Journal of Magnetics 9(4), 105-108 (2004)

Study on the Interaction of Compound Bonded Magnets

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(Received 1 July 2004)

The attempt for the addition of double-phase nanocomposite $Nd_2Fe_{14}B/Fe_3B$ powders, respectively, into several $RE_2Fe_{14}B$ (RE=Pr, Nd) powders with high magnetic properties was carried out. The powders were compounded and compressed to take shape bonded magnets. By means of investigating the variation of compound magnet B_r, the interaction between magnetic powders was revealed. The result shows that not chemical just but physical interaction exists between elements. The compound effect of $Nd_2Fe_{14}B/Fe_3B$-ferrite bonded magnets was detailed studied. The functional relation was revealed between magnetic properties and ferrite content. That is $Y = 5.42\,x^2 - 11.34\,x + 6.62$. The variation of $_iH_c$ temperature coefficient β_{iHc} with ferrite content was investigated. Following the ferrite content increased, β_{iHc} and h_{irr} were obviously decreased, compression-resistant strength was enhanced.

Key words : Nanocomposite, Bonded magnets, $Nd_2Fe_{14}B$, Fe_3B, Rare earth

1. Introduction

Much interest has recently been focused on double-phase nanocomposite magnets such as $RE_2Fe_{14}B/Fe_3B(\alpha\text{-Fe})$ (RE=Pr, Nd). Because of the lower cost, they are more suitable to apply widely than other NdFeB magnets with high magnetic properties. The intergrain exchange interactions between hard magnetic phases and soft magnetic phases exist in bonded magnets so that the magnets obtain high remanence and great energy product $(B{\cdot}H)_{max}$, However, the remanence is enhanced by increasing the Fe content at the expense of the coercivity [1-8]. At present, the experiment maximum energy product $(B{\cdot}H)_{max}$ of nanocomposite magnets is far from the $(B{\cdot}H)_{max}$ in theory (it exceeds 10^6 J/m^3 [9]). Especially for their bad thermal stability, the magnets are confined to apply in high temperature. Many researchers paid attention to investigating the nanocomposite powders. Accordingly, they studied the grain size, the volume fraction of hard and soft magnetic phases, the addition of some elements [10-14], and the fabricating processes [15]. In this study, the nanocomposite $Nd_2Fe_{14}B/Fe_3B$ powders were compounded with other magnetic powders in order to investigate the interaction between elements and to reveal the compound effect of bonded magnets. Besides, the experiment upon the addition of ferrite magnetic powder into $Nd_2Fe_{14}B/Fe_3B$ was made in order to indicate the compound effect of $Nd_2Fe_{14}B/Fe_3B$-ferrite bonded magnets and to verify the compensating effect of ferrite element on $_iH_c$ temperature coefficient β_{iHc}. The results show that the magnets didn't only achieve slightly high thermal stability, but cut down magnet cost. Owing to the positive value of ferrite's β_{iHc}, the thermal stability of $RE_2Fe_{14}B/Fe_3B(\alpha\text{-Fe})$ferrite compound magnet was improved.

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2. Experimental Procedure

The addition of two double-phase nanocomposite $Nd_2Fe_{14}B/Fe_3B$ powders with different properties ($1^\#$, $2^\#$) into magnetic powders with high magnetic properties ($3^\#$, $4^\#$) was made after every magnetic powder, respectively, was mixed with 4%(wt) bond master. Subsequently they were compressed to take shape $\phi 8$ mm $\times$ 10 mm cylinder magnets with single-pillar rectifying hydraulic presser. The green magnets were isothermally heat-treated at 145 °C for 30 minutes, then they were magnetized to saturation. B-H curves of the magnets were measured using the 2000-H Hysteretic Loops Instrument. Accordingly, the nanocomposite $Nd_2Fe_{14}B/Fe_3B$ and Ferrite powders were compounded to take shape bonded magnets as stated above. The magnetic and mechanical parameters were obtained at room temperature about 25 °C and high temperature about 100 °C. The magnetic properties of 1#~4# powders samples are listed in Table 1.

3. Results and Discussion

3.1. Compound effect of $Nd_2Fe_{14}B/Fe_3B$ powders and the powders with high magnetic properties

Figure 1~4 show the relation between compound magnet B_r and $Nd_2Fe_{14}B/Fe_3B$ content. Fig. 1 and Fig. 2 suggest the curves of 3# sample-based compound magnets. Fig. 3 and Fig. 4 suggest the curves of 4# sample-based compound magnets. It doesnt show the magnetic powersproperties but compound bonded magnets properties in figures.

