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Araştırma / Research

DRY GRINDING OF WALL TILE WASTES AND THEIR POSSIBLE USE IN THE WALL TILE BODY

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ABSTRACT

In the wall tile production, fired waste tiles of 5-8% occur due to the inappropriate body compositions or operational failures. The use of these sintered hard wastes is limited since it creates problems in the raw material wet grinding stage. The aim of this study is to determine dry grinding properties of these wastes and their possible use in the wall tile body production.

Dry grinding experiments were carried out in a laboratory type ball mill and the effect of feed size, ball/material ratio, mill rotational speed and material moisture content on the grinding efficiency was studied. The use of the ground waste in body composition was also investigated. As a result of grinding experiments, the optimum grinding conditions determined as feed size of -2 mm, ball/material ratio of 4, mill rotational speed of 53-46 rpm and material moisture of 0.6%. Ground products (wastes) obtained at optimum grinding conditions were tested in different body compositions and these results revealed that these wastes could successfully be used in the body composition.

Keywords: Dry grinding, Wall tile waste

DUVAR KAROSU ATIKLARININ KURU ÖĞÜTÜLMESİ VE DUVAR KAROSU BÜNYESİNDE KULLANILABİLİRLİĞİ

ÖZET

Duvar karosu üretiminde, uygun olmayan bünye kompozisyonları veya operasyonel hatalar nedeniyle % 5-8 oranında atık pişmiş karolar ortaya çıkar. Bu sinterlenmiş sert atıkların kullanımı, hammadde yaş öğütme aşamasında problem oluşturduğu için sınırlıdır. Bu çalışmanın amacı, bu atıkların kuru öğütme özelliklerinin belirlenmesi ve bunların duvar karosu bünye üretiminde kullanılabilirliğinin belirlenmesidir.

Öğütme deneyleri laboratuvar ölçekli bir bilyalı değirmende kuru olarak gerçekleştirilmiş ve öğütme verimliliği üzerindeki besleme büyüklüğü, bilye/malzeme oranı, değirmen dönme hızı ve malzeme nem içeriğinin etkisi incelenmiştir. Bünye kompozisyonunda öğütülmüş atıklarının kullanımı da araştırılmıştır. Öğütme deneyleri sonucunda, optimum besleme boyutunun -2 mm olduğu, bilya/malzeme oranının 4 olduğu, değirmen dönme hızının 53-46 d/d olduğu ve malzeme neminin %0.6 olduğu belirlenmiştir. Bünye kompozisyonunda optimum şartlarda öğütülmüş atıkların kullanılmasına yönelik deneyler, bu atıkların bünyede başarıyla kullanılabileceğini göstermiştir.

Anahtar Kelimeler: Kuru öğütme, Duvar karosu atığı

1. INTRODUCTION

The reuse of wall tile wastes may result in the reduction of environmental pollution, raw material cost and energy consumption in the ceramic industry. The wall tile production process includes generally wet grinding of raw materials, granulation, pressing, drying, glazing and firing steps. After firing steps, defective products occur

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due to inappropriate process conditions or raw materials. In the local ceramic industry, which produces floor and wall tiles, 6-8% of the products are refused due to the commercial reasons [1]. Currently, they are accommodated as industrial waste creating a disposal problem since most of these discarded materials cannot be recycled within the plant.

In wall tile production, materials such as clay, limestone, quartz, green and fired wastes are used for generating body compositions. These materials need to be ground and mixed according to the recipe before granulation step in spray drier. Illitic and montmorillonitic clays are plastic materials and have very fine particle sizes. These clays are ground and dispersed in blungers with water while non-plastic materials, such as kaolinite, limestone, quartz and fired wastes are wet ground in ball mills. The use of fired wastes do not create problems in product quality, however, they causes some problems in wet grinding steps due to the hardness of these materials compared to the other raw materials [2].

The traditional ball mill has been the primary method used for wet grinding of ceramic materials for hundreds of years, and is still considered to be one of the best mixers ever invented [3]. Nowadays, the continuous and batch ball mills are used for grinding of ceramic raw materials in the wet system. However, it is a well known that dry grinding has a lot of advantages compared to the wet system in ceramic tile manufacturing providing considerable reduction in electricity and heat energy consumption in following process steps as well as an extremely low emission of greenhouse gas and the lesser amount of consumption of water [4].

