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FURTHER WORK ON FABRICATION OF PRESSURELESS MADE POLYMER BONDED NdFeB MAGNET USING EPOXY RESIN TOUGHENED WITH REACTIVE LIQUID NATURAL RUBBER AS THE BINDER

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ABSTRACT

The paper presents the fabrication of pressureless bonded NdFeB magnet using a binder constituting of a toughened epoxy resin using reactive liquid natural rubber as the toughening additive. The effects of the additive on the magnetic and physical properties of the pressureless bonded NdFeB magnet are discussed. The production of the pressureless magnet involves mixing the NdFeB powder with the toughened epoxy resin and consolidating the mixture at room temperature without applying pressure. The result shows that the magnetic properties of the pressureless bonded NdFeB magnet using toughened epoxy resin as a binder exhibits superior magnetic and physical properties to that of its counterpart, the pressureless bonded NdFeB magnet using conventional epoxy resin binding material and to that of the ferrite magnet. Nevertheless, these properties are comparably lower to that of the compacted NdFeB permanent magnet.

INTRODUCTION

Generally, NdFeB based magnets are fashioned through sintering or rapid solidification [1]. The reason that sintered NdFeB magnets are popular is due to its exceptionally high maximum energy product (BH_{max}) compared to other types of permanent magnets [2].
Nevertheless, the cost of fabrication of sintered magnets are very costly as it needs a high sintering temperature in the range of 500°C to 1100°C [3]. As a consequence, much research has been done on the fabrication method of bonded magnetic materials, especially with the use of rare-earth alloys such as NdFeB.
The reason of using NdFeB is mainly due to the rapidly quenched melt-spun NdFeB powder which can be easily bonded with a polymer based binder material. The bulk bonded NdFeB magnet exhibits high temperature stability, high corrosion and oxidation resistance, superb magnetic and physical properties, able to produce magnetic parts with highly complicated shapes and of course of its economical production cost [3, 4].

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EXPERIMENTAL PROCEDURES

The extremely stable NdFeB isotropic powder, NQP-D, used in this study was produced by the melt spinning route. The toughened epoxy binder used, comprised of the epoxy binder, EPON 828, polymethylmethacrylate grafted natural rubber copolymer known as MG30 supplied by Green HPSP (M) Sdn. Bhd. and ASAHARD 828 as the curing agent [2].

The pressureless bonded NdFeB magnet [2] was modified by substituting the conventional epoxy binder with the toughened epoxy binder as mentioned above. The NdFeB melt spun powder was mixed with the toughened epoxy binder and the curing agent at room temperature, according to the required combination ratios to attain the targeted magnetic powder weight fraction of the final pressureless bonded magnets. The mixture was then consolidated by pouring it into aluminium moulds and left to solidify at room temperature for 12 hours. The curing process was then carried out at an average temperature of 120°C. For comparison purposes, compacted bonded magnets were fabricated by compressing the powder/epoxy/hardener mixture using a hand press machine with 5 tonnes load.

Mechanical and magnetic characteristics of the final pressureless bonded magnet was observed by carrying out microstructural imaging and EDAX analysis using a Nikon optical microscope and the Field Emission Scanning Electron Microscope (Leo 15250); the standard Vickers hardness test; hysteresis loop measurements using a Vibrating Sample Magnetometer (VSM); and specific density measurements.

RESULTS AND DISCUSSIONS

Observation from an optical microscope was made by viewing a cross section of the pressureless NdFeB magnet vertically from the top portion of the magnet to the bottom portion where the magnet touches the mould of where it was cast from. Under magnification, it can be seen that the magnetic NdFeB powder particles are distributed with an increasing concentration in the epoxy binder matrix, as observation was made downwards to the bottom of the mould. Due to the pressureless consolidation method, a large volume of the bonded magnetic material is occupied by toughened epoxy resin. When comparing the distribution of the magnetic NdFeB powder particles between a mixture ratio of 1:1 of epoxy to NdFeB powder and a mixture ratio 1:2 of epoxy to NdFeB powder, it can be seen that the later mixture ratio displays a more compact structure as can be seen in Figure 1(a) and Figure 1(b). The density of the 1:2 mixture ratio of epoxy to NdFeB is also higher (3.813 g/cm^3) to that of the 1:1 mixture ratio (3.480 g/cm^3). This observation is counter intuitive to what we would have expected, that is the density of both the mixture ratio should be very similar, as no compaction methods have been applied when consolidating the pressureless magnetic materials. It is believed that the extra weight of powder particles, one on top of the other, contributed in aligning the powder particles more closely together in the 1:2 mixture ratio. In both of the mixture ratios of the pressureless NdFeB materials, the powder particles are partially aligned compared to a compacted bonded NdFeB material. The micrograph of the 1:2 mixture ratio of pressureless magnet as shown in Figure 4(b) shows that the gaps

