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Breakage Properties of Porous Materials by Ball Milling

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ABSTRACT: This paper presents the breakage properties of five different porous materials based on a kinetic model, which was commonly used in the cement industry. For this purpose, firstly, standard Bond's grindability tests were made for five porous samples. Secondly, eight different mono-size fractions were ground between 1.7 mm and 0.106 mm formed by a V2 sieve series. Then, *S,* and *B,j* equations were determined from the size distributions at different grinding times, and the model parameters (5,, a_r,*a,y and* $) were examined. Finally, relationship between the Bond's grindability and breakage parameters were compared for five different porous samples.

The validity of the relationships between Bond's grindability with breakage parameters *(S,, ar,* $ and *y)* has been not confirmed with good correlation coefficients, through a regression analysis of samples. The reason of this negative result is the geological origin of porous materials which is not similar.

1 INTRODUCTION

Comminution is know to be a large consumer of the energy, which consumes 3-4% of the electricity generated world-wide and comprises up to 70% of all energy required in a typical mineral processing plant, and is one of the most important unit operations in mineral processing. The grinding process has many variables, some of which are difficult to understand.

Bond's grindability can be empirically related to the energy required for comminution and thus is useful for the design and selection of crushing and grinding equipment (Deniz et al., 1996).

In the recent years, matrix model and kinetic model, which are suggested by investigators, have been used in the laboratory and in the industrial areas. Kinetic model which an alternative approach is considered comminution as a continuous process in which the rate of breakage of particles size is proportional to the mass present in that size (Deniz and 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 years. Austin has reviewed the advantages of this approach and the scale-up of laboratory data to full-scale mills have also been discussed in a number of papers summarized by Austin et al. (1984).

The behaviour of porous materials in comminution processes differs substantially from that of non-porous materials. It is strongly affected by the type of porosity, which may be characterized by different void shapes and interconnection degrees.

This paper presents a comparison of the breakage parameters of five different porous materials under standard conditions in a batch laboratory ball mill, and relationships between Bond's grindability values with breakage parameter values of samples are investigated.

2 THEORY

When breakage is occurring in an efficient manner, the breakage of a given size fraction of material usually follows a first-order law (Austin, 1972). Thus, the breakage rate of material that is in the top size interval can be expressed as:

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

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

$$\log(w_i(t)) - \log(w_i(0)) = \frac{-S_i t}{2.3} \quad (2)$$

where, wi(t) is the weight fraction of the mill hold-up that is of size 1 at time t and Si is the specific rate of breakage The formula proposed by Austin et al (1984) for the variation of the specific rate of breakage S, with particle size is

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

wheie, X, is the upper limits of the size interval indexed by ;, mm, and aj and a 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 re-fractured The set of primary daughter fragments from breakage of size j can be represented by b,j, where b,j is the fraction of size j material, which appears in size ι on primary fracture, $n \geq \iota > j$ It is convenient to represent these values in cumulative form

$$B_{i,j} = \sum_{k=i}^{n} b_{k,j} \quad (4)$$

where, B,j is the sum fraction of material less than the upper size of size interval ; resulting from primary breakage of size./ material $b,j = B,j - B_{(i+1)j}$ Austin et al (1981) have shown that the values of B_{ij} 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,

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

where, $P,(t)$ is the fraction b\ weight in the mill charge less than size A it time r B_{ij} can be fitted to an empirical function (Au in and Luckie, 1972)

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

where

$$\phi_j = \phi_1 \left[X_1 / X_1\right]^{-\delta} \quad (7)$$

where, δ, ϕ, γ, and β are model parameters that depend on the properties of the material It is found that, B functions are the same for different ball filling ratios, mill diameters, etc (Austin et al, 1984). If B,j values are independent of the initial size, i e dımensıonally normahzable, then Sis zero

3. MATERIALS AND METHOD

3.1 Material

Five different porous samples taken from different region of Turkey were used as the experimental materials The chemical properties of the porous samples are presented in Table 1

Table 1 Chemical composition of porous samples using in experiments

Oxides	Pumice I	Pumice II	Trass	Amorphous Silica	Diatomite
SiO_2	63 50	57 37	58 82	90 91	89 58
Al_2O_3	14 56	18 74	17 78	0 13	177
Fe_2O_3	2 02	5 93	391	011	0 78
CaO	3 11	2 16	4 12	0 36	0 70
MgO	3 80	2 95	0 11	...	0 22
Na_2O	4 62	4 25	_	0 07	0 12
K_2O	4 50	3 66	...	006	0 21
SO3	0 10	123	...	0 27	161
LOI	2 80	175	3 66	4 95	4 99

3.2 The test of standard ball mill Bond grindability

The standard Bond grindability test is a closed-cycle dry grinding and screening process, which is carried out until steady state condition is obtained This test was described as follow (Bond and Maxson, 1943, Yap et al, 1982, Austin and Brame, 1983, Magdahnovıc, 1989)

The material is packed to 700 cc 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 $(P,)$ Standard choice for P, 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 cc 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 m 6 to 12 grinding cycles

After reaching equilibrium, the grindabilities for the last three cycles are averaged. The average value is taken as the standard Bond grindability.

