Work Index and Grinding Energy Assessment of Dilband Iron Ore, Pakistan

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ABSTRACT

Importance of comminution in mineral processing sector is highly acknowledged from energy perspective. In present study an attempt was made to understand the comminuting behavior of Dilband iron ore and to compute the grinding energy requirement for production of ultrafine particles up to mesh of liberation. In this regard standard grindability tests developed by the Chair of Mineral Processing Leoben Austria was used for calculating work index of Dilband iron ore. The grinding tests were conducted in rod and ball mills.

The work index value of two feed size fractions with 80% passing at 3800μm and 5200μm was noted to be 11.85 kwh/t and 9.3 kwh/ton respectively. Ball mill grinding test indicates that dry grinding in open circuit is not efficient and consumes more energy of 88.48kwh/t of ore for grinding 1000/40μm to 80% <40μm size.

Key Words: **Work index, Grinding Energy, Rod Mill, Ball Mill, Dilband Iron Ore.**

1. Introduction

The crushing and grinding are generally believed the energy intensive and most expensive steps involved in the mineral processing field, since the comminution is a large consumer of electricity in the mineral processing plant. The energy impact of comminution as reported in literature reveals that it consumes about 3-4% electricity produced worldwide and up to 70% of all energy required in mineral processing (Aksit, [1], Kelly and Spottiswood, [2], Petruk, [3], Weissberger and Zimmels, [4]). Fine ore grinding is furtherer experienced with poor energy efficient comminution process(Aksit, [1], and Khan, [5]). Therefore, estimation of the operational cost first dominated by energy costs and second by wear cost of grinding media, and thereby dimensioning mills and evaluation of mill performance has remained the stimulus to asses the energy required in particular comminution circuit. In this regard the Bond's grindability test has been widely used for calculating work index, predictions of tumbling mill energy requirements and for selection of plant scale comminution equipment (Aksani and Sönmez, [6], Deniz, [7-8], Deniz and Ozdag, [9], Ozkahraman, [10], Partyka and Yan, [11], Umucu, [12], Deniz, V., et. al. [13], Yekeler and Ozkan, [14]), despite acknowledging some drawbacks, such as being tedious,

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time consuming, require skill person, and very sensitive to procedural errors. Besides this Bond's work index is known to be extremely sensitive to test sieves and circulating load. Therefore, work index determined with particular test sieves with certain circulating load is regarded less valid for other set of test sieves with either same or different circulating load even for the same material. Thus design of industrial comminution circuit based on work index values have been regarded within certain error limits(Aksani and Sönmez, [6], Deniz and Ozdag, [9], Ozkahraman, [10], Partyka and Yan, [11]).

Keeping in view energy perspective of comminution process and to make meaning full contribution in understanding the comminution behavior of Dilband iron ore fundamental study of grindability tests were conducted in rod and ball mills. Consequently potential rewards of this study in terms of work index assessment, energy requirement, and energy efficient grinding root, either open circuit or closed circuit, to liberate the ore to mesh of liberation can be accepted. The work index was evaluated using the standard procedure of Bond's test.

2. Materials and Method

2.1 Rod Mill Grindability Test

For grindabiliy test in rod mill 674g of ore corresponding to 189cc volumetric weight; with 3800μm 80% passing and 3.57g/cc density, was grinded. For the first grinding cycle the mill, of trunnion overflow type with 0.154m inner diameter, was started with an arbitrarily chosen number of 350 revolutions. The grinding of ore carried out in closed circuit until steady state of specific mass per revolution at 1000μm test sieve achieved. After reaching equilibrium, the cumulative mass of fines (-1000μm) was plotted verses cumulative number of cycles, and finally the ratio of fines per cycle was used to compute the energy used to achieve the equilibrium grinding conditions at 1000μm test sieve. Sieve analysis of the product from last two equilibrium cycles was carried out so as to find out the 80% passing, and thereby Bond's work index of the Dilband iron ore was calculated using the standard Bonds equation.

