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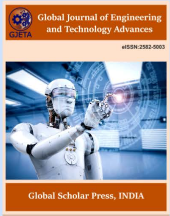

(Research Article)

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Study of mechanical and magnetic properties of magnet composite hybrid Fe3O4-NdFeB with matrix polyvinyl alcohol

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Abstract

In the present study material composite magnetite were synthesized by polyvinyl alcohol (PVA) matrix and filler hybrid Fe3O4-NdFeB, for enhancing mechanical and magnetic properties. Fe3O4 is obtained from the iron sands of East Lombok. The filler hybrid has gained its importance due to its low cost, substitute for pure BaFe. It's possible to use it as a interest for many applications, especially as theragnostic agents for magnetic hyperthermia, drug delivery, and magnetic resonance imaging. This study aims to investigate the compressive strength, remanent magnetization value (Mr), coercivity (Hc) and maximum energy product value (BH) max. The composition of filler hybrid Fe3O4-NdFeB was varied at 10%: 50%, 20%: 40%, 30%:30%, and 40%: 20 % from a total mass (wt) of 5 grams. In addition, matrix PVA 40% wt. The test specimens produced the vacum infussion method. The results of this study indicate that the addition of Fe3O4 composition causes a decrease in mechanical properties (density, compressive strength), on the other hand, the addition of Fe3O4 causes an increase in the magnetic properties (Magnetic remanence (Mr), coersivity (Hc), maximum energy product (BH)) of the Fe3O4 - NdFeB hybrid magnetic composite material, with PVA binding matrices.

Keywords: Material Composite Magnet; Filler Hybrid Fe3O4-NdFeB; PVA Matrix; Mechanical; Magnetic Properties

1. Introduction

The island of Lombok, Indonesia has natural resources in the form of iron sand which is very potential. Iron sand is a raw material for the manufacture of ferrite-based permanent magnets with various applications (1) . The high use of permanent magnets in Indonesia, especially in the electronics and automotive industries, has made Indonesia the second largest permanent magnet market in the world. As for meeting these needs, 100% of the permanent magnets on the market are imported from Japan and China. In fact, Indonesia has the potential to produce its own without having to import, because the availability of raw materials for permanent magnets is very abundant in the country, especially iron sand (2).

Macroscopically, magnetization is the response of a magnetic material to an external magnetic field (3), while microscopically, magnetization comes from the spin magnetic moment resulting from the spin motion of the material (4). Therefore, when viewed microscopically, the magnetic properties of a material depend on its magnetic moment (5). This is stated in the Langevin equation about the effect of the magnetic moment (M) on magnetization (6) which is written in equation 1.

$$M = M_s(\cot\left(\frac{\mu.H}{kB.T}\right) - \left(\frac{kB.T}{\mu.H}\right) \dots\dots(1)$$

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Ms, kB, H, T, and respectively represent magnetic saturation, Boltzman constant, external magnetic field and absolute temperature, as well as the magnetic moment of each particle, with the value of the magnetic moment.

Iron sand is the main ingredient in the manufacture of ferrite-based permanent magnets. The type of ferrite magnet that is commonly used is barium ferrite (BaFe) because it has strong mechanical properties and is not easily corroded (7). However, ferrite magnets have a weakness, namely low magnetic properties. The magnetic remanence (Mr) of these magnets is only 1/3 of that of rare earth magnets (NdFeB).

Therefore, in this study, a hybrid between Fe3O4 (Ferric Oxide) and NdFeB (Neodyum Iron Boron) was carried out to improve the mechanical and magnetic properties of magnetic composite materials. To simplify the manufacturing process to make it easier, the method used is bonded magnet with the addition of a polyvinyl alcohol (PVA) matrix / binder. The average temperature for dissolving the matrix is less than 25 ^{0}C. In addition, the PVA matrix has good durability and chemical resistance (8). In this research, Fe3O4 and NdFeB were varied at a certain composition, so that a trend was obtained from the mechanical and magnetic properties of the hybrid magnetic composite material being studied. The testing of the mechanical properties of magnets includes observation of particle distribution images, density measurements, and compressive strength. The magnetic testing was carried out using a permagraph to determine the value of the magnetic parameters which included remanence (Mr), coercivity (Hc) and maximum energy product (BHmax). Furthermore, it will be studied and analyzed the resulting mechanical and magnetic properties trends as a function of Fe3O4 variations.

