The Investigation of Effect of Wet-Dry Grinding Condition and Ball Types on Kinetic Model Parameters for Kaolin

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Summary

Ceramics are products made from inorganic materials that are first shaped and subsequently hardened by heat. Many ceramic raw materials require crushing or disintegrating followed by dry or wet grinding to various degrees. Most of the energy is consumed in the grinding operations for the ceramic industry. As it is known, some of the energy during grinding is converted to heat that is fully not utilized in the grinding process. Thus, grinding is not a very efficient operation and it needs to be paid attention in detail. However, it is possible to set up a grinding system with a low energy consumption and higher efficiency of fineness before they can be used in ceramic manufacture. The type of grinding media exerts significant influence on milling performance in terms of product size and energy consumption. In recent years, various shapes of grinding media including rods, pebbles, and cylinders have been used as an alternative to balls. Cylinders have received particular attention because they have a greater surface area and higher bulk density than balls of similar mass and size. The objective of this study is to compare the wet and dry grinding of most frequently used ceramic raw materials namely, kaolin with the grinding of alumina ball type and cylbebs (pebbles).

Keywords: kinetic model, wet grinding, fine particle, breakage distribution function, kaolin

Introduction

Every year several billion tons of metallic ores, minerals, cement and various other solids used in the ceramic and chemical industries are subjected to size reduction in ball mills. The specific energy consumption value for grinding of these materials typically ranges from 5 to 50 kWh/ton. Thus, a significantly large amount of electrical energy is consumed during the ball mill grinding operation. It is, therefore, important to establish the optimum values of various mill operating parameters, such as the mill speed, ball load, ball diameter , ball type and particle load, from the energy consumption point of view [9].

In the recent years, matrix and kinetic models have been used in the laboratory and in the industrial areas. Kinetic model, an alternative approach, considers comminution as a continuous processing which rate of breakage of particles size is proportional to the mass presented in that size [8].

Over the past decade, ball mills have begun to be used extensively in many industries, including mineral, ceramic, metallurgy, paint, chemical, agriculture, food, medicine and energy. On the other hand, two grinding modes including dry and wet modes are applied in the grinding processes. The choice between dry and wet grinding is influenced by several factors. The condition of the raw material and the downstream use as a powder or slurry determinate the grinding process in many cases. Regarding wet grinding, impact action is created by the constant impinging of the grinding media due to its irregular movement. Shearing action is present as the balls (media) in their random movement are spinning in different rotation and therefore, exerting shearing forces on the adjacent slurry. As a result, both liquid shearing force and media impact force are occurring. Such combined shearing force and impact results in the size reduction as well as good dispersion [14].

Ultrafine grinding in the submicron range has currently attracted much attention in connection with the development of new ceramic and electronic materials, and quite a few investigations have been reported on wet-process experimental work using different grinding media. As mills using grinding media, i.e. conventional ball mills, vibration mills, planetary mills and stirred mills, are common machines, particular attention is paid to ultrafine grinding which uses grinding balls less than 1 mm in diameter [13].

The type of grinding media exerts significant influence on milling performance in terms of product size and energy consumption. In recent years, various shapes of grinding media including rods, pebbles, and cylinders have been used as an alternative to balls. Cylinders have received particular attention because they have a greater surface area and higher bulk density than balls of similar mass and size.

Analysis of the influence of grinding media shapes on the kinetics breakage parameters can provide guidance for improving the grinding efficiency of cement clinker. However, the effects of grinding media shape on breakage parameters of clinker have not yet been systematically studied. The main purpose of this study is to investigate and compare the effects of grinding media shapes on the specific rate of breakage and the primary breakage distribution function in a typical laboratory batch ball mill [12].

The objective of this study is to investigate the effects of process variable, such as grinding time and ball type on mill grinding performance. To this end, batch wet and dry grinding tests were performed in a laboratory ball mill using kinetic model.

Background

By assuming that a grinding mill is equivalent to a chemical reactor with a first-order phenomenological rate of reaction kinetics, Reid [10] analyzed the particle size reduction in grinding mill. It has been experimentally confirmed that the rate of decrease in particle size during the batch grinding of brittle material in ball mill can be described by the first-order equation. The breakage rate of such material has been expressed in the literature as [3]:

$$w_1(t) = w_1(0)\exp(-S_1 t) \tag{1}$$

where S_i is the specific rate of breakage of feed size i, and $w_i(t)$ is the mass fraction of the total charge. Additionally, as it is often the case, i=1, Eq. (1) can be rewritten as:

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

The value of S_1 for different particle sizes can be estimated by performing the same experiment with a uniform-sized material. Different values of S_1 versus size can then be plotted on log–log paper, giving a straight line if all the sizes obey the first-order law of grinding kinetics.

