In-plane Magnetic Anisotropy of Cold Rolled Amorphous Fe_5Co_<70>Si_<15>B_<10> and Fe_<19>Co_<59>Si_<10>B_<12> Alloys

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In-plane Magnetic Anisotropy of Cold Rolled Amorphous $Fe_5Co_{70}Si_{15}B_{10}$ and $Fe_{19}Co_{59}Si_{10}B_{12}$ Alloys*

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Synopsis

The in-plane twofold magnetic anisotropy of the cold rolled amorphous $Fe_5Co_{70}Si_{15}B_{10}$ and $Fe_{19}Co_{59}Si_{10}B_{12}$ alloys was examined by the magnetization curve and the magnetic torque measurements.

In the case of the magnetostrictive $Fe_{19}Co_{59}Si_{10}B_{12}$ alloy, the magnetizing energy was pronouncedly increased by cold rolling in any direction irrespective of the roll direction. The difference between the energies measured in the directions parallel and perpendicular to the roll direction or the induced anisotropy energy was small and not reduced by annealing even beyond the crystallization temperature. The result of annealing temperature dependence is consistent to that obtained by the torque measurement. While, the isotropic term of the magnetizing energy increased by cold rolling was reduced by annealing easily.

It was considered that the isotropic term was arised by the stress-magnetostriction effect but the anisotropic term was arised by the anisotropic atomic arrangement in the deformation band.

I. Introduction

It is well known that the soft magnetic properties of as-quenched and cold-rolled amorphous alloys are improved by annealing at temperatures below the crystallization temperature. This improvement by annealing has been considered to be primarily due to the relaxation of internal stresses frozen in the alloy during the solidification[1,2] process.

In contrast with the annealing effect on the soft magnetic properties, the in-plane magnetic anisotropy measured by a torque

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magnetometer is not reduced by annealing at temperatures even beyond the crystallization temperature[3].

In order to understand the reason of this difference, we have investigated the detailed characters of the in-plane roll magnetic anisotropy by the magnetization curves and its annealing-temperature dependence. The results have been compared with those of the in-plane magnetic anisotropy measured by the torque magnetometer. The annealing-temperature dependences of the coercive force have been also examined.

II. Experiments

Amorphous $Fe_{19}Co_{59}Si_{10}B_{12}$ and $Fe_5Co_{70}Si_{15}B_{10}$ ribbons were prepared by rapid quenching from the melt. As-quenched ribbons were placed between two sheets of an annealed stainless steel, and then cold rolled up to 18% reduction along the edge of the ribbon. For the measurement of magnetization curve, two specimens in the form of 3 mm in width and 5 cm in length were cut from the rolled ribbon. Their long axes are parallel and perpendicular to the roll direction, respectively.

For the anisotropy measurements, specimens were always magnetized along the long axis with the external magnetic field of up to 100 Oe. For the coercive force measurement, B-H curves were measured up to 20 Oe for the $Fe_{19}Co_{59}Si_{10}B_{12}$ alloy, and up to 1 Oe for the $Fe_5Co_{70}Si_{15}B_{15}$ alloy.

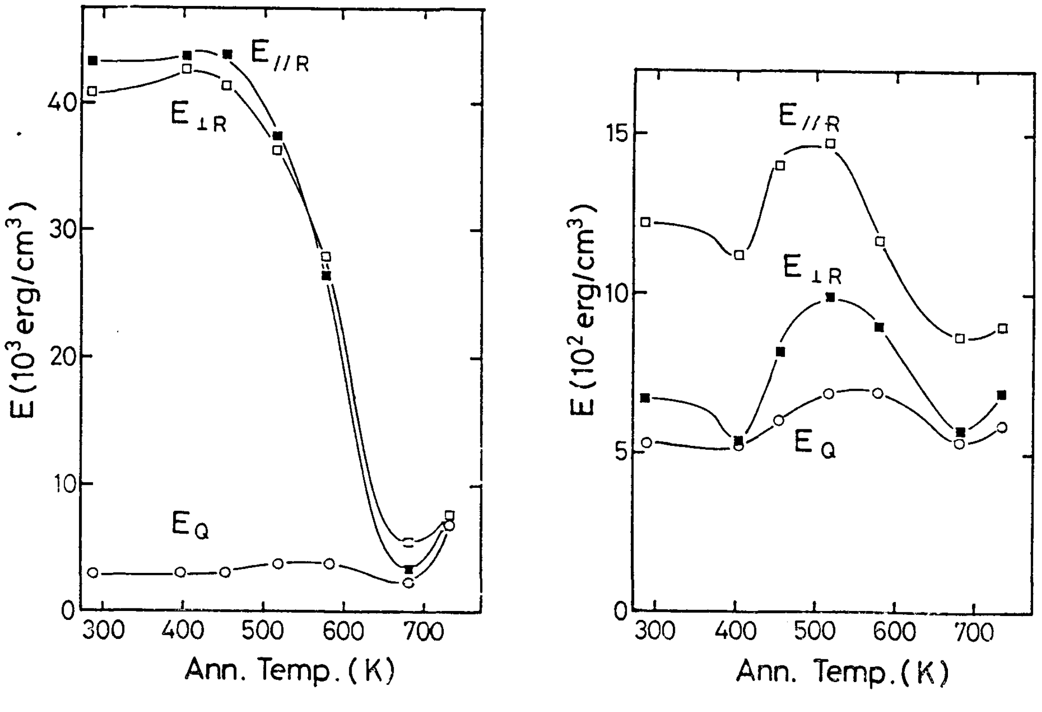
Magnetic torque curves were measured in the magnetic field of 15 kOe by a high sensitive automatic torque magnetometer, using disk specimens of 2-3 mm in diameter. The amplitude of twofold component Lu of the torque curve was determined by means of the Fourier analysis, and the anisotropy constant Ku was obtained as $Ku = Lu/2$.

