Effect of Stress on the Bamboo Domains and Magnetization Process of CoSiB Amorphous Wire

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Abstract **- In this work we have studied the behavior of the bamboo domains under stress (σ), tension (+σ) as well as compression (-σ), with the aim of making the domain model of the negatively magnetostrictive (-λ_s) CoSiB wire clear. It is observed that the growth of the surface bamboo domains due to σ has directivity depending on the orientation of the underlying core domain. In one orientation the black bamboo domain grows, while in the opposite orientation the white domain grows. From the stress behavior of the bamboo domains we have concluded that the domain model of -λ_s wire consists of two spiral domains of opposite rotation and proposed a new model.**

Index Terms - bamboo domains, domain model, spiral domains of opposite rotation, stress

I INTRODUCTION

Amorphous wires prepared by the rapid quenching method have unique magnetic features such as large Barkhausen jump (LBJ) of longitudinal flux, Matteucci effect etc, which are very suitable for sensor application [1]. Basically, these features have their origin in the distribution of residual stress induced in the wire by the rapid quenching process, which results in a unique domain structure [2].

In an attempt to understand the origin of the unique features several people [2] have studied the magnetic properties of the wires. Whereas most of the studies have concentrated on positive magnetostrictive iron based wire with consideable success, the study of the negative magnetostrictive wire has not been as fruitful leaving many questions unanswered. Certainly, the fact that the wire has a bamboo domain structure on the surface rather than being a single domain is puzzeling since the absence of walls would reduce the wall energy. The fact that axial reversal by a LBJ is observed in the Co based wire implies that there is an axially magnetized core domain underlying the bamboo domains. However, analysis of the stress distribution in a rapidly quenched wire shows that the axial component of the stress is tensile in nature, meaning that in the -λ_s wire the axial direction is a hard magnetization axis. This is contradicting. Besides, assuming the wire has a core-sheath model we still don't know the shape of the core-sheath boundary.

Needless to say, obtaining comprehensive and conclusive answers to all these questions lies in elucidating the domain structure model of the -λ_s wire. Previously we reported that the domain model of the -λ_s wire consists of the core-sheath structure and the viable mechanism for triggering the LBJ is the nucleation of a reverse domain and its subsequent propagation along the wire axis [3]. In the present work we have studied the behavior of the bamboo domains under stress with the aim of obtaining a more detailed model and an insight into the reason for the existence of the bamboo domains.

II EXPERIMENTAL DETAILS

The sample used is $Co_{72.5}Si_{12.5}B_{15}$ wire. It is about 6cm long with a diameter of 125 μm. Fig. 1 shows the set-up used to apply -σ. To ensure that the bending caused by compressing is negligible, the wire is inserted into a hole made through solidified resin. The diameter of the hole is just slightly larger than that of the wire to allow free insertion and removal of the sample. The resin is polished near the center to expose a small portion of the wire for domain observation. The protruding ends of the wire are inserted into small holes in the movable and fixed plates by which -σ is applied. The -σ is applied via a non magnetic spring attached to the movable plate and its value is evaluated from the shrink of the spring. Domain structure is observed by kerr microscope.

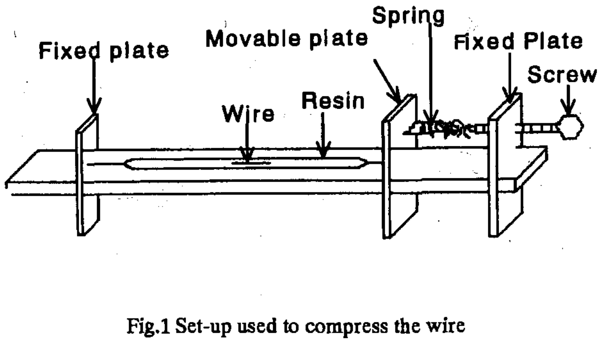

Fig.1 Set-up used to compress the wire

Manuscript received on February 11, 1998 (paper submitted for review on October 27, 1998)

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ent frictions are represented by

$$Fa = \mu N / (1 - \mu \tan\theta) \quad (1)$$

$$Fb = \mu N / (1 + \mu \tan\theta). \quad (2)$$

Here Fa and Fb are the apparent frictions in the left and right directions respectively, N is the normal reaction, μ is the frictional coefficient, and θ is the equivalent contact angle. From the equations (1) and (2), it is found that Fa is always larger than Fb. In particular, if θ satisfies the following condition:

$$\theta \geqq \tan^{-1}(1/\mu), \quad (3)$$

Fa becomes infinity and thus the tip of the leg is self-locked in the right direction. In general, the angle that satisfies equation (3) is estimated to be more than 70 -80 deg.

