A Methodology to Estimate Ores Work Index Values, Using Miduk Copper Mine Sample

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Abstract

It is always attempted to reduce the costs of comminution in mineral processing plants. One of the difficulties in size reduction section is not to be designed properly. The key factor to design size reduction units such as crushers and grinding mills, is ore's work index. The work index, w_i, presents the ore grindability, and is used in Bond formula to calculate the required energy. Bond has defined a specific relationship between some parameters which is applied to calculate w_i, which are control screen, fine particles produced, feed and product d_{80}.

In this research work, a high grade copper sample from Miduk copper concentrator was prepared, and its work index values were experimentally estimated, using different control screens, 600, 425, 212, 150, 106 and 75 microns. The obtained results from the tests showed two different behaviors in fine production. According to these two trends the required models were then defined to present the fine mass calculation using control screen. In next step, an equation was presented in order to calculate Miduk copper ore work index for any size. In addition to verify the model creditability, a test using 300 microns control screen was performed and its result was compared with calculated ones using defined model, which showed a good fit. Finally the experimental and calculated values were compared and their relative error was equal to 4.11% which is an indication of good fit for the results.

Keywords: Modeling, Work Index, Miduk Copper, Control Screen, Bond Ball Mill

1- Introduction

To meet the increasing metal demands of various industries, the efforts to explore and extract the various ores has been extended. Mineral processing plants have the task to produce economic concentrates, and one of its major sections is ore grinding and comminution. The size reduction section in any mineral processing plant consumes the most amount of energy, so it is always to work in optimized condition to avoid consuming useless energy for material breakage and/or to avoid producing more fine/slime particles which are not suitable for further process.

One of the difficulties in size reduction section, crushing and grinding, is not to be designed properly. The key factor to design size reduction equipments such as crushers and grinding mills, is ore's work index which is experimentally calculated. The work index, w_i, is a parameter which presents the ore grindability and is used in Bond formula. The required energy to break and reduced ores size is calculated by "Bond law" which is presented as equation 1[1]. In equation 1, W is the minimum required energy in kwh/st and F and P are d_{80} of feed and product in microns. The w_i is called "work index" in kwh/st, and is a measure of ore grindability which is experimentally determined.

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

Work index presents the material grindability, and higher work index means more required energy to break the material/ore. Different standard methods and procedures were defined and published, to measure/estimate ores work index, in which particular equipments are used[1, 2]. These methods are such as Bond Rod Mill work index, Bond Ball Mill work index, Bond low-energy impact crushing work index[2]. One of the most common methods applied for ores is standard Bond Ball Mill method[1]. This Bond Ball Mill is 12×12 inches (diameter×length) which uses 20125g of

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different ball sizes. The procedure of test is explained by Bond, and work index is experimentally estimated by applying equation 2 to the test results. Different test parameters are measured and presented as follows[1]. In equation 2, G_i is fine mass produced per revolution of mill (g/rev.), P_i is control screen size (µm), and F, P are sizes of feed and product in which 80% of their particles are finer (µm).

$$w_i = \frac{44.5}{(P_i^{0.23})(G_i^{0.82})}\left(\frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}}\right)^{-1} \qquad (2)$$

It is considered that in equation 2, the work index depends on P_i which was defined as size of control screen and/or which describes the fine mass production. It is achieved that the change of grind limit and/or fine mass size (P_i) would accordingly change the amount of work index. In addition, it should be noted when P_i is changed, the other parameters such as G_i and P are also varied. The usual grind limit in work index experiments is 100-150 micron as control screen size (P_i)[1]. It comes from the last grinding step, Ball Mill product size in different mineral processing plants. However, when coarser grinding product (coarser than 100-150 microns) is concerned, the work index of material is accordingly changed, and therefore the breakage energy consumption is accordingly differed, as well.

It is in interest to model and define work index parameters with ores characteristics and ball mill performance, and some works were previously conducted to correlate of ball mill grindability as a measure of its performance [3, 4 and 5]. For example the ore friability which stems from ores' characteristics and properties could effectively change the work index values of ores[6].

In this regards, some research works were performed[7, 8, 9 and 10]. The results of these works showed that material work index is a key parameter describing its grindability, is not constant and depends on the size of grinding product[7]. Therefore it could practically be expected some difficulties and errors to estimating the required energy according to Bond formula (equation 1). Because when grinding product is varied from one size to finer and/or coarser size, therefore w_i is then changed. The experimental works have been done using various ores such as copper, andesite, limestone, lead & zinc, and dolomite[7, 8 and 9].