III. Results and Discussion

In order to examine the effect of the magnetic anisotropy which originates from strain-magnetostriction interaction on the magnetization curve, two characteristic amorphous alloys are used in this work. One is the amorphous $Fe_5Co_{70}Si_{15}B_{10}$ alloy which has very small magnetostriction and the other is the amorphous $Fe_{19}Co_{59}Si_{10}B_{12}$ alloy which has large magnetostriction.

It has been found that the magnetic properties of amorphous alloys become hard by cold rolling. The magnetic hardness is related to the magnetizing energy E difined as $E = \int_0^{Is} H dI$, where I_s is the saturation magnetization.

Figures 1a and 1b show the annealing-temperature dependence of the magnetizing energies $E_{//R}$ and $E_{\perp R}$ measured along and across the roll direction, respectively. The specimens were annealed for 1 h at each temperature. For comparison, the magnetizing energy E_Q of the as-quenched specimens are also shown in the figures. The as-quenched specimens are magnetized in the direction parallel to the edge of ribbon. Cold rolling increases the magnetizing energy of both specimens, and the values of $E_{//R}$ and $E_{\perp R}$ of as rolled $Fe_{19}Co_{59}Si_{10}B_{12}$ are larger than those of $Fe_5Co_{70}Si_{15}B_{10}$. Since the former specimen has larger magnetostriction than the latter, this result agrees with the explanation that the roll magnetic anisotropy of amorphous alloys originates mainly from the strain-magnetostriction interaction. It should be noticed in Fig. 1a that in the case of magnetostrictive specimen, though the increase in $E_{//R}$ or $E_{\perp R}$ is very large but the values of them are nearly the same, and the difference between them is only about 2% of them. Both $E_{//R}$ and $E_{\perp R}$ are reduced remarkably by annealing atove 450 K. This annealing-temperature dependence coin-



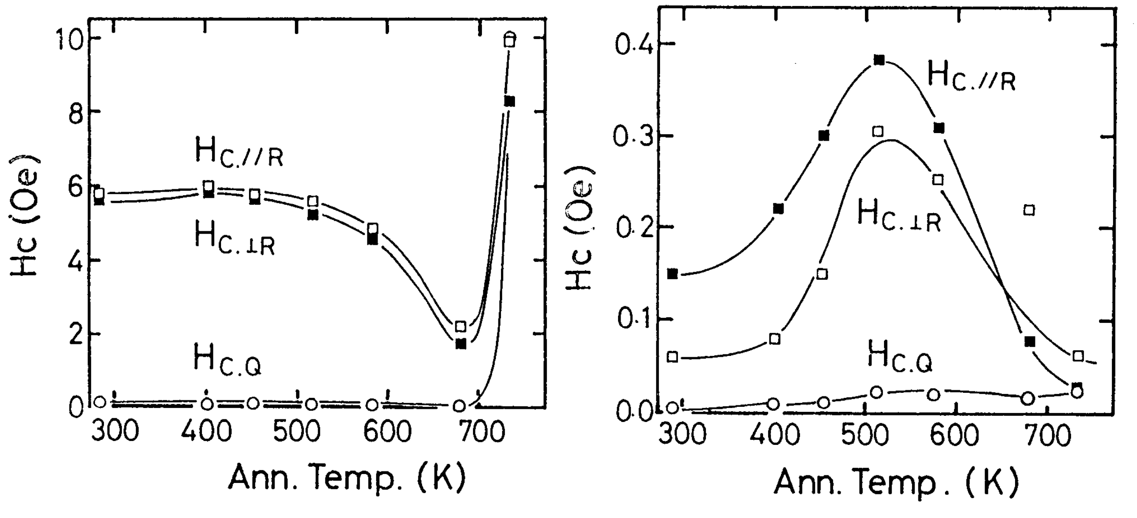
1a 1b

Figs. 1a and 1b The annealing temperature dependence of the magnetizing energy of the cold-rolled amorphous $Fe_{19}Co_{59}Si_{10}B_{12}$ (Fig. 1a) and $Fe_5Co_{70}Si_{15}B_{10}$ alloys (Fig. 1b), togather with that of the as-quenched alloy. $E_{//R}$, $E_{\perp R}$ and E_Q are the magnetizing energies measured along, across the roll direction, and along the edge of the ribbon, respectively.

cides with that of a stress relief[4].

