18th International Mining Congress and Exhibition of Turkey-IMCET 2003, <ô 2003, ISBN 975-395-605-3

# Relationships Between Bond's Grindability ($G_{bg}$) and Breakage Parameters of Grinding Kinetic on Limestone

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ABSTRACT: The grindability of a material is the only factor used to determine the required size of a grinding machine. Although, Bond's grindabilty test is widely used to the estimate power required of an industrial grinding mill. Recently, kinetic model has been mostly used to the design of grinding circuits.

In this study, the relationship between the Bond's grindability (Ghj.) and breakage parameters (S„ a-r, y and ß) were examined. The validity of the obtained relationship parameters of S„ a-r, ß and *y* has been confirmed with correlation coefficients of 0.96, 0.92, 0.90 and 0.78, respectively, through a regression analysis of samples of limestone.

## I INTRODUCTION

Grindability data, based on various techniques to measure comminution characteristics, are used to evaluate the crushing and grinding efficiency in mineral processing operations. The importance of achieving improved comminution efficiency, in terms of energy consumption, has been emphasized increasing in the cost of electricity, recently (Horst and Bassarear, 1976).

Many expressions of grindability have been proposed over the years, but two of these have come into prominence because they have become the recognised basis for design of certain types of mill. One of them is the Hardgrove index, associated mainly with vertical spindle mills and the other is Bond's grindability. associated with tumbling mills (PrasherJ987).

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).

İn 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).

This paper presents a comparison of the breakage parameters of six different limestones in a batch laboratory ball mill under standard conditions, and also the relationship between Bond's grindability and breakage parameter values of limestone samples.

## 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:

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

Assuming that S| does not change with lime (that is. a first-order breakage process), this equation integrates to

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

where, W|(l) is the weight fraction of the mill hold-up that is of size I at time *t* and 5/ 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

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

where, X, is the upper limits of the size interval indexed by *i,* mm, and ax 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 refractured. The set of primary daughter fragments from breakage of size *j* can be represented by b,.,, where $b_M$ is the fraction of size *j* material, which appears in size /' on primary fracture, *n > i >j.* It is convenient to represent these values in cumulative form.

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

where, B,, is the sum fraction of material less than the upper size of size interval *i* resulting from primary breakage of size / material: />;-,= $B_u$ - ß,+/·, . Austin et al. ( 1981 ) have shown that the values of $B_M$ can be estimated from a size analysis of the product from short time grinding of a starling mill charge predominantly in size *j* (the one-size fraction BI1 method). The equation used is,

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

where, P,(t) is the fraction by weight in the mill charge less than size X, at time *t.* $B_u$, can be fitted to an empirical function (Austin and Luckie, 1972 ).

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

where

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

where *ô, cf>, y,* and *ß* 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,.| values are independent of the initial size, i.e. dimensionally normalizable, then 5 is zero.

## 3 MATERIALS AND METHOD

### *3.1 Material*

Six limestone samples taken from different regions of Turkey were used as the experimental materials. The chemical properties of the limestone samples arc presented in Table 1.

Table I. Chemical composition of limestone samples using in experiments.

| Oxides (%) | GI | G2 | G3 | Yi | Y2 | Y3 |
|---|---|---|---|---|---|---|
| C;iO | 31.03 | 39.09 | 53.56 | 55.43 | 57.20 | 48.99 |
| SiO | 0.05 | 1.65 | 0.08 | 0.59 | 0.05 | 10.60 |
| AhO, | 0.90 | 1.37 | 1.27 | 0.99 | 0.90 | 1.07 |
| He.0, | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.59 |
| MsO | 22.42 | 13.92 | 0.75 | 0.40 | 0.22 | 1 II |
| SO, | 0.02 | 0.03 | 0.03 | 0.12 | 0.02 | 0.09 |
| NibO | 0.07 | 0.07 | 0.06 | 0.05 | 0.05 | 0.04 |
| K,0 | 0.10 | 0.16 | 0.09 | 0.10 | 0.09 | 0.08 |
| Loss un ignition | 45 24 | 43.05 | 43 41 | 42.05 | 42.74 | 38.72 |

