The Recycling and Optimum Use of Wall Tile Wastes in the Production of Ceramic Body

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ABSTRACT: In ceramic production, the cracked or broken tile, which are not accepted as commercial products, are around 5-8 % of total products. There are some attempts to utilize these waste materials by adding to the recipes. Currently, these wastes can only be used partly as raw materials in ceramic factories. Therefore, the huge amount of fired tiles accumulated near factories and subject to environmental problem. The aim of this work is to search the higher rate of the use in economic and technically feasible way.

This paper illustrates the optimum use of wall tile waste in the production of ceramic body. The characterizations of sintered wall tile wastes were carried out by using XRF and XRD. Then the optimum grinding condition was sought by using fully instrumented laboratory ball mill. The wall tile waste is ground to the finesses of 2,0 % residue of 63 micron sieve. The ground powder was added by 10,15,20,25 and 30 % to the recipes of ceramic body composition. XRD and dilatometer, color values, water absorption and shrinkage of sintered bodies were determined.

It has been concluded that the optimum use of wall tile waste can be as high as 15 % without any problem provided that readjusting the body composition especially the clay component. The use of larger amount of sintered tile waste avoids the environmental problems and considerably reduced to the production costs of raw materials. Additionally, the use of tile wastes in ceramic production provides a more stable structure as the phase transitions of tile waste was already completed.

1. INTRODUCTION

Economic and demographic growth demands increasingly high indices of industrial activity, which implies two major environmental problems. Firstly, it ultimately feeds on natural non-renewable resources that are becoming scarce and will be sooner or later depleted. Secondly, it produces increasing amounts of waste materials, which are more and more difficult to dispose [1, 2]. Millions of tons of inorganic wastes are produced every day in the world [1]. Generally, a large part of these wastes are not recycled and the storage causes the problems in terms of the economic aspect and the environmental pollution. Inevitably, the use of product waste gives an advantage that may provide the manufacturer a highly competitive position in the market due to economic issues involved and the opportunity of marketing products particularly emphasizing on the ecological aspect.

In this way, some investigation was made to the use of the industrial waste in ceramic tile formulations [3]. The use of granite sawing wastes in the production of ceramic bricks and tiles were also investigated [4]. The possibility of the use of mining wastes in the production of the glasses and glass–ceramics was studied by some researchers [5].

The use of granite waste, granite sawing waste and fly ashes in the production of different types of ceramic were also investigated [6-8].

The ceramic industry generates a large amount of sintered tile waste which cause environmental problem. The ceramic

body is prepared by using raw materials in different ratios of feldspar, kaolin and clay. The granules are produced by milling, mixing, and spray drying process. Then, it is subjected to the processes of forming, drying, bring aesthetic and finally sintering. The body which is exposed to sintering process undergoes serious changes. The sintered ceramic body has the general features as follow;

- It is an inert material which completed its phase formation (mullite, anorthite, etc.),
- Density of material increased due to grain growth,
- Material formed a more stable structure,
- Material completely lost plasticity and flow characteristics.

For these reasons, the use of sintered tile waste in body recipes will make positive changes in technical values of ceramic products. As the material has completed forming of phases, it will become more stable structure.

Kaleseramik Inc. is one of the biggest ceramic tile producers in the world. The sintered tile waste continually forms because of the providing 100 % quality about the manufacture of ceramic tile. Around 21000 tons of sintered wall tile waste per year is generated in the Kaleseramik Factories. The aim of this research is to assess to the use of sintered wall tile waste and the determination of optimum usage rate in the production of ceramic body.

2. MATERIALS AND METHOD

2.1. Material Characterization

Firstly, the currently used process for wall tiles starts with crushing-screening unit. At that part, the aim is to prepare raw materials, such as siliceous kaolin, calcite and wall tile wastes for wet grinding feed down to 1 cm particle size. In addition, clay materials are prepared at a homogenizing process plant. Secondly, the crushed raw materials and wall tile wastes are transported to silos for wet grinding in ball mills. On the other hand, clay materials are dissolved to remove from such impurities in a blunger system. These two slurries are homogenized in a mixing pool at ordered ratio and the bulk density of the final slip is 1642 g/L for wall tile. The mixing ceramic slurry is separated from iron impurities in a wet magnetic separator and sieved on a vibrating screen. The final ceramic slip is pumped to spray dryer, where ceramic granule is produced. The flow chart of the currently used process is shown in Figure 1.

