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KINETICS OF GRINDING CERAMIC BULK CONSIDERING GRINDING MEDIA CONTACT POINTS

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Results of experiments carried out in a pilot-plant ball mill are discussed in the paper. The objective of the experiments was to determine the effect of the number of contact points between grinding media on the rate of grinding. The experimental material was ceramic body used in the production of floor and wall tiles. Main component of the feed was a mixture of feldspar and clay with antiemulsifiers. The feed was subjected to wet grinding. During grinding the rate of comminution of particular size fractions was determined. Changes in particle size distribution of ground material in time were analysed and the effect of ball size, mill filling with the feed and the number of grinding media on the process rate was described.

Main objective of the study was to define the effect of changes in the number of grinding media contact points on the grinding rate. Additionally, the effect of mill filling with the feed on changing specific rate of grinding of particle fractions was determined. The change in time of the particle size composition enabled to calculate the grinding rate of particular fractions. In the calculations Gardner and Austin differential equation was used for discrete values of fractions.

key words: ball mill, specific grinding rate

INTRODUCTION

The process of grinding in ball mills is determined by a complex character of grinding media impact on the raw material being ground. Basic geometric dimensions of the drum and the size and type of grinding media motion have an influence on the process rate and final composition of the ground product.

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The comminution process proceeds mainly due to complex action of grinding media on the material being ground and additionally the interactions between grinding elements and the inner drum surface. Material which is between the surfaces of moving balls is subjected to attrition and shearing with possible crushing (Drzymała et al., 1990; and Mattan, 1971; Lynch, 1974; Shipway, 1994). These mechanisms of comminution occur mainly in the avalanche motion of grinding media. The cascade motion of balls involves additionally an impact mechanism resulting from collisions of balls falling down to the bed of balls and feed which is at the bottom of the drum (Heim et al., 2004) and (Heim et al., 2004). The type of motion at which impact mechanisms prevail, occurs at rotations frequency close to the critical frequency. This phenomenon is very desirable because of grinding intensity, but the size of industrial ball mills and resulting inertia forces reduce the character of mill operation at velocities close to the critical frequency. For this reason, if we choose lower rotations speeds of the mill, the contribution of particular comminution mechanisms can be changed by changing the size and number of grinding media. It is obvious that at the same volume of the bed of grinding media and ball filling of the mill, the bigger are the balls, the smaller is their number. An increase of the ball size determines an increase of a single ball mass and extension of mutual interactions between the grinding media. An enlarged size of the grinding media, at unchanged ball filling of the mill, causes a decrease of the number of contact points. This induces a decrease of mini-regions in which breaking stresses may occur leading to destruction of ground material particles. Ball diameters are selected according to the ground material strength and particle diameter of the mill feed. For bigger particles that require a higher breaking strength, the balls should be bigger, while for smaller particles and materials with lower strength better results are obtained when the number of ball contacts, and consequently the number of balls, increases at the cost of their diameters.

Simplicity of the mill construction does not keep up with grinding process efficiency. Low process efficiency makes technologists look for such a composition of balls and ball filling of the mill at which the mean particle diameter decreases at the fastest rate. This will enable a more economic use of the mill operating time.

Having this in mind, results of comminution in a mill with different number and size of balls as well as different load filling of the mill were analysed. Ceramic body was subjected to wet grinding.

GRINDING PROCESS AND EQUIPMENT PARAMETERS

Changes of particle size distribution in time were studied in a pilot-plant mill. Basic technical data of the mill are given in Table 1.

Table 1. Main parameters of a pilot-plant mill

Inner diameter [m]	0.5
Total volume [m^3]	0.112
Rotations speed n[min^{-1}]	31
n/n_{kr}	0.54

The comminution process was carried out in wet regime (water solution with antiemulsifiers). The feed was a mixture of rock material, mainly feldspar and clay. Grinding was performed for different feed compositions. The difference in feed composition was determined by the assignment of the ground product and was related directly to the assortment of final products obtained from the ceramic body. A differentiated feed composition depended on specific utility requirements. The technology of ceramic body production for floor tiles requires an increased percentage of harder components (feldspars). In wall tiles the feldspar percentage is reduced to a minimum. Table 2 gives compositions of feed comminuted in the tested mill for two groups of products, wall and floor tiles.

