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Migratory Nature of the Disaccommodation Phenomenon Depending on the Relaxation Time

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One of the characteristics of the amorphous state is metastability, which results in structural relaxation even at low temperatures. These relaxations contribute to the magnetic properties of amorphous alloys, such as the value of the coercive field, losses from hysteresis and magnetic susceptibility. In amorphous materials, as opposed to crystalline ones, the description of relaxation phenomena is difficult due to the fact that these processes are described by the activation energy spectrum and occur in a wide temperature range. The paper presents the results of the analysis of migration processes based on the adopted H. Kronmüller model, in which the reorientation of atoms takes place in areas of a reduced volume called free volumes.

topics: bulk amorphous alloys, injection casting, disaccommodation

1. Introduction

Structural relaxation can have a decisive impact on the properties of various types of alloys. Very interesting metallic materials include amorphous materials showing the so-called soft magnetic properties [1, 2]. Virtually all types of metallic materials are subjected to a tempering process, which can also be called the relaxation process. Of course, in the case of conventional steel, hardening processes are used, and only after them, the tempering process follows, which allows for cleaning the steel from gas residues in its volume and increasing its impact toughness at the expense of hardness. The change of these properties is possible as a result of introducing an appropriate amount of energy into the system to enable beginning of the tempering process. Regarding crystalline materials, the description of processes leading to changes in properties is commonly known and thoroughly described in the literature, with a breakdown for specific types of alloys [3]. In the case of amorphous materials, which are characterized by a completely different structure, the relaxation processes that do not lead to the transformation of the structure into a crystalline one take place in the field of short- and medium-range interactions between atoms [4]. Even a very small reconstruction of the amorphous structure can lead to large changes in the magnetic properties of the tested material.

Additionally, in the process of magnetization of amorphous material, similarly to crystalline materials, there are areas characterized by reversible and irreversible processes. In the range of low magnetic fields delimiting the Reilegh region up to $0.4H_C$, where H_C is the coercive field, there are reversible relaxation processes in the motion of the domain wall. Using the transformer method, it is possible to investigate the change in magnetic susceptibility over time from the moment of demagnetization of the test sample with alternating current of amplitude decreasing to zero. This phenomenon is related

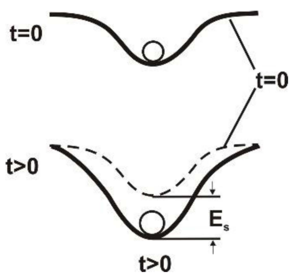

Fig. 1. Formation of the stabilization potential of the domain wall over time.

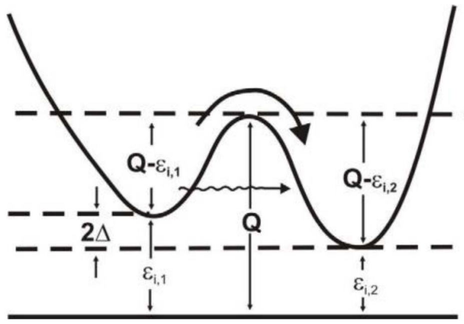

Fig. 2. Model of an asymmetric two-level system showing the change in activation energy caused by the energies of the magnetic interaction [14].

to the so-called magnetic viscosity, otherwise known as magnetic delay. Disaccomodation of magnetic susceptibility in metastable materials such as amorphous alloys occurs even at low temperatures. These processes, unlike in crystalline materials, take place over a wide range of temperatures and are described by the activation energy spectrum. A model that describes this phenomenon well is the one developed by H. Kronmüller et al. [5–8]. In this model, for the vast majority of Fe-based amorphous materials, a wide band of magnetic susceptibility disaccomodation is observed, ranging from room temperature to about 500 K. Above the critical temperature determining the stability of the ferromagnetic structure, the Hopkinson maximum was observed, and when it was exceeded, the material went into a paramagnetic state. The disaccomodation maximum, according to the theory of H. Kronmüller, is related to the reorientation of the axis of pairs of atoms with respect to spontaneous magnetization in domain walls within point defects, which are more often called free volumes in the case of amorphous materials [9, 10]. The maximum disaccomodation of magnetic susceptibility may also be related to the relaxation of shear stress [11]. In the case of reversible relaxation in Fe alloys, the average activation energy is usually in the range of 1.5–2.0 eV, and the pre-exponential factor in the Arrhenius law is on the order of 10^{-13}–10^{-15} s. Using the magnetic susceptibility disaccomodation study, one can study chemical changes and the topological arrangement of atoms in amorphous alloys.

The paper presents the results of the research on magnetic susceptibility disaccomodation for the alloy $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.03}W_{0.03}B_{0.18})Y_3$ in the solidified state.

