Preparation and characterization of epoxy resin bonded magnet prepared by using jet milled NdFeB

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Abstract. The preparation of bonded magnets is done by mixing the magnetic powder of NdFeB product jet mill with a non-magnetic binder (epoxy resin). Comparison of variation of NdFeB magnetic powder composition with a binder (%wt) 97:3, 95:5, 92:8 of total mass 5 grams. After mixing the powder, then compacted with a hydraulic press, using a 1.8 cm diameter mold with a force of 5 tons, with a compaction time of 5 minutes. The pellet samples were characterized by physical and magnetic properties. Characterization of physical properties includes measurement of density, mechanical properties and corrosion resistance. Characterization of magnetic properties includes measurements of magnetic field strength and magnetic properties characteristics. Measurement of magnetic field strength using Gaussmeter and measurement of characteristic magnetic properties using VSM (Vibrating Sample Magnetometer). The results showed that the optimum physical properties density is the sample with the addition of 3 %wt epoxy resin (density of 5.285 g/cm³) and optimum physical properties compressive strength is the sample with the addition of 8 %wt epoxy resin (compressive strength 10 kgF/cm²) and optimum physical resistance corrosion is the sample with the addition of 3 %wt epoxy resin (with mass change 5.48 gram with time immersion 504 hours). And for the optimum magnetic properties obtained in the test sample with the addition of an epoxy resin binder composition of 3 %wt (magnetic field strength 1029.02 Gauss, remanence 62.21 emu/gram, coercivity 9457 Oe and saturation 101 emu/gram).

1. Introduction
Magnets are defined as matter that has a field. This field is called a magnetic field [1]. The types of permanent magnets are divided into traditional magnets (steel magnets, AlNiCo magnets, Ferrite magnets) and modern magnets (SmCo magnets and rare earth metal magnet). Because the price is relatively affordable compared to SmCo magnets, the earth metal magnets are rarely used today [2]. NdFeB based permanent magnets with excellent magnetic properties are usually fabricated by sintering or bonding methods [3]. NdFeB have magnetic remanence higher than 1 T, coercivity above 1000 kA/m, and Bhmax larger than 200 kJ/m³ [4]. In this material used is rare earth metal magnetic powder of NdFeB with type MQP-B+ results jet mill. In this research discusses the preparation and characterization of NdFeB rare earth metal permanent magnets combined with binders. It is hoped that after doing this research more information will be obtained about the rare earth metal magnet NdFeB for development in the magnetic field.

2. Experiment
The material used in this research is NdFeB powder type MQP-B+ results jet mill. This powder functions as a raw material used to make magnet bonded. The binder used is epoxy resin. The stages of preparation of raw materials that is NdFeB powder type MQP-B+ results of jet mill and epoxy resin binder with ratio of 97:3, 95:5, 92:8 (%wt) and a total mass of 5 gram of test sample. The two ingredients are then mixed through the mixing process using a measuring cup. The making of the test sample with the technique of compression (dry compression molding). NdFeB powder type MQP-B+ result of jet mill that have been mixed with a binder are put into a mold and then compacted with a hydraulic press with a pressure 5 tons with time of 5 minutes. The drying process of the NdFeB bonded with a temperature of 80 °C and holding it for 1 hour. The dried samples were then magnetized using Magnet-Physic Dr. Steingroever GmbH Impulse Magnetizer K-Series. The sample was given a shock voltage of 1.8 kV and with an average current of 6 kA. For the characterization of the sample physical properties were tested, that is density, compressive strength, and sample morphology. Testing morphology used Scanning Electron Microscope (SEM). Magnetic properties testing included magnetic field strength using gaussmeter and magnetic properties using a Vibrating Sample Magnetometer (VSM). Corrosion resistance testing using water media with room temperature.

3. Results and discussions

3.1. Density
The first physical test is density. This test for all samples with different binder compositions. Density measurement uses the equation Archimedes [5]. The results of the density measurement are shown in Figure 1.

![Figure 1](image)

**Figure 1.** Graph of the relationship between variations in composition and density.

Based on Figure 1 it is known that the more addition of epoxy resin binder composition, the smaller the density value of the test sample. This happened because of the influence of mixing the binder on the NdFeB bonded magnet material. The initial density of each ingredient is (the density of magnetic powder NdFeB = 7.63 gram/cm$^3$, density of epoxy resin = 1.18 gram/cm$^3$ [6]). Binder density that is too small with a lot of composition in bonded magnets causes the density of the bonded magnet to decrease. So that the results of the density of the test sample with the greatest density is obtained in the test sample by adding a binder composition of 3% of the total mass. The density of the sample is 5.285 gram/cm$^3$.

3.2. Compressive Strength
Next the testing physical properties is compressive strength. This test is for all samples with different binder compositions. The results of the compressive strength measurement are shown in Figure 2.
Based on Figure 2, it is known that the more addition of epoxy resin binder composition, the greater the compressive strength value. This shows that the greater the addition of epoxy resin binder composition, the better the ability of the test sample to maintain themselves. This happens because the function of the binder itself is as a binding. So that the more binders the more hardened the test sample will be. In addition, this also happens because the compaction process between the binder and the magnetic powder interacts well.