Table 1. The magnetic properties of 1#~4# powder samples

Sample No.	B_r (kGs)	$_iH_c$ (kOe)	$(B{\cdot}H)_{max}$ (MGOe)
1#	95	34	70
2#	108	25	79
3#	91	95	16
4#	87	120	146

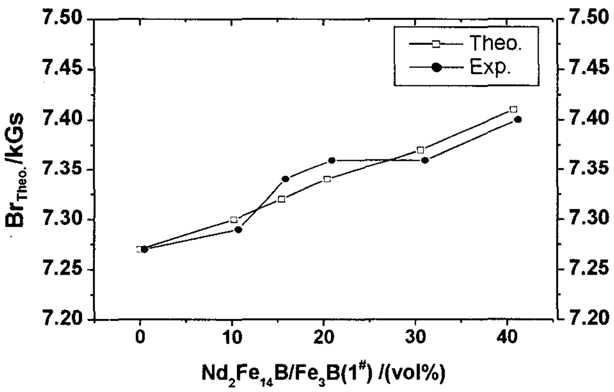

Fig. 1. Variation of compound magnet B_r versus sample 1# content.

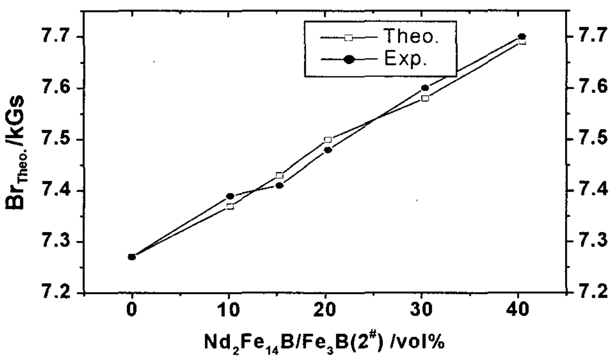

Fig. 2. Variation of compound magnet B_r versus sample 2# content.

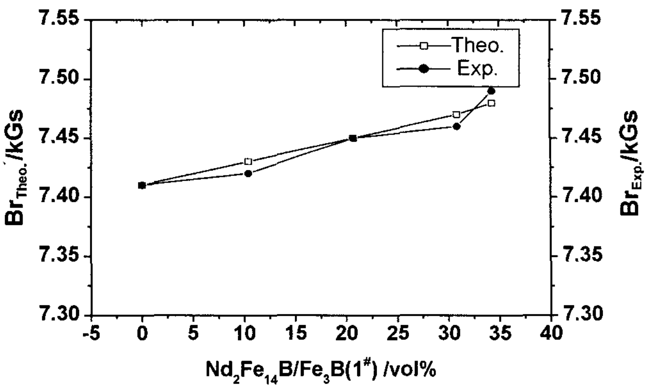

Fig. 3. Variation of compound magnet B_r versus sample 1# content.

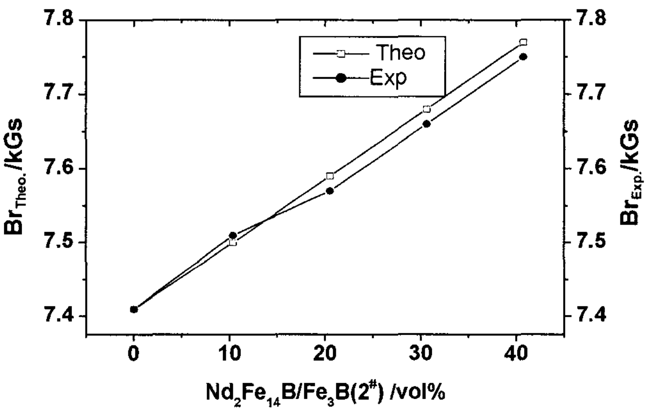

Fig. 4. Variation of compound magnet B_r versus sample 2# content.

The curves of theoretic $B_r(B_{rTheo.})$ and experimental $B_r(B_{rExp.})$ are quite consistent in the figures. Thereby, comparing the theoretic curve of compound magnet B_r with the experimental curve, B_r is approximately linear with the variation of $Nd_2Fe_{14}B/Fe_3B$ content. The results indicate that the $Nd_2Fe_{14}B/Fe_3B$ with high B_r takes a compensatory effect on lower compound magnet B_r. Not chemical but simple physical relation exists in every compound magnet. As for the manufacturers, the functional relations between the magnetic properties and different element content can be formed so that the process of mixing magnetic powders to reach a certain magnetic properties will be probably simplified.

