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Free Volumes and Their Influence on Disaccomodation of Magnetic Susceptibility

M. Nabiałek*

Department of Physics, Czestochowa University of Technology, Armii Krajowej 19 Av., 42-200 Częstochowa, Poland

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*e-mail: marcin.nabialek@pcz.pl

In weak magnetic fields, there are changes in the arrangement of atoms, which are otherwise called magnetic relaxations. The exact phenomenon that will be investigated in this paper concerns the disaccomodation of magnetic susceptibility, which is one of the most frequently observed effects of magnetic lag. During this magnetic delay, there is a reorientation of the axes of pairs of atoms corresponding to two different energy levels. This energy is related to the energies of exchange and spin–orbit coupling. The paper presents the results of magnetic susceptibility disaccomodation and describes its influence on the relaxation time matching spectrum.

topics: bulk amorphous alloy, disaccomodation of magnetic susceptibility

1. Introduction

The phenomenon of magnetic delay, also called magnetic viscosity, in crystalline materials is related to the migration of atoms and defects in the crystal lattice. Based on the equation

$$D_d = \frac{a^2}{36\tau}, \tag{1}$$

where:

τ — relaxation time,

a — lattice constant,

D_d — diffusion coefficient,

the diffusion coefficient can be calculated. As a result of the large dependence between the relaxation time and temperature, the phenomenon of magnetic delay occurs in a narrow temperature range [1, 2]. The result of the narrow temperature range describing the phenomenon of magnetic delay in crystalline alloys is the thermostable nature of this type of material. Changes in magnetic properties in crystalline alloys are abrupt and are related to the presence of well-defined defects in their volume in the form of vacancies or interstitial atoms. It follows that relaxation processes in crystalline materials are the result of providing the system with energy of a specific value in a very narrow temperature range. This energy is called activation energy. However, in amorphous alloys the structure is not well described and is characterized by a metastable state. This means that structural relaxations can occur in amorphous materials even at low temperatures. These relaxations occur in a certain temperature range and are described by the activation energy spectrum [3–5] and not by a discrete value, as in the case of crystalline materials.

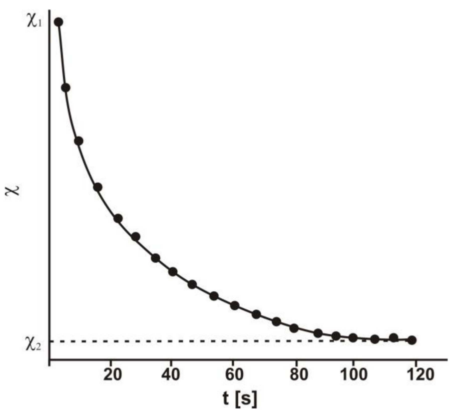

Fig. 1. Magnetic susceptibility disaccomodation curve.

Disaccomodation of magnetic susceptibility involves a decrease in time of the magnetic susceptibility of a sample demagnetized with an alternating current with an amplitude decreasing to zero [6, 7]. The disaccomodation of magnetic susceptibility is calculated according to the equation [7]

$$\Delta\left(\frac{1}{\chi}\right) = \frac{1}{\chi(t_2)} - \frac{1}{\chi(t_1)}, \tag{2}$$

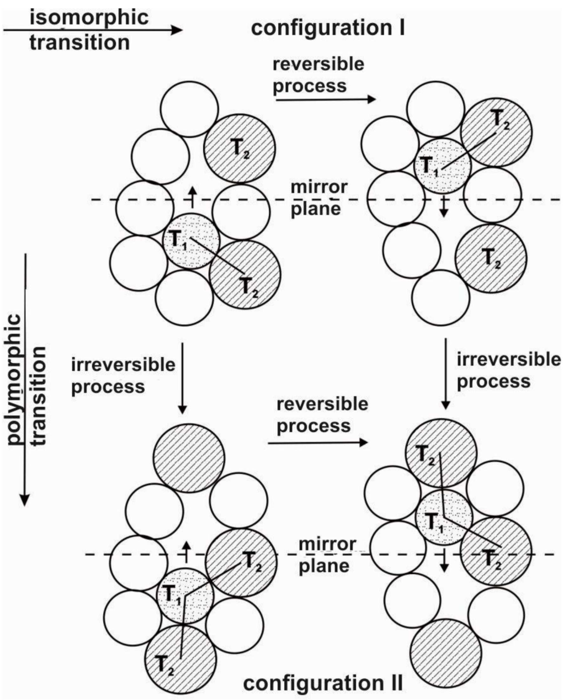

Fig. 2. The hard-sphere model describing two orientations of the axis of atom pairs for two energy levels [8].

