MAGNETOSTRICTION DEPENDENCE OF THE MAGNETIC PERMEABILITY AFTEREFFECT OF AMORPHOUS FERROMAGNETS AT LOW TEMPERATURES

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Abstract. – Low-temperature measurements show that the magnetic permeability aftereffect of Fe-based alloys is always proportional to the square of the magnetostriction constant, indicating that the nature of the ordering processes responsible for the aftereffect is essentially the same over an extended range of temperatures.

Introduction

The disaccomodation of the magnetic permeability, measured in Fe-based amorphous alloys between fixed times after sample demagnetization has been experimentally shown to be proportional, at room temperature, to the square of the measured magnetostriction constant, λ_s [1]. The results of Co-based alloys are less clear, although also in that case the aftereffect is generally observed to increase with increasing λ_s [2].

The experimental evidence has lead to a model for the aftereffect, based on the recognition of the role of the atomic-level shear stresses inherently present in an amorphous metallic matrix, and of the local magnetoelastic energy associated to them [1]. These stress concentrations are viewed as structural defects, able to take (at least) two slightly different positions in the configuration space, according to the direction of the local magnetization vector, and treated as classical two-level systems. Different approaches emphasize the effects of other microscopic coupling energies between ordering defects and magnetization [3]. Anyway, the presence of a significant contribution of the magneto-elastic energy is now accepted in all existing approaches to the problem.

So far, however, the dependence of the aftereffect on the squared magnetostriction has been systematically verified only at 77 K and 300 K [6]. It may be interesting to extend such a measurement to lower temperatures, in order to establish the range of validity of the assumptions leading to the structural model in its present form.

In fact, the magnetic aftereffect of amorphous ferromagnets can be observed at temperatures as low as 4.2 K. Such a behavior is usually justified in terms of a broad distribution of activation energies for the two-level systems. It cannot be excluded, in principle, that the processes responsible for the aftereffect at very low temperatures are of different nature than the ones activated at room temperature.

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Experimental and results

Measurements of permeability aftereffect, saturation magnetization I_s and saturation magnetostriction λ_s have been performed at fixed points (room temperature, $T = 4.2$ K and $T = 77$ K) on a set of Fe-based amorphous alloys whose compositions are given in figure 1.

The measurements of the permeability aftereffect were performed by means of an impulsive technique [4]. The intensity of the aftereffect is defined as $(\mu(T_1) - \mu(t_2)) / \mu(t_2)$. In the present case the time limits were $t_1 = 1$ s and $t_2 = 10$ s, respectively.

The saturation magnetization was measured by means of a vibrating-sample magnetometer. The saturation magnetostriction was determined through the small-angle oscillation technique [5]. All measurements were performed at UNICAMP.

The results are reported in figure 1 in the usual form of an aftereffect product $(\Delta\mu / \mu)\ H_e\ I_s$, where H_e is the value of the applied magnetic field [1]. The aftereffect product $(\Delta\mu / \mu)\ H_e\ I_s$ is found to be proportional to λ_s^2 at all examined temperatures, all the proportionality factors being comparable.

In all examined samples, the intensity of the aftereffect product is higher at $T = 4.2$ K than at room temperature and at $T = 77$ K. This behaviour is not in contrast with the temperature variation of the proportionality factor A, which is larger at RT than at 4.2 and 77 K (see Fig. 1), merely reflecting the fact that all λ_s values are considerably lower at RT than at the other considered temperatures (see abscisses in Fig. 1).

Discussion

The present measurements show that the λ_s^2 – law retains its validity over a wide range of temperatures. This result indicates that the nature of the microscopic ordering processes responsible for the magnetic aftereffect is probably the same at very low temperatures as well as at room temperature.

As a consequence, the set of the two-level systems responsible for the permeability aftereffect may be