Ball charge of the mill was assumed to be 45% of the mill volume for the full feed load. The ceramic body was ground at changing ball composition. Mass of size fractions and ball dimensions for each experimental series are given in Table 3. To differentiate grinding series according to ball composition, each of them was given a symbol A, B and C.

Table 2. Components of raw material used in the production of wall and floor tiles

	Wall tiles	Floor tiles
Solid components [kg]	66	66
- feldspar [kg]	18	36
- clay [kg]	29	25
- quartz [kg]	11	5
- carbonates [kg]	8	-
Liquid components [kg]	19.7	19.7
- water [kg]	19.5	19.5
- sodium tripolyphosphate [kg]	-	0.2
- liquid glass [kg]	0.2	-

RESULTS AND DISCUSSION

Grinding was a batch process. Samples of ground material were taken at every 1000 revolutions of the mill. Particle size analysis of the samples was made using an ANALYSETTE 22 laser particle size analyser (FRITSCH).

Table 3. Composition and dimensions of balls

Series	A	B	C
Ball diameter, [mm]	Ball mass, [kg]		
10	12.4	2	-
20	24.6	25	22.6
30	24.6	25	29.4
40	20.4	30	30
Total, [kg]	82	82	82

On the basis of the particle size analysis comminution rates were calculated for particular size fractions. In the calculations, Gardner and Austin equation (1) was used in the differential form for discrete values of the fractions, assuming an ideal mixing of the ground material.

$$\frac{\mathrm{d}w_i(t)}{\mathrm{d}t} = -S_i w_i(t) + \sum_{j=1,i>1}^{i-1} S_j b_{i,j} \cdot w_j(t) \tag{1}$$

The form of equation describing a change of coefficient $b_{i,j}$ was also assumed:

$$b_{i,j} = \phi \left(\frac{d_i}{d_j} \right)^{\gamma} + (1-\phi) \left(\frac{d_i}{d_j} \right)^{\beta} \tag{2}$$

Rate coefficients S_i in equation (1) for grinding of material used for wall tiles production for series A, B and C are given in Table 4. Similar calculations of rate coefficient S_i in equation (1) were made for grinding of material used in the production of floor tiles.

Knowing the particle size distribution also the mean particle size was calculated from the formula

$$d_s = \sum_{i=1}^{n} d_{si} \cdot x_i \tag{3}$$

Using Statistica®, the correlation equations of changes in the comminution rate as a function of particle size fraction d_i were generated. This allowed us to present process kinetics in the form of a relationship between the rates S_i for particular size fractions and the filling of mill with the feed and grinding media.

As an equation describing the rate of grinding particular size fractions, the following function was used:

$$S(i) = K_S \cdot d_S(i)^{n_s} \cdot e^{-b_s \cdot d_{si}} \tag{4}$$

Coefficients K_S, n_s and b_s for each measuring series are given in Table 5.

Table 4. Rate coefficients S_i for grinding of wall tile material in series A, B and C

Ball composition	Series A	Series B	Series C
$d_{śr}$	S_{iA} x 10000	S_{iB} • 10000	S_{iC} • 10000
704.28	5.25	6.01	18.8
545.115	7.2	1.18	48.7
418.03	10.9	28.4	8.03
320.34	19.9	51.2	6.53
245.565	19	29.1	36.9
188.25	7.05	0.67	22.3
`144.31	3.16	1.67	12
110.625	2.65	1.96	6.47
84.805	2.22	1.79	4.3
65.01	1.27	1.08	4.5
49.835	0.198	0.15	3.13
38.205	0.368	5.74	1.19
29.29	0.532	7.31	1.29
22.45	0.65	7.98	1.65
15.695	0.713	0.83	3.07
10.115	0.714	0.81	5.66
7.755	-0.66	0.69	7.42
5.945	-0.606	-0.53	7.28
4.555	-0.594	-0.4	5.99
3.49	-0.605	-0.32	4.3
2.675	-0.577	-0.27	2.7
2.05	-0.496	-0.26	1.56
1.575	-0.399	-0.25	0.88
1.21	-0.316	-0.24	0.47
0.925	-0.255	-0.23	0.22
0.71	-0.215	-0.23	0.04
0.545	-0.19	-0.24	-0.11
0.415	-0.195	-0.28	-0.19
0.32	-0.212	-0.35	-0.26
0.245	-1	-1.22	-0.34

