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# Analysis of the effect of compaction variations on the hardness of sponge iron reduction from iron sand, South Aceh Regency

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ABSTRACT

The properties of sponge iron produced from iron sand and its alloys from the Manggamat Simpang Dua region in South Aceh are discussed in this research. Sponge iron is produced in pellet form by combining 75 percent iron sand (Fe), 20 percent carbon (C), and 5 percent bentonite adhesive. Pellet manufacturing consists of five press variants, namely 50, 60, 70, 80, and 90 kg/cm$^2$, which are reduced by acetylene gas at a burning temperature of 1200°C with a holding period of 45 minutes. The reduced to spongy pellets exhibited a dominating hematite (Fe2O3) phase fraction pattern of 59.8 percent and a magnetite phase (Fe3O4) of 40.2 percent, with a weight percentage of Fe of 66.57 percent and C of 2.30 percent. The greatest sponge iron material hardness results on average at 287.35 HV at a pressure of 70 kg/cm$^2$ with a void size of 0.4 mm, showing the optimal compressive value (compaction) on iron sand pellets. It may be inferred that iron sand collected from the South Aceh region can be used as an alternate raw material in the steel manufacturing process.

ABSTRAK

Penelitian ini membahas tentang karakteristik *sponge iron* berbahan baku pasir besi dan paduannya, berasal dari daerah Manggamat Simpang Dua, Aceh Selatan. *Sponge iron* dibuat dalam bentuk pelet dengan pencampuran yang terdiri dari pasir besi (Fe) sebanyak 75%, karbon (C) sebanyak 20%, dan zat perekat bentonit sebanyak 5%. Pembuatan pelet terdiri dari lima variasi tekan yaitu 50, 60, 70, 80 dan 90 kg⁄cm$^2$, yang direduksi dengan gas asitelin pada temperatur pembakaran 1200°C dengan waktu penahanan 45 menit. Hasil pengujian XRD menunjukkan pelet yang direduksi menjadi *sponge* memiliki pola fraksi fasa hematit ($Fe_2O_3$) yang dominan sebesar 59,8% dan fasa magnetit ($Fe_3O_4$) sebesar 40,2% dengan persentase berat Fe sebesar 66.57% dan C sebesar 2,30%. Hasil kekerasan material *sponge iron* tertinggi rata-rata pada 287,35 HV pada penekanan 70 kg⁄cm$^2$ dengan besar void 0,4 mm, menunjukkan nilai tekan (kompaksi) optimum pada pelet pasir besi. Dapat disimpulkan bahwa pasir besi yang diperoleh dari daerah Aceh Selatan dapat menjadi pilihan bahan baku alternatif dalam proses pembuatan produksi baja.

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## 1. Introduction

One of Indonesia's natural resources potential is mineral material, namely iron sand. Aceh province has mineral potential in the form of gold, copper, and iron sand. The Aceh government has also placed iron sand as one of the leading export commodities [1]. Government Regulation No. 27 of 1980 concerning minerals, mineral materials in iron sand are classified into group B minerals [2]. This iron sand can mostly be found in Aceh Pidie District, North Aceh, Bireuen, Aceh Besar, West Aceh, South Aceh, and the Sabang Islands [3].

The iron sand formation is a chemical and physical process from rocky with acidic composition to andesitic to basaltic rock. When exposed to the sun, iron sand tends to heat up. Iron sand has constituent elements in the form of magnetite ($Fe_3O_4$) and the composition of other elements in small amounts such as vanadium, manganese, silica, and calcium [4]. Iron sand is found along the shore in general, and it is generated by the weather's disintegration of mountainous rock, which is subsequently carried by rivers and deposited along the shoreline.