where (t_1) and (t_2) are the values of magnetic susceptibility measured during 2 s and 120 s after demagnetizing the sample with an alternating current with amplitude decreasing to zero.

Figure 1 shows the magnetic susceptibility disaccomodation curve. The reduction of susceptibility from the maximum value occurs in the time from the moment of demagnetization to the minimum value for an infinitely long time.

Magnetic relaxation processes in amorphous alloys occur as a result of the reorientation of the axes of atom pairs. It is assumed that in amorphous alloys containing two elements T_1 and T_2, pairs of atoms T_1T_1, T_1T_2, T_2T_2 can be formed. The change in the axis of atom pairs can take two orientations and occurs around free volumes. To change the orientation of the axis of atom pairs, an appropriate amount of energy is needed, called activation energy, most often thermal energy. This phenomenon is well described by the double-well model. As a result of different magnetic interaction energies and different structural configurations between the two orientations of atom pairs, we can determine the splitting energy 2Δ.

This energy is the sum of structural configurations ($2\Delta_s$) and the energy of magnetic interactions ($2\Delta_m$) [7], i.e.,

$$2\Delta = 2\Delta_s + 2\Delta_m. \qquad (3)$$

For different energy levels, the orientations of the axis of atom pairs can be represented using the hard-sphere model (Fig. 2) [6, 8]. Reversible (isomorphic transition) and irreversible (polymorphic transition) processes occur in amorphous materials. The orientation of the axis of atom pairs is a mirror image in the marked plane. Figure 2 shows the migration of the atom according to the orientation of the arrowhead. The numerical analysis of the magnetic susceptibility disaccomodation curve for the continuous spectrum of relaxation times is presented as [9]

$$\Delta\left(\frac{1}{\chi}\right) = \sum_{i=1}^{l} \int_{-3\beta_{\tau i}}^{+3\beta_{\tau i}} \frac{\mathrm{d}z}{\beta_\tau\sqrt{\pi}} \frac{I_{\mathrm{pi}}T_{pi}}{T}\, \mathrm{e}^{-(z/\beta_{\tau i})^2} \times \left(\mathrm{e}^{-t_1/\tau_{mi}\exp(z)} - \mathrm{e}^{-t_2/\tau_{mi}\exp(z)}\right), \qquad (4)$$

where:

τ_m — average value of the relaxation times τ,

T — temperature, at which the maximum occurs,

I_{pi} — intensity,

β — distribution width

z — intensity of the i-th process at the peak temperature.

This function allows to present the temperature dependence of magnetic susceptibility disaccomodation for several relaxation processes.

The paper will present the results of magnetic susceptibility disaccomodation tests performed for a bulk amorphous alloy $Fe_{63}Co_8Y_8W_1B_{20}$ in the form of a rod with a diameter of 1 mm and a ribbon after solidification.

2. Experimental procedure

Test samples were made of high-purity ingredients: Fe — 99.99 at.%, Co — 99.999 at.%, Y — 99.99 at.%, Nb — 99.9999 at.%, Zr — 99.99 at.%. Boron was introduced in the form of an alloy with the chemical composition of $Fe_{45.6}B_{54.4}$. The first stage of producing test samples was the preparation of a crystalline ingot. Weighed alloy components in 10 g portions were melted in an arc furnace. Smelting took place in an inert gas atmosphere. The ingots were melted three times on each side to mix the alloy components well. The ingots prepared in this way were cleaned mechanically and in an ultrasonic bath. Then they were divided into lighter pieces, which were used in the further process of preparing research material. Prepared portions of the material were placed in a quartz capillary, which was placed between a copper mold and compressed argon. The alloy melted using eddy currents was injected under argon pressure into a copper mold with a hollow core in the form of a rod with a diameter of 1 mm and a length of 20 mm. The structure of the rods was checked using a Bruker X-ray diffractometer, model ADVANCE 8. The sample was scanned in the 2θ angle range from 30 to 100° with a measurement step of 0.02° and a measurement time