Table 5. Coefficients γ, β and ϕ in equation (2) and K_s, b_s and n_s in equation (4)

Parameter Series		γ	β	φ	K_S *10^6	b_s	n_s	R^2
Wall tiles	A	3.227	3.114	0.618	0.128	0.0146	3.9	0.83
	B	1.066	1.083	0.756	0.0061	0.0139	3.4	0.72
	C	0.15	3.4	0.88	35.5	0.0073	2.5	0.98
Floor tiles	A	4.8	4.15	0.78	58.9	0.0135	2.4	0.80
	B	3.654	1.538	0.7973	5.18	0.0199	3.6	0.82
	C	0.1496	2.465	0.6269	393	0.0141	2.2	0.74

To present a clearer picture of the change in comminution rate of particular size fractions of the feed, the range of changes in the mean particle diameter d_s was reduced to 200 μm (Fig. 1). As follows from calculated coefficients of equations 2 to 4 and from the diagram shown in Fig. 1, the best results were obtained for series B and a mixture of raw materials used in the production of floor tiles – line gB. Series B was characterised by the most differentiated composition of balls with the largest differences between the smallest and the biggest ball diameter. Slightly worse, although still relatively high grinding rates were obtained for series mC (material for wall tile production). Series C was characterised by the greatest number of balls with the biggest diameters. They determine the biggest breaking forces required to comminute the material. Within the size fraction above 250 μm, the grinding rate is the highest for series C (Fig. 2.). The lowest grinding rate in the whole range of particle size changes was obtained in series A with grinding of the raw material used in the production of floor tiles – curve fA. For other measuring series, the grinding rates were similar in the whole size range of particles.

Interesting are the profiles of curves wC and fB. A bigger number of balls with increased diameters (series C) determines the stronger impact forces which has a favourable effect on grinding of big size fractions. For small particle sizes, smaller than ca. 220 μm, the rate of grinding depended not on the ball sizes but on an increased number of contact points of feed with grinding media.

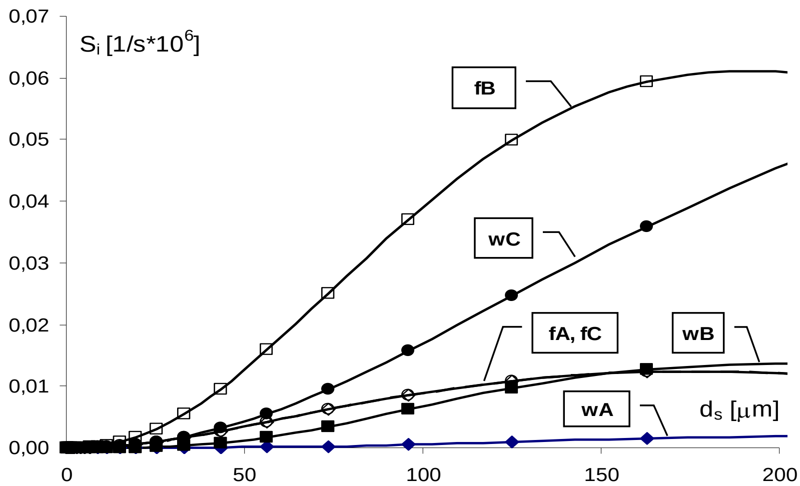

Fig. 1. Change of comminution rate S_i of wall tile material (*w*) and floor tile material (*f*) for series A, B and C. Correlation function (4), range of particle size changes 0÷200 μm

This tendency was more pronounced with the increase of the number of particles with high mechanical strength in the mill feed. In the mixture used in floor tile production, the content of hard feldspar fractions was twice as high as in the mixture used in the production of wall tiles. The calculation shows that negative values of comminution rate (Table 4) occurred for particle size fraction below 5 μm. This can be explained by agglomeration of the smallest particles of the feed which was caused by interparticle interactions. This is an unfavourable phenomenon that has an influence on grinding of coarser fractions. The smallest fractions can stick to the grinding media decreasing in this way the impact of grinding media on the comminuted material.