The sorting by sea waves and the accumulation of iron sand deposits makes iron sand which has a high economic value. Mineral processing, especially iron and nickel sands that have been recorded at the Ministry of Energy and Mineral Resources, has not been fully registered due to the large area and low awareness of entrepreneurs in reporting their production officially [4]. Sponge iron is a product produced from the iron and steel manufacturing process through a direct reduction in iron sand. One of the raw materials for steel production is sponge iron. Testing the production of sponge iron begins with making pellets from the raw material of iron sand and several other compositions, which are reduced to sponge iron by a combustion process using acetylene gas. Research has been carried out on metal processing in iron sands into sponge iron by a direct reduction process with a temperature of 1200°C obtained from the coast of Sigandu, Batang. The research was conducted by varying the composition of the pellets with a few percent mixing, namely wood charcoal as a reducing agent by 20%, tapioca starch as an adhesive by 5%, and iron sand as the primary raw material as much as 75% [5].

Kusuma [6] has researched the magnetic properties of iron sand and analyzed the crystal structure obtained from the Bengawan Solo River. The iron sand extraction process is carried out by utilizing magnetic properties to separate iron sand from other minerals. The research includes the characterization of elements contained in mineral samples, the measurement of crystal size in iron sand samples, and magnetic properties. Characterization (XRF) showed that the dominant element contained hematite ($Fe_2O_3$), with concentrations ranging from 68% to 72%. The crystallite grain size obtained ranged from 52 nm to 84 nm.

In the sponge iron process for the advanced process of making steel, first, the iron sand is made in pellets with sizes between 80 to 120 mm. The research method published by Amin [7] uses raw materials of iron sand waste and iron rust waste to make sponge iron. The process of making pellet composition using a pelletizing device with a composition of 77% iron sand and iron rust, 3% bentonite, adhesive, and 20% coal as a reducing agent. After forming the pellets, they were dried in an oven set to 110°C, and density measurements were taken. The following process is to reduce pellets at a temperature of 1200°C for 2 hours. After the sponge iron is reduced, the cooling process is continued. Sri et al. [8] also tested the characteristics of iron sand using XRD to obtain the value of the change in the magnetite crystal structure with the length of the milling process.

Further research has been carried out to see the effect of reducing agents and temperature variations that produce sponge iron in iron ore raw materials using a rotary kiln (DRI). The ratio of the pellet forming elements in the given weight unit between iron ore, wood charcoal, and coal is 77 to 20 compared to 3. The reduction temperature variations are 900, 1050, and 1200°C, while wood charcoal and sub-bituminous coal are the type variables. It is a reducing agent. Comparison of research results shows that coal will be better if it has a low wood charcoal content. The reduction for 2 hours at a temperature of 1200°C resulted in the percentage of sponge iron 97.43% with wood charcoal as a reducing agent. In contrast, the reduction value of sponge with coal as a reducing agent is 96.7% [9].

Other studies have also been carried out on raw materials consisting of iron sand from Suweru Jepara beach to make sponge iron. Pellets are made from a mixture of iron sand, carbon, and adhesive with a weight ratio of 75, 20, and 5%. The amount of Suweru beach sand used is 5 kg. After being reduced, it is obtained as much as 3.3875 kg of iron sand through a process using permanent magnets. Then, sorting or sieving large sizes of sand with a mesh of 100 to obtain iron sand as much as 2.2710 kg. After mixing with 2.25 kg of iron sand, 0.6% C, and 0.15 kg of adhesive, the total weight of the alloy is 3 kg and can be made into pellets of 70 pieces with about 43 grams each. The reduction of sponge iron for three test specimens respectively weighed 13.98, 14.83, and 17.97 g and resulted in a reduction value of 36.68% [10]. Based on the description of the research variables, this study was conducted to analyze the properties and characteristics of iron sand originating from mountainous rocks in Manggamat Simpang Dua Village, South Aceh Regency. The author will analyze the mechanical properties of sponge iron due to pellet reduction from the iron sand.

