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The effect of Na_2O addition on the magnetic properties of $BaFe_{12}O_{19}$ ferrites

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The effect of Na_2O addition on the magnetic properties of isotropic $BaFe_{12}O_{19}$ ferrites from hot-rolled mill scale was investigated. Na_2O was added up to 0.2%. The values of coercivity and energy product maximum are significantly increased, notably $(BH)_{max}$ from 0.8 to 0.9 $\times$ 10^6 Oe G, and those of intrinsic coercivity rise drastically from 2500 to 4000 Oe when Na_2O up to 0.15% is added after calcination. On the other hand, the magnetic properties of the ferrites gradually deteriorate and the values of intrinsic coercivity vary very little when Na_2O up to 0.2% is added prior to calcination. The densification of ferrites is slightly decreased in the presence of the Na_2O, regardless of the time at which it is added.

1. Introduction

The effect of oxide addition on the magnetic properties of $BaFe_{12}O_{19}$ ferrites was recently investigated by Gadalla *et al.* [1] and Yamamichi and Watanable [2]. The effect of oxides on the liquid-phase composition was reported by Arendt [3]. It appears that the effect of Na_2O on the magnetic properties of $BaFe_{12}O_{19}$ ferrites has scarcely been reported in the literature.

It was incidentally found that hot-rolled mill scale and α-Fe_2O_3 from the pickling solution contained a considerable amount of Na_2O which fluctuated widely, i.e. Na_2O = 0.02 to 0.20% from 18 mill-scale samplings and Na_2O = 0.02 to 0.22% from ten α-Fe_2O_3 samplings [4]. The purpose of the present investigation is to study the effect of Na_2O addition on the magnetic properties of $BaFe_{12}O_{19}$ ferrites.

2. Experimental procedures

The mill scale used in the present work was produced from heavy steel plates during hot-rolling processes. The other raw materials included industrial-grade barium carbonate containing 98.5% $BaCO_3$ and reagent-grade Na_2CO_3. The chemical composition of the raw materials is given in Table I.

The hot-rolled mill scale, passed through a 2.362 mm opening screen, was ground in sequence by a ball mill and an attritor mill down to -0.044 mm. These powders were leached with deionized water to remove Na_2O. The leached mill scale contained $\approx 0.06\%$ Na_2O and was used to prepare isotropic barium ferrites with $n = 5.3$, where n is related to the chemical formula $BaO \cdot n\ Fe_2O_3$.

Calcination was carried out in an electrical furnace at 1100° C for 4 h. The average particle size of the ground barium ferrite was $\approx 1.0\ \mu m$ which was determined by a Fisher sub-sieve sizer. Discs of 22 mm diameter and $\geqslant 5$ mm thickness were formed under a pressure of 1.0 ton cm^{-2} by die-pressing dry powder. Sintering was also conducted in an electrical furnace at 1180° C for 2 h.

3. Results and discussion

3.1. The effect of Na_2O addition before calcination on the magnetic properties

All the magnet specimens were supplemented with 0.3% SiO_2, 0.2% SrO and 0.1% Al_2O_3 prior to calcination as additives to achieve a commercial quality level. The influence of Na_2O addition on the magnetic properties is shown in Figs 1 to 3. As can be seen, the coercivity H_c, remanence B_r and energy product maximum $(BH)_{max}$ all decreased with increasing Na_2O content. It is believed that the deterioration of magnetic properties is most probably caused by the increasing amount of glassy phase and the decreasing densification of the ferrites (Fig. 4) in the presence of Na_2O. It is beneficial to limit Na_2O contamination from the water treatment of the iron oxides obtained from mill scale or pickling solution in a steel plant.

Fig. 5 demonstrates that the intrinsic coercivity iH_c varied very little below 0.1% Na_2O and then increased slightly with increasing Na_2O content up to 0.2%. According to Cowie [5], the magnitude of iH_c depends on crystalline perfection and grain size. As little as 0.2% Na_2O in barium ferrites will apparently slightly promote crystalline perfection and not cause a significant grain growth to occur.

TABLE I Chemical composition of hot-rolled scale*

Constituent	Content (wt %)
Total Fe	74.9
SiO_2	0.054
Al_2O_3	0.046
MnO	0.320
MgO	0.006
CaO	0.002
K_2O	0.060
Na_2O	0.024

*After leaching with water.

