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Research on Magnetic Anisotropy in Amorphous Materials with Soft Magnetic Properties

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During the magnetization process, the increase in magnetization is blocked by the increase in the magnetic field strength. The reason for these magnetic delays may be the magnetic anisotropy of the tested material. In crystalline materials, this phenomenon is quite well described and is related to the parameters of the crystal lattice. For amorphous alloys, which do not have long-range atomic order, this phenomenon has been much less studied. The paper presents the results of studies on the primary magnetization curves for two different alloys showing soft magnetic properties measured in three different directions: parallel to the casting direction, perpendicular to this direction, and perpendicular to the alloy surface. As indicated by the research, in amorphous materials, one can distinguish the direction of difficult magnetization and two easier ones, which means that the phenomenon of magnetic anisotropy occurs in them.

topics: bulk amorphous alloys, magnetic anisotropy, coercive field

1. Introduction

Magnetization of magnetic materials is a phenomenon that consists in the increase in the magnetization of the material under the influence of an external magnetic field. The mechanism of magnetization is strongly dependent on the structure of the material, namely the type of structure (crystalline or amorphous structure) and its directionality, related to the manufacturing process (isotropy–anisotropy). In crystalline materials, magnetic anisotropy is related to the orientation of the basic structural cell of the material. The phenomenon results from the configuration of the crystal lattice. Parameters such as the magnetic anisotropy constant and anisotropy energy are directly related to the symmetry of the lattice and spin interactions [1, 2]. In the case of amorphous materials, there is no long-range ordering of atoms. In the area of the nearest atomic neighbors, there are orders similar to crystalline systems (various types of polyhedra), however, in the volume, the amorphous alloy is characterized by a disordered structure [3]. Amorphism consists in introducing randomness in the arrangement of atoms, which prevents the activation of anisotropy known from the crystal lattice. However, the results of research for amorphous materials indicate possible effects of magnetic anisotropy. In this context, the study of various factors that may influence the occurrence of the phenomenon of magnetic anisotropy becomes an important aspect.

Previous studies show that in amorphous materials, different directions of magnetization can be distinguished, of which at least one is more difficult [4]. This indicates the occurrence of magnetic anisotropy, despite the lack of long-range atomic ordering. Such an effect is obvious for classical amorphous materials in the form of ribbons. In this case, the manufacturing process affects the orientation of the structure and, consequently, the presence of an easier and more difficult direction of magnetization.

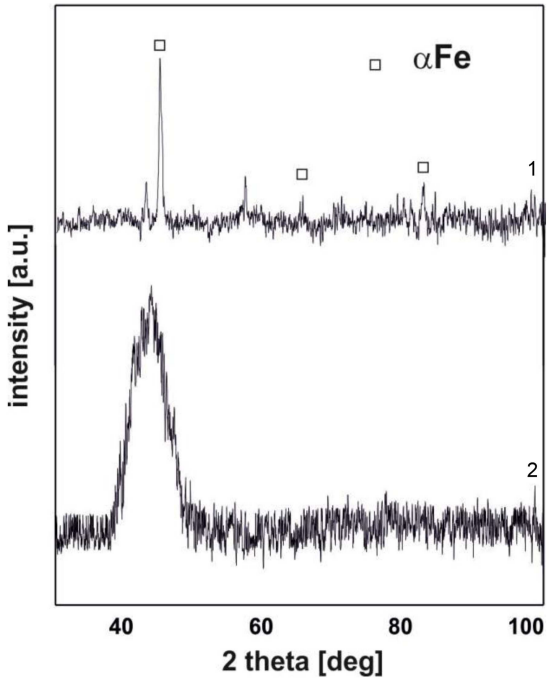

Fig. 1. X-ray diffraction patterns for the samples of the $(Fe_{92,5}Si_{2,5}Hf_{2,5}Nb_{2,5})_{79.5}B_{19.5}$ alloy: line 1 — polycrystalline, line 2 — amorphous.