## 2. Research Methodology

### *2.1. Location of Taking Test Specimens*

Manggamat Simpang Dua Village, Kluet Tengah District, South Aceh Regency is located in Aceh Province, Indonesia. The district administration is located in Tapak Tuan, with the 6th largest population in Aceh Province. Most of the people's livelihoods are farmers and fishermen [11]. Geographically, the location of Manggamat Simpang Dua is in Kluet Tengah District, South Aceh Regency. The distance from Manggamat Village is about 30 kilometers from Tapak Tuan City and the travel time is about 1.5 hours (Figure 1).


**Figure 1. Location of Manggamat Simpang Dua.**
Source: Google Earth [12].

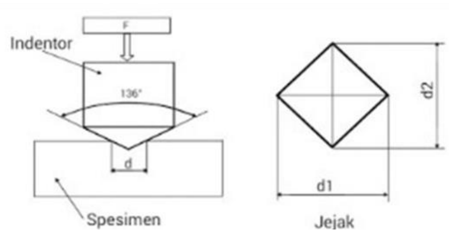


**Figure 2. Vickers test indenter**

### *2.2. Analysis and Extraction Techniques*

Laboratory analysis in this study used an Olympus DP12 type Optical Microscope to observe the surface of the test specimen and was assisted by the OptiLab Advance V2 tool to take measurements. The JEOL 360 LA type x-ray diffraction (XRD) instrument was used to measure the predominant crystallites formed due to the sponge iron reduction process. In calculating the percentage of magnetic minerals (Magnetic Degree) or MD, and non-magnetic, it is by comparing the weight of iron sand after extraction (gr) and the initial weight of the raw material (gr), then the value of the degree of magnetism is obtained:

$$\text{MD} = (\text{Weight of iron sand})/(\text{Initial weight}) \times 100\% \quad (1)$$

In this study, the test sample in the form of iron sand taken from the research site was 10 kg which had undergone enrichment with a mesh size of #100 to obtain uniform size. Next, the iron sand is washed with detergent to remove any impurities or contaminants in the sand. The cleaned sand is then dried and placed in a container to separate or extract iron sand. The extraction process uses a magnetic separation method. This process is repeated until the iron sand is clean of non-magnetic sand.

### *2.3. Mechanical Testing*

The hardness test method chosen in this study is the Vickers test [13-14]. This test employs the method of pressing the test specimen with a diamond indenter in a pyramid with a large angle of 136° from the surface to the face. Pressing by the diamond indenter will produce an indentation on the surface of the test specimen, as shown in Figure 2. The test loads used range from 1 kgf to 120 kgf for the Vickers hardness test, and test loads are commonly used in the range 5, 10, 30, and 50 kgf. In the Vickers hardness test method, the test object must have a flat surface, smooth and free from impurities.

The Vickers hardness value can be obtained by the formula:

$$HV = 1.854 \frac{P}{d^2} \quad (2)$$

where,
HV = The Vickers hardness value
P = Test load (kgf)
D = Average trace diagonal

### *2.4. Pellet Making Process and Pellet Reduction*

In making pellets, as much as 10 kg of iron sand is separated conventionally by sieving using a #100 mesh sieve. The results of sifting leave iron sand weighing 6.84 kg. The extraction process is then carried out using a magnetic separator to separate impurities and non-magnetic particles. Using equation (1), the content of the degree of magnetism of iron (Fe) obtained is 0.456% or 3.12 kg of iron sand, which is ready to be processed as raw material for sponge iron. The separation results with a magnetic separator are better than the conventional process because the separation is not based on the size of the particles but the magnetic properties of iron sand containing Fe3O4 (magnetite) or other compounds that have magnetite properties [15]. In this study, the process of forming iron sand into pellets was carried out. Pellets from iron sand processed for combustion using acetylene gas will turn into sponge iron, as shown in Figure 3. This process is carried out to obtain a comparison of pellet composition and is reduced to sponge iron.

