Papers submitted to the Conference "Applications of Physics in Mechanical and Material Engineering"

Magnetic Relaxation Occurring in Weak Magnetic Fields in Amorphous Materials

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The phenomenon of magnetic susceptibility disaccommodation occurs in weak magnetic fields. This phenomenon consists in the decrease in time of the magnetic susceptibility of a sample that has been demagnetized with an alternating current of amplitude decreasing to zero. This phenomenon, described in the literature as magnetic viscosity, makes it possible to study the real structure of alloys. The study investigates the phenomenon of magnetic susceptibility disaccommodation for amorphous samples. Magnetic susceptibility curves as a function of temperature and isochronous magnetic susceptibility disaccommodation curves were determined.

topics: bulk amorphous alloys, injection casting, disaccommodation

1. Introduction

Bulk amorphous alloys are materials containing at least three or more elements. The atomic radii of their main components must differ by more than 12%, and additionally, negative heat of mixing between components should appear [1, 2]. Amorphous alloys are characterized by a lack of long-range ordering of atoms. However, short-range ordering is observed.

During the heat treatment of these materials at temperatures much lower than the crystallization temperature, rearrangement of atoms occurs, which can lead to time and thermal instability of their physical properties. These processes are called structural relaxations and occur during the production of amorphous alloys and even at room temperature. One can distinguish between reversible and irreversible relaxation [3]. As a result of irreversible relaxation, it occurs, among others reduction of free volumes frozen in the alloy during its production. Whereas reversible relaxations are caused by small reversible displacements of atoms, and the phenomenon of magnetic susceptibility disaccommodation can be used for their research [4].

This phenomenon consists in the decrease in time the magnetic susceptibility of a sample demagnetized with an alternating field with the amplitude decreasing to zero (see Fig. 1). The theory of disaccommodation of magnetic susceptibility in amorphous alloys was developed by P. Allia and F. Vinai [5–7] and H. Kronmüller [4, 8–12].

The theory of P. Allia and F. Vinai does not fully explain the phenomenon of disaccommodation in amorphous alloys. According to this theory, the disaccommodation intensity is proportional to the square of the effective magnetostriction and the square of the shear stresses. Therefore, in amorphous alloys with saturation magnetostriction of the order of 10^{-8}, the intensity of disaccommodation should be close to zero.

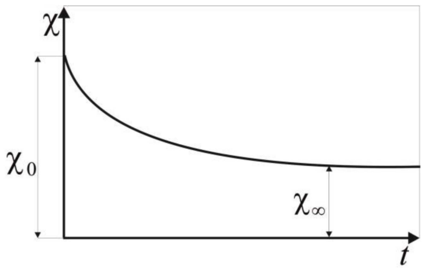

Fig. 1. Magnetic susceptibility curve (χ_o — susceptibility at time $t = 0$, χ_∞ — susceptibility for $t \to \infty$).

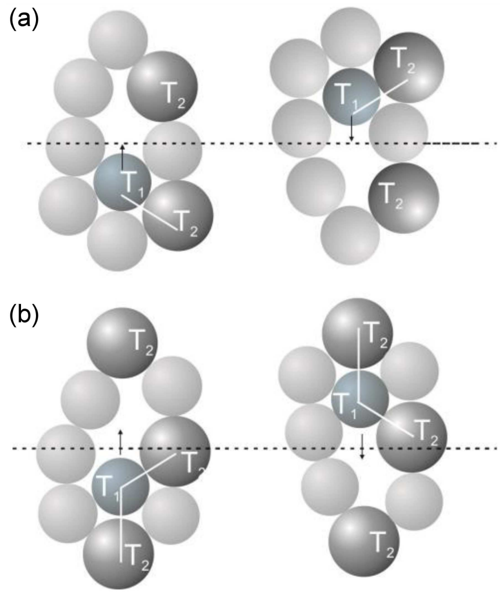

Fig. 2. Two-level system model showing changes in the axes orientation of the T_1 and T_2 atoms of transition metals, i.e., (a) reorientation of the axis of pairs of atoms and formation of new pairs, (b) creating new pairs by shifting atoms [4].

The P. Allia and F. Vinai theory is very consistent with the experimental results explained by the H. Kronmüller's theory [4, 8–12]. Let us recall, according to this theory, the phenomenon of disaccommodation in amorphous alloys is related to the ordering of pairs of atoms near the free volumes (Fig. 2).

The aim of the study is to investigate the influence of the content of yttrium in the alloy on its susceptibility and its disaccommodation.

2. Experimental details

The alloy ingots with the nominal compositions $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{99}Y_1$ and $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{98}Y_2$ were prepared by arc melting of high purity elements. The bulk amorphous alloys in the form of rods, 1 mm in diameter and 2 cm long, were produced by an injection casting method in a protective argon atmosphere [13]. The low-field magnetic susceptibility was studied using a fully automated setup by the transformer method. Before the measurements, the samples were demagnetized in an alternating magnetic field with an amplitude decreasing from 800 A/m to 0 during 1.1 s. Isochronal disaccommodation curves were constructed according to the following expression

$$\Delta\left(\frac{1}{\chi}\right) = \frac{1}{\chi\left(t_2\right)} - \frac{1}{\chi\left(t_1\right)}, \tag{1}$$

where χ_2 and χ_1 are the magnetic susceptibility measured at $t_2 = 120$ s and $t_1 = 2$ s, respectively, after demagnetization of the sample.

These measurements were performed in low magnetic fields, i.e., in the Rayleigh range.