The primary objective of this study was to investigate the effect of various parameters on the dry grindability of wall tile wastes. The parameters studied were feed size, ball/material ratio, mill rotational speed and material moisture content. The secondary aim of this study was to determine the possible use of dry ground product in the wall tile body composition.

2. MATERIAL AND METHOD

2.1. Material

The wall tile wastes used in this study were taken from Kale Seramik, Çanakkale, Turkey. The chemical and mineralogical analysis of the wastes were carried out by X- ray fluorescence device (Rigaku ZSX Primus) and by X- ray diffraction device (Rigaku Rint 2000), respectively. The chemical and mineralogical analyses of wall tile wastes are presented in Table 1. Table 1 shows that quartz, anorthite, diopside and mullite were detected as main crystalline phases.

Table 1. Chemical and mineralogical analysis of the wall tile wastes.

	LOI	**SiO_2**	**Al_2O_3**	**TiO_2**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**
Chemical	0.57	63.91	20.95	0.78	1.62	8.67	0.71	0.74	2.08
Mineralogical	Quartz 33%, Anorthite 36%, Diopside 3%, Mullite 3%, Glassy Phase 26%, Others 2%								

2.2. Ball mill tests

The grindability of the tile wastes was determined by using a laboratory type ball mill (Figure 1). The mill is cylindrical in shape and its size is 37x57 cm. The mill has flat shape alumina liners. Alumina balls with the diameter of 15, 20, 30, 40, 50 and 60 mm were used for preparing four different ball size distributions for four different feed sizes and distributions as illustrated in Table 2 and 3, respectively. Specific gravity of balls is 3.657 gr/cm^3. Inverter motor and control panel were mounted to the mill to adjust mill rotational speed and to measure grinding time and energy consumption. The mill was covered by the metal box to reduce noise and for safety reasons. Energy consumption and grinding time were determined according to a grinding residue of less than 6.5% over 63 μm sieve.

Table 2. Ball size distributions used for each feed size.

Ball size (mm)		**60**	**50**	**40**	**30**	**20**	**15**	**Total (%)**	**Total (kg)**
Ball size distribution for each feed size (%)	-8 mm.	32	37	16	10	5	-	100	51
	-3 mm.	-	26	36	24	14	-	100	51
	-2 mm.	-	14	26	19	41	-	100	51
	-1mm.	-	-	5	32	38	25	100	51

Table 3. Particle size distributions of crushed wall tile wastes.

Sieve range (µm)	**Amounts (%)**			
	-8 mm.	**-3 mm.**	**-2 mm.**	**-1 mm.**
-8000+5000	17.65	-	-	-
-5000+3150	41.90	-	-	-
-3150+2000	8.65	13.26	-	-
-2000+1000	10.28	36.70	45.92	-
-1000+500	3.42	16.33	17.96	33.59
-500+250	1.57	9.42	9.93	21.43
-250 +150	0.68	4.72	4.80	10.64
-150 +63	0.71	4.45	4.60	8.26
-63	15.14	15.12	16.79	26.08
Total	100	100	100	100

Figure 1. The laboratory ball mill.

2.3. Ceramic technological tests

Technological tests on the wall tile wastes were also carried out to investigate the sintering behaviours. After grinding the waste tile, the water is added to ground product for reaching 6% moisture. Then, the sample was sieved through 3 mm sieve to obtain granules. The granules were pressed at 325 kg/cm^2 pressure to obtain tablets of 5 cm in diameter. After that, the tablets were dried and sintered in the conditions as of wall tile production at 1150°C for 36 minutes. After thermal treatments, the water absorption (according to the ISO 10545-3), the linear shrinkage (according to the ISO 10545-2) and the color values of the tablets were measured by using a UV-Vis spectrophotometer (Minolta 3600d). The results are given in Table 4.

Table 4. Technological characteristics of wall tile wastes.

