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Magnetostriction of the rapidly quenched $\text{Co}_{80}\text{Nb}_8\text{B}_{12}$ alloy: Dependence on quenching rate, structural relaxation, and temperature

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Ribbons of nominal composition $\text{Co}_{80}\text{Nb}_8\text{B}_{12}$ have been prepared by the single roller quenching method using different wheel velocities ranging from 26 to 42 ms^{-1} . X-ray diffraction patterns for ribbons prepared at low velocities show crystalline peaks but characteristic for the amorphous state for samples prepared at velocities above 36 ms^{-1} . Room-temperature values of the magnetostriction constant λ_s depend on the quenching rate and changes from 4×10^{-7} to -1×10^{-6} as the wheel speed increases. Zero magnetostriction samples are obtained at about 34 ms^{-1} . Thermal treatments change the values of the magnetostriction in the same way as a decrease in the quenching rate does. A dependence of the magnetostriction constant on the applied stress has been found. This dependence, fully reversible, is observed at room temperature.

INTRODUCTION

The magnetostriction constant of Co-rich metallic glasses shows very interesting features. Nearly zero magnetostriction alloys can be obtained by adding small amounts of other metals like Fe, Cr, V, etc., to Co-based glasses.¹ In some of these alloys the magnetostriction constant λ_s exhibits an anomalous thermal behavior. The compensation temperatures, i.e., temperatures at which $\lambda_s = 0$, were found for these alloys to be below the Curie temperature.^{1,2} This behavior has been explained by assuming two different microscopic contributions to the macroscopic magnetostriction (single-ion and two-ion) with opposite signs and different variation.³ The composition dependence of the one-ion and two-ion contributions has been recently studied in $(\text{Co}_{1-x}\text{Fe}_x)_{75}\text{Si}_{15}\text{B}_{10}$, $(\text{Co}_{1-x}\text{Ni}_x)_{75}\text{Si}_{15}\text{B}_{10}$, and $[\text{Co}_{1-x}(\text{FeNi})_x]_{75}\text{Si}_{15}\text{B}_{10}$ glasses.⁴⁻⁶ Magnetostriction in such compounds is intimately related to short-range order⁷ and is very sensitive to structural relaxation, depending even on the applied stress, especially in those compositions which have a very low value of λ_s .⁸⁻¹¹

A very special temperature dependence of λ_s has been reported for the $\text{Co}_{80}\text{Nb}_8\text{B}_{12}$ alloy.¹² In this compound the magnetostriction constant has a negative values at room temperature but goes to zero as the temperature increases and vanishes in a wide temperature range below the Curie temperature. This behavior has been attributed to a phase change of the crystalline clusters present in the amorphous matrix. Variations of the quenching rate have been used as a tool for studying structural arrangements in some glasses.¹³ In the present work we present magnetostriction measure-

ments in $\text{Co}_{80}\text{Nb}_8\text{B}_{12}$ ribbons as a function of the quenching rate, temperature, structural relaxation, and applied stress, in order to get a deeper understanding of this compound.

EXPERIMENT

Ribbons of nominal composition $\text{Co}_{80}\text{Nb}_8\text{B}_{12}$ were produced by rapid quenching of the melt on a copper wheel spinning at different velocities. The linear speed at the surface of the wheel was changing from 26 to 42 ms^{-1} . More details about the fabrication procedure are given elsewhere.^{14,15}

X-ray diffraction was used to check the structure of the as-quenched samples. Figure 1 shows some examples. Sharp crystalline peaks were present for the samples made at the lower quenching rate, but no known phases were identified. For velocities greater than 36 ms^{-1} diffraction patterns were characteristic of amorphous materials. Some amounts of crystallinity seem to be present for intermediate quenching rates although x ray cannot detect crystals smaller than 100–200 Å. The magnetic moment per atom was determined from the saturation magnetization and density measurements.¹⁵ No changes were observed in the crystalline samples as compared with the amorphous ones.

