulk metallic glasses. The chemical composition of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ alloy in form of rod were tested first time..

Keywords: Metallic glasses; Bulk Metallic Glasses; Glass-forming ability; Fe-based alloy

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1. Introduction

Nowadays, great focus is put on bulk metallic glasses (BMGs) and their development in the direction of practical application. The BMGs are superb class of functional and structural materials with a unique combination of physical, chemical and mechanical properties. In last decade, the Fe-Co-B-Si-Nb bulk glassy alloys were successfully obtained and thoroughly tested [1-7].

Fe-based bulk glassy alloys in Fe-Co-B-Si-Nb system were studied by A. Inoue et al. [8-11]. As a result of the tests it was noted that the alloys exhibit super-high fracture strength of 3900-4250 MPa, Vickers hardness (H_v) of 1150-1220, elastic strain (ε_e) of 0.02, plastic strain (ε_p) of 0.0025 and Young's modulus [E] of 190-210 GPa [6].

Besides, at the same time, the super-high strength glassy alloys exhibit very good soft magnetic properties, i.e. low coercivity below 3 A/m, high permeability of $1.6\text{-}2.1\cdot10^4$ and high magnetization of 0.8-1.1T [1].

Inoue A. et al. [8] have conducted investigation of glass-forming ability of $[(Fe_{1-x}Co_x)_{0.75}B_{0.2}Si_{0.05}]_{96}Nb_4$ (x=0-0.5) amorphous alloys, as well. As a results of the tests it was observed that the glassy alloys exhibit distinct glass transition, followed by a supercooled liquid region and crystallization process. They have investigated the supercooled liquid region and reduced glass transition temperature which show maximum value of 50 K and 0.59, respectively.

On the basis of the study of glass forming ability of Fe-based alloy [12-14], the author concluded that obtained samples in form of plate and rod show high thermal properties. The width of supercooled liquid region (ΔT_x) equals 47 K for plate and 46 K for rod, which indicates that tested Fe-based alloy possesses a sufficient stability of the supercooled liquid. The reduced glass transition temperature (T_{rg}) is going to achieve a value of 0.6 and increases from 0.5922 for alloy in form of plate to 0.5958 for alloy in form of rod. The alloys which are characterized by such a reduced glass transition temperature values are easily obtained by super cooling.

The Fe-Co-B-Si-Nb bulk glassy alloys have the highest strength for all Fe-based metallic materials [1,8,10]. These high values of this alloy system properties are interpreted to result from strong bonding nature among the constituent elements as it is expected from the mixing enthalpies with large negative values [1].

In the Fe-Co-B-Si-Nb alloy system the enthalpy of mixing is -39 kJ/mol for the B-Nb pair; -25kJ/mol for the Co-Nb pair; -21 kJ/mol for the Co-Si pair; -18 kJ/mol for the Fe-Si pair; -16 kJ/mol for the Fe-Nb pair; -11 kJ/mol for the Fe-B pair; -9 kJ/mol for the Co-B pair. Furthermore, the difference between the radii of the atoms of the components should be and is more than 12%. This would ensure the fact that crystalline solution does not form, and that the multicomponent alloy will be characterized by good glass-forming ability i.e. The atomic size difference between Co and B atoms is significant as the radius is 0.125 nm for Co atom and 0.09 nm for B atom [8].

The aim of the presented work is investigation of the microstructure and thermal properties of selected Fe-Co-B-Si-Nb bulk amorphous alloy.

2. Material and methodology

The studies were carried out on bulk metallic glasses as rods. Multicomponent alloy with nominal composition of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ were investigated. Fe-based ingot were prepared by induction melting of the pure Fe, Co, B, Si, Nb elements in argon atmosphere (Table 1). The ingot was melted several times. From the master alloy, samples were prepared by pressure die casting method in an argon atmosphere. The pieces of master alloy was melted in a quartz crucible using an induction coil and pushed in a copper mould by applying an ejection pressure. The investigated materials were cast in form of rods with diameters of ø=1.5 mm and ø=2 mm.

Table 1.
Chemical composition of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ alloy

No	Elements	mass. [%]	at. [%]
1	Fe	43.23	37.44
2	Co	42.11	34.56
3	B	4.29	19.20
4	Si	2.68	4.80
5	Nb	7.69	4.00

The structure of rapidly solidified rod specimens was examined by X-ray diffraction using a Seifert - FPM XRD diffractometer with Co Kα radiation at 35 kV. The data of diffraction pattern lines were recorded by means of the stepwise method within the angular range of 30º to 90º.