Thus, it should be noted that there is no data found in the literature that would explain the possibility of using Fe3O4 from iron sands in Lombok Island as a magnetic composite filler, so that the mechanical and magnetic properties are better, for industrial use. This study aims to determine the mechanical and magnetic properties of the Fe3O4 - NdFeB hybrid magnetic composite with PVA matrix which is very much needed by the industry, as an alternative solution to the more expensive rare earth magnetic composite material.

2. Material and methods

2.1. Materials

The material used in this research is Fe3O4, NdFeB which is made into a powder with a size of 250 mesh, shawn in Figure 1. The binder matrix is PVA (polyvinyl alcohol). PVA is a hydrophilic biodegradable polymer that has good film-forming properties, is soluble in water, easy to process, non-toxic, and biocompatible. The research supporting equipment used includes a glass beaker, magnetic stirrer, rotary ball mill, spatula, stainless steel mold, solenoid press, technical scales, Permagraph Magnet Physik Germany and compressive strength test equipment.

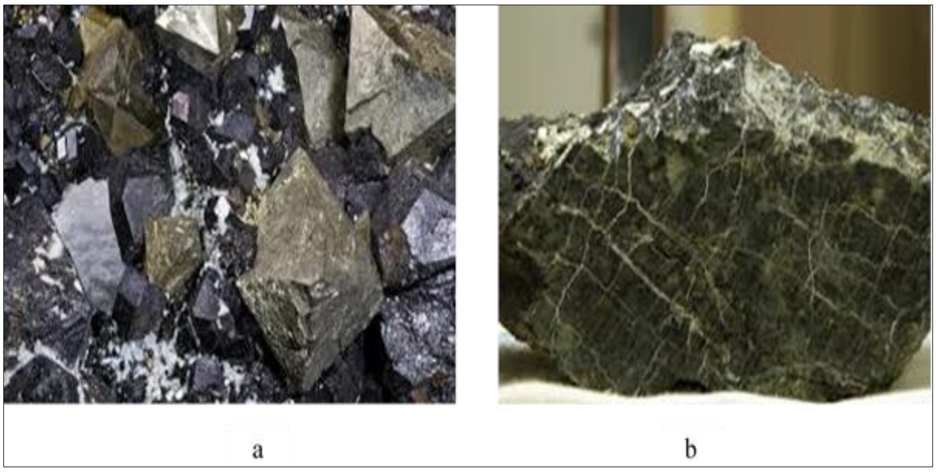

Figure 1 a. Ferric Oxide (Fe3O4). b. Neodyum Iron Boron (NdFeB)

2.2. Methods

The magnetic composite synthesis process is carried out as shown in the flow chart in Figure 2. Magnetic materials of Fe3O4 and NdFeB (filler composite) with a mass of 50 grams were pulverized using a rotary ball mill for 60 minutes, using a ratio of large balls to small balls is 1:4.

The dissolution was carried out by mixing the magnetic material with 60% toluene (6 mL). The addition of toluene can reduce the oxidation of Fe3O4 and NdFeB due to particle friction with steel balls and ball mill walls.

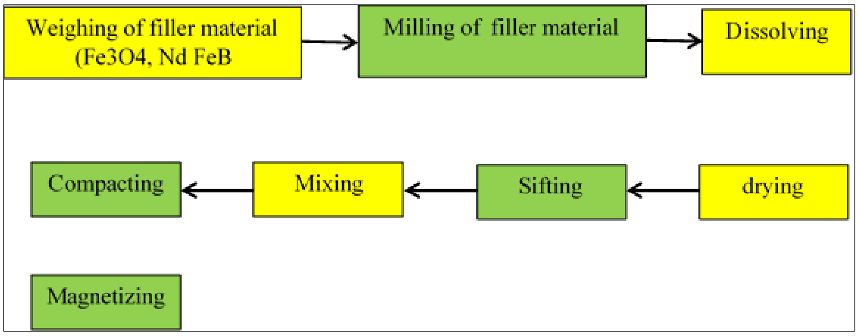

Figure 2 Flow chart of magnet composite synthesis process

Fe3O4 and NdFeB powder which has been pulverized then dried and sieved using a technical sieve, to obtain a grain size of 250 mesh. After obtaining the particles of that size, then a hybrid magnetic composite was made with variations in the mass ratio of Fe3O4: NdFeB 10%: 50%, 20%: 40%, 30%:30%, and 40%: 20% from a total mass (wt) of 5 grams.

