The Evaluation of Grinding Behaviors of Quartz and Feldspar

Yakup Umucu[1], Vedat Deniz[2]

[1] Süleyman Demirel University, Department of Mining Engineering, Isparta, Türkiye
[2] Hitit University, Department of Chemical Engineering, Çorum, Türkiye
yakupumucu@sdu.edu.tr

Abstract: Quartz crystals are used in the electronic industry, frequency control oscillator and frequency filters. Milk quartz and quartz glass by grinding and preparation procedures through the glass, detergent, paint, ceramic, sand, fill, and metallurgical industries, fine sizes (micronized) are used. Micronized feldspar group minerals, ceramics and glass industries within the limits of a certain quality have an important market due to the grinding of raw materials are widely used. In the size reduction, energy-intensive process is consumed about 3% of the energy produced in the industrialized countries in the world (Schonert, 1979; Narayanan, 1987). The size reduction operations are spent on approximately 55-70 % of the total energy consumed in the mineral processing plants (Cohen, 1983; Lynch et al., 1986). In this study, the behavior of quartz and feldspar broken into the same grinding conditions was presented Bond Grinding test and then analyzed using the kinetic model. The results obtained experimental works in each of two methods is compared.

Keywords: Kinetic Model, Breakage Rate, Industrial Raw Materials

Introduction

Quartz is the second most abundant mineral in the Earth's continental crust. There are many varieties of quartz, which occurs in nearly all types of igneous, metamorphic and sedimentary rocks. Hence, it found as a main impurity in all kinds of valuable ore deposits.

Regular and clean quartz crystals are used in optical and electronic industry and the ornamental stone. Quartz crystals fine grinding are used in the electronic industry, frequency control oscillator and frequency filters. The grinding of quartz and milk quartz are finely ground and are been mineral preparation used for glass, detergents, paints, ceramics, sand, fill, and metallurgical industries.

The largest consumption areas of feldspar produced in Turkey have been ceramic, glass industries, painting, welding electrodes and plastic industry. The biggest challenge in producing K-Feldspar is due to the production of glaze K-Feldspar and grinding of the K-Feldspar. This is a fact that the coming years will be even more important. In particular, as the productions of granite - ceramic with natural ceramics in factories are passed, Production of K-feldspar require to excusive grinding preparation.

The demand for fine, or ultrafine particles is increasing in many industries. The energy required for the size reduction increases with a decrease in feed or produce particle size, and research and development to find energy-saving size reduction processes have been performed for years.

For all dry grinding applications, chemical industries, mineral industries and cement production are certainly the most important. Energy necessity is very high in grinding processes. There are many grinder manufactures and several of machines made for grinding minerals. The correct selection between all alternative is a difficult problem (Deniz, 2011 & Deniz, 2011)

In the design of grinding circuits, the Bond method is widely used to evaluate the performance and to determine the powder required and mill size for a material. This method is complex and takes a very long time. In addition to this, it is very sensitive to procedural errors. For this reason, many investigators have proposed alternative methods to the Bond method (Deniz, Özdağ, 2003; Deniz, 2004).

In the recent years, matrix and kinetic models have been used in the laboratory and in the industrial areas. Kinetic model, an alternative approach, considers comminution as a continuous process in which the rate of breakage of particles size is proportional to the mass presented in that size (Deniz, Onur, 2002).

The analysis of size reduction in tumbling ball mills using the concepts of specific rate of breakage and primary daughter fragment distributions have received considerable attention in recent years. Austin (1972) and

Austin et al. (1984) reviewed the advantages of this approach, and the scale-up of laboratory data to full-scale mills has also been discussed in a number of papers.

In this study, the behaviors of quartz and feldspar comminution in the same grinding conditions are investigated that firstly Bond Grinding test and then analyzed using the kinetic model. Results of both methods are compared.

Theory

1. Kinetic Model

Population balance modeling is a widely used tool for the quantitative analysis of comminution processes at the process length scale. The traditional size-discrete form of the population balance equation for batch comminution is linear and assumes first-order breakage kinetics (Austin, 1972).

$$\frac{dw_i(t)}{d_t} = -S_i W_i(t) + \sum_{j=1}^{i-1} b_{ij} S_j W_j(t), \tag{1}$$

Thus, the breakage rate of material that is in the top size interval can be expressed as:

$$\frac{-dw_1}{dt} = S_1 w_1(t) \tag{2}$$

Assuming that S_1 does not change with time (that is, a first-order breakage process), this equation integrates to

$$\log(w_1(t)) - \log(w_1(0)) = \frac{-S_1 t}{2.3} \tag{3}$$

where $w_1(t)$ and is the weight fraction of the mill hold-up that is of size 1 at time t and S_1 is the specific rate of breakage. The formula proposed by Austin et al. (1984) for the variation of the specific rate of breakage S_i with particle size is

$$S_i = a_T X_i^{\alpha} \tag{4}$$

where X_i is the upper limits of the size interval indexed by i, mm, and a_T and α are model parameters that depend on the properties of the material and the grinding conditions.

