Nigerian Journal of Technology (NIJOTECH)
Vol. 42, No. 2, June, 2023, pp.244 - 248
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v42i2.12

DETERMINATION OF BOND WORK INDEX OF BAGEGA GOLD MINERAL DEPOSIT OF ZAMFARA STATE, NIGERIA

E. O. Oji[1,*], A. D. Omah[1], and Y. H. Onymisi[2]

[1]Department Of Metallurgical & Materials Engineering, University Of Nigeria, Nsukka, Enugu State.
[2]Department Of Mechanical Engineering, Federal Polythenic Offa, Kwara, State.

*corresponding author (Email: emmanuel.oji@unn.edu.ng)

Article history: Received 14 April, 2022. Revised 14 December, 2022. Accepted 20 April, 2023. Published 31 July, 2023. *CC BY-NC-ND Licence*

Abstract
The study determined the bond work index of Begaga gold mineral deposit of Zamfara State Nigeria using Berry and Bruce modified bond method. Sample of gold mineral was sourced using random sampling method. Reference mineral (Granite) of known weight and work index of 15.13Kwh/ton was ground for thirty minutes at a particular speed and power consumed was determined from the power rating of the ball mill. An identical weight of Bagega gold mineral whose work index was to be determined was ground in the same ball mill under same condition as that of reference mineral. Size analysis of the ball mill under same condition as that of the reference mineral was performed. Size analysis of the ball mill feed and discharge for both ores was carried out and 80% passing particle size of the ball mill feed and discharge for the two ores were estimated mathematically using correlation approach. The work index of the Bagega gold mineral was determined by equating the power consumed in the two indexes of the ore. It was found to be approximately 14.24Kwh/ton which is within the acceptable range of 10 - 15.14Kwh/ton indicated in literatures as standard work index range of gold. This value of the work index means that 14.25Kilowatts hour of energy is required to reduced one tonne of the gold ore from 80% passing particle size of 1117.32μm to 80% passing particle size of 800.00μm, it should serve as the work index of Bagega gold.

Keywords: Bond work index, Bagega gold mineral deposit, Modified bond method, Reference mineral, Granite, Mineral processing, Reference ore, Test ore, Ball mill, Graindability, Comminution, Berry and Bruce method.

1.0 INTRODUCTION

Bond index in other word referred to as ore grindability, simply described the ease in which the mineral ore can be comminuted. It is useful in designing of grinding system in mineral processing [2], for a newly discovered ore it is very important to determine its hardness and grinding characteristics so that suitable power can be selected for its comminution [3].

Comminution in mineral processing plant or mill takes place as a sequence of unit operations involving crushing and grinding processes. Crushing reduces the particle size of run-off mines ore to such a level that grinding can be carried out on the mineral and gangues are substantially produced as separated particles [3].

The choice of appropriate comminution equipment is very important because comminution is energy intensive operation which aids liberation choice. In fact it has been established that fifty percent of the energy used in processing of mineral is consumed at the comminution stage [8].

The most widely used parameter to measure ore grindability is the bond work index which is numerically the work index which defines the energy required in Kwh/short tones to reduce a given material from theoretical infinite size to 80% passing of 100microns [10].

The earlier methods of grindability test were the simple open circuit batch test; this method was found to be only suitable for materials which are homogenous in nature such as coal because the grindability of the ore was reported as either harder or softer than the required reference ore which has undergone the same processes [3]. Closed circuit grindability test were later introduced to overcome the problems of the open-circuit test. The grindability was given as the rate of production of net grains of under-size passing a specific mesh of grinding per unit time [2].

The development of Bond's theory in 1952 and his methods of determining grindability of ore which are similar to closed circuit grindability test were empirically modified to be the work index of the ore [3]. A number of methods of grindability test which are simpler and faster and at the same time produced comparative results with choice of Bond's were devised. One of these methods was derived by Berry and Bruce [2, 8].

The determination of work index using modified Bond's method can be compared to method of determining it by Berry and Bruce in 1966. This method requires the use of a reference ore of known grindability [8]. The standard Bond test is time-consuming, capital intensive and required a standard mineral processing plant with the necessary facilities. Based on this, a number of methods have been used to obtain the indices related to the Bond work index. Smith and Lee 1968 used batch-type grindability tests to arrive at the work index, and compared their results with work indices from the standard Bond tests, which require constant screening out of undersize material in order to simulate closed-circuit operation. The batch-type tests compared very favourably with the standard grindability test data. The advantages being that less time is required to determine the work index [6].

