



Research Article

AN INVESTIGATION OF GRINDING CHARACTERISTICS OF NA-FELDSPAR BY MEANS OF THE KINETIC MODEL PARAMETERS

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ABSTRACT

In this study, the specific rates of breakage (S_i) and the primary breakage distribution (B_{ij}) values of Na-feldspar were determined for four mono-sized feed fractions; -0.106+0.090 mm, -0.090+0.075 mm, -0.075+0.063 mm, and -0.063+0.045 mm. Batch dry grinding tests were carried out for 0.25 and 0.50 minutes of grinding time by using laboratory grinding mill having cylpebs with 10 mm diameter. And then the kinetic model parameters (S_i , a_T , α , γ and \square_j) were calculated and presented in a comparative manner for different grinding times.

Keywords: Breakage parameters, cylpebs milling, kinetic model, na-feldspar.

1. INTRODUCTION

The fine grinding in the micron range has recently become important in connection with the development of new functional materials such as new ceramics and electronic materials in various industrial fields. For grinding mills using spherical balls as grinding media, the effectiveness of small grinding balls on the fineness of ground products has been recognized as an important experimental factor [1-4].

The existence of a grinding limit is a problem that is inherent with fine grinding. Experimental study shows that particles that are larger than a certain limit experience breakage if subjected to enough intensive stress, while the smaller ones undergo plastic deformation only [5,6]. The nature of this phenomenon can be explained using concepts carried over from the physics of fracture.

Fine grinding is an intermediate case between coarse grinding and mechanical activation. Similar to coarse grinding, it is intended for size diminishing. However, it does not allow simple scaling because of its more complex physical background. Quantitative changes in particle size brings up qualitative changes in the nature of the process, so producing fine and ultrafine powders demands a more fundamental understanding of the physics of mechanical energy relaxation [7]. This circumstance makes fine grinding analogous to mechanical activation.

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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 years. Austin et al. (1984) reviewed the advantages of this approach; and the scale-up of laboratory data to full-scale mills were discussed in a number of papers summarized by different researchers [8].

In this study, some problems concerning the relation between fine grinding and kinetic model parameters of the grinding time were explained. The main questions to be considered are the change of kinetic model parameters in fine size particles. In particular, how model parameters changed in fine particle size has not been demonstrated by researchers.

In this study, especially the breakage distribution function parameters were put forward in the fine particle sizes (-106+45 μm). In addition, the Na-feldspar used in the study is also used in ceramic sanitaryware industry. Determining the grinding conditions of Na-feldspar and revealing the fragmentation characteristics will have contributions at industrial scale.

2. BACKGROUND

When breakage occurs in an efficient manner, the breakage of a given size fraction of material usually follows a first-order law [9]. Thus, the breakage rate of the material that is in the top size interval can be expressed as below:

$$\frac{-dw_1}{dt} = S_1 w_1(t) \tag{1}$$

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

$$\log[w_1(t)] - \log[w_1(0)] = \frac{-S_1 t}{2.3} \tag{2}$$

where $w_1(t)$ is the weight fraction of the mill hold-up of the 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 grain size is:

$$S_i = a_T (X_i)^\alpha \tag{3}$$

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

On breakage, grains 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 re-fractured. 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, $n \geq i \geq j$. It is convenient to represent these values in a cumulative form.

$$B_{i,j} = \sum_{k=n}^i b_{k,j} \tag{4}$$

Here, $B_{i,j}$ is the sum fraction of the 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) showed that the values of $B_{i,j}$ could 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) [10]. The equation is:

$$B_{i,j} = \frac{\log[(1-P_i(0))/\log[(1-P_i(t))]]}{\log[(1-P_{j+1}(0))/\log[(1-P_{j+1}(t))]]}, \quad n \geq i \geq j + 1 \tag{5}$$

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 [4].

$$B_{i,j} = \phi_j [X_{i-1}/X_j]^\gamma + (1 - \phi_j) [X_{i-1}/X_j]^\beta, \quad n \geq i \geq j \tag{6}$$

$$\phi_j = \phi_1 [X_i/X_1]^{-\delta} \tag{7}$$

Here, δ , \square , γ and β are the model parameters that depend on the properties of the material. γ is the slope of the lower section of the $B_{i,j}$ curve; and β is the slope of the steeper section of the $B_{i,j}$ curve as in Figure 1 [8,12].

