Journal of Achievements in Materials and Manufacturing Engineering

VOLUME 61
ISSUE 2
December
2013

# A study of the mechanical properties of amorphous iron-based alloy produced by the injection-casting method

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Received 11.10.2013; published in revised form 01.12.2013

Properties

## ABSTRACT

**Purpose:** The paper present determine the basic mechanical properties of amorphous alloy based on iron ($Fe_{61}Co_{10}Zr_5W_2Y_2B_2$), produced by injection.

**Design/methodology/approach:** The study was carried out the following steps: at fist microhardness were performed with using microhardness tester Future Tech FM 7 by Vicker's method with load 970.7 mN. Second step were performed abrasion tests on ball-tester with zirconium ball. These tests were performed in 3 steps – first (study was conducted in one hour), second (study was conducted in two hours), third (study was conducted in three hours). Third kind of study was roughness performed on profilometer Hommel T1000. The sample surface was examined in the section 4.8 mm. After high-resolution photos were then taken with a scanning electron microscope (JEOL JSM - 6610 LV). In contrast images with areas threadbare, made using an optical microscope Axiovert 25.

**Findings:** Tests results of samples in of the alloy ($Fe_{61}Co_{10}Zr_5W_2Y_2B_2$) in the form of plates were confirmed higher microhardness amorphous alloy than material with same chemical composition but with crystalline structure.

**Originality/value:** Receipt of amorphous alloys with unique mechanical properties for electronics applications.

**Keywords:** Receipt of amorphous alloys with unique mechanical properties for electronics applications

**Reference to this paper should be given in the following way:**
M. Szota, M. Supernak, A. Bukowska, M. Nabialek, P. Pietrusiewicz, A study of the mechanical properties of amorphous iron-based alloy produced by the injection-casting method, Journal of Achievements in Materials and Manufacturing Engineering 61/2 (2013) 289-293.

## 1. Introduction

Carefully controlled chemical composition and quenching speed of alloy during the production process facilitate the creation of Fe-based alloys without periodical crystalline structure and long-range atomic order [1,2]. In the amorphous Fe-based alloys, magnetocrystalline anisotropy is present, which allows creation of materials characterized by a very small value of coercivity and a high value of initial magnetic susceptibility, i.e.: materials that exhibit so-called 'soft' magnetic properties [3,4].

During the last forty years, researchers have devoted substantial time to researching Fe-based amorphous alloys. These materials are characterized by very good mechanical properties and unique physicochemical properties, which cannot be obtained by materials with a crystalline structure [3].

The first bulk amorphous alloys were fabricated in the shape of ribbon, at quenching speeds of $10^4$-$10^6$ K/s. However, the thickness of the ribbons was limited to a maximum of approximately 35 μm, which significantly restricted the range of possible applications. This is why increasing the dimensions of bulk amorphous alloys became an important issue for technological development.

In the last twenty years, technologies facilitating production of the bulk amorphous alloys have been developed [5]. Two of these methods are: suction- and injection-casting; these involve either the suction or injection, respectively, of the liquid alloy into a copper die.

In this paper, the results of investigations into the microstructure and chosen mechanical properties of the $Fe_{61}Co_{10}W_2Y_2B_{20}$ alloy, in the plate form, are presented. The sample for investigation was obtained using a quenching speed of $10^4$-$10^6$ K/s.

## 2. Materials and methods

The samples used in these investigations were made using high-purity elements: Fe, Co, Zr, W, Y = 99.98%. Boron was added as a ready-prepared alloy in the form of FeB.

The initial stage of the manufacturing process for bulk amorphous alloys is that of preparing the ingots. All components were re-melted several times using arc-melting under a protective atmosphere of neutral gas. The final ingots were subjected to cleaning, and then ground down into smaller charge portions. Finally, the molten alloy was injected into a copper die, and the final sample in the shape of a plate shape was obtained (Fig. 1).

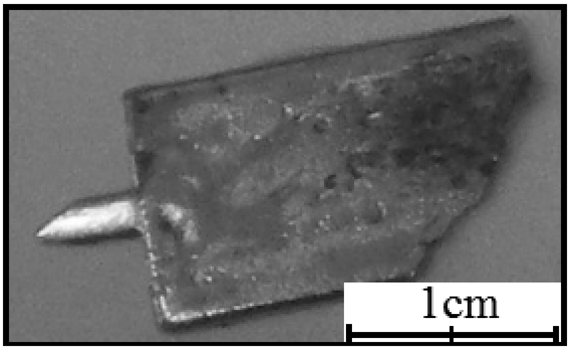


Fig. 1. Example image of the $Fe_{61}Co_{10}W_2Y_2B_{20}$ alloy sample, in the form of a plate, obtained by the injection-casting method