On breakage, particles of given size produce a set of primary daughter fragments, which are mixed into the bulk of the powder and then in turn have a probability of being refractured. The set of primary daughter fragments from breakage of size j can be represented by $b_{i,j}$, where $b_{i,j}$ is the fraction of size j material, which appears in size i on primary fracture, $n \geq i > j$. It is convenient to represent these values in cumulative form.

$$B_{i,j} = \sum_{k=n}^{i} b_{k,j} \tag{5}$$

where $B_{i,j}$ is the sum fraction of material less than the upper size of size interval i resulting from primary breakage of size j material: $b_{i,j} = B_{i,j} - B_{i+1,j}$. Austin et al.(1981) have shown that the values of $B_{i,j}$ can be estimated from a size analysis of the product from short time grinding of a starting mill charge predominantly in size j (the one-size fraction BII method). The equation used is,

$$B_{i,j} = \frac{\log[(1-P_i(0))]/\log[(1-P_i(t))]}{\log[(1-P_{j+1}(0))]/\log[(1-P_{j+1}(t))]}. \quad n \geq i \geq j+1 \tag{6}$$

where $P_i(t)$ is the fraction by weight in the mill charge less than size X_i at time t. $B_{i,j}$ can be fitted to an empirical function (Austin and Luckie, 1972).

$$B_{i,j} = \phi_j \left[X_{i-1}/X_j\right]^{\gamma} + (1-\phi_j)\left[X_{i-1}/X_j\right]^{\beta} \quad n \geq i \rangle j \tag{7}$$

where

$$\phi_j = \phi_1 \left[X_i / X_1\right]^{-\delta} \tag{8}$$

where δ, ϕ_j, γ, and β are model parameters that depend on the properties of the material. If $B_{i,j}$ values are independent of the initial size, i.e. dimensionally normalizable, then δ is zero (Austin et al., 1984).

***2.* Bond Grindability Test**

Laboratory Bond grindability tests were conducted with -3.35 mm dry feed materials in a standard ball mill (30.5 x 30.5 cm) following a standard procedure outlined in the literature (Yap et al., 1982; Deister, 1987; Ipek, 2003). The BWI was determined at a test sieve size of 106 µm. Mill has no lifters and all the inside comers are rounded. It is operated at 70 rpm and is equipped with a revolution counter. The grinding charge consists of 285 iron balls weighing 20.125 grams with a calculated surface area of 842 inc^2.

The standard Bond grindability test is a closed-cycle dry grinding and screening process, which is carried out until steady state conditions are obtained. This test was proposed by Bond and Maxson (1943) and used by different researcher (Yap et al, 1982; Austin and Brame, 1983; Magdalinovic, 1989). The material is packed to 700 cm^3 volume using a vibrating table. This is the volumetric weight of the material to be used for grinding tests. For the first grinding cycle, the mill is started with an arbitrarily chosen number of mill revolutions. At the end of each grinding cycle, the entire product is discharged from the mill and is screened on a test sieve (P_i). Standard choice for P_i is 106 micron. The oversize fraction is returned to the mill for the second run together with fresh feed to make up the original weight corresponding to 700 cm^3. The weight of product per unit of mill revolution, called the ore grindability of the cycle, is then calculated and is used to estimate the number of revolutions required for the second run to be equivalent to a circulating load of 250%. The process is continued until a constant value of the grindability is achieved, which is the equilibrium condition. This equilibrium condition may be reached in 6 to 12 grinding cycles. After reaching equilibrium, the grindability for the last three cycles is averaged as a Bond grindability index (G_B).

The products of the total final three cycles are combined to form the equilibrium rest product. Sieve analysis is carried out on the material and the results are plotted, in order to find the 80% passing size of the product (P_i). The coal samples are crushed by a laboratory scale jaw crusher and the standard Bond grindability test were performed in the laboratory. BWI values are calculated from Equation 1. G_B and BWI values are presented in Table 2.

$$\mathrm{BWI} = 1.1 \frac{44.5}{P_i^{0.23} G_B^{0.82} \left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)} \tag{9}$$

where W_i is Bond work index in kWh/t, P_i is sieve size at which the test is performed in µm, G_B is Bond's standard ball mill grindability in g/rev, P_{80} and F_{80} are sieve opening at which 80% of the product and feed passes, respectively in µm.

