Advances in Science and Technology Vol. 92 (2014) pp 121-126
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doi:10.4028/www.scientific.net/AST.92.121

Determination of dry grinding properties of floor tile wastes

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Keywords: Floor tile, reuse of floor tile waste, dry grinding,

Abstract. In ceramic production, there are around 5-8 % of floor tile defects occurred due to unsuitable body compositions or operational failure. The reuse of those fired products creates problems due to the difficult grindability features. These kinds of wastes are stored near factories and create vital environmental problems. There are some attempts to utilize these waste materials by adding to the recipes at small amounts. However, the grinding efficiency of the system is detrimentally affected and the grinding costs increases sharply.
The aim of this work is to determine the dry grinding properties of floor tile wastes in order to utilize more and economical manner in the process. This paper includes grinding experiments in the laboratory dry ball mill. It is driven by inverter motor and control panel that allow to adjust the mill rotational speed, measure the grinding time and required energy consumption. Systematic grinding tests were carried out to observe the effect of feed particle size, feed rate, material moisture and mill rotational speed on the grinding efficiency. Finally, it was sought to use the dry prepared powder in glazed porcelain body composition. It was found that there are no inconvenient results on the sintered body up to usage of 20%.

Introduction

The reuse of floor tiles wastes has many important effects on the reduction of environment pollution, energy consumption and the raw materials cost in ceramic industry. The ceramic floor tile production includes preparation of raw materials, pressing, and application of engobe, glaze and firing steps. After firing process, there may be seen some defect products caused by process steps or raw materials. In the local ceramic industry, which produces floor and roof tiles, 6-8% of the products are refused, due to the commercial reasons. Currently, most of these discarded materials cannot be recycled within the plant that accommodates as industrial waste and therefore pose a disposal problem.
In floor tiles; clayey materials, feldspar, quartz, green and fired wastes are used in the body compositions. Materials used in body compositions need to be ground before granulation step. The ceramic wastes cause some trouble due to the difficulty of grinding compared to other raw materials [1].
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 [2]. However it is a well-known fact that dry grinding provides some advantages such as providing considerable reduction in electricity consumption and heat energy consumption in following process [3]. Different preparation processes generally produce ceramic powders with different properties. Currently, the ceramic powders for floor tiles are mainly produced by wet grinding and spray drying [4]. Ceramic balls with regular density are usually porcelain balls and the high density balls are made with high alumina oxide content and they are more abrasion resistant.

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The basic properties of the milling balls are their mass and size, wear rate, its influence on the particle breakage rate and energy efficiency of the grinding process [5, 6, 7, and 8].

The purpose of this study was to determine the dry grinding characteristics of floor tiles wastes in an efficient manner. The effect of feed size, feed rate, moisture content and mill rotational speed on grinding efficiency were sought. Also the use of dry prepared floor tile waste in the body composition was sought.

Methodology

Material Characterization. The floor tile wastes were taken from Kaleseramik which is the largest ceramic factory in Turkey. These wastes were characterized XRF and XRD. The chemical and mineralogical analyses of floor tile wastes are shown in Table 1.

Table 1 Chemical and mineralogical analysis of floor tile wastes

Chemical	**L.O.I.**	**SiO_2**	**Al_2O_3**	**TiO_2**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**
(mass %)	0,37	68,55	20,60	0,76	1,33	1,51	0,44	2,82	3,36
Mineralogical	Quartz, Mullite, Albite								

Technological tests of the floor tile wastes were also carried out to investigate the sintering behaviors. After applying the size reduction, the weathering applied to reach the 6 % moisture in sample. Then, the sample was sieved through 3 mm sieve hence the granules were obtained in laboratory. The granules were pressed to having 5 cm diameter samples at 325 kg/cm^2. After that, the samples were dried and sintered in the conditions of floor tile production that is at 1170°C, 40 minutes. After thermal treatments, the water absorption of the samples (according to the ISO 10545-3), the linear shrinkage that is the difference in the length of the test specimen before and after firing (according to the ISO 10545-2) and the color values were measured. The result is given in Table 2.

Table 2 Sintering behaviors of floor tile wastes

Maximum sintering temperature (°C)	**Furnace cycle (min.)**	**Linear shrinkage (%)**	**Water absorption (%)**	**Colour measurements**		
				L	a	b
1170	40	14,74	0	48,45	7,09	14,39

The Laboratory Ball Mill Tests. The mill is cylindrical shape having the diameter of 37 cm and length of 57 cm. It is lined by flat shape alumina liners. Alumina balls having the diameter of 15, 20, 30, 40 and 50 mm; in total of 51 kg, were charged to the mill. The specific density of the balls is 3,657 gr/cm^3. The ball charge distribution was given in Table 3.

