The epoxy resin variation effect on microstructure and physical properties to improve bonded NdFeB flux magnetic density

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Abstract. NdFeB magnets have been fabricated from a mixture of powder NdFeB (MPQ-B+) and epoxy resins (ER) with a variation of 0% wt, 2% wt, 4% wt and 6% wt. The pellets samples were made by pressing 4 tons of the mixture powder at room temperature before curing at 100°C for 1 hour. The SEM-EDX results showed the microstructure with ER were evenly smeared the NdFeB magnetic particles due to higher percent C and lower transition metals value. Sample with 2% wt epoxy resin was able to achieve the highest density of 5.35 g/cm³ and the highest magnetic flux of 2121 Gauss. The magnetic properties characterization using the permagraph indicates that the sample pellets with 2% wt epoxy resin has a value of remanence (Br) = 4.92 kG, coercivity (Hc) = 7.76 kOe, and energy product (Bhmax) = 4.58 MGOe. Despite low remanence value in the pellet samples, the resistance to demagnetization value was still acceptable.

Keywords. Bonded Isotropic NdFeB Magnet, Epoxy Resin, Structure, Magnetic Properties

1. Introduction

Permanent magnet is a very strategic material to be developed in the future. At present, polymer-bonded magnets with different specifications are used in various applications to convert electrical energy to mechanical energy or vice versa. Three important specifications which describe permanent magnet performance are the remanence (Br), intrinsic coercivity (Hci), and maximum energy product (BHmax) [1]. However, the absence of local manufacturers of permanent magnets in the country causing dependency on imported products which mainly come from Japan and China–Tiongkok. Therefore, we need an intensive research to develop a permanent magnet and encourage the growth of local industry. Nonetheless, Indonesian researchers had done research on the manufacture of bonded NdFeB permanent magnets [2, 3,4,5]. However, there are still opportunities to improve the processing technology of the bonded NdFeB magnetic performance. In the present work, the research main topic is to analyze the effect of ER %wt variations on their microstructure and physical properties of a certain particle size bonded NdFeB by using flux magnetic density test and permagraphic characterization. Changes in microstructure and physical properties is caused by ER %wt variations on improve bonded NdFeB flux magnetic density.
2. Experimental

Materials used in this study are magnetic powder with a brand name MQP-B+ (100 mesh), epoxy resin (ER), and hardener. The samples were made by varying the ER %wt; 0 %wt (sample1), 2 %wt (sample2), 4 %wt (sample3), 6 %wt (sample4). The magnetic powder was manually mixed with liquefied epoxy resin for at least 5 min before adding the hardener to achieve a homogeneous mixture. The mixture was molded in a cylindrical cast with a diameter of 12 mm by using hot press method of 4 tonne pressure at 30°C. The sample characteristics were determined from the bulk density, microstructure, and magnetic properties (flux magnetic density and magnetic hysteresis loop). The microstructure of the sample was analyzed using the Scanning Electron Microscope SEM (Secondary electron SE; backscattered electron BSE; energy dispersive X-ray EDX and mapping). Typical remanence (Br) intrinsic coercivity (Hc), and maximum energy product (BHmax) of the samples were obtained from magnetic hysteresis loop derived by permagraph test.

3. Results and Discussion

3.1 The Effect of %wt epoxy resin (ER) to carbon content of compacted bonded Nd$_2$Fe$_{14}$B

The microstructural profiles of compacted 100 mesh bonded Nd$_2$Fe$_{14}$B was observed using SEM-SE (Secondary Electrons) as shown in Figure 1.

![Figure 1. SEM SE figure (a) sample 1, (b) sample 2, (c) sample 3, (d) sample 4](image-url)
The carbon C content of the samples was determined by using EDX analysis to relate the C content from ER %wt (0 %wt, 2 %wt, 4 %wt, 6 %wt) on the bonded Nd$_2$Fe$_{14}$B particles. The bonded Nd$_2$Fe$_{14}$B particles have been smeared with resin evenly. The compacted powder NdFeB of all sample (fig.1a to 1d) is homogeneous and dense as the pores between the powders is tight. Meanwhile, the epoxy resin material fill in the space between powders in the second sample based on the SEM-SE microstructural characterization. Higher the epoxy resin percentage resulting in greater epoxy resin material filled the space between powders causing the powders more compact from each other. Based on the analysis, the atomic percentage of the carbon (C) element contained increases as the ER %wt increases, i.e: 23.0 %at C (sample 1/fig.1a); 33.1 %at C (sample2/fig.1b); 41.9 %at C (sample 3/fig.1c) and 69.7 %at C (sample 4/fig.1d). The C content in sample 1 is derived from a polymer material that cover the material Nd$_2$Fe$_{14}$B. However, the addition of C content is related to the increase of epoxy resin content. From the experiment it was found that the atomic percentage of the carbon element content will likely to increase as the epoxy resin %wt increase.

3.2 The Effect of %wt ER to Nd, Pr, and Fe content of compacted bonded Nd$_2$Fe$_{14}$B

Figure 2 shows the relation and profiles of Nd, Pr, Fe content and ER %wt (0 %wt, 2 %wt, 4 %wt, 6 %wt) of compacted 100 mesh bonded Nd$_2$Fe$_{14}$B at 30°C temperature and 4 tonne real pressure.

