Saturation magnetostriction and its annealing behavior of Fe$_{100-x}$B$_x$ and Co$_{100-x}$B$_x$ amorphous alloys

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Boron content dependences of saturation magnetostriction $\lambda_s$ at room temperature in as-quenched and annealed Fe$_{100-x}$B$_x$ (15 $\leq$ x $\leq$ 25) and Co$_{100-x}$B$_x$ (19 $\leq$ x $\leq$ 24) amorphous alloys were measured. The value of $\lambda_s$ in Fe-B alloys peaks at x = 20, while $\lambda_s$ in Co-B alloys decreases with increasing boron content. For two series of alloys, nearly quadratic relations between magnetostriction and saturation magnetization $M_s$ were found. After 1 hour annealing at 250°C, both $\lambda_s$ and $M_s$ in Fe-B and Co-B alloys increased. The increase in $\lambda_s$ of Fe-B alloys was within 8%, and was larger than that of Co-B alloys. For annealed Fe-B and Co-B alloys, quadratic relations were also observed, which suggests that the increase in magnetostriction arises from the increase in magnetization.

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INTRODUCTION

In the amorphous alloys, magnetic properties such as coercive force strongly depend on the magnitude of magnetostriction, because of the absence of magneto-crystalline anisotropy. From this point of view, knowledge for the behavior of magnetostriction is important. Up to now, only a few papers have been reported on the metalloid content dependence of magnetostriction for iron based alloys \cite{1,2,3}, but few for cobalt based alloys. For Fe$_{100-x}$B$_x$ amorphous alloys, Tsuya et al. \cite{2} found a peak of magnetostriction and a drastic increase in magnetostriction after annealing. On the other hand, O'Handley \cite{4} has reported in his work on the magnetostriction that magnetostrictions in (Fe$_{1-x}$Ni$_x$)$_{10}$B$_2$ and (Fe$_{1-x}$Co$_x$)$_{10}$B$_2$ amorphous alloys show quadratic and linear dependences on magnetization, respectively, at room temperature. He also suggested such dependence for Fe$_{100-x}$B$_x$ alloys \cite{5}.

In this paper, we report the experimental results on the magnetostriction and its dependence on magnetization in the as-quenched and annealed Fe$_{100-x}$B$_x$, Co$_{100-x}$B$_x$ amorphous alloys.

EXPERIMENTAL

Amorphous ribbons were prepared by rapid quenching from the melt using iron and copper roller as a substrate for Fe-B and Co-B alloys, respectively. Cross sectional dimensions of the ribbons were typically 20$\mu$m x 1mm. From the X-ray diffraction data, Fe$_{100-x}$B$_x$ with 15 $\leq$ x $\leq$ 25 and Co$_{100-x}$B$_x$ with 19 $\leq$ x $\leq$ 24 were found to be in amorphous state. It was confirmed for these alloys that the Curie temperature in Fe-B alloys and the crystallization temperature in Co-B alloys are similar to the results reported by Hasegawa and Ray \cite{6}. Saturation magnetostriction $\lambda_s$ at room temperature was determined from the tensile stress dependence of anisotropy field, which was measured for 12cm long single ribbon utilizing "small angle magnetization rotation". The details of this method will be reported elsewhere \cite{7}. Saturation magnetization at room temperature was measured with a vibrating sample magnetometer in a field up to 15kOe. For this measurement about 50mg weight stack composed of 5mm long ribbon pieces was used. Annealing was performed in vacuum of 2 x 10$^{-2}$torr.

RESULTS AND DISCUSSION

A. Saturation magnetostriction in Fe-B and Co-B alloys

The saturation magnetostriction $\lambda_s$ at room temperature are shown as a function of boron content in Fig.1 (a) and Fig.1 (b) for as-prepared Fe$_{100-x}$B$_x$ and Co$_{100-x}$B$_x$ amorphous alloys. In each figure, compositional dependence of saturation magnetization $M_s$ at room temperature is also shown. The saturation magnetostriction

![Graph showing saturation magnetostriction and saturation magnetization](image-url)

The increase in $\lambda_s$ of Fe-B alloys was within 8%, and was larger than that of Co-B alloys. For annealed Fe-B and Co-B alloys, quadratic relations were also observed, which suggests that the increase in magnetostriction arises from the increase in magnetization.
As-quenched Cx >..............