In this research work, Berry and Bruce method of determining mineral grindability is used in determining the work index of Bagega gold mineral deposit because of its advantages. Bond developed an equation which is based on the theory that, the work input into either a crusher or grinding mill is proportional to the new crack tip length produced during the particle breakage which is equal to the work represented by the product minus that represented by the free Bond's equation, given as:

$$W = \frac{10W_i}{\sqrt{P}} - \frac{10W_i}{\sqrt{F}}$$

$$W = 10W_i\left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}\right)$$

Where,

W_i represents the work index of the material being broken

P represents the diameter in micron meter with 80% of the product passes

F represents the diameter in micron meter which 80% of the feed passes

W represents work input in Kilowatt hour per short tonne.

The objective of this research work is to determine the grindability of Bagega gold mineral deposit located in Zamfara state of Nigeria using modified Bond's Method**.** Grindability test helps in the designing of plant capacity, its energy requirements and other parameters required for mineral liberation.

2.0 MATERIALS AND METHODS

Representative sample of the mineral (Test ore) were obtained from the deposit site in Bagega village. Granite (Reference ore) of known work index from Furaka village in Jos North Local Government Area, Plateau State was obtained, using random sampling method, which involves collection of samples at various spot of the mining site, five meters apart; fifty kilogram of each material was obtained for the study. Samples were broken manually with a sledge hammer to provide the required size acceptable to laboratory Denver Jaw crusher, then to cone crusher and finally roll crusher. The samples were crushed and pulverized, part of pulverized samples was weighed for sieve analysis, and this was carried out at the National Metallurgical Development Centre (NMDC), Jos. The modified Bond's method of determining the net work index of ore involves the use of reference ore of known grindability was adopted.

The procedures were as follows:

1.100g each of the test ore and the reference ore were crushed and pulverized in the laboratory ball mill for an hour.

2. The samples of test and reference ores were taken and seized by sieving into a number of size fraction using the automatic sieve shaker for thirty minutes.

3. Each size fraction of the test and the reference ores were weighed and the value noted "feed"

4. The "feed" test and reference ores were each gathered together and introduced into the laboratory ball milling machine and mill for thirty minutes.

5. The test and the reference ores from the laboratory ball mill machine were sized and each sieve fraction was weighed and the value noted as the product or discharge.

6. Sieve analysis. The ground samples were sieved into the following sieve size fractions;+1400 μm,+1000 μm,+710 μm,+500 μm,+355 μm,+250

© 2023 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
(http://creativecommons.org/licenses/by-nc-nd/4.0/)

µm,+180 µm,+125 µm,+90 µm,+63µm,-63µm using automatic Denver sieve shaker for thirty minutes.

The weight of materials retained on each sieve size was then tabulated against the sieve size for both the reference ore (Granite) of 15.13kwh/ton work index and the test mineral [16].

3.0 RESULTS AND DISCUSSION

3.1 Results

The results of the tests are given in Table 1 to 4

Table 1: Sieve analysis of Feed to ball mill of test ore

Sieve Size Range (µm)	Weight retained (g)	% Weight retained	Cumulative % weight retained	Cumulative % weight Passing
+1400	12.52	12.52	12.52	87.48
-1400 + 1000	15.83	15.83	28.34	71.66
-1000 + 700	13.54	13.54	41.88	58.12
-700 +500	11.64	11.64	53.52	46.48
-500 +355	9.87	9.87	63.39	36.61
-355 +250	8.54	8.54	71.93	28.07
-250 +180	8.62	8.62	80.55	19.45
-180 +125	8.41	8.41	88.86	11.04
-125 +90	6.55	6.55	95.51	4.49
-90 +63	2.52	2.52	98.03	1.97
-63	1.96	1.96	100.0	-

Calculation 1:
If 1000 μm = 71.66%
X µm = 80%

$$X = \frac{80*1000}{71.6} = 1117.32\ \mu m$$

Table 2: Sieve analysis of Product of ball mill of test ore

Sieve Size Range (µm)	Weight retained (g)	%Weight retained	Cumulative % weight retained	Cumulative % weight Passing
+1400	-	-	-	100
-1400 + 1000	-	-	-	100
-1000 + 700	-	-	-	100
-700 +500	0.22	0.22	0.22	99.78
-500 +355	0.53	0.53	0.75	99.25
-355 +250	13.60	13.60	14.35	85.65
-250 +180	49.88	49.88	64.23	35.77
-180 +125	19.33	19.33	83.56	16.44
-125 +90	10.80	10.80	94.36	5.64
-90 +63	3.50	3.50	97.86	2.14
-63	2.14	2.14	100.0	-