On the other hand, in the case of the nonmagnetostrictive $Fe_5Co_{70}Si_{15}B_{10}$ alloy, the values of $E_{//R}$ and $E_{\perp R}$ are small but different significantly (Fig. 1b). It is further noticed that the annealing effect is small and $E_{//R}$ or $E_{\perp R}$ remains even beyond the crystallization temperature. The maximum of each curve which appears at about 500 K may be related to the fixing of magnetic domains due to the annealing effect by internal magnetic field[5].

From the Figs. 1a and 1b, it became clear that the magnetizing energy induced by cold rolling contains both isotropic and anisotropic terms. Since the isotropic term appears remarkably only in the magnetostrictive specimen and is reduced easily by annealing at below the crystallization temperature, this term can be attributed to local anisotropies resulted from stress-magnetostriction interaction. These anisotropies are considered to fluctuate microscopically from part to part in the specimen, and their easy axes are oriented randomly so that the specimen is isotropic macroscopically. By the inducement of such a local anisotropy by cold rolling, the coercive force will be increased[6]. Figures 2a and 2b show the coercive force for the cold rolled specimens togather with those for the as-quenched specimens. $H_{c//R}$ and $H_{c\perp R}$ are the coercive forces measured along and across the roll direction. H_{cQ} is the coercive force of the as-quenched specimen. Both $H_{c//R}$ and $H_{c\perp R}$ of the as-rolled magnetostrictive $Fe_{19}Co_{59}Si_{10}B_{12}$



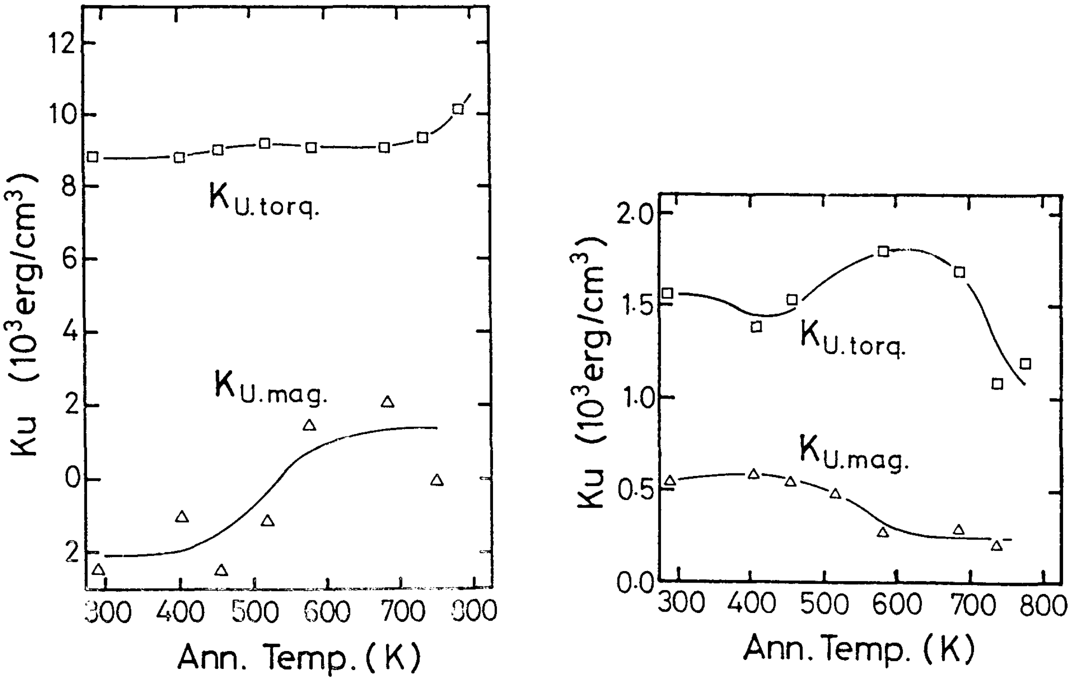
2a

2b

Fig. 2a and 2b The annealing temperature dependences of the coercive force of the cold-rolled amorphous $Fe_{19}Co_{59}Si_{10}B_{12}$ (Fig. 2a) and $Fe_5Co_{70}Si_{15}B_{10}$ alloys (Fig. 2a), together with that of the as-quenched alloy. $H_{c//R}$, $H_{c\perp R}$ and $H_{c\cdot Q}$ are the coercive forces measured along, across the roll direction, and along the edge of the ribbon, respectively.

