EFFECTS OF GRINDING MEDIA SHAPE IN MILLING OF CERAMIC RAW MATERIALS

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ABSTRACT: Communition is an important process in ceramic raw material preparation. It is an energy intensive process and also plays an important role in granule quality. Wet ball mills having spherical alumina media are predominantly used in ceramic body slip preparation.
In this study, the effects of media shape and media size distribution on grinding efficiency were sought. Grinding experiments were performed in the laboratory wet ball mill. It is cylindrical shape having the diameter of 42 cm and length of 60 cm. The mill is lined by flat shape flint stone liners. It is driven by inverter motor and control panel that allow adjusting the mill rotational speed and measure the grinding time and energy consumption. Systematic grinding tests were carried out to observe the effect of the spherical balls and cylindrical balls on the grinding efficiency. Electricity consumption and grinding time were measured to obtain the 45 µm. sieve residue is 4.1 - 4.6% for floor tile body slip.
The efficiency of grinding using spherical and cylindrical shape media charge and media charge distribution were determined in systematic tests. The tests show that the use of cylindrical media provides advantages over the grinding with spherical ball charge in terms of energy consumption. Also two steps grinding using both coarse and fine media size distribution has contributed on the grinding efficiency of ceramic raw materials. The full results are illustrated in this article.

1. INTRODUCTION

The general process of manufacturing ceramic tiles consists of preparation of raw materials, pressing, and application of engobe, glaze and firing steps.

Raw materials used in the body compositions need to be ground before granulation step. Wet grinding is the most commonly used system in the ceramic body preparation process and has an important impact on the energy consumption. Nowadays, the continuous and discontinuous ball mills are used for grinding of ceramic raw materials in the wet system. The traditional ball mill has been the common method used to grind ceramic materials for many years and it is still considered to be one of the best mixers ever invented [Carl, 2011].

In common, the ball mill grinding is an ineffective action and the grinding efficiency is affected by many factors. Wet ball mill's efficiency is evaluated by its achieved capacity at certain product size and the specific energy consumption. The performance of grinding process is highly related with mill design and operational parameters such as;

- Diameter and size of the mill
- The design of mill linings
- Shape, length and specific density of grinding media
- Mill rotational speed
- Ball and product load factor

- Viscosity of the ground material
- Grindability of material and the particle size distribution of feed and product [Hoppert, 1996]

The impact forces and abrasion forces are predominant for coarse and fine particles respectively in the grinding process. Impact force increases and interaction between grinding media and raw materials decreases while diameter of the mill and ball size grow [Vari et al., 2004]. Thus, this situation has become effective while grinding bigger particles in the first step of grinding process. In the second step of grinding process friction force is used efficiently for fine grinding.

Grinding media shape has also some significant influence on milling performance in terms of product size and energy consumption. It was defined by the producer (Doering International) cylindrical shape media (Cylpebs) that provide 25% more grinding media surface area for size reduction. The grinding performance of the Cylpebs should then be correspondingly higher compared with the spherical balls [Doering website: www.doering-sinn.de].

Spherical alumina balls are widely used for grinding of raw materials in ceramic body preparation plants however cylindrical alumina grinding media could be an alternative to reduce the energy consumption and to increase the output so as to increase the milling efficiency. In this study, the grinding media shape and two steps milling were sought on the grinding efficiency of ceramic raw materials.

2. METHODOLOGY

2.1. Material characterization

The raw materials of kaolin, feldspar, clay and floor tile waste are used in the production of floor tiles. The experimental study was performed in Kaleseramik Factory, which is the largest ceramic producer in Turkey and also one of the biggest producers in the world. The chemical compositions of raw materials were obtained by XRF that was illustrated in Table 1.

Table 1: Chemical analyses of raw materials.

	Feldspar 1	**Feldspar 2**	**Tile Waste**	**Kaolin 1**	**Kaolin 2**	**Clay 1**
L.O.I[a]	2.0	1.6	0.3	6.5	2.3	8.0
SiO_2	67	77	67	64	75	58
Al_2O_3	18	13	20	22	14	27
TiO_2	0.5	0.2	0.8	1.1	0.2	1.4
Fe_2O_3	0.2	0.8	1.8	2.6	1.4	1.5
CaO	1.1	0.4	1.1	0.2	0.4	0.4
MgO	1.7	0.2	1.2	0.5	0.3	0.5
Na_2O	8.0	2.1	3.4	0.2	0.8	0.4
K_2O	0.5	4.7	2.9	1.7	5.2	2.0

a: Loss of ignition

These raw materials were analyzed by X-Ray Diffraction to characterize the mineralogical structures. Table 2 includes mineralogical analysis of the raw materials.

Table 2: Mineralogical analyses of raw materials.

Feldspar 1	Quartz, Muscovite, Albite Clinochlore, Magnesite
Feldspar 2	Quartz, Albite, Microcline Muscovite
Tile Waste	Quartz, Albite, Mullite
Kaolin 1	Quartz, Kaolinite, Illite Anatase
Kaolin 2	Quartz, Kaolinite Albite Ortoclase, Illite
Clay 1	Quartz, Illite, Kaolinite Anatase

The raw materials were ground to 45 µm sieve residue of 2%. Table 3 includes the densities, flow times and grinding times of the raw materials slurries. Moreover, 0.45% of Na_2SiO_3 and 0.16% of NaTPP were used as electrolytes.