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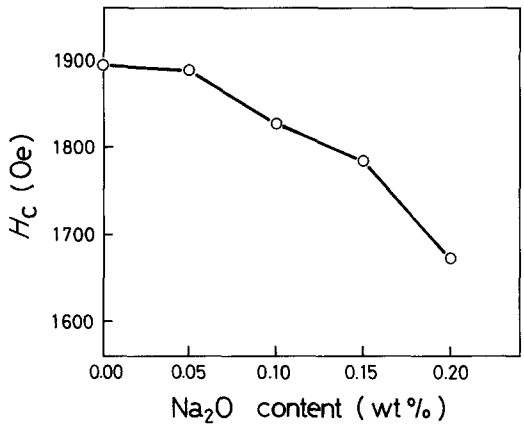

Figure 1 Variation of coercivity with Na_2O content added before calcination to $BaFe_{12}O_{19}$ ferrites.

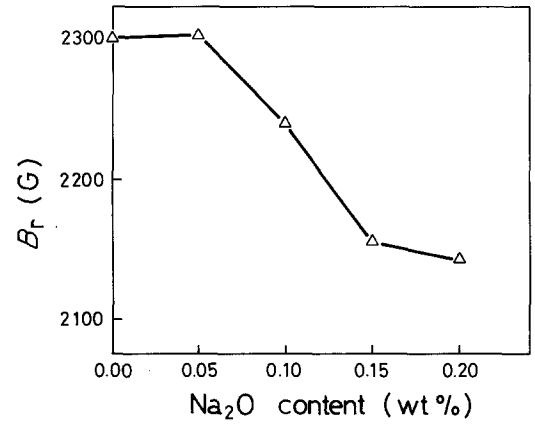

Figure 2 Variation of remanence with Na_2O content added before calcination.

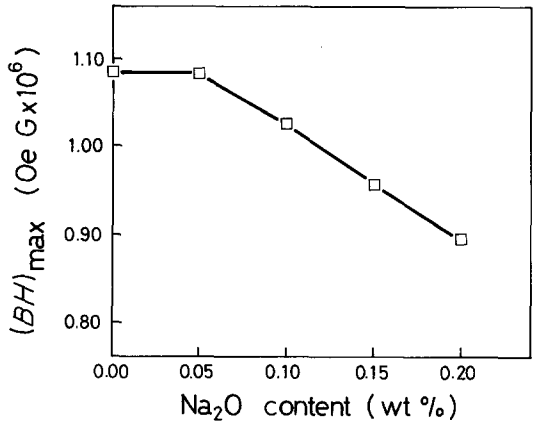

Figure 3 Variation of energy product maximum with Na_2O content added before calcination.

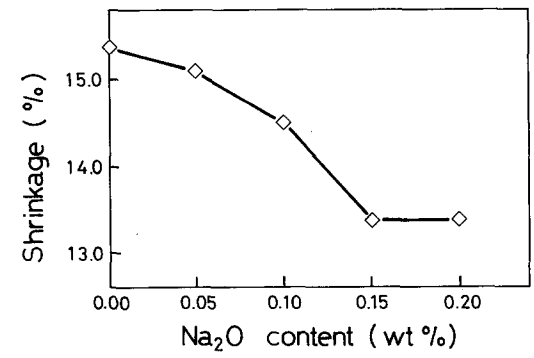

Figure 4 Variation of shrinkage with Na_2O content added before calcination.

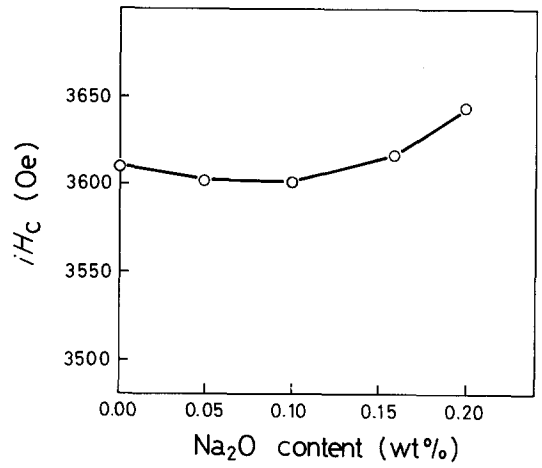

Figure 5 Variation of intrinsic coercivity with Na_2O content added before calcination.