### *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 ct al., 1982; Austin and Brame, 1983; Magdalinovic, 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 (Pi). 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 in 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* six limestone samples. Result of tests. Bond grindability values of limestone samples were appeared 6.14 g/rev, 2.89 g/rev, 2.58 g/rev, 2.48 g/rev, 2.42 g/rev and 1.54 g/rev, respectively. Then, the standard sets of grinding conditions used are shown in Table 2, for a laboratory mill of 6283 cm 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 em-[1] | | | | | |
| Mill Speed | Critical | 101 rpm | | | | | |
| | Operational (0 = 75 90 | 76 rpm | | | | | |
| Balls | Diameter (mm) | 25.4 mm | | | | | |
| | Specific gravity | 78 | | | | | |
| | Quality | Alloy Steel | | | | | |
| | Assumed porosity | 40 % | | | | | |
| | Ball filling volume fraction (J ) | 20% (J =0 2) | | | | | |
| Matenal | Powder gravity, g/cm' | G-1 2.78 | G-2 2.76 | G-3 2.65 | Y-1 2.62 | Y-2 2.63 | Y-3 2.69 |
| | Interstitial filling (U%) | 52 5%(U = 0 525) | | | | | |
| | Powder filling volume (f 9f ) | 4.2 %( f =0.042) | | | | | |

*4.1 Determination of the specific rate of breakage*

The first-order plots for various feed sizes of limestone samples are illustrated in Figure 1-6. The results indicated that grinding of all size fractions, six 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 7 shows the values of S, for grinding of the six different limestone 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 8. Limestone samples show a typical normalised behaviour, and the progeny distribution does not depend on the particle size, and it followed that the parameter ô was zero. Model parameters supply by cumulative distribution and these parameters are presented in Table 3.

Table 3.Bond's gnndability values and characteristic breakage parameters tor samples of limestone.

| Material | Ghe gr/rev | S, (0.212-0.150 mm) (mm" ) | ar (mm[1]) | a | Y | £ | ß |
|---|---|---|---|---|---|---|---|
| G-1 | 6.14 | 1.15 | 4.01 | 0.785 | 0.478 | 0.51 | 1.199 |
| G-2 | 2.89 | 0.69 | 2.61 | 0.988 | 0.531 | 0.38 | 1.509 |
| G-3 | 2 58 | 0.67 | 2.79 | 1 161 | 0.722 | 0.30 | 1.716 |
| Y-1 | 2.48 | 0.63 | 2.11 | 1.564 | 0 368 | 0.24 | 1.699 |
| Y-2 | 2.42 | 0.53 | 2.30 | 1.178 | 0.897 | 0.32 | 1 571 |
| Y-3 | 1 54 | 0.50 | 0.87 | 0 228 | 1.218 | 0.41 | 1.712 |

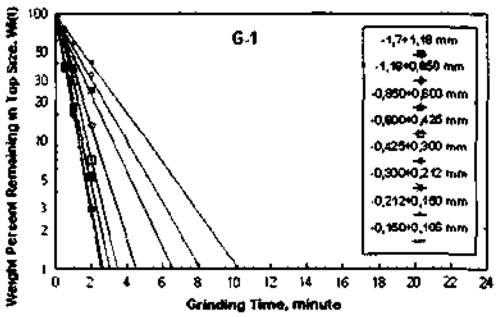


Figure 1. First-order plots for G-1.

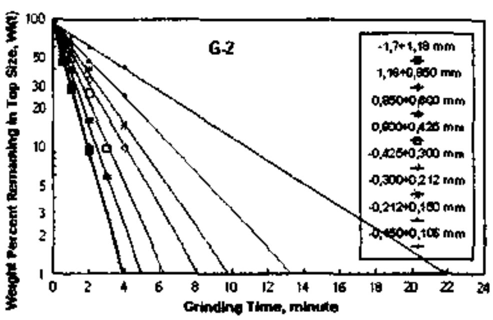


Figure 2. First-order plots for G-2.

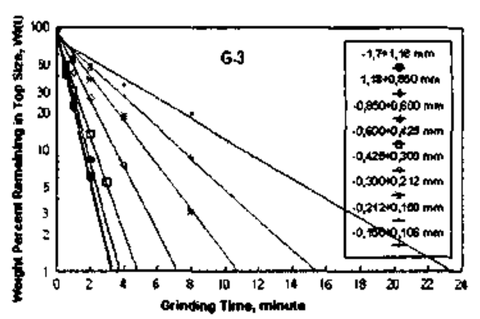


Figure 3 First-order plots for G-3.