Materials and Method

The samples taken from different regions of Turkey were used as the experimental materials. Feldspar, quartz samples are taken from deposits in Aydın – Çine in Turkey.

Materials were broken -3,36 mm for grinding tests. The standard set of grinding conditions used was shown in Table 1. Ten mono-size fractions (-3,35+2,8;-2,8+1,7;-1,7+1,18; -1,18+0,850; -0,850+0–600; -0,600+0,425; -0,425+0,300; -0,300+0,212; -0.212+0,150; -0,150+0,106 mm) were prepared and ground batch wise in a laboratory-scale ball mill for determination of the breakage functions. Samples were taken out of the mill and dry sieved product size analysis.

Table 1: The standard set of grinding conditions

Mill	Diameter	200 mm
	Length	200 mm
	Volume	6283 cm^3
	Critical speed (Nc)[a]	101 rpm
	Operational (75, %)	78 rpm
Bilya	Diameter range	25.4 mm
	Specific gravity	7.8 g/ cm^3
	Quality	Alloy steel
	Assumed bed porosity	40%
	Ball filing volume *(J%)*[b]	30% (J=0,3)
Material	Feldspar	Quartz
Formal bulk density, g/cm^3	2,61	2.64
Interstitial filling *(U%)*[d]	0,83	0.83
Powder filling volume (f_c%)[c]	0.10	0.10

[a] *Calculated from Nc=42.3 /√D-d (D, d in meters)*

[b] *J=[(mass of balls / specific gravity of balls)/ mill volume]*1/ 0.6*

[c] *f_c=[(mass of materials / specific gravity of materials)/ mill volume]*

*U= f_c / 0,4*J*

Results and Discussion

1. Determination of Bond Grindability and work index

First, standard Bond grindability test was made for feldspar and quartz samples. Bond grindability and index values were given table 2.

Table 2: Grindability and work index values of feldspar and quartz

Samples	G_{bg} (g/r)	W_i (kwh/t)
Feldspar	2,30	9,81
Quartz	1,29	16,10

2. Determination of S Functions

The first-order plots for the various feed sizes of all samples and for the various feed sizes of samples were made. Typical first-order plots for grinding of all samples, at a low powder load corresponding to a formal interstitial filling of the void spaces of the ball bed of U% 0.83. The results indicated that breakage generally followed the first-order relation and values of Si could be determined. As a function of size, the values of Si were given figure 1 and figure 2. Parameters of specific rate of breakage to supply by first-order plots are presented in Tables 3.

Table 3: Model parameter values for quartz and feldspar

Samples	a_t	α	γ	ϕ_J
Quartz	0.88	1.52	1.59	0.45
Feldspar	0.33	1.14	0.65	0.49

The greater the amount of Si and a_T values, the more effective breakage and the faster broken in the undersize of original particle size. From the Table 3, it is seen that quartz was broken faster than feldspar in terms of the a_T values. On the contrary, the Bonds grindability value (G_{bg}) for feldspar was easier than quartz.

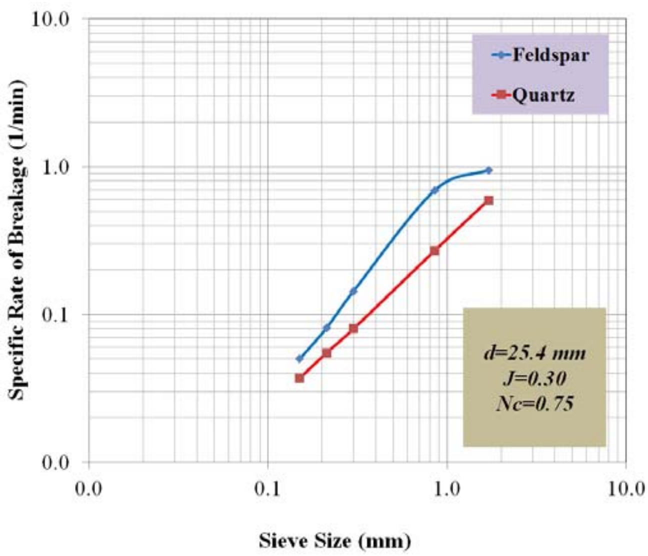

Figure 1: Specific rates of breakage for quartz and feldspar

3. Determination of B Functions

Determination of *B* Functions by definition, the values of *B* were determined from the size distributions at short grinding times. The parameters were determined according to the *BII* method (Austin et al. 1984), and are shown as graphical representations in Figures 2.

