The European Journal of Mineral Processing and Environmental Protection
Vol.4, No.2, 1303-0868, 2004, pp. 162-167

Technical Note

Investigation of breakage behaviour of two different pumice stones

V. Deniz*

Department of Mining Engineering, Mineral Processing Division, Suleyman Demirel University, TR32260, Isparta, Turkey

Received 22 August 2002; accepted 15 March 2004

ABSTRACT

In this study, the grindability properties of two different pumice stones, originated from the Karakaya and the Gelincik areas (Isparta, Turkey), are investigated at batch grinding conditions based on a kinetic model. For this purpose, experiments were carried out with eight different mono-size between 1.7mm and 0.106mm formed by a √2 sieve series fraction. Then, parameters of S_i and $B_{i,j}$ equations were determined from the size distributions at different grinding times, and the model parameters were compared for two different pumice stones. It was found out that, the Karakaya pumice is easier to grind than the Gelincik pumice, taking into account the quite different values of the model parameters.

Keywords: Grinding; Pumice; Mineralogical analysis

1. INTRODUCTION

Comminution is known 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 (Fuerstenau *et al.*, 1999; Deniz, 2003).

In terms of global quantities of material reduced in size, it has been estimated that the annual tonnage is of the order of several thousand millions, and in terms of the energy expended, the yearly megawatt hours amount to several hundred millions (Prasher, 1987).

The analyses 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 has also been discussed in a number of papers (Austin *et al.*, 1981).

The pumice is a natural volcanic material that is used as chemical additive, dental polisher, abrasive, cosmetic, cement, ceramic and glass industry. In these industries, ultra fine grinding of pumice is needed (Deniz and Onur, 2002).

In Isparta region (Turkey), pumice deposits, which are called the “Karakaya” and the “Gelincik” have two different chemical and mineralogical properties. This paper presents a comparison of the breakage parameters of these two pumice samples that have two different chemical and mineralogical compositions under identical conditions in a small laboratory ball mill.

2. THEORY

In an efficient breakage, the breakage of a given size fraction of material usually follows a first–order law (Austin, 1972). Thus, the breakage rate of material in the top size interval can be expressed as:

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

* Corresponding author. E-mail: vedat@sdu.edu.tr

Assuming that S_i 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 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:

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

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

On breakage, particles of given size produce a set of primary daughter size fractions which are mixed into the bulk of the powder and then in turn have a probability of being refractured. The set of primary daughter size fractions from breakage of size *j* can be represented by $b_{i,j}$, 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.

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

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 and Bagga (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:

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

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 into an empirical function (Austin and Luckie, 1972).

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

where

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

where, δ, ϕ, γ, and β are model parameters that depend on the properties of the material. It was found that, *B* functions are the same for different ball filling ratios, mill diameters, etc. (Austin *et al.*, 1984). If $B_{i,j}$ values were independent of the initial size, i.e. dimensionally normalizable, then δ is would be zero.

3. EXPERIMENTAL

3.1. Material and method

Two different pumice stones taken from deposits belong to ISBAS pumice plant in Isparta (Turkey). The samples called the Karakaya and the Gelincik were used as the feed materials. The chemical properties of pumice samples used in experiments are presented in Table 1.

Table 1
Chemical composition of pumice stones

Oxides (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	SO_3	Loos of ignition
Karakaya	57.37	18.74	5.93	2.16	2.95	4.25	3.66	0.45	1.23	1.75
Gelincik	63.50	14.56	2.02	3.11	3.80	4.62	4.50	0.30	0.10	2.80

The standard set used for is shown in Table 2, for a laboratory mill 6283cm^3 in volume. Eight mono-size fractions (−1.7+1.18, −1.18+0.850, −0.850+0.600, −0.425+0.300, −0.300+0.212, −0,212+0.150, −0.150+0.106mm) were prepared and ground batch-wise in a laboratory-scale ball mill to determine breakage functions. Samples were taken out of the mill and dry sieved product size analysis was carried out.

