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The effect of variations in the size of milling balls on the magnetic properties and morphology of natural sand particles in the Rokan River

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ABSTRACT

Magnetic susceptibility, magnetic properties and morphological properties of natural sand from the Rokan river based on variations in milling ball size. Natural sand samples were put into the iron sand separator for separation between magnetic and non-magnetic particles which were then carried out in a ball milling process for 80 hours using iron balls with a diameter of 1, 2, and 3 cm. The results of the ball milling were then separated using NdFeB magnets, these products are called BM I, BM II, and BM III products. The susceptibility values generated in this study increased with increasing milling ball sizes, for milling ball sizes of 1, 2, and 3 cm the magnetic susceptibility values were 12906.293×10^{-5}, 13390.387×10^{-5}, and 14816.736×10^{-5}. The results of the VSM test showed that the saturation magnetization obtained by the BM I, BM II, and BM III products was 2.89, 2.28, and 4.71 emu/g, the remanent magnetization values obtained by 0.45, 0.35, and 0.27 emu/g and the coercivity obtained was 249.07, 263.89, and 275.85 Oe. The results of the SEM-EDX identification showed that Fe increased from 16.24% to 22.68%, while in non-magnetic elements Si decreased from 24.49% to 18.76% with an average particle size getting smaller with increasing size milling ball.

Keywords: Ball milling; magnetic susceptibility; natural sand; NdFeB; Rokan River

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INTRODUCTION

Indonesia is rich in natural resources containing natural minerals. However, many of these natural resources have not been processed and utilized optimally [1].

The use of iron ore in Indonesia is still limited to being used as an additional material in cement factories. Iron ore is generally exported in the form of raw materials, but because iron ore can be further processed and used more efficiently, the price becomes higher [2]. This iron sand has a characteristic black color and is found in abundance on beaches, rivers and mountains. Iron sand contains magnetic minerals consisting of magnetite (Fe_3O_4), hematite ($\propto$-Fe_2O_3) and maghemite (γ-Fe_2O_3), widely used in the magnet manufacturing industry. The minerals contained in iron sand have excellent electromagnetic properties, so they can be used in the biomedical field such as heavy metal adsorption and magnetic sensors [3-5].

The sample used was natural sand from the Rokan River, in Ujung Batu, Riau Province. Magnetic and non-magnetic particles in natural sand were separated using iron sand separator (ISS), and iron sand was refined using ball milling, its magnetic properties were determined using vibrating sample magnetometer (VSM), and its morphological properties were determined using scanning electron microscope using energy dispersive X-rays (SEM-EDX).

RESEARCH METHODS

The sample was natural sand from the Rokan River in Ujung Batu, Riau Province. The sample was inserted into the ISS to separate magnetic and non-magnetic particles, then ground using ball milling for 80 hours using variations in the size of iron balls, namely, 100 pieces of 1 cm iron balls, 48 pieces of 2 cm iron balls, and 16 pieces of 3 cm iron balls with a tube rotation speed of 100 rpm. Furthermore, the magnetic susceptibility value of natural sand samples, ISS products, and ball milling products was determined. The magnetic properties of the ball milling products were tested using the VSM test and the morphological properties of the ball milling products were tested using the SEM-EDX test.

RESULTS AND DISCUSSION

Magnetic Induction Measurement

Measurement of the magnetic induction of a coreless solenoid as a function of current, the amount of current given is 200 mA, 400 mA, 600 mA, 800 mA, 1000 mA with a fixed distance from the Pasco probe magnet to the solenoid of 1 mm.

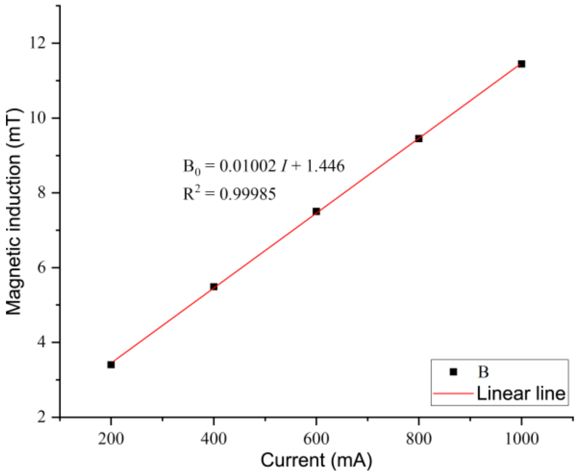

Figure 1. Graph of the magnetic induction of a coreless solenoid (B_0) as a function of current.

Figure 1 shows the magnetic induction value increases with increasing electric current given. The magnetic induction value at a current of 200 mA of 3.404 mT increases at a current of 1000 mA of 11.568 mA.

