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ADP012174 thru ADP012259

Mat. Res. Soc. Symp. Proc. Vol. 703 © 2002 Materials Research Society V6.23

Rapid-Solidification Effect on Magnetostriction in Iron-based Ferromagnetic Shape Memory Alloy

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ABSTRACT

Fe-29.6at%Pd ferromagnetic shape memory alloy (FSMA) ribbon formed by rapidly solidified, melt-spinning methods is expected to be useful as a new type of material which shows giant magnetostriction as well as quick response. The giant magnetostriction in the rolling direction depends strongly on applied magnetic-field direction and has a maximum value of 8×10^{-4} when the field is normal to the surface. This phenomenon is caused by the rearrangements of activated martensitic twin variants. The inverse phase transformation temperatures (As) obtained from Laser micrographs and magnetization vs. temperature curve are ~307 K and 400~440 K, respectively. We analyze magnetostriction, magnetic property and crystal structure of Fe-29.6at%Pd bulk sample before rapid solidification and the ribbon sample. From these results, it can be concluded that remarkable anisotropy of giant magnetostriction of ribbon sample is caused by the fine structure formed by the melt-spinning method. It may be possible to apply this method successfully to other FSMA and Ni_2MnGa, which is difficult to manufacture owing to its brittleness.

INTRODUCTION

Ferromagnetic Fe-Pd shape memory alloy is useful as a micromachine and intelligent / smart material system controlled by a magnetic field. Martensitic twin's initiations and the following its movements depending on magnetic field are thought to be closely related with a new type of magnetostriction[1]. The previous studies [2,3] showed that the rapidly solidified Fe-29.6 at%Pd alloy ribbon has stronger crystal anisotropy, giant magnetostriction as well as shape memory effect. Magnetostriction is changed with temperature and has a maximum of 18 $\times10^{-4}$. However, the mechanism of magnetically induced strain has not yet been discussed. We think that a directional dependence of magnetostriction is probably caused by fine columnar microstructure formed by rapid solidification methods. To confirm this hypothesis, in the present study, at first, we analyze magnetostriction, magnetic property and crystal structure of Fe-29.6at%Pd bulk sample before rapid solidification and compare these properties with those of the ribbon sample. Next, we investigate the

relation between a phase transformation from martensite (fct) to austenite (fcc) to martensitic twin's mobility during magnetization process.

EXPERIMENTAL DETAILS

The rapidly solidified Fe-29.6at%Pd 60 μm-thin ribbon samples were prepared by originally designed electro-magnetic melt-spinning single- or twin-roll method from bulk alloy [3]. Samples were annealed at 1173 K for 0 and 0.5 h in vacuum to study the effect of heat treatments on magnetostriction. The magnetization, M vs. applied magnetic field, H loop was measured by VSM method. The magnetostriction, ε was measured by strain-gauge attached on the sample which was set in a furnace between the electromagnets. The sample can be rotated in H, and the rotation axis is set to be the rolling direction (RD). H was applied perpendicular to RD and strain changes were measured along RD with increasing θ from 0° to 90° , where θ is the rotation angle (see Fig.1(b)). The X-ray diffraction (XRD) was obtained with Cu Kα line for ribbon and bulk samples.

RESULTS AND DISCUSSION

The M vs. H loops of the melt-spun ribbon prepared by single-roll method (S-0 h ribbon) are shown in Fig.1 (a). Figure 1 (b) is schematic diagram of measurement method. The loops for θ =0° and H $\parallel$ RD saturate at H>1 kOe and have small coercive force Hc(~25 Oe). While, the loop for θ =90° dose not saturate still at H=5 kOe because of large demagnetic field, and has large Hc(~60 Oe) because of magnetically anisotropic microstructure. The results suggest that the melt-spun Fe-29.6at%Pd thin ribbon sample has a strong crystal anisotropy in the surface direction perpendicular to RD. On the other hand, the bulk sample, which is annealed for 0.5 h at 1173K in order to take off strain caused by cutting, also shows the similar M vs. H loops but its Hc is small.

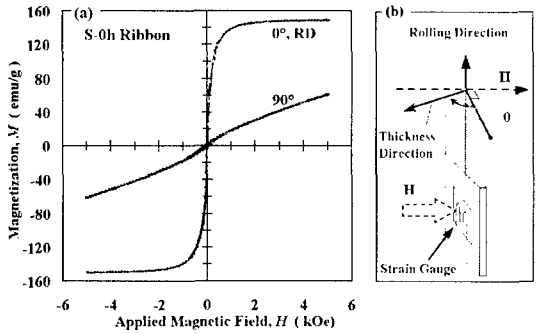

Fig.1 Direction dependence of magnetization in the ribbon sample (a), and schematic diagram of measurement method (b).

