Dependence of Magnetic Properties of $(Fe_{50}Co_{50})_{78}Si_7B_{15}$ Amorphous Wire on the Diameter

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Abstract - The dependence of the magnetic properties of amorphous wire on the diameter have been investigated. The anisotropy constant, hence the internal stress, of the wire increases with the wire diameter. The size of the pinned reverse domain at the wire end increases with the wire diameter. Domain observation shows that irrespective of the change in the wire diameter, the domain structure basically consists of chevron domain layer sandwiched between the surface maze domain and the inner core domain.

INTRODUCTION

The as-quenched amorphous wires of positive magnetostriction constant show highly sensitive and stable large Barkhausen jump, in addition to their excellent mechanical and chemical properties. Owing to these properties they are widely employed as sensor elements in rotary encoders security sensors etc.[1]. The magnetic properties of the wires have therefore been widely investigated [2]. However, the investigation has been restricted to medium diameter wires because they are relatively easier to make and they are more suited to practical application, considering the size of the wire and the magnitude of the voltage pulse generated due to magnetization reversal.

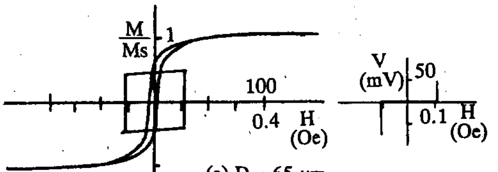
Recently, however, it has become technologically possible to produce wires with diameters as large as 300 μm. In this work, we have investigated the dependence of the magnetic properties on the diameter of the wire.

SAMPLES AND EXPERIMENT METHOD

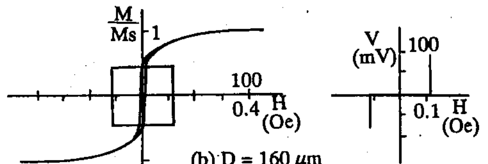
The samples used in the experiment have positive magnetostriction constant and were prepared by the in-rotating water quenching technique. Their diameters are in the range 65-315 μm. The 65μm wire was prepared in our laboratory while the other wires were supplied by Unitika Co (Kyoto, Japan). The domain structure was observed by a Kerr microscope employing an image processor to enhance the domain contrast. To observe the inner domain structure the wire was mechanically polished using diamond paste. Since the domain change caused by flux reversal is too sudden to observe, the domain structure was observed on 4cm long samples in order to control the nucleation of the reverse domain by the enhanced demagnetization of the shorter wire. The other data was taken on samples having at least the respective minimum length required for magnetization reversal in the core region. The minimum length is about 3, 7, 8, 10 and 30cm for 65, 130, 142, 160, and 315μm wires, respectively.

RESULT AND DISCUSSION

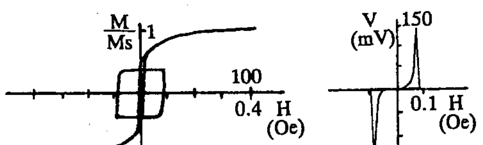
Fig. 1 shows the ac (60Hz) minor and major M-H loops of 65, 160, and 315 μm wires, respectively. The value of magnetic field (100Oe) shown on the upper side of the x-axis corresponds to the major M-H loop, while the value on the lower side is that of the minor loop. On the right hand side of the figure, the pulse voltage induced in a search coil due to flux reversal in the respective wire is shown. By comparing the volume ratios and the ratios of the pulse amplitudes it is observed that the two ratios do not tally, that is, the latter are smaller than the former.



(a) D = 65 μm



(b) D = 160 μm



(c) D = 315 μm

Fig. 1 Major and minor M-H loops and the corresponding pulse voltage induced by magnetization reversal

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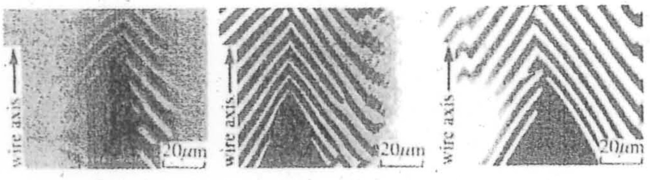
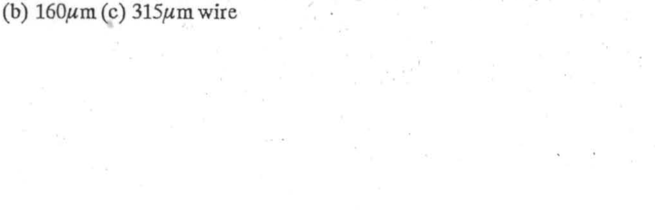
In a cylindrical magnetic specimen, the eddy current in the core is directly proportional to the square of the radius of the cylinder. It is thus expected that as the wire diameter increases the effect of the eddy current on the velocity of the domain wall in the core should increase. This appears as a spread in the pulse width and a decrease in the amplitude. The discrepancy between the volume and pulse amplitude ratios of the wires is therefore considered to have its origin in the eddy current.