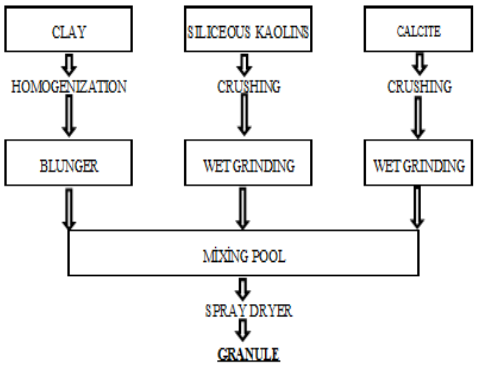


Figure 1. Currently used wall tile granule preparation system.

In this research, the uses of conventional ceramic raw materials together with different amount of wall tile wastes were investigated. The wall tile waste was dry ground to the finesses of 2 % residue of 63 micron sieve and the ground powder was added by 10, 15, 20, 25 and 30 % to the recipes of ceramic body composition.

The chemical composition of sintered wall tile waste was obtained by XRF that was given in Table 1. It can be observed that the wastes have high amount of SiO_2 and low value of loss on ignition that

shows the reaction of gas evolution finished.

Table 1. Chemical composition of the sintered wall tile waste.

LOI[a]	**SiO_2**	**Al_2O_3**	**TiO_2**	**Fe_2O_3**
0.57	63.91	20.95	0.78	1.62
CaO	**MgO**	**Na_2O**	**K_2O**	
8.67	0.71	0.74	2.08	

a: Loss of Ignition

These wastes were also analyzed by X-Ray diffraction to characterize the mineralogical structures. Figure 2 shows the X-Ray Diffraction patterns of the sintered wall tile waste. The diffraction patterns of the sintered wall tile waste gives the peaks of quartz, anorthite, gehlenite and wollastonite as seen in Figure 2.

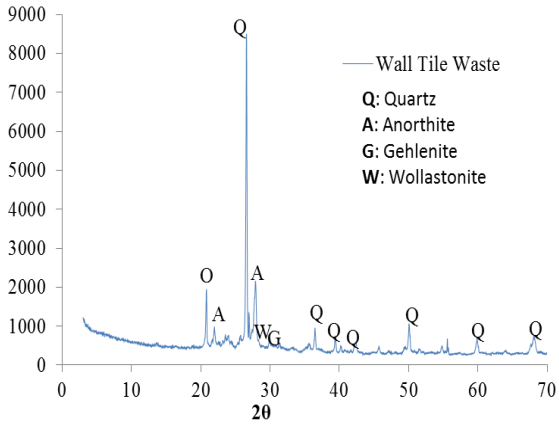


Figure 2. X-ray diffraction patterns of the sintered wall tile waste.

2.2. Methods and Technological Tests

Technological tests of wall tile wastes were also carried out to investigate the sintering behaviors. After applying the size reduction, weathering applied to reach the 6 % moisture in sample. Then, the sample was sieved through 1 mm sieve hence the granules were obtained in laboratory. The granules were pressed to having 5 cm diameter tablets at 325 kg/cm^2. After that, the tablets were dried and sintered in the conditions of wall tile production that is at 1150°C, 36 minutes. After thermal treatments, the water absorption of the samples (according to the ISO 10545-3), linear shrinkage that is the difference in the length of the test specimen before and after firing (according to the ISO 10545-2) and color values were measured. Sintering behavior of the wastes was determined by sintering in the conditions of wall tile sintering conditions. The result is given in Table 2.

Table 2. Technological properties of wall tile wastes.

Max. Sintering Temp. (°C)	1150	
Furnace Cycle (min.)	36	
Linear Shrinkage (%)	4.47	
Water Absorption (%)	15.98	
Color	L	73.24
	a	6.76
	b	17.72

The similar tests were applied to the original slurry of wall tile mixture that was prepared without addition of sintered wall tile waste. Then, the body compositions were obtained by adding 10, 15, 20, 25 and 30 % of dry ground sintered wall tile waste. The slips were dried 12 hours in an oven at 110 ◦C to obtain powders suitable for shaping and breaking tests. The test specimens were prepared by adding 6 % water to the dried powders in form of disk. It is followed by pressing at 325 kg/cm^2. Then, the tablets dried and sintered in the conditions of wall tile at 1150, 36 minutes for investigating technological properties. The firing behavior of the materials has been studied by evaluating the water absorption, linear shrinkage and color values.

The densities of slurries were determined by using a picnometer. Dilatometer was used to measure thermal expansion of sintered tablets by the heating rate of 10 °C/min till 750 °C.

3. RESULTS AND DISCUSSION

3.1. Process Parameters

The different recipes prepared using different ratios of ground floor tile waste and other components as are shown in Table 3.