Max. sintering temp. (°C)	**Furnace cycle (min)**	**Linear shrinkage (%)**	**Water absorption (%)**	**Colour**		
				L	a	b
1150	36	4.47	15.98	73.24	6.76	17.72

In order to examine the use of dry ground wall tile waste in the recipe, the ground wall tile waste was added to the standard mix with various amounts (Table 5) and the slip was dried to reach 6% moisture. Similar technological test procedures mentioned above were followed for these samples.

Table 5. Tested wall tile compositions.

Recipe information	Unit	Standard	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Calcite		13.5	13.5	13.5	13.5	13.5	13.5
Siliceous kaolin		57	49	49	49	49	49
Clay	%	36	36	36	36	36	36
Total slurry mix		106.5	98.5	98.5	98.5	98.5	98.5
Dry ground tile waste		0	10	15	20	25	30
Total		106.5	108.5	113.5	118.5	123.5	128.5

3. RESULTS AND DISCUSSION

3.1. Ball mill tests

Various parameters such as feed size, ball/material ratio, mill rotational speed (rpm) and material moisture on the efficiency of ball mill were studied and the results obtained are given below. The residue left on a certain sieve size after milling is typically used as a parameter to evaluate the degree of fineness achieved [5]. In grinding tests, a grinding residue of less than 6.5% over 63 μm sieve were used to evaluate the degree of fineness and further on it is named as target size.

3.1.1. Effects of feed size on the grinding efficiency

The effect of feed size on the grinding efficiency were studied at two different ball/material ratios namely 4:1 and 3:1and the results are presented in Table 6 and 7, respectively.

Table 6. Effect of feed size on milling time and energy consumption (53 rpm and 0.6% moisture).

Feed size (mm)	Milling time (min)	Material residue +63 μm (%)	Total energy consumption (watt)	Specific energy consumption (watt/kg)
-8	600	6.01	1919	145.84
-3	360	6.52	1166	89.09
-2	270	4.80	782	58.67
-1	360	5.20	1112	83.79

Table 6 shows that grinding time of 600 minutes or 145.84 watt/kg specific energy consumption was necessary to attain target size at -8 mm feed size. Table 6 also shows that grinding time of 270 minutes or 58.67 watt/kg specific energy consumption was necessary to attain approximately the same target size at -2 mm feed size. These results show that as the feed size increases milling time or energy consumption increases. However, at -1 mm feed size, grinding time of 360 minutes or 83.79 watt/kg specific energy consumption was necessary to attain approximately the same target size.

Table 7. Effect of feed size on milling time and energy consumption (53 rpm and 0.6% moisture).

Feed size (mm)	Milling time (min)	Material residue +63 µm (%)	Total energy consumption (watt)	Specific energy consumption (watt/kg)
-8	960	6.34	2957	168.83
-3	720	6.58	2183	124.96
-2	360	3.72	1176	65.32
-1	300	4.70	1400	78.56

Table 7 shows that grinding time of 960 minutes or 168.83 watt/kg specific energy consumption was necessary to attain target size for -8 mm feed size. Table 7 also shows that grinding time of 360 minutes or 65.32 watt/kg specific energy consumption was necessary to attain approximately the same target size for -2 mm feed size. These results also show that as the feed size increases milling time or energy consumption increases. However, at -1 mm feed size, grinding time of 300 minutes or 78.56 watt/kg specific energy consumption was necessary to attain approximately the same target size.

Comparison of Table 6 and Table 7 results shows that higher ball/material ratio has positive effect on the grinding efficiency for all feed sizes except at -1 mm.

3.1.2. Effects of mill rotational speed on the grinding efficiency

In the first mode of these group experiments, sample was milled for 270 minutes at 53 rpm mill rotational speed. In the second mode of these group experiments, sample was milled first at 53 rpm for 150 minutes then 46 rpm for 120 minutes. Effects of mill rotational speed on the grinding efficiency are given in Table 8. As can be seen from Table 8, changing mill rotational speed from first mode to second mode decreased energy consumption from 83.79 watt/kg to 78.56 watt/kg.

