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Analysis of the Physical, Mechanical, and Magnetic Properties of Hard Magnetic Composite Materials NdFeB Made Using Bakelite Polymers

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Composite hard magnet NdFeB materials were made using powdered rapidly quenched Nd-Fe-B (MQP-B) and polymers (bakelite). The proportion of the polymer matrix was varied (2.0, 5.0, 7.0, and 10 wt.%). The composite hard magnet NdFeB materials were compacted using one-sided uniaxial hot pressing at 160 °C for 20 min. The bulk density of the composite hard magnet NdFeB was measured using the Archimedes method. Compression tests were carried out using the Universal Testing Machine. The results show that a permanent magnet composite with a 2 wt.% bakelite binder composition exhibits higher bulk density and superior magnetic parameters (i.e., remanence, coercivity, and energy product), but slightly lower compressive strength of approximately 845 kgf/cm^2.

Key words : composite magnet, polymer binder, hot pressing, remanence, coercivity

1. Introduction

Hard magnetic materials can be classified into two groups: conventional magnets such as steels, AlNiCo magnets, and ferrite magnets, and a modern magnetic group including Sm-Co magnets, Nd-Fe-B magnets, and others [1]. Research in the field of hard magnetic materials is still developing and is mainly focused on improving the magnetic, mechanical, physical, and chemical properties in order to broaden their applications [2]. Permanent magnets based on rare earth metals, such as Nd-Fe-B, are classified as hard magnetic materials that have a very high coercive force and energy product, but have a low temperature coefficient [2, 3]. In the field of hard magnetic materials, attention is generally directed at the structures of the intermetallic phases of rare earth metals such as Nd-Fe-B that show excellent hard magnetic properties [4]. Polymer composite materials with a magnetic filler have physical, magnetic, and thermal properties superior to those of polymers, are easy to process, and have a low production cost. If the polymer composite material is made using a hard magnetic filler such as NdFeB, then this material is called a composite hard magnet NdFeB. The properties of polymer composite hard magnet NdFeB depend on the matrix and filler characteristics as well as on their technological processing and environmental action [5]. The environmental condition is very important in the production process because NdFeB material is classified as being highly reactive with oxygen at room temperature [6]. The physical and mechanical properties of the composite hard magnet NdFeB depend mostly on the percentage of magnetic powder and polymer used as a binder and the processing technology employed [7]. The proportion of the polymer in the manufactured composite hard magnet NdFeB affects the magnet's mechanical and magnetic properties [6, 7]. The composite hard magnet NdFeB has many advantages: using it is a simple technology, its properties can be varied, and it has lower manufacturing costs because of its inexpensive finishing and ability to form as any shape [7, 8]. There are many types of polymer materials that are generally used for the manufacture of a composite hard magnet NdFeB, such as low- and high-density polyethylene, copolymers with polystyrene end blocks and a rubbery polyethylene-butylene mid block, natural rubber, silicone polymers, polyethylene glycol and styrene butadiene rubber, and pentaerythritol tetrapolyethylene glycol ether with four thiol-modified terminals. Because bakelite has

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been widely used for electrical components and automotive accessories, it can be used as an adhesive in the manufacturing of magnets. Bakelite is the synthetic plastic form of polyoxy benzyl methylen glycolanhydride. It is a thermosetting phenol formaldehyde resin. The molding temperature of bakelite is 160°–180 °C and it has a density value of approximately 1.4 g/cm^3 [9]. Many authors have conducted research on permanent magnet composites using polymers such as rubber, epoxy resin, nylon, and polyvinyl butiral [10, 11]. To date, much effort has been spent on improving the magnetic and mechanical properties of manufactured magnetic composite. The magnetic composites can be prepared using conventional techniques or new technological breakthroughs. Conventional techniques generally involve extrusion and compression, and the improvement of such techniques generally depends on the selection of the polymer type and increased loading of the magnetic particles [12]. Conversely, modern techniques are being developed by researchers, which include improvements such as the development of surface modification by adding surface agents, using selective laser melting methods, and using advanced 3D printing [12, 13]. The new technological breakthroughs have many advantages: they can produce permanent magnet components with no limitations on shape and dimension and can result in superior magnetic properties [13, 14]. The composite hard magnet NdFeB is used for small electric motors, generators, and hard-disk electromagnetic and radio-frequency interference shielding for electronic devices and electrostatic dissipation [15, 16]. In this paper, the results of an experimental study of the manufacture and characterization of composite hard magnets with a bakelite polymer matrix and Nd-Fe-B magnetic fillers are presented. The composite hard magnet NdFeB is analyzed and conclusions regarding the effect of the polymer and filler content on the physical, mechanical, and magnetic properties are presented.

