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Influence of Defects in Amorphous Structure on the Change of the Course of the Primary Magnetization Curve

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In ferromagnetic crystalline materials, structural defects are well-defined, and many physical phenomena are explained using them. Apart from crystal grains, they play a decisive role in the magnetization process and shape the course of the primary magnetization curve. On the other hand, in amorphous materials, structure defects are very difficult to define, and their direct observation is impossible. The paper presents a method of indirect observation of amorphous structure defects based on the theory of approach to ferromagnetic saturation.

topics: amorphous alloys, Kronmüller theory, free volumes

1. Introduction

Classical amorphous alloys are obtained in the form of ribbons, wires, or powder at high cooling rates of the order of 10^5 K/s [1, 2]. Due to the low ability to form the amorphous state, the thickness of ribbons or the diameter of wires does not exceed 50 μm. As is known, the formation of the amorphous state is the result of competition between the liquid and crystalline phases. Therefore, the amorphous phase can be obtained from the liquid phase if the cooling rate is high enough to prevent the crystallization of the alloy. Amorphous alloys are characterized by unique magnetic properties, which are mainly influenced by their structure [3–6]. These alloys lack structural defects such as dislocations or grain boundaries, which is why amorphous alloys of transition metals are magnetically soft ferromagnets. However, these alloys contain defects such as free volumes and pseudo-dislocation dipoles, which are a source of internal stresses and, as a result of magnetoelastic interactions, cause an inhomogeneous distribution of magnetization. Structural defects that are a source of long-range stresses are centers that inhibit the movement of domain walls during the magnetization of the amorphous alloy. Fluctuations in parameters such as exchange interaction or local anisotropy may also occur in amorphous alloys. In strong magnetizing fields, where there is no domain structure, the decisive role in the remagnetization process is played by defects, which are the source of internal stresses. As a result, the alloy sample is not magnetized to saturation. Magnetoelastic interactions between stress and magnetization contribute to the formation of non-collinear magnetic structure. With the increase in the magnetizing field intensity, an increase in magnetic polarization is observed due to microscopic rotations of magnetic moments and damping of thermally excited spin waves. Using the theory of approaches to ferromagnetic saturation [7–10], we can determine the type of defects that affect the alloy magnetization process.

The aim of this work was to investigate the structure and microstructure of amorphous ribbons and to determine the defects affecting the rotations of the magnetization vector in strong magnetizing fields.

2. Experimental procedure

The alloy presented in the work was prepared from the starting polycrystalline alloy, namely $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$. Elements with a purity exceeding 99.99% of the batch material were weighed to the nearest 0.001 g. The amorphous ribbons with a thickness of 2 mm and a width of 30 mm were prepared in an argon atmosphere by a single-roller melt-spinning technique. The microstructure of these ribbons was studied by X-ray diffractometry and Mössbauer spectroscopy. The X-ray diffractometer was equipped with a Cu K_α lamp. The test was carried out for an angle of 2θ over the range from 30° to 100°. The transmission Mössbauer spectra were measured at room temperature

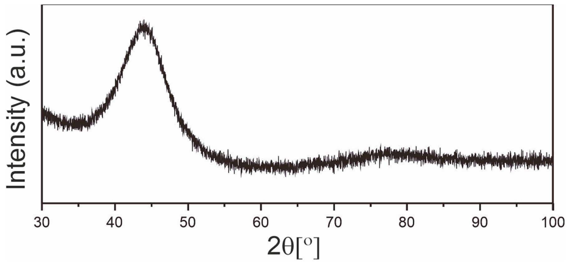


Fig. 1. X-ray diffraction pattern for the $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$ alloy.