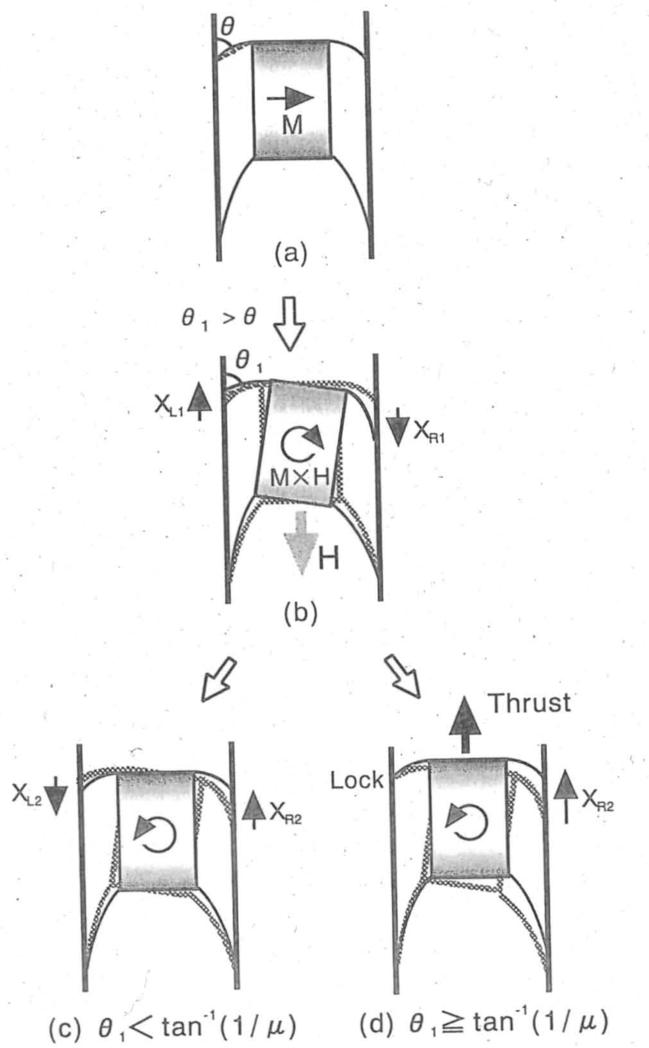

Fig. 3 Predicted actuation of the mover during a half cycle.

Fig. 3 shows the simple model of the predicted operation of the mover during the half cycle. In this model, two assumptions are made: first, the contribution of the back legs to the thrust is negligible compared with that of the front legs; second, the equivalent angle θ of the front legs doesn't satisfy the equation (3) in the initial shape shown in Fig. 3(a). Firstly the magnetic field is applied in the negative direction, as shown in Fig. 3(b). The mover rotates in the clockwise direction according to magnetic torque $\boldsymbol{T}$, which is given by

$$\boldsymbol{T} = \boldsymbol{M} \times \boldsymbol{H} \quad (4)$$

where $\boldsymbol{M}$ is the magnetic moment of the magnet and $\boldsymbol{H}$ is the applied magnetic field. Then the right front leg is pressed against the wall and slides in the negative direction, while the left front leg slides in the positive direction at the same time and the equivalent angle increases from θ to θ_1. Next the magnetic field decreases, causing the mover to rotate reversely due to the elastic forces of the legs. In this case, two operations are possible as shown in Figs. 3(c) and (d). If the amplitude of the vibration is small, each front leg slides backward its original position, as shown in Fig. 3(c). Since the sliding distance of the legs depends on many factors such as the contact conditions and the load, it is difficult to determine the moving direction in this actuation mode. On the other hand, if the amplitude of the vibration is large enough for θ_1 to satisfy the equation (3), the left front leg is self-locked and the thrust is produced in the positive direction. As a result, the mover moves in the positive direction.

IV. Results and Discussion

Fig. 4 shows the experimental apparatus. The stator coil was kept in the vertical position. In order to measure the velocity, a ribbon with a scale, 0.12 g in weight, was attached to the bottom of the mover. In this experiment, the no-load velocity and the standstill thrust were measured.

The prototype was successfully operated and the mover smoothly moved in the travel range of 100 mm. Fig. 5 shows a no-load velocity as a function of the excitation frequency when the alternating magnetic field of 4.8 kA/m was applied. The sign of the velocity means the moving direction indicated

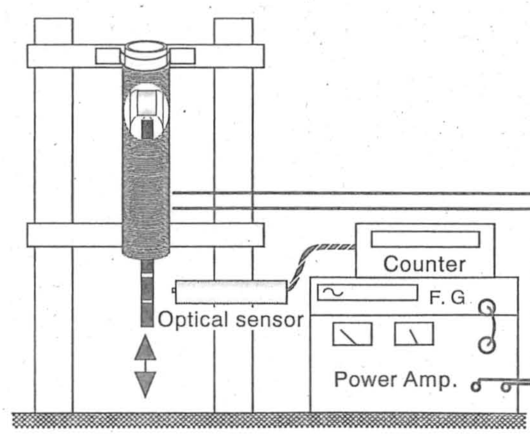

Fig. 4 Experimental apparatus.

