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Influence of the structural rearrangements on the stress sensitivity of magnetostriction in a Co-rich amorphous alloy

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One of the more striking features of nearly nonmagnetostrictive amorphous alloys is that their saturation magnetostriction λ decreases with the applied tensile stress at a rate of 10^{-10} MPa^{-1}. In the comparison of different models developed to account for this phenomenon, the experimental analysis of the dependence of the stress derivative of magnetostriction A on the thermal history of the samples has a singular significance. In particular, it is of great importance to determine whether A changes after annealing. The experiments presented in this work deal with the magnetostriction behavior in a sample of composition $(Co_{0.95}Fe_{0.5})_{80}Si_{10}B_{10}$ annealed at constant temperature for different annealing times, under applied stress. The measurements of the magnetostriction as well as its stress dependence, which were carried out by different experimental techniques, confirm that the absolute value of A decreases as the structural relaxation takes place.

INTRODUCTION

Different microscopic mechanisms have been invoked to explain the origin of the stress dependence of the magnetostriction of low magnetostrictive metallic glasses. As is well known the experimental magnetostriction, λ^{expt}, behaves as

$$\lambda^{\mathrm{expt}}=\lambda(0)-A\sigma \tag{1}$$

where $\lambda(0)$ is the experimental value of λ at zero applied stress, σ is the applied tensile stress and A is a coefficient that ranges from 1×10^{-10} to 6×10^{-10} MPa^{-1} for the experiments reported.[1–3]

The stress dependence of λ has recently been invoked by O'Handley *et al.*[4] as cause of the deviation of the surface magnetostriction value with respect to the bulk value. Moreover, a deeper understanding of the phenomenon at microscopic scale should be quite useful in order to improve the possibilities of using magnetostriction measurements as a microstructural probe.

The microscopic model of Furthmüller *et al.*[5] correlates A with the second strain derivative of the local anisotropy coefficients which are determined by the local symmetry and chemistry. Therefore only those thermal treatments which produce irreversible phase transformations in the local symmetry of the amorphous structure are expected to affect the subsequent value of A. It is to be noted that different experimental hints of such type of transformations have been observed and reported for Co-rich metallic glasses.[6,7]

However, the model developed by Szymczak *et al.*[8] describes the stress dependence of λ as a consequence of the bond orientational anisotropy induced by the stress. Therefore, in the framework of Szymczak's model, thermally activated processes must be involved in the mechanism giving rise to the stress dependence of λ. Moreover, it is expected that the action of the tensile stress at room temperature should be drastically affected by the strength and orientation of any bond anisotropy induced previously at higher temperature.

Hernando et al. and Vázquez et al.[9] have shown that fluctuations of the local anisotropy and therefore of the local magnetostriction, which is the strain derivative of the local anisotropy, would lead to an experimental behavior of the macroscopic λ as that expressed by (1). In particular they found A to be a proportional to the mean square deviation of the local magnetostriction distribution. Therefore, in this last model, the influence of the thermal treatments on the local magnetostriction fluctuations should be reflected in a similar influence on the stress derivative A.

In a recent work Herzer[10] did not find any variation of A larger than the experimental accuracy ($\approx 0.4\times10^{-10}$ MPa^{-1}) after annealing several samples of different compositions. According to his conclusions, this result is in line with the Furthmüller model and seems to contradict the Szymzcak model at least in the sense that the stress dependence should involve thermally activated process.

It is well known that magnetic anisotropies can be induced in amorphous samples by applying suitable thermal treatments. Such anisotropies exhibit longitudinal as well as transverse easy axis according to the polarizing effect (magnetic field, tensile stress, or combination of both) applied during the annealing process. The strength of the anisotropy is a complex but well-studied function of the annealing temperature and time and of strength of the polarizing effect.[11] The possibility of inducing macroscopic anisotropies provides a suitable probe to inquire about the origin of A.

In this work we report experimental results obtained by measuring the change of A after applying different thermal treatments during which anisotropy is induced. In particular we have tried to check (i) the existence of changes in A, (ii) the influence of the orientation of the magnetization easy axis on the behavior of A, and (iii) the kinetics of the possible changes of A in comparison with the kinetics of the induced anisotropy and magnetostriction evolution.

EXPERIMENTAL

An amorphous ribbon of composition $(Co_{0.95}Fe_{0.05})_{80}Si_{10}B_{10}$, was obtained by melt spinning technique. Figure 1 shows the temperature dependence of the spontaneous magnetization. It can be seen that the Curie point of the amorphous state is higher than the crystallization temperature which is 400 °C.

First, two samples were annealed at 370 °C during 10 min under a longitudinal and a transverse saturating magnetic field, respectively.[12] After cooling down a macroscopic anisotropy with longitudinal and transverse easy axes were, respectively, observed.

