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FINE DRY GRINDING WITH CYLPEBS OF QUARTZ SAND IN THE ŞILE, DISTRICT OF İSTANBUL, TURKEY

Glass and ceramic industries are the main consumption areas of quartz sand, which is a formed as a result of the weathering of igneous metamorphic rocks. In such industries, it is very important to select the correct ball size in order to grind the raw material to the desired particle size in optimum time. In this study, the changes in the specific rate of breakage of the quartz sand sample were investigated by using cylpebs of three different sizes. For this purpose, three different mono-size samples were prepared according to $\sqrt[4]{2}$ series in the range of 0.090-0.053 mm. The quartz sand prepared in these three intervals were ground with 10×10, 20×20 and 30×30 mm cylpebs for different durations. Specific rate of breakage values were obtained from the particle size distributions acquired after various grinding periods. As a result of grinding tests, an increase in rate of breakage is observed due to the increase in cylpebs diameter.

Keywords: quartz sand, breakage function, specific rate of breakage, fine comminution

1. Introduction

Quartz sand is formed as a result of the decomposition of magmatic metamorphic rocks. It contains quartz with a particle size of less than 2 mm. It is usually white in colour, however, depending on the iron oxide content it can be also pink, brown, or red in colour. It contains a high amount of silica. Although it can be found pure in nature, it may contain small amounts of feldspar, clay, carbonates, or iron oxides. Certain ore preparation processes are applied in order to bring the requested physical, chemical, or thermal properties depending on the intended use. Quartz sand is generally used in the glass, ceramic and casting industry. Apart from these areas of application, it is also used in industries such as ceramic, construction, plastic, dyeing, and

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abrasive, which is used for removing rusted surfaces, corroded surfaces, old paint, as well as for shaping glass and marble. The open-pit mining method is applied as the production method from the pit. The ratio of thickness of the cover layer to the thickness of the quartz sand layer shouldn't exceed 4 m^3/tonne level, to assure an economic production of quartz [1].

Quartz and quartz sand are very common in Turkey. Şile region, which is very rich in terms of deposit of quartz sand and contains clay deposits, is one of the most important mining basins of Turkey. Over 4 million tons of quartz sand is produced annually from the Şile Basin and this quartz sand is processed through sand washing, enrichment and classification processes. It is estimated that the quartz sand reserves of the Istanbul Şile region, which provides raw materials to many sectors of Turkey such as ceramics, casting industry, construction and so on, are over 100 million tons.

Quartz sands are enriched by gravity method, flotation or extraction according to their intended use, and the impurities it contains are removed. As the particle size gets smaller, it becomes more difficult to enrich by gravity method. Some impurities in the quartz sand are found or can be liberated at particle sizes below 0.075 mm. In this case, the quartz sand should be grinded and enriched by flotation [2,3].

In this study, quartz sand of Şile region, which is used in the production of ceramic sanitary ware, is preferred. This quartz sand undergoes washing and classification processes in the mining company. This quartz sand, which is procured by ceramic sanitaryware factories, consists of particles of approximately –1+0.090 mm. For this reason, non-plastic raw materials such as quartz sand are ground before being added to the ceramic sludge. Alumina balls are generally preferred for grinding. The non-plastic composition is ground to a particle size finer than 0.060 mm with the grinding process. After the grinding process, the Fe_2O_3 content in the ceramic sludge is removed with magnetic holders. Ball mills are preferred for intermediate grinding (P80; 0.040 to 0.40 mm) in plants producing traditional ceramic products such as sanitaryware, tile, tableware. Since the grinding process is under 0.1 mm particle size, most of the energy used is converted into heat energy. Specific energies of ball mills increase exponentially in these fine particle sizes where the grinding efficiency decreases economically [4-8].

