THE ALIGNMENT OF SR-FERRITE POWDERS AND MAGNETIC PROPERTIES IN FABRICATION OF MULTI-POLE ANISOTROPIC SINTERED SR-FERRITES BY POWDER INJECTION MOLDING

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Abstract: For the fabrication of a multi-pole anisotropic Sr-ferrite magnet by powder injection molding, it is important to control effectively the alignment of magnetic powders during the injection molding process. The effect of the fluidity of powder/binder mixture on the powder alignment was studied with changing the particle sizes and the volume fraction of Sr-ferrite magnetic powders. The critical volume fraction of Sr-ferrite powders increases from 58 vol.% to 64 vol.% as the mean powder size increases from 0.8 μm to 1.2 μm. A Sr-ferrite powder alignment greater than 80 % is achieved at the conditions of an apparent viscosity lower than 1000 poise at 1600 sec^{-1} shear rate, an applied magnetic field higher than 4 kOe, and a powder volume fraction 8 vol.% lower than the critical fraction. The powder alignment obtained during the injection molding process is not much affected by the subsequent processes of debinding and sintering, showing the magnetic properties of 3.8 kG of remanent flux density and 3.37 kOe of intrinsic coercivity.

I. INTRODUCTION

The powder injection molding (PIM) is a promising technique for fabricating multi-pole anisotropic Sr-ferrite magnets since it is possible to achieve a combination of the properties peculiar to the conventionally sintered magnets and to the resin-bonded magnets. For the fabrication of a multi-pole anisotropic Sr-ferrite magnet by PIM, Sr-ferrite magnetic powders are first mixed with binders. The powder/binder mixture is then injection-molded into a desired shape under externally applied magnetic fields. After molding, the binders are removed from the molded compact and the remaining powder compact is finally sintered to achieve near full density [1-2]. Since individual Sr-ferrite (hcp) powders used for PIM show a strong magnetic anisotropy with an easy direction along the crystallographic c-axis, it is desirable to align all the powders to have the same direction of their c-axis. This powder alignment is achieved by applying an external magnetic field during injection molding and the magnetic properties of the finally sintered magnet depend strongly on the degree of the powder alignment. The alignment of Sr-ferrite powders is generally enhanced by increasing the fluidity of the powder/binder mixture.

The purpose of this paper is to find the relationships among the fluidity of powder/binder mixture and the powder alignment so as to determine an optimum condition for fabricating Sr-ferrite magnets by PIM. For this purpose, we employed three different mean particle sizes of Sr-ferrite magnetic powder; about 0.8 μm, 1.0 μm, 1.2 μm. The fluidity of powder/binder mixture is controlled by varying the mean particle sizes and the volume fraction of the Sr-ferrite powders to binder mixture at a fixed binder composition.

II. EXPERIMENTAL PROCEDURE

The average size of Sr-ferrite powders used in the experiment was three different mean particle sizes of about 0.8 μm, 1.0 μm, and 1.2 μm in diameter. The properties of individual binder components were measured and are listed in Table 1.

Table 1. The properties of binder components

	PW	CW	HDPE
Melting Point (℃)	52	87	132
Heat of Fusion (J/g)	142	207	200
Density (g/cm^3, 25℃)	0.902	0.970	0.964
Molecular Weight (g)	360	1400	40000

The mixing of Sr-ferrite powders with the binder mixture was performed at a temperature of 150℃ for 1 hours using a mixer of Z-blade type. The composition of binder mixture employed in the experiment was PW:CW:HDPE=50:20:30 (wt.%). The volume fraction of Sr-ferrite powder in the powder/binder mixture was varied from 52 vol.% to 60 vol.%, regardless of Sr-ferrite particle sizes.

Injection molding was carried out at 200 ℃ under magnetic fields ranging from 0 to 8 kOe. The molding temperature was determined by considering the fact that PW decomposes at temperatures above 200℃. In the debinding process, PW was first removed by solvent extraction using n-heptane and then CW/HDPE by thermal debinding [4-5]. The powder compact was finally sintered at 1200℃ ~ 1250℃ in the ambient of air.