Table 3: Rheological properties of raw materials slurries.

Raw Materials	Density (gr/lt)	Flow Time (sec)	Grinding time (min)
Feldspar 1	1787	29	26
Feldspar 2	1681	-	26
Tile Waste	1780	29	32
Kaolin 1	1496	-	14
Kaolin 2	1486	29	14
Clay 1	1470	-	7

Table 4 shows the ratios of the raw materials that used for grinding tests in the floor tile body composition.

Table 4: Floor tile body composition.

Raw Materials	Quantity %
Feldspar 1	30.67
Feldspar 2	26.67
Tile Waste	6.67
Kaolin 1	16.00
Kaolin 2	6.67
Clay 1	13.32
Total	**100**

Size analysis was performed to obtain feeding grain size of floor tile body composition which was used for grinding tests (Table 5). According to the result, feeding grain size of floor tile body's sieve residue for 45 µm was 67.51%.

Table 5: Feeding grain size of hard material composition.

Sieve Range µm	Quantity %
+5000	12.72
-5000+2000	11.50
-2000+1000	6.79
-1000+500	7.12
-500+250	9.63
-250+100	13.17
-100+45	6.58
-45	32.49
Total	**100**

2.2. The laboratory ball mill and used grinding media

Horizontal laboratory mill was used for grinding experiments. The mill has cylindrical shape with the diameter of 42 cm and length of 60 cm. It is lined by flat shape flint stone liners (Figure 1).



Figure 1: Laboratory horizontal mill.

The mill is driven by inverter motor and control panel that allows to adjust the mill rotational speed, grinding time and to measure energy consumption.

Spherical balls and cylpebs media were used for grinding tests (Figure 2).

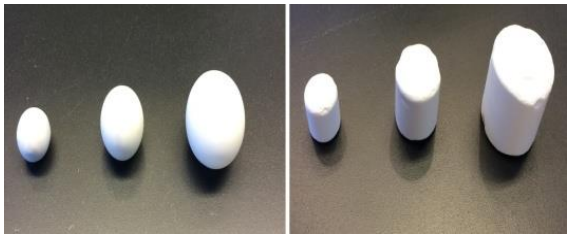


Figure 2: Alumina spherical and cylindrical grinding media.

Specific weights of the grinding medias were measured. It was found that 3.65 gr/cm^3 for spherical media and 3.64 gr/cm^3 for cylindrical media.

2.3. Experimental Work

The experimental program involved grinding tests with spherical and cylindrical grinding medias on the floor tile body composition using the laboratory ball mill.

25 kg of floor tile body composition was loaded to the mill in dry form and the density of the slip was adjusted to 1700 gr/lt. 51 kg of ball charged to the mill having the ball size distributions that were given in Table 6 and Table 9. The grinding tests were done with 45 rpm mill speed and the material was ground to 4.1–4.6 % residue for 45 μm.

The tests show the effects of different grinding media combinations have gradually increased the efficiency of grinding.

2.3.1. Comparison of grinding media shape on efficiency

It was decided to use alumina spherical and cylindrical grinding medias so as to evaluate the media shape effect on grinding efficiency. Table 6 shows the grinding media charge distributions that is used for evaluating the media shape effect on grinding efficiency.

Table 6: Spherical and cylindrical media charge distribution used for comparison of grinding media shape.

Spherical		**Cylindrical**	
Diameter (mm)	%	Size (mm)	%
60	8	40*40	20
50	18	30*30	30
40	37	25*25	24
30	29	20*20	26
25	8	Total	100
Total	100		

Table 7 shows the grinding test that was done by spherical grinding media. It was seen that after 420 min of grinding time the residue was 4.37% and total energy consumption was 3599 watts.

Table 7: Grinding test results used spherical grinding media.

Grinding Time (min.)	Energy Consumption (watts)	Residue 45 μm. %
60	540	41.10
120	1050	30.69
180	1580	19.86
240	2095	12.77
300	2591	8.76
360	3079	5.96
395	3359	5.21
420	3599	4.37

Table 8 shows the grinding test that was done with cylindrical grinding media. It was seen that after 295 min of grinding time, the 45 μm. residue was 4.20% and the total energy consumption was 2636 watts.

Table 8: Grinding test results used cylindrical grinding media.

Grinding Time (min.)	Energy Consumption (watts)	Residue 45 µm. %
60	535	41.35
120	1072	27.36
180	1607	15.17
240	2133	9.01
285	2511	4.79
295	2636	4.20

As a result, it was observed that cylindrical grinding media had very positive effects on the grinding time and energy consumption compared to the spherical media for one step grinding.

2.3.2. The effect of two steps grinding on grinding efficiency

Grinding conditions was changed to observe the effect of two steps grinding on efficiency. In the first step, the normal spherical grinding media charge was used. In the second step, the small charge distributions of spherical and cylindrical grinding media usage were compared in order to evaluate the shape effect on fine grinding.