Quartz sand acts as a grinding medium on other non-plastic raw materials that form the ball mill phase in ceramic production. In addition, it causes abrasion of the alumina ball surface that forms the grinding medium. For this reason, the grinding of quartz sand is more difficult in comparison to other raw materials in the mill. Generally, the breakage of quartz sand particles occurs as conchoidal fragment ruptures from the crack surfaces. This is because quartz has no cleavage [9]. For this reason, quartz sand samples do not show smooth breakage during crushing and grinding processes. The breakage is conchoidal (mussel shell) and irregular. It can be said that irregularly developed cracks cause breakage. Contrary to traditional thinking, cylpebs may be preferred for lower grinding medium wear and more efficient breakage.

Grinding medium size is an important variable affecting the grinding capacity and efficiency of the ball mills. There are some studies in the literature on the selection of the grinding medium size in the ball mill [4,10-14]. In addition, there are studies of breakage rate parameters of some raw materials [15-17].

In this study, the effect of different sizes of cylpebs on specific rate of breakage (S_i) was investigated. The quartz sand used in grinding works was supplied by a private mining company. The variation of the specific rate of breakage of quartz sand was investigated using 10×10, 20×20, and 30×30 mm steel cylpebs. For the grinding tests carried out in dry conditions, the ball filling ratio (J) in the mill was taken as 0.20, 0.35, and 0.40. Experimental studies were conducted at a constant material fill rate ($f_c = 0.120$). For this purpose, the kinetic model, the basis of which was developed by Austin et al. (1984), was applied. In this model, mathematical expressions are defining the breakage distribution and breakage rate of raw material [18]. Studies with kinetic model-based grinding and the values obtained in the laboratory are suitable for simulation in an industrial environment [19].

2. Materials and methods

The quartz sand used in the grinding studies based on the kinetic model was obtained from a private mining company located in Şile district of İstanbul province. Chemical analysis values of quartz sand are given in Table 1.

TABLE 1

Chemical analysis of the quartz sand

SiO_2	91.16
Al_2O_3	5.18
Fe_2O_3	0.34
TiO_2	0.43
Na_2O	0.62
K_2O	0.37
CaO	0.05
SO_3	0.03
Loss on ignition	1.82

In this study, specific rate of breakage values of quartz sand in three mono-sized fractions (S_i) were determined. For this purpose, quartz sand was prepared in mono-sized fractions of –0.090+0.075, –0.075+0.063, –0.063+0.053 mm according to the $\sqrt[4]{2}$ sieve series. In order to determine the specific rate of breakage values of quartz sand, a laboratory-sized ball mill measuring 15x15 cm (diameterxlength) made of steel material was used. The preferred grinding medium in the ball mill was 10×10, 20×20, and 30×30 mm cylpebs. Each mono-sized fractions, prepared according to the $\sqrt[4]{2}$ size interval, was ground batchwise to determine breakage functions. After each grinding period (1, 2, 4, 8, 16, 32, and 64 minutes), all of the quartz sand in the mill was discharged, and a representative sample was taken for particle size measurement. Malvern Hydro 2000G brand and model device was used to determine the particle size distribution of the samples belonging to the grinding periods. Based on the each time period of grinding, semi-logarithmic graphs of the material fractions staying in the high points of the particles size limits were drawn in contact with the grinding periods. The first-order zone of breakage is represented by the zone in which this graph decreases linearly. The slope of the line in the first-order breakage zone gives us the specific rate of breakage of the material in that particle size range. The formula for the specific rate of breakage is shown in Equation 1.

$$S_i = a(x_i/1\,\text{mm})^{\alpha} Q_i \tag{1}$$

The symbol "a" given in Equation 1 is the model parameter. This parameter depends on the raw material and milling conditions. "x_i" symbolizes the upper dimension (mm) in the fraction i.

Q_i is the correction factor and taken as 1 for small size particles. "α" value is a positive number and varies between 0.5 and 1.5 depending on material properties [18].