2. Experiments

The materials of the composite hard magnet NdFeB were made using powdered rapidly quenched Nd-Fe-B (MQP-B) and bakelite polymers. The average particle diameter of the MQP-B-type NdFeB was 47.82 μm and that of the bakelite polymer was 26.64 μm. The amount of the polymer was varied to be 2.0, 5.0, 7.0, and 10 wt.% Both raw materials were weighed and mixed to obtain various compositions of the bakelite polymer using a pestle and mortar, and the total weight for each composition was 30 g. Then, the mixed powders were formed using an automatic hydraulic hot press machine (one-sided uniaxial hot pressing) at 160 °C for 20 min to obtain pellets with a diameter of 15 mm and a thickness of approximately 20 mm. The bulk density of the composite hard magnet NdFeB was measured using the Archimedes method with water as the liquid media. The bulk density was calculated using the following formula [17, 18]:

$$\text{Bulk density} = \frac{md}{md - mw} \times \rho l \quad (1)$$

where :

md = dry mass sample (g)
mw = sample mass hung in water (g)
ρl = water density at room temperature (g/cm^3)

The compression strength test was conducted using the Universal Testing Machine (UTM-18000-USA) at room temperature with a compression rate of 4 mm/min. The compressive strength was calculated as follows [19]:

$$\sigma = \frac{F}{A} \quad (2)$$

Where :

σ = compressive strength (kgf/cm^2)
F = force (kgf)
A = area of surface sample (cm^2)

An examination of the magnetic properties (hysteresis curve) of the composite materials was carried out at room temperature using the Permeagraph Physic Dr Steingroever GmbH, with a maximal external field of 2.5 T. The microstructure of the pellet sample was observed using the SEM-Hitachi SU-3500.

3. Results and Discussion

The bulk densities of the samples with varying bakelite polymer composition are presented in Fig. 1.

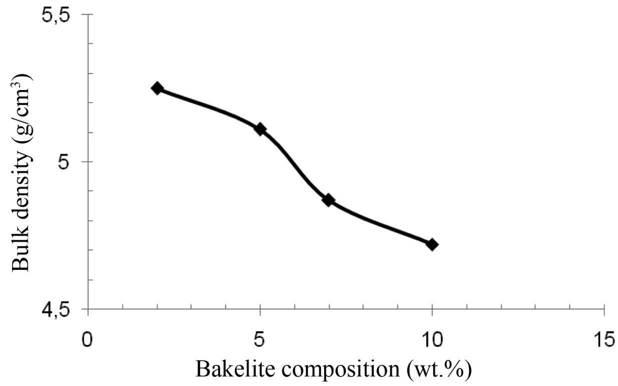


Fig. 1. The curves of bulk density as function of percentages of bakelite polymer binder.

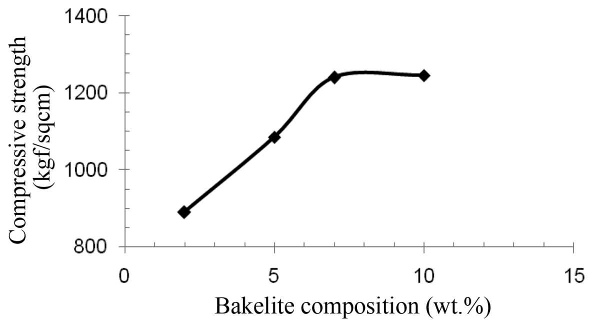


Fig. 2. Mechanical property curves as a function of the composition of polymer binder.

The results shown in Fig. 1 indicate that as the polymer binder composition increases, the bulk density tends to decrease. This is due to the difference in the density of the NdFeB particle (r = 6–7 g/cm^3) and bakelite (r = 1–2 g/cm^3), the bakelite density is much lower than that of NdFeB. If the bakelite composition increases or the NdFeB filler composition decreases, the density of the composite will decrease. Figure 2 shows the mechanical property curves of samples as a function of the composition of the polymer binder; the larger the composition, the greater the compressive strength.

According to the results shown in Fig. 2, the highest compressive strength is approximately 1240 kgf/cm^2 for a sample with 7 wt.% bakelite binder and a hot press temperature of approximately 160 °C.

The magnetic properties of all the samples were measured using the Permeagraph. Data from the permeagraph curves such as the remanence, coercivity, and energy product are presented in Fig. 3.