The primary breakage distribution (Bi,j) is also defined in an empirical form in the literature as Eq. (3) [1]:

$$B_{i,j} = \phi_j\left(\frac{X_{i-1}}{X_j}\right)^{\gamma} + (1-\phi_j)\left(\frac{X_{i-1}}{X_j}\right)^{\beta} \tag{3}$$

where $B_{i,j}$ is the mass fraction of primary breakage products, x_i is the largest size, and the parameters φ, γ and β define the size distribution of the material as being ground. When plotting size versus $B_{i,j}$ on log paper, the slope of the lower portion of the curve gives the value of γ, the slope of the upper

Tab. 1. Chemical composition of kaolin

Tab. 1. Skład chemiczny kaolinu

Samples	SiO_2	Al_2O_3	Na_2O	CaO	MgO	K_2O	Fe_2O_3	TiO_2	SO_3	LOI.
Kaolin	64,71	24,21	0,08	0,09	0,05	0,21	0,64	0,34	0,47	9,02

Tab. 2. Ball mill characteristics and test conditions

Tab. 2. Cechy młyna kulowego i warunki testowe

Mill	Diameter, D (mm)	150.00	
	Length, L (mm)	150.00	
	Volume (cm^3)	2650.00	
	Mill speed Critical, *Nc* (rpm)	114.00	
	Operational speed	85.50	
Media (Balls)	Grinding Diameter, d (mm)	10.00	
	Media (balls) Specific gravity (g/cm^3)	6.44	3.70
	Quality Alloy	Cylbeps	Alumina
	Assumed porosity (%)	40.00	
	Ball-filling volume fraction, J_b *(%)*	0.30	
Material	Specific gravity (g/cm^3)	2.53	
	Powder-filling volume fraction f_c *(%)*	0.12	
	Interstitial filling *U (%)*	1.00	

portion of the curve gives the value of β, and φ is the intercept [15–17].

Experimental Studies

Materials

Kaolin was chosen as the feed mineral for this study, because this mineral is major raw material of ceramic industrial. The density of these raw materials, measured by a pycnometer, is averaged as 2.53 g/cm^3 over three measurements and Bond Work Index (*Wi*) of this material is 7.13, kWh/t. The Bond work index is determined by using the standard Bond test procedure [4].

The kaolin was characterized by X-ray fluorescence (XRF) using a Spectro equipment, model X-Lab 2000; X-Ray diffraction (XRD) using Philips equipment, model X'Pert MPD, with radiation Cu Kα (45 kV/40 mA). Chemical analyses of this material and X-Ray Diffraction (XRD) are also given in Table 1 and Fig 1.

The sample are run on the diffractometer (air-dried) and then run again following various treatments such as solvation with ethylene glycol, and heating to specified temperatures for specified times. Peak positions, shapes and intensities and changes between these treatments are diagnostic for the identification of different clay minerals. To this end, the kind of clay is kaolinite. Quartz and magnetite exist in kaolinite.

Grinding tests

The breakage parameters were determined experimentally using one size fraction technique [8]. 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 particles pass by weight at 0.106 mm size and 100% of particles remain at 0.090 mm. The standard set of grinding conditions used is shown in Table 2 for a laboratory mill with a 6283-cm^3 volume.

Results and Discussion

Determination of S parameters

The results indicate 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, Figs. 2 and 3 show