The rotational speed of the ball mill was chosen in experimental studies to be 70% of the critical speed value of the ball mill. Mill rotational speed was calculated using Equation 2. Amounts of material to be fed to the mill with Equations 3 and 4 respectively (f_c) and the mill's interstitial filling rates (U) were found.

$$\text{Critical speed}\left(N_c\right)=\frac{42.3}{\sqrt{\left(D-d\right)}} \tag{2}$$

In Equation 2, D represents the mill diameter (m) and d represents the ball diameter (m).

$$J=\frac{\text{Mass of balls / Ball density}}{\text{Mill volume}}*\left(\frac{1}{0.6}\right) \tag{3}$$

$$U=\frac{f_c}{0.4*J} \tag{4}$$

The properties and experimental conditions of the ball mill used in the grinding tests are given in Table 2.

TABLE 2

Ball mill characteristics and test conditions

Mill	Diameter, D mm	150		
	Length, mm	150		
	Volume, cm^3	2650		
Mill speed	Critical (N_c), rpm	113	117	122
	Operational ($\varnothing_c$ = 70%), rpm	79	82	85
Ball	Quality	Steel cylpebs		
	Specific gravity, g/cm^3	6.75		
	Diameterxlength, d mm	10x10	20x20	30x30
	Fractional ball filling, J	0.20	0.35	0.40
Material	Specific gravity, g/cm^3	2.65		
	Fractional powder filling, f_c	0.12		
	Powder-ball loading ratio, U	1.5	0.86	0.75

Shoji et al. (1982) found a simple relationship between ball load and powder filling in the mill [20]. It is given in Equation 5. In Equation 6, the net mill power (m_p) as a function of ball load was fitted by the empirical function. Equation 7, which is the combination of Equations 5 and 6, was used to calculate the specific grinding energy as a function of ball filling. Combining Equations 5 and 6 gives the result shown in Figure 1 [18].

$$S\left(f_c,J\right)\propto a\propto\frac{1}{1+6.6J^{2.3}}\exp\left[-cU\right],\quad 0.5\le U\le 1.5,\quad 0.2\le J\le 0.6 \tag{5}$$

where c is 1.2 and 1.32 for dry and wet grinding respectively.

$$m_p \propto \frac{1-0.937J}{1+5.95J^5}, \quad 0.2 \le J \le 0.6 \tag{6}$$

$$\text{Specific grinding energy} \propto \left\{\frac{1-0.9375J}{1+5.95J^5}\right\} / \left\{\frac{Ue^{-1.2U}}{1+6.6J^{2.3}}\right\} \tag{7}$$

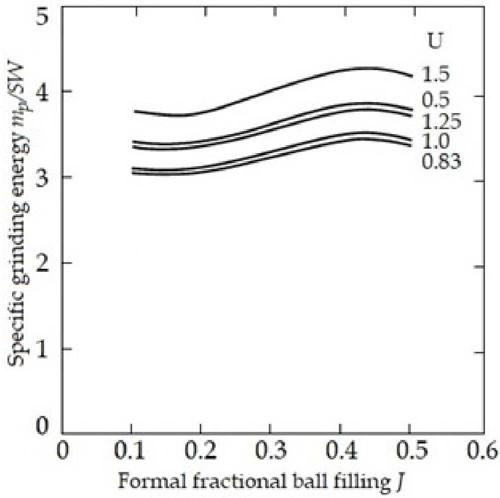

Fig. 1. Relative specific grinding energy as a function of ball filling dry grinding in a laboratory mill [18]

Austin et al. (1984) explains the relationship between ball load and specific grinding energy as follows: "Although capacity of a laboratory mill is a maximum at 40 to 45% ball load, the relative specific grinding energy m_p/SW is a minimum at about 15 to 20% ball load. In practice, ball loads less than 25% are not normally used because low ball loads can give excessive liner wear. In addition, mill capacity is clearly lower for lower ball loads [18]." Taking into consideration Equation 7 and Figure 1, the values of specific grinding energy changes based on the ball loads J and powder-ball loading ratio U. Accordingly, in this study the specific grinding energy values are obtained from Equation 7 for 0.20, 0.35 and 0.40 ball filling ratios were calculated as 3.80, 3.38 and 3.48, respectively.