Calculation 2:
If 1000 μm = 100%
X µm = 80%

$$X = \frac{80*1000}{100} = 800.00\ \mu m$$

Table 3: Sieve analysis of Feed to ball mill of reference ore

Sieve Size Range (µm)	Weight retained (g)	% Weight retained	Cumulative % weight retain	Cumulative % weight Passing
+1400	13.00	13.00	13.00	87.00
-1400 + 1000	15.11	15.11	28.11	71.89
-1000 + 700	13.13	13.13	41.24	58.76
-700 +500	11.42	11.42	52.66	47.34
-500 +355	9.67	9.67	62.33	37.67
-355 +250	8.10	8.10	70.43	29.57
-250 +180	7.82	7.82	78.25	21.75
-180 +125	6.24	6.24	84.49	15.51
-125 +90	7.49	7.49	91.98	8.02
-90 +63	4.12	4.12	96.10	3.90
-63	3.90	3.90	100.0	-

Calculation3:
If 1000 μm = 71.89%
X µm = 80%

$$X = \frac{80*1000}{71.89} = 1112.81\mu m$$

Table 4: Sieve analysis of the product of reference ore

Sieve Size Range (µm)	Weight retained (g)	% Weight retained	Cumulative % weight retained	Cumulative % weight Passing
+1400	-	-	-	100.00
-1400 + 1000	0.51	0.51	0.51	99.49
-1000 + 700	1.12	1.12	1.72	98.28
-700 +500	2.01	2.01	3.73	96.27
-500 +355	3.12	3.12	6.85	93.15
-355 +250	22.02	22.02	28.87	71.13
-250 +180	56.03	56.03	84.90	15.10
-180 +125	8.32	8.32	93.22	6.78
-125 +90	3.82	3.82	97.04	2.96
-90 +63	1.63	1.63	98.67	1.33
-63	1.42	1.42	100.0	-

Calculation 4:
If 1000 μm = 99.49
X µm = 80%

$$X = \frac{80*1000}{99.49} = 804.10\ \mu m$$

Modified Bond's equation states that;

$$W = W_t = W_{ir} = W_{it} = \left(\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}\right)$$

$$W_{it} = \left(\frac{W}{\sqrt{P_t}} - \frac{W}{\sqrt{F_t}}\right) \quad \text{(Bond, 1952)}$$

Therefore,

$$W_{it} = \frac{W_{ir}\left(\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}\right)}{\left(\frac{W}{\sqrt{P_t}} - \frac{W}{\sqrt{F_t}}\right)}$$

Where,
P_r = diameter of reference ore product of 80% passing through 100µm aperture is (804.10 µm)
P_t = diameter of test ore product of 80% passing through 100µm aperture is (800.00 µm)
F_r = diameter of reference ore feed of 80% passing through 100µm aperture is (1112.81µm)
F_t = diameter of test ore feed of 80% passing through 100µm aperture is (1117.32µm)
W_{ir} = Work index of reference ore (granite) is 15.13Kwh/ton
W_{it} = Work index of test ore (Kwh/ton)

Solving for W_{it}, gives:

© 2023 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
(http://creativecommons.org/licenses/by-nc-nd/4.0/)

$$W_{it}=\frac{W_{ir}\left(\frac{10}{\sqrt{P_r}}-\frac{10}{\sqrt{F_r}}\right)}{\left(\frac{10}{\sqrt{P_t}}-\frac{10}{\sqrt{F_t}}\right)}$$

$$W_{it}=\frac{15.13\left(\frac{10}{\sqrt{804.10}}-\frac{10}{\sqrt{1112.81}}\right)}{\left(\frac{10}{\sqrt{800.00}}-\frac{10}{\sqrt{1117.32}}\right)}=14.71Kwh/tons$$

$W_{it}=14.71Kwh/tons$ for Bagega ore

3.2 Discussion

The most widely used parameter to measure ore grindability is the Bond work index (W_i), which is the energy required in kilo watt per short ton to reduce a given material from theoretical infinite size to eighty percent (80%) passing size of hundred microns (100µm). Bond index is useful in designing of grinding system in mineral processing [4]. The higher the hardness of an ore sample the higher the energy required for its grinding [3]. The result of the work index determined through alternative Bond method known as Berry and Bruce method is 14.71kwh/ton, which is not far from the standard work index of gold already established to be 14.83Kwh/ton while that of the reference mineral (granite) is 15.13kwh/ton as reported in the literature [10,11]. The determined work index is in agreement with international acceptable range of gold work index reported in the literature. The determined value should serve as a guide for subsequent research and practical works.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The study shows the work index of Bagega gold-bearing mineral is 14.71Kwh/ton, meaning 14.71kwh/ton of energy is required to reduce one ton of mineral sample to eighty percent passing.