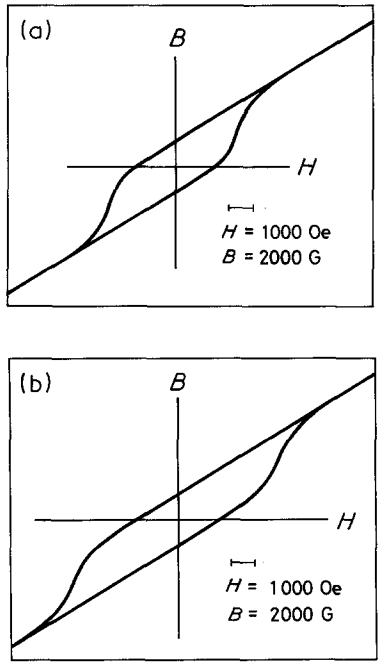

Figure 6 *B–H* curves of $BaFe_{12}O_{19}$ ferrites (a) without Na_2O, (b) with 0.15% Na_2O added after calcination.

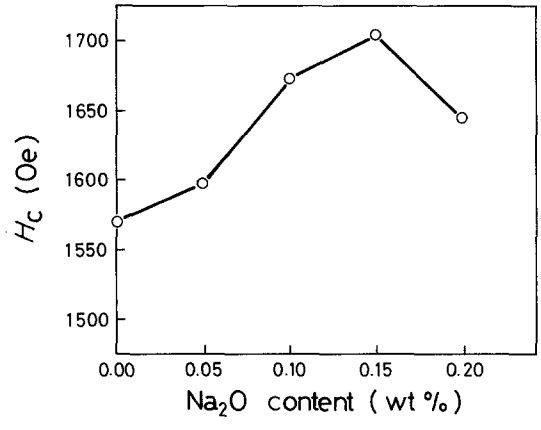

Figure 7 Variation of coercivity with Na_2O content added after calcination.

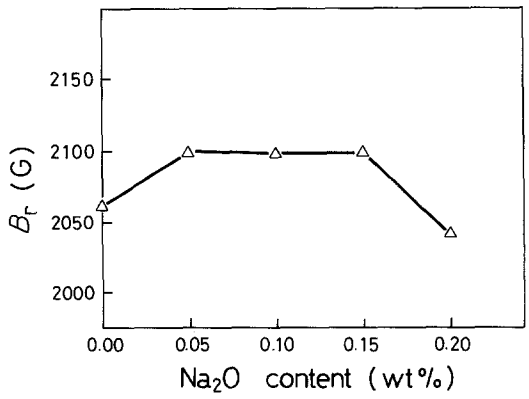

Figure 8 Variation of remanence with Na_2O content added after calcination.

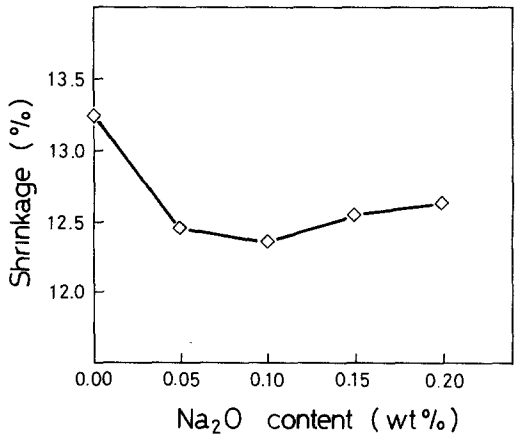

Figure 10 Variation of shrinkage with Na_2O content added after calcination.

3.2. The effect of Na_2O addition after calcination on the magnetic properties

The magnet specimens were given no additives other than Na_2O. Fig. 6 shows that 0.15% Na_2O addition to the magnet strikingly changed the shape of the B–H curve. The influence of Na_2O addition on the magnet properties is demonstrated in Figs 7 to 9. It can be clearly seen that the values of H_c and $(BH)_{max}$ are significantly increased in the presence of Na_2O up to 0.15% and then decreased; those of B_r increased very little up to 0.15% Na_2O and then also decreased. Fig. 10 shows that the densification was slightly decreased in the presence of as little as 0.05% Na_2O and then varied very little with Na_2O content up to 0.2% Na_2O.

