The Effects of Ball Types on Breakage Parameters of Barite

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Summary

Spherical balls are the dominant media shape used in the tumbling mills. However spherical balls wear into nonspherical fragments as a result of breakage due to impact and different wearing mechanisms inside the mill. Thus at any one time a mill charge is a mixture ranging from larger spherical balls to worn irregular. There is not much work done to assess the impact of balls on mill performance.

An experimental work was made in this study about the effect of media shape on grinding of barite. Existing studies focus on grind performance in ball mills. The absolute fineness of the ball type is important factors for the optimal operation of a ball mill. Therefore, the effects on breakage kinetics of the ball type were investigated on the barite powder at batch grinding conditions based on a kinetic model. For this purpose, firstly, four different fine mono-size fractions were carried out between 0.106 and 0.045 mm formed by $a\sqrt{2}$ sieve series. Then, Si and Bi,j equations were determined from the size distributions at different grinding times, and the model parameters were compared for three different ball type. The results of tests, the effect of ball type on the grinding were found to be different than other investigators regarding some results.

Keywords: ball mill, ball type, barite, breakage parameter

Introduction

Barite is being produced in various region of Turkey, mainly in Adana, Konya, and Isparta that is widely used as oil drilling, painting, paper and plastic sector, etc. In these industries, grinding of barite mineral is needed (Deniz, 2012).

It is well known that it is very difficult to reach ultrafine sizes by dry grinding in a tumbling ball mill. It has been also reported by many researchers that there is no further size reduction after some hours of grinding of some materials in laboratory ball mills (Hukki and Reddy, 1967).

Since fine grinding consumes a great deal of energy and may lead to high abrasive wear, most current research is focused on these scientific and technical problems. In addition, the unit operation of grinding has been subjected to a detailed theoretical examination in the last a few decades, aiming not only to improve the process but to make better use of the machines employed (Austin et al.,1984).

It is long believed that a load comprised of a different media shape other than spherical balls might influence the performance of a tumbling mill through variations in load behavior, charge segregation and power drawn by the mill as well as the breakage kinetics. The extent of this influence has not yet been established. Even with the very little done toward studying media shape effects (Shi, 2004, Herbst, et al., 1989, Yildirim, et al., 1998, Austin, et al.,1984) all efforts have exclusively been focused on breakage rate, ignoring other parameters defining mill performance such as load behavior and mill power.

Spherical balls are the dominant media shape used in the tumbling mills. However spherical balls wear into nonspherical fragments as a result of breakage due to impact and different wearing mechanisms inside the mill. Thus at any one time a mill charge is a mixture ranging from larger spherical balls to worn irregular fragments (Banisi et al., 2000; Vermeulen and Howat, 1988). There is not much work done to assess the impact of balls on mill performance.

The analysis of size reduction in tumbling ball mills using the concepts of specific rate of breakage and primary daughter fragment distributions has received considerable attention in recent years (Austin, et al, 1984, Austin, et al., 1981). Austin 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, and are summarized by Austin et al. (1981).

In the present study, the effect of different grinding media on breakage parameters was investigated in fine sieve size (-0.106+0.045 mm). Alumina, steel and casting balls were used as the grinding media.

It was observed that the grinding of barite obeyed first-order breakage kinetics in the case of alumina steel and casting balls, with a constant ball diameter (30.00 mm) and rotational speed of mill ($\varphi c = 0.75$).

Material and methods

Material

Barite was chosen as the feed mineral for this study, because this mineral is major raw materials of painting, paper and plastic sector, etc. The density of barite mineral, measured by a pycnometer, is averaged as 4.50 g/cm3 over three measurements. Chemical analyses of barite are also given in Table 1.

Methods

When breakage is occurring in an efficient manner, the breakage of a given size fraction of material usually follows a first-order law (Deniz et al., 2011). Thus, the breakage rate of 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:

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

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

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

where X_i is the upper limits of the size interval indexed by i, mm, and a_T and α are model parameters 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 $b_{i,j}$, 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 cumulative form (Deniz, 2013).

$$B_{I.J} = \sum^{i} b_{k.i} \tag{4}$$

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: $b_{i,j}=B_{i,j} - B_{i+1,j}$. Deniz (2011; 2012) 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

$$B_{i,j} = \frac{\log[(1-P_i(0))/(1-P_i(t))]}{l\,og[(1-P_2(0))/(1-P_2(t))]}, \quad n \geq i \geq j+1 \tag{5}$$

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 (Deniz et al., 2011).

$$B_{i,j} = \phi_j \left(\frac{X_{i-1}}{X_j}\right)^{\gamma} + (1-\phi_j)\left(\frac{X_{i-1}}{X_j}\right)^{\beta} \tag{6}$$

where

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

where δ, $\varphi_{\varphi,}$ γ and β are model parameters that depend on the properties of the material. If Bi,j values are independent of the initial size, i.e. dimensionally normalizable, then δ is zero (Deniz et al., 2011; Deniz, 2012; Deniz, 2013).

