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Comminution Tests Required to Assess the Energy Requirement Prior to Commissioning Crushing and Grinding Plants

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ABSTRACT: In this paper, an attempt is made to communicate to the mineral industrialists that to set up any comminution plants the essential tests are Unconfined Compressive Strength (UCS - mpa), Drop Weight Tests (DWT), Bond Crushing Work Index (CWI), Bond Abrasion Index (Ai), Bond Rod Mill Work Index (RWI), Bond Ball Mill Work Index (BWI) and Hard Groove Index for coal. These comminution tests are required to assess the energy requirement before commissioning the crushing and grinding plants. This study helps all the mineral industries to utilize the optimum energy required for comminution units in the mineral processing industries.

KEYWORDS: Crushing, Grinding, Bond Index, Brittleness, Compressive strength

I. INTRODUCTION

Comminution is the process of crushing and grinding. The crushing is done in two stages such as crushing with the jaw crusher and crushing with the roll crusher. When the movable jaw plate of the jaw crusher machine is driven by a belt and belt wheel towards to fixed jaw plate, the material is crushed or ground. The motor drives the movable jaw up and down through an eccentric shaft. The angle between the toggle plate and movable jaw increases when the movable jaw moves up. The rocks are crushed in this process. The angle between the toggle plate and movable jaw decreases when the movable jaw moves down, the movable jaw moves away from the fixed jaw by the pulling of rod and spring, the stuff crushed will be discharged from the output opening. This process will repeat. The moving jaw will crush and discharge the stuff circularly. The sample was huge around 80 mm size; so that first the sample was crushed with a jaw crusher to make the sample is of below 6mm size by using the above procedure.The jaw crusher product was sent roll crusher for further crushing. Smooth Double Roll Crushers are normally used as Secondary & Tertiary Crushers where a narrow spectrum of grain analysis is desired. Reduction Ratio less than 1:4 and rolls can be set to 0.5 to 0.8 mm. Feed size, setting & roll diameter are to be so selected that the material gets nipped. Material fed centrally into the valley formed by rolls, uniformly, continuously throughout the width of rolls, at a velocity very near to the surface velocity of rolls. One roll was fixed and the other roll was floating spring-loaded or hydraulically loaded to kick-back in the case of overload or uncrushable coming into the crushing zone and the same roll can be moved closer or away to get the desired gap. Gap setting arranged 0.5 mm gap to get the finished products [1].

Milling of ore particles is to be carried out either by standard ball mill or other types of commercial mill or rod mills. In any mineral separation plant, the comminution circuit consumes 50% of energy [1-3]. Thus, most of the capital expenditure will be spent in the comminution area. Hence comminution tests are essential before commissioning the plant. Comminution tests are broadly classified as

a) Unconfined Compressive Strength (UCS - mpa)
b) Drop Weight Tests (DWT)
c) Bond Crushing Work Index (CWI)
d) Bond Abrasion Index (Ai)
e) Bond Rod Mill Work Index (RWI)
f) Bond Ball Mill Work Index (BWI)
g) Hard Groove Index (Hi)

a) Unconfined Compressive Strength (UCS - mpa)

It is determined from core or sample drilled from rock specimens.The parameters indicate to select the type of primary jaw crusher.

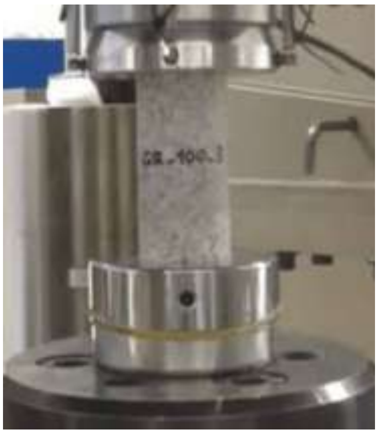
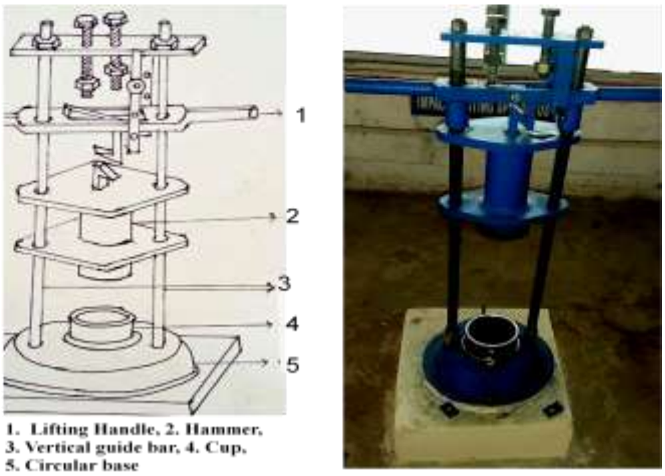


Fig.1.Unconfined Compressive Strength Test of Rock

b) Drop Weight Tests (DWT)/Impact Crushing Tests

The reduction ratio of the sample and energy consumption is measured by this method. Sample requirement is at least 70 kg of representative broken rock in the size range -76 +6mm or 70 kg of whole uncut drill core at a diameter greater than 63mm. This procedure was repeated for 5,10,15 drops and stage crushed to generate narrow size ranges of rock fragments [10].