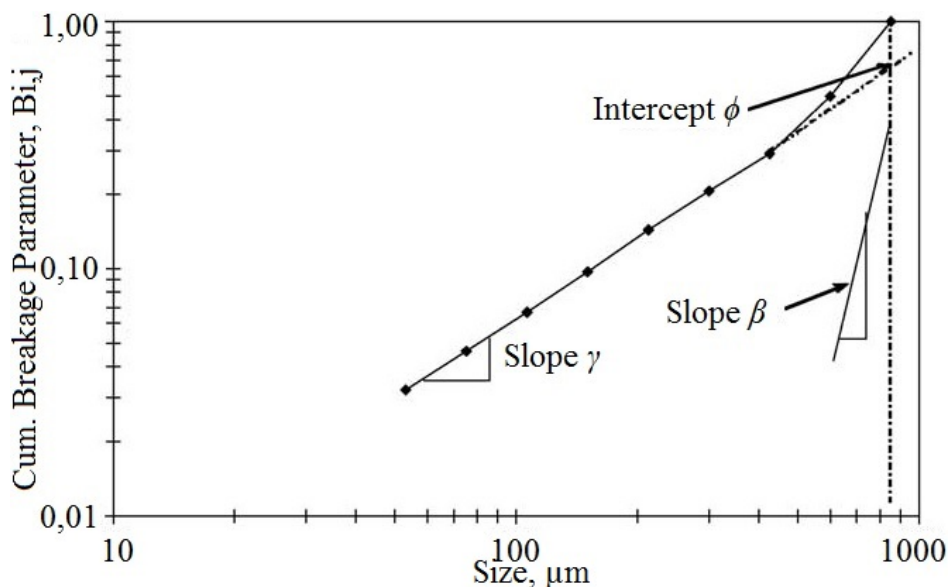


Figure 1. Obtaining the primary breakage distribution function parameters for any single size fraction feed ground in the mill

3. MATERIALS AND METHOD

Feldspar minerals are major commodities used in the production of glass and ceramics. In a significant proportion of feldspar ores, Na-Feldspar (albite; $\text{NaAlSi}_3\text{O}_8$) and K-feldspar (KAlSi_3O_8 ; microcline or orthoclase) exist in the same matrix, usually in quantities of about 3-5% Na_2O and K_2O .

Na-feldspar (Milas deposit in Turkey) were chosen as the feed mineral for this study. Na-feldspar was characterized with X-ray fluorescence (XRF) using Spectro equipment, model X-Lab 2000; X-ray diffraction (XRD) using Philips equipment, model X'Pert MPD, with radiation Cu-K α (45 kV/ 40 mA). The densities of Na-feldspar, measured by a pycnometer, are averaged as 2.58 g/cm³ over three measurements and Bond work indexes (W_i) of this material are 13.27 kWh/t, respectively. The Bond work index is determined by using the standard Bond test procedure for 0.106 mm test sieve size [8].

The breakage parameters were determined experimentally using one size fraction technique [11]. The size fractions chosen for tests were, -0.106+0.090, -0.090+0.075, -0.075+0.063 and -0.063+0.045 mm. For example, -0.106+0.090 mm denotes that 100% of the grains pass by weight at 0.106 mm size and 100% of grains remain at 0.090 mm. The standard set of grinding conditions used is shown in Table 1 for a laboratory mill with a 2650 cm³ volume.

Table 1. Ball mill characteristics and test conditions

Mill	Diameter, D mm	150	
	Length, mm	150	
	Volume, cm^3	2650	
	Critical (N_c) ^a , rpm	113	
	Operational ($\emptyset_c=75\%$), rpm	84.75	
Mill charge	Quality	Cylpebs	
	Diameter, d mm	10	
	Specific gravity, g/cm^3	6.75	
	Ball filling volume, J ^b	0.30	
Media charge	Sample	Na-feldspar	
	Specific gravity, g/cm^3	2.58	
	Powder weight, g	656.53	820.66
	Powder filling volume, f_c ^c	0.096	0.120
	Powder-ball loading ratio, U ^d	0.80	1.00

$$^a N_c = 42.3/\sqrt{D-d} \quad (D, d \text{ in metres})$$

$$^b J = ((\text{mass of balls}/\text{ball density})/(\text{mill volume})) \times (1.0/0.6)$$

$$^c f_c = (\text{mass of powder}/\text{powder density})/(\text{mill volume})$$

$$^d U = f_c/0.4J$$

4. RESULTS AND DISCUSSION

4.1. Properties of Na-Feldspar

Table 2 presents the chemical composition of Na-feldspar. The amount of K_2O , MgO and Fe_2O_3 in the Na-feldspar was 0.36, 0.21 and 0.18 mass-%, respectively. As a result of XRD analysis, biotite was identified in the Na-feldspar (Figure 2), because it is known that K_2O , MgO and Fe_2O_3 are the components of biotite.