Table 3. The recipes of wall tile by the additions of dry ground wall tile waste (%).

Items	Calcite	Siliceous Kaolin	Clay	Dry ground tile waste
STD	13,5	57	36	0
W10%	13,5	49	36	10
W15%	13,5	49	36	15
W20%	13,5	49	36	20
W25%	13,5	49	36	25
W30%	13,5	49	36	30

The density and flow time of wall tile recipes which were prepared by adding different ratio of sintered wall tile waste and original body were given in Figure 3. It is observed that the recipe prepared by addition of 15 % sintered floor tile waste has the suitable flow time value with the original one in Figure 3. Density of W % 15 is 1745 g/lt and its flow time value is 35 second while the density and flow time values of original recipe are 1642 g/lt and 20 second respectively. The 35 second of flow time value is a suitable value for the process.

3.2. Product Parameters

Changes of water absorption and linear shrinkage of the recipes prepared by the addition of waste and original recipe for wall tile were given Figure 4. 17.45% water absorption and 0.32% linear shrinkage were found on the original wall tile body while 15% sintered wall tile waste body has 0.36% linear shrinkage and 16.89% water absorption values, respectively. The measured linear shrinkage and water absorption values are similar with values of the original body. The 0.36 % linear shrinkage value is suitable for the process.

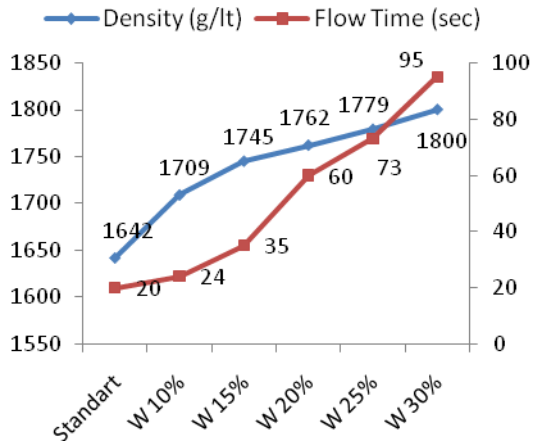


Figure 3. Density and flow time changes of wall tile mixing slurry.

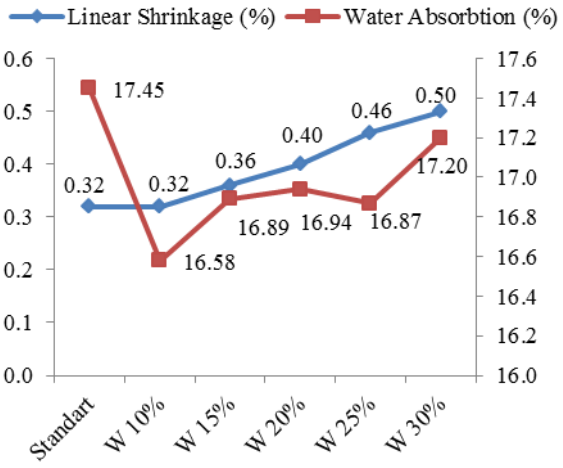


Figure 4. Linear shrinkage and water absorption changes of the original Wall tile body and recipes including waste.

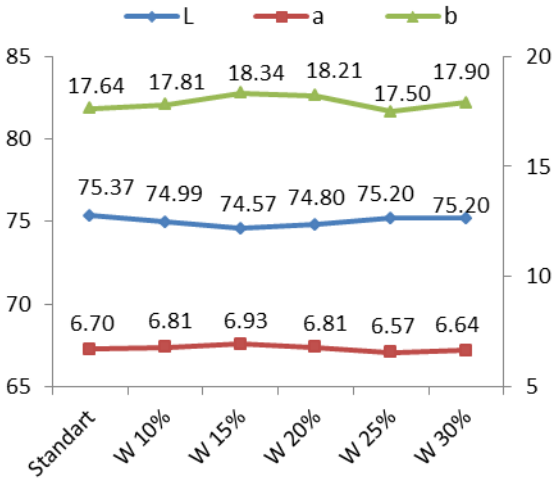


Figure 5. Changes of sintered color values of the original wall tile body and bodies including waste.

Figure 5 shows the color values of wall tile bodies which were prepared by adding different ratio of sintered wall tile waste and the original body. Color values of W 15 % are L: 74.57, a: 6.93, b: 18.34 when the color values of original wall tile body are L: 75.37, a: 6.70, b: 17.64. Both recipes have the similar color values.