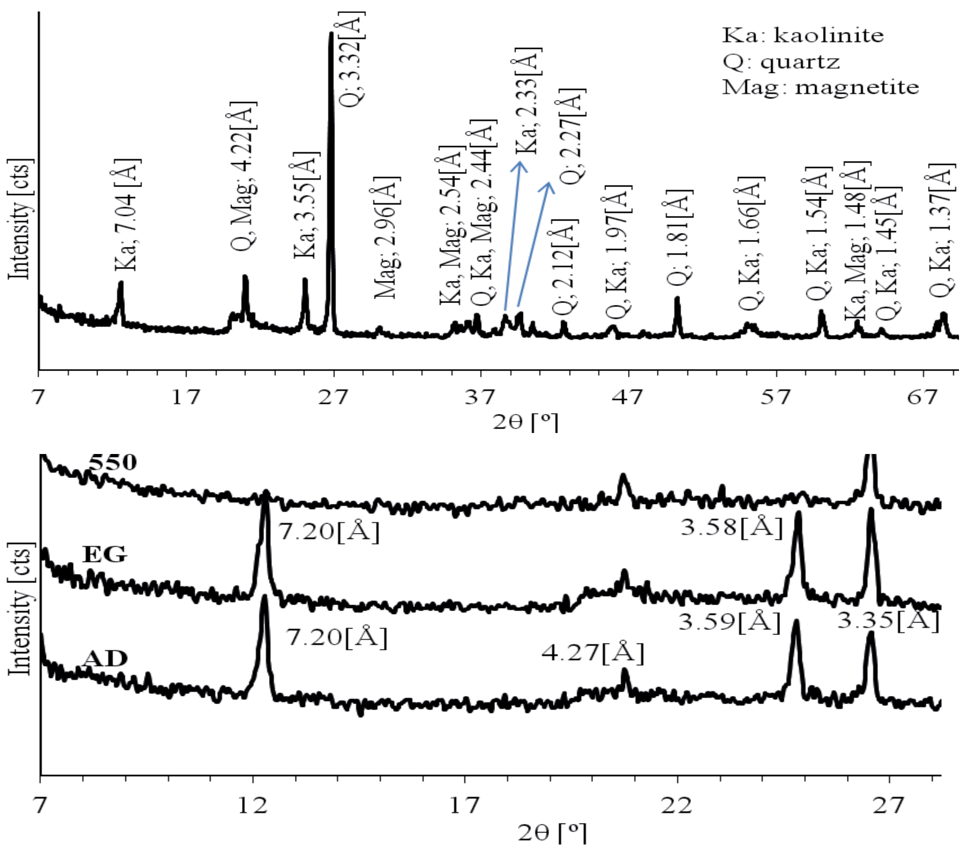

Fig. 1. Details Clay analysis of Kaolin used XRD method (AD air dried, EG: ethylene glycol, 550: heat-treated at 550°C.)

Rys. 1. Szczegółowa analiza glinu w Kaolinie przy użyciu dyfraktometrii rentgenowskiej (ang. skr. XRD) (AD suche powietrze, EG: glikol etylenowy, 550: temperatura procesu wynosi 550°C) the S_i in relation to the ball type and particle size for kaolin, respectively.

Fig.2 also shows the variations of the specific rates of breakage, S_i, values with the particle feed sizes ground in the mill for alumina ball. It is clearly seen that S_i values increase up to particle size -0.090+0.075 mm, only start decreasing at around -0.106+0.090 mm for cylbeps (pebble) type as illustrated Fig. 3. As cylbeps ball is not spherical and coarse grains are not comminuted, small grains will not be broken. Secondly, cylbeps balls is poorly clutch to material.

Breakage distribution functions

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 [3.5.8]. The values of $B_{i,j}$ against particle size obtained from BII calculations for each size fractions are plotted in Fig. 6. In order to get the $B_{i,j}$ values, BII calculation procedure [4] given below was applied for the shortest grinding time (0.5 min),

$$B_{i,j} = \frac{\log[(1-P_i(0))/(1-P_i(t))]}{\log[(1-P_2(0))/(1-P_2(t))]},\ i>1 \quad (4)$$

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, $P_i(t)$ = 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

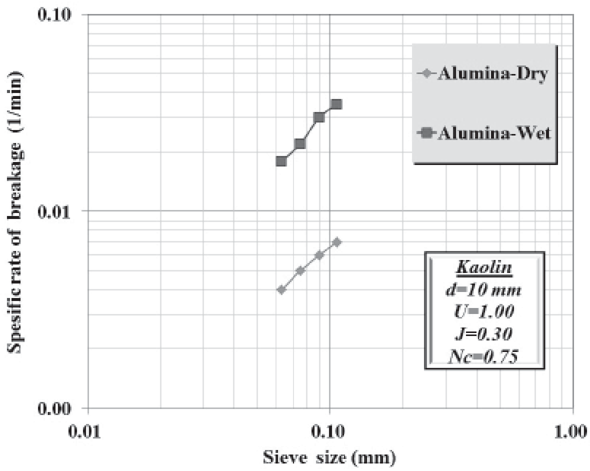

Fig. 2. Variation of S_i values of kaolin for alumina ball type in wet and dry grinding

