Saturation magnetostriction and its annealing behavior of $Fe_{100-x}B_x$ and $Co_{100-x}B_x$ amorphous alloys

K. Narita, J. Yamasaki, and H. Fukunaga

Department of Electrical Engineering, Kyushu University, Fukuoka 812, Japan

Boron content dependences of saturation magnetostriction λ_s at room temperature in as-quenched and annealed $Fe_{100-x}B_x$ $(15 \le x \le 25)$ and $Co_{100-x}B_x$ $(19 \le x \le 24)$ amorphous alloys were measured. The value of λ_s in Fe-B alloys peaks at $x = 20$, while λ_s in Co-B alloys decreases with increasing boron content. For two series of alloys, nearly quadratic relations between magnetostriction and saturation magnetization σ_s were found. After 1 hour annealing at 250° C, both λ_s and σ_s in Fe-B and Co-B alloys increased. The increase in λ_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 magnetocrystalline anisotropy. From this point of view, a 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[1,2,3], but few for cobalt based alloys. For $Fe_{100-x}B_x$ amorphous alloys, Tsuya et al[2] found a peak of magnetostriction and a drastic increase in magnetostriction after annealing. On the other hand, O'Handley[4] has reported in his work on the magnetostriction that magnetostrictions in $(Fe_{1-x}Ni_x)_{80}B_{20}$ and $(Fe_{1-x}Co_x)_{80}B_{20}$ 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[3].

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.

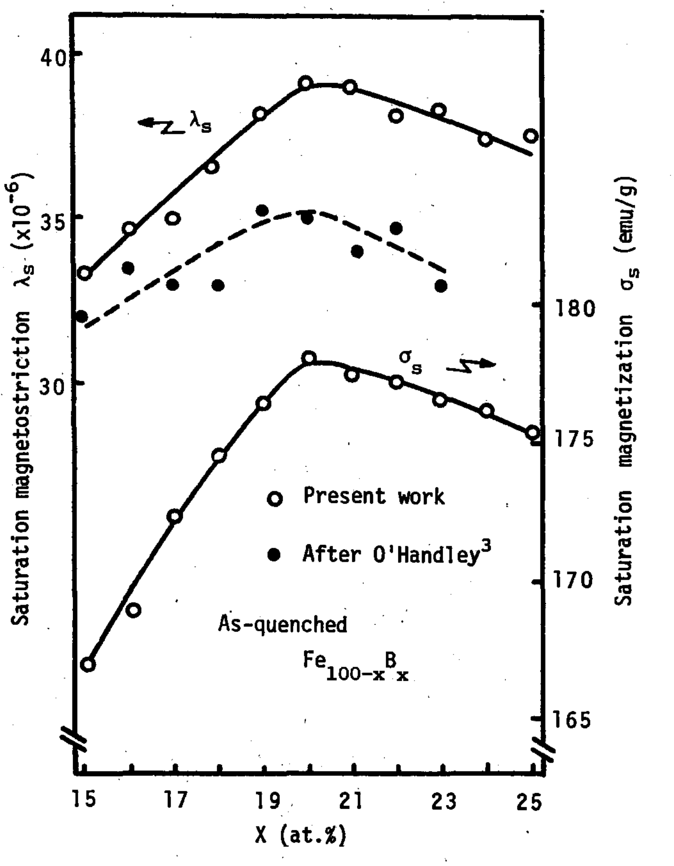
EXPERIMENTAL

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 20μm x 1mm. From the X-ray diffraction data, $Fe_{100-x}B_x$ with $15 \le x \le 25$ and $Co_{100-x}B_x$ with $19 \le x \le 24$ 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[5]. Saturation magnetostriction λ_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 eleswhere[6]. 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 2×10^{-5}torr.