### 3.3. Magnetic Field Strength

Testing of magnetic properties for know magnetic properties of the sample. This test is for all samples with different binder compositions. Measurements were made using a Gaussmeter. The results of measurements of magnetic field strength are shown in Figure 3.

Based on Figure 3 it is known that the more addition of e binder composition, the smaller the magnetic field strength of the sample. This happens because the nature of the binder itself is non-magnetic. So that when the composition of the binder composition increases, the magnetic field strength of the sample decreases (decreases) [7].
3.4. Characteristics of The Magnetic Properties

Testing the characteristics of magnetic properties for know the characteristics of the magnetic properties of the sample. This test is used sample by adding a binder composition of 3%. Table 1 shows the measurement results with VSM.

| Sample                  | Saturation (emu/gram) | Remanence (emu/gram) | Coercivity (Oe) |
|-------------------------|-----------------------|----------------------|-----------------|
| Sample with binder 3%   | 101                   | 62.21                | 9457            |

The hysteresis curve of the measurement results with VSM is shown in Figure 4.

![Hysteresis Curve](image)

**Figure 4. Hysteresis Curve**

From Table 1 and Figure 4 above can be seen the basic properties of magnetism of a material. This can be observed one by one. The first magnetic property is saturation. Saturation is the high point of the sample magnetism. The second magnetic property is remanence. Remanence is the residual magnetism of the sample after being given a magnetic field from the outside. This shows the ability of the test sample to maintain the magnetic field from the outside being removed. The third magnetic characteristic is coercivity. Coercivity is the magnetic intensity that must be applied to reduce the magnetization of the material to zero after magnetization of the test sample is pushed to the point of saturation. Coercivity is used to distinguish hard magnets and soft magnets. The greater the coercivity value, the sample tends to have hard magnetic or hard magnetic properties.

3.5. Corrosion Resistance

Corrosion resistance testing is a characterization related to the physical properties of the test sample. In this test the test sample measured its corrosion resistance by immersing the test sample in water with a temperature according to room temperature of 29 °C. Testing is done by looking at changes in mass from the test sample. Figure 5 shows the results of corrosion test curves.
Corrosion is a process of material degradation and loss of quality of a material due to the influence of chemical reactions in an electrochemical process with a corrosive environment [8]. From the graph above it can be seen that the test sample with the addition of an epoxy resin binder experienced a change in mass during this test. The mass of the sample increases with increasing immersion time. This increase in mass is one indicator of the corrosion test sample. This corrosion process occurs because the NdFeB bonded magnet test sample interacts with water (H₂O). Because of this interaction, the binder in the sample has decreased function and the addition of elements in the sample so that the sample mass increases from the initial mass and over time the sample will experience damage. So that at the time of testing if the sample is deformed, the test is stopped. In addition, testing can also be stopped when the magnetic field strength of the test sample has decreased far enough.

3.6. Morphology Sample

The next test is testing using SEM. The samples tested using SEM were samples with the addition of a 3% binder composition. The following are the results of shooting using SEM:

Based on microstructure analysis with magnification of 2.00 k x SE (SE = Secondary Electron) in the picture above can be seen that the grain size is not homogeneous. Based on SEM photos above NdFeB powders have grain sizes ranging from 0.456 μm to 14.327 μm. It appears that the grain looks...
enveloped. This can be observed in the presence of a more concentrated powder color that is seen enveloping the grain. The grain are NdFeB powders while the powder that covers the epoxy resin binder. Or it can be observed that the NdFeB particle is shown in gray and the binder is shown in dark gray. After knowing the material in the sample, then it is necessary to analyze the composition of the NdFeB grain and the binder using EDX. In Figure 7 shows spot epoxy resin. In Figure 8 shows spot grain NdFeB.

![Figure 7. Spot Binder (Epoxy)](image1)

![Figure 8. Spot Grain NdFeB](image2)

Here is a table of element distribution in NdFeB bonded magnet samples:

**Table 2. Elements distribution table in bonded Magnet NdFeB**

| Element | Weight (%) | Atomic (%) |
|---------|------------|------------|
| C K     | 10.59      | 34.67      |
| O K     | 6.94       | 17.06      |
| Fe K    | 55.71      | 39.22      |
| Co K    | 4.41       | 2.94       |
| Zn K    | 0.03       | 0.02       |
| Nd L    | 22.32      | 6.08       |
| Totals  | 100.00     |            |

Table 2 shows that NdFeB bonded magnets with epoxy resin binders contain elements, C, O, Fe, Co, Zn, and Nd. The Boron element is not identified because EDX can only detect elements that have a larger atomic number and photon energy than the boron element. Low photon energy is difficult to detect by EDX detectors.

4. Conclusions

The results showed that the optimum physical properties density is the sample with the addition of 3 %wt epoxy resin (density of 5.285 g/cm³) and optimum physical properties compressive strength is the sample with the addition of 8 %wt epoxy resin (compressive strength 10 kgF/cm²) and optimum physical resistance corrosion is the sample with the addition of 3 %wt epoxy resin (with mass change 5.48 gram with time immersion 504 hours). And for the optimum magnetic properties obtained in the test sample with the addition of an epoxy resin binder composition of 3 %wt (magnetic field strength 1029.02 Gauss, remanence 62.21 emu/gram, coercivity 9457 Oe and saturation 101 emu/gram).

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