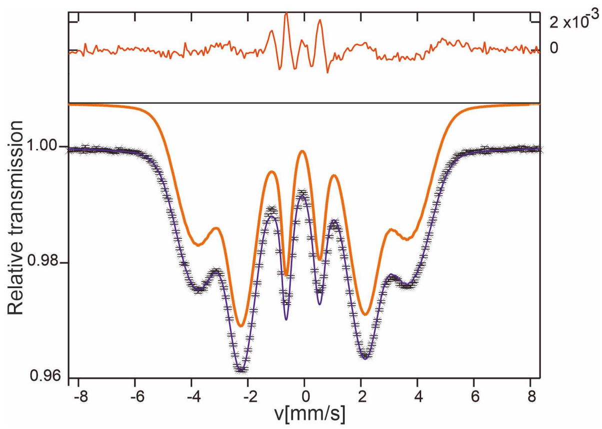


Fig. 2. Transmission Mössbauer spectra for the amorphous alloy $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$ in the form of ribbons.

by means of a conventional constant acceleration spectrometer with ^{57}Co in Rh source of 50 mCi activity. From Mössbauer spectra analysis, the average hyperfine field at the ^{57}Fe nuclei was determined. X-ray diffraction patterns and Mössbauer spectra were recorded at room temperature for powdered samples. The high-field magnetization was measured by a vibrating sample magnetometer. The magnetization as a function of magnetizing field ($\mu_0 H$) near ferromagnetic saturation may be expressed by [11]

$$\mu_0 M\left(H\right) = \mu_0 M_S \left(1 - \sum_{n=1}^{4} \frac{a_{n/2}}{\mu_0 H^{n/2}} + \chi \mu_0 H + b(\mu_0 H)^{1/2}\right), \qquad (1)$$

where M_S is the saturation magnetization, μ_0 — vacuum magnetic permeability for point-like defects, $i = 1$ or 2 for quasi-dislocation dipoles, and the last term describes so-called Holstein–Primakoff paraproces [12]. The coefficient is related to the spin wave stiffness parameter [13] by the relationship

$$b = 3.54 g \mu_0 \mu_{\mathrm{B}} \left(\frac{1}{4\pi D_{sp}}\right)^{3/2} k_{\mathrm{B}} T \left(g \mu_{\mathrm{B}}\right)^{1/2}, \qquad (2)$$

where g is Lande's fission coefficient, and μ_{B} — Bohr's magneton.

3. Results

The general shape of the presented X-ray diffraction patterns for the powdered sample (Fig. 1) is typical for materials with an amorphous structure. For Fe-based amorphous alloys, only the broad maximum at the angle of $2\theta = 45°$ is usually observed. X-rays are scattered from randomly arranged atoms in an amorphous material, for which it is difficult to define a unit cell that constitutes a structural pattern. Therefore, the effect of this scattering of X-rays reflected from an amorphous sample is a broad, low-intensity diffuse peak.

The transmission Mössbauer spectra and corresponding hyperfine field induction distributions are presented in Figs. 2 and 3.

The spectrum is asymmetric and consists of broad, overlapping lines, which is characteristic of amorphous ferromagnets. In the hyperfine field distributions $P(B_{hf})$, at least two components can be distinguished, corresponding to areas with different iron concentrations.

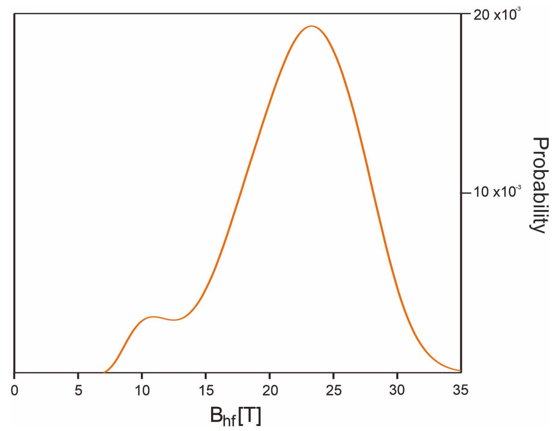


Fig. 3. Corresponding hyperfine magnetic field induction distribution for the amorphous alloy $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$ in the form of a ribbon.

