DETERMINATION OF THE BOND'S WORK INDEX OF BABAN TSAUNI (NIGERIA) LEAD-GOLD ORE

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Abstract

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. The Bond's work index has generally been accepted as a measure of the grindability of an ore. This study used quartz as a reference ore via a comparative method to determine the Bond's work index of Baban Tsauni Nigeria) ore. The same amount of energy was utilized in grinding the reference and test ore with the same particle size distribution under the same grinding conditions. Typical feed load and mill speed in practice were used in order to make the grinding environment as close as possible to that in large scale grinding. The Bond's work index of Baban Tsauni (Nigeria) ore was found to be 11.52kWh/tonne.

Keywords: Grindability, comminution, energy, mineral, comparative

Introduction

In a world with limited energy resources the need to design the energy requirements of engineering processes cannot be overemphasized. In the mineral industry, comminution is the highest consumer of energy. Napier-Munn *et al*. (1996) stated that 30 -50 per cent of the total plant power consumption for mineral processing plants and up to 70 per cent for hard ores is attributed to comminution. Whittles *et al*. (2003) observed that about 1.5 per cent of the annual electrical energy production in the United States of America is used in comminution processes in the minerals industry. Grindability is the ease with which materials can be comminuted and the data obtained from grindability tests are used to evaluate energy requirements and grinding efficiency.

Literature review

The Bond work index W_i is used as a measure of grindability of an ore (Deniz, 2003; Wills and Napier-Munn, 2006). The work index 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 100μm (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 (Gupta and Yan, 2006). The standard Bond test requires constant screening out of undersized material in a closed circuit operation. The standard Bond experiment has been applied for the determination of Bond work indices of several minerals by different researchers (Levin, 1992; Deniz, 2003; Doll and Barratt, 2011). The mill size specified for the test is 305mm in length by 305mm in diameter at a mill speed of 70rpm. The breakage characteristic of real mineral ores is a function of size (Levin, 1989; Schneider, 1995; Muhammad et al., 2011). Levin (1989) indicated that the standard Bond test should be used for coarse materials (+3.3mm) and suggested a comparative method for fine materials.

Olatunji and Durojaye (2010) adopted the comparative grindability test for the determination of the work index of Birnin-Gwari iron ore in Nigeria. A reference ore is ground for a certain time period and the power consumption recorded. 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. Equation 1 gives the work index of the test ore;

$$W_{it} = \frac{W_{ir}\left(\frac{1}{\sqrt{P_r}} - \frac{1}{\sqrt{F_r}}\right)}{\left(\frac{1}{\sqrt{P_t}} - \frac{1}{\sqrt{F_t}}\right)} \qquad 1$$

where W_{it} and W_{ir} are the work index of test and reference ores respectively, $P_t/_r$ is the diameter in microns which 80 per cent the products passes and $F_t/_r$ is the size which 80 per cent the feed passes. Gupta and Yan (2006) observed that reasonable values of work indices could be obtained by this method if the reference and test ores are ground to about the same product size distribution.

Experimental procedures

The comparative method was used for the determination of the work index of the Baban Tsauni ore. Quartz was used as the reference ore. The reference ore was crushed in a jaw crusher followed by a roll crusher, and ground for 10minutes in a ball mill. The size analysis of the particles was carried out and a cumulative per cent mass passing against particle size plot was made to determine the 80% passing size of the feeds. In order to start with the same size distribution for both the reference ore and the test ore, the lead ore was passed through the same jaw crusher and roll crusher in the same order. Five different sets of the test ores were ground for 10minutes each and sieved to generate the same number of close sized particles as the reference ore. The Jones riffle sampler was then used to divide the various close sized particles of the test ore to obtain the same particle size distribution as the reference ore.

In order to avoid overloading or under-loading of the mill, the mass of the feed and media for this experiment were calculated by applying Equations 2 and 3 respectively (Gupta and Yan, 2006);

$$J_O = \frac{[\frac{M_O}{\rho_O}]}{V_M}(\frac{1}{[1-\varphi]}) \qquad 2$$

where J_O = fraction of mill occupied by the ore, M_O = mass of ore charge, ρ_O = ore density, V_M = mill volume, φ = bed porosity and

$$J_B = \frac{[\frac{M_B}{\rho_B}]}{V_B}(\frac{1}{[1-\varphi]}) \qquad 3$$

where J_B = fraction of mill occupied by the balls, M_B = mass of ball charge, ρ_B = ball density, V_M = mill volume, φ = bed porosity.