Tab. 1 Chemical composition of material

Tab. 1 Skład chemiczny materiału

Oxides (%)	$BaSO_4$	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_3	LOI
Barite	98.82	0.51	0.02	0.06	0.13	0.42	0.02	0.02	40.93	21.89

Tab. 2 Ball mill characteristics and test conditions

Tab. 2 Charakterystyka i warunki testu w młynie kulowym

Mill	Diameter, D (mm)	200		
	Length, L (mm)	200		
	Volume (cm^3)	6283		
	Mill speed Critical, *Nc* (rpm)	102.59		
	Operational speed	77		
Media (Balls)	Grinding Diameter, d (mm)	30.00		
	Media (balls) Specific gravity (g/cm^3)	7.8	2.7	7.5
	Quality Alloy	Alloy steel	Alumina	Casting
	Assumed porosity (%)	40		
	Ball-filling volume fraction, *J_b (%)*	0.30		
Material	Specific gravity (g/cm^3)	4.50		
	Powder-filling volume fraction *f_c (%)*	0.120		
	Interstitial filling *U (%)*	1.00		

Tab. 3 Characteristic breakage parameters of different ball types obtained from the laboratory test

Tab. 3 Charakterystyka parametru rozdrabniania dla różnych typów młynów kulowych otrzymane w testach laboratoryjnych

Ball Type	α_T	α	μ	Λ	Φ_j	γ	β	δ
Alumina	1.07	2.42	0.00	0.00	0.277	3.696	14.730	0.00
Steel	1.16	2.17	0.00	0.00	0.393	5.305	19.560	0.00
Casting	1.43	1.63	0.00	0.00	0.631	8.064	15.769	0.00

Experimental

Firstly, Standard Bond Work index test was made for barite sample. As a result of test, Bond Work index value of sample was appeared 7.03 kWh/t. The breakage parameters were determined experimentally using one size fraction technique (Austin et al., 1984). 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, where for example , -0.106 + 0.090 mm denotes that 100% of the particles are passing by weight at 0.106 mm size and 100% of particles are remaining at 0.090 mm. The standard set of grinding conditions used is shown in Table 2 for a laboratory mill with a volume of 6283-cm^3.

Results and discussion

Determination of S parameters

The results indicated that breakage generally follows the first order relation, and values of S_i could be determined from the slope of straight line of first-order plots. In addition, Figure 1 show the S_i in relation to the different ball type and particle size for barite, respectively. It is clearly seen that Si values increase up to a maximum particle size (-0.106+0.090 mm), and then start decreasing at around -0.090+0.075 mm for all of the ball type in Figure 1. Grinding media directly affect the load behavior and consequently the operations of industrial mills in terms of product size, energy consumption and grinding costs. This was due to grinding speed, up to the size of barite grains increased liberalization, after the size of liberalization decelerated the grinding speed. The model parameters are also given in Table 3.

Determination of B parameters

From the size distributions at the shortest grinding times, the values of cumulative breakage distribution functions, $B_{i,j}$, which is commonly used to characterize the size distributions resulting from breakage of material from a particular size interval to a smaller size were determined using the *BII* method (Deniz, 2003; Umucu, et al., 2012). The values of $B_{i,j}$ against particle size obtained from *BII* calculations for each size fractions are plotted in Figure 3. In order to get the $B_{i,j}$ values, *BII* calculation procedure (Austin et al., 1984) given below was applied for the shortest grinding time (0.5 min)

$$B_{i,j} = \frac{\log[(1-P_i(0))/(1-P_i(t))]}{\log[(1-P_2(0))/(1-P_2(t))]},\ i>1 \tag{8}$$

where $P_i(0)$ = cumulative weight fraction of time 0 for ith interval, $P_2(0)$ = cumulative weight fraction of time 0 for second interval, $Pi(t)$ = cumulative weight fraction of time $_t$ for interval t, $P_2(t)$ = cumulative weight fraction of time t for second interval.