Table 2. Chemical composition of Na-feldspar

SiO_2	Al_2O_3	Na_2O	MgO	K_2O	CaO	Fe_2O_3	TiO_2	LOI
69.84	18.07	10.30	0.21	0.36	0.56	0.18	0.17	0.31

Figure 2 shows the X-ray diffraction patterns of Na-feldspar. Na-feldspar consists of albite [ICDD (01-089-6423)], quartz [ICDD (01-085-1054)] and biotite [ICDD (00-002-0057)]. The XRD result was confirmed by a chemical analysis.

4.2. Determination of S parameters

The initial grinding results obey the first-order breakage form as in Eq. (3). When the values of S_i are fitted to the expression; the a_T value is obtained by inserting a and x_i . Using Eq. (3), S_i , a_T and α were obtained for Na-feldspar and outlined in Table 3 as the breakage parameters to use for simulations of the product size distributions. In Figure 3, the a_T value is the specific rate of breakage at 1000 μm grain size, and α is the inclination of the breakage rate curve.

Variations in specific rates of breakage at different feed particle sizes for cylpebs grinding charges are shown in Figure 3. The specific rate of breakage increases up to -90+75 μm feed size, but above this size, fraction breakage rates decrease sharply for powder filling ratios. The particles have a slow specific rate of breakage. This was due to the efficiency of the largest feed

sizes that were not nipped properly by the balls in the mill. This means the feed sizes larger than 90 μm will not be ground efficiently in this mill with these ball sizes.

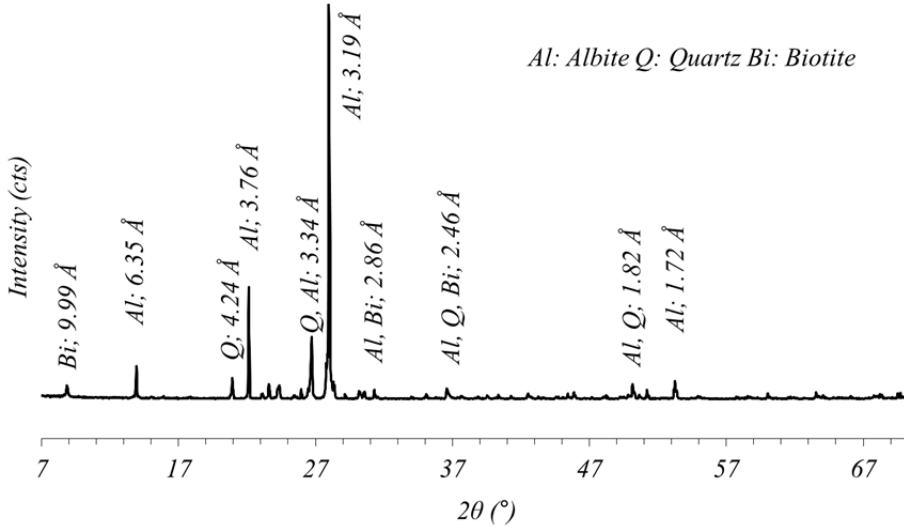


Figure 2. X-ray diffraction patterns of Na-feldspar

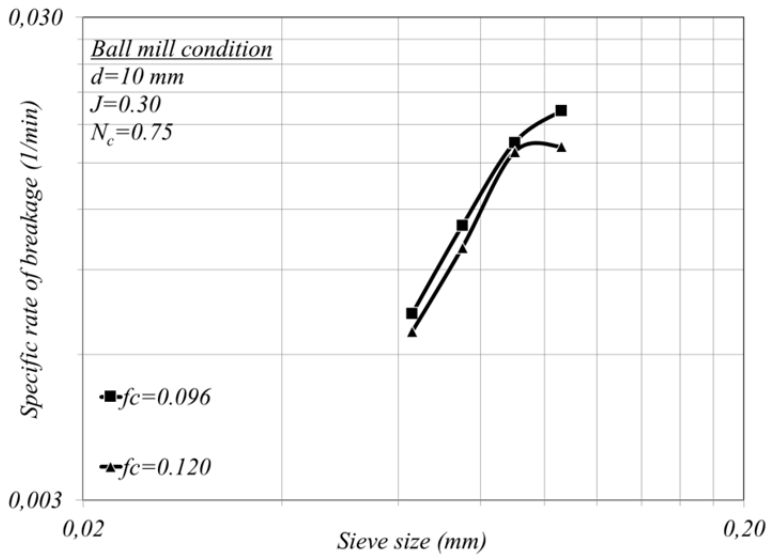


Figure 3. Variation of S_i values of Na-feldspar with particle size for the different