These works attempted to explain mathematically, the tendency of different parameters which are effective in material work index. They concluded the linear relationship between $(P_i)^{0.5}$ with G_i and P with P_i as well.

As a very preliminary question, it has been worked on the modeling of these parameters, to avoid any discrepancies occurring within the w_i experiments. In fact in this work, it is attempted to explain physically and mathematically the behavior and trend of work index (w_i) values, fine mass production (G_i), control screen size (P_i) and product d_{80} size (P). As it was mentioned the aim of this research is to present the relationship of work index with its effective parameters for a specific ore.

In fact it is aimed to model these parameters to simplify the bond work index equation. However the main question is to know the work index is changed with changing the ore's size, which means how ore's grindability would vary with its size. This research conclusion could perhaps decrease the risk of ore breakage energy calculation.

However to understand the trends of variation of parameters which are effective in work index estimation, a high grade copper ore sample from Miduk Copper Mine was used. Miduk is one the most significant copper ore mines and concentrators in Iran which is located in Kerman province.

2- Experimental Works

2-1- Sample Preparation

To perform the target of this work a sample was prepared from Miduk Copper Mine. This mine is one the most significant copper mines in Iran which located in Kerman Province. The prepared sample was initially analyzed using Atomic Absorption and its Cu content was equal to 2.47%. It showed that used sample was a high grade copper sample, so in order to find out its constitutive minerals, the XRD tests were then performed to distinguish the sample main minerals and its clay minerals as well. The X-Ray diffraction data were collected using a Bruker D8-Advance with a copper tube (40 kv, 30 mA). Diffraction patterns were collected in the angular range 4-70 2θ, with a 0.02 step size and counting 1 second per step. The XRD results indicated that the main minerals in sample were: quartz, feldspar, mica, clay minerals (illite, kaolinite, chlorite, montmorilonite), chalcopyrite and pyrite (Figure 1).

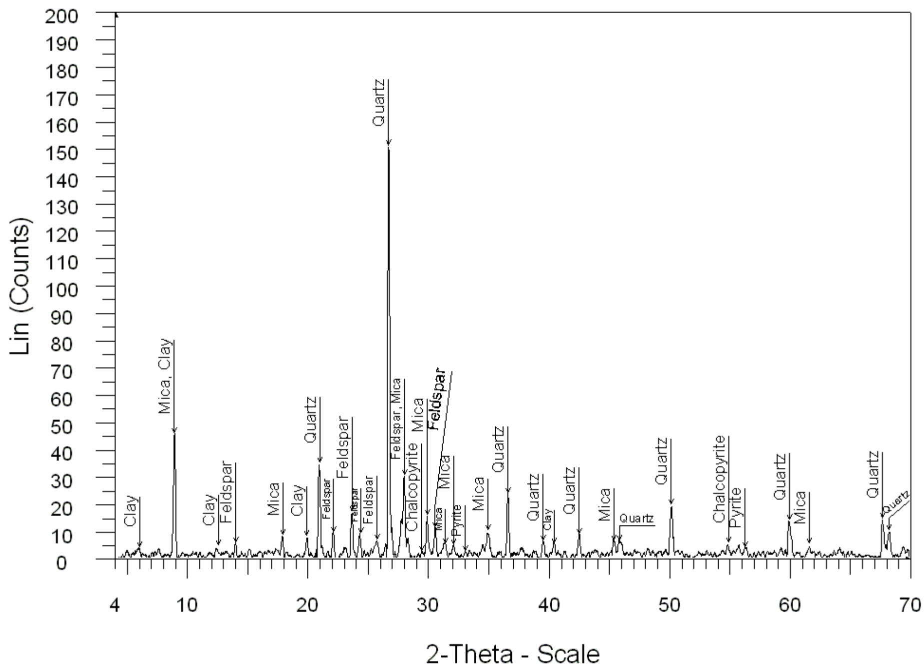

Figure 1: The X-Ray diffraction pattern of sample.

In order to run the work index tests, prepared sample was first crushed and ground down to 100% finer than 2380 microns which was defined in Bond standard method[1]. It was then size analyzed using screen analysis test which showed that d_{80} of sample was 1476 microns. In addition, as ore's bulk density is necessary to be used for work index estimation, so it was measured for the prepared sample which was equal to 1.41g/cm^3.