To evaluate the test sieve-sensitivity of work index, as reported in literature, another grinding test on a feed material with 5200μm 80% passing to achieve 80% 420μm size was determined.

2.2 Ball Mill Grinding Test

The grindability of Dilband iron ore was determined by feeding 1022g mass of material needed to fill the 473cc internal volume of ball mill. The size fraction of feed material is shown in Fig. 1. The grindability was estimated by measuring the production rate of specific surface area per unit energy input. For this after every arbitrarily number of grinding cycles the total material was discharged from the mill and 10gram of representative sample, for measurement of specific surface area and percent fines, was separated. The remaining material was recharged in to ball mill and grinded for other set of arbitrary cycles. The procedure repeated until 80% of material passed from 40μm sieve.

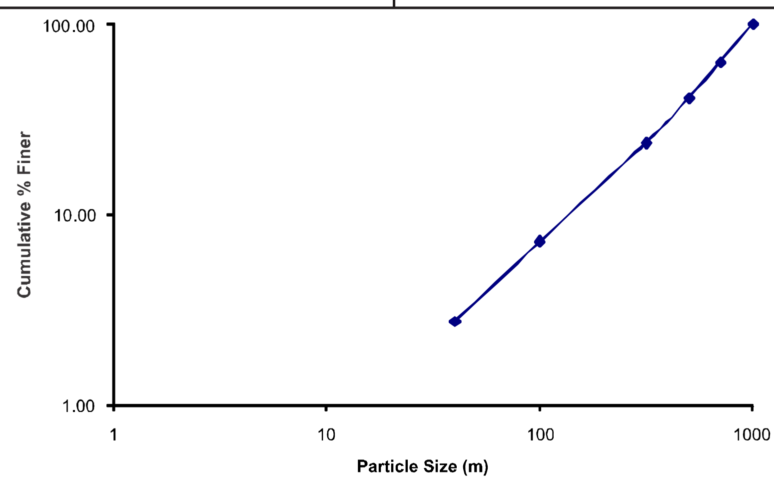

FIG. 1. PARTICLE SIZE DISTRIBUTION OF BALL MILL FEED ORE

2.3 Blaine Air Permeability Test

The specific surface area was measured using Blaine Air Permeability Apparatus, whereas percent of fines produced were determined by using test sieves of 100, 70, and 40µm. Air jet screener was used to improve the dry sieving efficiency by mitigating auto clotting of fine particles. After achieving certain degree of fineness wet sieving was conducted as and when air jet screening efficiency was supposed to be ambivalent with specific surface area measurements.

Since specific surface area measurements seems more accurate and reliable than percent fines readings, therefore grindability of Dilband iron ore was represented in terms of average specific surface area to specific energy input. For calculating the energy input per grinding cycle the ball mill was calibrated in terms of torque before and after the test.

3. RESULTS AND DISCUSSION

The standard grindability test developed by the Chair of Mineral Processing Leoben was used for calculating work index of Dilband iron ore. The test is based on the Bond's test procedure. The test includes a closed-cycle dry grinding and screening process, which is carried out until steady state condition is obtained likewise the Bond's test. The beauty of the grindability test developed by Chair of Mineral Processing is that it is not equipment sensitive and calculates the work energy value used for creating the fines. It does not consider the energy needed to rotate the mill but rather the energy input directly to grind the material (Abro, M.I., [15]). Therefore, the energy determined by Bond's test method remains approximately 20% higher than the energy calculated by present test method. Following equations were used for calculating the energy input (Δ_e) and work index (W_i).

$$\Delta_e = C_p.g.D_i.M_r.\frac{U}{F} \tag{1}$$

$$\Delta_e = W_i\left(\frac{10}{\sqrt{80\%P}} - \frac{10}{\sqrt{80\%F}}\right) \tag{2}$$

Where C_p is the power factor and is equal to 1.1 for rod mill used for grinding test, g is gravitational force (9.8m/Sec^2), D_i is the internal diameter of the mill equal to 0.154m, M_r is the mass of rods (7.838 kg) and U/F is the specific mass of fines per rpm, P and F is the particle size of the fines at 80% passing produced and feed respectively.