The B_0 value obtained is B_0 = 0.01002 I + 1.446 and R^2 = 0.99985 where R is the graph error value, if the R value approaches 1 then the graph can be said to be linear. The linear equation shows that when the electric current flow in the solenoid is stopped, the magnetic induction value of the solenoid is not immediately zero, but there is still a residual magnetic induction of 1.4466 mT. This happens because of the influence of the earth's magnetic field which is still stored in the solenoid.

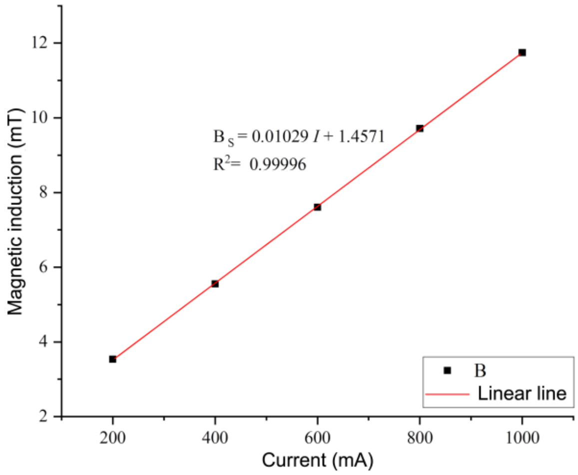

Figure 2. Magnetic induction graph of the solenoid with a natural sand core from the Rokan River (B_S) as a function of current.

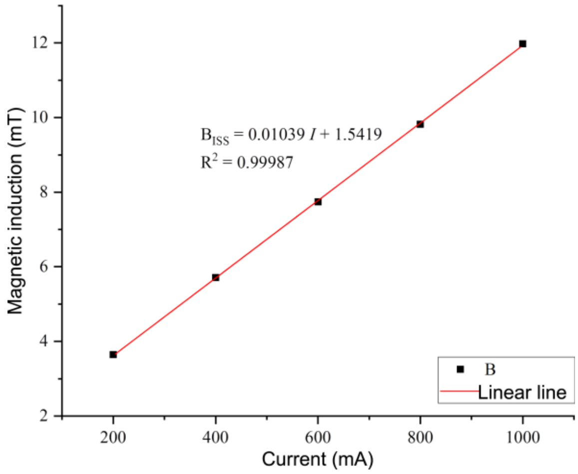

Figure 3. Magnetic induction graph of the ISS product sample (B_{ISS}) as a function of current.

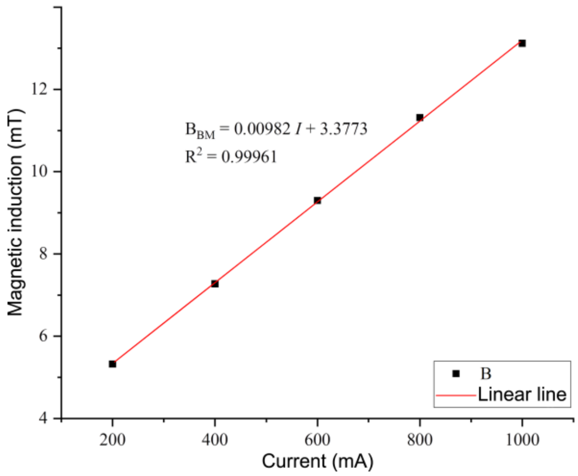

Figure 4. Magnetic induction graph of BM I product sample as a function of current.

The increase in the magnetic induction value for the ISS product sample contains more magnetic particles than the magnetic induction value of the natural sand sample. The increase in the induction value is due to the large number of non-magnetic particles that are separated from the iron sand particles during the separation process in the ISS. The magnetic induction value increases with the increase in the electric current given.

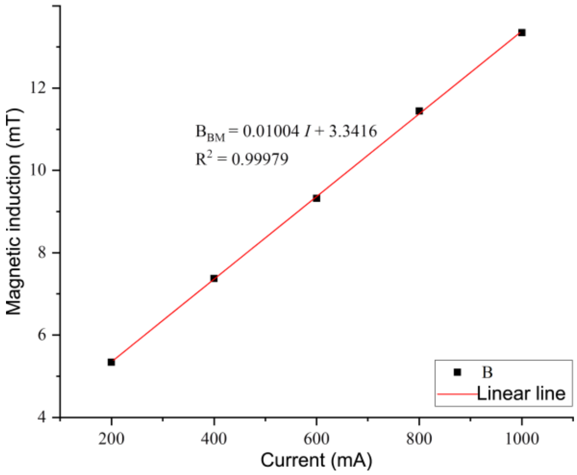

Figure 5. Magnetic induction graph of BM II product as a function of current.