Fig. 2 shows the domain structure observed at remanent state on the surface of 65, 160, and 315μm wires, respectively. Since the surfaces of the larger diameter wires are quite rough, making it difficult to observe the domain structure, the wires were slightly polished using diamond paste, but to such an extent that there is little effect on the surface domain. It is observed that irrespective of the change in the wire diameter the surface domain is basically the typical maze pattern, characteristic of radial anisotropy. However, the maze domain becomes inclined from the axial direction of the wire as the diameter increases. The inclination is caused by the increase of the anisotropy constant with the wire diameter. In each case, if the wire is polished chevron domain layer and then core domain layer are observed with increasing depth of polishing. This is shown in Fig. 3, where the chevron domain and a part of the core domain are visible. Here, we note that the depth of polishing required to observe the chevron and core domain gets larger with the diameter and the chevron domains are observed over a particular narrow range of polishing depth which depends on the diameter. Beyond this depth only the core domain is observed. Moreover, the polished surface is semicircular in shape hence the polishing depth decreases gradually from the center of the polished section towards the edge. Therefore, the section of the image plane where a part of the core is visible is nearer to the center of the polished section. In a nutshell, the basic domain structure in each of the wires, starting from the wire surface, consists of maze domain, chevron domain, and core domain.



(a) (b) (c)

Fig. 2 Domain structure observed on the surface of wire at remanent state for (a) 65μm, (b) 160μm, (c) 315μm wire



(a) (b) (c)

Fig. 3 Domain structure observed on the polished surface of (a) 65μm (b) 160μm (c) 315μm wire

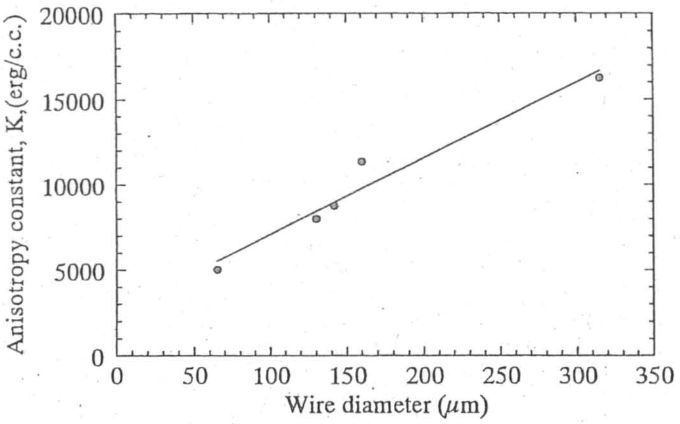


Fig. 4 Variation of anisotropy constant with wire diameter

Fig. 4 shows the variation of the anisotropy constant (estimated from the magnetization curve with axial field) of the shell region with the wire diameter. The anisotropy constant is averaged over the entire volume of the wire, but reflects the behavior of the anisotropy constant of the shell region as the wire diameter changes. Amorphous wires have no crystal anisotropy. Therefore, the anisotropy in the wire can wholly be considered to be magnetostrictive in origin. The samples used in the experiment were prepared by the in-rotating water quenching method in which the melt is ejected into the rotating water. In this method, the surface of the wire first comes into contact with the water and solidifies. As the solidification proceeds towards the core, the pre-solidified mass stresses the solidifying material. As a result residual stress comes to exist in the wire. The residual stress increases with the lapse between the instant the outer surface solidifies and that when the inner core solidifies. This time interval increases with the wire diameter, resulting in the increase of internal stress, hence the anisotropy constant of the wire.

Fig. 5 shows the variation of the critical wire length required for large Barkhausen jump (LBJ) with wire diameter.