The results of rod mill grinding tests are given in Tables 1-2, and plotted in Figs. 2-3.

The grindability test results indicated that about 2.2 kwh/t of power is required to grind the 674g Dilband iron ore from 3800µm 80% passing to 825µm 80% passing. Whereas to grind coarser material with feed size of 5200-410µm size with 80% passing, the power consumption is increased to about 3.24 kwh/t. Similarly work index value from 11.85 kwh/t for grinding 3800µm 80% passing to 825µm 80% passing decreased to 9.3 kwh/t for material with feed size of 5200-410µm size with 80% passing. The changes in work index from one set of sieve to other confirms the sieve sensitivity, and suggest that work index of one set of test sieve could not be taken valid for other set of test sieve. Besides this decreasing trend in work index indicate that friability of the material decreases with decreasing the particle size. Concomitantly increasing

TABLE 1. ROD MILL GRINDING OF 80% 3800µm DILBAND IRON ORE DOWN TO 80% 825µm

No. of Cycle	Speed	Cummulative Speed	Feed Weight (g)	Weight (g) of Coarser (>1000µm)R	Finer (<1000µm)		Circulating Load (%)	Spedific Mass of Finer/rpm (g/rpm)	Fresh Feed for Next Cycles (g)F
					Weight (g)	Cummulative Weight(g)			
1.	350	350	674	65.2	608	608	933.74	1.74	608.8
2.	212	562	674	348	326	934	93.68	1.66	326
3.	219	781	674	320.4	353.6	1287.6	110.36	1.65	353.6
4.	219	1000	674	324.3	349.7	1637.3	107.83	1.64	349.7
5.	217	1217	674	312.2	361.8	1999.1	115.89	1.64	361.8
6.	217	1434	674	318.9	355.1	2354.2	111.35	1.64	355.1
7.	202	1636	649.4	328.9	320.5	2674.7	97.45	1.63	320.5

trend in power consumption resulted. The decreasing trend in friability is the well recognized behavior of the fine particles (Deniz, [3], Kolacz and Sandvik, [7], Partyka and Yan, [9]).

Literature pertaining to the work index value of world iron ores revealed that the work index value of Dilband iron ore is quite in agreement with the values of oolitic iron ores. For instance the work index value of Wadi Fatma, Saudi Arabia (Manieh [16]) and Tilden mines, USA (Edward et. al. [17]) is 11.34 and 14 kwh/t respectively. The marginal variation in work index value of the Dilband iron ore as compared to Wadi Fatima and Tilden mines can be attributed to variation of mill dimensions, and size distribution of feed and mill product. Furthermore significance of mineralogy and petrography of the ore over other factors in governing the work index can be ascribed. Taking into account the marginal variation of work index economical comminution of Dilband iron likewise Wadi Fatima and Tilden mines can be anticipated.

The ball mill grinding test results are given in Table 3 and shown in Fig. 4. Ball mill grinding results of Dilband iron ore indicated that energy required to grind the Dilbnad

TABLE 2. ROD MILL GRINDING OF 80% 5200µm DILBAND IRON ORE DOWN TO 80% 420µm

No. of Cycle	Speed	Cummulative Speed	Feed Weight (g)	Weight (g) of Coarser (>500µm)R	Finer (<500µm) Weight (g)	Finer (<500µm) Cummulative Weight(g)	Circulating Load (%) (F/R*100)	Spedific Mass of Finer/rpm (g/rpm)	Fresh Feed for Next Cycles (g)F
1.	331	331	674	409	265	265	64.79	0.80	265
2.	298	629	674	402	272	537	67.66	0.85	272
3.	370	999	674	337.3	336.7	873.7	99.82	0.87	336.7
4.	370	1369	674	318.5	355.5	1229.2	111.62	0.90	355.5
5.	355	1724	674	335.5	338.5	1567.7	100.89	0.91	338.5
6.	355	2079	674	337	337	1904.7	100.00	0.92	337
7	355	2434	649	312	337.4	2242.1	108.14	0.92	337.4
8	355	2789	650	313.9	336.5	2578.6	107.20	0.92	336.5
9.	355	3144	651	422	229.4	2808	54.36	0.89	229.4
10.	355	3499	653	315.8	337.6	3145.6	106.90	0.90	337.6
11.	355	3854	654	316.9	337.5	3483.1	106.50	0.90	337.5
12.	355	4209	655	341	233.4	3716.5	92.20	0.88	314.4
13.	355	4564	656	316.6	339.8	4056.3	107.33	0.89	339.8