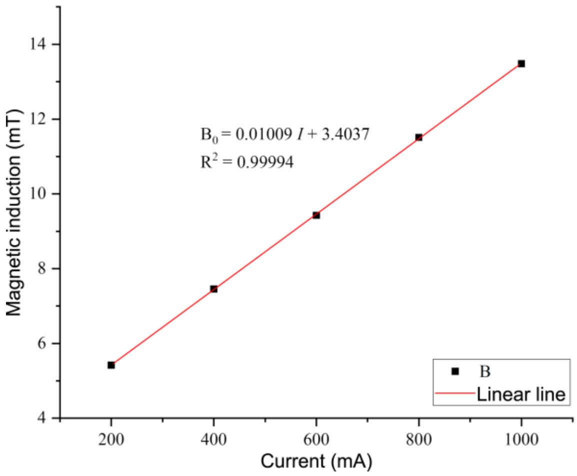

Figure 6. Magnetic induction graph of BM III product as a function of current.

The measurement of the magnetic induction of the solenoid of BM I, BM II, and BM III products shows a graph that increases linearly. The increase in this graph is influenced by the variation in the size of the milling ball where the iron ball used is 1, 2, and 3 cm. This is because the larger the ball used, the smaller the particles produced and the resulting induction value will increase.

Magnetic Susceptibility

Magnetic susceptibility is a quantity that describes the relationship between the magnetic susceptibility of a material and an external magnetic field (H). When an external magnetic field is applied, the magnetic moment is in the same direction as the external magnetic field, which is called magnetization (M).

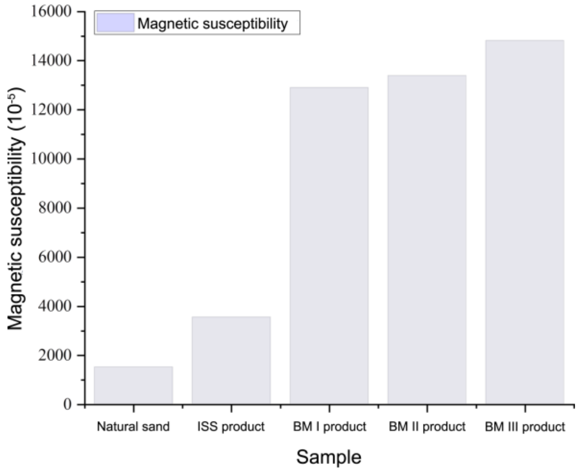

Figure 7. Graph of magnetic susceptibility values (χm) of natural sand, ISS products, BM I products, and BM II products, and BM III.

Figure 7 shows an increasing bar graph. The magnetic susceptibility value of the natural sand sample is 1521.439 × 10^{-5}, the ISS product is 3552.905 × 10^{-5}, the BM I product is 12906.293 × 10^{-5}, the BM II product is 13390.38 × 10^{-5} and the BM III product is 14816.736 × 10^{-5}.

Figure 7 shows the relationship between the size of the milling ball will affect the magnetic susceptibility value produced, where the larger the size of the ball used to smooth the particles, the greater the magnetic susceptibility value obtained. The resulting susceptibility value is directly proportional to the increasing size of the milling ball.

Magnetic Properties Using VSM

Magnetic properties testing using VSM produces saturation magnetization (M_S), remanent magnetization (M_r), coercivity (H_c), loop square (M_r/M_S), and hysteresis loop area. Natural sand separated by ISS is smoothed for 80 hours in ball milling using iron balls with diameters of 1, 2, and 3 cm. Then testing is carried out using VSM and the VSM results are presented in the form of a hysteresis curve.

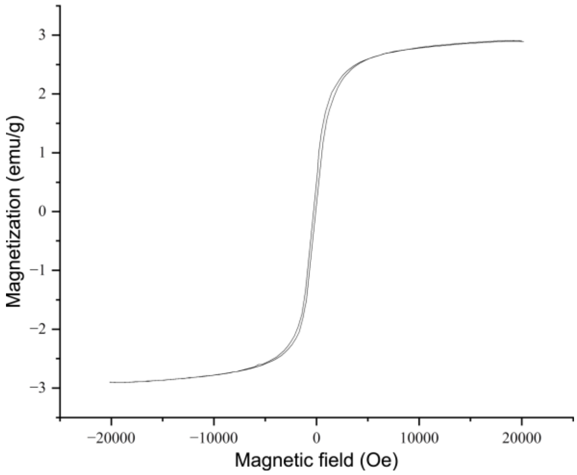

Figure 8. Hysteresis curve of BM I product.