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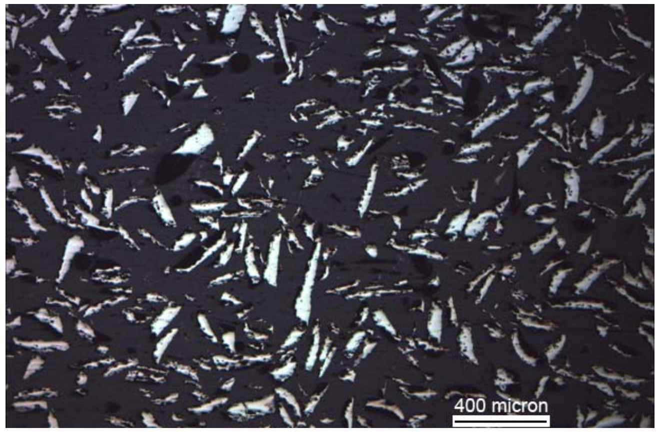
between the NdFeB particles are much wider compared to those of the compacted NdFeB material as in Figure 4(c).



(a)

(b)

Figure 1: (a) and (b) show the optical micrograph of pressureless bonded NdFeB Magnet with a mixture ratio 1:1 and 1:2 of epoxy to NdFeB powder, respectively.

Using the Leo 1525 Field Emission Scanning Electron Microscope (FESEM) equipped with an Energy Dispersive Spectrometer (EDS), the microstructure of the bonded magnets was further investigated. The electron morphologies, EDAX analysis and chemical composition of the bonded magnets are depicted in Figure 2, Figure 3, Table 1 and Table 2.Table 1 and Table 2 shows the chemical composition of the pressureless and compacted bonded magnets analysed using SEM with EDAX. The results show that the fundamental elements, neodymium and iron, usually found in NdFeB materials are present. Boron is present within the NdFeB magnets but cannot be detected by the SEM analysis

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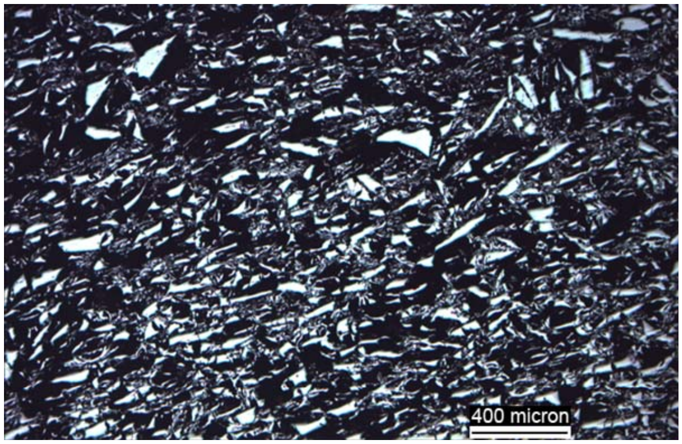

Figure 1(c): Optical micrograph of compacted bonded NdFeB Magnet with a mixture ratio 5:95 of epoxy to NdFeB powder.

Figure 2(a): Electron micrograph of pressureless bonded magnet. Magnification 200x.

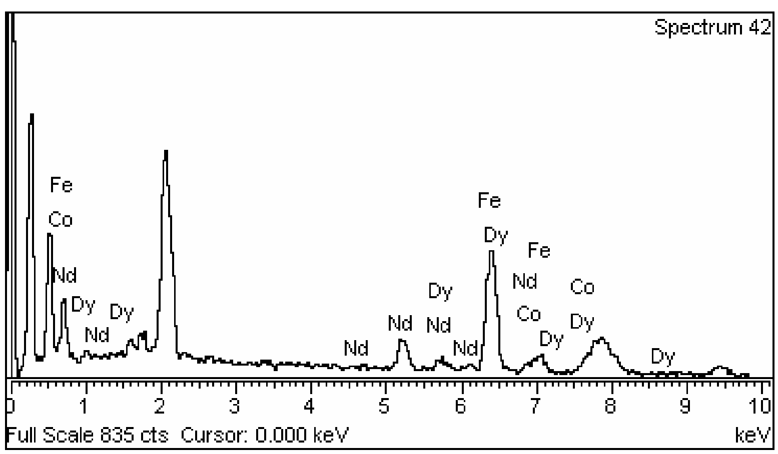

Figure 2(b): Quantitative analysis of pressureless bonded magnet.