The synthesized magnet is a bonded-based magnet so that in each variation it is mixed with 40% PVA matrix (40% = 40 gram/100mL water). The mixing process uses the wet mixing method, namely by mixing variations of magnetic material with 40% PVA which has been dissolved in 10 mL of distilled water. While stirring using a spatula, the mixture was heated at a temperature of 20 C for 10 minutes until the mixture dries. After drying, it was then molded using a stainless steel magnetic mold with an inner diameter of 12.1 mm and pressed using a solenoid press at a pressure of 120 kg/cm^2, held for 15 seconds. . The printed magnet samples were then allowed to stand for 24 hours for the age hardening process so that the magnets produced were harder and bonded well.

3. Results and discussion

3.1. The mechanical and magnetic properties of magnet composite hybrid Fe3O4-NdFeB with matrix PVA

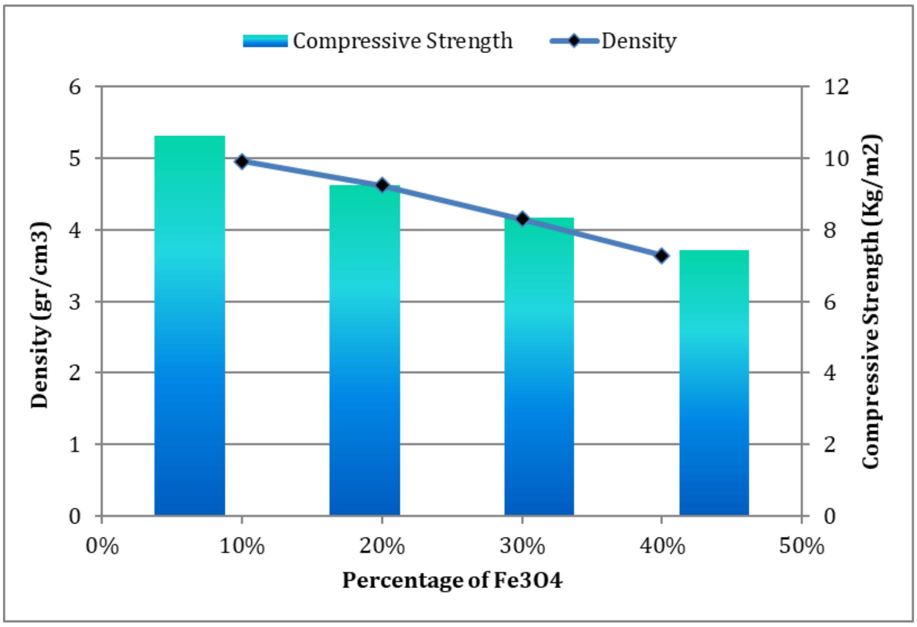

Figure 3 Mechanical properties of magnet composite hybrid Fe3O4-NdFeB with matrix PVA

The mechanical properties tested were density and compressive strength. The density of all samples was measured to determine the density trend resulting from the Fe3O4-NdFeB hybrid as a function of variations in the composition of Fe3O4. The density measurement method is carried out by weighing the mass of the sample and measuring the dimensions of the sample, then calculating and obtaining the sample volume, then the density value can be calculated based on the ratio of the mass and volume of the sample. The compression test was carried out according to the ASTM D 695-96 standard on magnetic composite specimens, using the CBR Tester TI04 compression tester with a load capacity of 50 KN. The results of the density and compressive strength tests are shown in Figure 3.

Based on Figure 3. The results of density and compressive strength testing are influenced by variations in the addition of Fe3O4. Sample variation shows that the addition of Fe3O4 composition in the sample is inversely proportional to the density and compressive strength of the specimen. From the results of the compressive test, the compressive strength of the specimens was obtained by, arrangements variations of percentage of Fe3O4 as shown in Figure 2. The density of the magnet composite, with the percentage addition of Fe3O4, 10%, 20%, 30% and 40%, respectively, was 4.96; 4.62; 4.15; 3.64 gr/m^3, while the compressive strength is as follows: 10.62; 9.26; 8.34; 7.42 Kg/m^2. The decrease in the density of the magnet composite is due to the fact that the density of Fe3O4 is smaller than the density of NdFeB. The density of Fe3O4 is 5.272 gr/cm3 the density of NdFeB is 7.58 gr/cm3. The decrease in density causes the compressive strength of the specimen to decrease as well. Because the filler in the composite acts as a reinforcement, it can withstand compressive loads. When compared to the results of the research by (9) showed the same pattern of change with a range of values around 1.8 – 2.95, so that compared to the results obtained in this study, the difference was not significant (10).