The thermal stability associated with glass transition temperature, supercooled liquid region and crystallization temperature was investigated by differential scanning calorimetry and differential thermal analysis at a constant heating rate of 20 K/min.

The microscopic observation of the fracture morphology of studied amorphous materials in rods form with different diameter was carried out by means of the Supra 25 made by Zeiss factory scanning electron microscope, within different magnification.

3. Results of researches

The bulk alloy samples in rod form were produced and investigated. The structure of as-cast $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ rods were examined by X-ray diffraction and SEM method. Whereas, thermal properties were tested by DTA and DSC method.

3.1. X-ray analysis

At first, the structure of produced $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ rods were examined by X-ray diffraction method. The samples of determined chemical composition with a diameter of 1.5 and 2

mm consist of a single glassy phase as was evidenced from a main halo peak without crystalline peaks in their X-ray diffraction patterns. One of the obtained halo peak of tested rod is presented in Fig. 1.

The diffraction pattern of the second studied $Fe_{57.6}Co_{7.2}Ni_{7.2}B_{19.2}Si_{4.8}Nb_4$ rod shows the broad diffraction halo characteristic for amorphous structure of Fe-based glassy alloys, too. The diffraction record of tested material is shown in Figure 2.

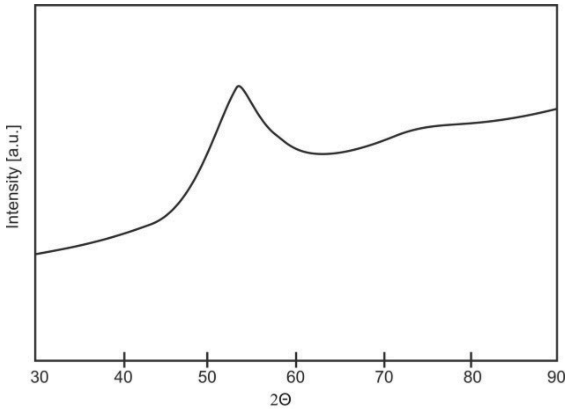

Fig. 1. X-ray diffraction pattern of the $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ alloy rod with diameter of 1.5 mm

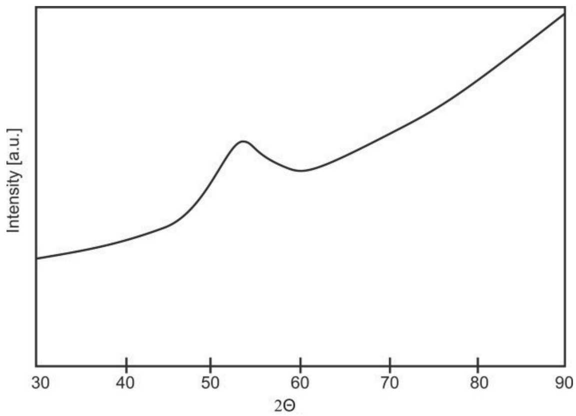

Fig. 2. X-ray diffraction pattern of the $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ alloy rod with diameter of 2 mm

3.2. Microscopic observation

In Fig. 3 and Fig. 4 micrographs of the fracture morphology of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ amorphous rods in as-cast state with diameter of 1.5 mm in different magnification were shown. Morphology of rods is changing from smooth fracture to “river” and “shell” patterns.

Figs. 3-6 show the fracture surface morphology of the tested Fe-based bulk metallic glasses. The fracture surface consists of some little fracture zones and their zone planes appear in the direction of applied load during preparing the rods to fracture surface morphology observations. The nearly simultaneous generation of a few smaller fracture zones is presumably due to easy initiation of fracture at some sites. The easy initiation of fracture may result from the mechanism in which the initiation of crack occurs at a very high stress level and the shock wave caused by its initiation induces the generation of cracks at different sites because of high fracture stress level due to strong bonding forces among the constituent elements [6]. The amorphous structure is proved by from the enlarged micrograph of the fracture surface revealing smooth surface with “river” and “shell” patterns which appear in the vicinity of the walls of mould, as shown in Figs. 4 and 6.