The high-resolution images of the microstructure of the investigated alloy were obtained using a 'JEOL JSM-6610 LV' scanning electron microscope. The sample was etched using nital (a solution of alcohol and nitric acid), which revealed the underlying microstructure. In order to obtain the chemical composition of the sample, energy-dispersive X-ray spectroscopy (EDS) analysis was performed during a scanning electron microscope (SEM). The microhardness of the samples was measured with a 'FutureTech 740', using the Vickers method. The average value was taken from 5 prints, created from the edge towards the centre of the plate using a 100 G load with a pressure time of 6 s. The abrasion resistance of the sample was measured by means of a 'Kulotester'. The latter method relied on surface area measurements of an abrasion, created by friction between a rotating stainless steel ball and the surface of the sample. The ball was set in motion by a roller-drive mechanism, resulting in a spherical-section grind-mark on the surface. Hence, the ball had three contact points: two on the roller drive and one on the surface to be tested. The resulting measurements were performed after: 1, 2 and 3 hours duration. The surface profile of the investigated sample was taken by means of a Hommel TESTER T1000. Images of the samples, with abraded areas after the abrasion test, were taken using an optical microscope.

## 3. Results of the investigations

An image of the microstructure of the produced sample, obtained by means of a high-resolution microscope, is shown in Fig. 2.

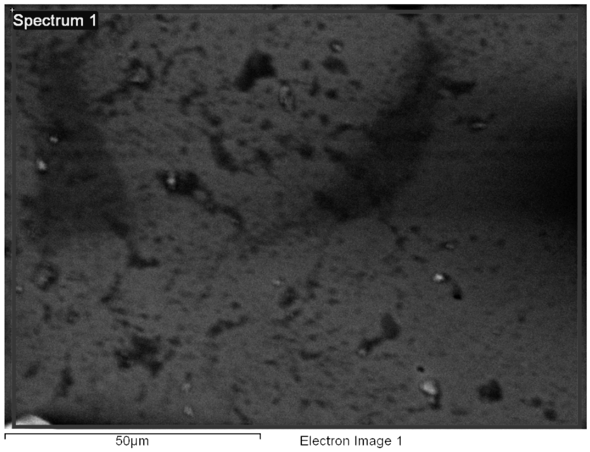


Fig. 2. An image of the investigated sample, obtained using a scanning electron microscope

The results of the investigations into the chemical composition of the sample are presented in Fig. 3.

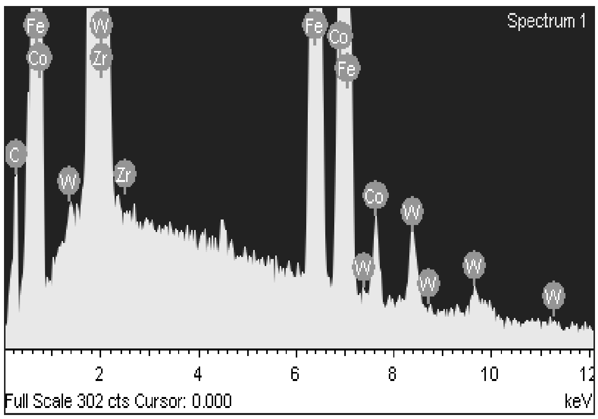


Fig. 3. Spectrum of the chemical elements present on the surface of the investigated sample

The chemical composition of the alloy, after the production process, is presented in Table 1.

Table 1.
Chemical composition of the sample in the as-cast state

| Element | Weight % | Atomic % |
|---|---|---|
| C | 5.69 | 23.66 |
| Fe | 65.97 | 58.94 |
| Co | 13.16 | 11.15 |
| Zr | 7.77 | 4.25 |
| W | 7.40 | 2.01 |
| Total | 100 | 100 |

On the basis of the composition analysis presented in Table 1, it was stated that the produced, plate-shaped, sample had a high degree of homogeneity. The microhardness measurements, performed using the Vickers method with load of 100 G and applied pressure time of 6 s yielded results which are presented in Table 3.

Table 3.
The results of the microhardness measurements

| Lp. | Microhardness [HV0.1] |
|---|---|
| 1 | 1162.5 |
| 2 | 1124.8 |
| 3 | 1138.9 |
| 4 | 1140.7 |
| 5 | 1148.8 |
| Average | 1143.1 |

The obtained bulk amorphous alloy is characterized by a much higher value of microhardness than the equivalent crystalline counterpart. The average microhardness for amorphous alloys is in the order of 1100 HV0.1 [26], whereas that for their crystalline counterparts is below 600 HV0.1 [27]. The improvement of the microhardness in the produced amorphous alloy is connected to the 'freezing' of the atomic structure during the rapid quenching process.