2-2- Test Works

In order to study on the variation of work index with control screen changes, the prepared sample was used in different 6 experiments. These experiments were carried out in Bond Ball mill and based on the Bond standard procedure[1]. The only change in these tests was the control screen which was 600, 425, 212, 150, 106 and 75 microns. It means that each test was performed with one of the introduced screens as grinding product size control to measure produced fine mass. According to the obtained results from these experiments, the relevant work index value was estimated using equation 2. Table 1 presents the tests results for different effective parameters. It is observed that the work index is differed from minimum 9.072kwh/st for screen 75 microns to maximum 10.699kwh/st for 600 micron control screen (P_i). It means that w_i is increased with increasing P_i. It is accordingly concluded that the other parameters, P and G_i were also increased with increasing of control screen size, P_i. Albeit in finest three control screen sizes tests, using 150, 106 and 75 microns the amount of P was almost constant and did not show significant discrepancy.

The tendency of variation for different parameters is presented in Figures 2 and 3. The different behaviors for the G_i versus P_i are observed (Figure 2). This change is started from about 150 microns, and could be found in P_i and P values as well (Figure 3), although its inclination is relatively low and slow. This comes from the fact of higher fine mass production from coarse particles due to existing more flaws/cracks and weak fissures in coarse particles. Therefore, for sizes finer than 150 microns the production of fines was decreased comparing with coarser sizes. It is also observed that for sizes finer than 150 microns, the fine was constantly produced indicating that particles achieved their stable structure, in term of breakage.

Table 1: Results of experimental work index values, using Bond Ball Mill.

d_{F80}=1476 (µm)			
w_i (kwh/sht)	P (µm)	G_i (g)	P_i (µm)
9.072	59.2	1.98	75
10.005	75.7	1.92	106
10.202	91.0	1.98	150
10.141	142.2	2.63	212
10.201	310.9	4.66	425
10.699	467.4	6.64	600

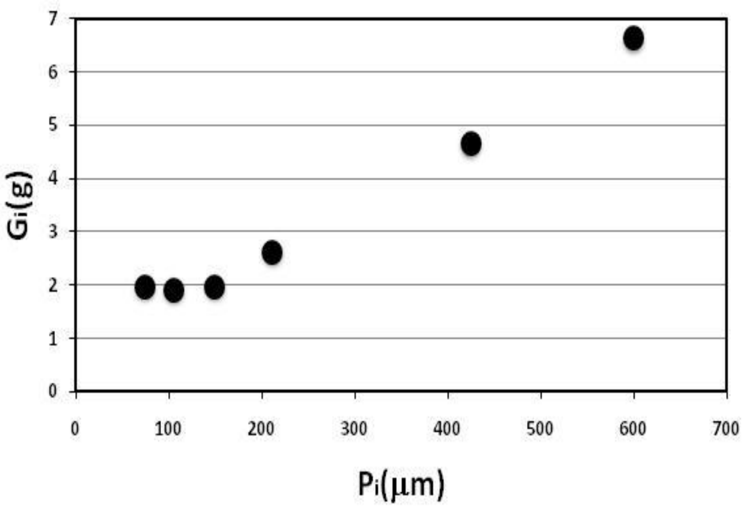

Figure 2: Variation of G_i and P_i.

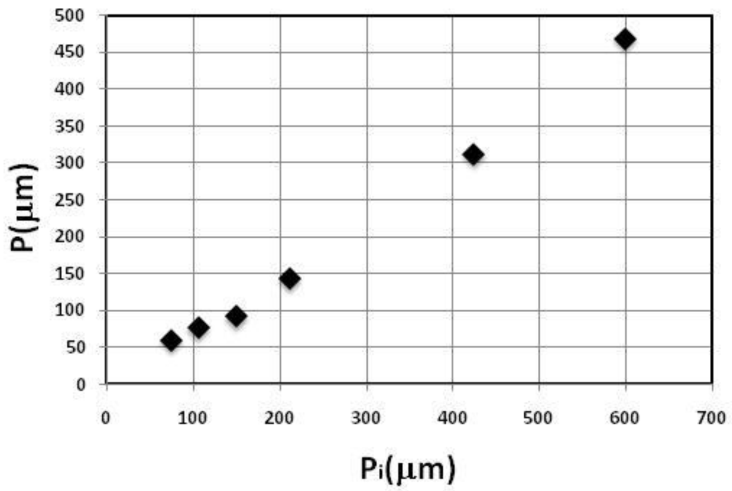

Figure 3: Variation of P and P_i.

