Assessing the Grindability Behaviour of Anka (Zamfara State, Nigeria) Manganese Ore towards Effective Manganese Mineral Liberation

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Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Bond standard grindability test provides a Work Index that is widely used to estimate the energy required for ore grinding. The research investigates the work index of Anka Manganese ore at Anka deposit in Zamfara state, Nigeria. The reference ore (Quartz) was sourced from the studied ore overburden in the mine. The test ore and the reference ore were characterized using Energy Dispersive X-ray fluorescence spectrometer, X-ray Diffractometer and the Scanning Electron Microscope equipped with Energy Dispersive Spectrum. 500 g each of the manganese ore and quartz were sampled and prepared by crushing and grinding to 100% passing 1200 μm sieve. 100 g of prepared ores were charged into array of sieve arranged in √2 series from 1000 μm to 63 μm. Set of sieves were mounted on the Automated Pascal Denver sieve shaker (16153) and was in operation for 20 minutes. The work index of reference ore was used to calculate the work index of the test ore using Gaudin Schuman expression to obtain a work index of 14.16 Kwh/ton for test ore and it lies within the work index of 10-15.14 Kwh/ton for manganese ore stated in the literature and the energy expended to achieve comminution at mineral liberation size was calculated to be 3.3984 Kw/ton.

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1. INTRODUCTION

Manganese ore is an important and indispensable input raw material for steel making and steel production and its consumption is among the key indicators of industrial development in any country [1-3]. Ore is an aggregate of economically important minerals from which a valuable metallic constituent can be profitably extracted within an ore body; the valuable minerals are surrounded by gangue minerals. It is due to this primary reason; there’s need for mineral processing. It is necessary to liberate and concentrate those valuable minerals from the bulk mass through suitable concentration techniques [4]. Mineral processing involves the enrichment of concentrate by separating the grains of valuable mineral from the gangue and since most ore minerals are usually finely intimately associated with gangue minerals, the various metallic minerals must be liberated before they can be collected as separate products. Therefore, the first part in mineral processing involves the crushing and grinding which is also known comminution of the ore which is the gradual reduction in size of the particles [5,6]. Therefore, the objective of this study is to determine the grindability behaviour of Anka Manganese ore.

1.1 Work Index Determination

The work index is the energy required to reduce a given material from theoretical infinite size to 80% passing size of 100 μm and the Bond index method is useful in designing of grinding system as its parameters are used to measure ore grindability which involve the use of a test ore and reference ore [7-9]. The method requires the use of a reference ore with a known energy requirement value. The determination of work index of an ore will help in calculating the energy requirement for comminution of the ore and selection of appropriate comminution equipment. Using the modified bond’s equation the work Index of an ore is determined by:

\[
W = W_t = W_r = \left(\frac{10}{Pr} - \frac{10}{Pt}\right)
\]

\[W_t = W_r \times \left(\frac{10}{Pr} - \frac{10}{Pt}\right)
\]

Where;
\[W_t\] is the work index of test ore
\[W_r\] is the work index of reference ore

\[Pr\] is the diameter of the reference ore through which 80% of the product passes through 100μm
\[Pt\] is the diameter of the test ore through which 80% of the product passes through 100 μm

2. MATERIALS AND METHODS

2.1 Materials

5kg sample of Anka Manganese ore of which 2 kg of the sample used in this research work was obtained from the Anka deposit located in the northern axis of Zamfara state bounded by the geological coordinates, latitude 12°06'30"N and longitude 5°56'00"E which is a reserve that is still under investigation by the Nigerian Geological Survey (NGS). The quartz sample used as reference ore was sourced from Anka deposit overburden, in Zamfara state.

2.2 Method

The modified Bond’s method was used to determine the work index of ore which involves the use of a reference with a known grindability value. The sample of the reference ore (Quartz) was broken with a sledge hammer to provide required size acceptable as feed to the Fritsch Pulveristte Laboratory Jaw Crusher (Model LF6797AC). 100 g each of the test (Anka Manganese) and the reference ore (Quartz) were crushed. 100 g each of the test and reference samples were then charged into the set of sieves which was placed on the Automated Pascal Denver sieve shaker (16153) which vibrates the sieve in a vertical plane for 20 minutes and each sieve fraction retained of the test and reference ore were weighed and the value noted as the feed product. 100 g each from crushed samples was pulverized in the Denver Laboratory Milling Machine (Size: D-12) and was also charged into the set of sieves which was placed on the Automated Pascal Denver sieve shaker (16153) which vibrates the sieve in a vertical plane for 15 minutes and each sieve fraction retained of the test and reference ore were weighed and the value noted as the milled product.
Plate 1. Sequential order of Manganese ore sample collection and preparation