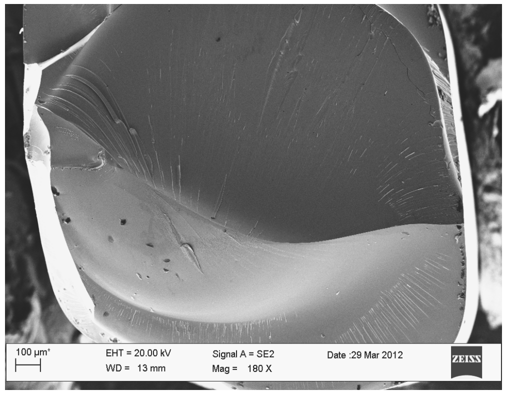

Fig. 3. SEM micrographs of the fracture morphology of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ rod in as-cast state with diameter of 1.5 mm

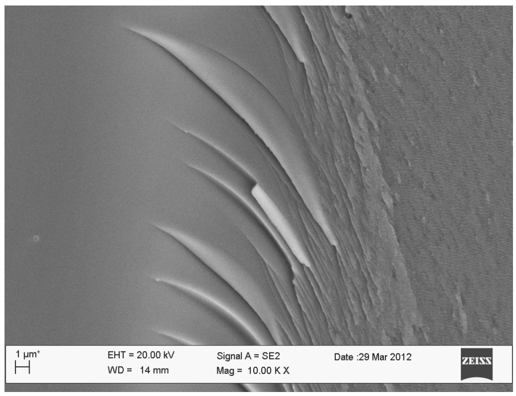

Fig. 4. SEM micrographs of the fracture morphology of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ rod in as-cast state with diameter of 1.5 mm

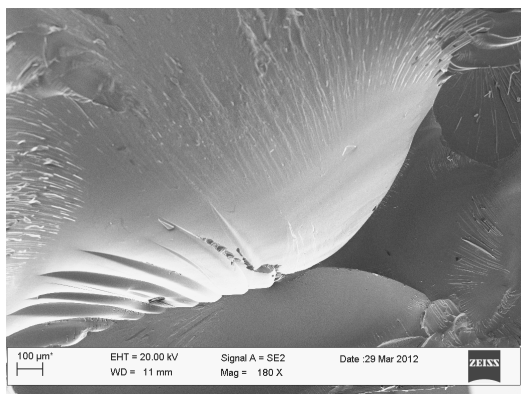

Fig. 5. SEM micrographs of the fracture morphology of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ rod in as-cast state with diameter of 2 mm

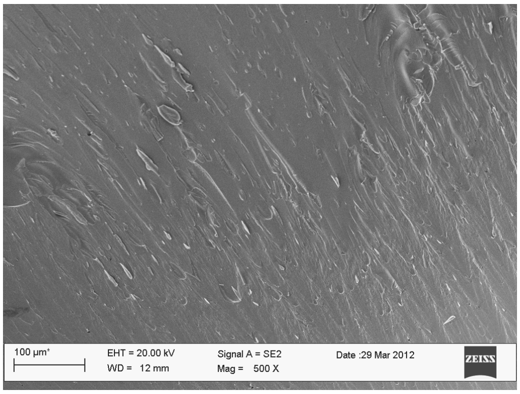

Fig. 6. SEM micrographs of the fracture morphology of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ rod in as-cast state with diameter of 2 mm

3.3. Thermal analysis

The DSC curves obtained for amorphous rods with diameter of 1.5 and 2 mm in as-cast state for $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ alloy are shown in Figure 7 and Figure 8. Results of DSC investigations for studied samples showed that glass transition temperature increase from 838 K to 839 K with increasing of sample diameter from 1.5 to 2 mm.