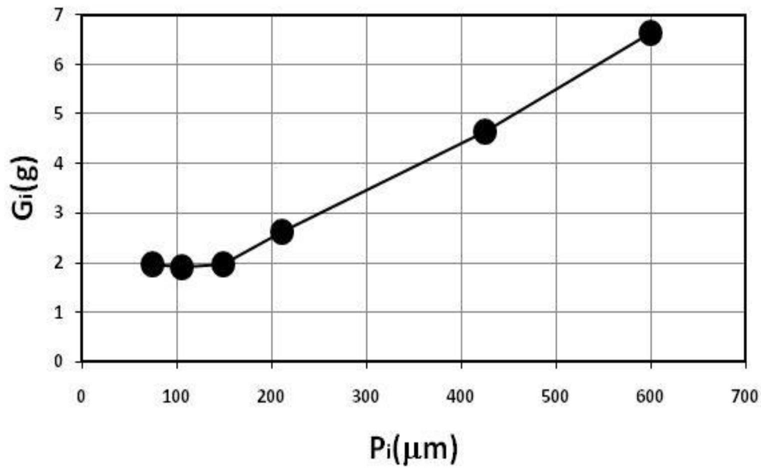

Figure 4: Linear trends for the G_i and P_i.

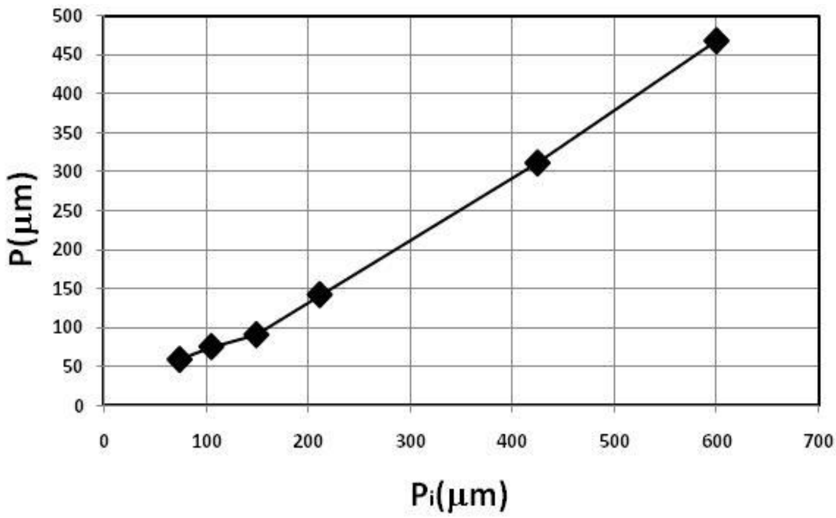

Figure 5: Linear trends for the P and P_i.

Figures 4 and 5 present the linear trends of P_i & P and G_i & P_i values, which were showed in Figures 2 and 3. It is clear that the linear equation would easily be fitted. Therefore, the linear equations were accordingly achieved from Figures 4 and 5, which are defined as following.

For control screen size of $75<P_i<150$ µm, P and P_i showed linear trend which was defined with equation 3, and for $150<P_i<600$ µm, the linear trend of P and P_i was described with equation 4. For control screen size of $75<P_i<150$µm, G_i and P_i showed linear trend which was modeled with equation 5, and for $150<P_i<600$ µm, the linear trend of G_i and P_i was described with equation 6. Finally, using equations 3, 4, 5 and 6, the general model (equation) to calculate the work index values for the Miduk copper ore was defined as equation 7 for two different control screen size of $75<P_i<150$ µm (equation 7-a), and for $150<P_i<600$ µm (equation 7-b).

$$P = 0.4189P_i + 29.084 \quad (3)$$

$$P = 0.812P_i - 24.252 \quad (4)$$

$$G_i = 1.95 \quad (5)$$

$$G_i = 0.0102P_i + 0.4254 \quad (6)$$

$$w_i = \frac{44.5}{(P_i^{0.23})(1.95^{0.82})}\left(\frac{10}{\sqrt{0.4189P_i + 29.084}} - \frac{10}{\sqrt{1476}}\right)^{-1} \quad (7\text{-a})$$

$$w_i = \frac{44.5}{(P_i^{0.23})(0.0102P_i + 0.4254)^{0.82}}\left(\frac{10}{\sqrt{0.812P_i - 24.252}} - \frac{10}{\sqrt{1476}}\right)^{-1} \quad (7\text{-b})$$