3. Results and discussion

Figure 3 shows the dependence of magnetic susceptibility on temperature at the magnetic field amplitude of 0.26 A/m for the investigated alloys in the as-quenched state. The magnetic susceptibility of the alloy $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{99}Y_1$ increases slightly with increasing temperature and reaches its maximum value at a temperature of about 480 K. A slight increase in magnetic susceptibility is associated with a decrease in the effective anisotropy constants and saturation magnetization with increasing temperature. Such a course of the magnetic susceptibility curve proves the high thermal stability of this material. Above 500 K, a sharp decrease in magnetic susceptibility is observed, which is related to the transition of the sample from the ferro to paramagnetic state. In the case of the sample $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{98}Y_2$, a significant decrease in the value of magnetic susceptibility is observed, which proves the high heterogeneity of this alloy. Additionally, the curve shows that this material is highly temperature unstable.

The isochronal disaccommodation curves for the tested alloys are presented in Fig. 4. According to the Kronmüller theory, the phenomenon of disaccommodation in amorphous alloys is related to the ordering of pairs of atoms near the free volumes, which play a similar role as point defects in crystalline materials. The achieved examination results indicate a strict correlation between the structure of the alloy and the intensity of disaccommodation. Specimens produced at lower quenching rates exhibited a lower intensity of disaccommodation. During their fabrication the free volumes are reduced due to the irreversible structural relaxations, what in turn results in more stable structure and homogenization of the material.

Significantly lower intensity of disaccommodation was observed for the sample with lower yttrium content. It is well-known that the intensity of disaccommodation of magnetic susceptibility is

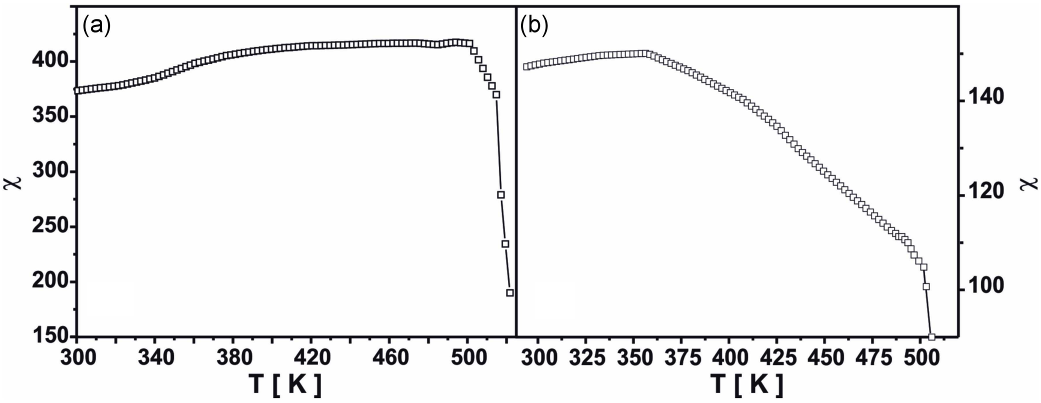

Fig. 3. Initial magnetic susceptibility versus temperature for bulk amorphous alloy in the as-quenched state in the form of a rod; (a) $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{99}Y_1$, (b) $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{98}Y_2$.

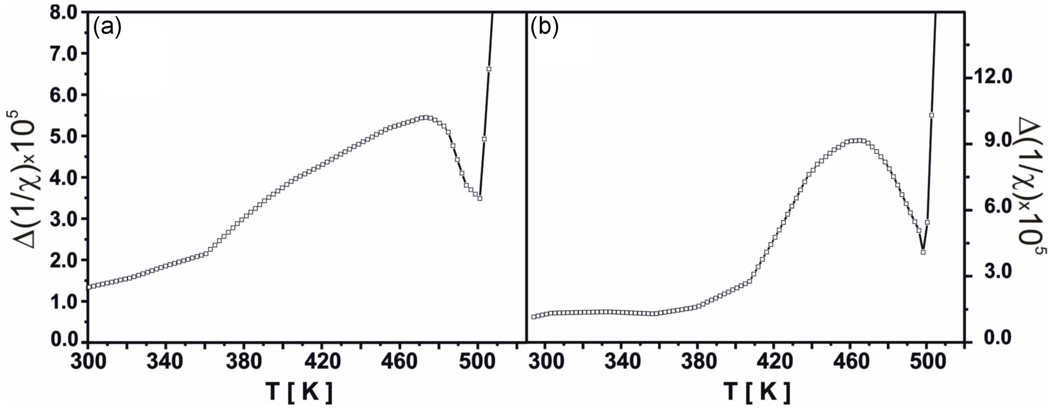

Fig. 4. Isochronal disaccommodation curves for bulk amorphous alloy in the as-quenched state in the form of a rod; (a) $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{99}Y_1$, (b) $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{98}Y_2$.

proportional to the concentration of relaxing defects. The decrease in the maximum intensity indicates blocking of some relaxing defects resulting from the reduction of free volumes. Lower intensity of the disaccommodation value for the $(Fe_{74}B_{20}Nb_2Hf_2Si_2)_{99}Y_1$ bulk amorphous alloy indicates a higher atomic packing density in this material.

4. Conclusions

In this paper, the influence of the yttrium content in the alloy on the magnetic susceptibility and its disaccommodation was investigated. According to the theory of H. Kronmüller, the phenomenon of magnetic susceptibility disaccommodation in amorphous alloys, similarly to crystalline alloys, is closely related to their microstructure. The conditions of alloys production and their chemical composition affect the intensity of magnetic susceptibility disaccommodation. On the basis of the obtained results, it can be concluded that a slight change in the chemical composition has a clear effect on the magnetic structure of the resulting material.

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