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DETERMINATION OF GRINDABILITY AND WORK INDEX OF ITAKPE IRON ORE

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ABSTRACT

Laboratory studies were carried out to determine the grindability and work index of Itakpe Iron ore, Okene, Nigeria. The Bond work index was measured in this study due to its reasonable application in the range of conventional ball mill and rod mill grinding as well as its wide acceptability in designing full scale mill in most mineral processing establishment. From the result of the analysis, the grindability and work index of Itakpe iron ore were found to be approximately 0.92g/rev and 13.45kwh/tonne respectively. The work index obtained for the Itakpe iron ore has a close correlation with 13.84kwh/tonne for specular Hematite.

(Key words: grindability, ore, analysis, index, correlation)

INTRODUCTION

Grindability and work index are important physical properties of ore that refer to the ease with which the ore material can be comminutted. It is important to measure these parameters for newly discovered ore as well as ore from the existing mine periodically in order to assess the efficiency of the selected equipment. Appropriate comminution equipment should be carefully selected because of their high energy intensities. Wills (1998) reported that about 50% of the energy utilized in processing of ore minerals is consumed at the comminution stage. Therefore a reasonable knowledge of the ore grindability on laboratory scale as well as the net power per tonne required for the degree of desired fines will be a useful tool in determining the mill power requirement of an ore.

Various theories such as Rittinger's, Kick's, Hukki's and Bond's Laws have been developed to determine grindability and work index of mineral ores. Smith and Lee (1968) compared Bond grindability with straight batch-type grindability and showed that they are empirically related. Hence, it is possible to estimate Bond grindability from batch-test. Berry and Bruce (1966) developed a comparative method of determining the work index of an ore. Using Bond's equation, they obtained an empirical equation.

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$$Wit = Wir\left(\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}\right) \Big/ \left(\frac{10}{\sqrt{P_t}} - \frac{10}{\sqrt{F_t}}\right) \quad \text{............1}$$

Where Wit = Work index for test ore,(kwht^{-1}), Wir = Work index for reference ore,(kwht^{-1}), P_r = 80% passing size of circuit product for reference ore, P_t = 80% passing size of circuit product for test ore, F_r = 80% passing size of new feed for reference ore, F_t = 80% passing size of new feed for test ore.

Yaro (1996) employed this method on Ririwai lead-zinc ore and concluded that the ore is of average resistance to grinding. All these theories assume that the material is brittle so that no energy is absorbed in processes such as elongation or contraction which is not finally utilized in breakage, Wills (1989). This present study was undertaken to measure the grindability and work index of Itakpe iron ore which has Fe_2O_3 (30.88%) and Fe_3O_4 (19.90%) geochemical composition by weight.

THEORETICAL CONSIDERATION

According to the standard Bond test, the work index (W_i) is found by simulating dry grinding in closed or locked circuit in a ball mill until the 250% circulating load has been achieved (Bond,1961).The net weight of undersize (-75μm) material found during a cycle is

$$W_{net} = W_n - \frac{(W_{n-1}X)}{100} \quad \text{..........................2}$$

Table 1: Geochemical analysis of Itakpe iron ore % composition by weight

Fe_2O_3	30.88	S	0.03
Fe_3O_4	19.90	Co_2	0.38
SiO_2	42.05	H_2O	0.41
CaO	1.25	Na_2O	0.52
Al_2O_3	3.20	K_2O	0.64
TiO_2	0.17	Pb	0.005
MgO	0.35	Zn	0.007
P	0.095	Cu	0.005

where W=weight of undersize in ground product,(g), n=number of cycle,X= percentage of undersize in feed. The grindability of nth cycle given as G_n is calculated as

$$G_n = W_n - \frac{(W_{n-1}X)}{100N_n} \quad \text{..............................3}$$

where N_n = number of revolution of mill in the nth cycle. Therefore, from the circulating load assumption the net weight (W_{net}) of undersize material to be produced in successive cycle is equal to the "intended product passing" (IPP) less weight of undersize in new feed, i.e.

$$W_{net} = 0.286W - \frac{(W_{n-1}X)}{100} \quad \text{.....................4}$$

The number of revolution for nth cycle is derived as

$$N_n = \frac{W_{net}}{G_{n-1}} \quad \text{...................................... 5.}$$