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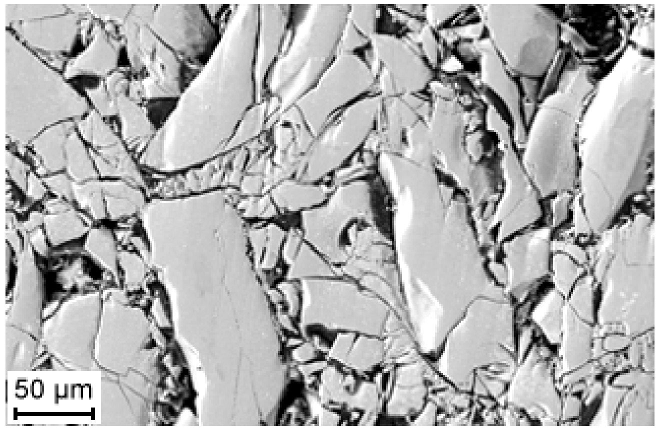

Figure 3(a): Electron micrograph of compacted bonded magnet. Magnification 200x.

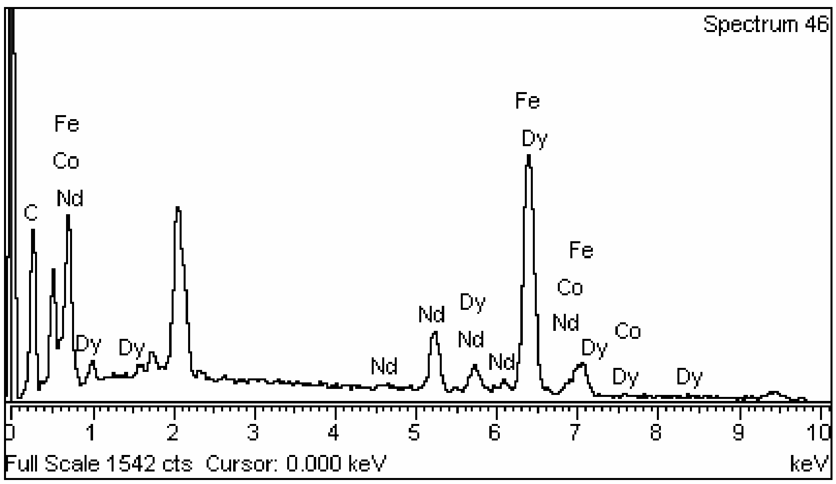

Figure 3(b): Quantitative analysis of compacted bonded magnet.

Table 1: Quantitative analysis of pressureless bonded magnet.

Element	Weight%	Atomic%
Fe K	70.15	82.57
Co K	5.84	6.51
Nd L	23.44	10.68
Dy L	0.57	0.23
Totals	100.00	

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Table 2: Quantitative analysis of compacted bonded magnet.

Element	Weight%	Atomic%
C K	21.24	59.98
Fe K	54.78	33.26
Co K	3.39	1.95
Nd L	19.42	4.56
Dy L	1.17	0.24
Totals	100.00	

since boron constitutes only about 1 wt% or less of the NdFeB magnetic alloy. Other than that, dysprosium and cobalt also emerge on the EDAX analysis.

From the SEM and optical microscope images, some pores are found in the bonded magnets. This can be the result of debonding occurring between the epoxy and NdFeB powder, as the powder is not wet well enough to be firmly bonded with the epoxy and LNR matrix. The average thickness of the melt spun powders of the pressureless bonded NdFeB magnet is 30µm in accordance with previous studies [3] and the texture of the powder particles are seen to be flaky. Meanwhile for the compacted bonded NdFeB magnet, the average thickness is also 30µm and the powder particles are found to be in very small fragments, presumably crushed during the compaction consolidation process.

Table 3: Physical properties of the magnetic materials analysed at room temperature (295 K), Vickers hardness test, ρ = density.

