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Change of Magnetic Saturation Polarisation as a Function of Temperature in Bulk Fe-Based Amorphous Alloys

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This paper presents the results of research on the magnetic saturation polarisation, as a function of temperature, for rapidly-cooled iron alloys with an amorphous structure. The rapidly-cooled Fe-based amorphous alloys are characterised by good magnetic properties. The Curie temperature is one of the main parameters that determine the stability of the ferromagnetic properties of such alloys. The tested materials met the assumptions of Heisenberg's theory; therefore, the critical factor, $\beta = 0.36$, was used to determine the Curie temperature. It was found that both of the tested alloys have one Curie temperature pertaining to the amorphous matrix — which proves their effective homogenisation.

topics: magnetic weight, bulk amorphous materials, magnetic saturation polarisation, Curie temperature

1. Introduction

The constantly developing market of electrotechnical materials and their growing use have forced scientists to develop new materials with the desired properties [1, 2]. Commonly used devices operate up to a critical temperature of about 100 °C. Above this temperature, electrical systems lose their properties. In many cases, this temperature is also insufficient due to the nature of the device. Therefore, it is important to develop materials for which the Curie temperature is stable to a range in excess of 100 °C and the material properties do not deteriorate. The Curie temperature is the main parameter that determines the stability of the ferromagnetic state; above it the material becomes paramagnetic [3–5]. In terms of use, it loses its properties and the device no longer meets the set standards.

In the 1990s, a new group of materials called the bulk amorphous materials was developed [6–8]. These materials are amorphous alloys, whose thickness is greater than 100 μm. Amorphous ribbons, which had been commonly produced since the 1970s, did not meet many application requirements and it was necessary to develop new volumetric amorphous materials. It turned out that this is impossible for materials with larger thicknesses. Therefore, a search for methods and rules for the production of bulk materials began. It was not until 1989 that A. Inoue and his colleagues at Tohoku University set out three criteria, the observance of which makes it possible to systematically produce volumetric amorphous alloys [8]. They assumed that there should be more than three components in the alloy composition, the atomic rays of which (at least their main components) will differ by more than 12% and, in addition, these components should have a negative mixing heat. These assumptions have a decisive impact on reducing the migration of atoms in the volume of a liquid alloy over greater distances. Blocking atoms in the coagulation process block the internal energy of the system.

The resulting thermodynamically unstable state is typical of amorphous or nanocrystalline materials [9–15]. Of course, a further supply of energy to the system, usually thermal, causes groups of atoms to jump through individual pits of potential and eventually the minimum energy corresponding to the crystalline state is reached [9, 16].

Bulk amorphous alloys are produced using a number of production methods, but the most popular ones include the method of injection and suction of a liquid alloy into a water-cooled copper form [17–21]. The amorphous structure is definitely different from the crystalline structure and is characterized by slightly different properties. Regarding the Curie temperature, it is necessary to talk about its narrow range rather than its discrete value.

This work presents the results of structure studies and thermomagnetic tests performed for two amorphous alloys, (i) $Fe_{70}Y_5Nb_5B_{20}$ and (ii) $Fe_{70}Y_5Nb_5Mo_1B_{20}$, produced using the method of sucking the liquid alloy into a copper water-cooled mold.

2. Materials and methods

Rapidly-cooled test samples were made from high purity ingredients: Fe — 99.98%, Co — 99.99%, Y — 99.98%, Nb — 99.99%, Mo — 99.99%, and B — 99.98%. All ingredients were weighed to the nearest 0.0001 g. The weighed ingredients were melted using an arc furnace and crystalline ingots were obtained. A pre-melting procedure was carried out in a protective atmosphere of argon (Ar). In order to mix the ingredients well, the ingot was melted four times on each side. Before each melting, pure titanium was melted, which acted as an absorbent for oxygen remaining inside the chamber. Such prepared ingots were cleaned of oxides mechanically and by using an ultrasonic cleaner. They were then divided into smaller portions using a mechanical guillotine. Pieces of the ingot were placed on a copper plate. The charge was melted using a tungsten electrode. A liquid alloy was sucked into a copper water-cooled form. Samples produced were plates with 0.5 mm thickness and approximately 100 mm^2 area. The post-solidified samples were subjected to structure measurements using a BRUKER ADVANCE 8 X-ray diffractogram. The measuring apparatus was equipped with a cobalt lamp and worked in Bragg Brentano geometry. The prepared preparation in the form of the obtained low-energy powder was irradiated by Roentgen rays at room temperature in the range of angle 2θ from 30 to 120° with an exposure time of 7 s per measuring step of 0.02°. The test samples were crushed in agate mortar within toluene.

The measurements of magnetic saturation polarisation as a function of temperature were made using Faraday's magnetic balance. About 25 mg of the sample was placed in a platinum basket axially coupled to a 1 m quartz holder. The measurements were made in a vacuum in the temperature range of up to 800 K with a build-up time of 10 K/min.

