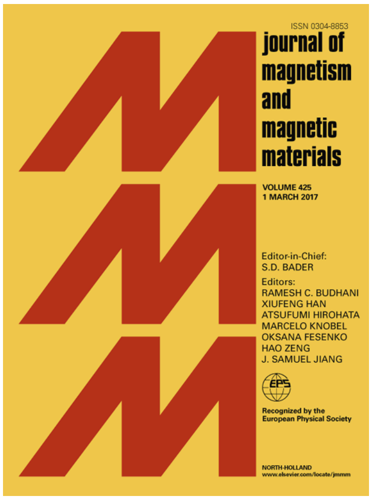

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Influence of $CaCO_3$ and SiO_2 Additives on Magnetic Properties of M-type Sr Ferrites

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Abstract—**An experiment was carried out to investigate the influence of $CaCO_3$ and SiO_2 additives on the magnetic and physical properties of M-type Sr ferrites by changing experimental parameters such as the additive composition and Ca/Si ratio. Specimens were prepared by conventional ceramic techniques. It was found that the magnetic properties (B_r = 4.42 kG, iH_c = 3.32 kOe and $(BH)_{max}$ = 4.863 MGOe) were considerably improved upon adding $CaCO_3$=1.1% and SiO_2=0.4 wt% together with Co_3O_4, and the mechanical properties thereof were acceptable for motor applications. It was revealed that $CaCO_3$ and SiO_2 additives led to an upswing in the magnetic properties via the enhancement of uniform grain growth, particle alignment, and the densification of Sr ferrite.**

Keywords— **Hard magnet, Sr ferrites, M-type, Additives, Microstructure**

1. INTRODUCTION

MANY reports on the magnetic properties and synthesis of M-type hexagonal ferrites $MFe_{12}O_{19}$ (M=Pb, Sr, Ba) with magnetoplumbite structure are available [1]–[4]. Their distinct magnetic properties such as high Curie temperature, high magnetization per formula unit ($20\mu_B$ at 0K), high permeability, high coercivity (iH_c), excellent chemical stability, corrosion resistivity, and low production cost [4]–[6], have made M-type ferrites an increasingly popular topic for industrial applications such as rotors in Brushless DC electric motors (BDCM) [7].

The critical issue of M-type ferrites for BDCM applications is the development of ferrite grades with large coercivity (iH_c), remanence (B_r), and maximum energy product ($(BH)_{max}$). The magnetic properties of M-type ferrites are greatly influenced by the stoichiometry, cation distribution in the crystal lattice, grain size, porosity, and anisotropic grain growth [8]–[9]. Large B_r demands a high-sintered density and growth anisotropy, whereas large H_c requires small grain size. In practice, Sr ferrite (without Lanthanum, La) for typical high magnetic properties has coercivity iH_c = 3.1–3.2 kOe and remanence B_r = 4.0–4.2 kG. The limitation of the above magnetic properties results from (1) the composition of ferrite being lacking the stoichiometry $SrO \cdot n(Fe_2O_3)$ with a mole ratio of n=6 (Sr hard ferrites are usually prepared with an excess of SrO) and (2) some unavoidable residual porosity causing decreased sintered density and an anisotropy factor (α) [or orientation ratio (OR)] of particles being non-ideal. Importantly, a large remanence $B_r=4\pi M_s \cdot \alpha \cdot \rho$ requires a large saturation magnetization $4\pi M_s$, high density ρ and high anisotropy factor (α). A large saturation magnetization $4\pi M_s$ is essential to precisely tailor the applicable raw material Fe_2O_3, (i.e. purity and SSA) [7] suitable additives, calcined condition, and sintered condition. A sufficiently strong applied magnetic field is needed to align single-crystal particles in the process of wet pressing powders to obtain a high α. The applied magnetic field overcomes the resistance to alignment to align the easy direction of each particle's magnetization, owing to its strong crystalline anisotropy. To increase the dispersion of the solids and thus maximize the solids concentration within the slurry, a dispersant is normally added to the slurry to decrease the slurry viscosity without the necessity of adding excessive water. Besides, the shape anisotropy of the particles and the existence of particles with multigrains will reduce the degree of alignment, which should be avoided [10]. In this work, dispersant was added to the slurry before the fine milling process to facilitate ball milling (mixing homogeneously with the powders) and subsequent wet pressing process to increase degree of alignment. It is crucial to precisely tailor the material stoichiometry and ceramic process, which in turn control the complex interplay between particle grain growth and the sintered density, when manufacturing hard ferrite with a large B_r. However, a large H_c can be achieved by absolutely eliminating the magnetic domain boundaries with a grain size smaller than the critical size for the single domain particle of approximately 1 μm [11]–[12]. The coercivity iH_c can be described by i$H_c = bH_a - N(B_r+J_s)/\mu_0$, where b, H_a, N, B_r, and J_s are respectively the grain size factor, the magnetocrystalline anisotropy field, the grain demagnetization factor, remanence, and the saturation magnetization [13]–[15]. The factor b increases as the grain size decreases. The two magnetic properties B_r and H_c are always in a trade-off.

The residual orbital magnetic moment of Co^{2+} plays a crucial role in increasing coercivity [16]. The Co^{2+} is known to change