The magnetostriction constant was determined by using the well-known SAMR method. The transverse field being produced by an ac current flowing along the ribbon.^{2,17} This allows the sample to be heated by Joule effect, and the temperature dependence of λ_s can be obtained by measuring at different currents. The temperature of the sample as a function of the ac current intensity was determined from satura-

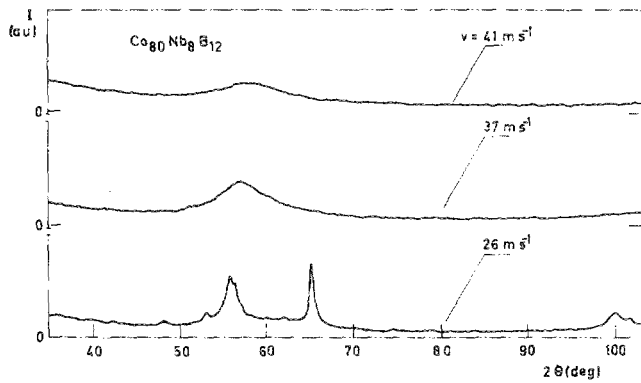


FIG. 1. X-ray diffraction patterns for ribbons produced at different quenching rates, as indicated by the wheel velocity (v). FeK α radiation was used.

tion magnetization measurements as has been reported in detail elsewhere.¹⁸ The crystallization temperature monitored by coercive force determination is 735 °C.

RESULTS AND DISCUSSION

Figure 2 shows the room temperature values of the magnetostriction as a function of the quenching rate. A continuous variation from a positive value in the crystalline sample (4×10^{-7}) to a negative one in the amorphous sample (-1×10^{-6}) is observed. A change of sign of λ_s , originated by structural relaxation has previously been reported for a nearly zero magnetostriction amorphous compound.² However, the absolute variation of λ_s , shown in Fig. 2 which is about an order of magnitude seems to be rather large to invoke structural relaxation as a possible cause. In order to explain this behavior, it can be assumed that small crystallites, with positive magnetostriction, are clustered in the amorphous matrix which has negative magnetostriction. Crystalline clusters would increase as the quenching rate decreases and compensate the magnetostriction of the amorphous matrix at a wheel speed of about 33 ms^{-1} .

Measurements of λ_s , as a function of the temperature are shown in Fig. 3. The heating current together with the tem-

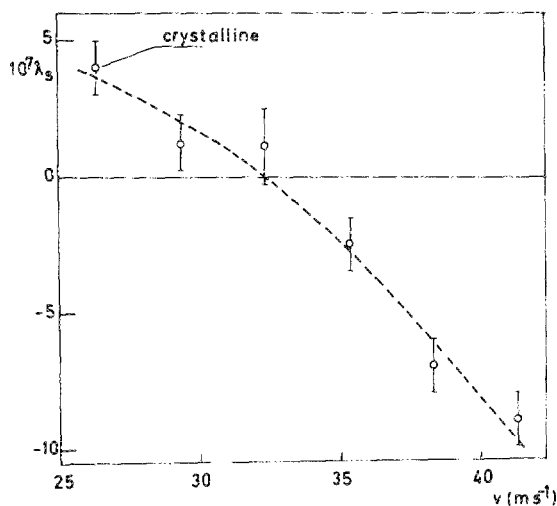


FIG. 2. Room-temperature magnetostriction constant (λ_s) as a function of the wheel velocity. The error bars indicate the dispersion found for different pieces of the same batch.

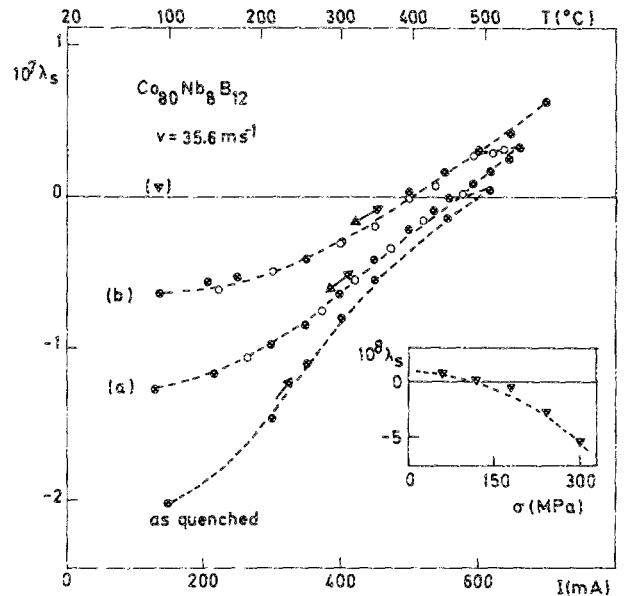


FIG. 3. Temperature dependence of the magnetostriction determined with a load of 80 MPa in a low magnetostriction sample. Full points were obtained on heating and empty ones on cooling. The triangle in brackets is the value at the end of the treatments. The inset shows the influence of the applied stress measured at room temperature.