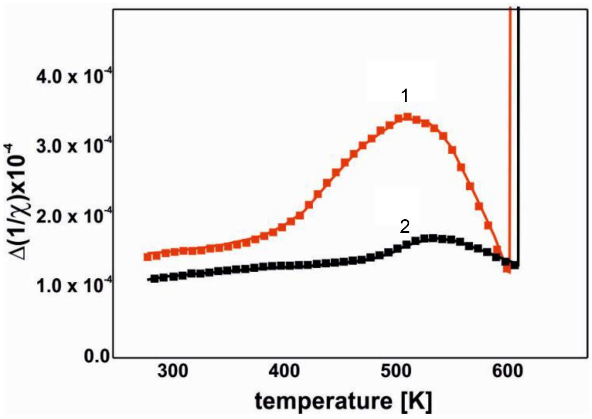

Fig. 3. Isochronous disaccomodation curves of magnetic susceptibility for the $\mathrm{Fe_{63}Co_8Y_8W_1B_{20}}$ alloy in the form of: (line 1) ribbons with a thickness of 30 μm, (line 2) rod with a diameter of 1 mm.

of 3 s. The disaccomodation of magnetic susceptibility was measured on an automated system based on the transformer method. The measurement was made from room temperature to the temperature at which the Hopkinson peak was observed. The rods were closed with a yoke made of superpermalloy, which allowed the magnetic flux to flow. Then, 30 turns of the secondary and primary windings were wound on the sample.

3. Results

Figure 3 shows the temperature dependence of the disaccomodation of the initial magnetic susceptibility measured in the temperature range from 300 to 600 K. Disaccomodation is a measure of the temporal stability of magnetic susceptibility, which can be observed in the range of low magnetic fields up to $0.4H_C$, the so-called Rayleigh area.

Magnetic susceptibility disaccomodation measurements carried out for samples of the tested alloy after solidification were performed three times in a given temperature range, which was intended to remove irreversible structural relaxations (polymorphic transitions) occurring during the measurement. These relaxations constitute a more stable energy configuration compared to that corresponding to reversible relaxation processes (isomorphic transitions).

Isochronous magnetic susceptibility disaccomodation curves are clearly dependent on the manufacturing method. Higher magnetic susceptibility disaccomodation rates can be observed for the sample produced at a higher cooling rate during melt-spinning. For the injection method, the magnetic susceptibility disaccomodation curve is much lower.

The isochronous disaccomodation curve of the magnetic susceptibility can be divided into three areas:

1. The area where only temperature-independent relaxation amplitudes are observed,

2. The area where the maximum of disaccomodation occurs, describing precisely the intensity of this phenomenon, where all thermal features of the entire process can be observed,

3. An area where a sharp decrease in the intensity of disaccomodation is observed, occurring just below the Curie temperature. This behavior of disaccomodation is related to the so-called Hopkinson maximum [10], which occurs when there are rapid changes in the constants of the ferromagnetic material near the ferro–paramagnetic phase transition.

The second area is where most point relaxations occur. These relaxations are related to the cooling rate of the alloy and not to its chemical composition itself.

4. Conclusions

The shape of the isochronous disaccomodation curves of magnetic susceptibility is related to the presence of free volumes. A larger amount of free volumes occurs in the sample produced at a higher cooling rate. The structure then suddenly freezes, which results in an increased number of free volumes being created. The extended solidification time favors the free movement of atoms in the sample volume and the creation of configurations with lower internal energy. This state of affairs has a direct impact on the reduction of free volumes, which is clearly shown by the research results presented in this work.

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