The maximum bed porosity in practice (40%) and the minimum fraction of mill volume occupied by ore (20%) were used. This choice was aimed at working within the range of values in practice. Substituting into Equation 2 a mean density of 3069.62kg/m^3 for reference and test ore yields,

$$0.2 = \frac{[\frac{M_O}{3069.62}]}{0.002389}(\frac{1}{[0.6]})$$

where the volume of mill = 0.002389m^3, and 1- φ = 0.6

Therefore the mass of sample = 0.880kg.

Adopting the preferred J_O/J_B ratio of 0.4, we have:

J_B = 0.5 and Equation 3 yields,

$$0.5 = \frac{[\frac{M_B}{4650}]}{0.002389}(\frac{1}{[0.6]})$$

Therefore the mass of steel balls, M_B = 3.333kg

Charging the mill with steel balls and reference ore (or lead ore) feed samples involved arranging a layer of balls in the cylinder, followed by a layer of ore and a repetition of this order until all steel balls and samples were charged. This pattern was followed for all mill charging operations.

The mill was placed on the rollers and a speed of 101rpm (equivalent to $0.77V_c$, where V_c is the critical velocity) was selected. The machine was switched on and allowed to run for ten minutes. After grinding, the particle size analyses of both ores were carried out by sieving on a laboratory sieve shaker for six minutes at amplitude setting of 8mm. The samples retained on each sieve were weighed with a digital weighing machine and the cumulative per cent mass passing each sieve size was calculated. The cumulative per cent mass passing each sieve size was plotted against particle size on spreadsheets to determine the 80% passing size of products for both reference and test ores. Previous works (Deniz, 2003; Levin, 1992; Muhammad, 2011; Olatunji and Durojaiye, 2010; Wills and Napier-Munn, 2006) used log-log linearization plots which were developed prior to the advent of computer programming while in this work the polynomial equation of the curve generated by the computer programme was used to calculate the 80% passing size.

Results and discussion

The comparative method for determination of work index has been adopted for this work. This method requires the 80% passing sizes of feeds and products from grinding operations under the same condition for both the reference ore and the test ore. In order to determine the 80% passing sizes for the feeds and products from grinding, the results of sieve analyses (Tables 1 to 3) were plotted with cumulative per cent mass passing on the ordinate and the particle size (in microns) on the abscissa as shown in Figures 1 to 3.

Table 1: Particle size analysis of feed samples for grindability test.

Sieve size (μm)	Mass retained (g)	Mass (%) Retained	Cummulative mass (%) retained	Cummulative mass (%) passing
-2800 to 2000	117.3	13.330	13.330	86.670
-2000 to 1400	107.1	12.170	25.500	74.500
-1400 to 1000	84.9	9.648	35.148	64.852
-1000 to 850	31.3	3.557	38.705	61.295
-850 to 710	49.2	5.591	44.295	55.705
-710 to 500	89.6	10.182	54.477	45.523
-500 to 250	203.4	23.114	77.591	22.409
-250	197.2	22.409	100.000	0.000

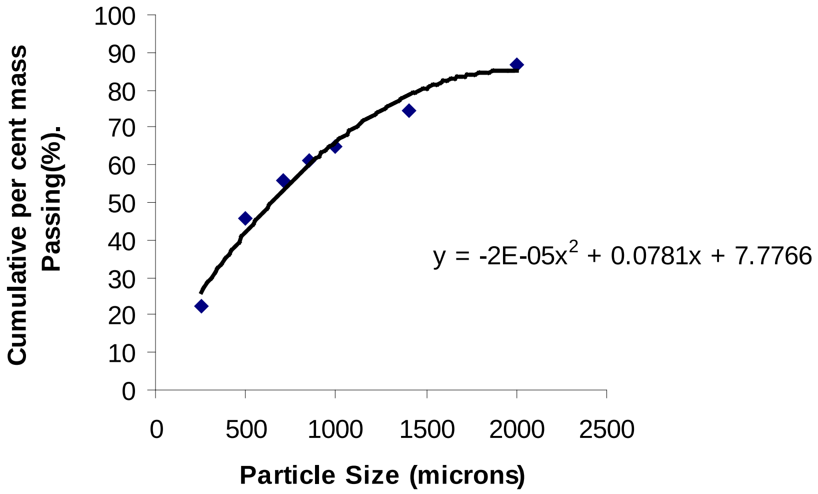

Figure 1: Particle size analyses of feed samples for grindability test

From Figure 1 the equation of the line is,

$$y = -2*10^{-5}x^2 + 0.0781x + 7.7766 \qquad 4$$

The eighty per cent passing size (F_{80}) for the feed is obtained by putting y=80 in Equation 4 and it yields,