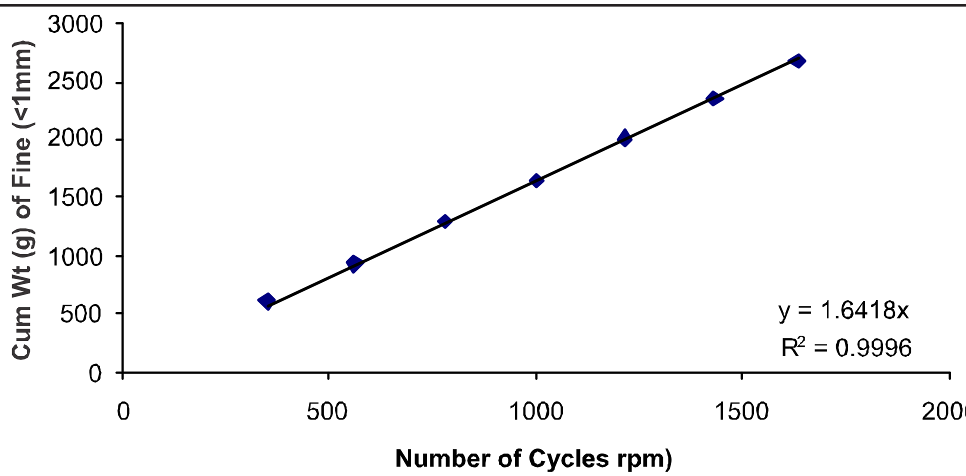

FIG. 2. ROD MILL GRINDING OF 80% 3800µm DILBAND IRON ORE DOWN TO 80% 825µm

iron ore increase with increase in production of fines. The less production rate of fines per specific energy input (Fig. 4) suggests that the grinding power of ball mill has been poorly utilized. A major reason that could be ascribed for the poor energy efficient ball mill grinding is thought to be the self clogging effect of fines onto the balls and mill surface. Thus effective crushing tendency of balls is prevented.