3.2. Properties of $Nd_2Fe_{14}B/Fe_3B$-Ferrite compound magnets

By the investigation of $Nd_2Fe_{14}B/Fe_3B$-ferrite compound magnets ($Nd_2Fe_{14}B/Fe_3B$ is 2# as above), the functional relation between B_r of compound magnets and ferrite

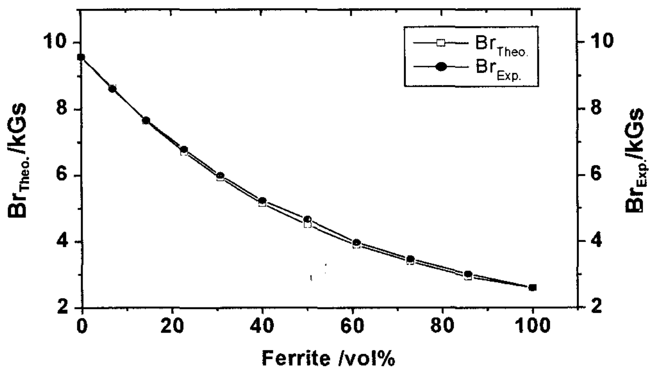

Fig. 5. Variation of compound magnet B_r versus ferrite content.

contents shown in Fig. 5. It shows that the two overlapping curves of $Nd_2Fe_{14}B/Fe_3B$ ferrite compound magnet. B_r was respectively obtained by theoretic calculation and experiment.

As above, the linear relation between compound magnet Br and ferrite content still exists in compound magnets. Hence, the secondary function was gotten by mathematical calculation. That is $Y = 5.42\ x^2 - 11.34\ x + 6.62$ (Y : MGOe; x : wt% of ferrite). The error between theoretic and experimental values is ± .5%.

Fig. 6 shows the curves of theoretic and experimental $(B{\cdot}H)_{max}$. Thats to say, the theoretic curves of $(B{\cdot}H)_{max}$ can be easily obtained by linear calculation. At the same time, the result of secondary function will make experimental process of mixing powders easy. $Nd_2Fe_{14}B/Fe_3B$ bonded magnets were restricted to apply in high temperature due to their bad thermal stability. The compound effect of $Nd_2Fe_{14}B/Fe_3B$-ferrite bonded magnets leads the β_{iHc} of single-element $Nd_2Fe_{14}B/Fe_3B$ magnets to change from –0.57%/°C to positive value. The results are showed in Fig. 7.

Following the ferrite content increasing, the β_{iHc} gradually tends to zero, the thermal stability of compound magnets were enhanced. In Fig. 7, the enhancing tendency of β_{iHc} accelerates when ferrite exceeds 50%

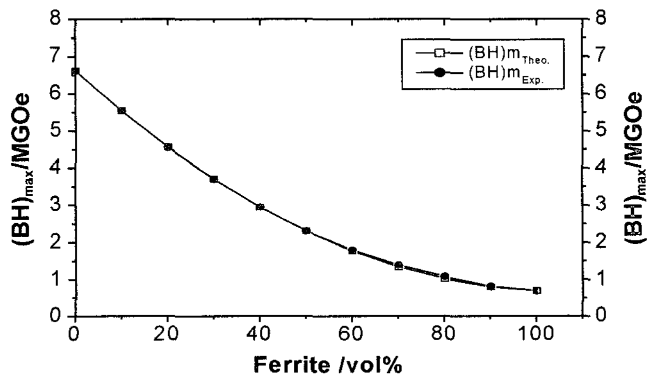

Fig. 6. Variation of $(B{\cdot}H)_{max}$ versus ferrite content.