Magnetic properties testing was carried out using a Permagraph Magnet Physik Germany, at BRIN LIPI Bandung. Characterization of magnetic properties (Magnetic remanence (Mr), coersivity (Hc), maximum energy product (BH)) of magnetic composite material obtained from the permagraph as shown in Figure 4.

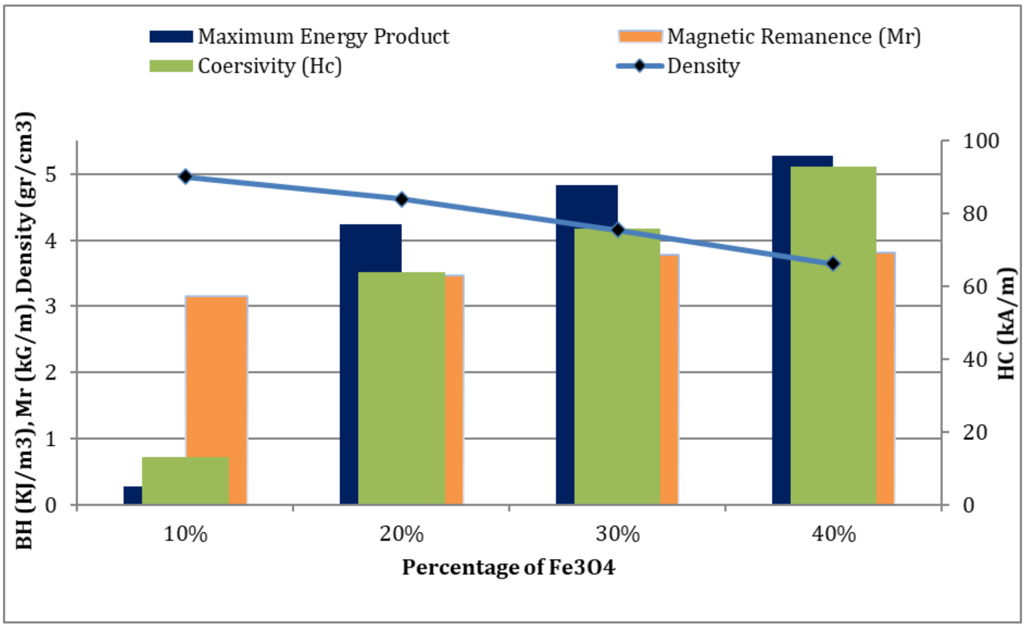

Figure 4 Magnetic properties of magnetite composite hybrid Fe3O4-NdFeB with matrix PVA

Figure 4. Shows the Magnetic properties of magnetite composite hybrid Fe3O4-NdFeB with matrix PVA. It is seen that the magnetic properties of specimen influenced by the addition of Fe3O4 filler. As the percentage of Fe3O4, the magnetic properties of the specimens also increased. This phenomenon shows that Fe3O4 is magnetic. Magnetic properties of a material are indicated by its magnetic parameters, namely magnetic strength which is represented by magnetic remanence and permanent which is represented by coercivity and maximum energy product (9). These parameters are contained in the hysteresis curve which is a continuation of the magnetization curve. The magnetic remanence (Mr) of the specimens increased, namely 3.16, 3.46, 3.78, and 3.82 kG/m, respectively for the addition of 10, 20, 30, and 40% Fe3O4 respectively. Likewise for the price of coersivity (Hc), the maximum energy product (BH) also increased, namely 13, 64, 76, and 93 kA/m for Hc, 0.27, 4.24, 4.83, and 5.28 kJ. /m3 for bra.The addition of Fe3O4 filler to the composite specimen of the Fe3O4-NdFeB hybrid filler magnet, with PVA matrix tends to increase the three parameters of the magnetic properties of the specimen. The increase in the three parameters of the magnetic properties of the specimen was caused by the increase in the magnetic moment due to the addition of Fe3O4. Microscopically, the magnetization comes from the spin magnetic moment resulting from the spin motion of the material (11). Therefore, when viewed microscopically, the magnetic properties of a material depend on its magnetic moment (12) .