Table 3 Ball charge distribution

Ball size (mm)	**50**	**40**	**30**	**20**	**15**
%	7,8	12,2	25,0	25,0	30,0

Inverter and control panel were mounted to the mill for adjusting the mill rotational speed and grinding time and to measure energy consumption. The mill was covered by the metal box for noise dampening and confident discharging of ground materials as seen in Figure 1.



Figure 1 The laboratory ball mill

Ball mill operational parameters have a crucial impact on the grinding efficiency. The impact forces and abrasion forces are predominant for coarse and fine particles respectively in ball mills. The ball size distribution and rotational speeds of the mill affects the exertion of these forces. In the light of this research, the cracked pieces of floor tiles were crushed and ground to obtain the product having particle size of 45 µm. sieve residue of 4,5%. At the first stage, the mill was operated one hour to measure the energy consumption of the empty mill. The energy consumption of mill was measured with only ball charge without material (Table 4). Then the efficiency of ball mills to achieve the desired particle size distribution are measured at different feeding size, feed rate, moisture content and mill rotational speed.

Table 4 Empty mill and ball charged mill energy consumption in the 53 rpm mill speed

	Milling time (min.)	**Energy consumption (watt)**
Empty mill	60	158
51 kg. ball charged mill	60	198

Two feeding sizes of -3 and -1 mm materials were used to evaluate the effect of feed size on grinding efficiency. Particle size distribution of feed materials is given in Table 5.

Table 5 Particle size distributions of crushed floor tile wastes

Sieve range	**(µm)**	**+2000**	**-2000 +1000**	**-1000 +500**	**-500 +250**	**-250 +150**	**-150 +63**	**-63**	**Total**
Quantity for following sizes (%)	-3 mm.	14,56	27,15	26,95	11,86	5,57	4,82	9,09	100
	-1 mm.	-	0,65	19,32	28,25	14,91	15,12	21,75	100

Test Results. Table 6 shows the grinding test results that were done with different feed sizes, mill speeds and feed rates. Milling time and total energy consumption were measured by mill control panel. Specific energy consumptions were calculated for comparison purposes by using total energy consumption measured at grinding tests and the amount of materials passed under 45 µm size.

It was observed that the small feed size and feed rate reduced the grinding time so as to specific energy consumption.

The constant mill speed of 49 rpm provides advantages compared to the two steps of rotational speed of 49 and 41 rpm.

Table 6 Grinding tests

Feed size (mm.)	Milling time (min.)	Ground material residue +45 µm (%)	Total energy consumption (watt)	Specific energy consumption (watt/kg.)	Feed rate (Ball/raw material charge)	Mill speed (rpm)
-1	120	4,50	384	80,42	10,2	49
-1	120	2,10	382	45,91	6	49
-3	180	4,51	554	116,03	10,2	49
-3	120	2,04	388	46,60	6	49
-1	180	2,92	532	109,60	10,2	49-41
-1	180	1,09	552	65,66	6	49-41
-3	180	4,21	569	118,80	10,2	49-41
-3	120	2,67	563	68,05	6	49-41

The optimum grinding conditions were obtained on feed size of -1 mm, feed rate of 6:1, and rotational speed of 49 rpm. The specific energy consumption was 45,91 watt/kg at the reached optimum conditions while it was 118,80 watt/kg at the worst grinding condition among the tests performed.

The effect of moisture on the grinding efficiency was observed for 0,3% and 1,2%. The tests were done with feed size of -1 mm, feed rate of 6:1 and mill rotational speed of 49 rpm. The grinding efficiency was slightly reduced by the increase of material moisture.

Technological Properties. The dry prepared floor tiles wastes were added to glazed porcelain body slip compositions to create different recipes. The standard composition and the newly prepared glazed porcelain compositions are listed in Table 7.

Table 7 The glazed porcelain tile body compositions and technological properties

	Recipe information	Unit	Standard	Sample 1	Sample 2	Sample 3
Body composition	**Feldspar A**		22	19	14	13
	Feldspar B		21	20	23	21
	Kaolin A		17	16	13	11
	Clay A	%	10	10	10	10
	Clay B		25	25	25	25
	Tile waste		5	-	-	-
	Dry ground tile waste		-	10	15	20
	Total		100	100	100	100
Technological properties	**Powder humidity**	%	6			
	Specific pressure	kg/cm^2	325			
	Max. firing temperature	C°	1175			
	Firing cycle	min.	40			
	Shrinkage	%	7,83	7,80	7,75	7,71
	Water absorption	%	0,22	0,27	0,40	0,39
	Color	L	54,80	54,60	55,08	55,08
		a	5,31	5,22	4,89	5,04
		b	13,48	13,04	13,96	14,22