A quite important observation was related to the results of these thermal treatments. The value of A in the sample as quenched, obtained by using the inverse susceptibility method, ISM,[13] was $(3.7\pm0.6)\times10^{-10}$ MPa^{-1}. After inducing, by means of the longitudinal field annealing, a longitudinal anisotropy the value of A changed to $(1.0\pm0.6)\times10^{-10}$ but for the sample exhibiting a transverse easy axis, after transverse field annealing, A took nearly the same value, $(1.1\pm0.6)\times10^{-10}$ MPa^{-1}. Both values were also obtained by ISM.

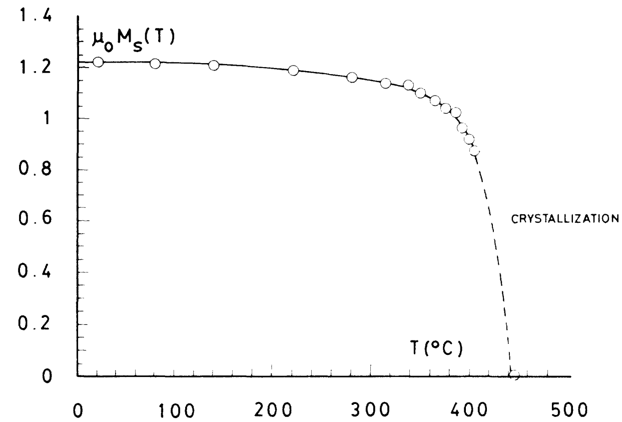

FIG. 1. Spontaneous magnetization as a function of the temperature. Measurements were performed up to temperatures below the crystallization point which, for this composition, is lower than the Curie point of the amorphous state.

These results confirm that A changes by annealing and furthermore that this change is independent of the orientation of the easy axis within the experimental error.

Subsequently a sample was annealed under tensile stress of 800 MPa, at the same temperature of 370 °C during different annealing times ranging from 60 to 2700 sec. The behavior of the transverse induced anisotropy strength, K, induced during the stress annealing as well as that of $\lambda(0)$ and A was monitored after every treatment. The measurements were performed by using both ISM and the constant magnetization procedure, CMM,[9] the latter method was used for five different values of the magnetization.

In Fig. 2 the changes of K, $\lambda(0)$, and A as a function of the annealing time are plotted. The observation of these curves point out the following remarkable points: (i) the kinetics of $\lambda(0)$ and A are rather similar and faster than the kinetics of the induced anisotropy, (ii) the values of A fluctuate with amplitude larger than expected from the experimental error along the ribbon length and also change with the experimental method but its relative change after annealing is insensitive to these aspects and reaches a value close to 50% in all cases, and (iii) A decreases as the structural relaxation proceeds.

DISCUSSION

The results reported so far indicate that the direction of the macroscopic easy axis does not affect the value of A. Therefore it seems unlikely that anisotropic bond reorientation can account, only by itself, for the stress dependence of magnetostriction. The origin of the induced anisotropy in Co-rich amorphous ferromagnets has been widely accepted to be due to the appearance of a phase characterized by a remarkably anisotropic structural units.[6,7,14] Therefore the disordered as-quenched state evolves during the structural relaxation toward the configuration of equilibrium which at low temperature is characterized by the anisotropic short-