Fig. 11 demonstrates that the values of intrinsic coercivity iH_c are increased drastically from 2500 to 4000 Oe when the Na_2O content is raised to 0.15%. Apparently, Na_2O is quite effective for the enhancement of intrinsic coercivity if its content is up to 0.15%. As mentioned previously [5], the rise of iH_c values is caused by the crystalline perfection and the decrease of iH_c values is possibly caused by grain growth.

Fig. 12 demonstrates that 1% Na_2O addition to the ferrite apparently promotes crystalline perfection but causes remarkable grain growth.

4. Summary

The effect of Na_2O addition on the magnetic properties of isotropic $BaFe_{12}O_{19}$ ferrites was investigated. Hot-rolled mill scale was used and Na_2O was added up to 0.2% for the preparation of ferrites. The values of the coercivity H_c and energy product maximum $(BH)_{max}$ are significantly increased, notably $(BH)_{max}$ from 0.8 to 0.9 $\times$ 10^6 Oe G and those of the intrinsic coercivity iH_c rise drastically from 2500 to 4000 Oe when Na_2O up to 0.15% is added after calcination. However, the magnetic properties of the ferrites gradually deteriorate and the values of intrinsic coercivity are varied very little when Na_2O up to 0.2% is added prior to calcination. The densification of ferrites is slightly decreased in the presence of Na_2O, regardless of the time at which it is added.

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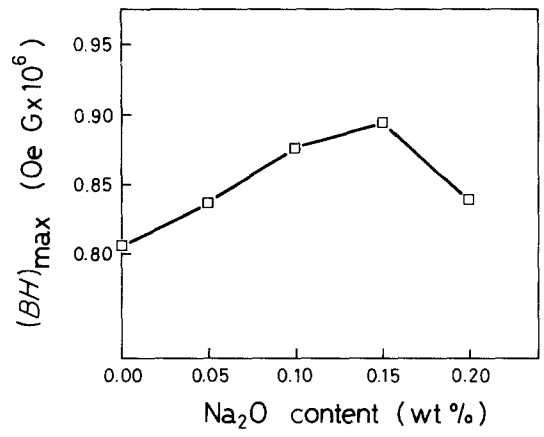

Figure 9 Variation of energy product maximum with Na_2O content added after calcination.

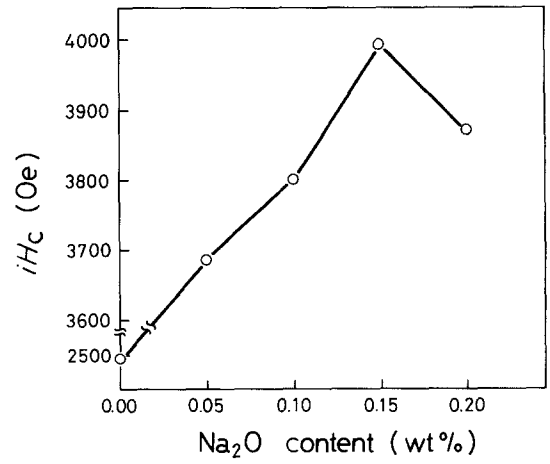

Figure 11 Variation of intrinsic coercivity with Na_2O content added after calcination.

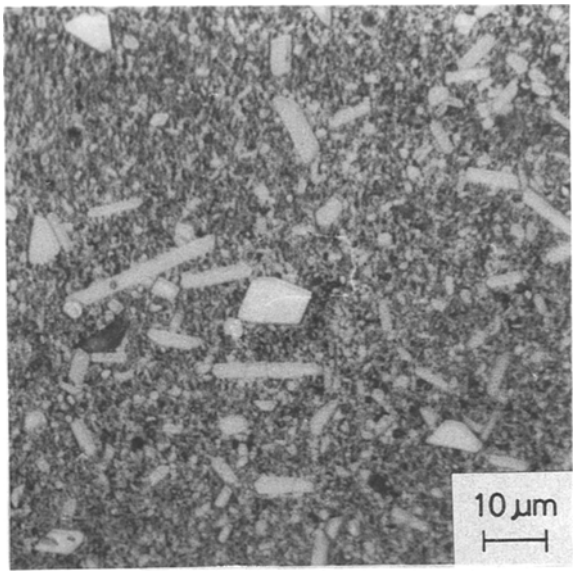

Figure 12 Optical micrograph of $BaFe_{12}O_{19}$ ferrite with 1.0% Na_2O added after calcination.

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