$$80 = -2*10^{-5}x^2 + 0.0781x + 7.7766$$

That is, $80-7.7766 + 2*10^{-5}*x^2 - 0.0781x = 0$

Dividing through by the coefficient of x^2 and rearranging yields,

$$x^2 - 3905x + 3611170 = 0 \qquad 5$$

The two roots of Equation 5 are:

$$x= \frac{3905 \pm \sqrt{(3905^2 - 4*3611170)}}{2} = 2400.93\mu m \text{ and } 1504.074\mu m$$

The first root (2400.93μm) is not realistic since its value falls outside the range of particle sizes in the sample and hence the 80% passing size of the feed samples is 1504.074μm.

Table 2: Particle size analysis of ball mill discharge for the reference ore (quartz).

Sieve size (μm)	Mass retained (g)	Mas (%) Retained	Cummulative mass (%) retained	Cummulative mass(%) passing
-2800 to 2000	21.4	2.43	2.43	97.57
-2000 to 1400	63.7	7.24	9.67	90.33
-1400 to 1000	86.9	9.88	19.55	80.45
-1000 to 850	36.9	4.19	23.74	76.26
-850 to 710	56.7	6.44	30.18	69.82
-710 to 500	100.6	11.43	41.61	58.39
-500 to 250	216.5	24.60	66.22	33.78
-250	297.3	33.78	100.00	

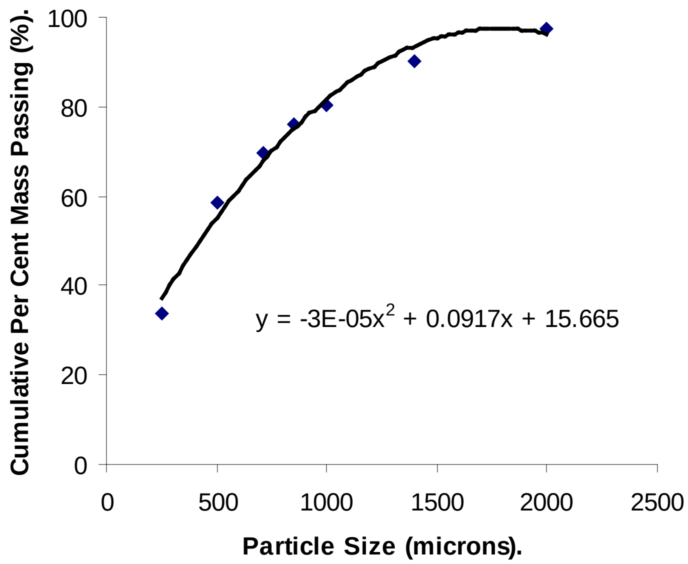

Figure 2: Reference ore (quartz) discharge, particle size analysis

From Figure 2, the equation of the line is,

$$y = -3*10^{-5}x^2 + 0.0917x + 15.665 \qquad 6$$

The eighty per cent passing size (P_{r80}) for the grinding product of the reference ore (quartz) is obtained by putting y=80 in Equation 6 and it yields,

$$80 = -3*10^{-5}x^2 + 0.0917x + 15.665$$

That is, $80\text{-}15.665 + 3*10^{-5}*x^2 - 0.0917x = 0$

Dividing through by the coefficient of x^2 and rearranging yields,

$$x^2 - 3056.6667x + 2144500 = 0 \qquad 7$$

The two roots of Equation 7 are:

$$x= \frac{3056.6667 \pm \sqrt{(3056.6667^2 - 4*2144500)}}{2} = 1965.72\mu m \text{ and } 1090.952\mu m$$

The first root (1965.72μm) is not realistic since its value falls outside the range of particle sizes in the sample and hence the 80% passing size of the grinding product, P_{r80} = 1090.952μm.