3- Evaluation of Work Index Model

In order to evaluate the creditability of equation 7, to calculate the work index in various sizes, a test using 300 microns control screen was carried out in Bond ball mill. The work index was estimated according to the obtained results from this experiment which was equal to 9.948 kwt/st. Then the work index for this size, 300 microns, was calculated using equation 7 which was 10.3756 kwh/st. It is observed that the discrepancy of experimental and calculated work index values for 300 microns control screen was low with 4.11% relative error. This low error is an indication of defined model creditability. Table 2 shows the experimental and calculated results. In next step the work index values which had experimentally been estimated for various sizes of control screens (Table 2), were calculated using equations 7-a (for control screen size: $75<P_i<150$ µm) and 7-b (for control screen size: $150<P_i<600$ µm). These results are graphically presented in Figure 6, in which there is relatively good fit for two graphs.

Table 2: Experimental & calculated work index values using 300μm screen.

d_{F80}=1476 (μm)				
Results	w_i (kwh/sht)	P (μm)	G_i (g)	P_i (μm)
Experimental	9.948	212	3.547	300
Calculated	10.375	219	3.480	300
Relative Error (%)	4.11	3	2	-

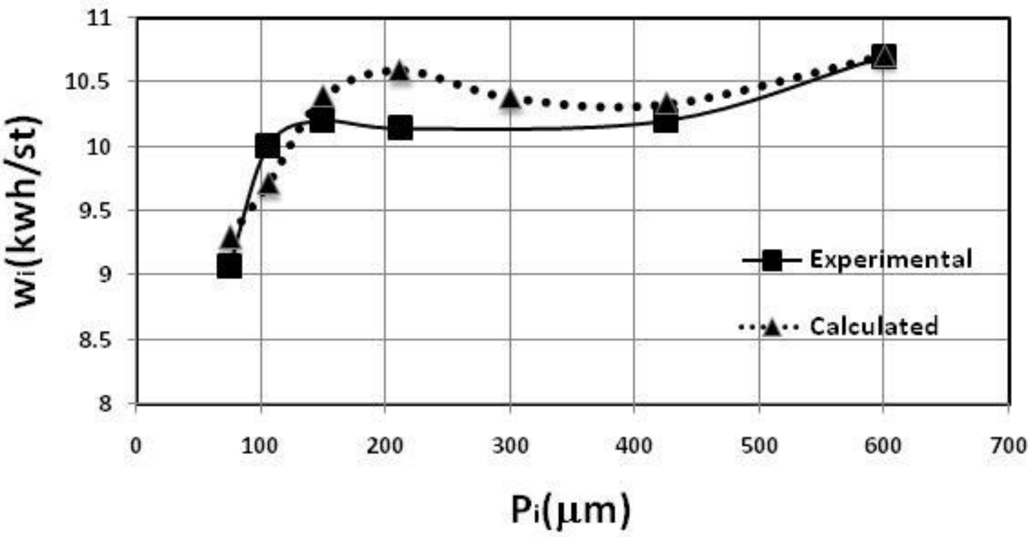

Figure 6: Experimental & calculated work index values.

4- Conclusions

It was attempted to explain physically and mathematically the behavior of work index (w_i), fine mass production (G_i), control screen size (P_i) and product d_{80} size (P), using sample from Miduk Copper Mine. Thus some experiments with standard Bond ball mill were performed. The control screens were changed in these experiments, and the variation of other parameters, G_i, P_i and P were defined and modeled. However the following conclusions were made:

- The work index values for the Miduk copper ore were experimentally estimated, using different control screens 600, 425, 212, 150, 106 and 75 microns in Bond ball mill.
- Results obtained from experiments showed two different trends for the various parameters which are effective for work index estimation, P, G_i. This trend differs from about 150 microns size.
- Using experimental results, the required linear models were fitted for P & P_i, and G_i & P_i, and they were creditably evaluated.
- According to the obtained results from experiments, and using defined linear models, equations for two different size fractions were proposed, in order to calculate the work index value for any control screen (product) size, using Miduk copper ore.
- In order to evaluate the creditability of defined model (equation 7), a test using 300 microns control screen was carried out. The work index was estimated to 9.948 kwt/st and the calculated value using equation 7 was 10.3756 kwh/st.
- It was observed that the discrepancy of experimental and calculated work index values for 300 microns control screen was low with 4.11% relative error. This low error is an indication of defined model creditability.

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