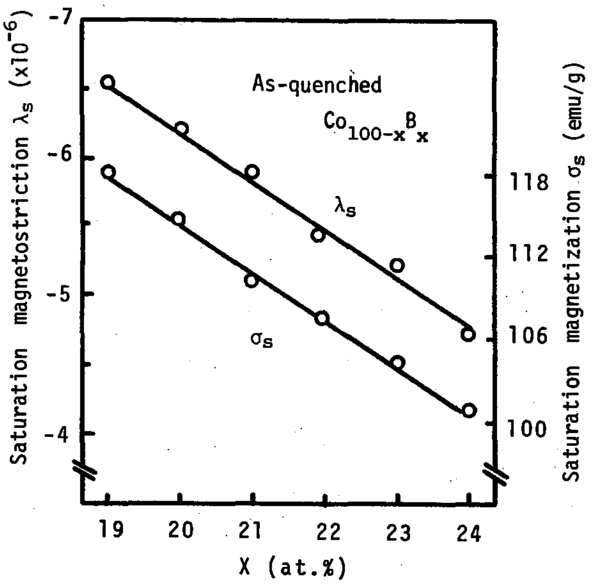
RESULTS AND DISCUSSION

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

The saturation magnetostriction λ_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 σ_S (room temperature) is also shown. The saturation magneto-

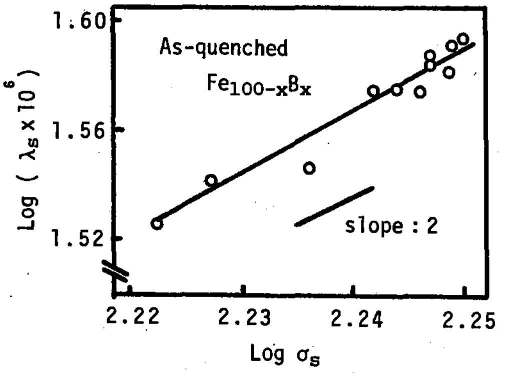


(a) Fe-B

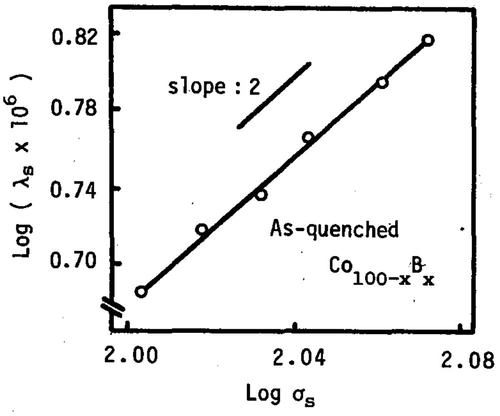


(b) Co-B

Fig.1 Saturation magnetostriction λ_s and saturation magnetization σ_s in as-quenched $Fe_{100-x}B_x$ and $Co_{100-x}B_x$ alloys as a function of boron content X.



(a) Fe-B



(b) Co-B

Fig.2 Logarithmic plots of saturation magnetostriction λ_s vs. saturation magnetization σ_s in as-quenched $Fe_{100-x}B_x$ and $Co_{100-x}B_x$ alloys.

striction in Fe-B alloys increases first with increasing boron content and takes a peak value of about 39×10^{-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[2] have reported the value of 42×10^{-6} near $Fe_{84}B_{16}$ alloy. A composition where magnetostriction peaks in the present work is in good agreement with that reported by O'Handley et al[3]. 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) on magnetization, as well as ternary (Fe, Ni $)_{80}B_{20}$ alloys[4].

B. Change of saturation magnetostriction by annealing

The lowest crystallization temperature in the present alloys was about 330°C for $Fe_{85}B_{15}$ 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 $Fe_{83}B_{17}$ alloy. It can be seen from the figure that the increments in both magnetostriction