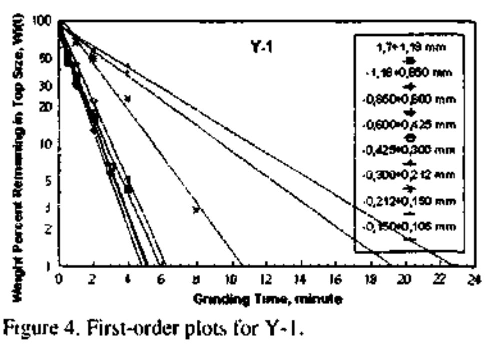


Figure 4. First-order plots for Y-1.

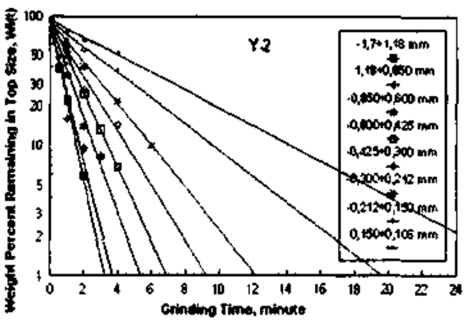


Figure. 5. First-order plots for Y-2.

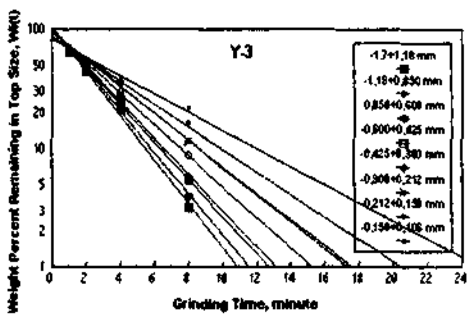


Figure 6. First-order plots for Y-3.

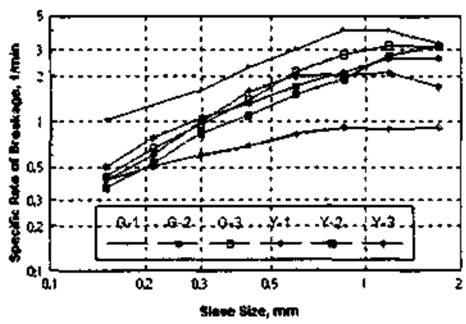


Figure 7. Variation of specific rates of breakage with particle size for samples of limestone.

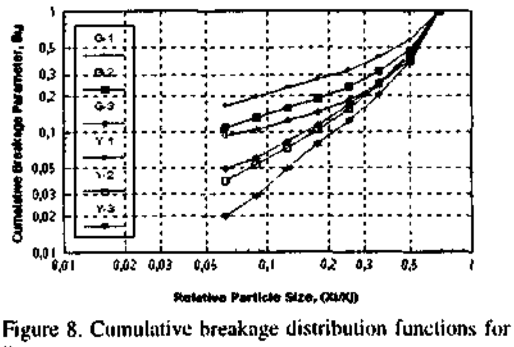


Figure 8. Cumulative breakage distribution functions for limestone.

## 5 VALIDATION OF THE RELATIONSHIPS BETWEEN BOND'S GRINDABILITY AND BREAKAGE PARAMETERS

### 5. / *Variation of specific rate of breakagefS,) with Bond's grindability values(Gi,$_t$)*

For the same purposes, variation of specific rate of breakage (S,) with Bond's grindabilty (Gh$_S$) for six limestone samples was investigated, and it is shown in Figure 9. The values of S, seem to satisfy a linear with Gb$_S$ with a correlation coefficient 0.96 that can be expressed as follows:

$$S_i = 0.192 + 0.178 G_{bg} \quad (8)$$

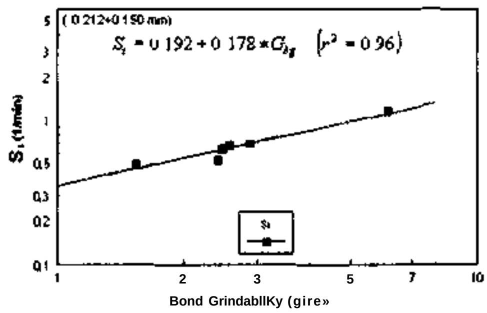


Figure 9. Variation of S, with Gb$_S$.