Bond test has been shown to take 5-7 cycles of sieve analysis of the undersize to find the 80% passing size of the product. On a laboratory scale, Bond has shown that the work index, (W_i), can be derived from the expression:

$$W_i = 1.1 \frac{16}{G^{0.82}} \sqrt{\frac{P_i}{100}} \quad \text{..........................6.}$$

This expression was further modified to yield the following equation:

$$W_i = \frac{4.45}{P_i^{0.22} G^{0.82} (P^{-0.5} - F^{-0.5})} \quad \text{........................7}$$

where W_i = Bond work index (kwht^{-1}), P_i = test sieve mesh (μm), G = Weight of test sieve fresh undersize per mill revolution (g/rev.) i.e. grindability, P=Opening of the tested sieve size passing 80% of the last cycle sieve undersize product (μm) and F=test sieve mesh passing 80% of the feed before grinding (μm).

In this work, appropriate parameters of equation 7 were measured and from which the work index (w_i) was determined.

MATERIALS AND METHODS

The material used in this work was obtained from Itakpe iron ore mine located near Okene in Kogi State. The chemical composition of the ore (NIOMP,1992) is given inTable 1.Comminution process as well as size analysis of the ore were carried out by the use of laboratory crushers, ball mill and sieve shaker.

About 3kg of the iron ore was crushed to about 6mm in stages thereby avoiding excess fines. The sieve analysis was carried out for a representative sample (approximately 300g) of the crushed feed. The feed size, F, that is the size in microns through which 80% of the feed passed was determined from the plot of the sieve analysis (Fig.1). The feed sample was placed in a measuring cylinder to a 500ml level and compacted by shaking to yield a volume of 350ml. This unit volume of 350ml was selected as the volume of the ore always present in the mill during close circuit grinding test.

For this test, a circulating load of 250% was assumed. For this circulating load, the mill throughput was 350% of the mill product and at equilibrium, mill product is equal to mill feed. So, the weight of the product to be produced in each cycle was 100/3.5 or 28.6% of the total mill feed.This is called the intended product passing or IPP which was 0.286W.The oversize (i.e. +75μm) from a cycle was the circulating load during the cycle. The combined product from the final three cycles forms the equilibrium test product,Venkatachalam and Degaleesan(1980). The mill, charged with the balls and 350ml feed was run for 100 rev. (N_1). At the end of the cycle, the ground product