4 EXPERIMENTS

Firstly, Standard Bond's grindability tests were made for five porous samples. Result of tests, Bond grindability values of porous samples were appeared 2.96 g/rev, 2.67 g/rev, 2.45 g/rev, 1.74 g/rev and 8.12 g/rev, respectively. Then, the standard sets of grinding conditions used are shown in Table 2, for a laboratory mill of 6283 cm^3 volume. Eight mono-size fractions (-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 specific rate of breakage. Each sample was taken out of the mill and dry sieved product size analysis.

Table 2. The standard set of grinding conditions

Mill	Diameter	200 mm				
	Length	200 mm				
	Volume	6283 cm^3				
Mill Speed	Critical	101 rpm				
	Operational ($<\backslash>_c$ = 75 %)	76 rpm				
Balls	Diameter (mm)	25.4 mm				
	Specific gravity	7.8				
	Quality	Alloy Steel				
	Assumed porosity •	40%				
	Ball filling volume fraction (J)	20 % (J = 0.2)				
Material	Powder gravity, g/cm^3	Pumice 1 0.96	Pumice2 1.15	Trass 1.35	Amorphous Silica 0.67	Diatomite 0.58
	Interstitial filling (U%)	52.5 % (U = 0.525)				
	Powder filling volume (f_c %)	6.4 % (f_c = 0.064)				

4.1 Determination of the specific rate of breakage

The first-order plots for various feed sizes of porous samples are illustrated in Figure 1-5. The results indicated that grinding of all size fractions, five samples could be described by the first-order law. In additional, parameters of specific rate of breakage to supply by first-order plots are present in Table 3. The specific rates of breakage of each mono-size fraction that exhibited first-order grinding kinetic behaviour were determined from the slope of straight-line of first-order plots. Additional, Figure 6 shows the values of *S,* for grinding of the five different porous samples, as a function of size.

4.2. Determination of *B* function

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 show the graphical representation on Figure 7. Porous samples show a typical normalised behaviour, and the progeny distribution does not depend on the particle size, and it followed that the parameter 5 was zero. Model parameters supply by cumulative distribution and these parameters are presented in Table 3.

Table 3,Bond's grindability values and characteristic breakage parameters for samples of porous materials

Material	g/rev	S, (0.212-0.150 mm) (min^{-1})	*ai-imin*^{l})	. *a*	*r*	*
Pumice-1	2.96	0.174	0.42	0.619	0.291	0.347
Pumice-2	2.67	0.182	0.88	0.998	0.597	0.389
Trass	2.45	0.315	1.11	1.458	0.299	0.234
Amorphous Silica	1.74	0.342	2.33	1.406	0.729	0.324
Diatomite	8.12	0.825	9.12	1.866	0.526	0.442

