EFFECT OF Nb ADDITIONS ON THE IRREVERSIBLE LOSSES OF Nd-Fe-B TYPE MAGNETS

M. Tokunaga, H. Harada and S.R. Trout*
Hitachi Metals Ltd.
Magnetic and Electronic
Materials Research Laboratory
5200 Mikajiri Kumagaya, Saitama, JAPAN
*Hitachi Magnetics Corporation
Edmore, MI 48829 USA

ABSTRACT

While Nd-Fe-B magnets have outstanding magnetic properties at room temperature (1) and below, their usefulness at higher temperatures is limited by three factors: irreversible loss, reversible loss of B_r and reversible loss of H_{ci}. This work examines the beneficial effects of Nb additions to Nd-Fe-B, Nd-Dy-Fe-B and Nd-Dy-Co-Fe-B magnets, in particular to reduce the irreversible loss.

EXPERIMENT

Magnets for the study were made by conventional vacuum melting and powder metallurgy techniques. The sintering and heat treating conditions were similar to those reported previously (2,3). Magnetic properties were measured by a recording hysteresisgraph. Irreversible loss was determined by first measuring the demagnetizing curve after exposure to temperature, and then resaturating the sample and remeasuring the curve. The difference between the two measurements is irreversible loss, eliminating any effect of permanent loss.

DATA AND DISCUSSION

Magnetic properties at room temperature and irreversible loss data on the samples studied are given in Table I and plotted in Fig. 1. Samples 147, 148 and 149 are a $Nd(Fe_{.92-x}B_{.08}Nb_x)_{5.4}$ alloy and the loss data are reported after exposure to 100°C for five hours at a B/H = 1 condition.

Samples 153, 154 and 155 are a $Nd_{.88}Dy_{.12}(Fe_{.92-x}Nb_x)_{5.6}$ alloy. The loss data for these samples are reported after exposure to 150°C for five hours at a B/H = 1 conditon.

Samples A-F are a $Nd_{.8}Dy_{.2}(Fe_{.86-x}Co_{.06}B_{.08}Nb_x)_{5.5}$ alloy. The loss data for these samples are reported after exposure to 200°C for five hours at a B/H = 2 condition.

The data show several trends due to the Nb additions. The addition of Nb decreases B_r due to the displacement of Fe by Nb in the alloy. Usually H_k and H_{ci} increase and irreversible losses decrease as the Nb content increases. Typically, $(BH)_{max}$ decreases as Nb is added, but this pattern is not consistent. Since adding Nb can improve the squareness of the curve, $(BH)_{max}$ can increase, even when B_r decreases.

The effect of Nb additions on irreversible losses and loop squareness seems more pronounced in the Nd-Fe-B-Nb and Nd-Dy-Fe-B-Nb alloys. In the Nd-Dy-Co-Fe-B-Nb alloy the effect of Nb additions is smaller. Perhaps the other alloying elements are having a similar influence on irreversible losses. The irreversible losses of the Nd-Dy-Co-Fe-B-Nb alloys actually increase and then decrease with increasing Nb content, but overall are much less than the other alloys, when compared at the same temperature and load line. While Nb additions can improve irreversible loss behavior, the loss is also sensitive to many process parameters, which have been held as consistently as possible for this experiment.

Data on the magnetic properties at temperature of selected samples are given in Table II. Additions of Nb reduce the reversible temperature coefficient of B_r (α), by roughly 7%, and to a lesser extent the reversible temperature coefficient of H_{ci} (β), by roughly 1%, over the temperature range of 23 to 125°C.

Figs 2, 3 and 4 show the microstructures of samples 153, 154 and 155, respectively, as shown by optical microscopy. As the Nb content increases, the grain size decreases. Qualitatively, we observe that the irreversible losses become smaller as the average grain size decreases.

CONCLUSION

The effects of Nb additions have been examined for several Nd-Fe-B type alloys. In most cases Nb additions improve loop squareness, decrease B_r slightly and reduce irreversible losses. The findings are of interest in making Nd-Fe-B alloys with improved stability at elevated temperatures.

The actual mechanism for Nb substitution is not clear from these data. The increase in H_{ci} and H_k show that Nb could be found in the grain boundaries. The fact that B_r is also affected, indicates Nb may also be found in the matrix. In fact, it may be in both locations, with a more detailed explanation left to future investigators.

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Table II. MAGNETIC PROPERTIES AT VARIOUS TEMPERATURES

TEMP (°C)	Br (kG)	Hc (kOe)	Hk (kOe)	Hci (kOe)	(BH)max (MGOe)	α (%/°C)	β
$Nd(Fe_{.92}B_{.08})_{5.6}$							
23	12.09	11.5	15.8	17.14	34.8		
98	11.15	8.25	8.04	8.58	29	-.104	-.666
125	10.8	6.1	5.9	6.24	26.7	-.105	-.623
$Nd(Fe_{.911}B_{.08}Nb_{.009})_{5.6}$							
22	11.99	11.41	16.88	18.48	34.2		
100	11.11	8.71	8.46	8.98	29.1	-.094	-.659
125	10.75	6.6	6.37	6.7	27.1	-.100	-.619
$Nd(Fe_{.905}B_{.08}Nb_{.015})_{5.6}$							
22	11.87	11.31	17.12	19.23	33.6		
100	10.99	9.32	9.1	9.62	28.4	-.095	-.641
125	10.67	6.9	6.62	7.0	26.5	-.098	-.617

*The reversible temperature coefficients of B_r and H_{ci} are given by α and β, respectively. The coefficient is calculated between the stated temperature and room temperature.