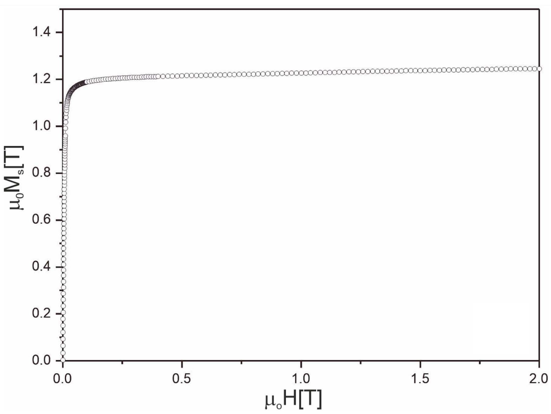
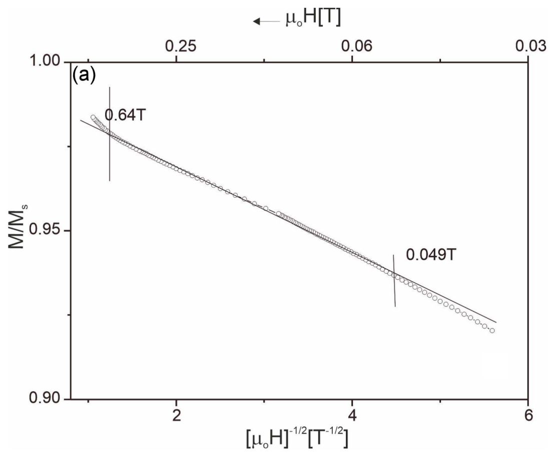


Fig. 4. Primary magnetization curve $M_s(\mu_0 H)$ for the $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$ ribbons.



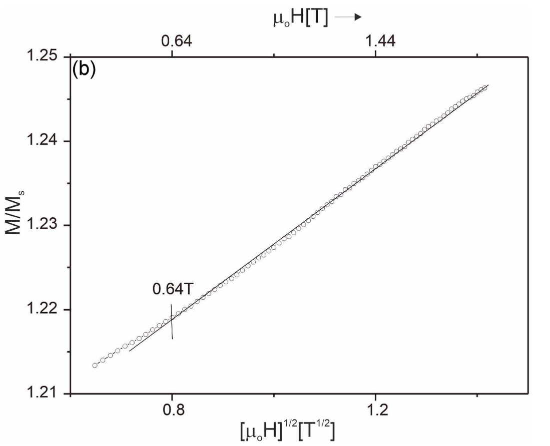


Fig. 5. Saturation magnetization M_s as a function of the magnetizing field induction $\mu_0 H$ (a) and high-field magnetization curves $M/M_s((1/\mu_0 H))$ (b) and $M/M_s((\mu_0 H)^{1/2})$ (c) for the amorphous alloy $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$ in the form of ribbons.

Figure 4 shows the primary magnetization curve measured for $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$.

By analyzing the primary magnetization curve (Fig. 4) in an area called the ferromagnetic saturation approach, using H. Kronmüller's theory, the type of defect occurring in the sample was determined.

In Fig. 5a–b, the curves of magnetization versus induction of the magnetizing field for the investigated ribbons are shown.

In the field induction range, a linear dependence is observed (Fig. 5b), which indicates that in this range of magnetic fields, the magnetization process occurs through microscopic rotations of magnetic moments near free volumes. The free volumes present in these alloys play a similar role to point defects in crystalline alloys. The free volumes facilitate the process of atomic diffusion and lead to thermal and temporal instability of the physical properties of amorphous alloys.

In higher magnetic fields, a linear dependence is observed. Such a dependence indicates the presence of the Holstein-Primakoff paraprocess.

4. Conclusions

On the basis of the obtained results, it could be stated that:

- The alloy in the as-quenched state is fully amorphous, which was confirmed by the results of X-ray and Mössbauer tests.
- Magnetization studies near ferromagnetic saturation have shown that the overmagnetization process of the alloys studied in strong magnetic fields is related to the rotation of magnetic moments near defects that are sources of short-range stresses and the damping of thermally excited spin waves by the magnetic field. Similarly to soft magnetic properties, the changes in magnetization in strong magnetic fields depend on the chemical composition of the alloy. In the case of the $Fe_{65}Co_{11}Zr_2Hf_2B_{20}$ alloy, the magnetization process in strong fields is caused by point defects.
- In stronger magnetic fields, the increase in magnetization occurs due to the suppression of thermally excited spin waves (Holstein–Promakoff paraprocess).

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