The roughness parameters are important in deciding on the likely abilities and applications of the alloy. The abrasion areas obtained after: 1, 2 and 3 hours are presented in Fig. 4.

On the basis of the obtained images, it could be stated that the largest diameter of the abrasion area was observed for the sample after the 3 hours test duration (Table 4). This means that, after the previous two tests, the surfaces of the sample had not been hardened.

Table 4.
Measurement data obtained from the roughness test

| Lp. | Zone description | Time of test | Cut diameter [μm] |
|---|---|---|---|
| 1 | A | 1 hour | 2250 |
| 2 | B | 2 hours | 2100 |
| 3 | C | 3 hours | 2950 |

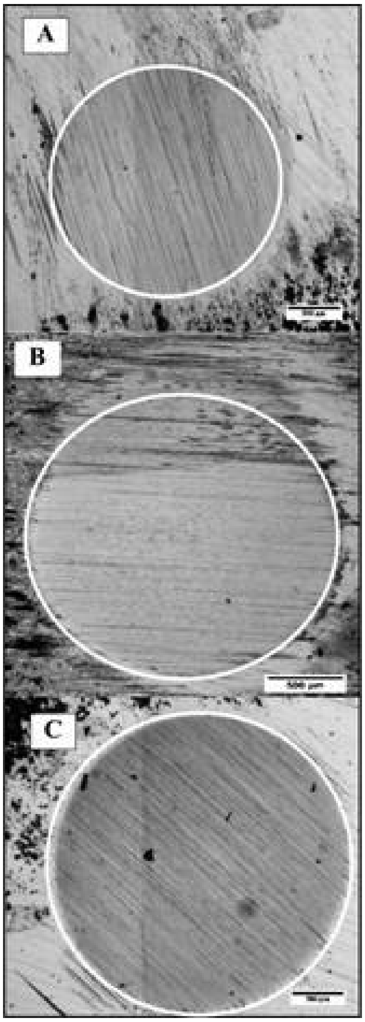


Fig. 4. Images of the abrasion areas, obtained with the magnification of 50x. Time of test: A - 1 hour, B - 2 hours, C - 3 hours

The results of the investigations on the surface of the sample plate, obtained by means of the profilometer, are presented in Figs 5-8. The surface was measured on a length of 4.8 mm.

Analysis of the curves presented in Figs. 5-8 facilitated the calculation of the main roughness parameters.

Table 5.
Roughness parameters, obtained for the investigated alloy

| Parameter | Measurement | | | | Average |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| $R_a$ [μm] | 1.83 | 1.70 | 1.56 | 3.07 | 2.04 |
| $R_z$ [μm] | 12.67 | 11.18 | 9.83 | 14.40 | 12.02 |
| $R_{max}$ [μm] | 26.43 | 22.16 | 12.85 | 35.22 | 24.17 |

A description follows, for the roughness parameters presented in Table 5:

- $R_a$ - arithmetic mean of the roughness of the abrasion profile,
- $R_z$ - average profile height,
- $R_{max}$ - maximal profile height.

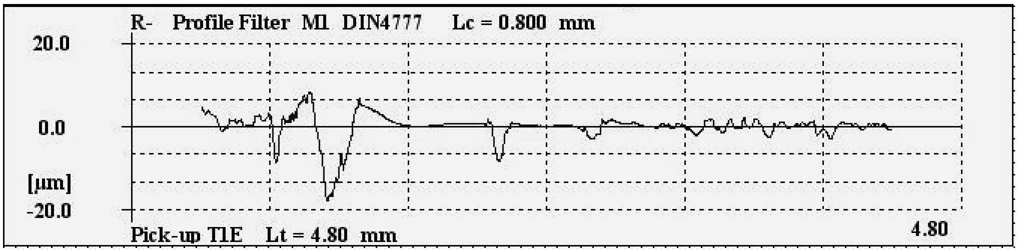


Fig. 5. First measurement of the abrasion profile for the $Fe_{61}Co_{10}W_2Y_2B_{20}$ sample in plate form

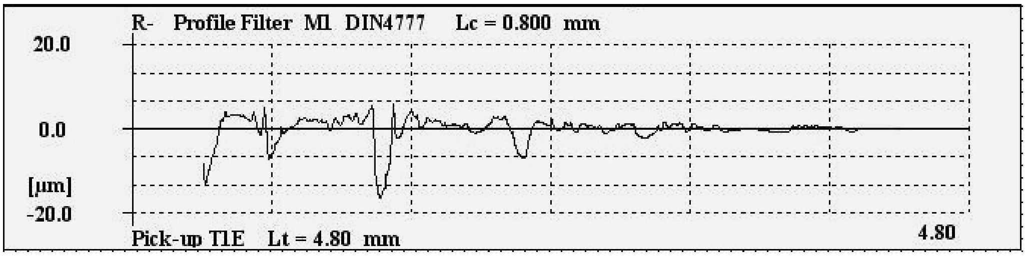


Fig. 6. Second measurement of the abrasion profile for the $Fe_{61}Co_{10}W_2Y_2B_{20}$ sample in plate form