3. Results and discussion

Three different sizes of cylpebs were used to grind quartz sand in three different particle size fractions at linearly increasing grinding times. At the end of each grinding period, graphs of material fractions remaining in the upper particle size range versus grinding times were plotted. The graphs of the first-order breakage lines obtained for three different ball fillings are given in Figures 2-4. The first-order zone of breakage is represented by the zone in which this graph decreases linearly. The slope of the line in the first-order breakage zone gives us the specific

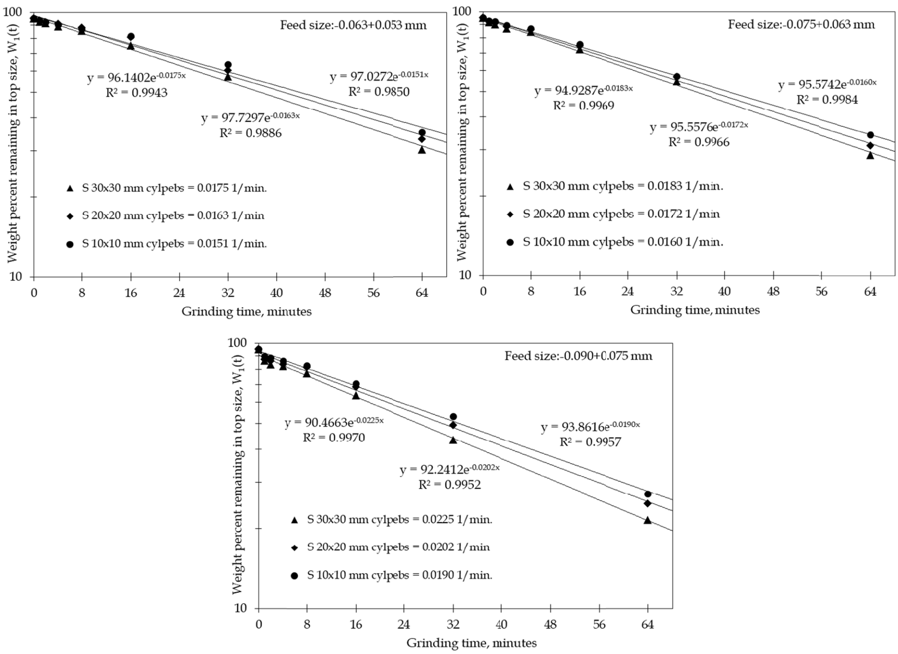

Fig. 2. Mass fraction of feed remaining during quartz sand dry grinding up to 64 minutes for $J = 0.2$