Figure 2 (a) shows the dependence of ε on H of the S-0h ribbon. ε depends on remarkably and has a maximum, -8.3×10^{-4} at $\sim 85^{\circ}$. Figure 2 (b) is the dependence of ε on θ for bulk sample, where ε has a maximum, $+60 \times 10^{-6}$ at 0° and a minimum, -42×10^{-6} at 90°, as ordinarily expected. A comparison of direction dependence of Hc between the ribbon and bulk samples is shown in Fig. 3. The Hc of the ribbon depends on θ remarkably and has a maximum,98 Oe at $\theta = 85^{\circ}$. Similar dependency is seen for ε (See Fig.2(a)). The Hc of the bulk depends hardly on θ, that is magnetically isotropic texture.

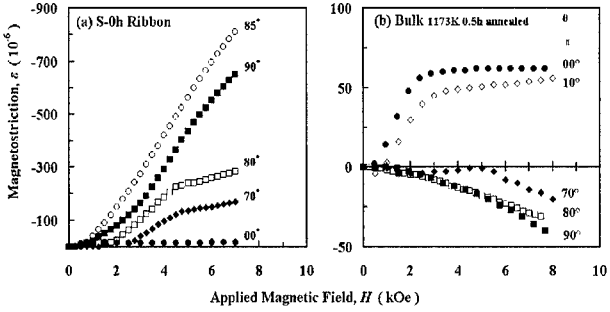

Fig.2 Direction dependence of magnetostriction measured at room temperature for (a) S-0 h ribbon sample and (b)

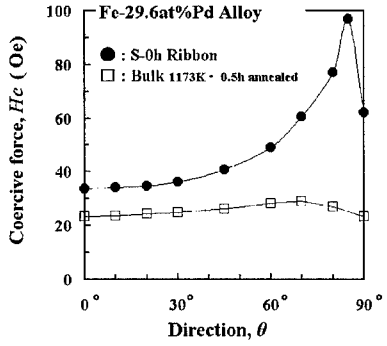

Fig.3 Comparison of direction dependence of coercive force between the ribbon and bulk samples.

Figure 4 shows magnetization dependence of the maximum magnetostriction, ε_m for two different material processings. A ratio of ribbon ε_m to bulk one is larger than 30. A comparison of XRD

patterns obtained for the two sample surfaces is shown in Fig.5. For bulk, there are fcc and bcc structures equally. On the other hand, for ribbon obtained after the rapidly solidification, the bcc structure decreases and martensite phase, fct structure appears. Consequently, the {200} peak at 293 K has three structures : fct (200), fcc (200) and fct (002).

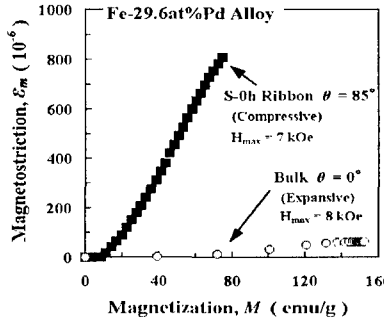

Fig.4 Magnetization dependence of the Maximum magnetostriction for two different material processings.

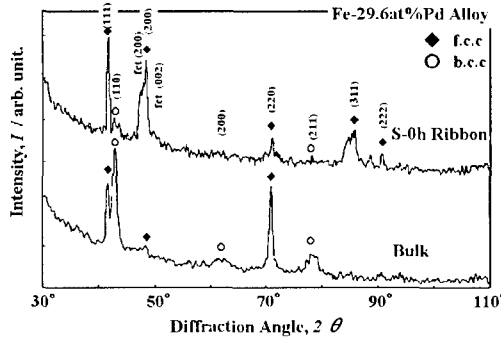

Fig.5 Comparison of X-ray diffraction pattern for two different material processings.

Figure 6 shows the temperature dependence of ε at θ =80° ~85° for S-0 h ribbon and 1173 K · 0.5 h annealed ribbon which was prepared by twin- roll method (T-0.5h ribbon). When T-0.5 h ribbon temperature increases (see processes (1) and (1')), ε first decreases from 6.3×10^{-4} to 5.2×10^{-4} and then increases reaching a maximum at 400 K, and finally decreases suddenly to 1.4×10^{-4} at 440 K. A jump and discrepancy from (1) to (1') was caused by the experimental discontinuity of heating procedure. Thereafter, we let the temperature down (see process (2)). ε increases again to 3.5×10^{-4} at 400 K and decreases 1.6×10^{-4} at 190 K. Then, we elevate the temperature again (see process (3)).