Figure 8 shows the hysteresis curve obtained from magnetic properties testing using VSM of BM I product with a variation of 1 cm milling ball with a constant time of 80 hours. In the BM I product, the saturation magnetization value (M_S) was obtained at 2.89 emu/g, the remanent magnetization value (M_r) was 0.45 emu/g, the coercivity value (H_c) was 249.07 Oe, the loop squareness value (M_r/M_S) was 0.16 and the hysteresis loop area value (A) was 217.7 kOe. emu/g.

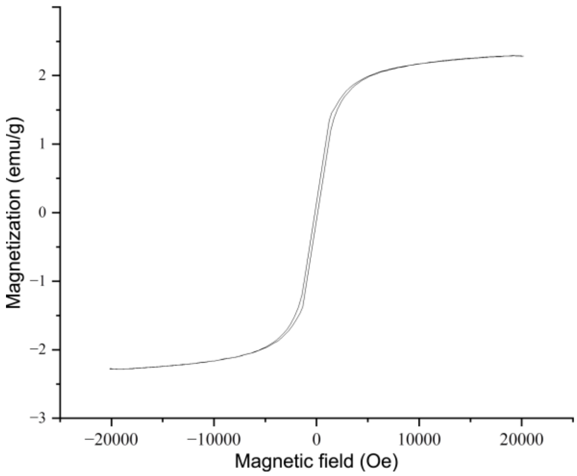

Figure 9. Hysteresis curve of BM II product.

Figure 9 shows that the BM II product obtained a saturation magnetization value (M_S) of 2.28 emu/g, the resulting remanent magnetization value (M_r) of 0.35 emu/g, the coercivity value (H_c) of the BM II product of 263.89 Oe, the loop squareness value (M_r/M_S) of 0.15 and the loop hysteresis area value (A) obtained of 195.9 kOe.emu/g.

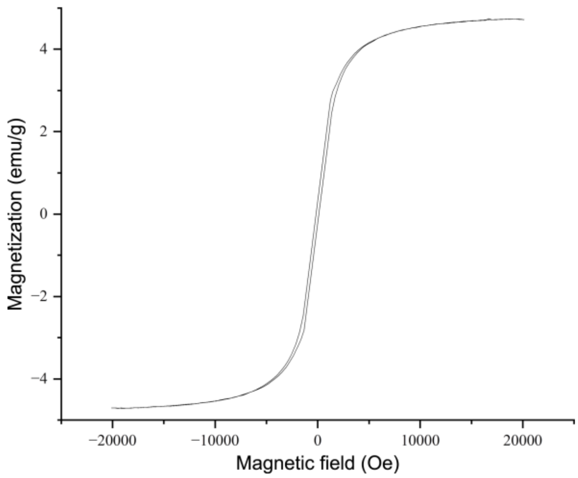

Figure 10. Hysteresis curve of BM III product.

Figure 10 shows that the BM III product obtained a saturation magnetization value (M_S) of 4.71 emu/g, the resulting remanent magnetization value (M_r) of 0.27 emu/g, coercivity value (H_c) of 275.85 Oe, loop squareness value (M_r/M_S) of 0.38 and hysteresis loop area value (A) obtained of 352.5 kOe.emu/g.

Based on the test results that have been obtained, the coercivity value of the 1 cm ball BM product is 249.07 Oe, the 2 cm ball BM product is 263.89 Oe, and the 3 cm ball BM product is 275.85 Oe. So the highest coercivity value (H_c) is owned by the 3 cm milling ball and the lowest coercivity value is on the 1 cm milling ball. This shows that the greater the coercivity value in a magnetic material, the more difficult it is to eliminate its magnetic properties.

Morphological Properties of Particles Using SEM-EDX

The results of the particle size test were used in SEM-EDX and ball milled for 80 hours with variations in the size of the iron balls of 1, 2, and 3 cm with a magnification of 5000 times.

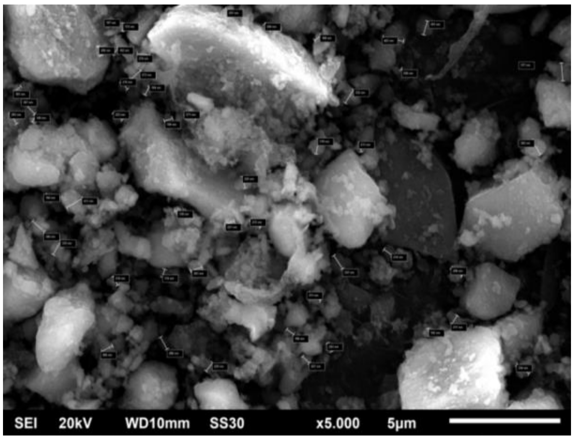

Figure 11. Particle size of BM I product with 5000 times magnification.