### 5.2. *Variation of first-order breakage constant (ar) with Bond's grindability values (Gi,$_K$)*

The values reported in Table 3 have been plotted in Fig, 10 referring to relation for different G$_{bs}$. The values of *aj* seem to satisfy a logarithmic with Gb$_f$ with a correlation coefficient 0.92 that can be expressed as follows:

$$a_T = 0.254 + 2.177 \ln(G_{bg}) \quad (9)$$

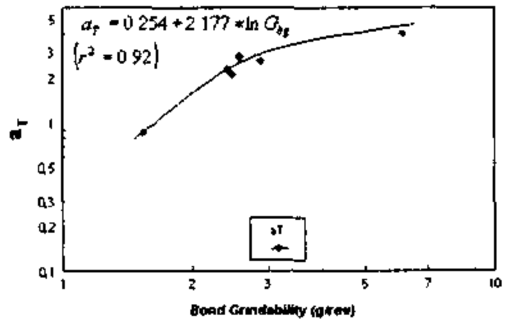


Figure 10. Variation of $a_T$ with $G_{bg}$.

### 5J *Varation of primary cumulative breakage constant (ß) with Bond's grindability values (G$_h$)*

For the same purposes, variation of primary cumulative breakage constant (/}) with Bond's grindabilty (Gi,$_b$) for six limestone samples was investigated, and it is shown in Figure II. The values of *ß* seem to satisfy a logarithmic with Gh$_f$ with a correlation coefficient 0.90 that can be expressed as follows:

$$\beta = 1.99 e^{-0.0821(G_{bg})} \quad (10)$$

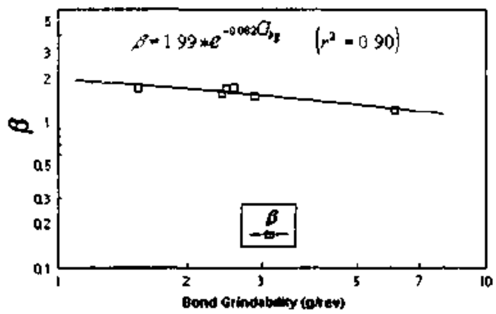


Figure 11. Variation of *ß* with Gi,$_s$.

### 5.4 *Variation of primary cumulative breakage constant (y) with Bond's t>rindabilit\' values (GiJ*

The values reported in Table 3 have been plotted in Fig. 10 referring to relation for different Gt,$_f$. The values of y seem to satisfy a power with Gb$_S$ with a correlation coefficient 0.78 that can be expressed as follows:

$$\gamma = 1.426(G_{bg})^{-0.669} \quad (11)$$

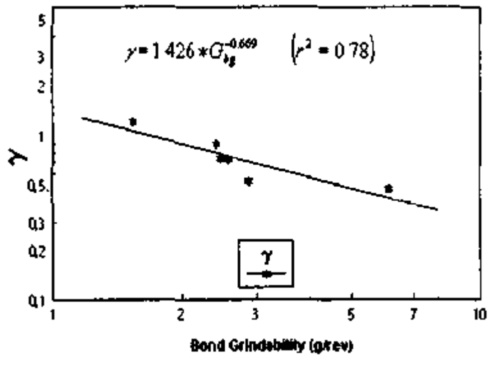


Figure 12. Variation of y with Gh$_E$.

## 6 CONCLUSIONS

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

The values of the primary daughter fragment distributions and the values of a in S^orX" are different in the samples of limestone. As the amount of S, or *ci]*- values increase, the effective breakage increases, and breaks as very fast in the undersize of original particle size. The experimental values show that grinding is faster grinding for samples as fraction of bond grindability values ($Gh_C$) increase. Thus, Gl is faster grinding of original particle size than other samples of limestone.

The y value, which is the fineness factor, is lower for GI than other sample of limestone, indicating that more fines are produced in limestone grinding. Similarity, the Bond's grindability value ($Gh_g$) for G1, which is the easy grindability, is higher than other samples of limestone.

As a result of comparison for four breakage parameters, a high correlation coefficient is obtained. These four relationships may be used to provide an estimate of Bond's grindability for limestone.

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