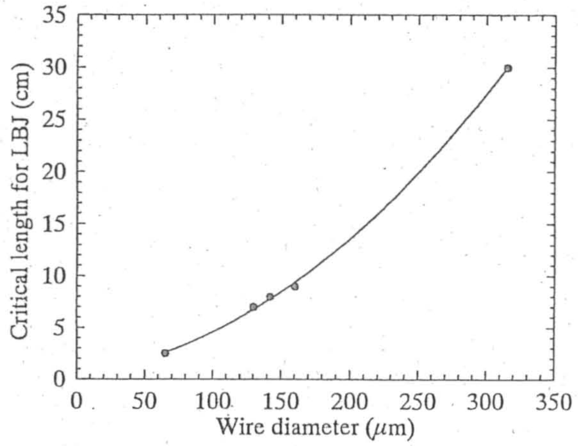
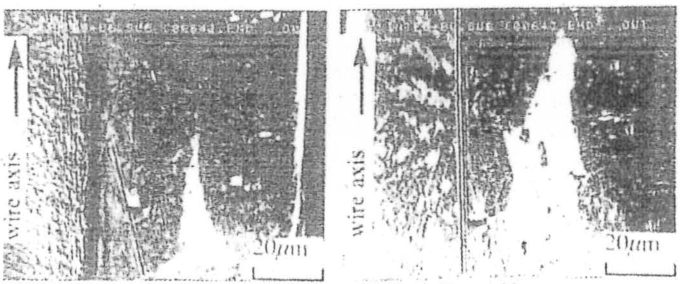


Fig. 5 Variation of critical wire length for (LBJ) with wire diameter

The length is estimated by starting with a wire which is long enough to support the LBJ characteristic and then reducing the length by cutting a small part at the end until the the LBJ characteristic disappears. The LBJ is confirmed for each length by observing the minor loop. The approximate length at which this characteristic disappears is the length we define as the critical length. The flux reversal in positively magnetostrictive wires occurs by the depinning of the reverse domain which exists at the wire end to account for the demagnetization field [2]. Large Barkhausen jump is observed only in wires which have at least a certain critical length dependent on the wire diameter. This length is deeply related to the length of the residual domain, the longer the domain the longer the critical length [2]. The length of the residual domain increases with the diameter due to the larger demagnetization field. Consequently, the critical length increases with the diameter.

Fig. 6 shows the residual reverse domain observed at about 1mm from the end of 65 and 142 μm wires, respectively. The residual reverse domain appears at the wire ends to account for the demagnetization field that would result if the wire were to be magnetized uniformly up to the end. It is observed in this figure that the size of the reverse domain increases with the wire diameter. This is considered to be due to the increase of demagnetization field.



D = 65 μm

D = 142 μm

(a) (b)

Fig. 6 Residual reverse domain observed at the wire end at remanent state for (a) 65μm (b) 142μm

In wires of positive magnetostriction constant, the re-entrant flux reversal is set off by the propagation of the pinned reverse domain from one wire end to the other [5], in other words a depinning mechanism. The pinning of the reverse domain and the core occurs by magnetic coupling to the shell domain and the core magnetization is expected to play a major role in determining the pinning strength. On the other hand, the depinning field should be correlated to the pinning strength. The critical field for flux reversal is therefore deeply related to the core magnetization [2].

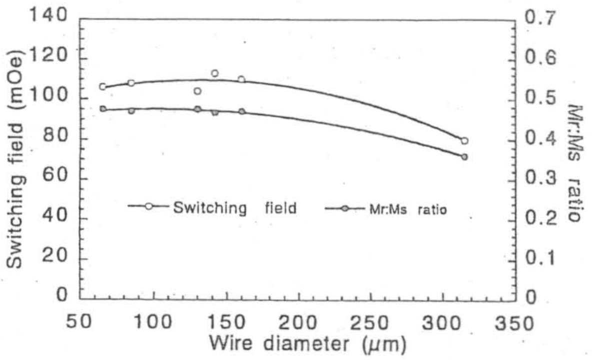


Fig.7 Variation of Mr:Ms ratio and switching field with wire diameter

Fig. 7 shows the switching field and the remanence to saturation magnetization (Mr:Ms) ratio as a function of the wire diameter. The switching field is taken at the minimum wire length for LBJ since at longer lengths the field is virtually length independent. The former and the latter show quite a similar dependence on the diameter. The variation of the switching field with the diameter is thus attributed to the variation of the core magnetization as reflected by the Mr:Ms ratio.

CONCLUSIONS

(1) The anisotropy constant of the wire increases with the wire diameter. This is considered to emanate from the larger residual stress resulting from the larger lapse between the instant at which the outer surface of the wire solidifies and that when the inner core solidifies.

(2) Irrespective of the wire diameter, the basic domain structure of the wire consists of the chevron domain sandwiched between the surface maze domain and inner core domain.

(3) The size of the residual reverse domain at the wire end increases with the wire diameter due to the increase of demagnetization field. Consequently, the critical wire length for LBJ also increases with the wire diameter.

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