Fig.2.Impact crusher for drop weight tests



The drop weight test is used to calculate the energy that is expanded in breaking the particle as shown in Equation (1)

$$E1 = Mg(h - XM) \qquad (1)$$

Where:

- E1 = Energy used for breakage
- M = Drop weight mass
- g = Gravitational constant
- h = Initial height of drop weight above the anvil
- XM = Final weight of the drop weight above the anvil

b.1. Brittleness Test

The experimental setup for the brittleness tests to find out the friability value (S1) is shown in Fig. 3. To carry out brittleness tests to find out the friability values of all the selected six variety samples are to be crushed separately. Each sample is to be screened at 80 mm and 19 mm sizes [5,6].

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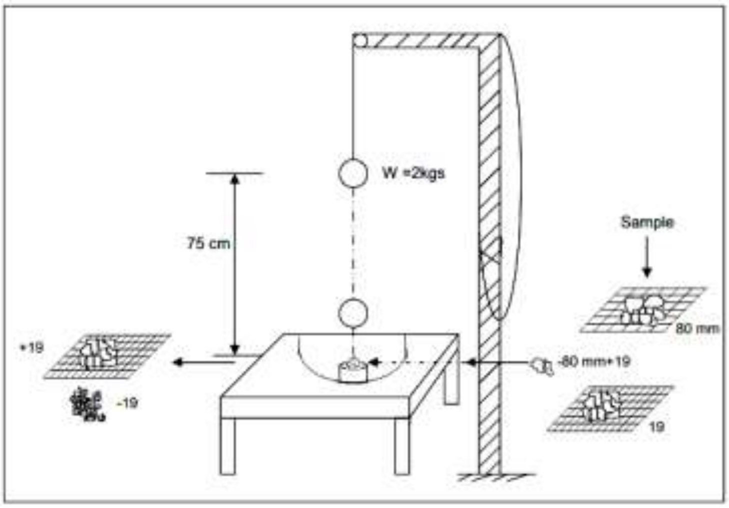

Fig.3.Brittleness test for measuring the friability value S1

The selected rock sample of -80+19 mm size fraction is to be subjected to impact crushing for brittleness tests. In this connection, a test apparatus has been designed as shown in Fig.3 to suit rock strength characteristics used in industrial size production. The weight dropped is 2kgs from a height of 75cm. In general, the drop weight tests of a minimum of three or four parallel tests are to be carried out and the mean value to be considered for the determination of friability values. The friability (S1) calculation is shown in Equation (2):

F = The broken weight passes 19 mm (gms)/ Sample weight X 100 (2)

Thus the friability value S1 equals the percentage of undersized material, which passes through the 19 mm size after crushing. The energy calculation for drop weight at each fall is shown in Equation (3).

$E = m*g*h$ (3)

Where

- m = mass of the weight drop on the sample
- E = Energy of each fall, J
- g = gravitational force, m/s^2
- h = height from where the falls on the sample, m

c) Bond Crushing Work Index (CWI)

It is used to calculate actual crusher power requirements. This index describes the competency of the ore at larger particle sizes. In this test representative rock specimens in the size range -76+50mm are to be broken under the impact of twin pendulums. Equation (4) and (5) shows the calculation of Bond Crushing Energy (E_b) and Bond Crushing Work Index (CWI) respectively [9].

Fig.4.Bond Impact Crushing Work Indexunit [by the impact of twin pendulums]

$E_b = K*[1-\cos(a)]$ (4)

Where

- E_b= Bond Crushing Energy
- a = the angle through which the pendulums fall
- K = 82, a constant

The Bond Crushing Work Index (CWI) is then calculated from the formula developed by F.C. Bond

$CWI = [2.59*K*E_b/d/sg]$ kWh/t (5)

Where:

- E_b = Bond crushing energy for an individual rock
- K = 82, a constant
- a = the angle through which the pendulums fall
- sg = the specific gravity of the individual rock
- d = the thickness of the rock specimen

c.1. Crushability Test

Pieces of broken rock passing a 3-in. square and retained on a 2-in. square are mounted between two opposing equal 30-lb weights which swing on wheels. When the wheels are released the weights strike simultaneously on opposite sides of the measured smallest dimension of the rock. The height of the fall is successively increased until the rock breaks. The impact crushing strength in foot-pounds per inch of rock thickness is designated as C, and Sg is the specific gravity [2,3]. As shown in Equation (6) the work index is found from the average of 10 breaks,

Wi = 2.59 C/Sg (6)

d) Bond Abrasion Index (Ai)

This index, devised by F.C. Bond [2,3] in the 1940s, quantifies the abrasivity of an ore. The index can be used to calculate metal wear rates in crushers and ball consumption rates in ball mills. In this test procedure about 10 kg of -55+38mm representative ore is required. The abrasion indices (Ai's) vary from a low of 0.026 for limestone through 0.18 for quartz and 0.25 for magnetite to 0.69 for quartzite and taconite. Ai'sover 1 have been experienced in the gold industry.