The aim of this article is to present the results of research on the magnetization curves of amorphous alloys, which are subjected to functional properties analysis. In these studies, the primary magnetization curves and static magnetic hysteresis loops measured in two perpendicular directions were analyzed.

2. Experimental procedure

The elements were weighed to the nearest 0.0001 g. Polycrystalline alloys were produced in an arc furnace on a water-cooled copper plate. The melting process was carried out in a protective atmosphere of argon using a non-consumable tungsten electrode, using a current intensity of 180–300 A. The ingot was melted several times, each time turning it over to the other side to mix the components, preceded by melting the titanium getter to capture the remaining oxygen in the working chamber. The bulk rapid-cooled alloy was produced using the extrusion method. The process was carried out in a protective atmosphere of argon after previously obtaining an appropriate vacuum in the working chamber of the order of 10^{-5} mbar. The charge was placed in a quartz crucible in a hole with a diameter of 1 mm, and the melting itself was carried out using eddy currents. The liquid alloy was pressed into a copper mold under argon pressure. Samples were obtained in the form of 0.5 mm thick plates.

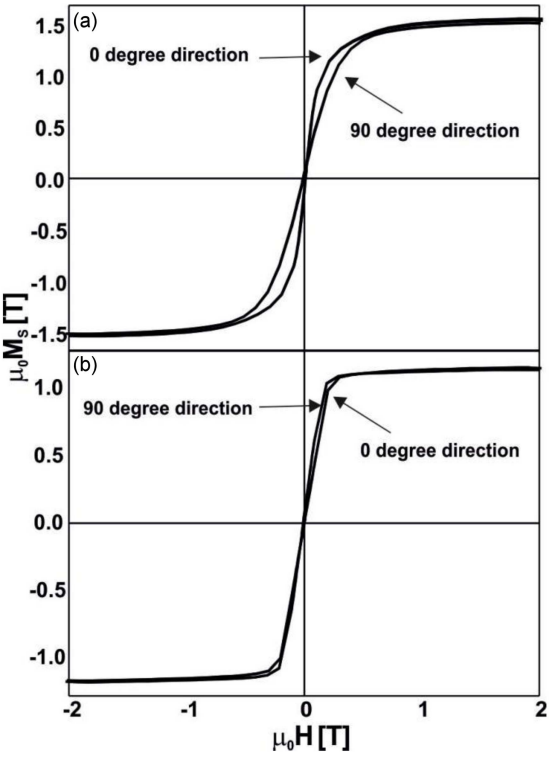

Fig. 2. Static magnetic hysteresis loops measured in two directionsfor the samples of the $(Fe_{92,5}Si_{2,5}Hf_{2,5}Nb_{2,5})_{79.5}B_{19.5}$ alloy: (a) polycrystalline, (b) amorphous.

The structure of the produced alloys was studied using X-ray diffraction. A Bruker D8 ADVANCE X-ray diffractometer was used. Measurements were carried out in the range of 30–100° of the 2θ angle, with a measurement step of 0.02° (exposure time 7 s per measurement step). Samples were measured in powder form at room temperature. A polycrystalline ingot and an amorphous alloy were tested.

Static magnetic hysteresis loops and primary magnetization curves were measured using a Lake Shore 7307 vibrating sample magnetometer in the range of external magnetic field intensity up to 2 T. A polycrystalline ingot and an amorphous alloy were tested, and measurements were carried out in two mutually perpendicular directions.

3. Results

Figure 1 shows the X-ray diffraction patterns measured for the $(Fe_{92,5}Si_{2,5}Hf_{2,5}Nb_{2,5})_{79.5}B_{19.5}$ alloy samples.