Material	Epoxy : NdFeB ratio	Hardness (HV)	ρ (g/cm^3)
Pressureless NdFeB Magnet	1 : 1	Metal : 691.4 Epoxy : 9.6 Overall : 350.5	3.480
	1 : 2	Metal : 661.0 Epoxy : 9.9 Overall : 335.4	3.813
Compact NdFeB Magnet	5 : 95	Metal /Overall: 813.7	5.564

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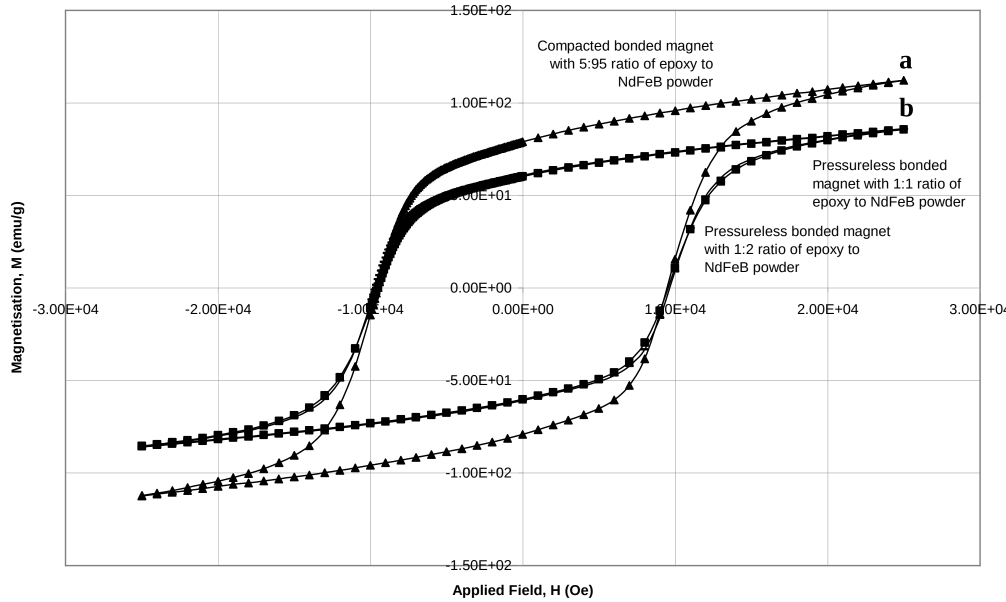

Figure 4: Hysteris loop for compacted bonded magnet (a) and pressureless bonded magnet with a mixture ratio 1:1 of epoxy to NdFeB powder (b).

The physical and magnetic properties were analysed using Vickers hardness test, specific density measurements; and hysteresis loop measurements using a Vibrating Sample Magnetometer (VSM). From Table 3, it is shown that the compacted NdFeB magnet exhibits higher physically characteristics when compared to the pressureless NdFeB magnet. Nevertheless, these physical characteristics of the pressureless bonded NdFeB magnet are adequate for commercial use as the magnetic characteristics of the pressureless bonded magnet are superior to that of a ferrite magnet [3]. Figure 4 provides the results of the magnetic characteristics tests. These results were calculated from the values obtained from the hysteresis loops of magnetic field perpendicular to the surface of the samples, measured by a Vibrating Sample Magnetometer (VSM). The pressureless bonded NdFeB magnet can achieve a coercivity, H_c of 9.6 kOe; a saturatisation magnetisation, M_s of 85.9 emu/g; a remnant magnetisation, M_r of 61.0 emu/g and a BHmax of 1.64 MGOe. The pressureless bonded NdFeB magnet can achieve a relatively higher remnant magnetisation from that of a ferrite magnet which has an M_r value of 35.69 emu/g [3]. The pressureless bonded NdFeB magnet also exhibits similar H_c value to that of the compacted NdFeB magnet.

CONCLUSIONS

Summing up the physical and magnetic characteristics of the pressureless bonded NdFeB magnet, the compacted bonded NdFeB magnet and the ferrite magnet [1], the compacted bonded NdFeB magnet shows a clear lead of desired physical and magnetic properties. However, the pressureless bonded NdFeB magnet has superior magnetic properties compared to that of the ferrite magnet [1] and has a simple and low production cost. With these results in mind, the pressureless bonded NdFeB magnet

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with a toughened epoxy as a binder is a relevant nominee to be chosen for the manufacture of magnetic parts.

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REFERENCES

[1]. Azwar Manaf, (2000); *Bonded Nd-Fe-B based permanent magnets derived from rapidly solidified alloys*, ASEAN-INDIA Workshop on Nd-Fe-B Magnets and Material-Advancements, Application and Market Growth, Kuala Lumpur.

[2]. D. Howe, (1994); *Proceedings of the 13h International Workshop on Rare-Earth Magnets and their Applications*, Birmingham, **1**, pp.17.

[3]. Hussain, P., Ishak, S., Saleh, M. H., Mohammad, M., Shaban, A., Omar, S. and A. Idris, (2005); *Fabrication of pressureless made polymer bonded NdFeB magnet and its magnetic and physical properties in comparison to compacted bonded magnet and ferrite magnet*, The 2nd ASEAN Science Congress and Sub-Committee Conference on Material Science and Technology, Jakarta.

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