ε increases and goes approximately back over its way. From these results, we conclude that large magnetostrictive phenomenon was caused by rearrangements of the activated martensitic twin variants responding to H. Furthermore, it is suggested that the austenite phase starting (As) and finishing (Af) temperatures, are about 400K and 440K, respectively. Figure 6 also suggests that As and Af of S-0 h ribbon are 376K and 460K, respectively.

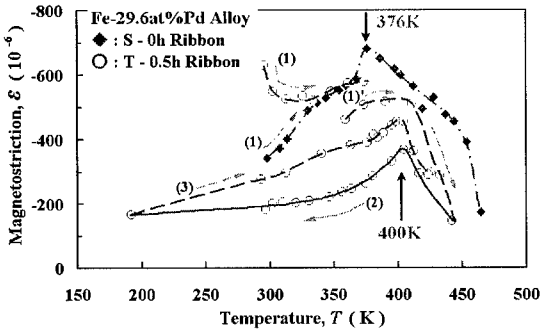

Fig.6 Maximum magnetostriction, ε vs. temperature, T curves for two ribbons.

Figure 7 shows the photographs of the S-0 h ribbon surface in process of heating obtained by the Laser microscope. The martensite twin stripe-pattern observed at 303K almost disappears at 307K.

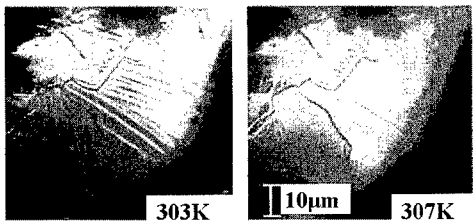

Fig.7 The photograph of martensite twin boundaries of S-0 h ribbon surface observed by the Laser microscope.

We note a discrepancy between the measured temperatures of the phase transformation. To clear the origin of the discrepancy , we investigate a shape memory effect for the S-0 h (◇) and T-0.5 h (○) ribbons, as seen in Fig. 8(a) where the shape recovery ratio, Φ_{T2}/Φ_{T1} is shown. Φ_{T1} and Φ_{T2} are the diameters defined in (b) at $T = T_1$ and $T = T_2$, respectively. The ratios for both ribbons increase with

temperature. Especially, the ratio raises sharply in temperature ranges of 300~330 K and 380~420 K, which correspond to the As determined by microscope observation and ϵ vs. T measurements, respectively. It can be concluded that the surface and the inner bulk of ribbons consist of different texture.

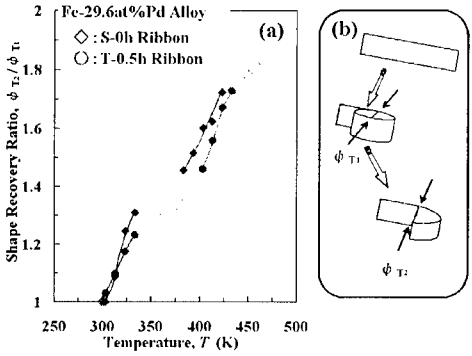

Fig.8 (a) temperature dependence of shape memory effect for the S-0 h ribbon (◇) and the T-0.5 h ribbon (○), and (b) measurement technique.

CONCLUSION

The rapid-solidified, melt-spun Fe-29.6 at%Pd alloy ribbon has large magnetostriction of 8×10^{-4}, which is caused by rearrangements of the activated martensitic twin variants. The analysis of X-ray diffraction shows that martensite phase fct structure is created by the rapidly solidification. Two phase transformation temperatures As of ~303K and ~400K are observed for the ribbon sample. It can be considered that the surface and the inner bulk of ribbon consist of different texture.

REFERRENCES

1. K. Ullakko, J. K. Huang, V. V. Kokorin and R.C.O. Handley : Scripta Mater., 36, 1133(1997).
2.Y. Furuya, Proceedings of 1st Japan-France Intelligent Materials and Structures Seminar, Sendai, 113(1998).
3.Y. Furuya, N. W. Hagood, H. Kimura and T. Watanabe, Mater. Trans. JLM, 39, 1248(1998).