alloy are remarkably large and nearly the same value. They are reduced by subsequent annealings. On the other hand, the effect of cold rolling on the coercive force of the nonmagnetostrictive $Fe_5Co_{70}Si_{15}B_{10}$ alloy is small. These results imply that the increase in the coercive force by cold rolling of the magnetostrictive specimen is also attributed to the stress-magnetostriction interaction. The maximum which appears around 500 K in the Fig. 2b are also related to the fixing of magnetic domains due to the annealing effect by internal magnetic field.

As can be seen in Figs. 1a and 1b, $E_{\perp R}$ is slightly smaller than $E_{//R}$. This fact means that the magnetizing energy has a small anisotropic component, and its magnetic easy axis is in the direction perpendicular to the roll direction. This result agrees well with the previous results of torque measurement, which has shown that the torque curves of cold rolled amorphous alloys have mostly twofold symmetry and the direction of easy magnetization is perpendicular to the roll direction[7]. Therefore, the in-plane twofold roll magnetic anisotropy Ku·mag will be expressed as the difference between $E_{//R}$ and $E_{\perp R}$. Figures 3a and 3b show the values of Ku·mag obtained from $E_{//R}$-



3a

3b

Figs. 3a and 3b The annealing temperature dependence of the in-plane magnetic anisotropy constant of the cold-rolled amorphous $Fe_{19}Co_{59}Si_{10}B_{12}$ (Fig. 3a) and $Fe_5Co_{70}Si_{15}B_{10}$ alloys (Fig. 3b). Ku·torq and Ku·mag are the in-plane magnetic anisotropy constant obtained from the torque curve and the magnetization curve, respectively.

$E_{\perp R}$, togather with the values of Ku·torq obtained from the torque curves. However, for both specimens, a large difference between the values of Ku·mag and Ku·torq can be seen. This difference may be due to the insufficient strength of magnetic field used for the magnetization curve measurement. In the case of the $Fe_{19}Co_{59}Si_{10}B_{12}$ alloy, since the anisotropic term of magnetizing energy is very small compared to the isotropic term (Fig. 1a), it is difficult to obtain the correct value of the roll magnetic anisotropy from the magnetizing energy. But , it is emphasized that the value of Ku·mag does not vanish by annealing at temperatures higher than the crystallization temperature T_X, in agreement with the annealing temperature dependence of Ku·torq. In the case of the $Fe_5Co_{70}Si_{15}B_{10}$ alloy, the value of Ku·mag decreases slightly by annealing, but both the values of Ku·mag and Ku·torq also remain over T_X.

Because, as already known, the internal stress induced by cold rolling is relieved almost completely by annealing at temperatures below T_X, the in-plane twofold magnetic anisotropy that remains after the annealing must be explained by the other effects such as the anisotropic atomic arrangements which may be induced in the deformation band.

In conclusion, it should be mentioned that the magnetizing energy of the cold rolled amorphous alloys contains both isotropic and anisotropic terms. The isotropic term is resulted from the stress-magnetostriction interaction which fluctuates from part to part in the specimen and reduced by annealing. The anisotropic term is attributed to an anisotropic atomic structure which is induced by cold rolling. In the case of the magnetostrictive specimen, the isotropic energy term is very large compared to the anisotropic energy term. This is the reason that the annealing effect on magnetization curves is different from that on the in-plane magnetic anisotropy measured by the torque method.

References

(1) T. Egami, P. J. Flanders and C. D. Graham, Jr., Appl. Phys. Letters, 26 (1975) 128.

(2) H. Fujimori, T. Masumoto, Y. Obi and M. Kikuchi, Japan J. Appl. Phys., 13 (1974) 1889.

(3) H. Morita, H. Fujimori and Y. Obi, Appl. Phys., 20 (1979) 125.

(4) H. Morita, H. Fujimori and Y. Obi, J. Magn. Magn. Met., 15-18 (1980) 1359.

(5) H. Fujimori, S. Ohta, T. Masumoto and K. Nakamoto, Rapidly

Quenched Metals III Vol. 2, Edited by B. Cantor (The Metals Society, London, 1978) 232.

(6) F. E. Luborsky, J. L. Walter and D. G. LeGrand, IEEE Trans. Magnetics, MAG-12 (1976) 930.

(7) H. Morita, H. Fujimori and Y. Obi, Japan J. Appl. Phys., 18 (1979) 683.

(8) T. Masumoto, H. Kimura, A. Inoue and Y. Waseda, Mater. Sci. Eng. 23 (1976) 141.