Apparent viscosity of the powder/binder mixture, which measures the degree of fluidity, was measured with a capillary rheometer at the injection-molding temperature, 200℃. The capillary has a radius of 0.765 mm and length of 7.866 mm. Using D.C. fluxmeter, the degree of powder alignment (DPA) in the molded compact and the sintered compact was determined from the equation expressed as

$$DPA(\%)=[B_r(\parallel)/\{B_r(\parallel)+B_r(\perp)\}]\times 100, \qquad (1)$$

where $B_r(\parallel)$ and $B_r(\perp)$, respectively, are the remanent flux densities measured along the parallel and perpendicular directions to that of the magnetic field applied during the injection molding process.

III. RESULTS AND DISCUSSION

Fig. 1 shows the densities of powder/ binder mixture as functions of Sr-ferrites volume fraction for three different mean particle sizes. The critical volume fraction of powders, which corresponds to the fraction giving the maximum density of powder/binder mixture, increases from about 58 vol.% to about 64 vol.% as the mean particle sizes increases from 0.8 μm to 1.2 μm. When the powder volume fraction is increased above the critical value, the density of powder/binder mixture decreases since a more amount of voids is formed in the powder/binder mixture. The critical volume fraction of monosized, spherical powders was theoretically predicted to be about 64 vol.% [6]. The critical fraction of powders increases as the powders exhibits a more broad size distribution. However, the critical fraction of Sr-ferrite powders, which has the distribution of particle sizes from 0.3 μm to 2.5 μm, was below 64 vol.% in powder/binder mixture. This is attributed to the agglomeration of powders which is more acute as the particle size decreases below about 1 μm [7]. The decrease in the critical volume fraction of Sr-ferrites with decreasing the mean particle size is due to the fact that the cohesion among particles is increasing and thus that a more powder agglomeration occurs.

Fig. 2 shows the dependence of the alignment of Sr-ferrite magnetic powders on applied magnetic fields for the three, different mean particle sizes when the Sr-ferrite fraction is fixed to 60 vol.%. The critical volume fractions of Sr-ferrite powders with mean particle sizes of 0.8 μm, 1.0 μm, and 1.2 μm were about 58 vol.%, 60 vol.%, and 64 vol%, respectively. For a given value of the applied magnetic field, the powder alignment in powder/binder mixture increases as the mean particle sizes increases. That is, for an applied field of 8 kOe, the alignment of Sr-ferrite powders increases from 64.0 % to 86.9 % as the mean particle size of powders increases from 0.8 μm to 1.2 μm.

The apparent viscosities of the powder/

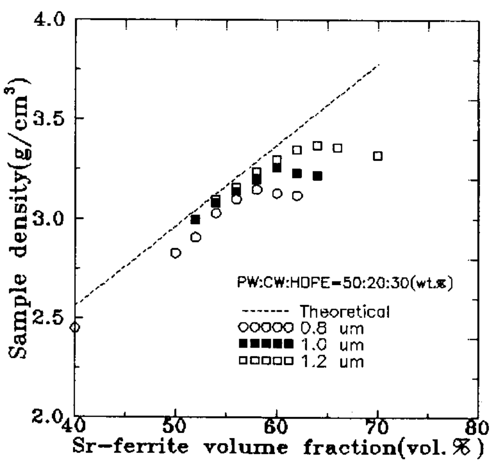

Fig. 1 The density of powder/binder mixture as a function of powder volume fraction at three different particle sizes of Sr-ferrites.

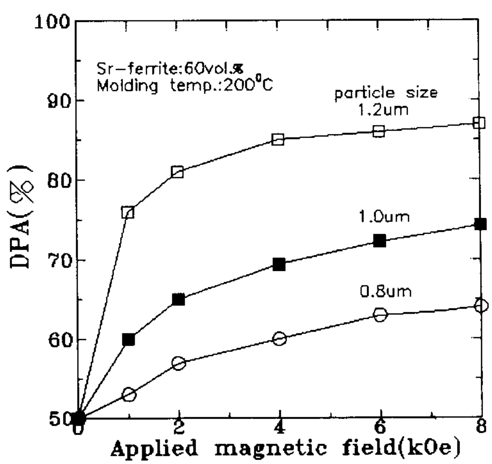

Fig. 2 The degree of Sr-ferrite powder alignment as a function of magnetic field at three different particle sizes of Sr-ferrites.

binder mixture and the powder alignment of the injection-molded compact were measured at 200℃ for the different particle sizes and volume fractions of Sr-ferrites. These results is summarized in Table 2. The apparent viscosity of powder/binder mixture, which measures the degree of fluidity, decreases as the volume fraction of powder increases [8].