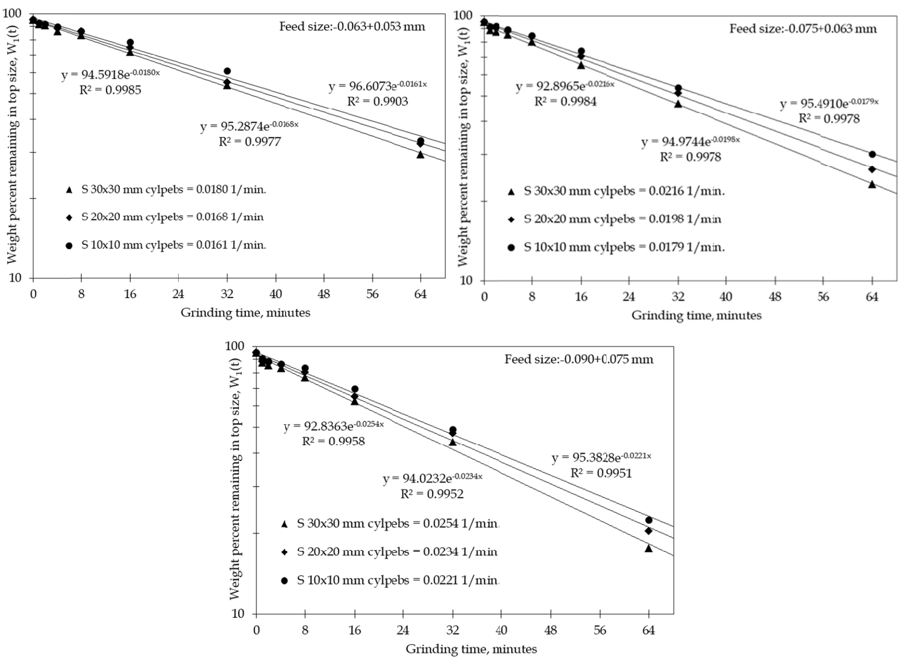

Fig. 3. Mass fraction of feed remaining during quartz sand dry grinding up to 64 minutes for $J = 0.35$

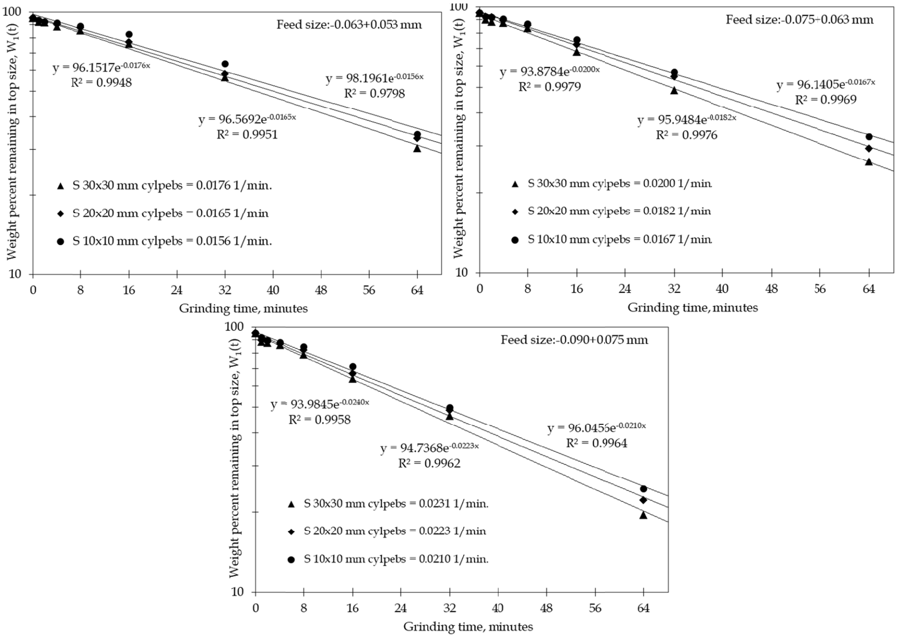

Fig. 4. Mass fraction of feed remaining during quartz sand dry grinding up to 64 minutes for $J = 0.40$

rate of breakage of the material in that particle size range. After determining the specific rate of breakage for three mono-sized fractions breakage exhibiting the first-order breakage kinetics behavior, particle size breakage graphics against the values of S_i were plotted. From these curves, the breakage rate parameters were determined as a_T and α. These graphs are given in Figure 5.

Parameters of specific rates of breakage a_T and α were obtained by non-linear regression (from Fig. 5 and Eq. (1)), and are 0.14, 0.79 for 10×10 mm ($J = 0.20$) and 0.14, 0.75 for 20×20 mm ($J = 0.20$) and 0.19, 0.86 for 30×30 mm ($J = 0.20$) and 0.26, 1.00 for 10×10 mm ($J = 0.35$) and 0.29, 1.01 for 20×20 mm ($J = 0.35$) and 0.33, 1.03 for 30×30 mm ($J = 0.35$) and 0.23, 0.97 for 10×10 mm ($J = 0.40$) and 0.25, 0.97 for 20×20 mm ($J = 0.40$) and 0.27, 0.98 for 30×30 mm ($J = 0.40$), respectively. In Figure 5, it can be seen that specific breakage rates also increased depending on the increase in ball size in general. In addition, when the graphics in Figure 5 are evaluated depending on the particle size, it can be seen that the breakage rates decrease as the particle size intervals decrease. The presence of a maximum is quite logical because large lumps obviously will be too strong to be broken in the mill. Austin et al. (1984) states that "the theory of fracture implies that smaller particles are relatively stronger because larger Griffith flaws exist in larger particles and they are broken out as size is reduced. The fact that the specific rates of breakage are a simple power function of size has not been adequately explained on a theoretical basis, but it has been amply demonstrated by many experiments [18]."