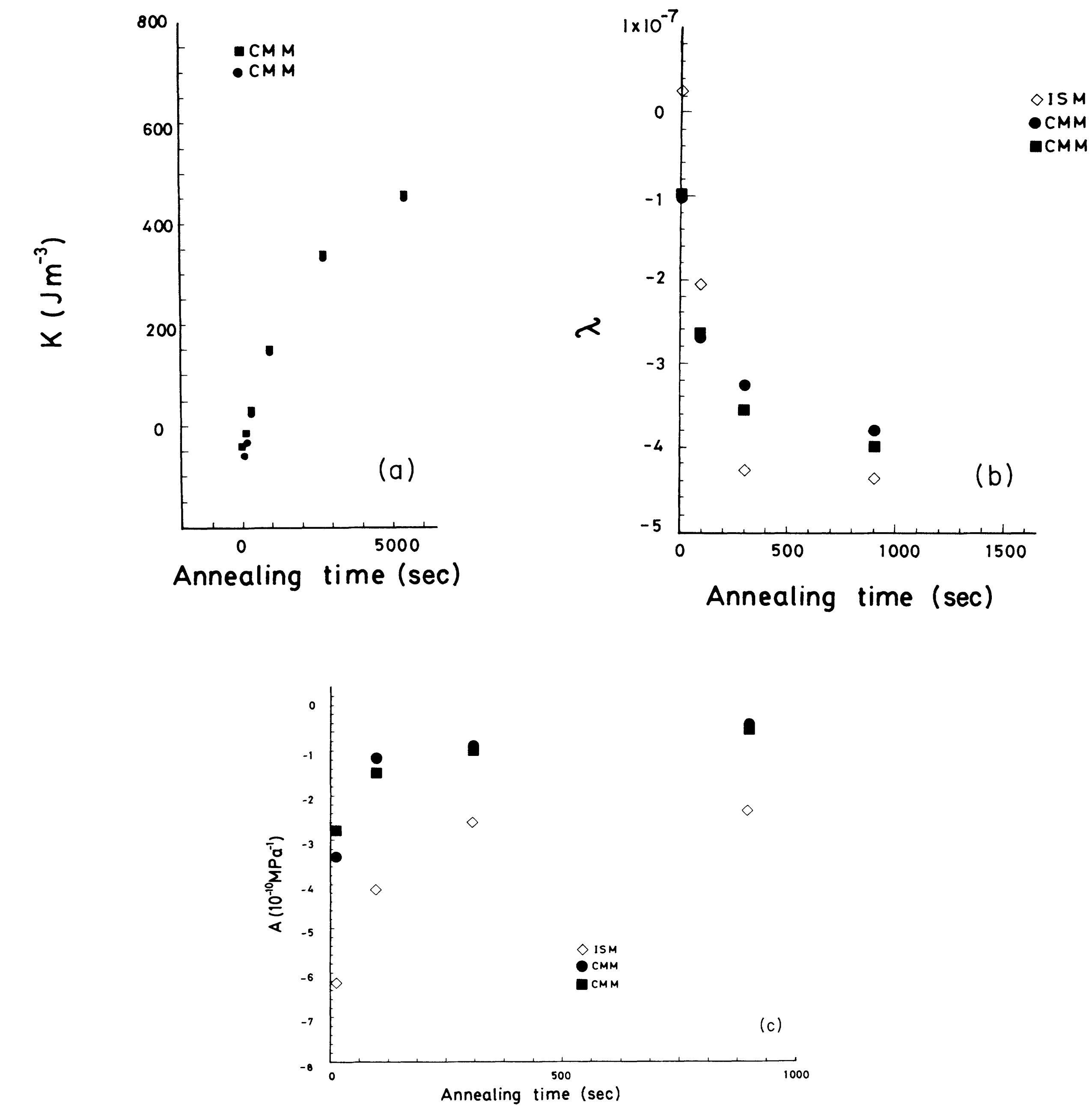

FIG. 2. Results obtained after annealing under tensile stress of 800 MPa at 370 °C for different annealing times. (a) The strength of the induced transverse anisotropy as a function of the annealing time for two samples of the same batch. The measurements were performed by ISC and by CMM. (b) Magnetostriction at zero stress, $\lambda(0)$ as a function of the annealing time. Measurements were also performed by ISM and CMM. (c) Stress derivative of the magnetostriction A as a function of the annealing time.

range order. But to get a macroscopic anisotropy a polarizing effect must act during the formation process of the anisotropic phase. According to this picture the experiments reported in Fig. 2 show that the behavior of A seems to be related closely to the formation of the local anisotropic structural units rather than to the macroscopic orientation of such units. Since the formation of the anisotropic structural units leads to a change in the local symmetry but also to a possible decrease of the structural fluctuations, the variation of A could be explained by both the Furthmüller as well as the fluctuations model. Further experiments based on the results reported in this work are expected to elucidate the actual controversy.

[1]G. Herzer, in *Proceedings of the Conference on Soft Magnetic Materials* (European Physical Society, Cardiff, 1985), p. 355.

[2]J. M. Barandiarán, A. Hernando, V. Madurga, O. V. Nielsen, M. Vázquez, and M. Vázquez López, Phys. Rev. B **35**, 5066 (1987).

[3]A. Siemko, H. K. Lachowicz, and B. Lisowski, Acta Phys. Pol. A **72**, 197 (1987).

[4]S. W. Sun and R. C. O'Handley, Phys. Rev. Lett. **66**, 21, 2798 (1991).

[5]J. Furthmüller, M. Fähnle, and G. Herzer, J. Phys. F **16**, L255 (1986).

[6]B. W. Corb, R. C. O'Handley, J. Megnsar, and M. J. Grant, Phys. Rev. Lett. **51**, 1386 (1983).

[7]J. M. Riveiro, V. Madurga, and A. Hernando, Phys. Rev. B **39**, 11 950 (1989).

[8]H. Szymczak, Acta Magn. Suppl. **84**, 259 (1984).

[9]A. Hernando, C. Gómez-Polo, E Pulido, G. Rivero, M. Vázquez, A. García Escorial, and J. M. Barandiarán, Phys. Rev. B **42**, 10, 6471 (1990); M. Vazquez, A. Hernando, and H. Kronmüller, Phys. Status Solidi A **125**, 657 (1991).

[10]G. Herzer, Ann. Fis. B **86**, 157 (1990).

[11]A. Hernando, Phys. Scr. T **24**, 11 (1984).

[12]This temperature was shown to correspond to the maximum strength of the field induced anisotropy. See J. González and K. Kulakowski, J. Magn. Magn. Mater. **82**, 94 (1989).

[13]The ISM can be applield in samples exhibiting or not macroscopic anisotropy when the magnetostriction constant is negative. A brief description of the method can be seen in Ref. 2 and therein.

[14]G. Suran, K. Ounagdela, and M. Machizand, Phys. Rev. Lett. **57**, 24 (1986); **57**, 3109 (1986).