All samples show a typical normalized behavior, and the progeny distribution did not depend on the particle size, and it followed that the parameter δ was zero. Model parameters supply by cumulative distribution and these parameters are presented in Tables 3.

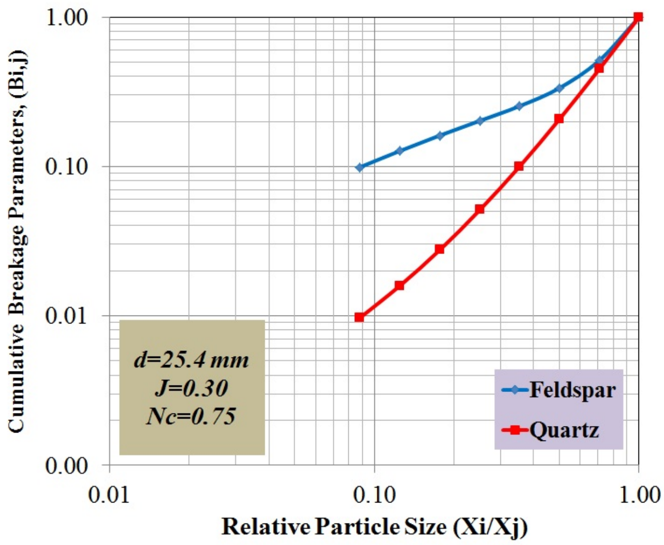

Figure 2: Cumulative breakage distribution functions of quartz and feldspar

The slope of the lower portion of the $B_{i,j}$ curve can be denoted by χ with smaller values of χ and indicating that once particles of a certain size break, they produce many much smaller progeny fragments. Thus, feldspar samples produce finer material than quartz by considering the χ value of $B_{i,j}$. The values of the coefficient ϕ_j is related to coarse end of the breakage distribution function and show how fast fractions close to the feed size passes to smaller size interval. The ϕ_j value (0.49) was higher for Feldspar than other samples indicating that acceleration in the breakage of the top size for feldspar and deceleration for quartz (0.45).

Conclusions

Bond grindability test gives information about the materials of strength to grindability and comminution and helps us to determine energy consumption, in the selection of crushing equipment.

Bond grindability values of two samples are obtained 1.29 g /rev of quartz and 2.30 g/rev of feldspar. In addition, Bond Work Index for each of two samples is calculated 10.16 kWh / t of quartz and 9.81 kWh / t for feldspar, respectively. Grindability of feldspar is easier than quartz from grindability and Bond work index values.

In the experimental study of Austin et al (1984), is appeared that if Si values are being high particulates will be more efficient break and the original particulate can be reduced more quickly reported. According to this approach, feldspar is broken faster than quartz.

γ, ϕ_j values is provide information that large quantity or low quantity of amount of fine material and coarse sieve size to fine sieve size gives an idea about the breakage rate. The materials are to be grinding more quickly from high of these values. According to this approach it was emerged feldspar was ground faster than quartz.

In the grinding studies depend on Bond grindability and kinetic model, it was showed that grinding of feldspar and quartz samples is a similar trend. In the previous studies on Bond grindability values and kinetic model parameters were not observed similar trends.

In the study of Deniz (2011), Bond grindability values and kinetic model parameters were emerged a different behavior. In this study, the kinetic model parameters on grindability of materials that is difficult appeared a similar trend.

Key Terms:

J	fraction of mill volume filled by the ball bed
fc	fraction of mill volume filled by the powder bed
U	fraction of the interstices of the ball bed filled by powder
d	ball diameter (mm)
W	total powder mass in the mill
t	grinding time (min)
$w_1(t)$	weight fraction of mill hold-up that is of size 1 at time t
i	an integer indexing a √2 screen interval
Si	specific rate of breakage (min^{-1})
Xi	the upper limits of the size interval indexed by i (mm)
aT	model parameter
α	model parameter
bi,j	breakage distribution function, part of interval j falling into interval i
Bi,j	cumulative breakage distribution function
$P_{i(0)}$	cumulative weight fraction at time 0 for size interval i
$P_{i(t)}$	cumulative weight fraction at time t for size interval i
χ	model parameter
β	model parameter
φ_j	model parameter
δ	model parameter

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