The ground floor tile powder was added by 10, 15 and 20 % into the slurry. Moreover, the slurry were dried to reach the 6% moisture in the samples. The granules were pressed to having 5 cm diameter samples at 325 kg/cm^2. After that, the samples were dried and then sintered in the conditions of production that is at maximum 1175°C, for 40 minutes. The technical properties of the samples such as water absorption and linear shrinkage were measured according to ISO

Standarts 10545-2. The color properties of the fired samples were determined using colormeter instrument. The results were shown in Table 7.

Results and Discussion

Figure 2 shows the effect of feed rates of 10,2:1 and 6:1 on the specific energy consumption together with feed sizes of -1 mm and -3 mm particle size distribution.
As seen in Figure 2, the decrease of feed size and feed rate results in reduction in the specific energy consumption at the constant rotational speed of 49 rpm.

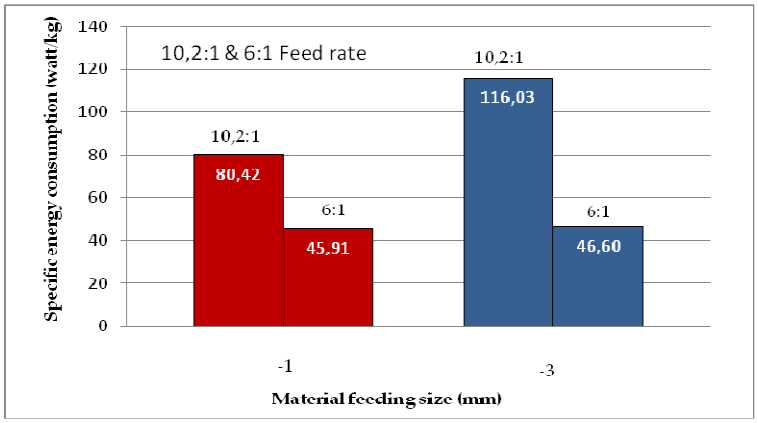


Figure 2 Feed rate effect on the specific energy consumption

Figure 3 shows the effect of rotational speed at different feed sizes of -1 mm and -3 mm and at constant feed rate of 6:1.

As seen in Figure 3, the rotation speed of 49 rpm results in less energy consumption than two steps rotation speed of 49 – 41 rpm at the constant feed rate of 6:1.

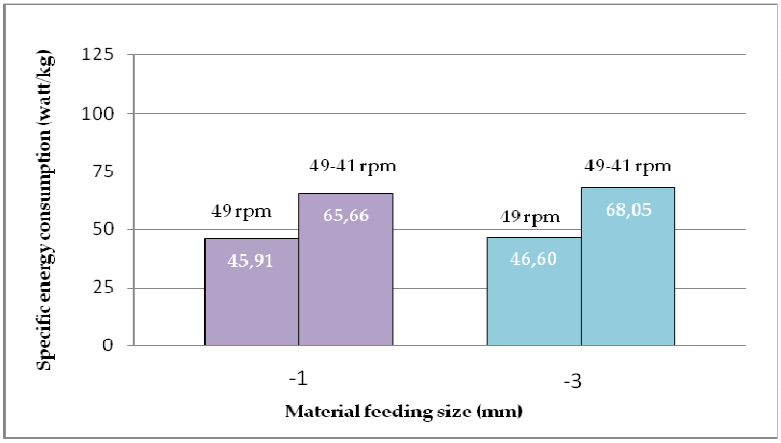


Figure 3 The effect of mill rotational speed on the specific energy consumption

It was found that floor tile waste can be used in glazed porcelain body composition up to 20% providing that rearranging the raw materials ratios.

Conclusions

It is aimed that to find the most efficient dry grinding conditions of floor tile waste. The effect of different feed sizes, feed rates, material moisture content and mill rotational speed were sought at laboratory grinding tests. The feed size of -1 mm, ball/material feed ratio of 6:1, mill rotational speed of 49 rpm and the maximum material moisture of 1% were found as the most efficient

grinding conditions for reference to this study in that the floor tile waste were ground to -45 μm with a maximum of 4,5% sieve residue. The results have also shown that the dry ground floor tile waste can be used in the floor tile recipes up to 20% providing that re-arranging the raw material ratios.

Acknowledgements

This research has been done in Kaleseramik Research and Development Center that is supported by Republic of Turkey, Ministry of Science, Industry and Technology.

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