Table 2
The standard set of grinding conditions

	Diameter (D), mm	200	
Mill	Length, mm	200	
	Volume, cm^3	6283	
Mill	Critical (N_c), rpm	101	
Speed	Operational (ϕc), %	76rpm (ϕc= 75%)	
	Diameter(d), mm	25.4	
	Specific gravity (gr/cm^3)	7.8	
Balls	Quality	Alloy Steel	
	Assumed porosity, %	40	
	Ball filling volume fraction (J%)	20% (J = 0.2)	
		Karakaya	Gelincik
	Specific gravity(g/cm^3)	2.45	2.37
Material	Powder filling volume fraction (f_c, %)	4.8% (f_c = 0.048)	
	Interstitial filling (U%)	60% (U = 0.6)	

3.2. Mineralogical analysis

Mineralogical analysis of Karakaya pumice contained decomposed feldspar minerals and pyroxene minerals. Opaced and localized limonitized biotite minerals to be care be are seen present. There are places where pyroxene, biotite and plagioclase minerals accumulated. Abrasive minerals such as feldspar, sanidine, pyroxene and amphibole are rather more. Matrix has considerable porosity.

In mineralogical analysis of Gelincik pumice, oxidised biotite and hornblende minerals can be recognised. In addition, sanidine, is an alkali-feldspar mineral, was also noticed. Plagioclase minerals in Gelincik pumice are coarser than Karakaya pumice. Sanidine, pyroxene and feldspar minerals, which are abrasive minerals in Gelincik pumice, are much less than in Karakaya pumice.

4. RESULTS AND DISCUSSION

4.1. Determination of *S* function

The first-order plots for various feed size of two different pumice samples are illustrated in Figures 1 and 2. The results indicated that grinding of all size fractions, only two samples could be described by the first-order law. In addition, parameters of specific rate of breakage are given in Table 3, were determined by first-order plots.

The specific rates of breakage of each mono-size fraction, which exhibited first-order grinding kinetic behaviour, were determined from the slope of straight-line of the first-order plots. In Figure 3, S_i values of the two samples used are given as a function of time.

4.2. Determination of *B* function

By definition, the values of B were determined by the size distributions at short grinding times. The parameters were determined according to the BII method (Austin *et al.*, 1984), and Table 3 shows the fitted values, while their graphical representation is given in Figure 4. Both of pumice samples show a typical normalised behaviour, and the progeny distribution does not depend on the particle size. It followed that the parameter δ was zero. Model parameters obtained from cumulative distribution and these parameters are presented in Table 3.

The Karakaya and the Gelincik pumice samples demonstrated entirely distinct characteristics in the selection function and the breakage function model.

Table 3
Model parameter values

Samples	a_T	α	γ	ϕ	β
Karakaya	1.08	1.11	0.687	0.40	1.65
Gelincik	0.42	0.69	0.367	0.37	1.38