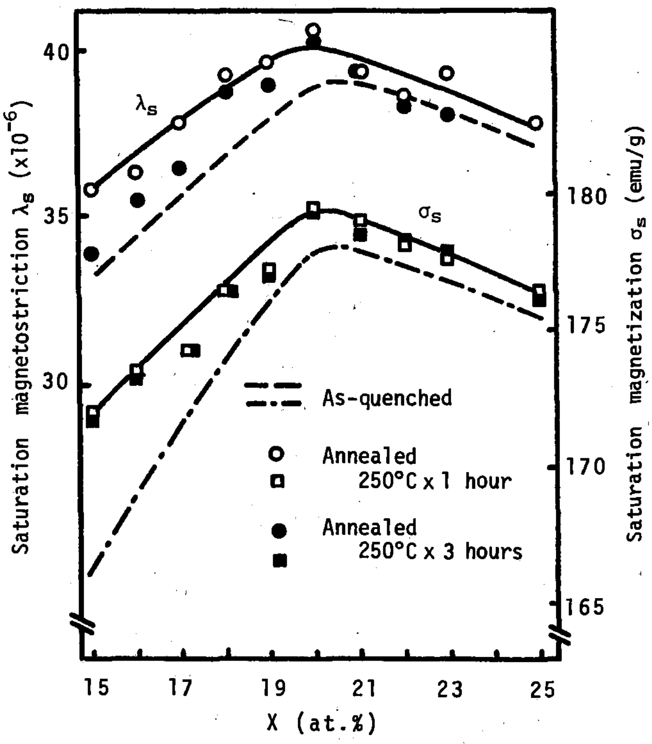
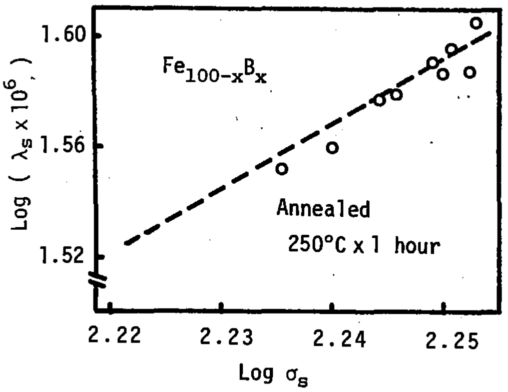
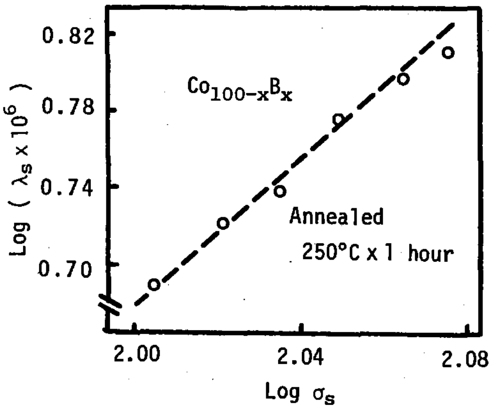


Fig.3 Saturation magnetostriction λ_s and saturation magnetization σ_s in annealed $Fe_{100-x}B_x$ alloys as a function of boron content X.



(a) Fe-B



(b) Co-B

Fig.4 Logarithmic plots of saturation magnetostriction λ_s vs. saturation magnetization σ_s in annealed $Fe_{100-x}B_x$ and $Co_{100-x}B_x$ alloys, together with those for as-quenched alloys(broken lines).

and magnetization for alloys with $15 \leq x \leq 20$ are large as compared to those for alloys with $x \geq 21$. For these Fe-B alloys with metalloid content less than 20 at.%, significant structural change with boron content was reported[5]. Subsequent annealing of 2 hours causes the magnetostriction to decrease, but not the magnetization. The change of magnetization is completed by 1 hour annealing. Such behavior of magnetization was also reported by Hatta et al[7] for $Fe_{86}B_7C_7$ amorphous alloys recently. The rate of increase in magnetization for Fe-B alloys is nearly equivalent to that measured by them.

For the annealing effect on magnetostriction in Fe-B amorphous alloys, Tsuya et al[2] have found the drastic increase in magnetostriction after 3 hours annealing at 300°C. Our value at first annealing stage is small as compared to their value. Another different result is that the magnetostriction in our specimen drops for annealing time shorter than theirs. They identify the decrease in magnetostriction with crystallization. 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[8]. 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 λ_s versus log σ_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

1. H. A. Brooks and H. S. Chen, J. Appl. Phys. 48, 4837 (1977).
2. N. Tsuya, K. I. Arai and T. Ohsaka, IEEE Trans. on Mag. Mag-14, 947 (1978).
3. R. C. O'Handley, M. C. Narasimhan and M.O.Sullivan, J. Appl. Phys. 50, 1633 (1979).
4. R. C. O'Handley, Solid State Commun. 21, 1119 (1977).
5. R. Hasegawa and R. Ray, J. Appl. Phys. 49, 4174 (1978).
6. K. Narita, J. Yamasaki and H. Fukunaga, (unpublished).
7. S. Hatta, T. Egami and C. D. Graham, Jr., Appl. Phys. Lett. 34, 113 (1979).
8. G. C. Chi, H. S. Chen and C. E. Miller, J. Appl. Phys. 49, 1715 (1978).