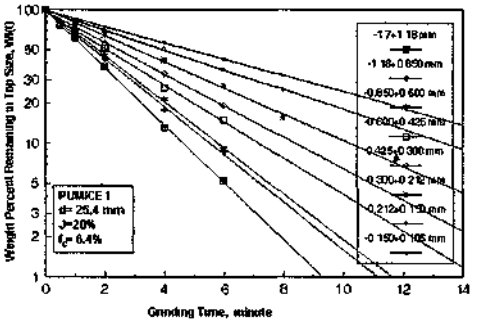

Figure 1. First-order plots for Pumice-I

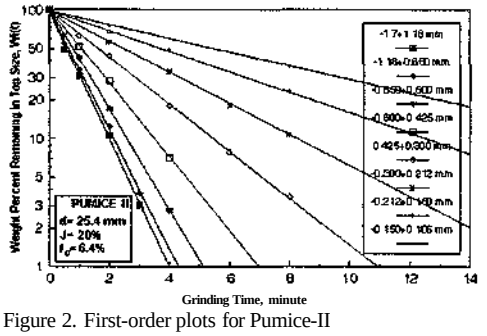

Figure 2. First-order plots for Pumice-II

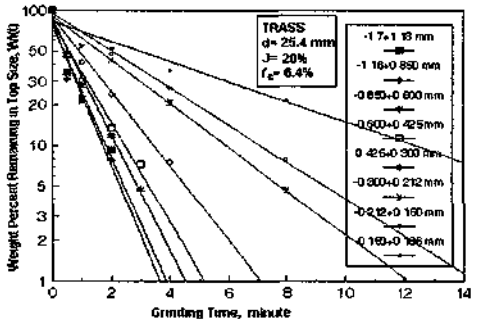

Figure 3. First-order plots for Trass

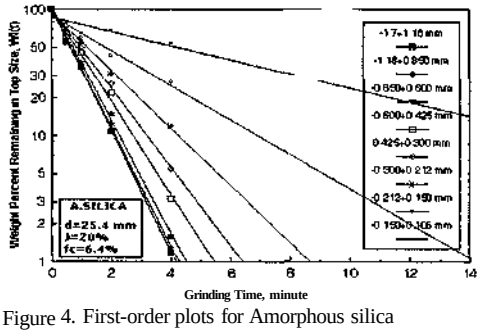

Figure 4. First-order plots for Amorphous silica

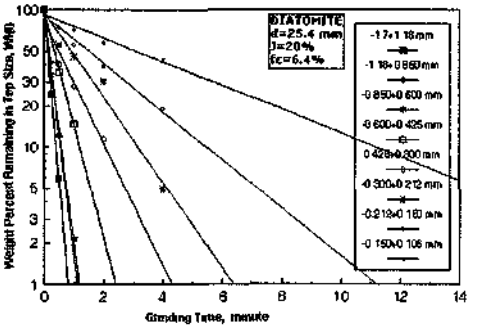

Figure 5. First-order plots for Diatomite

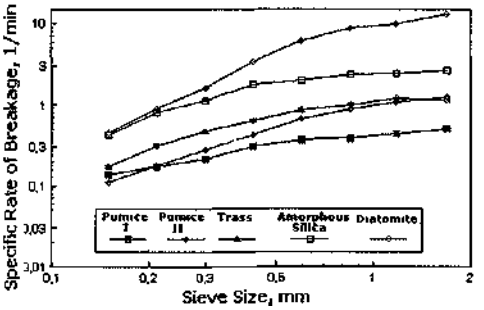

Figure 6. Variation of specific rates of breakage with particle size for samples of porous materials

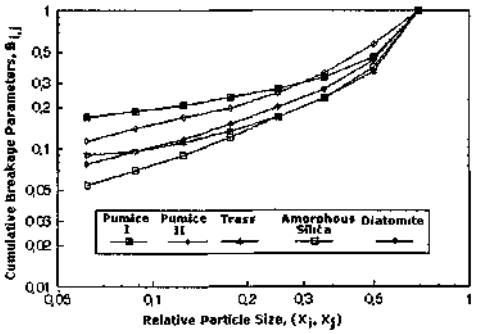

Figure 7. Cumulative breakage distribution functions for porous materials

5 THE RESULTS AND DISCUSSION

Further work was done Deniz (2004) to study relationships between Bond's grindability and breakage parameters of grinding kinetic on limestone. The results from the research were the validity of the obtained relationships parameters has been confirmed with good correlation coefficients.

In this study, a relationship between Bond's gnndability and breakage parameters of grinding kinetic on porous samples was not obtained Reason of this negative result, geological origin of porous materials is not similar

This study showed that a relationship between breakage approaches with chemical analysis results, $Si0_2$ contents values, was not expressed The experimental values show that diatornite and amorphous silica are higher porosity, however, diatornite is faster grinding, while amorphous silica is slowly grinding

Furthermore, effect of porosity on breakage approach of porous materials is not clear Therefore, it has appeared that the grinding kinetics for each material must be evaluated to lower the energy costs m the grinding process

ö CONCLUSIONS

The dry grinding of size intervals of porous samples showed that these samples followed the first-order breakage law with constant normalized primary breakage distribution function

The values of the primary daughter fragment distributions and the values of a m $S,=arX^{\alpha}$ *ate* different in the samples of porous As the amount of $S,$ or $\ddot{U}T$ values increase, the effective breakage increases, and breaks as very fast in the undersize of original particle size The lower y values, the fineness factor, contribute more for the large parameter values of the finer size fractions, $ values contribution mainly towards the coarser size fractions

Although, diatornite is higher SlO2 content than other samples, it is faster grinding of original particle size than other porous

Pumice samples lesser than diatornite sample to respect to contam S1O2, pumice samples showed a slowing down of breakage rate fine dry grinding, while amorphous silica, more contam S1O2, showed deceleration of grinding rate

From the Table 3, it is seen that diatornite is broken faster than amorphous silica in terms of the *ar* values Similarity, the Bond's gnndability value (Gb_g) for diatornite is easer than other samples On the contrary, the Bond's gnndability value for amorphous silica is harder than these samples, while amorphous silica is broken faster than pumice-I, pumice II and Trass in terms of the *ar* and $S,$ values

Additional, pumice-I and trass samples produce finer material than diatornite by considering the *y* value of B_n while diatornite easy grinding than pumice-I and trass samples

The $ value (0 442) is higher for diatornite than other porous samples, indicated that breakage of the top size showed acceleration, and deceleration for trass (0 234)

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