The Stress Effect on Magnetic Domain Structure of Fe–Co Amorphous Alloys

Y. Obi
The Research Institute for Iron, Steel and Other Metals, Tohoku University, Sendai, Japan

Received 22 September 1978/Accepted 23 October 1978

Abstract. The stress effect on magnetic domain structure has been studied for the Fe–Co amorphous alloy system. The domain structure was dominated by the magnetostriction–internal stress coupling. By applying the tensile stress, the domain structure was changed significantly according to the magnitude and sign of magnetostriction. The value of internal stress estimated was about $3 \times 10^8$ dyn/cm$^2$ and nearly constant for all the alloy composition.

PACS: 75.60

It has experimentaly been found that amorphous ferromagnets are magnetically very soft although the magnetostriction plays an important role to the magnetization process [1, 2]. Since amorphous alloys are produced by rapidly quenching from the melt, it seems that a stress is inevitably stored inside the specimen and its local fluctuation causes magnetoelastic anisotropy or coercivity in magnetization. However, the detailed character and origin of the internal stress are not well understood yet. In order to clarify the stress character, we have investigated the effect of applied stress on the magnetic domain structures for positive and negative magnetostrictive amorphous alloys. From the analysis of the stress dependence of perpendicular magnetic anisotropy associated with the maze magnetic domains, the magnitude of the internal stress amplitude is estimated.

Experiment

The amorphous alloys ($\text{Fe}_{1-x}\text{Co}_{x}\text{P}_{13}\text{C}_7$ ($0 \leq x \leq 0.75$) and ($\text{Fe}_{1-x}\text{Co}_x\text{Si}_{15}\text{B}_{10}$ ($0.65 \leq x \leq 1$) used were produced by the centrifugal solidification method described in the previous paper [3]. The electrical, thermal and basic magnetic properties were already measured and reported in the previous paper [1]. In the present investigation, the observation of the magnetic domain patterns under external stress is performed by using a conventional Bitter's technique.

Results and Discussion

Figure 1 shows the domain patterns for the as-prepared amorphous alloys $\text{Fe}_{80}\text{P}_{13}\text{C}_7$ and $\text{Co}_{75}\text{Si}_{15}\text{B}_{10}$, observed under the tensile stress applied along the long axis of the ribbon specimen (x-axis). In the case of zero external stress, the domain structures of the two alloys are similarly consist of the maze and 180°-domains. Contrary, the domain structures under the tensile stress are different between both the alloys. That is, in the case of $\text{Fe}_{80}\text{P}_{13}\text{C}_7$, the maze domains and the 180°-domains along the width of the ribbon (y-axis) smear out with increasing the stress strength and then the additional 180°-domains along the x-axis appear over the whole range of the surface (see Fig. 1 Ab and c). A stress of $11.7 \times 10^8$ dyn/cm$^2$ results in a complete disappearance of the maze domain as seen in Fig. 1 Ac. In the case of $\text{Co}_{75}\text{Si}_{15}\text{B}_{10}$, the maze domain and 180°-domain along the y-axis do not disappear even by applying the stress as large as $20.9 \times 10^8$ dyn/cm$^2$, but there can be seen the change that the 180°-domains surrounding the maze domains become more straight perpendicularly to the x-axis (see Fig. 1Bb and c).

For the interpretation of the stress dependence of domain structure observed above, it should be noted that the magnetostriction is positive for $\text{Fe}_{80}\text{P}_{13}\text{C}_7$ and is negative for $\text{Co}_{75}\text{Si}_{15}\text{B}_{10}$ [4]. The stress experiments carried out for all the alloys have further
revealed that the change in domain structure of the positive magnetostrictive alloys (0 ≤ x < 0.94) is similar to that of Fe₈₀P₁₃C₇ while the change of the negative magnetostrictive alloys (0.94 < x ≤ 1) is similar to that of Co₇₁Si₁₅B₁₀. The critical value of the applied tensile stress, σ_c where the maze domains just disappear was obtained for all the positive magnetostrictive alloys. In Fig. 2, the σ_c thus obtained is plotted as a function of composition x. In the previous paper [5], we measured the magnetic field dependence of the maze domains for the same amorphous alloys, and we explained the origin of the maze domain as follows; maze domains appear due to the existence of the perpendicular magnetic anisotropy originated from the magnetoelastic energy, $E_{magn} = -K_p \cos^2 \theta$, where $K_p$ is the perpendicular anisotropy constant and can be assumed to be equal to $(3/2)\lambda \sigma_i \theta$ the angle between the magnetization vector and the direction normal to the specimen surface, $\lambda$ the magnetostriction constant and $\sigma_i$ the internal stress component normal to the specimen surface. Assuming that the internal stress varies locally in the specimen, we have considered that the maze domains appear in the tensile regions ($\sigma_i > 0$) for the positive magnetostrictive alloys and in the compressive regions ($\sigma_i < 0$) for the negative magnetostrictive alloys, respectively. Consequently, the maze domains do not appear in the alloys having a vanishingly small magnetostriction. This has been evident by the experiment [2].

Now, the present result further supports the proposed concept. If the external stress is applied along the specimen axis, the internal tensile stress normal to the specimen surface ($\sigma_i > 0$) will decrease and the maze domains for the positive magnetostrictive alloys will smear out with increasing the external stress (see Fig. 1A). Contrary, the internal compressive stress ($\sigma_i < 0$) can not be canceled by the applied stress, so that the maze domains for the negative magnetostrictive alloys do not disappear (see Fig. 1B).

In the case of the positive magnetostrictive alloys, the condition that the internal stress is canceled out with the external stress may be described as $\sigma_i = \nu \sigma_e$, where $\nu$ is the Poisson’s ratio, $\nu$ is related to the Young’s modulus $E$ and the shear modulus $G$ as follows: $\nu = (E - 2G)/2G$. Many crystalline metals and alloys have the values of Poisson’s ratio between 0.2 and 0.4. In the amorphous materials, the measurement of Poisson’s ratio has only been done for a few alloys, M-Pd-Si (M = Cu, Ag, Au, Ni) and Pt-Ni-P, for example [6], whose values of $\nu$ are all about 0.4 which is not much different from those of the crystalline materials. It may, therefore, be reasonable to assume that the values of $\nu$ for the present alloys are 0.4 for all composition range. On the other hand, the result of Fig. 2 shows that the values of $\sigma_i$ are not strongly dependent on composition x. The mean