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Liberation Size and Work Index of Kurungu Iron Ore Deposit, Kogi State, Nigeria

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ABSTRACT

The liberation size and work index of Kurungu iron ore deposit located in Ajaokuta Local Government Area of Kogi State, Nigeria was determined in this study. Samples were collected from the ore site and prepared for sieve analyses and testing. The modified Bond work index method was used to determine the work index, using granite with known work index as the reference ore. The test sample (Kurungu iron ore) collected from different pits was homogenized, pulverized and sieved using the shaking machine. The various sieved size fractions of the ore were analyzed using X-ray Fluorescence (XRF), and the liberation size was determined to be 250 µm containing 45.33% Fe. The work index was calculated to be 13.96 kWh/t. Hence the liberation size and energy required for comminution has been established for the Kurungu Iron ore.

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1. INTRODUCTION

Iron can be said to be the cheapest metal but its combination with carbon to produce steel makes it and its alloys the most versatile basic engineering material for the manufacturing and construction industries (DeGarmo, 1997). There is therefore a positive correlation between iron and steel consumption and industrial and infrastructural development (He and Wang, 2017).

It has been proven that Nigeria is endowed with lots of solid minerals including but not limited to precious metals, stones and industrial minerals. The Federal Ministry of Mines have found over five hundred (500) locations of mineral deposits in the country and identified nine (9) that they would want to concentrate and promote, and these include coal , tin ore, gold, bitumen, iron ore, columbite –tantalite, lead-zinc, Wolframite and industrial minerals (Allen 2017). Few of these mineral deposits have been fully explored and their level ascertained, while further investigation is still required to determine the reserves of the occurrence of many others, which are not yet listed (Obassi et al., 2015).

In the mineral industry, mineral processing is a critical stage in the primary production of high-quality mineralogical concentrates from ores. This is accomplished via comminution which has a sequence of crushing and grinding processes (Pryor, 2012). Comminution is the highest consumer of energy, and records have shown that 30-50 % of the total plant power consumption is used in the mineral processing plants and up to 70 % for hard core is attributed to comminution (Nagaraj, 2000). Crushing reduces the particle size of runoff mine ore to significant level that grinding can be carried out until the mineral and gangue are substantially produced as separate particles. The energy required to grind one tonne of an ore from a given feed size to a specified product size is a material property that needs to be determined for different ore deposits (Allen, 2017). One of the major objectives of comminution is the liberation or release of the valuable minerals from the associated gangue mineral at the coarsest possible particle size. If this aim is achieved, then not only is energy saved by the reduction of the amount of fines produced, but any subsequent separation stages become easier and cheaper to operate (Obassi et. al., 2015). If high grade solid products are required, then good liberation is essential (Dos Santos and Galery 2018).

When a maximum amount of the mineral of interest is separated by comminution from the parent rock at a particular size fraction, that size is usually known as the liberation size (Ogundeji et al., 2018). Liberation size of an ore is very significant component in any process design as it gives the operators a clear view of the sieve size the grinding operation should target (Usaini et al., 2014). This information is of great importance as it prevents over grinding and hence saves a great deal of cost

Grindability is the ease with which a mineral can be comminuted and the data obtained from the grindability tests are used to evaluate the energy requirement and grinding efficiency. The most commonly used parameter to measure ore grindability is the bond work index.

The Bond work index (Wi) expresses the resistance of the material to grinding. It represents the kilowatt hours per tonne required to reduce the material from theoretically infinite feed size to 80 percent passing 100 μm (Wills and Napier-Munn, 2006). Bond devised several methods for predicting ball-mill and rod-mill energy requirements and provided an accurate measure of ore grindability (Egbe *et al.,* 2013).

Obassi et al. (2014) and Olatunji and Durojaye (2010) used the Bond comparative grindability test to determine the work index of Eyigba lead ore and Birnin-Gwari iron ore respectively. The test involved grinding a reference ore of know work index and specific weight for a certain period of time and then recording the power consumed. An identical weight of the test ore is then ground for a length of time such that the power consumed is identical with that of the reference ore. In a world with limited energy resources, there is need to design the energy requirements of engineering processes. Hence this study attempts to determine the liberation size and work index of the Kurungu Iron ore.

2. MATERIALS AND METHODS

2.1. Location of the Study Area

The study area is Kurungu village located along Okene Ajaokuta Expressway, Kogi State, Nigeria. The deposit is on an elevation of 233 m. The deposit is a banded iron formation (BIF) and sedimentary in nature. Kurungu iron ore deposit covers a land mass area of about 320,000 m^2 and has an estimated reserve of over 50 million tonnes (Preliminary estimation) (RMRDC 2010).

2.2. Materials Collection

The ore used was collected from Kurungu village in Ajaokuta Local Government Area of Kogi State Nigeria. The sample was collected from different pits at interval of 150 m apart at 3 m depth to get a representative sample of the ore deposit. The various samples were mixed thoroughly to produce a homogenous sample which was used for the analyses. Granite of known work index was used as the reference ore.