The upper part of Fig. 1 concerns the measurement for a polycrystalline sample. This diffraction pattern (line 1) is typical for a polycrystalline material. Due to the probable presence of many crystalline phases rich in Fe and B, a detailed analysis of the diffraction pattern is difficult. The presence

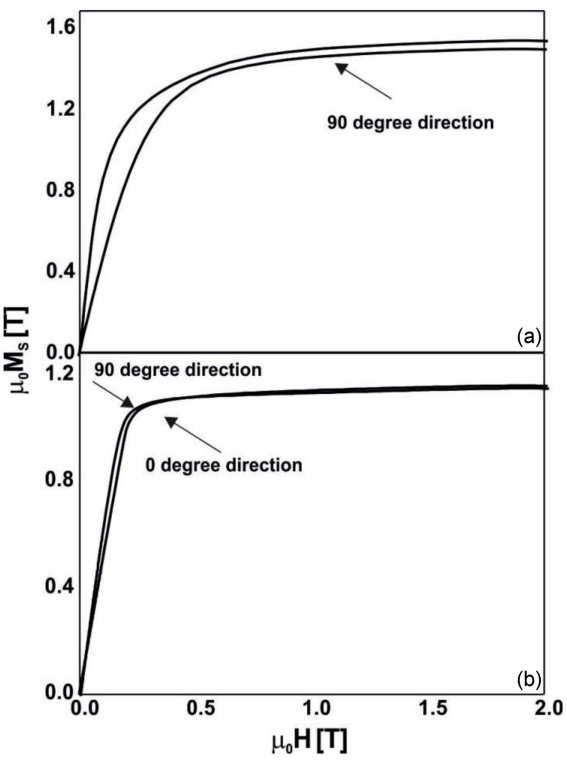

Fig. 3. Initial magnetization curves, measured in two directions for the samples of the $(Fe_{92,5}Si_{2,5}Hf_{2,5}Nb_{2,5})_{79.5}B_{19.5}$ alloy: (a) polycrystalline, (b) amorphous.

TABLE I

Values of $\mu_0 M_S$ — saturation magnetization [T], H_C — coercivity field [A/m], P_1 — anisotropy field in the first direction [kJ/m^3], and P_2 — anisotropy in the second direction [kJ/m^3] of the polycrystalline and amorphous alloy samples.

$(Fe_{92,5}Si_{2,5}Hf_{2,5}Nb_{2,5})_{79.5}B_{19.5}$	$\mu_0 M_S$	H_C	P_1	P_2
polycrystalline	1.51	1240	230	293
amorphous	1.16	31	134	112

of the αFe phase was identified with certainty, as indicated by the presence of at least three reflections. Line 2 in Fig. 1 is the diffraction pattern measured for the rapidly cooled alloy. In this case, only a wide, diffuse maximum characteristic of amorphous materials is observed.

Figure 2 shows static magnetic hysteresis loops for a polycrystalline ingot and an amorphous alloy. Based on the course of the loop, the values of the saturation magnetization M_S and the coercive field H_C were determined, and the data are included in Table I. Figure 3 shows the primary magnetization curves for a polycrystalline ingot and an amorphous alloy.

The primary magnetization curves measured for the polycrystalline ingot (Fig. 3a) are characterized by a different course compared to the curves measured for the amorphous alloy (Fig. 3b). The magnetization process for the amorphous sample is almost identical regardless of the sample position relative to the electromagnets, the curve courses almost coincide. It can be assumed that both magnetization directions are "easy." In the case of the polycrystalline sample, the situation is different — depending on the sample position, the magnetization process is more difficult. In the polycrystalline sample, there are easier and more difficult magnetization directions. In addition, different values of saturation magnetization are visible (Table I gives values for the magnetization direction 0°). Based on the curve courses, the value of magnetic anisotropy was determined (see Table I).

The magnetic anisotropy value for the polycrystalline sample is about twice as high as for the amorphous alloy sample. Furthermore, it is worth noting the relatively good soft magnetic properties of the amorphous alloy sample — in particular, the low coercive field value.

4. Conclusions

The conducted studies have shown that for amorphous alloys produced by the extrusion method, at least two "easy" magnetization directions can be distinguished. In the case of a polycrystalline sample, the magnetization process depends on the sample's positioning relative to the direction of the external magnetic field intensity. The research results indicate that the magnetic structure of bulk amorphous alloys is highly homogeneous. The randomness in the arrangement of atoms during the rapid solidification process prevails over the factor related to the directionality of casting the alloy sample.

References

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