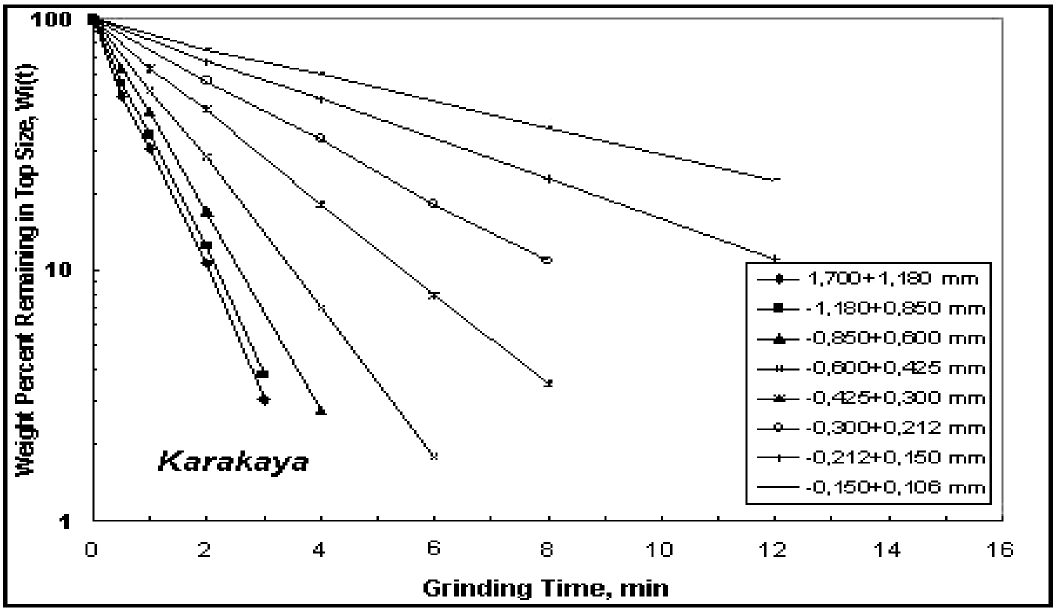

Figure 1. First-order plots for Karakaya pumice stone

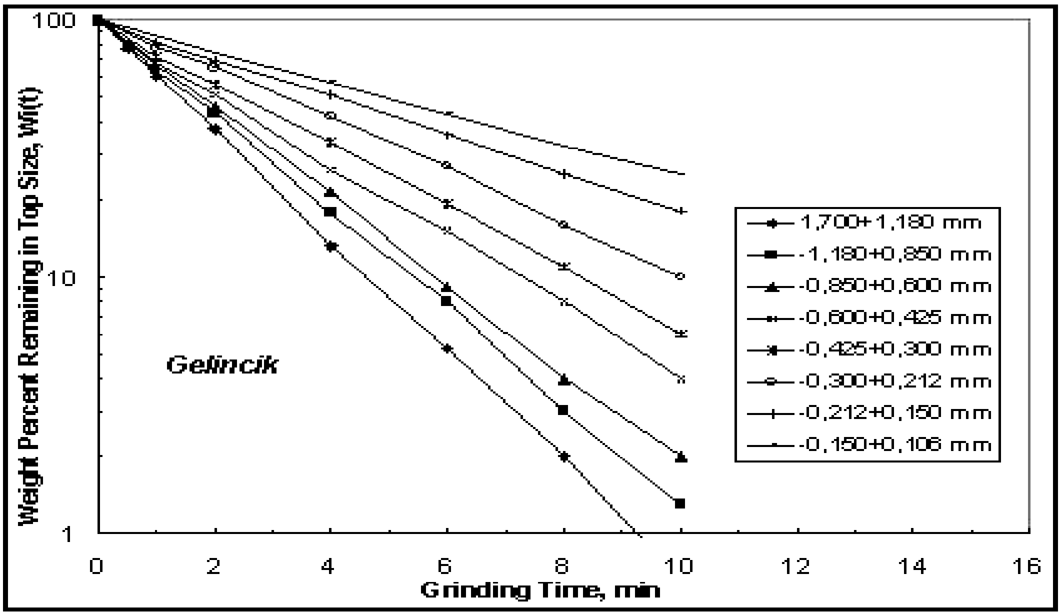

Figure 2. First-order plots for Gelincik pumice stone

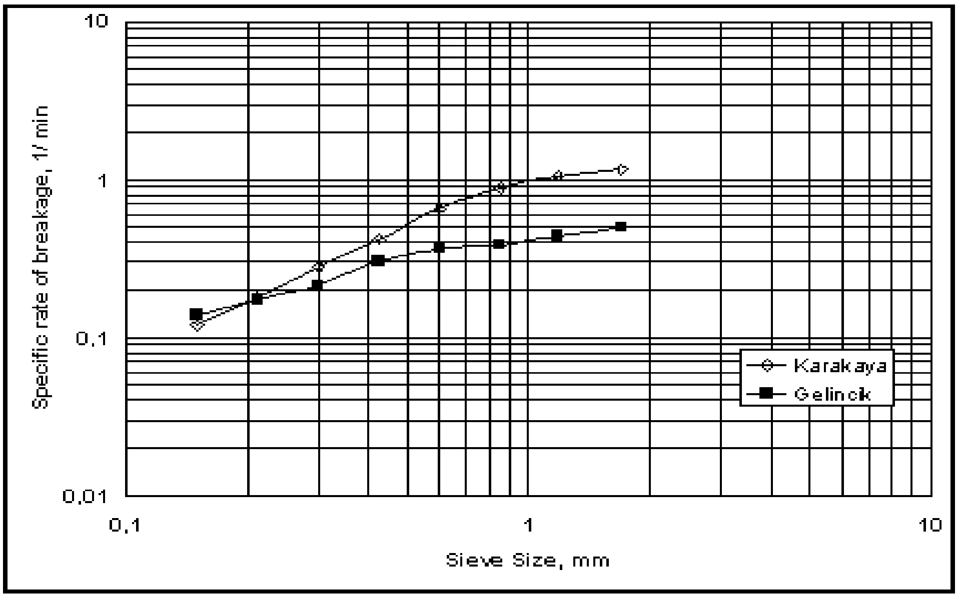

Figure 3. Specific rates of breakage for Karakaya and Gelincik pumice stones

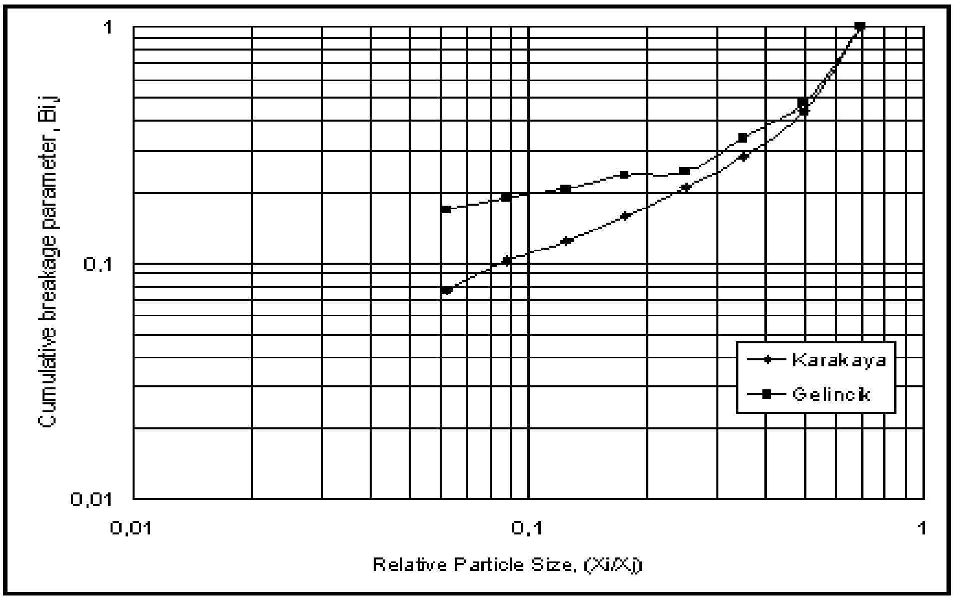

Figure 4. Cumulative breakage distribution functions for Karakaya and Gelincik pumice stones

5. CONLUSIONS

It was determined that dry grinding of size intervals of the Gelincik and the Karakaya pumice stones followed the first-order breakage law with constant normalized primary breakage distributions. In addition, these samples do not depend on the particle size from cumulative breakage distribution function.

The values of the primary daughter fragment distributions and the values of α in $Si = a_T X^{\alpha}$ were different in the Gelincik and the Karakaya. As the values of S_i or a_T increased, very fast breakage was observed in the undersize of the original particle size. It can be seen from experimentally obtained a_T values that grinding is faster for Karakaya (a_T= 1.08) than that of Gelincik (a_T= 0.42).

Since Karakaya pumice has a greater porosity than that of Gelincik pumice, the breakage of the top size showed acceleration for Karakaya pumice (ϕ = 0.40), and deceleration for Gelincik pumice (ϕ = 0.37). Even if, in chemical analysis, the SiO_2 content is higher in Gelincik pumice, SiO_2 is in amorphous form in the Gelincik pumice. Moreover, mineralogical analysis shows that Karakaya pumice is more abrasive.