Table 8. Effect of mill rotational speed on energy consumption (-2 mm feed size, 4:1 ball/material ratio and 0.6 % moisture)

Mill speed (rpm)	Milling time (min)	Material residue +63 µm (%)	Total energy consumption (watt)	Specific energy consumption (watt/kg)
53	270	5.02	782	83.79
53-46	270	4.80	762	78.56

3.1.3. Effects of material moisture content on the grinding efficiency

Materials which have 1.6% and 0.6% moisture contents were used to observe material moisture impact on the grinding efficiency. Effects of material moisture on grinding residue are given in Figure 2 and Table 9. As can be seen from Figure 2, grinding residues are higher for 1.6% moisture content at all milling times. This situation shows that an increase in material moisture has negative effect on the grinding efficiency.

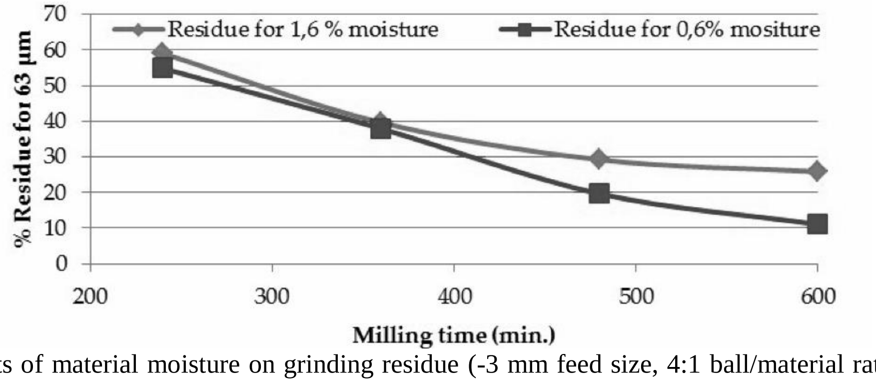

Figure 2. Effects of material moisture on grinding residue (-3 mm feed size, 4:1 ball/material ratio and 53 rpm mill rotational speed).

Table 9 shows effect of material moisture on grinding residue. At 600 minutes milling time grinding residue is 25.85% at 1.6% material moisture content, grinding residue is 11.06% at 0.6% material moisture while specific energy consumption is approximately the same.

Table 9. Effects of material moisture on grinding residue (-3 mm feed size, 4:1 ball/material ratio and 53 rpm mill rotational speed).

Milling time (min)	Material residue +63 µm (%)		Total energy consumption (watt)		Specific energy consumption (watt) /kg	
	1.6% H_2O	0.6% H_2O	1.6% H_2O	0.6% H_2O	1.6% H_2O	0.6% H_2O
600	25.85	11.06	1820	1818	89.09	88.96

3.2. Technological tests

Technological tests with the different amounts of ground wall tile wastes addition to the standard mix were also carried out to investigate the sintering behaviours. The results for 10, 15, 20, 25 and 30% dry ground material additions are summarized in Table 10. As can be seen from Table 10, shrinkage value of standard body is 0.32% while shrinkage values of ground material added bodies were changed from 0.32% to 0.50%. Water absorption value of standard body is 17.45% while water absorption values of ground material added bodies were changed from 16.58% to 17.20%. L values of specimens were also decreased while dry ground tile addition amount increased. However, these changes do not create any problems since the values are within the accepted limits.

Table 10. The effect of dry ground wall tile addition on the technological properties of the wall tile.

Recipe information	Unit	Standard	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Powder humidity	%			6			
Specific pressure	kg/cm^2			325			
Max. firing temperature	C˚			1150			
Firing cycle	min			36			
Shrinkage	%	0.32	0.32	0.36	0.40	0.46	0.50
Water absorption	%	17.45	16.58	16.89	16.94	16.87	17.20
	L	75.37	74.99	74.57	74.80	75.20	75.20
Colour	a	6.70	6.81	6.93	6.81	6.57	6.64
	b	17.64	17.81	18.34	18.21	17.50	17.90

4. CONCLUSIONS

The aim of this study was to determine dry grinding properties of wall tile wastes and use of the ground wastes in the wall tile body production. As a result of serious of experiments, it was found that high ball/material ratio and two stage grinding had positive effect on grinding efficiency while higher feed size and material moisture having negative effect on the grinding efficiency. The results also show that the use of dry ground wall tile waste in the wall tile body has no negative effect on the sintering behaviour of produced wall tile. Therefore, they could be successfully utilized in wall tile recipe after dry grinding.

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