Table 3: Particle size analysis of ball mill discharge for the test ore (lead-gold).

Sieve size (μm)	Mass retained (g)	Mass (%) retained	Cumulative mass retained (%)	Cumulative mass passing (%)
-2800 +2000	27.1	3.08	3.08	96.92
-2000 +1400	80.6	9.16	12.24	87.76
-1400 +1000	95.3	10.83	23.07	76.93
-1000 +850	18.7	2.13	25.19	74.81
-850 +710	64.9	7.38	32.57	67.43
-710 +500	114.6	13.02	45.59	54.41
-500 + 250	150.8	17.14	62.73	37.27
250	328	37.27	100.00	

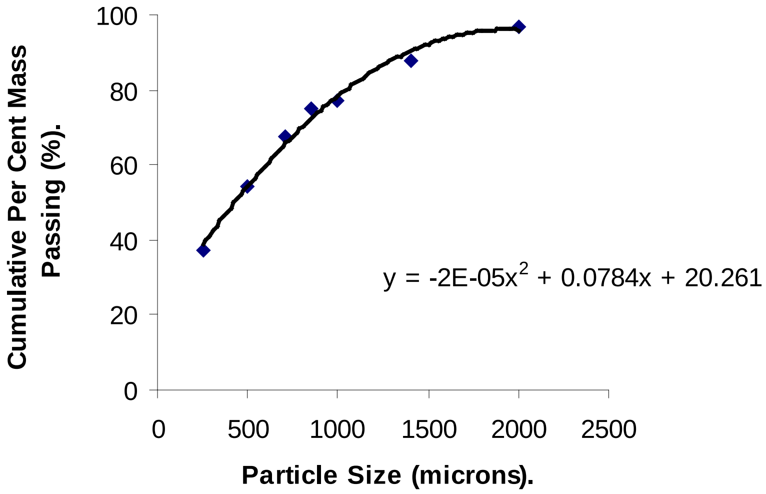

Figure 3: Lead-gold ore discharge particle size analysis.

From Figure 3, the equation of the line is,

$$y = -2*10^{-5}x^2 + 0.0784x + 20.261 \qquad 8$$

The eighty per cent passing size (P_{t80}) for the grinding product of the test ore (lead ore) is obtained by putting y=80 in Equation 8 and it gives,

$$80 = -2*10^{-5}x^2 + 0.0784x + 20.261$$

That is, $80-20.261 + 2*10^{-5}*x^2 - 0.0784x = 0$

Dividing through by the coefficient of x^2 and rearranging yields,

$$x^2 - 3920x + 2986950 = 0 \qquad 9$$

The two roots of Equation 9 are:

$$x = \frac{3920 \pm \sqrt{(3920^2 - 4*2986950)}}{2} = 2884.473\mu m \text{ and } 1035.5272\mu m$$

Again the first root (2884.473μm) is not realistic since its value falls outside the range of particle sizes in the sample and hence the 80% passing size of the grinding product, P_{t80} = 1035.5272μm.

The calculated 80% passing sizes from the foregoing are substituted into Equation 1.

The work index for quartz (the reference ore used) = 13.57kWh/tonne (Wills and Napier-Munn, 2006), F_r=F_t = 1504.074μm, P_r = 1090.952μm and P_t = 1035.53μm (as calculated from Figures 1 to 3). Substituting these values into Equation 1 yields,

$$W_{it} = \frac{13.57\left(\frac{1}{\sqrt{1090.952}} - \frac{1}{\sqrt{1504.074}}\right)}{\left(\frac{1}{\sqrt{1035.53}} - \frac{1}{\sqrt{1504.074}}\right)}$$

Therefore;

W_{it} = 11.52kWh/t.

The Bond's work index of Baban Tsauni lead-gold ore was found to be 11.52kWh/tonne and this implies that about 11.52kilowatts hour of energy is required to grind the ore from infinite size to 80 per cent passing 100microns in line with Bonds work index. The work index obtained applies to particle size in the range -2800μm to +250μm.

Conclusion

The Bond's work index of Baban Tsauni (Gwagwalada) Nigeria lead-gold ore was determined in this study. It is expected that this energy requirement (11.52kWh/tone) will aid the design of the grinding plant for beneficiation of the ore.

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