Figure 6 shows the X-ray diffraction patterns of the original sintered wall tile body and the sintered wall tile body contained 10%, 15%, 20%, 25% and 30% sintered tile wastes respectively. The diffraction patterns of the original sintered wall tile body gives the peaks of quartz (SiO_2), anorthite ($CaAl_2Si_2O_8$), gehlenite (Ca_2Al [$AlSiO_7$]), wollastonite ($CaSiO_3$). Also, the diffraction patterns of sintered wall tile body containing 10%, 15%, 20% wastes give the same peaks of quartz (SiO_2), anorthite ($CaAl_2Si_2O_8$), gehlenite ($Ca_2Al[AlSiO_7]$), wollastonite ($CaSiO_3$). The diffraction patterns of sintered wall tile bodies containing 25% and 30% waste gave peaks of quartz (SiO_2), anorthite ($CaAl_2Si_2O_8$), wollastonite ($CaSiO_3$), tridymite (SiO_2), gehlenite ($Ca_2Al[AlSiO_7]$).

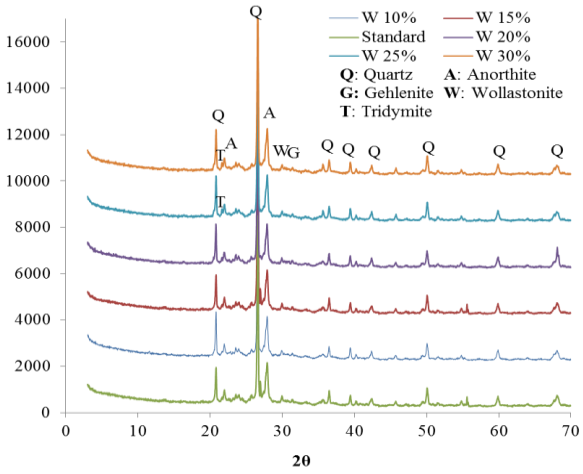


Figure 6. X-ray diffraction patterns of original wall tile body and sintered wall tile bodies including waste.

After standard wall tile body and wall tile waste added wall tile body were sintered, the DLM analyses were also made. The results of the analysis are shown in Table 4. Thermal expansion value (α_{400}) of original body is 67.26 $x10^{-7}K^{-1}$, the body of 15% wall tile waste added is 66.49 $x10^{-7}.K^{-1}$. It can be concluded that there is some decrement at the thermal expansion with increasing amount of sintered wall tile waste.

Table 4. Thermal expansion of the original wall tile recipe and recipes including waste.

DLM ($x10^{-7}.K^{-1}$)	α_{300}	α_{400}	α_{500}	α_{600}
Standard	64.8	67.3	70.8	81.8
W 10%	64.1	66.6	70.1	80.8
W 15%	63.9	66.5	70.0	80.9
W 20%	63.5	66.2	69.8	80.7
W 25%	63.6	66.3	69.8	80.7
W 30%	63.6	66.0	69.3	79.4

The slurry densities of the compositions by the addition of the dry ground wall tile wastes provide higher slurry density than standard compositions. Therefore, the energy consumption of the spray dryer is also reduced due to the use of high slurry density. The costs of natural gas and costs of raw material in current

production and at the case of 15% use of tile wastes were given in Table 5.
The optimum recipe is obtained by the use of 15% of waste according to the technological and economic criteria that is the recipe of W 15%. This recipe reduces the raw materials costs of wall tile recipe from 47.57 TL/ton to 44.83 TL/ton. Also the natural gas consumption costs of wall tile decreases from 40.23 TL/ton to 30.88 TL/ton.

Table 5. Costs of natural gas and raw material in current production and at the case of 15% added tile waste.

Cost of raw materials in current production (TL/ton)	47.57 (8% wall tile waste)
Cost of raw materials in the case of increased use of tile waste (TL/ton)	44.83 (15% wall tile waste)
The cost of natural gas in current production (TL/Ton)	40.23 (1642 g/lt)
The cost of natural gas in the case of 15% use of tile waste (TL/ton)	30.88 (1745 g/lt)

4. CONCLUSIONS

In the experimental study; the slurry of original mixture of wall tile was prepared without sintered wall tile waste. Then, the body compositions were obtained by addition of dry ground sintered wall tile waste. Technological and mineralogical properties of original body and the bodies that include different amount of sintered wall tile wastes were obtained in laboratory. XRD and dilatometer analyses, color values, water absorption and shrinkage of sintered bodies were measured to compare the differences of original body and the waste added bodies. It is found that the optimum usage rate is 15% of waste for wall tile composition that is given in the recipe of W 15%. The use of waste provides substantial reduction on energy consumption and the cost of raw material supply. It also prevents the potential environmental problem caused due to the storage of the waste.

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