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^{57}Fe Mössbauer effect study of Nd-Fe-B hybrid bonded magnets

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Abstract. An investigation of magnetic interaction between the particles of hybrid bonded magnets based on mixtures of Nd-(Fe,Co)-B and strontium ferrite powders was carried out. An enhancement of the magnet remanence and coercivity caused by the interaction between their components was observed. From Mössbauer effect study, it results that this enhancement can be correlated with the increase of an average hyperfine field at Fe sites in Nd-(Fe,Co)-B magnets with the strontium ferrite addition.

Key words: bonded magnets • Mössbauer effect • coercivity • remanence

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Introduction

Bonded permanent magnets are now widely produced and continuously investigated. They are fabricated from a mixture of hard magnetic powder with different kinds of polymers or resins. The magnetic, thermal, electrical and mechanical properties of bonded magnets depend on the kind and volume fraction of the hard magnetic components, the kind and volume fraction of the binder and used technology. The most important bonded magnets are based on Nd-Fe-B or ferrite powders. Despite the magnetic characteristic (the remanence and maximum energy product) of bonded magnets are not too high they have many advantages. Some of them are: relatively low cost of production, the possibility of forming the near net shape magnets with accurate dimensional tolerances and better mechanical properties.

One way of improving some physical properties of the bonded magnets is to produce the hybrid magnets prepared from a mixture of two powders with different hard magnetic characteristics. Then, one can get the magnets with the desired properties in a given application. For example, for a hybrid magnet made from a mixture of 80 wt% ferrite and 20 wt% Nd-Fe-B powders the temperature coefficient of coercivity above the room temperature is approximately equal to zero which means that such magnet can work at elevated temperature [1].

The hybrid magnets give a good opportunity to investigate the interaction between the particles of different magnet components.

In this work, the Mössbauer effect study has been carried out in order to establish whether or not the strontium ferrite influences the magnetic hyperfine field at iron sites in Nd-Fe-B magnets.

Material and experimental procedure

The samples investigated in this study were produced from a mixture of an isotropic commercial Magnequench MQP-B and ferrite powders using a compression-molding technique at a pressure of 900 MPa. The samples were cured at 180°C for 2 hours. The hard magnetic fractions of hybrid magnets investigated were as follows: (a) 100 wt% of MQP-B powder (sample I), (b) 80 wt% and 20 wt% (sample II), (c) 70 wt% and 30 wt% (sample III), (d) 60 wt% and 40 wt% (sample IV) of MQP-B and strontium ferrite powder, respectively and (e) 100 wt% of strontium ferrite powder (sample V). 2.5 wt% of epoxy resin was used as a binder. MQP-B is based on rapidly quenched ribbons from Nd-Fe-Co-B alloy.

The hysteresis loops measurements at room temperature were performed by a Bitter vibrating sample magnetometer with a maximum applied magnetic field of 14 T.

The Mössbauer spectra were recorded at room temperature using a conventional constant-acceleration spectrometer in transmission mode with a ^{57}Co of γ-ray source in a rhodium matrix. The spectrometer was calibrated by means of a standard α-Fe foil.

The measured spectra for hybrid magnets were fitted with six independent Lorentzian sextets corresponding to the six crystallographically non-equivalent Fe sites in the $Nd_2Fe_{14}B$ unit cell and five sextets corresponding to the five non-equivalent Fe sites in $Sr_2Fe_{12}O_{19}$. Hyperfine parameters were derived using the NORMOS fitting program. It was assumed that the relative intensities of six lines remain in the ratio 3:2:1:1:2:3 as the samples were in the powder form and all Lorentzian lines for a given sample have the same final width (0.287 mm/s, 0.260 mm/s, 0.248 mm/s, 0.300 mm/s for sample I, II, IV and V, respectively). The site assignment to proper sextet was done by correlating their intensity with site occupancy of Fe atoms in crystal structure of $Nd_2Fe_{14}B$ ($4c$, $4e$, $8j_1$, $8j_2$ $16k_1$, $16k_2$ [5–7]) and strontium ferrite ($2b$, $2a$, $4f_2$, $4f_1$, $12k$ [2, 4]).

Results and discussion

From the major hysteresis loops measured at the field of 14 T, the remanence and coercivity of the investigated magnets were derived. The dependence of these parameters on volume fraction of strontium ferrite is presented in Figs. 1 and 2. It can be seen that both the remanence and coercivity decrease with increasing volume fraction of ferrite but the changes are lower than that of the simple mixture of two independent components for which the dilution law is valid

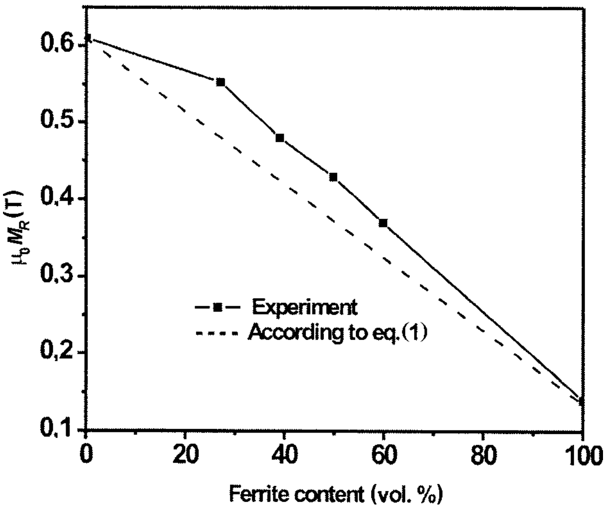


Fig. 1. Dependence of the remanence on the strontium ferrite content in hybrid bonded Nd-Fe-B magnet.