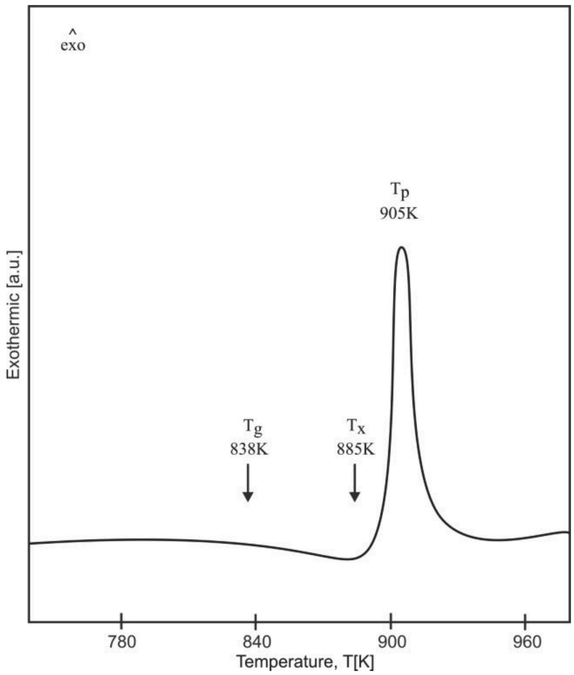

Fig. 7. DSC curve of $Fe_{57.6}Co_{7.2}Ni_{7.2}B_{19.2}Si_{4.8}Nb_4$ alloy in as-cast state in form of rod with diameter of 1.5 mm

The DSC examinations of rod with diameter of 1.5 mm allow to indicate the onset crystallization temperature equal T_x=885 K and determine the peak crystallization temperature, which has a value of T_p=905 K. Similarly, for sample with diameter of 2 mm: the onset crystallization temperature achieve a value of T_x=883 K and the peak crystallization temperature is T_p=903 K. The crystallization temperatures obtained from DSC curves are connected with thermal properties of studied Fe-based bulk metallic glass in form of rods in as-cast state.

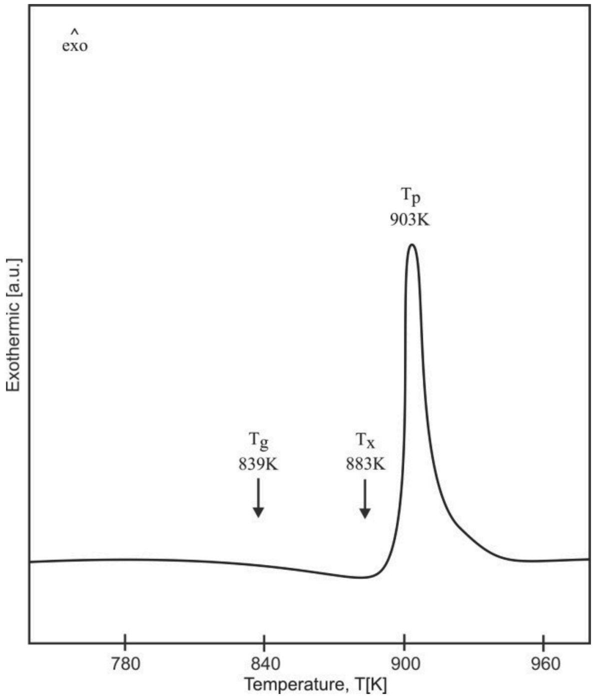

Fig. 8. DSC curve of $Fe_{57.6}Co_{7.2}Ni_{7.2}B_{19.2}Si_{4.8}Nb_4$ alloy in as-cast state in form of rod with diameter of 2 mm

4. Conclusions

Recently, there has been increasing interests in developing of bulk metallic glasses with great glass forming ability due to their unique properties different from these of conventional materials and the potential engineering applications.

The Fe-based bulk metallic glasses in form of rod with good glass forming ability were produced by die pressure casting method. The experimental results have shown us that it can be successfully cast into rod for the forming $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ alloy. On the basis of obtained results one can state that the rods of $Fe_{37.44}Co_{34.56}B_{19.2}Si_{4.8}Nb_4$ alloy have amorphous structure and good thermal properties. These tested rods with diameter of 1.5 and 2 mm exhibit similar characteristic temperatures (T_g, T_x, T_p). The exothermic peaks describing crystallization process of studied bulk metallic glasses is observed. The higher value of glass transition temperature and crystallization temperature may extend the application temperature region of the bulk metallic glasses in scheduled researches.

Morphology of cross section rods is changing having contact with copper mould during casting from smooth fracture inside rod to fine narrow dense veins pattern near to rod surface. These rods have smooth surface and metallic luster. The presented fractures are characteristic for metallic glasses, and more, exothermic reaction reveals occurrence of an amorphous phase.

The success of Fe-based bulk metallic glasses production in form of rod with obtained sizes is important for future progress in joining research of this material. That is why, it was necessary to determine structure and thermal properties of studied alloy.

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