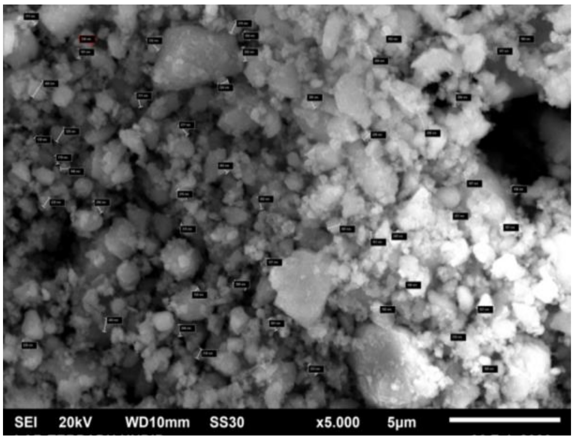

Figure 12. Particle size of BM II product with 5000 times magnification.

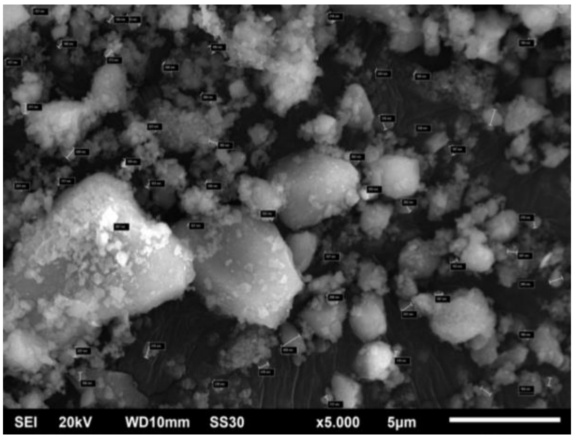

Figure 13. Particle size of BM III product with 5000 times magnification

The particle size of the natural sand sample from the Rokan River that had been ball milled for 80 hours using a 1 cm diameter iron ball was 378.18 ± 94.91 nm, on a 2 cm diameter iron ball it was 298.12 ± 86.67 nm and on a 3 cm diameter iron ball the particle size produced was 255.56 ± 68.25 nm. The results of particle size using a SEM-EDX showed that variations in the diameter of the milling ball used affected the particle size produced.

Table 1. Composition of BM I, II, and III products using SEM-EDX.

Element	Mass (%)		
	BM I	BM II	BM III
C	27.92	23.02	38.08
O	16.80	19.60	14.26
Na	1.13	1.71	0.67
Mg	1.18	1.55	0.45
Al	5.07	6.75	2.44
Si	24.49	20.59	18.76
K	0.89	1.45	0.93
Ca	2.11	2.13	0.58
Ti	1.80	0.58	0.25
Fe	16.24	21.56	22.68
Cu	1.65	1.06	0.90
Zn	0.72	0.00	0.00
Total	100.00	100.00	100.00

Table 1 shows the percentage composition contained in the natural sand samples of the Rokan River that have been ball milled for 80 hours with variations in the size of the iron balls of 1 cm, 2 cm, and 3 cm. There was an increase in the percentage of the magnetic element Fe in the BM I, BM II, and BM III products, respectively, namely 16.24%; 21.56%; 22.68%. In the composition of the non-magnetic element Si, there was a decrease in the percentage in the BM I, BM II, and BM III products, respectively, namely 24.49%; 20.59%; 18.76%. In the test of BM I, II, and III products using Scanning Electron Microscope with Electron Dispersive X-ray (SEM-EDX), it was shown that the ball milling product samples contained a lot of C, O, Fe and Si elements.

CONCLUSION

The magnetic susceptibility value increases with the increase in the electric current given in proportion to the increase in the size of the iron ball used, the magnetic susceptibility value of the BM I product is 12906.293 × 10^{-5}, the BM II product is 13390.38 × 10^{-5}, and the BM III product is 14816.736 × 10^{-5}. The remanent magnetization value (M_r) decreases and the coercivity value (H_c) increases. While the saturation magnetization value (M_S), loop squerness (M_r/M_S) and the area of the hysteresis loop have varying values when the diameter of the ball increases. The variation in the diameter size of the milling ball used affects the size and composition of the particles, the larger the milling ball used, the smaller the particle size produced and the composition of the magnetic element Fe increases and the non-magnetic element Si decreases.

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