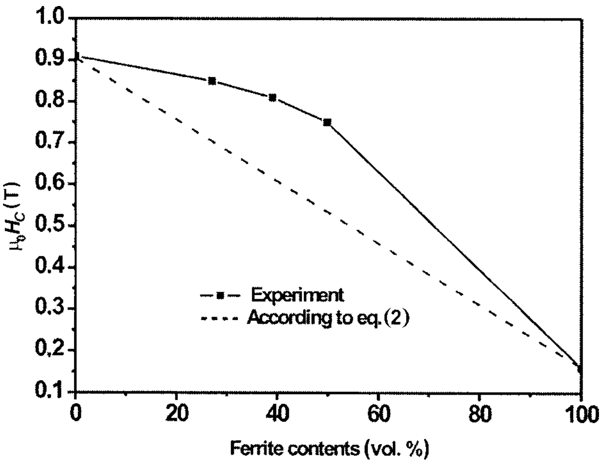


Fig. 2. Dependence of the coercivity on the strontium ferrite content in hybrid bonded Nd-Fe-B magnet.

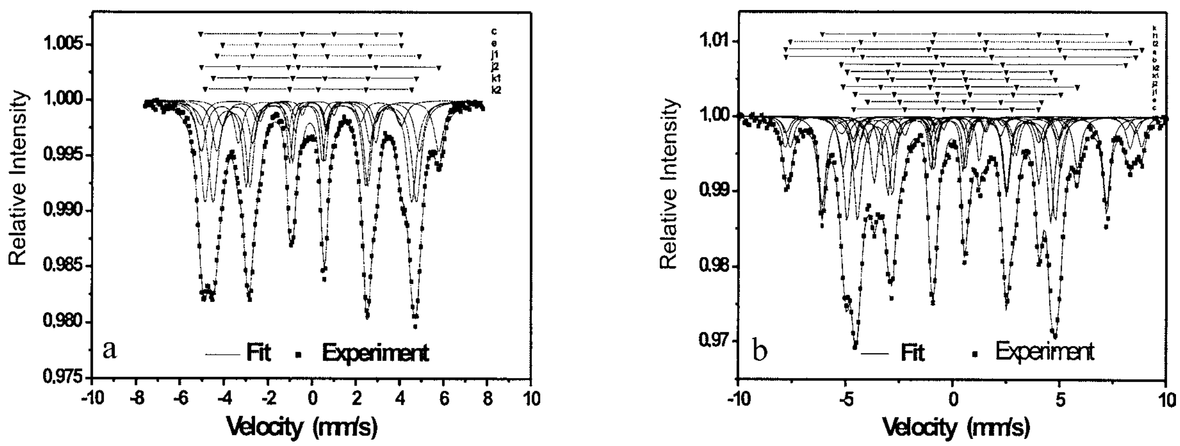
$$M_R^{hyb} = (1 - V)M_{R1} + VM_{R2} \quad (1)$$

$$H_C^{hyb} = (1 - V)H_{C1} + VH_{C2} \quad (2)$$

where M_R^{hyb}(H_C^{hyb}) is the remanence (coercivity) of hybrid bonded magnet, M_{Ri}(H_{Ci}) is the remanence (coercivity) of bonded magnet with hard magnetic fraction consisting of 100 wt% of MQP-B powder (i = 1) and 100 wt% of strontium ferrite (i = 2), V is the volume fraction of ferrite.

An enhancement of the magnetic parameters for hybrid magnets with ferrite may be attributed to the interaction between the particles of two magnetic components.

Mössbauer spectra were recorded for four samples I, II, IV and V. Three of them (sample I, II, V) are shown in Fig. 3a–c. On the top of each figure the line positions of all sextets are indicated. Our investigations confirm the earlier reported Mössbauer studies [5–7] and neutron diffraction ones [3] that the best fit may be obtained if the hyperfine fields at different Fe sites in MQP-B magnetic component of hybrid magnet follow the relations HF(j_2) > HF(k_2) > HF(k_1) > HF(j_1)



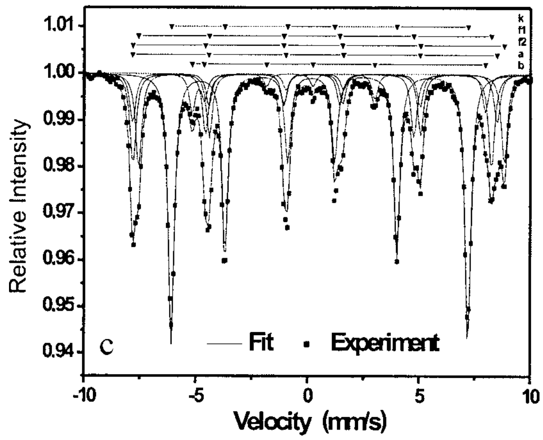


Fig. 3. ^{57}Mössbauer spectra of (a) sample I with 100 wt% of MQP-B powder, (b) sample II with 80 wt% of MQP-B and 20 wt% of strontium ferrite, (c) sample V with 100 wt% of strontium ferrite.