a

b


**Figure 3. Iron sand (a) Before burning (b) After burning**

The composition of this pellet is by mixing 75% iron sand, 20% carbon as a reducing agent, and 5% bentonite adhesive. Then water is added to facilitate the adhesion of iron sand with carbon evenly. After the three raw materials were mixed, the pellets were molded using a cylindrical mold with a diameter of 4 cm and a height of 4 cm. Furthermore, the raw materials in the mold are compacted to form a solid in the form of iron sand briquettes. The variations given in the compacting process consist of five variations in pressure, namely 50, 60, 70, 80, and 90 kg/cm$^2$. After the compaction process, the iron sand pellets were dried using a German brand Memmert type UN 30 oven at a temperature of 110℃ and a holding time of 45 minutes to reduce the moisture content of the briquettes. The method of reducing pellets made from iron sand is to use acetylene gas, where the temperature reaches 1200℃. The reaction that occurs during the reduction process is

$$\begin{gathered} 3Fe_2O_3 + C \rightarrow 2Fe_3O_4 + CO \\ Fe_3O_4 + C \rightarrow 3FeO + CO \\ FeO + C \rightarrow Fe + CO \end{gathered} \quad (4)$$

After completing the reduction process, the test specimen in the form of pellets was prepared for hardness testing by preparing the test surface and surface flatness by providing mounting from the resin (Figure 4).

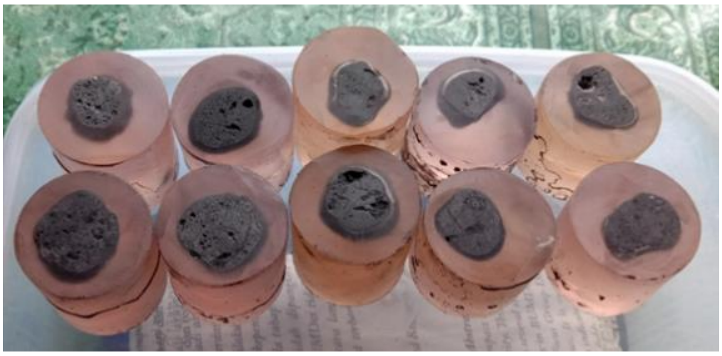

**Figure 4. Pellets after reduction and mounting.**

## 3. Results and Discussion

Tests on sand raw materials from Manggamat Simpang Dua, South Aceh, were carried out on a laboratory scale. These tests and observations need to be carried out to determine the mechanism from pellets to sponge iron and get the best hardness value from variations in pressure. Therefore, hardness testing was carried out on the sponge iron material using the Vickers Hardness Test tool. The hardness test results on sponge iron, in five variations in compression with three test points for each variation at a load of 60 kg (588N). The average hardness value of the sponge iron material from each varied specimen is not much different due to the same mixing composition and the same heat-treatment process. The hardness value of sponge iron is shown in Figure 4 as follows.

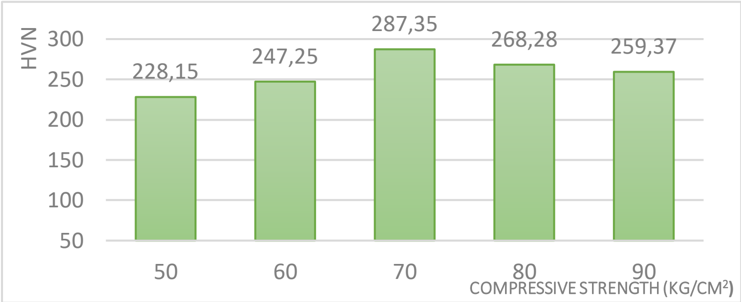


**Figure 5. Vickers hardness value on compressive strength.**

The bar chart in Figure 5 shows the effect of compressive strength on the hardness value of the surface of the sponge iron material. The lowest hardness value is obtained from a pressure variation of 50 kg/cm$^2$, which is around 228.15 HVN. In comparison, the highest hardness value at compaction is 70 kg/cm$^2$, which is 287.35 HVN. The increase in hardness is no longer too significant at the compaction values of 80 and 90 kg/cm$^2$. The compaction of the material strongly influences the value of the difference in hardness that occurs before reduction. Mechanically, the high density of material shows a correlation directly proportional to the value of increasing hardness. The difference in hardness values is also since the test material generated has space (voids) like a sponge so that the test material hardens on the outside of the surface during the combustion process. Observations were carried out to see the phenomenon of voids in sponge iron after the reduction process. The observed test samples were the highest hardness values (287.35 HVN) and the lowest (228.15 HVN) on sponge iron, as shown in Figure 6.