perature of the sample are plotted in the abscissa. An amorphous sample which exhibits a very low value of λ_s in the as-quenched state was used in these measurements. The absolute value of λ_s decreases as the temperature is raised and a compensation temperature occurs at about 500 °C. This behavior is not reversible, indicating that structural changes have taken place during the heating. After successive heating runs lower values of the compensation temperature are found, and finally a slightly positive values of λ_s is displayed at low temperature. However, the sample was shown to remain amorphous after the treatments by monitoring the coercive force (H_c).

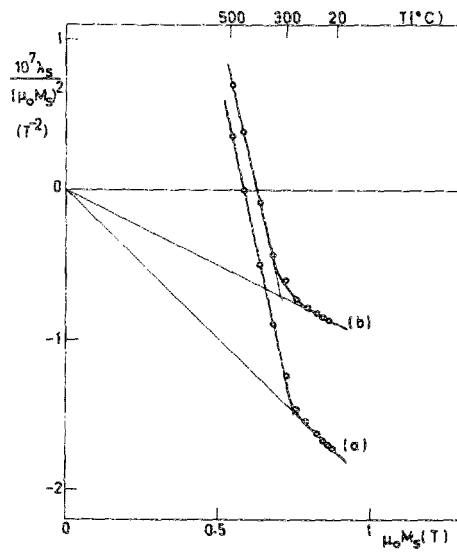


FIG. 4. Points of Fig. 3 replotted to obtain the single-ion and two-ion contributions to the magnetostriction. Labels (a) and (b) refer to the corresponding ones in Fig. 3.

It is to be noticed that all the values of λ_s have been obtained with the same, low applied stress of 80 MPa. Otherwise no comparison is possible because of the stress dependence of the magnetostriction. As shown in the inset of Fig. 3 the positive value obtained after relaxation becomes negative when higher stress is applied. This dependence of λ on σ is reversible and is observed at room temperature. Therefore, the influence of a possible stress-induced anisotropy in the variation of λ_s with σ must be disregarded.

As is well known,³ the one-ion contribution to the magnetostriction roughly depends on temperature as the cube of the spontaneous magnetization, and the two-ion contribution has a quadratic dependence on the spontaneous magnetization (M_s). The dependence on temperature of the macroscopic magnetostriction can be written as

$$\lambda_s(T) = \alpha |\mu_0 M_s(T)|^3 + \beta |\mu_0 M_s(T)|^2, \quad (3)$$

where α and β are temperature-independent coefficients. If so, a plot of λ_s/M_s^2 vs M_s will give straight lines from which α and β can be deduced. Figure 4 shows such a plot for the reversible parts of the curves in Fig. 3. Reversibility seems to indicate that we are dealing with the equilibrium temperature dependence of the magnetostriction, and no structural relaxation is superimposed. However, Eq. (3) is not obeyed in the whole temperature range. A transition from a low-temperature one-ion behavior to a high-temperature regime involving one-ion and two-ion contributions appears around 300 °C. This fact can be interpreted as arising from a phase transition occurring at this temperature.

The continuous dependence of the magnetostriction between the crystalline and the amorphous state, reported in this work, suggested us to use the nanocrystal concept to account for the observed behavior. This idea was used for explaining the magnetization dependence on temperature in a similar composition.¹²

It remains to be elucidated the microscopic mechanisms giving rise to the complex behavior of λ_s after annealing. According to our idea possible changes of phase of the crys-

talites,¹² structural relaxation of the amorphous matrix as well as segregation of new phases may contribute to the λ_s variations shown in Figs. 3 and 4.

New experiments have to be performed to inquire closely in the origin of the λ_s evolution with thermal treatment.

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