4.2 Recommendations

It is recommended that the work index obtained in this study should serve as a guide for designing a grinding plant for Bagega gold mineral deposit and other mineral processing plants of similar mineralogical characteristics.

REFERENCES

[1] Wills, B. A., and Tim Napier-Munn, T. "Mineral Processing Technology, An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery", 2006.

[2] Berry, T. F., and Bruce, R. W. "A simple method of determining the grindability of ores", *Canadian Mining Journal*, 1966.

[3] Broeckmann, C., and Andrew, G. Development of High Pressure Grinding Technology for Base and Precious Metal Mineral Processing. *Canadian Mineral Processors journal, Ottawa* 21, 2005, pp.1- 10.

[4] Cleary, P.W. "Predicting charge motion power draw, segregation and wear in ball mill using discrete element methods", 2012.

[5] Cleary, P. W. "Modeling comminution devices using DEM", *Int. J. Numer Anal. Meth.* Geomechan 25, 2015, pp.83 -105.

[6] Dance, A. "The importance of primary crushing in mill feed size optimization", SAG 2016 conference Vancouver, BC Canada, 2, pp.270-281; 2016.

[7] Deister, R. J. "How to determine the bond work index using lab. Ball mill grindability tests", *Engng. Min.J.*, 188, 2016.

[8] Gupta, C. K. (2003). "Chemical Metallurgy Principle and Practice", *Die Deutsche Biblotek*, Weinhein. pp.142 – 144, 2003.

[9] Megdalimovie, N. M. "Calculation of energy required for grinding in a ball mill", *Journal of Mineral Processing* 25, (Jan) 41, 1989.

[10] "Maximizing Grinding Circiut Productivity". *Outokumpu Mills group publications, Arizopa, USA.2*, pp.1 – 20, 2005.

[11] Normal, T. E., and Decker, J. D. *Mineral Processing Milling Journal*. www.practicalaction.org. retrieved June, 2016, pp.1- 15, 2012.

[12] Onenime., "Summary and Determination of the Bond Work index using an ordinary Laboratory Batch Ball Mill", 2000. http// www.onemine.org/serach summary.org

[13] Olatunji, K. J., and Durojaiye, A. G. "Determination of Bond Index of Birnin-Gwari iron ore in Nigeria", *Journal of Minerals and materials characterization and Engineering*, Vol 9, 2012; pp.637-642, jmmce.org USA.

[14] Oyelola, O. A., Yaro, S. A., and Hassan, B. "Determination of Bond Index of Wasagu Manganese Ore in Kebbi State, Nigeria", *International Journal of Science and Engineering research* vol 3. 2014; pp.1-6.

[15] Perry, R. O., and Chillon, C. H. *Chemical Engr. Handbook*. Die Deutsche Biblotek, Weinheim, 2006; pp.212-230.

[16] Prokech, M. E. "Selection and sizing of concentrate drying, handling and storage equipment in Mineral Processing Plant Design, Practice and Control" 2002.

[17] Townsend, I. "Automatic pressure filtration in mining and metallurgy". *Minerals Engng. vol* 16. 165, 2003.

[18] Warder, J., and McQuie, J. (2017). "The role of flash flotation in reducing overgrinding of

© 2023 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
(http://creativecommons.org/licenses/by-nc-nd/4.0/)

nickel at WMC's Leinster Nickel Operation", *in Proc. Centenary of Flotation Symp., ed (Jun.)* pp 931 – 938, 2017.
[19] Weiss, N. F. "Mineral Processing Handbook", *Society of Mining Engineers*, AIME volume 1, pp 24, 1985.
[20] Wiese, J., Harris, P. J., and Brdshaw, D. J. "The influence of the reagent suite on the flotation of ores from the Merensky reef", *Minerals Engineering* 18(2) 189-198, 2015.

© 2023 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
(http://creativecommons.org/licenses/by-nc-nd/4.0/)