> HF(c) > HF(e). Such relations are in accordance with the argument of approximate proportionality between the hyperfine field at a given Fe site and the number of its nearest neighbour Fe atoms. In order to distinguish the sextets with the same number of site occupancy, the presence of B and Nd atoms in the nearest neighbours of Fe atom had to be considered.

Hyperfine field at Fe sites in strontium ferrite follows the relations HF(f_2) > HF($2a$) > HF($4f_1$) > HF($12k$) > HF($2b$) which is also in good agreement with the earlier results [2, 4].

The average hyperfine fields at Fe sites in MQP-B and strontium ferrite for hybrid magnets are given in Table 1. When comparing these hyperfine fields, it may be concluded that the existence of the magnetic interactions (magnetostatic interaction) between the different magnetic components is manifested by an increase of the hyperfine field at Fe sites in MQP-B component by 0.36 T for sample IV (60 wt% of MQP-B, 40 wt% of strontium ferrite) and 0.5 T for sample II (80 wt% of MQP-B and 20 wt% of strontium ferrite). On the other hand, no enhancement of the average hyperfine field at Fe sites in strontium ferrite was observed. One may say that the observed enhancement of the hyperfine field at Fe sites in the samples with strontium ferrite is low (converted into mm/s units is of the same order as the line width) but several times higher than the error of measurement (Table 1).

Table 1. Average hyperfine field and remanence of the sample I (100 wt% of MQP-B powder), sample II (MQP-B 80 wt% + strontium ferrite 20 wt%), sample IV (MQP-B 60 wt% + strontium ferrite 40 wt%), sample V (strontium ferrite 100 wt%)

Sample	Average hyperfine field at Fe site in MQP-B (T)	Average hyperfine field at Fe site in strontium ferrite (T)	Remanence $\mu_0 M_R$ (T)	Remanence obtained from Eq. (1) $\mu_0 M_R$ (T)
MQP-B 100 wt% (sample I)	28.93 ± 0.09	–	0.61 ± 0.01	0.61
MQP-B 80 wt% + ferrite 20 wt% (sample II)	29.43 ± 0.10	46.86 ± 0.08	0.55 ± 0.01	0.48
MQP-B 60 wt% + ferrite 40 wt% (sample IV)	29.29 ± 0.09	46.75 ± 0.22	0.43 ± 0.01	0.37
Strontium ferrite 100 wt% (sample V)	–	46.69 ± 0.06	0.14 ± 0.01	0.14

Conclusion

Hybrid bonded magnets are not a simple mixture of two different magnetic components. They interact with each other and this interaction influences both the magnet remanence and the coercivity. From the Mössbauer spectra analysis, it was found that the existence of magnetic interactions between the different magnetic components is reflected by an increase of the hyperfine field at Fe sites in MQP-B component from 0.36–0.5 T for different ferrite additions.

References

1. Emura M, Neiva AC, Missel FP (1998) Magnetization processes in hybrid magnets. J Appl Phys 83:7127–7130
2. Evans BJ, Grandjean F, Lilot AP, Vogel RH, Gérard A (1987) ^{57}Fe hyperfine interaction parameters and selected magnetic properties of high purity $MFe_{12}O_{19}$ (M=Sr, Ba). J Magn Magn Mater 67:123–129
3. Herbst JF, Yelon WB (1986) Preferential site occupation and magnetic structure of $Nd_2(Co_xFe_{1-x})B$ systems. J Appl Phys 60:4224–4229
4. Liu X, Zhong W, Yang S, Yu Z, Gu B, Du Y (2002) Influence of La^{+3} substitution on the structure and magnetic properties of M-type strontium ferrite. J Magn Magn Mater 238:207–214
5. Onodera H, Yamaguchi H, Yamada M *et al*. (1984) Magnetic properties of a new permanent magnet based on a Nd-Fe-B compound (Neomax). J Magn Magn Mater 46:154–156
6. Onodera H, Yamaguchi H, Yamada M, Yamamoto H, Sagawa M, Hirosawa S (1987) Mössbauer study of the intermetallic compounds $Nd_2Fe_{14}B$. J Magn Magn Mater 68:15–27
7. Tharp DE, Yang Y, Pringle OA, Long GJ, James WJ (1987) A Mössbauer effect study of the magnetic properties of $Nd_2(Fe_{1-x}Co_x)_{14}B$ and $Y_2(Fe_{1-x}Co_x)_{14}B$. J Appl Phys 61:4334–4336