The magnetic properties of the NdFeB magnetic composite, such as remanence (Br), coercivity (Hic), and energy product (BHmax) are significantly influenced by polymer composition. With greater proportion of the polymer binder, Br and BHmax tend to decrease, but the Hic value tends to remain stable. Samples with 2 wt.%

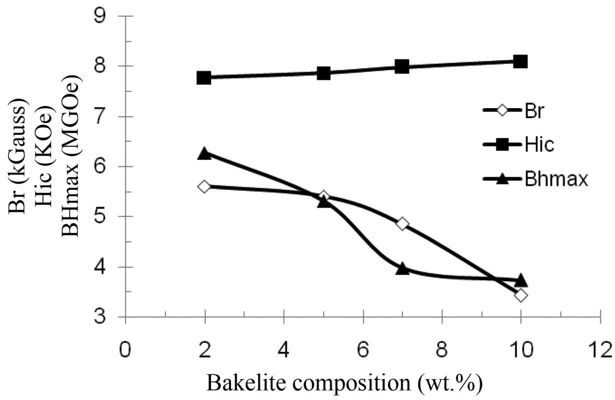
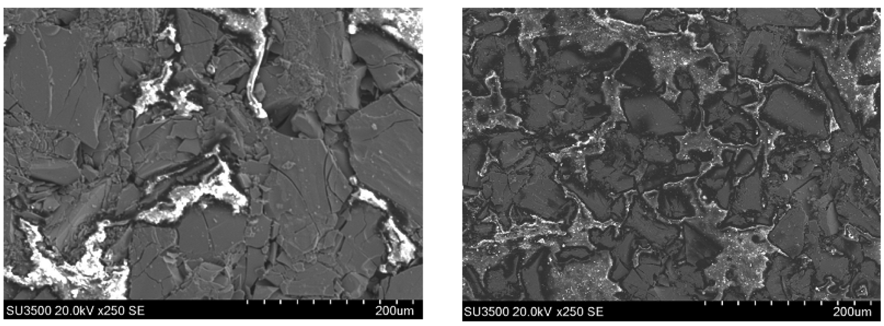


Fig. 3. The magnetic Properties curves as function of bakelite composition.

bakelite polymer have stronger magnetic properties. Based on the results of the test of magnetic properties (Fig. 3), the strongest magnetic properties were achieved using samples with a 2 wt.% bakelite composition, namely, Br = 6.25 kGauss, BHmax = 5.65 MGOe, and Hic = 7.78 kOe. Using more bakelite definitely increases bonding strength and so the compressive strength increases, which is in contrast to the results of the compressive strength test: the greater the bakelite polymer composition, the greater the compressive strength. Since the magnetic composite material is desirable because of its magnetic properties, a low polymer material composition is preferred; however, a certain level of mechanical strength is still required. The results of SEM for the samples with 2 wt.% and 5 wt.% bakelite are shown in Figs. 4(a) and (b). Figure 4(a) indicates the presence of white bakelite polymer between the grains that bind one grain to another.

Figure 4(b) indicates that polymeric bakelite is not only present in the grain boundary but also partly in the surface of the grain. In Fig. 4(a), the bakelite material can only be observed in the magnetic particle gaps (grain boundary), but in Fig. 4(b), which shows the sample with a larger bakelite composition (5 wt.%), the bakelite



(a) (b)

Fig. 4. Photo SEM of sample composite with (a) 2 % bakelite and (b) 5 bakelite.

material can be observed not only in the gaps between the magnetic particles but also covering some of them. With the increase in the bakelite composition and the influence of heat (160 °C), bakelite starts to melt, and because of the presence of external pressure (hot press), it starts to flow, filling the gaps between the particles and partly enveloping them. When the temperature returns to room temperature (cooling stage), the fused bakelite freezes and sticks to the surface of the magnetic particles. If there are more bakelite adhesives, the bond strength between the magnetic particles as well as the compressive strength tend to increase, but the magnetic properties tend to weaken. The SEM images indicate that the bonding mechanism of the bakelite is limited to the surface of the magnetic particles, which in fact means that the magnetic properties of the samples tend to weaken with more adhesive material on the surface of the particles. Furthermore, the weakening of the magnetic properties is also influenced by the density of the magnetic composite samples. With a greater bakelite composition, the magnetic particle loading decreases, which in turn tends to decrease the density and magnetic properties, because Br and BHmax are in direct proportion to the relative density of the magnet [20].

