Influence of compaction pressure on magnetic characteristics, density, and hardness of barium hexaferrite

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Abstract. The effect of varying compacting pressure has been observed in the preparation of permanent magnet barium ferrite. The compaction pressure affects the magnetic characteristic, physical properties, and mechanical properties. The technological process used in this study was a powder metallurgy process. The steps of processes were determination of chemical composition, mixed, calcined, milled, compacted, sintered, and characterization. The raw materials used were waste iron oxide (Fe2O3) and barium carbonate (BaCO3) with a composition ratio of 80:20% weight. Some additives were also added, such as silicon oxide (SiO2), calcium oxide (CaO), and polyvinyl alcohol (PVA). Calcinated temperature at 1200 °C with 3 hour holding time, sintered temperature at 1250 °C with one hour holding time. Compacted pressure varies at a pressure of 1, 2, 3, 4, 5, and 6 tons.cm\textsuperscript{-2}. The magnetic properties were obtained by Magnet Physik Permagraph. The optimum result is at compacting pressure of 6 tons.cm\textsuperscript{-2}, with a value of remanent induction (Br) = 2.03 KG, coercivity (Hc) = 2.156 Koe, maximum field strength (BHmax) = 0.74 MGOe, and density = 4.530 g.cm\textsuperscript{-3}. Hardness test result were obtained using Rockwell-C method of the sample with pressure of 6 tons.cm\textsuperscript{-2} was 42.5 HRc, but samples with pressure 1, 2, 3, 4, and 5 tons.cm\textsuperscript{-2} could not be analyzed because of crack. Samples that formed at pressure below than 6 tons.cm\textsuperscript{-2} had low hardness.

1. Introduction

Barium ferrite is a kind of permanent magnet that required by the electronics industry such as for loudspeakers, sensor, transducers, electric meters, water meters, DC motors, automotive industry etc [1,2]. These magnets are widely used because it is low cost, high saturation magnetization, high coercivity, and high temperature curie. In addition of these magnets also have high corrosion resistance with excellent chemical stability [3,4].

It is well known that the magnetic properties of permanent magnets such as remanence (Br), product energy maximum (BHmax), coercivity (Hc), etc., are depend on many characteristics including chemical compound, morphology structure, and physical properties (density and hardness) [5]. Z. Zhang [6] has observed the effects of the annealing temperature and the compaction pressure on the soft magnetic FeSi. It was found that high temperature and low compaction pressure are beneficial to decrease the core’s inner stress, while high compaction pressure is helpful to reduce the air gap. C. Clausel et.al. [7,8] have investigated the influence of compaction pressure on the electromagnetic properties of Cu-doped NiZn ferrites. The results show that the density increased and total porosity decreased. The relative density and avarage grain size influences magnetic permeability of NiZn ferrites.
D. Rodrigues [9] has been increase the density of NdFeB sintered by uniaxially pressed. He obtained the maximum density of samples are close to ~6.0 g.cm-3. The higher the density, the magnetic properties (Br and BHmax) are increasing, but Hc decrease with deformation during compaction.

In previous research, K. Okimoto [10] has studied the fact of mechanism that decrease in the Hc of hard ferrite during its pulverizing and compacting processes. The analysis results show that the decrease of magnetic materials are caused by the internal strain in its particles due to solid contacts between them in the compacting process.

Many factors can affect the magnetic properties of hard magnet materials, including method of preparation, the compositions, sintering temperature, sintering rate, sintering duration, compacting pressure, and additives [11]. All these factors must be in appropriate conditions to obtain the optimal magnetic characteristics. In this work, we report the synthesis and characterization of barium ferrite prepared by powder metallurgy method. We investigate influence of varying compaction pressure on magnetic properties of barium ferrite. Magnetic properties were measured by using Permagraph Magnet Physik. The density and hardness were also observed to determine the effect of pressure on the physical properties and mechanical properties. The density was measured by measuring the weight and volume of the sample, whereas the hardness was measured by Rockwell-C method.

2. Experiment
Using powder metallurgy method, the percentage composition of iron oxide (Fe2O3) barium carbonate (BaCO3) with ratio of 80:20% weight were mixed into alcohol by ball milling for 8 hours.

![Figure 1. Raw material Fe2O3 and BaCO3 powder before milling process](image)

The next step, the mixture was burned in a furnace (Thermolyne) at temperature 1200 °C for 3 hours. After burned, some additives silicon oxide (SiO2), calcium oxide (CaO), and polyvinyl alcohol (PVA) added to the mixture as much as 0.75 – 1.5 weight %. The mixture was milled again for 16 hours. After that, the mixture was dried at temperature 100 °C to get dry powder magnet barium ferrite materials that ready to be pressed. The amount of the samples was 2 g, was performed in disk shape with a diameter 11.55 mm and a thickness 5 mm. The compacting pressure was varied at 1, 2, 3, 4, 5, and 6 tons.cm⁻² by hydraulic press. The compact samples were placed on an alumina substrate and sintered at temperature 1250 °C in air atmosphere with one hour holding time and heating rate was 10 oC/minutes.