The values of *B* were determined from the size distributions at short grinding times using the *BII* method and are shown in Figure 2. The results showed a typical normalized behavior so that the progeny distribution did not depend on the feed particle size and the parameter δ was zero. The model parameters are also given in Table 3.

The slope of the lower portion of the B_{ij} curve can be denoted by γ with smaller values of γ indicating that once particles of a certain size break; they produce many much smaller progeny fragments. Thus, γ values tend to decrease with the change in the ball type which emphases that the grinding produces finer material. Additionally, higher value *Φj* for increase ball specific gravity shows the rapid grinding of barite powder especially at sizes close to feed size; Austin et al. (1984) contrarily, it was not found at the results.

Shi (2004) says, the different grinding media have different surface area, bulk density (implicitly the charge mass or volume when one of them is fixed) and contact mechanism in their grinding actions. All these factors need to be taken into account when comparing the different grinding media have different surface area, bulk density (implicitly the charge mass or volume when one of them is fixed) and contact mechanism in their grinding actions. All these factors need to be taken into account when comparing the milling performance using the different types of grinding media.

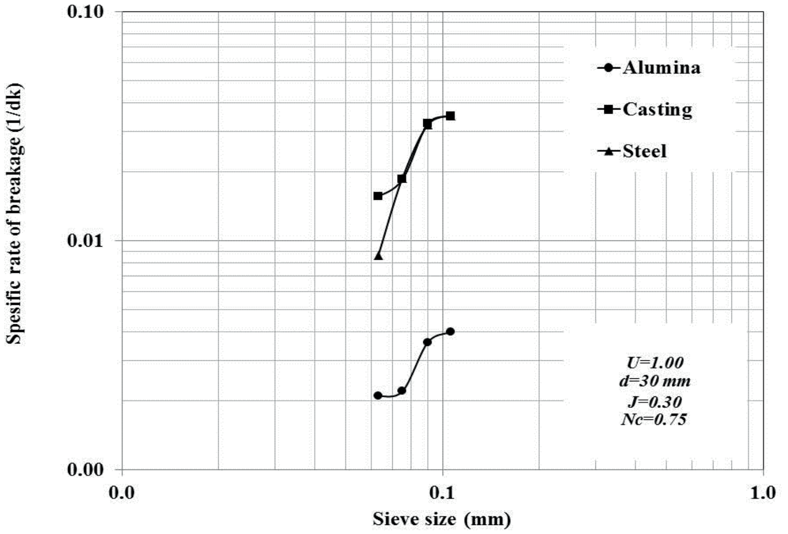

Fig. 1 Variation of Si values of barite with particle size for the different ball type

Rys. 1 Odchyłki wartości Si dla barytu o różnych wielkościach ziaren wielkości cząstek dla różnych typów kul

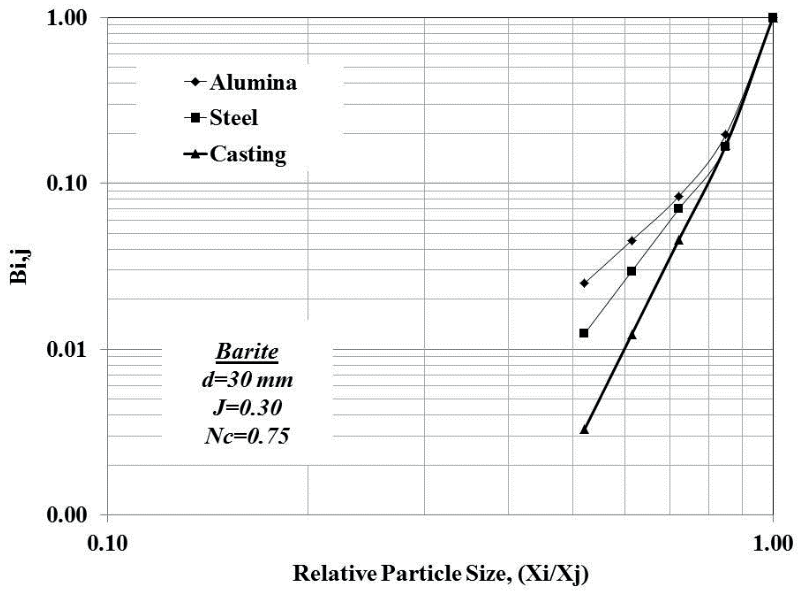

Fig. 2 Cumulative breakage distribution functions for different ball type
Rys. 2 Skumulowane dystrybuanty funkcji rozdrabniania dla różnego rodzaju kul

