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ELECTRICAL AND MAGNETIC PROPERTIES OF METALLIC GLASSES DURING TENSILE DEFORMATION

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Abstract. - The electrical resistance and the magnetization work of Co-based amorphous alloys have been measured during tensile test up to fracture. The magnetization work-strain curve exhibits a magnetic hardening in three stage. Stage II is attributed to a local martensitic-like transformation.

Introduction

In metallic glasses, large magnetic anisotropies may be induced by applied stresses even though these materials have a magnetostriction nearly zero [1]. The origin of this magnetic anisotropy has been recently attributed to structural anisotropy induced by mechanical deformation [2]. Stress-induced structural transformations have been directly observed through the changes of the radial distribution function in X-ray diffraction experiments [3]. Recently, evidence for reversible structural transformations has been reported in Co-based amorphous alloys [4] which seem to exhibit a martensitic-like behaviour [5]. It should be expected that stress-induced transformations change the electrical and magnetic properties of metallic glasses during deformation. To investigate this point we have carried out electrical and magnetic measurements in two Co-based amorphous alloys during tensile test.

Uniform cross section samples of approximately 140 x 8 x 0.025 mm³ were prepared from commercial ribbons of two Co-based amorphous alloys of very low magnetostriction: Co₆₆Si₁₅B₁₄Fe₄Ni₁ and Co₆₆Si₁₆B₁₂Fe₄Mo₂. The sample, lengthwise encircled by a small secondary coil and coaxialwise placed inside a primary coil, was mounted in the tensometer by means of special insulating grips. To measure the electrical resistance a sensitive four-probe device was used. The device could measure changes in the electrical resistance of the sample with an accuracy better than 10⁻⁴ %. The magnetization (M - H) cycles of the sample were continuously recorded during the tensile test. The magnetization work was determined by numerical integration of the recorded M - H curves. The tensile tests were performed at room temperature and at a strain rate of 5 x 10⁻⁶ s⁻¹.

Results and discussion

Even though these metallic glasses have a nearly zero magnetostriction, a remarkably magnetic hardening is observed for both metallic glasses during tensile test. Figure 1 shows the tensile strain effect on the M - H cycles of the alloy Co₆₆Si₁₅B₁₄Fe₄Ni₁. In figure 2, the magnetization work W and the electrical resistance R of this metallic glass are plotted as a function of the strain up to fracture, along with the corresponding stress-strain (σ - ε) curve. The W and R values over the low stress range seem to deviate from the expected behaviour. This probably is induced by the compliances of the machine and we are not going to discuss it. The σ - ε curves of these
alloys show a very strong inelastic behaviour exhibiting a well defined elastic limit. The total strain is almost completely recovered after removing the applied stress. This means that the main part of the inelastic deformation induced in this tensile tests is produced by anelastic flow.

Three stages are clearly distinguished on the $W = \varepsilon$ curves when the tensile tests are performed up to fracture, see figure 2. Stage I coincides with elastic region of the $\sigma - \varepsilon$ curve. Over this stage I the $R - \varepsilon$ curves exhibit the expected linear behaviour due to elastic deformation. The onset of stage II coincides with the elastic limit and with the onset of the departure from linear behaviour in the $R - \varepsilon$ curves. For this stage II a non-linear dependence is observed in the $R - \varepsilon$ curves. Stage III in the $W - \varepsilon$ curves seems to be accompanied with a subtle change in the increase rate of $R$ versus $\varepsilon$. The semilogarithmic plot of $W$ versus $\varepsilon$ shown in figure 2 suggests an exponential dependence in these three stages. It is found that stage I and stage III exhibit the same exponential dependence.

The sharp change in the increase rate of the $R - \varepsilon$ curves, observed at the elastic limit, suggests a structural transformation induced by stress which results in an increase of the resistivity due to the structure factor change upon this transformation, according to the current model of conduction electron diffraction in metallic glasses [6]. Inelastic deformation would induce a downward deviation from the linear behaviour in the curve $R - \varepsilon$ as it has been early discussed by Takayama and Maddin [7]. The stage II in the $W - \varepsilon$ curve could be tentatively attributed to an additional contribution of this stress-induced transformation to the magnetic hardening of the sample. However, since stage I and stage III show the same exponential dependence we think that this transformation does not take place in the total volume of the sample but only in localized regions. The following model is proposed to account for the results.

The magnetic hardening in stage I, i.e. during elastic deformation, is controlled by regions of the sample having a negative magnetostriction constant. In these regions the applied stress would induce a local magnetoelectric anisotropy perpendicular to the stress direction. This could yield the exponential magnetic hardening observed in stage I. Above the elastic limit, certain kind of local structural transformation is activated in other different regions, which did not contribute to the magnetic hardening in stage I. These transformations can also induce a new local magnetic anisotropy in the direction perpendicular to the applied stress so that this anisotropy would contribute to increase the magnetic hardening rate above the elastic limit. The transient character of this increase, and the sharp change in the increase rate of the $R - \varepsilon$ curve, support the above suggestion. If the hardening rate increase observed in stage II is indeed due to structural anisotropy, exclusively induced by the inelastic deformation associated to those regions controlling the magnetic hardening in stage I, stage III would not be observed since the inelastic deformation of these regions still continue in stage III and no change in the hardening rate would be expected. The fact that stage I and stage III exhibit equal hardening rate suggests the same magnetic hardening mechanism, i.e. induced-stress magnetic anisotropy in the effective regions for stage I is working in these two stages. The transformed regions during stage II do not seem to be contributing to the magnetic hardening in stage III. The applied magnetic field likely is not high enough to magnetize these transformed regions. The results support the model of local martensitic-like transformation put forward elsewhere [5].