3.2. The Microstructure of material magnet composite

The observation of the microstructure aims to determine the image distribution of Fe3O4-NdFeB hybrid filler particles in the PVA matrix on the specimen surface. Based on the observation of the microstructure with a USB digital Cooling Tech Microscope with a magnification range of 500 times, as shown in Figure 5. In the photo of the microstructure, it is clearly seen that the PVA-binding matrix particles under digital microscope observation with a scale of 500 times are indicated by a white particulate image, a solid black color indicates a surface cavity (Void) and the color between the two is a filler material for the Fe3O4 - NdFeB magnetic composite. The increasing variation of the addition of Fe3O4 magnetic composite filler (10% - 40%), causes the surface voids (voids) to decrease, as shown in Figures 5a - 5d. The black color in Figure 5a is more dominant when compared to Figures 5b, 5c and 5d. On the other hand, the color between them (white and black guides) increased, indicating that the hybrid filler was evenly distributed in the PVA matrix on the specimen surface. As a result, the magnetic properties of the specimen (10) are increased. The decrease in density is due to the density of Fe3O4 being smaller than the density of NdFeB. Likewise, the decrease in compressive strength was caused by the addition of the percentage of Fe3O4 filler, at a constant matrix condition of 40%. Because the matrix serves as a support and successor to the magnetic composite material.

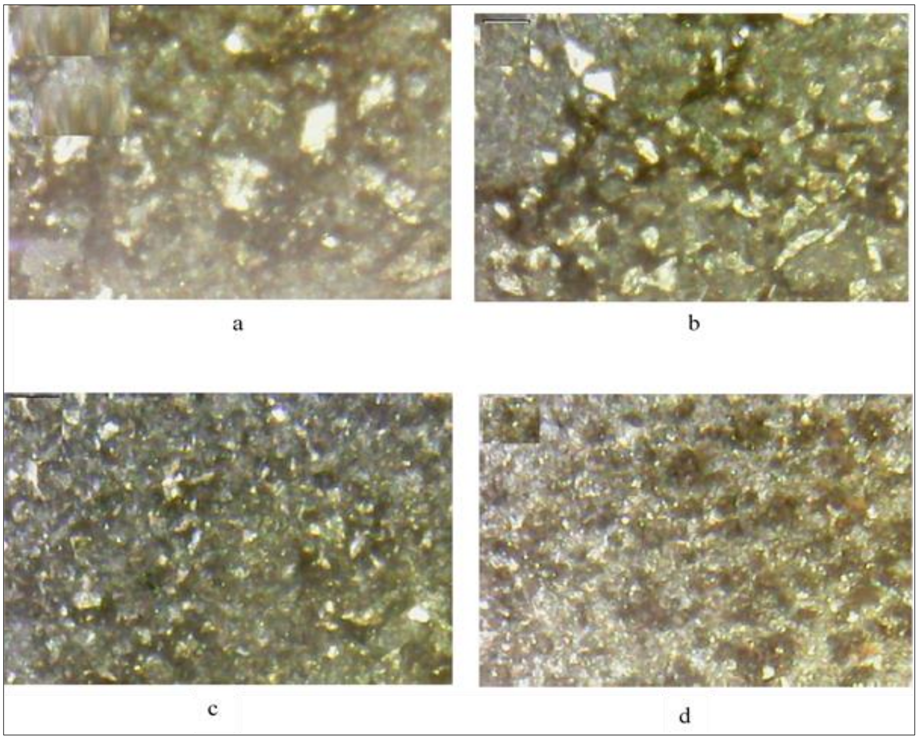

Figure 5 The Microstructure of magnet composite (a) 10% Fe3O4, (b). 20% Fe3O4, (c) 30% Fe3O4, (d) 40% Fe3O4

The addition of 10% Fe3O4 magnetic composite filler, Figure 5a shows the presence of a more dominant PVA matrix compared to the addition of 20%, 30% and 40% Fe3O4. As a result, the compressive strength value for the specimen in Figure 5a is the highest, 10.62 Kg/m^2 and for the specimen in Figure 5d, the value for the compressive strength is the lowest, 7.42 $Kg/m^{2.}$

4. Conclusion

The addition of Fe3O4 causes a decrease in mechanical properties (density, compressive strength), on the other hand, the addition of Fe3O4 causes an increase in the magnetic properties (Magnetic remanence (Mr), coersivity (Hc), maximum energy product (BH)) of the Fe3O4 - NdFeB hybrid magnetic composite material, with PVA binding matrices. The decrease in density is caused by the density of Fe3O4 compared to the density of NdFeB. The addition of Fe3O4 filler to the magnetic composite with a constant matrix condition causes a decrease in compressive strength. On the other hand, the addition of Fe3O4 filler causes an increase in the magnetic moment, so that the magnetic properties of the specimen increase.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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