The equipment used include global positioning system (Extex GARMIN 10), laboratory sledge hammer, laboratory jaw crusher (415 V, 50 Hz,4000 W & 8.1 A), pulverizer (220-240 V, 50 Hz, 370 W & 2x3.8 A), set of sieves (British Standard Test Sieve), laboratory sieve shaking machine (220-240 V, 50 Hz, 80 W & 2.3 A), weighing balance (Metlar MT-2000) and X-ray fluorescence machine (Mini-pal 4 EDXRF by Panalytical)

2.3. Methods

2.3.1. Sieve analysis

A part of the homogenous sample (1000 g) was subjected to sieve analysis. The arrangement of the sieves was done using a sieve scale in which the ratio of the aperture widths of adjacent sieves is the square root of two [$\sqrt{2}$]. Sieve sizes from +355 µm to 63 µm were arranged in a stack with the coarse sieve on the top and the finest at the bottom. A tight-fitting pan was placed below the bottom sieve to receive the final undersize and a lid was placed on top of the coarsest sieve to prevent escape of the sample. The arranged sieves were placed on an automatic rotap sieve shaker which vibrates the material vertically. The duration of the screening was set to 30 minutes by an automatic timer. During the shaking, the undersize material falls through successive sieves until it is retained on a sieve having apertures which were slightly smaller than the diameter of the particles. After a successful operation each size fraction retained on each sieve was collected, weighed and followed by XRF analysis

2.3.2. XRF analysis

The chemical composition of each sieve fraction was determined using Mini pal 4 X-Ray fluorescence machine as discussed elsewhere (Abduljalal, 2019)

2.3.3. Determination of work index

The modified Bond method of determination of work index was used in this work and it involves the use of a reference ore of known grindability (Egbe *et al.,* 2013). The reference ore of known weight was ground for 15 minutes and the power consumed was recorded after which the same weight of test ore was ground until it had consumed the same power as used for the reference ore (Abduljalal 2019) The 80% passing of the reference and test ores were determined and used to calculate the work index.

3. RESULTS AND DISCUSSION

3.1. Sieve Analysis

It was observed from the sieve analysis presented in Table 1, that of the total weight of 1000 g, 60 g was retained on the +355 µm sieve size, 100.1 g on 250 µm, 187.4 g on 180 µm , 273.6 g on 125 µm, 250.4 g on 90 µm and 95.9 g on 63 µm. This show the distribution of the ore within the various particle size fractions.

3.2. Chemical Analysis

From the chemical analysis conducted on all the six sieve sizes (Table 2), it was found that the +355 µm sieve contains 1.10% Ca, 14.38% Si, 0.87% Al and 39.84% Fe. 250µm contain 1.25%Ca, 11.74%Si, 1.02%Al and 45.33%Fe; 180µm contains 0.39%Ca, 13.24%Si, 0.24%Al and 44.15%Fe; 125µm contains 0.72%Ca, 16.17%Si, 0.64% Al and 40.81%Fe; 90µm contains 0.31%Ca, 19.08%Si, 0.46%Al and 35.35%Fe; while 63 µm contain 0.63%Ca, 18.75%Si, 0.70% Al and 37.19%Fe. This shows that the 250 µm size fraction contains the highest Fe content, hence confirm 250 µm to be the liberation size of Kurugu iron ore.

Table 1: Result of sieve analysis

Sieves range (µm)	Weight retained (g)	Weight retained (%)	Nominal aperture size (µm)	Cumulative weight retained (%)	Cumulative weight passing (%)
+355	60.0	06.00	355	06.00	94.00
-355+250	100.1	10.01	250	16.01	83.99
-250+180	187.4	18.74	180	35.75	64.25
-180+125	273.0	27.30	125	62.05	37.95
-125+90	250.4	25.04	90	87.09	12.91
-90+63	95.9	9.59	63	96.68	3.32
Pan	33.2	3.32		100	0.00

Table 2: Result of the chemical analysis of head sample in element form

Aperture size	355 µm	250 µm	180 µm	125 µm	90 µm	63 µm
Element	% Composition					
Ca	1.10	1.25	0.39	0.72	0.31	0.63
Si	14.38	11.74	13.24	16.17	19.08	18.75
Al	0.87	1.02	0.24	0.64	0.46	0.70
Cr	ND	ND	ND	ND	0.01	0.03
Mn	0.80	1.30	0.39	0.31	0.86	ND
Fe	39.84	45.33	44.15	40.81	35.35	37.19
Ti	ND	0.01	0.25	0.01	ND	ND
Zn	0.14	0.04	0.04	0.08	ND	0.02
Mg	ND	0.02	ND	ND	ND	ND
Le	7.825	4.335	6.595	4.332	6.213	4.454

3.3. Determination of Work Index

Tables 3 to 6 present the particle size distribution for the feed and product of the test and reference materials respectively.