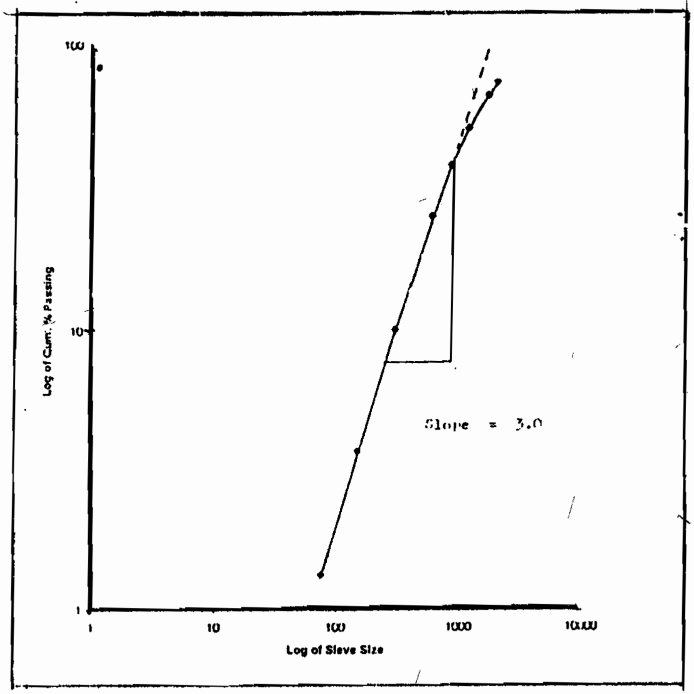

Fig. 1 Logarithm Plot of Cumulative Percent Passing Against Particle Size

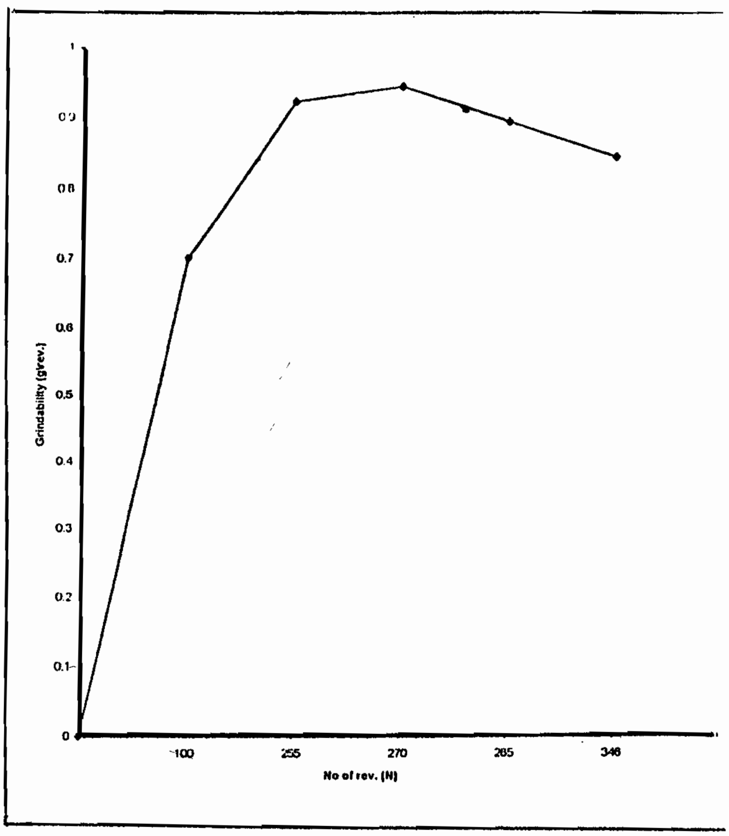

Fig. 2: Graph of grindability test against mill revolution of the ore .

was sieved through a 75μm sieve taking small proportion at a time to avoid sieve blindness and overloading. The -75μm particle size in the ground product was weighed (W_1g).The grindability of the first cycle, G_1 was obtained using equation (3). Closed circuit was achieved by screening through 75μm and replacing - 75μm fraction by fresh addition of feed at the end of each cycle. The number of revolutions, N_2, for the second cycle was calculated based on equations (4) and (5). During the second cycle, the mill was run for N_2 revolutions and the product was sieved accordingly and closed circuit was achieved during this process. G_2 and N_3 were determined and repeated for successive cycles.

Equations (3),(4) and (5) were used to determine the grindability, the net weight of product material and the number of revolutions

Table 2: Results of sieve analysis (Feed to the Ball mill)

Sieve size (μm)	Wt. Retained (g)	Wt. % retained	cumulative wt. % passing
2000	79.2	26.35	73.65
1700	22.85	7.6	66.04
1180	46.3	15.41	50.64
850	39.42	13.21	37.52
600	38.44	12.79	24.73
300	43.86	14.59	10.13
150	19.11	6.36	3.77
75	7.35	2.45	1.33
-75	3.99	1.33	0

Table 3: Results of grindability test done at 75μm.

Cycle (n)	No of rev. (N)	-75μm in product (g)	-75μm in feed (g)	Net - 75μm produced (g)	Grindability, G (g/rev)	New feed to be added (g)	-75μm in new feed (g)	No of rev. for next cycle (N)
1	100	81.46	1.31	70.15	0.7	81.46	1.08	346
2	346	290.2	1.08	289.15	0.84	290.23	3.85	285
3	285	258	3.85	254.19	0.89	258.04	3.43	270
4	270	257.8	3.42	254.38	0.94	257.81	3.42	255
5	255	237.3	3.42	233.85	0.92	237.27	3.15	261

Equivalent grindability, G = 0.92 (Average of last 3 cycles)

for nth cycle as given in Table 3. From the results given in Table 3, the work index was determined using equation (7).

RESULTS

Tables 2 and 3 show the results of sieve analysis (Feed to the ball mill) and grindability test done at 75μm respectively. Figure 1 is the logarithm plot of the cumulative percent passing against particle size while Figure 2 is the graph of mill revolution against grindability of the ore. Table 4 is the average work indexes by type of materials as examined by Bond to serve as reference in work index determination.