4. Conclusion

The binder polymer composition for the manufacture of permanent magnetic composites considerably influences their bulk density, mechanical properties, and magnetic properties. A permanent magnet composite with 2 wt.% bakelite binder has the highest bulk density (5.25 g/cm^3); the strongest magnetic parameters, namely, Br = 6.25 kGauss, BHmax = 5.65 MGOe, and Hic = 7.78 kOe; and a high compressive strength of approximately 845 kgf/cm^2.

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References

[1] Cristina Stancu, Petru V. Notingher, Valentin Ionita, Virgil Marinescu, and Denis Panaitescu, Electrical Engineering Series No 38, 98 (2014).
[2] Josef Fidler, Thomas Schrefl, Sabine Hoefinger, and Maciej Hajduga, J. Phys.: Condens. Matter **16**, 455 (2004).
[3] S. J. Collocott, J. B. Dunlop, H. C. Lovatt, and V. S. Ramsden, CSIRO Division of Telecommunications and Industrial Physics, Lindfield, NSW, Australia (2007).
[4] M. Drak and L. A. Dobrzański, J. of Achievements in Materials and Manufacturing Engineering, **24**, 63 (2007).
[5] Xiuhai Zhang, Weihao Xiong, Dameng Ye, Jun Qu, and Zhenhua Yao, Acta Metall. Sin. (Engl. Lett.) **22**, 174 (2009).
[6] David Sojer, Irena Kulj, Spomenka Kobe, Janez Kova, and Paul John McGuiness, MTAEC9, **47**, 223 (2013).
[7] A. Grujić, N. Talijan, D. Stojanović, J. Stajić-Trošić, Z. Burzić, and Lj. Balanović, J. Min. Metall. Sect. B-Metall. **46**, 25 (2010).
[8] Barbara Slusarek and Kazimierz Zakrzewski, Przegląd Elektrotechniczny (Electrical Review), 88 NR 7b, 123 (2012).
[9] Seree Tuprakay, International Journal of Structural and Civil Engineering Research, **6**, 263 (2017).
[10] D. Brown, B. M. Ma, and Z. M. Chen, J. Magn. Magn. Mater. **248**, 432 (2002).
[11] Monika G. Garrella, Albert J. Shihb, Bao-Min Mac, Edgar Lara-Curziod, Ronald O. Scattergood, J. Magn. Magn. Mater. **257**, 32 (2003).
[12] Ester M. Palmeroa, Javier Riala, Javier de Vicentea, Julio Camareroa, Björn Skårmanb, Hilmar Vidarssonb, Per-Olof Larssonb and Alberto Bollero, Development of permanent magnet MnAlC/polymer composites and flexible filament for bondi (2018).
[13] Ling Li, Kodey Jones, Brian Sales, Jason L. Pries, I. C. Nlebedim, Ke Jin, Hongbin Bei, Brian K. Post, Michael S. Kesler, Orlando Rios, Vlastimil Kunc, Robert Fredette, John Ormerod, Aaron Williams, Thomas A. Lograsso, and M. Parans Paranthaman, Additive Manufacturing **21**, 495 (2018).
[14] Görtler Michael, Huber Christian, Meier, and Benjamin, Metal Additive Manufacturing Conference 23 November 2018 (2018).
[15] Siti Aisyah Patthi, P. Hussain, M. H. Salleh, I. Zainol, M. Mohammad, and S. Omar, Solid State Science and Technology, **15**, 167 (2007).
[16] Abhijit P. Jadhav, Haoxuan Ma, Dong Soo Kim, Youn Kyung Baek, Chul Jin Choi, and Young Soo Kang, Bull. Korean Chem. Soc. **35**, 3 (2014).
[17] T. Moyo, P. R. J. Silva, and H. Saitovitch, Bulk Density Measurement of Small Solid Fragments, School of Pure and Applied Physics, University of Natal; Durban 4041, South Africa, CBPF-NT-005/03[2008]
[18] Weiren Lin, Osamu Tadai, Manabu Takahashi, Daisaku Sato, Takehiro Hirose,Wataru Tanikawa, Yohei Hamada, and Kentaro Hatakeda, Journal of Geoscience and Environment Protection, **3**, 72 (2015).
[19] D. Kuhinek, I. Zorić, and P. Hrženjak, Measurement Science Review, **11**, 112 (2011).
[20] Vladimir Popov, Andrey Koptyugb, Iliya Radulov, Fernando Maccari, and Gary Mulle, Procedia Manufactur **21**, 100 (2018).