Table 3: Result of sieve size analysis of the “feed” test material (Kurungu iron ore)

Sieve size range (µm)	Weight retained (g)	% weight retained	Nominal aperture	Cumulative % weight retained	Cumulative % weight passing
+355	6.20	6.20	355	6.20	93.80
-355+250	10.79	10.79	250	16.99	83.01
-250+180	10.85	10.85	180	27.84	72.16
-180+125	29.83	29.83	125	57.67	62.33
-125+90	17.67	17.67	90	75.34	24.66
-90+63	12.87	12.87	63	88.21	11.79
-63	11.79	11.79	-	100	0.00

If 180 µm = 72.16% (from Table 3)

Xµm = 80.00%

Using the Gaudin Schumann expression

$$\text{Size2} = \left(\frac{\text{percentage passing size 2}}{\text{percentage passing size 1}}\right)^2 \text{ x size1} \quad (1)$$

$$= \left(\frac{0.8}{0.7216}\right)^2 \text{ x } 180 = 221.2 \ \mu\text{m @80\%}$$

Table 4: Result of sieve size analysis of the "product" test material (Kurungu iron ore)

Sieve size range (µm)	Weight retained (g)	% weight retained	Nominal aperture	Cumulative % weight retained	Cumulative % weight passing
+355	0.48	0.48	355	0.48	99.52
-355+250	11.90	11.90	250	12.38	87.62
-250+180	8.52	8.52	180	20.90	79.10
-180+125	12.14	12.14	125	33.04	66.96
-125+90	30.20	30.20	90	63.24	36.76
-90+63	8.11	8.11	63	71.35	28.65
-63	28.65	28.65	-	100	0.00

If 180 µm = 79.1% (from Table 4)

X µm = 80.00%

Using the Gaudin Schumann expression:

$$Size\ 2 = \left(\frac{0.8}{0.791}\right)^2 \text{ x } 180 = 184.1 \ \mu\text{m @ 80\%}$$

Table 5: Result of sieve size analysis of the ‘feed’ reference material (Granite)

Sieve size Range (µm)	Weight retained (g)	% weight retained	Nominal aperture	Cumulative % weight retained	Cumulative % weight passing
+355	8.36	8.36	355	8.36	91.64
-355+250	19.36	19.36	250	27.72	72.28
-250+180	17.87	17.87	180	45.59	54.41
-180+125	11.91	11.91	125	57.50	42.50
-125+90	13.89	13.89	90	71.39	28.61
-90+63	13.81	13.81	63	85.20	14.80
-63	14.80	14.80	-	100	0.00

If 250 µm = 72.28% (from Table 5)

X µm = 80.00%

Using the Gaudin Schumann expression:

$$Size\ 2 = \left(\frac{0.8}{0.7228}\right)^2 \text{ x } 250 = 306.26\ \mu m\ @80\%$$

Table 6: Result of sieve size analysis of the "product" reference material (Granite)

Sieve size range (µm)	Weight retained (g)	% weight retained	Nominal aperture	Cumulative % weight retained	Cumulative % weight passing
+355	2.20	2.20	355	2.20	97.80
-355+250	17.93	17.93	250	20.13	79.87
-250+180	2.47	2.47	180	22.60	77.40
-180+125	3.68	3.68	125	26.28	73.72
-125+90	27.86	27.86	90	54.14	45.72
-90+63	14.61	14.61	63	68.75	31.25
-63	31.25	31.25	-	100	0.00

If 250 µm = 79.87% (from Table 6)

X µm = 80%

Using the Gaudin Schumann expression

$$Size\ 2 = \left(\frac{0.8}{0.7987}\right)^2 \text{ x } 250 = 250.81\ \mu m\ @80\%$$

Work index calculation using Bond modified equation:

$$Wit = Wir\ \frac{\frac{10}{\sqrt{Pr}} - \frac{10}{\sqrt{Fr}}}{\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Ft}}} \quad (2)$$

Where:

Wit = work index of the ore under test, Wir = work index of the reference ore, Fr = 80% passing feed of the reference ore, Ft = 80% passing feed of the ore under test, Pr= 80% passing product of the reference ore, Pt = 80% passing product of the ore under test

Wir = 15.13 kwh/t, Pr = 250.81 µm, Fr = 306.26 µm, Pt = 184.1 µm, Ft = 221.2 µm

Substituting the actual values in Equation 2 yields:

$$Wit = 15.13\ \frac{\frac{10}{\sqrt{250.81}} - \frac{10}{\sqrt{306.26}}}{\frac{10}{\sqrt{184.1}} - \frac{10}{\sqrt{221.2}}}$$

= 15.13 x 0.923 = 13.96 kWh/t

Thus, using the modified Bond' Energy method, the work index of Kurungu iron Ore was calculated to be 13.96 kWh/ton.

4. CONCLUSION

The liberation size and work index of the Kurungu iron ore were determined. The liberation size is 250 µm sieve size having the highest grade of iron (45.33% Fe). Using the modified Bond' energy method, the work index of the ore was found to be 13.96 kWh/ton. This is the approximate energy that is required to grind one tonne of the ore to 80% passing 184.1 µm.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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