Fig.5.Bond Abrasion Index (Ai) Tester

e) Bond Rod Mill Work Index (RWI) /Rod Mill Grindability Test

The feed is crushed to -1/2 in., and 1250 cc packed in a graduated cylinder are weighed, screen analyzed, and ground dry in a closed circuit with 100 percent circulating load in a 12 in. dia. by 24 in. long tilting rod mill with a wave-type lining and revolution counter running at 46 rpm. The grinding charge consists of six 1.25 in. dia. And two 1.75 in. dia. Steel rods 21 in. long and weighing 33.380 grams.

In order to equalize segregation at the mill ends, it is rotated level for eight revolutions, then tilted up 5º for one revolution, down 5º for another revolution, and returned to level for eight revolutions continuously throughout each grinding period.

Tests are made at all mesh sizes from 4 to 65 mesh. At the end of each grinding period, the mill is discharged by tilting downward at 45º for 30 revolutions, and the product is screened on sieves of the mesh size tested. The sieve undersize is weighed, and fresh unsegregated feed is added to the oversize to make its total weight equal to that of the 1250 cc originally charged into the mill. This is returned to the mill and ground for the number of revolutions calculated to give a circulating load equal to the weight of the new feed added.

The grinding period cycles are continued until the net grams of sieve undersize produced per revolution reaches equilibrium and reverses its direction of increase or decrease. Then the undersize product and circulating load are screen analyzed, and the average of the last three net grams per revolution (Grp) is the rod mill grindability [8].

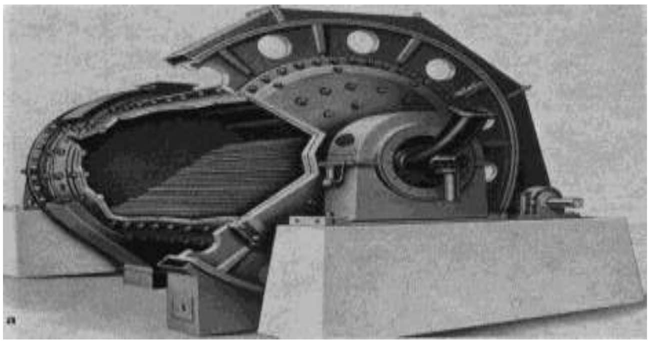

Fig.6.Rod Mill Work Index Unit

Where F is the size in microns which 80 percent of the new rod mill feed passes, and P_1 is the opening of the sieve size tested in microns, then the rod mill work index Wi[7] is calculated from the following revised (1960) Equation (7)

$$Wi = 62/(P_1)^{0.23} \text{ x } (Grp)^{0.625} \text{ x } \left(\frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}}\right) \quad (7)$$

This Wi value should conform with the motor output power to an average overflow rod mill of 8 ft interior diameter grinding wet in an open circuit. For dry grinding, the work input should be multiplied by 1.30. Where D is the mill diameter inside the lining in feet, the work input should be multiplied by $(8/D)^{0.20}$

Or the Bond rod mill work index (RWI) [7] is then given as shown in Equation (8)

$$RWI = 1.102 \text{ X } \frac{62}{(Pi)^{0.23} * (Grp)^{0.625} * \{\frac{10}{\sqrt{P80}} - \frac{10}{\sqrt{F80}}\}} \text{kWh/t} \quad (8)$$

Where:

- Grp = Rod mill grindability in g/revolution
- P = Product P80 in microns
- F = Feed P80 in microns
- Pi = Opening size in microns of the sieve size used

f) BondBall Mill Work Index (BWI)

Representative samples are to be prepared separately by stage crushing to all passing a 6 mesh sieve. The weight of the 700 cc sample is to be placed in the mill. These studies are to be carried out in a standard ball mill 300 mm X 300 mm size. The grinding media with steel balls weighing 20.125 Kgs has to be used [4,5].

The details of the number of balls used, its sizes are given below:

No. of balls	Size, mm
43	36.83
67	29.72
10	25.4
71	19.05
94	15.94

Fig.7.Ball Mill Work Index Unit

The weight of the material of 700 cc volume sample with the balls is to be charged to the ball mill and ground initially at 100 revolutions. The ground sample to be screened with the test sieve and the undersize sample is to be weighed and fresh unsegregated feed is to be added to the oversize to bring its weight back to that of the original charge. The number of revolutions required is to be calculated from the results of the previous period to produce a sieve undersize equal to 1/3.5 of the total charge in the mill [5].