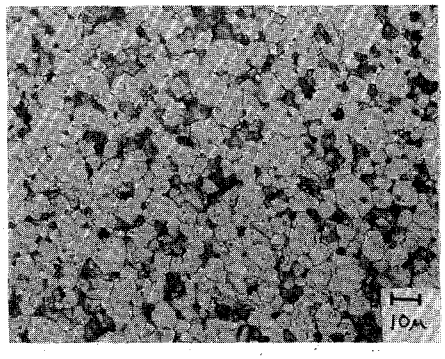

Fig. 4. Microstructure of a $Nd(Fe_{.905}B_{.08}Nb_{.015})_{5.6}$ alloy.

ACKNOWLEDGEMENT

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REFERENCES

(1) M. Sagawa, S. Fujimura, N. Togawa, H. Yamamoto and Y. Matsuura, J. Appl. Phys. 55 (1984) 2083.

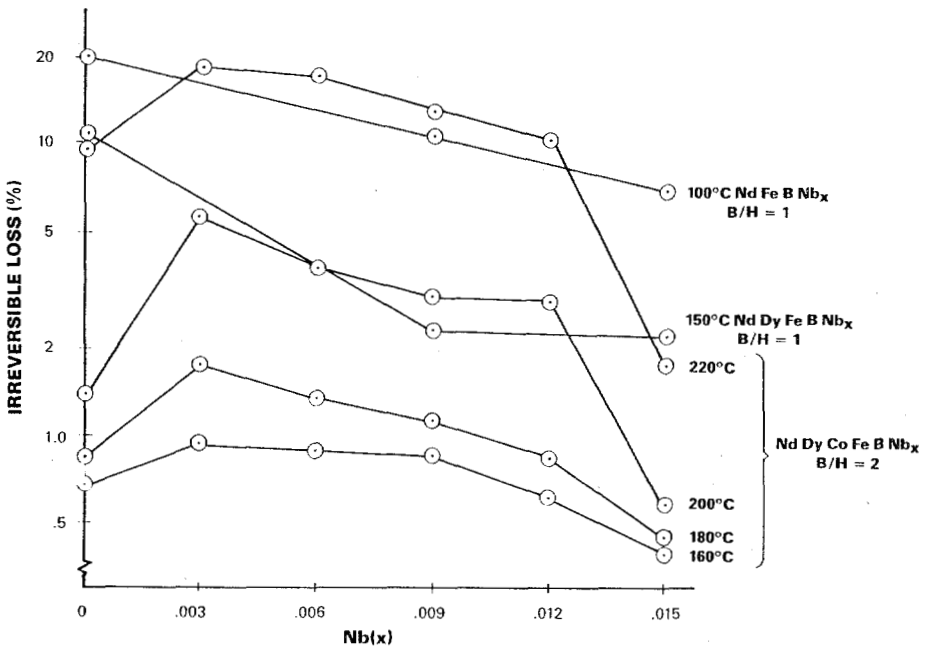
(2) M. Tokunaga, N. Meguro, M. Endoh, S. Tanigawa and H. Harada IEEE Trans. Mag 21 (1985) 1964.

(3) M. Tokunaga, M. Tobise, N. Meguro and H. Harada, IEEE Mag. 22 (1986) 904.

Table I. ROOM TEMPERATURE MAGNETIC PROPERTIES AND IRREVERSIBLE LOSS DATA

SAMPLE	Nb (x)	Br (kG)	Hc (k0e)	Hk (k0e)	Hci (k0e)	(BH)max (MGOe)	LOSS (%)
147-2	0	12	9.25	8.7	10.6	32	20.35
148-2	0.009	11.85	10.85	11.0	11.6	32.8	11.83
149-2	0.015	11.6	10.7	11.4	12.2	31.3	7.12
153-2	0	11.1	10.5	13.9	16.5	29.1	11.1
154-2	0.009	10.8	10.2	15.8	18.55	27.8	2.55
155-2	0.015	10.7	10.1	15.2	18.7	27.2	2.23
A	0	11.05	10.7	21.0	22.5	29.2	1.4
B	0.003	11.05	10.7	18.4	20.9	29.2	5.8
C	0.006	11.05	10.6	18.7	21.6	29.0	3.9
D	0.009	10.85	10.5	19.2	21.8	28.2	3.1
E	0.012	10.85	10.5	19.4	22.2	28.4	3.0
F	0.015	10.85	10.5	23.4	24.9	28.3	0.59

FIG. 1. IRREVERSIBLE LOSS VS Nb CONTENT



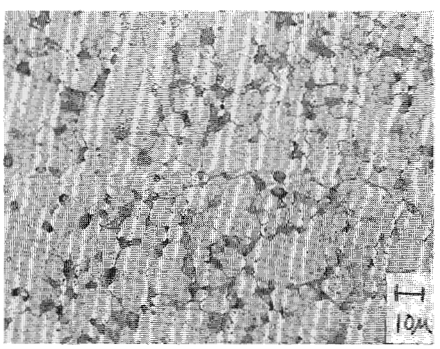


Fig. 2. Microstructure of a $Nd(Fe_{.92}B_{.08})_{5.6}$ alloy.

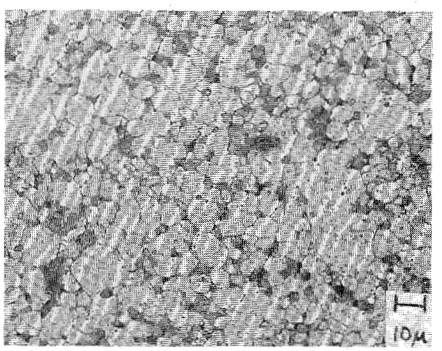


Fig. 3. Microstructure of a $Nd(Fe_{.911}B_{.08}Nb_{.009})_{5.6}$ alloy.