3. RESULTS AND DISCUSSION

3.1 Results

Table 1. Sieve Analysis of Anka Manganese Ore (Test Ore) Feed to Ball Mill

| Sieve size range (µm) | Weight retained (g) | % Weight Retained | % Cumulative weight retained | %Cumulative weight passing |
|-----------------------|---------------------|-------------------|-----------------------------|---------------------------|
| +1000                 | 2.50                | 2.51              | 2.51                        | 97.49                     |
| -1000+710             | 1.50                | 1.50              | 4.01                        | 95.99                     |
| -710+500              | 22.30               | 22.35             | 26.36                       | 73.64                     |
| -500+355              | 16.40               | 16.43             | 42.79                       | 57.21                     |
| -355+250              | 12.30               | 12.32             | 55.11                       | 44.89                     |
| -250+180              | 9.70                | 9.72              | 64.83                       | 35.17                     |
| -180+125              | 9.30                | 9.32              | 74.15                       | 25.85                     |
| -125+90               | 7.60                | 7.61              | 81.76                       | 18.24                     |
| -90+63                | 10.10               | 10.12             | 91.88                       | 8.12                      |
| -63                   | 8.10                | 8.12              | 100                         | 0                         |
Table 2. Sieve analysis of quartz (Reference Ore) feed to ball mill

| Sieve size range (µm) | Weight retained (g) | % Weight Retained | % Cumulative weight retained | % Cumulative weight passing |
|-----------------------|---------------------|--------------------|-----------------------------|---------------------------|
| +1000                 | 0.70                | 0.71               | 0.71                        | 99.29                     |
| -1000+710             | 1.60                | 1.62               | 2.33                        | 97.67                     |
| -710+500              | 28.20               | 28.51              | 30.84                       | 69.16                     |
| -500+355              | 18.70               | 18.91              | 49.75                       | 50.25                     |
| -355+250              | 13.30               | 13.45              | 63.20                       | 36.80                     |
| -250+180              | 10.20               | 10.31              | 73.51                       | 26.49                     |
| -180+125              | 13.50               | 13.65              | 87.16                       | 12.84                     |
| -125+90               | 5.20                | 5.26               | 92.42                       | 7.52                      |
| -90+63                | 5.0                 | 5.06               | 97.48                       | 2.52                      |
| -63                   | 2.5                 | 2.52               | 100                         | 0                         |

Table 3. Sieve analysis of Anka manganese Ore (Test Ore) milled product from ball mill

| Sieve size range (µm) | Weight retained (g) | % Weight Retained | % Cumulative weight retained | % Cumulative weight passing |
|-----------------------|---------------------|--------------------|-----------------------------|---------------------------|
| +1000                 |                     |                    |                             |                           |
| -1000+710             |                     |                    |                             |                           |
| -710+500              | 0.60                | 0.60               | 0.60                        | 99.4                      |
| -500+355              | 1.20                | 1.21               | 1.81                        | 98.19                     |
| -355+250              | 18.60               | 18.71              | 20.52                       | 79.48                     |
| -250+180              | 12.40               | 12.47              | 32.99                       | 67.01                     |
| -180+125              | 16.20               | 16.30              | 49.29                       | 50.71                     |
| -125+90               | 15.30               | 15.40              | 64.69                       | 35.31                     |
| -90+63                | 16.50               | 16.60              | 81.29                       | 18.71                     |
| -63                   | 18.60               | 18.71              | 100                         | 0                         |

Table 4. Sieve analysis of quartz (Reference Ore) milled product from ball mill

| Sieve size range (µm) | Weight retained (g) | % Weight Retained | % Cumulative weight retained | % Cumulative weight passing |
|-----------------------|---------------------|--------------------|-----------------------------|---------------------------|
| +1000                 |                     |                    |                             |                           |
| -1000+710             |                     |                    |                             |                           |
| -710+500              | 0.70                | 0.70               | 0.70                        | 99.30                     |
| -500+355              | 1.60                | 1.61               | 2.31                        | 97.69                     |
| -355+250              | 15.40               | 15.48              | 17.79                       | 82.21                     |
| -250+180              | 12.40               | 12.46              | 30.25                       | 69.75                     |
| -180+125              | 16.80               | 16.88              | 47.13                       | 52.87                     |
| -125+90               | 16.30               | 16.38              | 63.51                       | 36.49                     |
| -90+63                | 15.30               | 15.38              | 78.89                       | 21.11                     |
| -63                   | 21.00               | 21.11              | 100                         | 0                         |