Table 9: Grinding media charges used for two steps grinding.

Spherical			**Cylindrical**	
Diam. (mm)	Normal %	Small %	**Size (mm)**	Small %
60	8	-	40*40	20
50	18	-	30*30	30
40	37	-	25*25	24
30	29	18	20*20	26
25	8	40	**Total**	**100**
20	-	31		
15	-	11		
Total	**100**	**100**		

Table 9 shows the grinding media charge distributions used for two steps grinding.

In the first step floor tile body composition was ground 240 min. with normal spherical ball charge and the ground material's 45 µm sieve residue was measured as 12.77% (Table 10).

Table 10: 1st step grinding 240 min.

1st step Normal Spherical	
Grinding Time min.	Residue 45 µm. %
0	67.51
120	30.69
180	19.86
240	12.77

After that the prepared slip was ground with small spherical ball charge and cylindrical media charge distributions separately in the second step. Table 11 shows grinding test results.

Table 11: Test results for the 2nd steps grinding (First step 240 min. grinding time).

2nd step Spherical		2nd step Cylindrical	
Grinding Time min.	Residue 45 µm. %	Grinding Time min.	Residue 45 µm. %
0	12.77	0	12.77
30	8.34	30	8.90
60	5.27	60	6.25
70	4.14	77	4.44

In the first step, floor tile body composition was ground 120 min. with normal spherical charge distribution and ground material's 45 µm sieve residue was measured as 30.58 %. (Table 12).

Table 12: 1st step grinding 120 min.

1st step Normal Spherical	
Grinding Time min.	Residue 45 µm. %
0	67.51
60	40.99
120	30.58

After that the slip was ground with small spherical and cylindrical media charge distributions separately in the second step. Table 13 shows grinding test results.

Table 13: Test results for 2nd step grinding (First step 120 min. grinding time).

2nd step Spherical		2nd step Cylindrical	
Grinding Time min.	Residue 45 µm. %	Grinding Time min.	Residue 45 µm. %
0	30.58	0	30.58
30	15.07	30	15.07
60	5.32	60	5.56
70	4.35	80	4.55

It was found that 120 min grinding time at 1st step is more suitable when compared to 240 min. grinding time for the first step as grinding time was decreased dramatically in the 2nd step.
It was seen that small spherical media charge and small cylindrical media charge have the similar efficiency for fine grinding in two steps grinding. It should be noted that the cylindrical media size distribution is coarser than optimum size distribution due to the unavailability of small size media.

3. RESULTS AND DISCUSSIONS

Figure 3 shows the spherical and cylindrical grinding media comparison of grinding time to reach the 4.1-4.6% sieve residue of 45 µm for floor tile body composition. It was found that grinding time was 295 min. for cylindrical media and 420 min. for spherical media. Thus, cylindrical media results in lower grinding time compared to the spherical media.

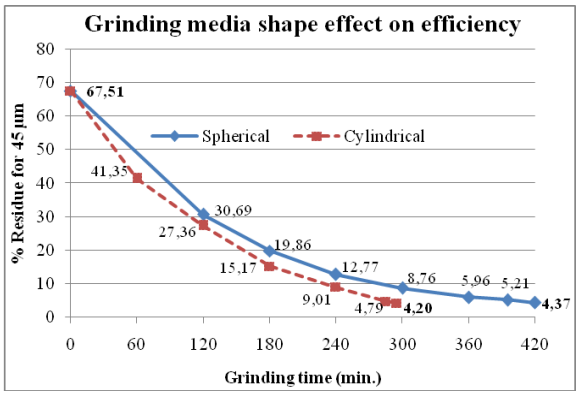


Figure 3: Grinding media shape effect on grinding efficiency.

Figure 4 shows the effect of two steps grinding on energy consumption. It is clear that 120 min. had 17% less energy consumption compared to 240 min. which were used in the 1st step of two steps grinding. In addition, the small spherical ball distribution's energy consumption was slightly less than small cylindrical distribution for fine grinding in the 2nd step.

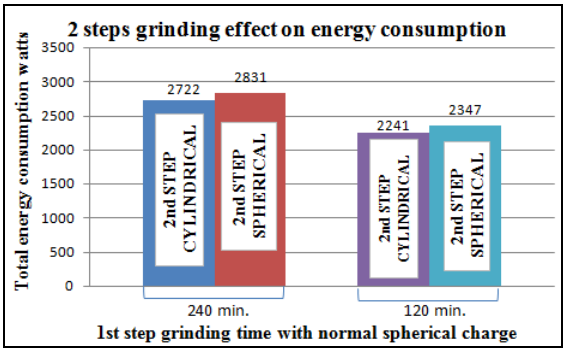


Figure 4: 2 steps grinding efficiency on energy consumption.

4. CONCLUSION

It was observed that cylindrical grinding media has very positive effects on the grinding time and energy consumption compared to the spherical media for one step grinding. It is also found that two steps grinding has very significant effects on energy consumption. However, the grinding duration of 1st step should be optimized as well as the grinding media size distribution for the the 2nd step.

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