It can be seen from the data in Table 3 that model parameter values of the different ball type. In the experimental of casting ball, a_T value was high. The model parameter γ value of casting balls is very higher than γ value of steel and alumina balls. In the experimental of different ball *Φj* value is observed the same trend. It can be based on a reason for increasing the rate of fine material in the alumina ball type because the surface of the material with alumina balls is the high. In addition, the densities of casting and steel balls are higher than alumina ball. Also in the mill, the alumina balls are lighter than the same volume. So during the grinding, alumina balls will be created the more produce finer barite, as it will be made effect of a cascade and cataracts.

Conclusions

In today, the experiments of grinding using a single type of ball have been performed on laboratory-scale studies. In fact, grinding experiments must have been attempted under similar conditions with the requirements of the industry.

The primary breakage distribution functions of barite were found to be non-normalized, i.e., dependent on initial feed size, in the case of both alumina balls steel and casting balls. By use of nonlinear regression techniques, the primary breakage distribution function parameters were recalculated and the parameters obtained were compared. It was found that there were significant differences between the grinding of with each media in terms of the primary breakage distribution parameters. In light of the above findings, it can be concluded that the breakage distribution function is dependent on the initial feed size and the media type. The effect of grinding time on the product size distribution was also investigated. While the results suggested that alumina balls produced fine size products than steel and casting balls, this may be due to several reasons such as the contact mechanism, and specific gravity of alumina balls. As a result of the low density alumina balls mill, the cause of cataracts is affect same rotation speed. However, because of the extra effect of the cascade, a thin material has been found that a slightly higher rate.

The dry-grinding of size intervals of steel and alumina balls showed that both samples followed the first- order breakage law with constant normalized primary breakage distributions. The values of the primary daughter fragment distributions and the values of a in $S_i = a_T X^{\alpha}$ were different in the steel ball, casting ball and the alumina ball. As the amount of S_i or a_T values increase, the effective breakage increases, resulting in breaking quickly to the undersize of original particle size. The experimental a_T values show that grinding is faster for the steel and casting ball. However, the reducing of original particle size was detected faster steel and casting ball than alumina ball.

The $B_{i,j}$ values for grinding are different for steel ball and alumina ball (Table 3). The γ value of alumina ball is lower than that of steel ball (γ = 3.696 for alumina ball; γ = 5.305 for steel ball; γ = 8.064 for casting ball), which emphasizes that the grinding with alumina ball produces finer material than the grinding with steel and casting ball.

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Wpływ typu kul na parametry pękania barytu

Kule sferyczne są dominującym kształtem używanym w młynach bębnowych. Jednakże kule sferyczne zużywają się tworząc niesferyczne fragmenty w skutek rozerwania spowodowanego uderzeniem i innych mechanizmów zużywania wewnątrz młyna. Zatem co jakiś czas wsadem do młyna jest mieszanina w zakresie od dużych kul sferycznych do zużytych nieregularnych. Niewiele jest prac poświęconych ocenie wpływu kul na wydajność młyna.
Wykonana została praca eksperymentalna na temat wpływu kształtu nośnika na mielenie barytu. Istniejące badania skupiają się na wydajności mielenia w młynach kulowych. Absolutny stopień rozdrobnienia danego typu kul jest ważnych czynnikiem dla optymalnej pracy młyna kulowego. Zbadano zatem wpływ typu kul na kinetykę rozpadu za pomocą porcji proszku barytowego w warunkach mielenia na podstawie modelu kinetycznego. W tym celu, początkowo, cztery różne drobne frakcje o jednym rozmiarze zostały uzyskane za pomocą serii sit a√2, między 0,106 a 0,045mm. Następnie równania Si i Bi,j zostały wyznaczone z rozkładów rozmiarów uzyskanych w różnym czasie mielenia i parametry modelu zostały porównane dla trzech różnych typów kul. W wyniku testów okazało się, że wpływ typu kul na mielenie odnośnie niektórych wyników jest inny niż wykazany przez innych badających.

Słowa kluczowe: młyn kulowy, typy kul, baryt, parametr rozdrobnienia