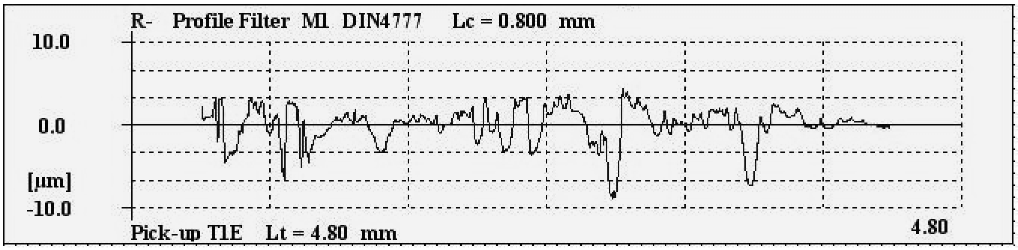


Fig. 7. Third measurement of the abrasion profile for the $Fe_{61}Co_{10}W_2Y_2B_{20}$ sample in plate form

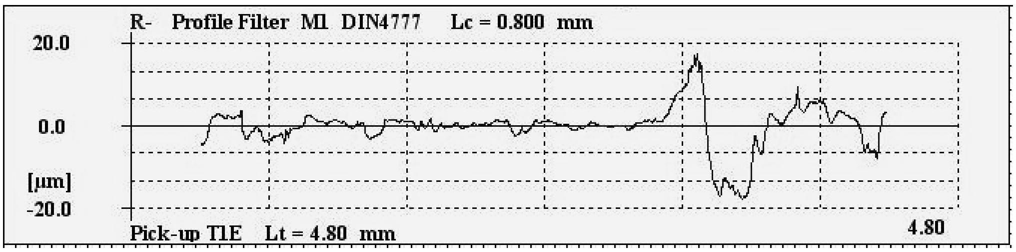


Fig. 8. Fourth measurement of the abrasion profile for the $Fe_{61}Co_{10}W_2Y_2B_{20}$ sample in plate form

The surface roughness parameters have a significant influence on the functional parameters of materials used for production of precision instruments for optical surgery, and also on the lifetime of machines and devices in which materials are being used for bearings. Excessive roughness of the surface could cause quicker wear of such equipment. The surface parameters also make up one area of the related technical acceptance parameters. It could be stated that the surface parameters for the investigated samples are within the range for materials obtained by casting methods.

The average of Ra measurements - arithmetic mean roughness of the abrasion profile for the investigated surface of the sample - was found to be equal to 2.04 µm. For the casting method, this parameter should be less than 5 µm.

## 4. Conclusions

The injection-casting method (i.e. injection of molten material into a cooled, copper die) allows for production of amorphous material samples with thicknesses significantly greater than those of ribbons obtained by the classic production method. The production process of bulk amorphous alloy is very complicated and therefore has to be designed correctly. To ensure that the production process is successful, several factors have to be taken into account: choice of the correct ingredients, selection of a suitable cooling speed and negative heat mixing between the main alloy components.

The measurements of the microhardness for the amorphous sample of $Fe_{61}Co_{10}Zr_5W_2Y_2B_{20}$ alloy, in the form of a plate, showed that the microhardness value is higher then for its crystalline counterpart. An increase in the microhardness value can be explained by changes in the microstructure. In amorphous materials, short-range interactions occur between atoms, which result in a higher degree of atomic packing and higher density. The 'freezing' of the liquid alloy in the glass state, and hence in the 'higher density of alloy' state, is the cause of the increase in microhardness.

On the basis of the abrasion measurement results, it can be stated that arithmetical mean of the roughness of the abrasion profile is within the range expected for materials produced by this method. Materials manufactured using this method would be able to fulfil quality requirements for technical acceptance, regarding roughness parameters.

The chemical composition of the sample in the measurement area differs significantly from the planned composition. This is attributed to a lack of long-range atomic ordering and periodicity of the crystalline structure.

The metallic glasses make up a very interesting group of materials because their properties differ from their crystalline counterparts. The number of applications for these alloys is growing rapidly. The issues are the high cost of the necessary high-purity elements and the synthesis process of the alloy. This is why many research centres currently are working on new methods of production.

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