In traditional ball mills, large balls are known to be responsible for the breakage of coarse particles and small balls are supposed to grind the fine ones. Austin et al. (1984) expressed the effect of ball diameter on breakage rate as "considering a representative unit volume of the mill,

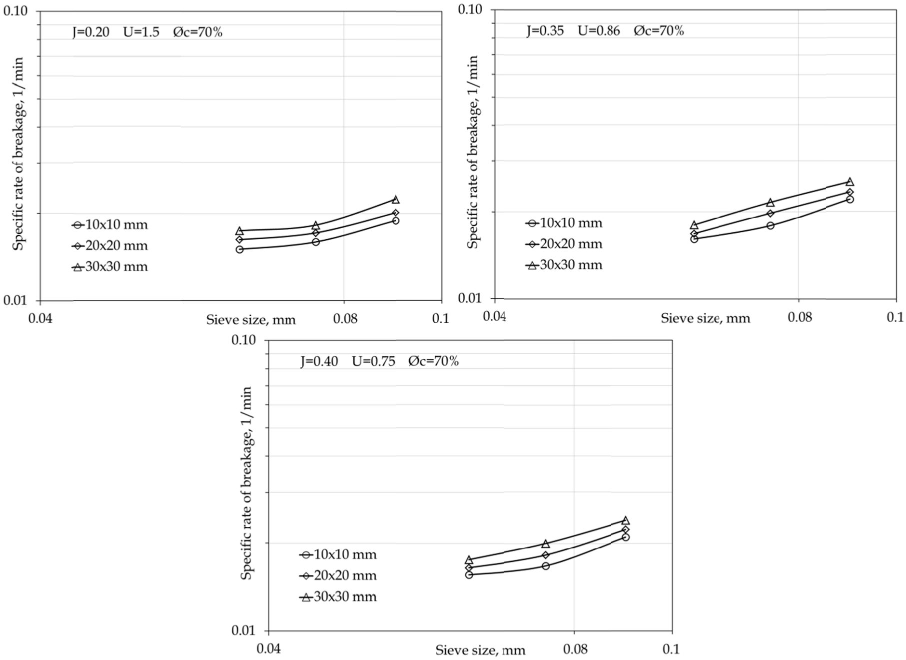

Fig. 5. Variation of the specific rate of breakage as a function of the maximum feed size for quartz sand ground with different cylpebs sizes