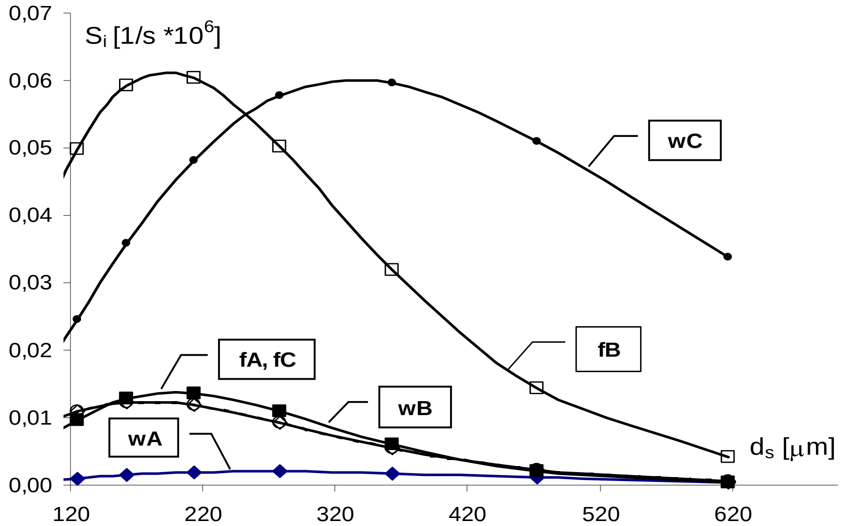

Fig. 2. Change in comminution rate S_i of wall (*w*) and floor (*f*) tile material in series A, B and C. Correlation function (4), range of particle size change 120 – 620 μm.

CONCLUSIONS

The following conclusions can be drawn on the basis of the results presented in this study.

The process of grinding in ball mills during the initial period when feed particles are relatively coarse, is affected by the size of balls and mill filling which determines the forces with which the balls act on each other.

After that, when particle size of ground material is much finer, we can observe the effect of the number of balls, or more precisely the number of contact points of grinding media between which material particles are comminuted.

The highest comminution rates for big fractions of the feed were obtained for the balls with the biggest diameters. Decreasing the number of balls with big diameters and replacing them with grinding media of smaller diameter cause a significant reduction of the comminution rate and lower variability of this parameter in the whole size range of the ground product.

NOMENCLATURE

$b_{i,j}$	– particle size distribution function
b_s, K_s, n_s	– parameters in correlation equation (4)
d_i, d_j	– particle diameters in size fractions *i* and *j,* respectively
d_s, d_{si}	– mean particle size and mean (arithmetic) size of particles in size fraction *i*, respectively
S_i, S_j	– specific rate (separation parameter) of grinding particles from fraction *i* or *j,* $w_i(t)$, $w_j(t)$ – weight fraction of particles *i* or *j* after grinding time *t*
x_i	– mass fraction of particles from size fraction *i* respectively
β, φ, γ,	– parameters in equation (*2).*

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W artykule omówiono wyniki badań przeprowadzonych w pół-przemysłowym młynie kulowym. Celem badań było określenie wpływu liczby punktów kontaktu, pomiędzy mielnikami a nadawą, na szybkość przemiału. Do eksperymentu użyto kul materiałów skalnych wykorzystywanych w produkcji ceramiki budowlanej. Rozdrabniany materiał składał się z mieszaniny skaleni oraz glinki z dodatkiem antyemulgatorów. Przemiał wykonano na mokro. W trakcie przemiału określano skład granulometryczny mielonego surowca. Zmiany wymiarów ziarna średniego w czasie, poddano analizie ze względu na wpływ wielkości mielników, wypełnienia młyna oraz liczby mielników, określając szybkość procesu rozdrabniania. Główny cel badań dotyczył określenia wpływu zmiany liczby punktów kontaktu mielników na szybkość właściwą rozdrabniania nadawy. Zmiana w czasie rozmiaru ziarn pozwoliła na określenie szybkości procesu dla poszczególnych klas rozmiarowych. Do obliczeń wykorzystano równanie Gardnera i Austina w formie dyskretnej.

słowa kluczowe: młyn kulowy, szybkość przemiału