![Figure 2. SEM BE figure (a) sample 1, (b) sample 2, (c) sample 3, (d) sample 4](image)

Their microstructural profile was observed using SEM BSE (Back-Scattered Electrons) while the metal Nd, Pr and Fe content was detected using EDX analysis. According to the SEM-BSE profile, the
Nd$_2$Fe$_{14}$B particle is quite compact after the compacting process. From the EDX experiment it was found that the atomic percentage of Nd, Pr, Fe element content will likely to decrease as the epoxy resin %wt increase. The results obtained from the EDX analysis shows the atomic percentage of Nd and Pr element decreases as the epoxy resin %wt increases, i.e: 7.6 %at (sample 1/fig. 2a); 6.2 %at (sample 2/fig. 2b); 5.6 %at (sample 3/fig.2c) and 1.6 %at (sample 4/fig.2d). The atomic percentage of Fe element also decreases as epoxy resin %wt increases, i.e: 66.3 %at (sample 1/fig.2a); 52.3 %at (sample2/fig.2b); 48.2 %at (sample 3/fig.2c) and 16.0 %at (sample 4/fig. 2d). From the experiment it was found that the atomic percentage of the sum of (Nd,Pr)Fe element content will likely to decrease as the epoxy resin %wt increase.

3.3 **SEM mapping patterns to detected Fe element distribution**

The previous observation results were strengthened with the pattern characterization results by using SEM mapping as shown in Figure 3. Darker pattern display of the SEM mapping shows less Fe contents on the sample surface as it has been tested on four compacted 100 mesh bonded Nd$_2$Fe$_{14}$B under different epoxy resin %wt (0 %wt/sample 1/fig.3a, 2 %wt/sample 2/fig. 3b, 4 %wt/sample 3/fig.3c dan 6 %wt/sample 4/fig. 3d) at 30°C temperature and 4 tonne real pressure.

![Figure 3. SEM mapping patterns. (a) sample 1, (b) sample 2, (c) sample 3, (d) sample 4](image-url)
From the experiment it was found that the atomic percentage of the Fe element content in the surface of sample will likely to decrease as the epoxy resin %wt increase.

3.4 The effect of ER %wt to bulk density and flux magnetic density of compacted bonded Nd$_2$Fe$_{14}$B

Figure 4 below show correlation between bulk density and epoxy resin %wt variations. Four compacted 100 mesh bonded Nd$_2$Fe$_{14}$B under different epoxy resin %wt (0 %wt, 2 %wt, 4 %wt and 6 %wt) at 30°C temperature and 4 tonne real pressure were plotted against the bulk density value, and the result shows that sample 2 (2 %wt ER) has the highest density which equal to 5.35%.

Figure 4. Relation of bulk density and ER %wt

Figure 5 shows the correlation between ER %wt and flux magnetic density (magnetization voltage was 1500V). The flux magnetic density value is remain constant. It was found that sample with 2 %wt ER (sample 2) has the slightly higher magnetic flux value of 1586 gauss from the magnetic flux density measurement using gauss meter.

3.5 The Effect of Magnesiatzation Votgage to Flux Magnetic Density and Permagraph Test of Compactd Bonded Nd$_2$Fe$_{14}$B 2 ER %wt

The magnetic hysteresis loop of permagraph test shows that the bonded NdFeB magnets with a mixture of epoxy resin is categorized as hard magnet by having 4.92 kG of remanence (Br) value in sample 2 and 4.94 kG in sample 3, 7.76 KOe of coercivity (Hcj) value in sample 2 and 7.34 KOe in sample 3, and 4.58 MGOe of maximum energy product (BHmax) in sample 2 and 4.95 MGOe in sample 3 (Table 1). The coercivity of sample 2 show the the highest result, although the remanence has the slightly lower than the value of sample 3. The coercivity value of the approached data sheet has value of 82.97% [7, 9, 10].

| Magnetic Properties | Sample 2 | Sample 3 |
|---------------------|----------|----------|
| Br (kG)             | 4.92     | 4.94     |
| Hcj (kOe)           | 7.76     | 7.34     |
| Bhmax (MGOe)        | 4.58     | 4.95     |
The relation between the magnetization voltage variation with flux magnetic is can be seen from sample 2 result where the magnetic flux increases as the applied voltage increases resulting in sample 2 pellets NdFeB, thus increase the magnetic properties performance. Sample with 2% wt epoxy resin was able to achieve the highest density of 5.35 g/cm$^3$ and the highest magnetic flux of 2121 Gauss (magnetization voltage was 1800V).

4. Conclusions
The effect of different epoxy resin %wt on microstructure and physical properties to improve bonded NdFeB magnetic flux density have been investigated in this research. It was found that the bulk density of the sample are 66-70% of the theoretical mass density (7.63 gr/cm$^3$). The bonded Nd$_2$Fe$_{14}$B magnet made with 2 %wt of epoxy resin has better magnetic performance compared to other epoxy resin variations. The magnetic properties characterization using the permagraph indicates that the sample pellets with 2% wt epoxy resin has a value of remanence (Br) = 4.92 kG, coercivity (Hc) = 7.76 kOe, and energy product (Bhmax) = 4.58 MGOe. Despite low remanence value in the pellet samples, the resistance to demagnetization value was still acceptable.

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