2. Experimental details

The test specimens were prepared in a vacuum arc furnace under an argon atmosphere. The alloy components were of high purity as Fe — 99.99%. Boron was added in the form of an FeB alloy. Samples in the form of bars with a diameter of 1 mm were made by sucking the liquid alloy into a copper water-cooled mold. Then the magnetizing and measuring windings were wound on the rod. Measurement of magnetic susceptibility disaccomodation was performed on an automated system, in which the transformer method is used. The measurement was carried out from room temperature to a temperature slightly above the Curie temperature.

3. Results and discussion

Considering the intensity of magnetic susceptibility in the temperature range for the same sample measured twice, one should expect a slightly different course of the magnetic susceptibility curve. For the first measurement, more relaxers are observed, which means that the random distribution of the axis orientation of the atom pairs in the sample volume is in more areas. However, after the full measurement process, a certain part of the relaxers is released, which results in changes in the magnetic susceptibility. Potential wells occur continuously from measurement to measurement in a smaller number of areas (Fig. 1, see [12]), which directly reduces the volumetric stabilization of the domain walls and increases the value of magnetic susceptibility. The observed phenomenon is directly related to the jumps of the axis of pairs of atoms, which align their axis with the spontaneous magnetization of the domain wall, causing the local anisotropy to decompose.

If we consider a single measurement in time from the demagnetization of the sample with an alternating current of amplitude decreasing to zero, the observed decrease in susceptibility is related to the temporal stabilization of the domain wall potential. The presence of structure defects and surface inhomogeneities in amorphous materials has a direct impact on the anchoring potential of the domain wall, i.e., its position. When describing the potential of the domain wall in accordance with [13], two energies can be distinguished described by the relationship

$$2\Delta = 2\Delta_s + 2\Delta_m. \qquad (1)$$

Here, Δ_s and Δ_m are the magnetic and structural fission energies between the two orientations of the atom pairs, respectively. The magnetic fission

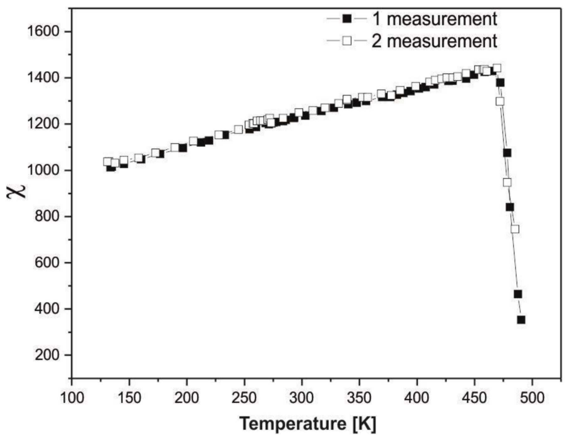

Fig. 3. Time curves of magnetic susceptibility for the $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.03}W_{0.03}B_{0.18})Y_3$ alloy; (a) first measurement, (b) after second measurement.

energy $2\Delta_m$ of the i-th pair of atoms is defined as the differences between the energies of magnetic interactions [6]. It is expressed by

$$2\Delta_m = \varepsilon_{i,2} - \varepsilon_{i,1}, \quad (2)$$

where $\varepsilon_{i,j}$ — energy of the magnetic interaction (Fig. 2, see [14]).

Figure 3 presents the curves for the alloy $(Fe_{0.61}Co_{0.10}Zr_{0.025}Hf_{0.025}Ti_{0.03}W_{0.03}B_{0.18})Y_3$ obtained from measurements of magnetic susceptibility in time from the demagnetization of the sample with an alternating current of amplitude decreasing to zero.

As indicated by the obtained test results, the susceptibility value increases for the test after the second measurement process. Such results confirm the correctness of the assumptions of the Kronmüller theory that the stabilization potential of the domain wall arises in a potential well formed within free volumes. Free volumes are areas of heterogeneity in which the direction of the magnetization vector changes. This means, according to the definition of magnetic susceptibility, that the increase in magnetization must be forced by the increase in the intensity of the magnetic field.

4. Conclusions

When examining the phenomenon of magnetic susceptibility disaccomodation, the degree of stress in the sample in the amorphous state should be taken into account. Changes in the value of magnetic susceptibility affect, among others, anisotropy, magnetization, or the value of the coercive field. Internal stresses in the solidified material affect the magnetic susceptibility value. A slight change in the Curie temperature value should also be expected. Changes in the orientation of the axis of pairs of atoms lead to an increase in the packing of the sample, thus changing the local structure and magnetic properties of the material. The change itself also depends on the duration of the measurement and the rate of temperature rise.

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