4.3. Breakage distribution functions

The values of B were determined from the size distributions at short grinding times (0.25 and 0.50 min) using the BII method, and are shown in Figure 4. The results showed a typical-

normalized behavior so that the progeny distribution did not depend on the feed grain size and the parameter δ was zero. The kinetic model parameters are also given in Table 3. As the amount of \square_j and γ values decreases, the effective breakage decreases, and breaks very slowly in the undersize of original particle size at 0.50 min. The lower γ values and the fineness factor contribute more to the large parameter values of the finer size fractions, and thereby \square_j values pave the way for the coarser size fractions. The values of the coefficient \square_j are related to the coarse-end of the breakage distribution function and show the rapidity with which fractions close to the feed size pass to the smaller size interval.

It should be noted that wet grinding of size intervals of Na-feldspar followed the first-order breakage law with constant-normalized primary breakage distributions. In addition, this sample does not depend on the grain size of cumulative breakage distribution function. Grinding time increased while the \square_j value and γ value were decreased with increasing grinding time.

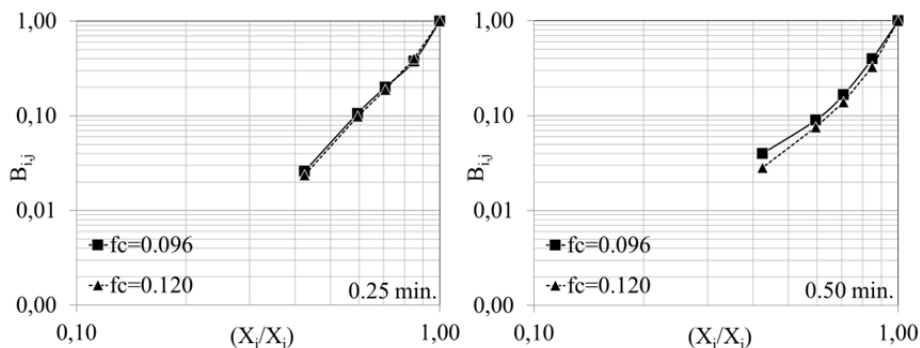


Figure 4. Cumulative breakage distribution functions for the different powder filling

Table 3. Characteristic breakage distribution functions of different grinding time

$f_c(\%)$	$U(\%)$	a_T	α	\square_j		γ		β	
				0.25	0.50	0.25	0.50	0.25	0.50
0.096	0.80	1.24	1.61	0.827	0.514	4.021	3.763	10.050	9.734
0.120	1.00	0.90	1.58	0.796	0.493	4.085	3.124	13.234	8.321

5. CONCLUSIONS

Kinetic model parameters for grain size below 106 μm were determined for the Na-feldspar sample, which is used in ceramic industry. When the studies are evaluated, it is observed that the materials above the 106 μm grain size were examined in them. With this study, it was understood that the $B_{i,j}$ parameter values (γ ; 0.5-1.5, β ; 2.5-5, \square_j ; 0.5-1) given in the literature is valid for materials that have grain size above 106 μm .

When the a_T values are considered (shown by a_T parameters in Table 3), it is determined that they were obtained as 1.24 and 0.90. Here, it is observed that more efficient refraction occurs in low material filling ratio, i.e. the original part is reduced into sub-dimension more quickly.

Φ_j , γ and β model parameter values from mill operating conditions were calculated from relative particle size graphics for $B_{i,j}$ values determined at different material filling ratios, and are given in Table 3. In both material filling ratios, the \square_j value decreased with the increasing grinding time, in other words, slower refraction occurred from top dimensions to a lower dimension. It is understood that the first refraction occurred in 0.25 minutes. It was determined that γ value was 3.763 and 3.124 at minute 0.50, in other words, fine material amount increased with the grinding time.

The primary breakage distribution functions of Na-feldspar were found to be normalized, which means that they are independent from the initial feed size in the case of cypelbs.

Grinding results of Na-feldspar showed that Na-feldspar does not obey first-order breakage kinetics law in the case of cypelbs. The specific rate of breakage values, S_i , increased up to 90 μm and then decreased sharply. This can be explained by the fact that fine particles are difficult to break and grind by the medium, and hence, the grinding efficiency decreased.

With this study, the number of the experiments will be decreased in various studies, the grinding circuit performance will be solved, the grinding costs will be decreased and the parameters that affect the grinding will be examined with more ease.

NOMENCLATURE

a_T model parameter

$B_{i,j}$ cumulative breakage distribution function

Greek symbols

α model parameter

β model parameter

γ model parameter

A model parameter

\square model parameter

μ grain size at which correction factor is 0.5

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