DISCUSSION

From Table 2, it is obvious that the highest weight percent retained is found with 2000μm sieve size which may be due to the low reduction ratio (7:1) of the pulverizer.The distribution modulus (m = 3.0) is the slope of the logarithm plot in Figure 1 and gives a measure of the size distribution. A large value of m (>2) indicates a narrower distribution. In practice, the size modulus can be approximately equal to 80% passing size obtained from the screen analysis data. This is the reason why the 80% passing size is usually recommended and widely used in grindability studies. Also the weight percent passing has a linear relationship with the sieve size. The results of the grindability test show that the net -75μm produced increases with increase in number of revolution and increase in grindability to a certain limit. That is, the highest grindability of 0.94g/rev. was attained at mill revolution of 270.,(Fig. 2). At this point any increase in mill revolution will lead to more energy input in the mill which is not being utilized for actual size reduction but in production of heat. The work index of Itakpe iron ore obtained from the

Table 4: Average work indexes.

By type of materials.
Caution should be used in applying the average Work Index Values listed here to specific installations, since the individual Variations between materials in any classification may be quite large.

Material	No of Tests	Aveage Specific Gravity (S)	Aveage Work Index (W_i)	Material	No of Tests	Average Specific Gravity (S)	Average Work Index (W_i)
All Materials Teste	1242	-	14.39	Iron ore			
Andesite	6	2.84	18.25	Hematite	61	3.53	12.84
Barite	7	4.50	4.73	Hematite (Specular)	3	3.28	13.84
Basalt	3	2.91	17.10	Oolitic	6	3.52	11.33
Bauxite	4	2.20	8.78	Magnetite	58	3.88	9.97
Cement clinker	16	3.15	13.45	Taconite	56	3.54	14.61
Cement raw material	19	2.67	10.51	Lead ore	10	3.35	11.90
Clay	7	2.51	6.30	Lead-zinc	16	3.36	10.93
Coal	2	1.40	13.00	Limestone	79	2.66	12.74
Coke	8	1.31	15.13	Manganese ore	12	3.53	12.20
Copper ore	204	3.02	12.73	Magnesite	9	3.06	11.13
Diorite	4	2.82	20.90	Molybdenum	6	2.70	12.80
Doiomiate	5	2.74	11.27	Nickel ore	8	3.28	13.65
Emery	4	3.48	56.70	Oil shale	9	1.84	15.84
Feldspar	8	2.59	10.80	Phosphate rock	17	2.74	9.92
Ferro-chrome	9	6.66	7.64	Potash ore	8	2.40	8.05
Ferro-manganese	5	6.32	8.30	Pyrite ore	6	4.06	8.93
Ferro-silicon	13	4.41	10.01	Pyrrhotite ore	3	4.04	9.57
Flint	5	2.65	26.16	Quartzite	8	2.68	9.58
Fluorspar	5	3.01	8.91	Quartz	13	2.65	13.57
Gabbro	4	2.83	18.45	Rutile ore	4	2.80	12.68
Glass	4	2.58	12.31	Shale	9	2.63	15.87
Gneiss	3	2.71	20.13	Silica sand	5	2.67	14.10
Gold ore	197	2.81	14.93	Silicon carbide	3	2.75	25.87
Granite	37	2.66	15.13	Slag	14	2.74	10.24
Graphite	6	1.75	43.56	Syenite	3	2.73	13.13
Gravel	15	2.66	16.06	Tin ore	8	3.95	10.90
Gypsum rock	4	2.69	6.73	Titanium ore	14	4.01	12.33
				Trap rock	17	2.87	19.32
				Zinz ore	12	3.64	11.56

After Bond (1949)

experimental work is approximately 13.45 $kwht^{-1}$. This means that about 13.45 kilowatts hour of energy is required to reduce one tonne of Itakpe iron ore from 80% passing particle size of 2200μm (feed) to 80% passing particle size of 75μm product.

CONCLUSION

From the results of the investigation, the following conclusion can be drawn:

1. The value of the work index(13.45$kwht^{-1}$) obtained for Itakpe iron ore was correlated with average work indexes of Bond concept (Table 4) and found to be valid as it is close to the value for specular Hematite(13.84$kwht^{-1}$).

2. The Itakpe iron ore is of average resistance to grinding for according to Yaro (1996), ore having a work index value of 11-15 kilowatts hours per tonne is considered to have an average resistance to grinding. Therefore, the ore can be fairly comminuted.

3. The work index can be profitably used in similar plant design work and can also be employed to improve existing mineral processing operations.

4. Utilisation of result of findings enables proper choice of comminution equipment and this will reduce cost of energy utilized during comminution.

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