Rys. 2. Zmienna wartości S_i kaolinu dla mielenia kulami aluminowymi w mieleniu mokrym i suchym

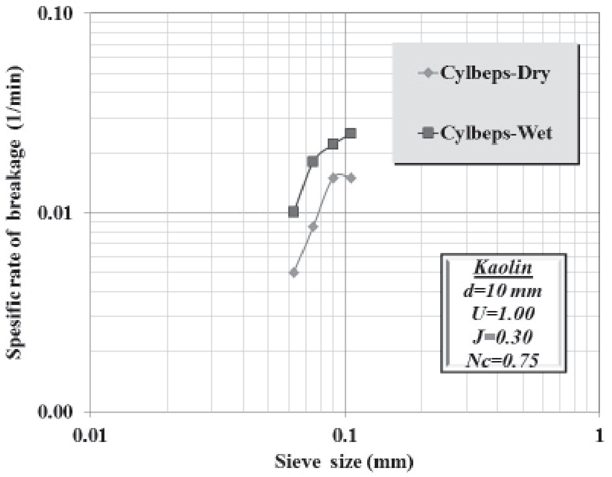

Fig. 3. Variation of S_i values of kaolin for cylbeps (pebble) ball type in wet and dry grinding

Rys. 3. Zmienna wartości S_i kaolinu dla mielenia kulami mielącymi cylpebs (kamyczki) w mieleniu mokrym i suchym method and are shown in Fig.4 and 5. 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 kinetic model parameters are also given in Table 3.

The rate at which the particles break or the breakage rate parameter has to be estimated and characterized with the operating variables namely, the grinding condition, grinding media and material feed rate to get the answer for the question 'how much' of the material fed to the mill is selected for breakage in the grinding chamber per unit interval of time. In fact, this parameter is considered to depend more on the type of grinding system than the breakage distribution parameter, which is related more to the properties of the material [12].

It can be seen from the data in Table 3. that model parameter values of the grinding media is similar to the literature for alumina ball type. Contrarily, model parameters of cylbeps are not the same in literature. Wet grinding studies for both of the ball type has been determined that the γ value is low. Consequently, the amount of fines is low too. Kaolin can feature in dispersion of the water under the wet grinding conditions. With regard to the studies about Cylbeps ball, breakage rate (a_T) was obtained as high. The reason for this is the fact that the alumina balls have low density.

Conclusions

The kinetic grinding model has been successfully used for predicting the outcome of various grinding systems. Therefore, this is only possible through the analysis of the grinding behavior during simultaneous grinding in relation to the kinetic grinding model.

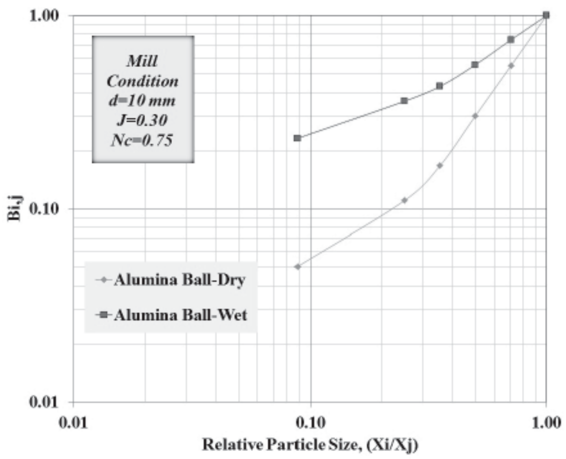

Fig. 4. Cumulative breakage distribution functions for alumina ball type

Rys. 4. Łączne funkcje rozkładu pęknięć dla kul typu aluminiowego

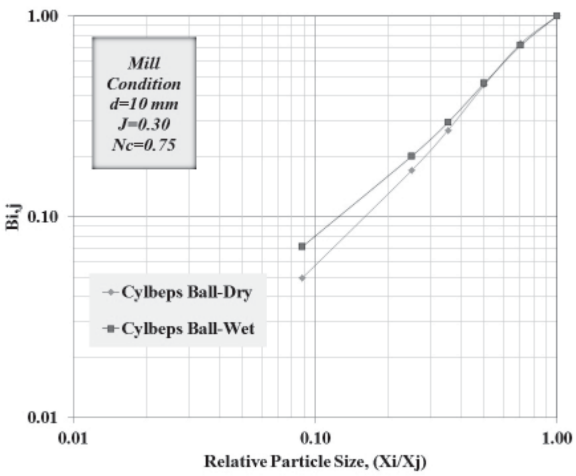

Fig. 5. Cumulative breakage distribution functions for cylbeps ball type

Rys. 5. Łączne funkcje rozkładu pęknięć dla kul typu cylpebs

Tab. 3. Characteristic breakage distribution functions of different powder-filling volume fraction fc (%) obtained from the laboratory test