Since Karakaya pumice has a greater content in abrasive materials than in Gelincik pumice, the primary breakage of the Karakaya gave the lower relative production rate of fines (γ = 0.367), while the Gelincik pumice yielded a greater proportion of fines (γ = 0.687).

In this study, it has been concluded that these experimental values for each sample must be seen in order to reduce the energy costs during the grinding process.

REFERENCES

Austin, L.G., A review introduction to the description of grinding as a rate process. Powder Technology, 1972, 5, 1-7.

Austin, L.G., Luckie, P.T., Methods for determination of breakage distribution parameters. Powder Technology, 1972, 5, 15-222.

Austin, L.G., Bagga, P., An analysis of fine dry grinding in ball mills. Powder Technology, 1981, 28, 83-90.

Austin L.G., Bagga, P., Çelik, M., Breakage properties of some materials in a laboratory ball mill. Powder Technology, 1981, 28, 235-241.

Austin, L.G., Klimpel, R.R., Luckie, P.T., Process engineering of size reduction: ball milling. 1984, A.I.M.E., S.M.E., NewYork, USA, 561 p.

Deniz, V., Onur, T., Investigation of the breakage kinetics of pumice samples as dependent on powder filling in a ball mill. Int. J. of Min. Processing, 2002, 67, 71-78.

Deniz, V., A study on the specific rate of breakage of cement materials in a laboratory ball mill. Cement and Concrete Research, 2003, 33, 439-445.

Fuerstenau, D.W., Lutch, J.J., De, A., The effect of ball size on the energy efficiency of hybrid-pressure roll mill/ball mill grinding. Powder Technology, 1999 105, 199-204.

Prasher, C.L., Crushing and grinding process handbook. 1987, John Wiley&Sons, Chichester, UK, 474 p.