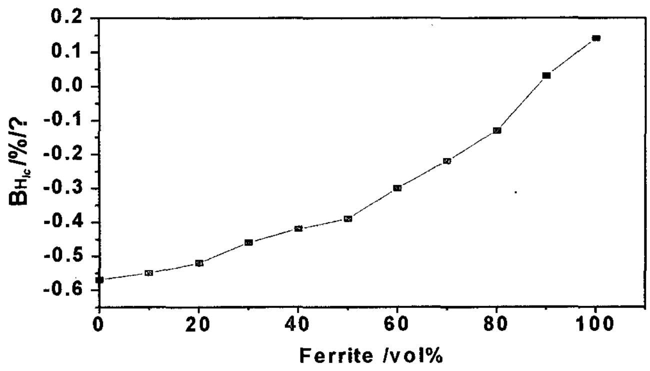

Fig. 7. Variation of compound magnet β_{iHc} versus ferrite content.

(wt). The reason is that the density of ferrite is lower than $Nd_2Fe_{14}B/Fe_3Bs$, thus ferrite volume percent has reached 60% as its weight percent is about 50%. At the moment, it has abundantly suffused in magnets so that it mainly takes an effect on the iHc of magnets.

The irreversible loss h_{irr} indicates the thermal stability of magnets. In Fig. 8, the lower value of h_{irr} the magnets possess, the steadier the magnetic materials have. Fig. 8

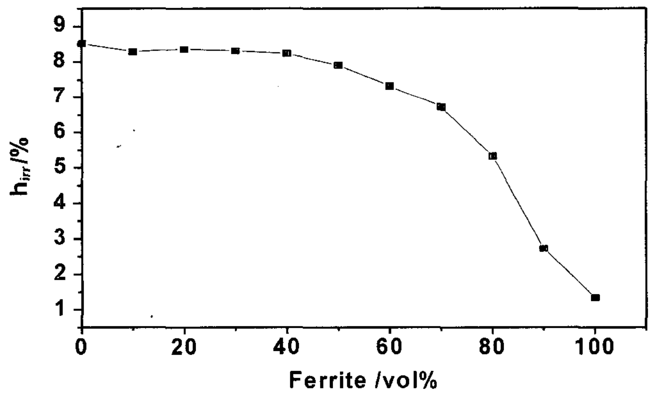

Fig. 8. Variation of compound magnet h_{irr} versus ferrite content.

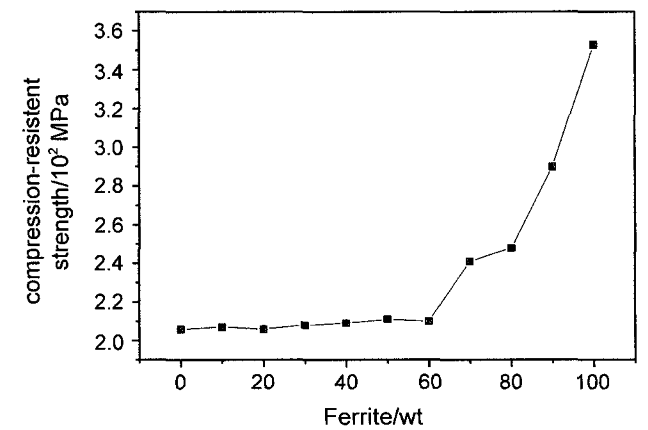

Fig. 9. Variation of compression-resistant strength with ferrite content.

shows that h_{irr} of the magnets heated at 100 °C for 100 h was measured at 25 °C. Magnet size is D/L=0.8. The h_{irr} of magnets gradually decreases as the ferrite content rises. h_{irr} keeps about 8.3% when the ferrite is lower than 40%(wt). As more than 40%(wt), the decreasing tendency of h_{irr} speeds up following the ferrite content rising. Thus, the compound bonded magnets can work at higher temperature owing to the addition of ferrite with better thermal stability.

Fig. 9 shows the effect of ferrite element on the compression-resistant strength of the compound magnets. In all, the addition of ferrite into bonded magnets can improve mechanical property of magnets, which results from that single-component ferrite bonded magnets possess high compression-resistant strength.

4. Conclusions

The interaction of magnetic powders in $Nd_2Fe_{14}B/Fe_3B$-based compound bonded magnets is not chemical but physical. The secondary function of maximum energy product $(B{\cdot}H)_{max}$ and ferrite volume percent, $Y = 5.42 x^2 - 11.34 x + 6.62$, was obtained. The addition of ferrite can decrease h_{irr} of compound magnets and improve mechanical property. $RE_2Fe_{14}B/Fe_3B(\alpha\text{-}Fe)$-ferrite compound bonded magnets replenish the blank space of the magnetic properties between single $RE_2Fe_{14}B/Fe_3B(\alpha\text{-}Fe)$ and single ferrite magnets.

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