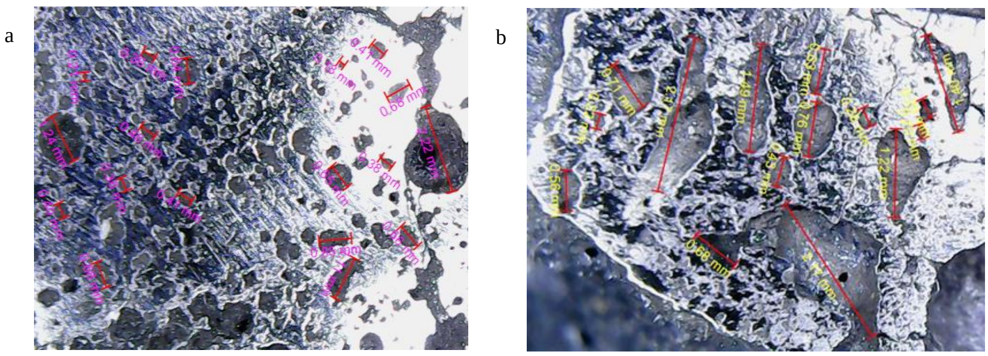


**Figure 6. Sponge iron with hardness value (a) 287.35 HVN (b) 228.15 HVN**

Figure 6 shows a comparison of the dimensions and the number of voids formed from the difference in the compressive strength of the test specimen after being a sponge iron product. The results of the micro-observations show where the voids formed at a compressive strength of 70 kg/cm$^2$ with a hardness value of 287.35 HVN, an average size of 0.4 mm, and evenly formed in sponge iron. Voids with a size between 0.7 to 1.5 with a compressive strength of 50 kg/cm$^2$ showed a significant effect of compressive strength on the reduction of iron sand in a sponge. The greater the value of the compressive strength of the pellet making process, the more uniform the size of the voids formed so that the hardness also increases.

The results of XRD analysis on sponge iron with a compressive strength of 90 kg/cm$^2$ show that there are peaks in the fraction relationship between the angle of fraction (2θ) and intercity (I) in Figure 7. From the fraction pattern, the formation of the dominant hematite ($Fe_2O_3$) phase is 59 .8%, and the magnetite ($Fe_3O_4$) phase was 40.2%. In the crystalline phase of $Fe_3O_4$, the percentage by weight of Fe is 66.57%, and C is 2.30% with a density value of

5.268 gr/$cm^3$. The value of this analysis shows that the pellet compressive strength interval between 50 to 90 kg/$cm^2$ can produce sponge iron which is dominated by crystalline hematite and magnetite phases.


**Figure 7. Graph of x-ray diffraction test results on sponge iron**

## 4. Conclusions

After conducting a reduction test on iron sand from the South Aceh region by varying the pellet pressure to obtain its physical and mechanical properties, it can be concluded that iron sand after being reduced to sponge has dominant hematite ($Fe_2O_3$) fraction pattern of 59.8%, and magnetite phase ($Fe_3O_4$) of 40.2% with a weight percentage of 66.57% Fe and 2.30% C. Furthermore, the hardness test on the test material obtained the lowest hardness value of 228.15 HV at a pressure of 50 kg/$cm^2$, and the highest pressure value was 287.35 HV with an emphasis of 70 kg/$cm^2$. The difference in hardness values is also since the test material generated has space (voids) like a sponge so that the test material hardens on the outside of the surface during the combustion process. This study indicates that iron sand obtained from the South Aceh region can be an alternative raw material choice in the steel production process.

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