3.1.1 Evaluation of grindability

Using Gaudin Schumann Expression

\[ P(X) = 100 \left( X + K \right)^a \]

\[ \alpha = \frac{\log P(X_2) - \log P(X_1)}{\log X_2 - \log X_1} \]

\[ X = \text{Sieve mesh size with 80% of particle size passing} \]

Thus: \[ R = \frac{F}{P} \]

Where

\[ R = \text{Reduction Ratio} \]
\[ F = \text{Diameter of feed particles} \]
\[ P = \text{Diameter of product particles} \]
Table 5. Sieve mesh size (500 µm and 250 µm) with 80% of particle size passing

| Sample    | 80% Passing of Feed Product (µm) (F) | 80% Passing Milled Product (µm) (P) |
|-----------|--------------------------------------|-------------------------------------|
| Test Ore  | 591                                  | 236.75                              |
| Reference | 663.5                                | 253.75                              |

3.1.2 Work index determination

Work index of test ore (W_{it}) was calculated using values in Table 5 substituted in Equations 1 and 2 respectively, with known work index of reference ore (Quartz) of 14.1 Kwh/ton. Therefore, W_{it} = 14.1, substituting this in equation 2.

\[ W_{it} = 14.1 \times \left( \frac{10}{\sqrt{236.75}} - \frac{10}{\sqrt{591}} \right) = 14.16 \text{ Kwh/ton} \]

3.1.3 Energy expended in grinding determination

Energy expended in achieving liberation size during comminution was achieved by substituting test work index into Equation 1.

\[ W_{t} = 10W_{it} \times \left( \frac{1}{\sqrt{236.75}} - \frac{1}{\sqrt{591}} \right) = 10 \times 14.16 \times \left( \frac{1}{\sqrt{236.75}} - \frac{1}{\sqrt{591}} \right) = 3.3984 \text{ Kwh} \]

3.2 Discussion

Table 1 – 5 present the result of the grindability of Anka Manganese ore as Test ore using Quartz as Reference ore (Overburden of the Anka mine site). The result revealed that 80% passing particle size fractions for feed to the ball mill (F, F_{r}) of both the reference ore and test ore was found to be 663.5 µm and 591 µm, likewise the 80% passing particle size fractions for product from the ball mill (P, P_{r}) of both the reference ore and test ore was found to be 253.73 µm and 236.75 µm respectively. The work index of the Anka (Zamfara State) Manganese Ore was computed to be 14.16 Kwh/ton and the value obtained means that 14.16 Kwh/ton of energy is required to reduce one ton of the Anka (Zamfara State) Manganese ore sample from 80% passing 591 µm to 80% passing 236.75 µm. The work index of the reference ore (Quartz) of 14.1 Kwh/ton and the value obtained means that 14.16 Kwh/ton of energy is required to reduce one ton of the reference ore (Quartz) of 14.1 Kwh/ton and the value obtained means that 14.16 Kwh/ton of energy is required to reduce one ton of the Anka (Zamfara State) Manganese ore sample from 80% passing 591 µm to 80% passing 236.75 µm. The work index of the Anka (Zamfara State) Manganese ore was found to be 14.16 Kwh/ton and it falls within the range indicated in literatures as standard which is 10-15.14 Kwh/ton [10,11]. The value was also used in calculating the amount of energy expended (W_{t}) in grinding the test ore using Bond’s equation and was found 3.3984 Kwh was the energy required. It is worth to know that only 1% of this energy (W_{t}) was actually used in the ore grinding process; while the rest was converted into noise, heat, etc [11].

4. CONCLUSION

Assessing the grindability behavior of Anka manganese ore towards effective manganese mineral liberation was investigated. This is very important to know the grinding characteristics of theore towards determination of suitable power to be selected for its comminution process and hence selecting suitable design parameters for construction of grinding machine suitable for comminution process of studied test ore to its liberation size avoid excess grinding or under grinding. Hence, the work Index and energy expended in grinding of Anka Manganese ore from Anka deposit located in the northern axis of Zamfara State, Nigeria has been computed to be 14.1 kwh/ton and 3.3984 Kwh respectively and its between the recommended values stated in literatures.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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