The grinding period cycles are to be continued until the net grams of sieve undersize produce per mill revolution reaches equilibrium. Then the undersize product and circulating load is to be screen analyzed and the last three net grams per revolution (Gbp) is the ball mill grindability. The test mesh used maybe 100 mesh (150 µm). The Bond Work index Wi [7] can be calculated from the following equation (9)

$$Wi = 44.5/(P1)^{0.23} \text{ X } (Gbp)^{0.82} \; [10/(P80)^{1/2} - 10/(F80)^{1/2}] \qquad (9)$$

Where

- F80 is the size in microns at which 80 percent of the new feed to ball mill passes
- P80 is the size in micron at which 80 percent of the last cycle sieve undersize product passes P1 is the opening in microns of the sieve size tested.

Standard ball size according to Bond's [Wi]		Ball size distribution according to Bond's (Calculated ball size)	
No. of balls	Size, mm	No. of balls	Size, mm
43	36.83	209	25
67	29.72	92	19
10	25.4	102	17
11	19.05	160	12
94	15.94		
20.125 Kgs		20.125Kgs	

Standard equations were prescribed by Bond relating these parameters that would produce efficient grinding. These equations are described below, Equations 10-14.

$$B1/B2 = [d1/d2]^{1/2} \qquad (10)$$

Where

- B1 and B2 = ball diameter, mm
- d1 and d2 = particle diameter, µm

Maximum Ball size [B] of the media is calculated as per the equation (11) below:

$B = [F/K]^{1/2} [Sg.Wi / 100\ CS\ D1/2]^{1/3}$ (11)

Where

- B = maximum ball size, inch
- F = feed 80% passing size, µm
- K = grinding media constant
- Sg = specific gravity of the feed material
- Wi = work index of the feed material, kWh/short ton
- CS = critical speed, percentage
- D = inside diameter of the mill, inch

The Bond Work index was calculated using Equation (12)

$W_i = 44.5/[(P_1)^{0.23} Gbp^{0.82} \{\frac{10}{P^{0.5}} - \frac{10}{F^{0.5}}\}]$ (12)

Where

- F is feed size in microns 80 percent passes
- P is product size in microns 80 percent passes
- P_1 is test sieve size aperture in microns
- Gbp is ball mill grindability, net gms/revolutions

Power requirement for grinding was calculated using Equation (13)

$P = 1.46\ W_i [\frac{1}{P^{0.5}} - \frac{1}{F^{0.5}}]$ (13)

Where

- Wi is the Bond Work index in kWh ton^{-1}
- F is feed size in microns 80 percent passes
- p is product size in microns 80 percent passes
- P is the power consumed, hp

Where Power consumption of ball mill is calculated as given in equation (14) below

- $PB = \sqrt{3} * VL * IL * Cos\ \Phi$ (14)

= 1.732*396.33*1.4*0.7
= 672.71Watt

Where

- VL = 396.33 Volt
- IL = 1.4
- $Cos\ \Phi = 0.7$

g) Hard Grove Index (Hi)

The Hard grove index experiments were carried out using ASTM D409 – type bearing mill. The experimental process as described by Haeseto be carried out. A representative sample of 50 gms. -1180 µm +600µm to be prepared separately. The same was ground in the Hard grove index mill [11-15]. The ground product is to be discharged after 60 revolutions of the unit. Then the product to be screened at 75 µm. The hardgrove index of the sample has been calculated as per the following formula, Equation (15)

$H = 13 + 6.93m_H$ (15)

Where

- H is the Hardgrove index
- mH is the mass (in gm) of the particles smaller than 74 µm.

The mean of two to three parallel measurements is to be considered. However, the relative deviation of which cannot exceed 3%.

Bond proposed a relationship between the work index Wi and the Hardgrove grindability index (HGI), Equation (16)

$W\ B, H = 435/H^{0.91}$ (16)

In due course,Haese modified and suggested that the Bond index can be estimated from the Hardgrove index using the following empiric formula, Equation (17)

$WB, H = 435/ H^{0.82}$ (17)

Fig.8.Hard grove Index

II. CONCLUSION

It is suggested in this paper the following tests are essential for estimation of energy required for each unit operation for crushing and grinding of the ore, minerals except coal. The tests are Unconfined Compressive Strength (UCS - mpa), Drop Weight Tests (DWT), Bond Crushing Work Index (CWI), Bond Abrasion Index (Ai), Bond Rod Mill Work Index (RWI). Bond Ball Mill Work Index (BWI) and Hard Groove index is used for coal.

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