CoSiB wire is negatively magnetostrictive. Hence, axial $+\sigma$ induces radial and circumferential easy directions and makes the magnetic moments rotate to these directions. To reduce the magnetostatic energy circumferential easy direction is preferred since it provides a natural closure path. Owing to this the bamboo domain will grow wider and deeper into the core until the wire saturates. For $-\sigma$, we suppose that the core magnetization will increase, since the Mr:Ms increases. But, in either case, since the sheath and the core are dependent domains change of the core affects the shell and vice versa.

Fig. 5 shows the evolution of domains on the polished surface due to $+\sigma$. The behavior of the domains after LBJ is also shown for comparison. From the figure the remarkable features are; (a) the bamboo domains are still observed even on deeply polished surface, possibly to reduce the magnetostatic energy by naturally providing a circumferential closure path. Note that there is greater tendency for the magnetization to orient in the circumferential direction because; it provides a naturally closed path; it is the easy direction induced by internal σ resulting from the rapid quenching and; it is also the easy direction induced by $+\sigma$; (b) triangular domains appear at the edges of the polished surface, seemingly, to reduce the magnetostatic energy because at the edges the circumferential flux is normal to the surface which increases the magnetostatic energy; (c) $+\sigma$ causes the triangular domains grow and spread to the center of the polished surface. $+\sigma$ induces circumferential easy direction which makes the triangular domains grow wider and deeper into the wire, eventually making the entire wire a single domain; (d) after LBJ there is a reversal in the contrast of the domains. This clearly shows that in this wire the outer and inner domains have no fixed boundary. Presumably, under $+\sigma$, the behavior of the domains in the unpolished wire is analogous to that observed on the polished wire.

The main experimental observations in the CoSiB wire are (i) the surface domains are bamboo structured (ii) either under stress or not the reversal of the core domain is reflected on the surface bamboo domains (iii) by application of stress there is directivity in the growth of the bamboo domains depending on the orientation of the core domain (iv) there is an axially magnetized domain resulting in LBJ of the longitudinal flux and the LBJ occurs under either circumferential or longitudinal field. The domain model to satisfy the above experimental facts is proposed as shown in figure 6. Previously we reported that the switching of magnetization in this wire starts by the nucleation of a reverse domain, presumably near the wire end, which then propagates along the wire [3]. In the cross section of the model if a white domain nucleates at the end it will then grow towards the center and connect with the white bamboo domains. By so doing, the sudden shrink of the black domains and vice versa observed after the LBJ is considered to occur.

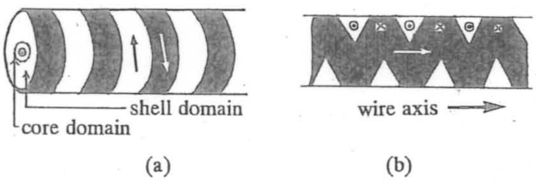

Fig.6 Domain model deduced from present experimental observations

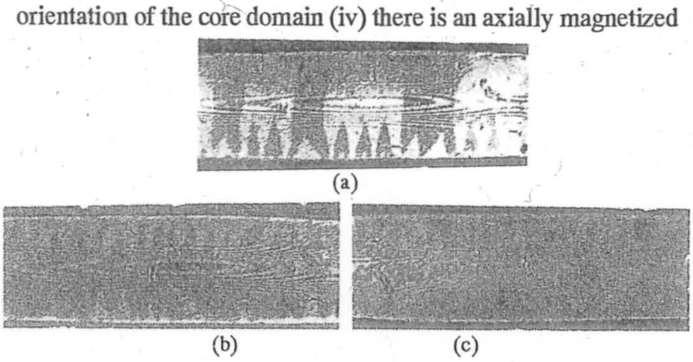

Fig.5 Change of domains on polished surface due to tension (a) for zero tension (b) for 79.4 MPa and before LBJ (c) for 79.4 MPa and after LBJ

Though at the moment we are not quite certain of the reason for this kind of model, we suppose the existence of this sort of domain structure is to minimize the exchange energy. The anisotropy of this wire is circumferential and it is natural to expect a circumferentially closed domain from the surface to the core of the wire. However, this sort of domain will greatly increase the exchange energy inside the wire. We presume that to avoid this two continuous spiral domains of opposite rotations are preferred, with one of the domains extending to the wire core and gradually tilting towards the axial direction as the wire core is approached.

IV Conclusions

The domain model of negative magnetostrictive wire consists of two continuous spiral domains of opposite rotations. One of the spiral domains extends to the wire core and gradually tilts towards the axial direction as the core is approached, possibly in an attempt to reduce the exchange energy. This kind of orientation of the domains is, presumably the origin of the bamboo domains and the LBJ of the longitudinal flux observed in the CoSiB wire.

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