3. Results

Roentgen diffraction images for the tested alloys in the post-solidification state are shown in Fig. 1. These diffractograms are all similar. There appears only a single wide maximum typical for amorphous materials. The maximum occurs in the 2θ angle range from 40 to 50°. The rest of the diffractograms are low-intensity backgrounds. The absence of a crystalline cell, which is periodically repeated in volume and more specifically the associated crystalline planes, results in the image observed in Fig. 1a and b. The test samples are magnetic materials with magnetically soft properties.

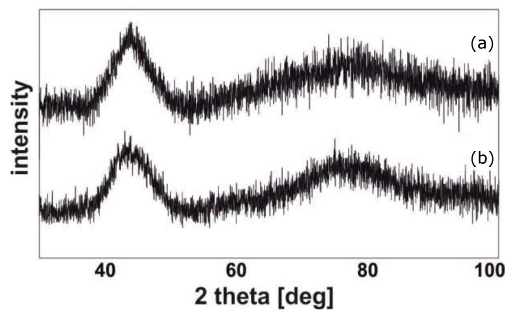

Fig. 1. X-ray diffraction patterns for the alloy samples: (a) $Fe_{70}Y_5Nb_5B_{20}$, (b) $Fe_{70}Y_5Nb_5Mo_1B_{20}$.

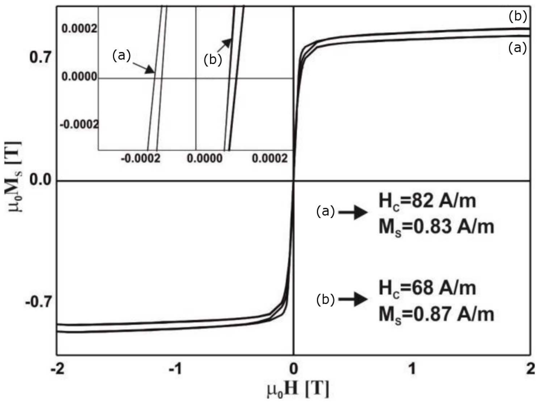

Fig. 2. Static magnetic hysteresis loops for tested alloys in solidified state: (a) $Fe_{70}Y_5Nb_5B_{20}$, (b) $Fe_{70}Y_5Nb_5Mo_1B_{20}$.

Figure 2 shows static magnetic hysteresis loops measured in the magnetic field intensity range up to 2 T.

The shapes of the static magnetic hysteresis loops for both samples are similar and typical for magnetically soft materials. Thermomagnetic curves and curves describing the relationship $\mu_0 M_S^{1/\beta}(T)$ are given in Fig. 3. The course of magnetic saturation polarity as a function of temperature indicates that both alloys have one Curie temperature. This means that there are no significantly different amorphous matrices in the produced alloys. This conclusion shows that the samples obtained were homogeneous. The very course of curves near 600 K reaches almost a zero magnetization value. Thus, it can be concluded that the material was fully amorphous, since there was no factor that increases the value of magnetization as the temperature increases.

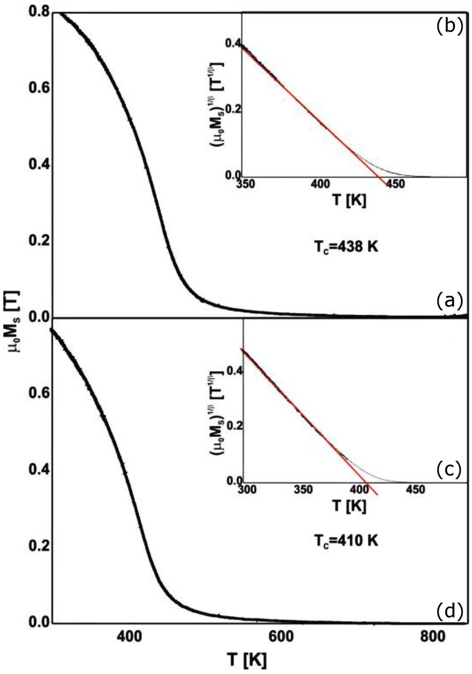

Fig. 3. Thermomagnetic curves for: $Fe_{70}Y_5Nb_5B_{20}$ alloy: (a) $\mu_0 M_S(T)$, (b) $\mu_0 M_S^{1/\beta}(T)$ and for $Fe_{70}Y_5Nb_5Mo_1B_{20}$ alloys: (c) $\mu_0 M_S(T)$, (d) $\mu_0 M_S^{1/\beta}(T)$.

It is clear that at higher temperatures, unfortunately beyond our measurement capabilities, there would be a change in the magnetization value due to the crystallization of the tested samples.

4. Conclusions

The tested samples show a fairly high Curie temperature. This means that they can be successfully used in devices that operate at temperatures up to 400 K. In addition, it can be concluded that the suction method gives the possibility to produce amorphous samples with good magnetically soft properties.

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