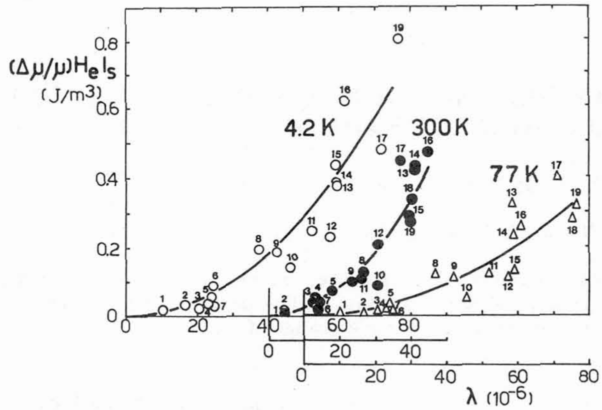

Fig. 1. – Aftereffect product *vs.* saturation magnetostriction in Fe-based alloys at different temperatures. Full lines: best-fit curves, $f(\lambda_s) = A(T)\ \lambda_s^2(T)$. $A(4.2\text{ K}) = 1.2 \times 10^8$ J/m^3; $A(77\text{ K}) = 0.6 \times 10^8$ J / m^3; $A(300\text{ K}) = 2.1 \times 10^8$ J/m^3. 1_$Fe_{20}Ni_{60}B_{20}$; 2_$Fe_{29}Ni_{49}P_{14}Si_{12}$ (Metglas 2826 B); 3_$Fe_{40}Ni_{38}Mo_4B_{18}$ (wheel velocity 48 m/s); 4-id. (wheel velocity 40 m/s); 5-id. (Metglas 2826 MB); 6_$Fe_{40}Ni_{40}P_{14}B_6$ (Metglas 2826); 7_$Fe_{40}Ni_{38}Mo_4B_{18}$ (wheel velocity 30 m/s); 8_$Fe_{78}Mo_2B_{20}$; 9 $Fe_{80}Nb_3B_{17}$; 10_$Fe_{80}Mn_3B_{17}$; 11_$Fe_{80}Cr_3B_{17}$; 12_$Fe_{80}B_{20}$ (Metglas 2605); 13_$Fe_{81}B_{13.5}Si_{3.5}C_2$ (Metglas 2605 SC); 14_$Fe_{80}Ni_3B_{17}$; 15_$Fe_{80}B_{20}$; 16_$Fe_{67}Co_{18}B_{14}Si_1$ (Metglas 2605 CO); 17_$Fe_{80}Ir_3B_{17}$; 18_$Fe_{80}Zr_3B_{17}$; 19_$Fe_{80}Rh_3B_{17}$.

viewed as an assembly of elementary processes having essentially the same type of coupling with the magnetization direction, and characterized by a single varying parameter, the value of the activation energy. In this picture, there is no need of invoking the existence of mechanisms other than the ones hypothized to be responsible for the aftereffect at room temperature.

The fact that a well defined λ_s^2 – law may be observed at temperatures as low as $T = 4.2$ K could seem at a first sight surprising. In fact, the prediction that the aftereffect product is proportional to the squared magnetostriction is derived, within the magneto-elastic model, under the assumption that the (root mean square) energy of coupling between defects and magnetization, $\langle\tau^2\rangle^{1/2}$, be very small compared with kT. Otherwise, higher powers of λ_s should be present [1].

Our results indicate that $\langle\tau^2\rangle^{1/2}$ must be much smaller than $4.2 \times k = 5.8 \times 10^{-16}$ ergs/at ($= 3.6 \times 10^{-4}$ eV per atom). Such a value is in good agreement with the predictions of the existing models for the magnetic aftereffect in these alloys. In the structural model, in fact, the rms coupling energy is assumed to be of the order of $3/2 \cdot \lambda_s \cdot \langle\tau^2\rangle^{1/2}$ ($= 2.5 \times 10^{-5}$ eV/atom when $\lambda_s = 25 \times 10^{-6}$), $\langle\tau^2\rangle$ being the second moment of the atomic-level shear stress distribution [1]. On the other hand, according to the Kronmuller's theory [3], the magneto-elastic energy term in a material with $\lambda_s = 25 \times 10^{-6}$ ($Fe_{40}Ni_{40}B_{20}$) takes a value of 1.4×10^{-3} eV for a cluster of about 20 atoms, corresponding to 7×10^{-5} eV per atom. According to the predictions of both models, significant deviations from the λ_s^2 – law could then be observed only at temperatures lower than 4.2 K.

Finally, the observed increase in the intensity of the aftereffect at low temperatures may be explained naturally in terms of the structural model. In fact, the aftereffect product is predicted to be proportional to $N_T\ \lambda_s^2\ \langle\tau^2\rangle\ /\ kT$, where N_T is the number of defects activated at the temperature T. If this number is almost independent of T in the considered temperature range, as in the case of a low-Q tail in the activation energy spectrum, the aftereffect product should approximately behave as $1/T$, increasing at low temperatures. Such an effect has been already observed in detail on a Fe-B-Si amorphous alloy [6]. The present measurements confirm these results, showing that the increase in the intensity of the aftereffect at very low temperatures is a general rule for amorphous ferromagnetic alloys.

The appearence of a minimum in the aftereffect *vs.* temperature curve of almost all the Fe-based amorphous alloys at about 77 K seems to be an interesting feature. However, to our knowledge, no specific theory has been developed so far to adequately explain this behaviour.

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