The lowest crystallization temperature in the present alloys was about 330°C for Fe85B15 alloy, so that annealing was carried out at 250°C for 1 hour and 3 hours. Figure 3 shows the compositional variation of the saturation magnetostriction and magnetization in the annealed Fe-B alloys. After 1 hour annealing both magnetostriction and magnetization increase. The maximum ratio of increment in magnetostriction was about 8% for Fe78B17 alloy. It can be seen from the figure that the increments in both magnetostriction

striction in Fe-B alloys increases first with increasing boron content and takes a peak value of about $39 \times 10^{-6}$ at $x = 20$, where saturation magnetization also shows maximum, then decreases. On the other hand, magnetostriction in Co-B alloys decreases monotonically. On the peak of magnetostriction in Fe-B alloys, Tsuya et al have reported the value of $42 \times 10^{-6}$ near Fe84B16 alloy. A composition where magnetostriction peaks in the present work is in good agreement with that reported by O’Handley et al. Their result are shown in Fig.1(a). However, our value is about 10% higher in magnitude than that measured by them using a metal foil strain gauge. This may arise from the differences in the specimen preparation condition and measuring method as suggested by them. In fact, magnetostriction changes by annealing as described later. It was confirmed for Metglas ribbons that the magnetostriction measured with our method shows a tendency to be higher than that measured with the strain gauge method.

It is seen from Fig.1(a) and Fig.1(b) that the variations of magnetostriction for both Fe-B and Co-B alloys are nearly parallel to those of saturation magnetization. Figure 2(a) and 2(b) show the log-log plots of magnetostriction versus magnetization for Fe-B and Co-B alloys. In the figures, lines with slope of 2 are shown for references. It can be seen that the magnetostriction in binary Fe-B and Co-B alloys shows nearly quadratic dependence (slope of 2.2 for Fe-B alloys and 1.9 for Co-B alloys) as well as ternary (Fe, Ni380P20) alloys.

B. Change of saturation magnetostriction by annealing

The lowest crystallization temperature in the present alloys was about 330°C for Fe85B15 alloy, so that annealing was carried out at 250°C for 1 hour and 3 hours. Figure 3 shows the compositional variation of the saturation magnetostriction and magnetization in the annealed Fe-B alloys. After 1 hour annealing both magnetostriction and magnetization increase. The maximum ratio of increment in magnetostriction was about 8% for Fe78B17 alloy. It can be seen from the figure that the increments in both magnetostriction
For our specimen at second annealing stage, obvious crystallization was not observed. The saturation magnetization did not increase as shown in Fig.3. But it was found that the specimens become to be brittle. This was especially true for the specimens with the boron content more than 23 at.% and less than 17 at.%. They were easily fractured by bending. It is considered that the decrease in magnetostriction at second annealing stage may be attributed to the increase in elastic constant due to the embrittlement. It has been reported that the temperature at which embrittlement takes place strongly depends on the quench rate. The fast drop in magnetostriction in the present study may be associated with the low embrittlement temperature due to the ribbon preparation condition with low quench rate.

In the Co-B alloys, similar behavior of saturation magnetostriction and magnetization to those for Fe-B alloys were observed. The magnetostriction increased first, then decreased by annealing at 250°C. But the changes were small and less that 2%. No boron content dependence for the increase in magnetostriction was observed.

Figure 4(a) and 4(b) show log $\lambda_2$ versus log $\sigma_s$ for 1 hour annealed Fe-B and Co-B alloys with increased magnetostriction and magnetization. Broken lines are for the as-quenched specimens. Although the data points for Fe-B alloys are scattered, from the figures nearly quadratic relations between magnetostriction and magnetization can be seen. Present results suggest for Fe-B and Co-B alloys that the increase in magnetostriction with annealing arises from the increase in magnetization due to ordering.

CONCLUSION

The saturation magnetostrictions for both Fe$_{100-x}$B$_x$ and Co$_{100-x}$B$_x$ amorphous alloys vary as the square of saturation magnetization at room temperature. Annealing at 250°C for 1 hour causes magnetostriction to increase. This increase may be attributed to the increase in saturation magnetization due to the relaxation of amorphous structure.

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REFERENCES