The apparent viscosity of powder/binder mixture increases from 860 poise to 1600 poise at the shear rate of 1600 sec^{-1} as the volume fraction of Sr-ferrite powders with the mean particle sizes of 1.0 μm increases from 52 vol.% to 60 vol.%. For a fixed powder fraction of 60 vol.%, the apparent viscosity of powder/binder mixture decreases from 2800 poise to 820 poise at the shear rate of 1600 sec^{-1} as the mean particle size of Sr-ferrites increases from 0.8 μm to 1.2 μm. The powder alignment decreases as the apparent viscosity of powder/binder mixture increases. Because the apparent viscosity of powder/binder mixture increases with changing the powder fraction from 52 vol.% to 60 vol.%, the alignment of powders with the mean particle size of 1 μm decreases from 83.7% to 74.3% at the applied magnetic field of 8 kOe. Because the apparent viscosity of powder/binder mixture, which has a powder volume fraction of 52 vol.%, decreases with changing the powder size from 0.8 μm to 1.2 μm, the alignment of powders increases from 77.5% to 89.2% at the applied magnetic field of 8 kOe.

Table 2. The apparent viscosities and the powder alignment for the different particle sizes and volume fractions of Sr-ferrites.

Sr-ferrite powders	0.8 μm			1.0 μm			1.2 μm		
volume fraction (vol.%)	52	56	60	52	56	60	52	56	60
Apparent viscosity (poise) (1600 sec^{-1})	1200	1740	2800	860	1150	1600	600	710	820
DPA (at 8 kOe) (%)	77.5	71.0	64.0	83.7	78.9	74.3	89.2	88.0	86.9

Fig. 3 depicts the dependences of powder alignment on the apparent viscosity of powder/binder mixture for several, magnetic fields applied during the injection molding process. For a given value of the applied magnetic field, the alignment of Sr-ferrite powders decreases with increasing the apparent viscosity. This type of figure can be used as a guidance for the design of molding die or for determining the optimum binder mixture for an established PIM equipment. For the powder/binder system considered in this paper, if the powder/binder mixture has

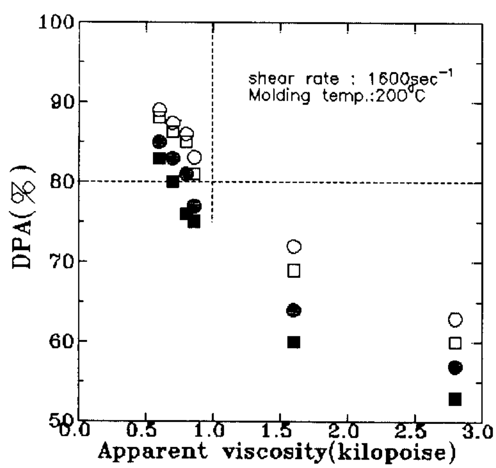

Fig.3 The degree of Sr-ferrite powder alignment as a function of apparent viscosity when several, different values of magnetic fieldmare applied during injection molding(■: 1kOe, ●: 2kOe, □: 4kOe, ○: 6kOe)

an apparent viscosity less than 1000 poise at the shear rate of 1600 sec^{-1}, the alignment of Sr-ferrite powders greater than 80% can be obtained with an applied magnetic field around 4 kOe.

The degree of alignment of sintered Sr-ferrite compact was 85%, implying that the alignment occurred during the injection molding process is hardly changed by the debinding and sintering processes. The sintered compact showed the magnetic properties: 3.8 kG of remanent flux density, 3.37 kOe of intrinsic coercivity, and 3.6 MGOe of maximum energy product.

Ⅳ. CONCLUSIONS

In order to obtain the optimum conditions of PIM for Sr-ferrite magnetic powders using the binder system of PW:CW:HDPE=50:20:30 (wt.%), the relationships among the apparent viscosity of powder/binder mixture and the alignment of Sr-ferrite powders were studied with varying the particle sizes and the volume fraction of Sr-ferrite magnetic powders and we conclude the followings:

(1) The critical volume fraction of powders increases from 58 vol.% to 64 vol.% as the mean particle sizes increases from 0.8 μm to 1.2 μm.

(2) A Sr-ferrite powder alignment greater than 80 % is achieved at the conditions of an apparent viscosity lower than 1000 poise at 1600 sec^{-1} shear rate, an applied magnetic field higher than 4 kOe, and a powder volume fraction 8 vol.% lower than the critical fraction.

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