The density of the samples were calculated based using the following equation:

\[ \rho = \frac{m}{V} \]  

\(\rho = \text{density}, \ m = \text{mass}, \ V = \text{volume}\)
3. Results and Discussion
The density results by varying compaction pressure show at figure 2. The density increased with increasing compaction pressure. The greatest density was obtained at the compaction process 6 tons.cm\(^{-2}\) was about 4.650 g.cm\(^{-3}\). The higher compaction pressure causes the grain boundaries of samples is reduced, the porosity decreases and the density increases.

![Figure 2](image1.png)

**Figure 2.** Influence of compaction pressure on density of barium ferrite

The all powders were compacted by powder metallurgy method will increase in density with increasing compaction pressure. As a comparison, see the diagram at figure 3. It shows density versus pressure curves for two commercial iron powders (NC100.24 and ASC100.29).

![Figure 3](image2.png)

**Figure 3.** Density Vs pressure curves for two commercial iron powders [12]

The magnetic characteristic of barium ferrite at table 1. Show that magnetic properties remanence induction and product energy maximum increased with increasing compaction pressure, but the coercivity value relatively stable or slightly decreased. Remanence Induction (Br) value at a pressure of 1 tons.cm\(^{-2}\) is 1.85 kG, relatively stable at increased to a pressure of 2 tons.cm\(^{-2}\) and began to increase at a pressure 3 tons.cm\(^{-2}\) is 1.92 kG. The Br value was continued to increase until the at pressure 6 tons.cm\(^{-2}\). The BHmax value increased from 0.62 MGOe to 0.74 MGOe at pressure 6 tons.cm\(^{-2}\), while the value of coercivity stable and slightly decreased in ranges 2.149 – 2.224 kOe.
Tabel 1. Magnetic properties of barium ferrite at varying compaction pressure

| Magnetic Properties | 1 (tons.cm²) | 2 (tons.cm²) | 3 (tons.cm²) | 4 (tons.cm²) | 5 (tons.cm²) | 6 (tons.cm²) |
|---------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Br (kG)             | 1.85        | 1.84        | 1.92        | 1.97        | 2.02        | 2.03        |
| HcJ (kOe)           | 2.224       | 2.231       | 2.203       | 2.166       | 2.149       | 2.156       |
| BH max (MGOe)       | 0.62        | 0.65        | 0.68        | 0.72        | 0.75        | 0.74        |

The hysteresis curve of samples as measured using the Permagraph can be seen on figure 4.

Figure 4. Magnetic characteristic of barium ferrite curves at compaction pressure 1 – 6 tons.cm²
Density greatly affect the magnetic properties because of the density related to the porosity. The higher the density, porosity will decrease. Porosity is a microstructure that is very important in a magnetic material, as it can affect the process of shifting the domain walls during magnetization that would affect to magnetic properties. Magnetization process that prevented the pores can be seen in figure 5. Magnetization process would be better if there are no pores.

![Magnetization process](image)

Figure 5. Magnetization process that prevented the pores on magnetic materials [13]

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting [14]. The principal purpose of the hardness test is to determine the suitability of a material, or the particular treatment to which the material has been subjected [15]. The hardness test result of samples using Rockwell method can be seen in Table 2.

| Compaction pressure (tons/cm²) | 1   | 2   | 3   | 4   | 5   | 6   |
|-------------------------------|-----|-----|-----|-----|-----|-----|
| Hardness (HRc)                | -   | -   | -   | -   | -   | 42.5|

Samples with a pressure of 1-5 could not be tested and broken, only sample was successfully tested at a pressure 6 tons.cm² with value 42.5 HRc. This is due to samples with a pressure of less than 6 tons.cm² were still very fragile and rupture. The pressure at 1-5 tons.cm² was not enough to form a solid and compact sample. Varying pressure is only performed until a pressure 6 tons.cm² because the sample was pressed at a pressure 7 tons.cm² have cracked before sintering.

4. Conclusions
The preparation of barium hexaferrite with influence of varying compaction pressure by powder metallurgy process on has been done. The density increased with increasing compaction pressure. The greatest density was obtained at the compaction process 6 tons.cm² was about 4.650 g.cm³. Magnetic properties remanence induction and product energy maximum increased with increasing compaction pressure, but the coercivity value relatively stable or slightly decreased. Remanence Induction (Br) value at a pressure of 1 tons.cm² is 1.85 kG, relatively stable at increased to a pressure of 2 tons.cm².
and began to increase at a pressure 3 tons.cm$^{-2}$ is 1.92 kG. The Br value was continued to increase until the at pressure 6 tons.cm$^{-2}$. The BHmax value increased from 0.62 MGOe to 0.74 MGOe at pressure 6 tons.cm$^{-2}$, while the value of coercivity stable and slightly decreased in ranges 2.149 – 2.224 kOe. Hardness test of samples with pressure 1-5 tons.cm$^{-2}$ could not be tested because broken. The samples can be tested at a compaction pressure 6 tons.cm$^{-2}$ with value 42.5 HRc. Based on these data, the compacting pressure can affect the magnetic characteristics, density, and hardness of the barium hexaferrite.

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