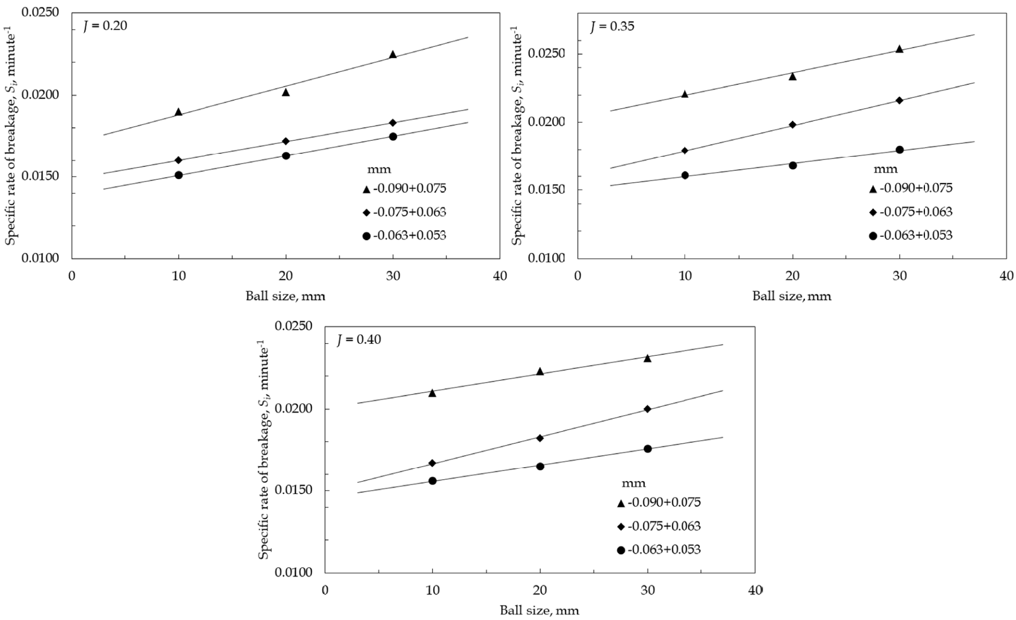

Fig. 6. Variation of ball diameter with first order breakage constant

the rate of ball-on-ball contacts per unit time will increase as ball diameter decreases since the number of balls in the mill increases as $1/d^3$. Thus, the rates of breakage of smaller sizes are higher for smaller ball diameters [18].” However, in the study mentioned, the specific rate of breakage of the 0.595×0.400 mm size raw material was determined using balls in the range of 20-50 mm. Conditions are different in this study. Three mono-sized fractions (–0.090+0.053 mm) were used according to the $\sqrt[4]{2}$ sieve series. The grinding process was carried out with cylpebs. As it is known, an important advantage of cylpebs over balls is that the balls provide a single point contact with each other, while the cylpebs provide superficial, linear, and point contact. Thus, the end product has a narrower granulometric distribution. In addition, the amount of space created by the balls consisting of single particle size during grinding is much lower in cylpebs due to its geometric shape.

In this study, Griffith-type cracks in quartz sand decreased, and grinding became difficult due to the work with very fine particle sizes. In Figure 6, the specific rate of breakage started to decrease because the grinding energy transferred by small-sized cylpebs onto the particles was insufficient. It is seen that a more effective breakage occurred with large cylpebs. This study was shown that d = 30×30 mm was the optimum cylpebs size for the maximum breakage rates.

4. Conclusions

The effect of cylpebs size on the grinding kinetics of quartz sand in the ball mill was investigated. In this study, it was observed that large-sized cylpebs played a more effective role in grinding quartz sand, and the impact and attrition effect on quartz particles was high. The energy transferred for grinding on quartz sand particles increased with the size of the cylpebs. In this study performed in different cylpebs sizes, it was observed that the most effective breakage was obtained with d = 30×30 mm sized cylpebs.

Composed of silica, quartz sand contains small amounts of impurities such as clay, feldspar, iron oxides and carbonates. It is generally not possible to use the quartz sand as it is produced from the quarry, since the quartz sand on which the cover layer is taken is not suitable in terms of quality. In order to make the obtained quartz sand usable, first sieving, then washing to remove the clay-type foreign materials from the body, and then, if necessary, flotation and magnetic separation are applied. In order to apply flotation to quartz sand, the minerals in it must be grinded to the liberation size (approximately 0.075 mm).

In this study, quartz sand of Şile region, which is used in the production of ceramic sanitary ware, was preferred. The grinding phase, which is formed with non-plastic raw materials such as quartz sand, is ground with alumina ball to finer grain size ranges than 0.060 mm. Quartz sand is necessarily subjected to grinding process either for flotation or to be used in ceramic products. Alternative balls such as cylpebs should be considered in addition to the use of traditional balls for the grinding process.

As a result, when the literature is examined, there is no data on the breaking rate of the raw materials belonging to some regions used in various branches of the industry. Breaking rate values of the raw material belonging to any region are affected by features such as the mineral ratio of the raw material, crystal structure, impurities, cracks, and so on. Grinding kinetics should be considered by raw material preparation facilities for these and other similar reasons in order to minimize the amount of energy consumed during the grinding process.

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