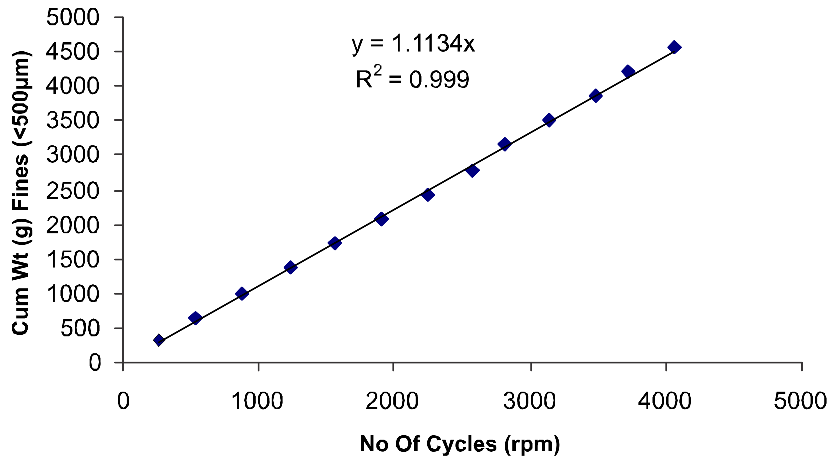

FIG. 3. ROD MILL GRINDING OF 80% 5200μm DILBAND IRON ORE DOWN TO 80% 420μm

ABLE 3. BALL MILL GRINDING (DRY) OF >500μm DILBAND IRON ORE DOWN TO 80% 40μm

No. of Passes	Number of Cycles	Integration Units	Grinding Time(s)	Integration Units Per Unit Time		Net Torque	Energy Input	Weight of Feed Ore	Mass Specific Engery Inpute (J/g)		Average Surfa
			[S]	Net (s-1)	Effective (s-1)	(Nm)	(J)	(g)	Δe	Σe	(cm²/g)
1.	200	13320	200	66.6	50.6566	3.3743	4240.26	1022	4.149	4.149	396.9
2.	500	33100	478	69.247	53.3035	3.55061	11154.6	1007	11.077	15.226	1366.6
3.	500	32850	478	68.724	52.7805	3.51577	11045.1	992	11.134	26.36	1846.7
4.	1000	65030	954	68.166	52.2222	3.47858	21856.6	977	22.371	48.731	3627.3
5.	1500	96900	1432	67.668	51.7232	3.44534	32471.6	962	33.754	82.486	5986.2
6.	2000	123400	1912	64.54	48.5953	3.23699	40677.2	937	43.412	125.9	7823.0
7.	10000	617000	9560	64.54	48.5953	3.23699	203386	921	220.83	346.73	12365

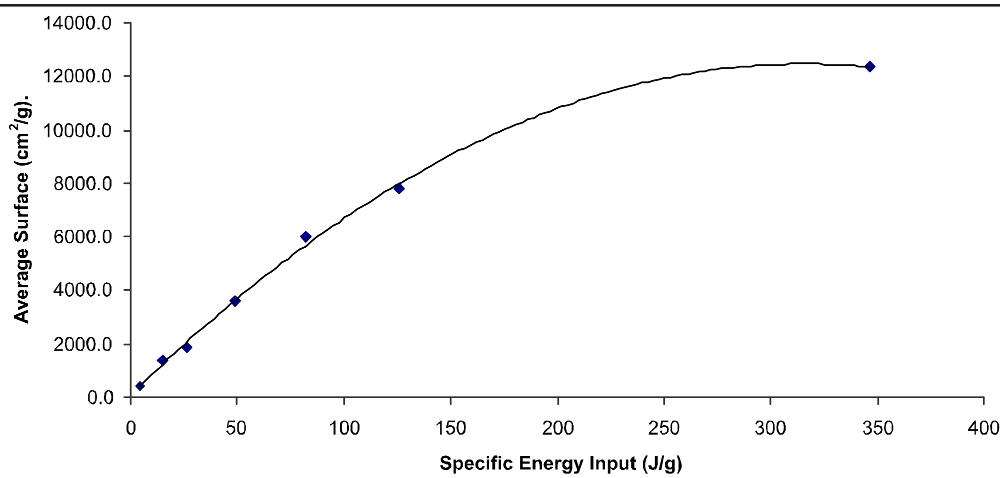

FIG. 4. SPECIFIC ENERGY IN PUT IN GRINDING (DRY) THE DILBAND IRON ORE FORM 500μm DOWN TO 80% 40μm PASSING

4. CONCLUSIONS

Based on the rod mill and ball mill grinding tests results following conclusions can be made:

(i) The sieve sensitivity of Bond's work index suggest that Bond's work index for one set of test sieve could not be taken valid for other set of test sieve, and its value increases with decreasing the size of test sieve.

(ii) The poor grindability of Dilband iron ore in ball mill due to coagulation of fines produced per cycle suggests that open grinding circuit is not appropriate. Therefore, closed grinding circuit would be energy efficient route.

(iii) About 2.2 kwh/t of power is required to grind the 674g Dilband iron ore from 3800µm 80% passing to 825µm 80% passing. Whereas to grind coarser material with feed size of 5200µm down to 80% 410µm size, the power consumption is increased to about 3.24 kwh/t.

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