Tab. 3. Charakterystyczne funkcje rozkładu pęknięć dla frakcji różnej ilości proszku wypełniającego fc (%) otrzymanych dzięki testowi laboratoryjnemu

Ball Type	Mill media	a_T	α	Φ_j	γ	β	δ
Alumina	Dry	0,13	1,01	0,377	0,836	2,446	0.00
	Wet	1,48	1,35	0,672	0,441	1,913	0.00
Cylbeps	Dry	2,08	1,85	0,936	1,214	0,830	0.00
	Wet	1,33	1,44	0,839	1,020	1,392	0.00

It should be noted that dry grinding of size intervals of the fuel samples followed the first-order breakage law with constant normalized primary breakage distributions. In addition, these samples do not depend on the particle size of cumulative breakage distribution function.

The values of the primary daughter fragment distributions and the values of α in $S_i = a_T X^\alpha$ were different in the ball type. As the amount of S_i or a_T values increase, the effective breakage increases, and breaks much faster in the undersize of original particle size. The lower γ values, the fineness factor, contribute more the large parameter values of the finer size fractions, and thereby *φj* values contribution paves the way for the coarser size fractions.

The breakage parameters of alumina ball type were compared to cylbeps ball type under similar experimental conditions. That is to say, it can be said that the kaolin was broken with cylbeps ball type (a_T = 2.08) faster than alumina ball type (a_T = 0.13) in dry grinding condition. However, the kaolin was broken fast in wet grinding condition in relation to alumina ball type.

On the other hand, alumina ball type (γ = 0.441) produces finer material than cylbeps ball type (γ = 1.020) regarding the γ value of $B_{i,j}$ in wet grinding condition, while cylbeps ball type was easier grinding than alumina ball type with regard to specific gravity of ball. At this point, it should be noted that the shape of ball is different.

In this study, kaolin sample is given effective breakage for cylbeps ball. In addition, grinding is faster grinding for dry grinding condition since it is suitable value of cylbeps ball type for kaolin sample.

In addition, in this study for the first time the kinetic model studies were performed on fine sieve size in wet grinding conditions.

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Badanie efektu warunków suchych i mokrych mielenia i typu kul na parametry modelu kinetycznego dla kaolinu

Produkty ceramiczne wykonane są z materiałów nieorganicznych, które najpierw się kształtuje, a następnie utwardza przy użyciu ciepła. Wiele surowych materiałów ceramicznych wymaga miażdżenia lub dezintegracji przy pomocy suchego lub mokrego mielenia w różnych stopniach. W przemyśle ceramicznym najwięcej energii zużywa się do reakcji mielenia. Jak wiadomo, część energii w trakcie mielenia zmienia się w ciepło, które nie jest w pełni wykorzystywane w procesie mielenia. Co oznacza, że mielenie nie jest zbyt opłacalną operacją i wymaga szczegółowej uwagi. Niemniej jednak, można ustawić system mielący z niższym wykorzystaniem energii i większą wydajnością rozdrabniania, zanim zostanie użyty w wytwórstwie ceramicznym. Rodzaj medium mielącego wywiera znaczący wpływ na proces mielenia w odniesieniu do rozmiaru produktu i konsumpcji energii. W ostatnich latach, jako alternatywę do kul wykorzystywano różnego kształtu medium mielącego, wliczając w to pręty, kamyki i cylindry. Największą uwagę zwrócono na cylindry, ponieważ posiadają większą powierzchnię właściwą i wyższą wielkość objętościową niż kule o podobnej masie i rozmiarze. Zamiarem badań jest porównanie mokrego i suchego mielenia najczęściej stosowanych materiałów ceramicznych, czyli kaolinu z mieleniem aluminiowymi kulami oraz przy użyciu cylbebu (kamyczków).

Słowa kluczowe: model kinetyczny, mokre mielenie, drobne cząstki, funkcja rozkładu pęknięć, kaolin