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

Kağan Kayacı[1], Ali Altıntaş[1], Yıldız Yıldırım[1], Çiğdem Yiğit Pala[1], Mert Kılıç[1], Emrah Durgut[1], Hasan Ergin[2], Selahattin Çimen[2]

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 floor tile waste in the production of ceramic body. The characterizations of sintered floor 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 floor tile waste is ground to the finesses of 5 % residue of 45 micron sieve. The ground powder was added by 10, 15 and 20 % 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 floor tile waste can be high as 20 % 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 already completed.

Keywords: environment, floor tile waste, raw material cost

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].

[1]*Corresponding author:* [2]*Hasan Ergin, İstanbul Teknik Üniversitesi Maden Mühendisliği Bölümü, 34469, Maslak/İstanbul ,Türkiye* hergin@itu.edu.tr

[1]*Kağan Kayacı, Kaleseramik AR-GE Merkezi Çan/Çanakkale,Türkiye* kagankayaci@kale.com.tr

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 16000 tons of sintered floor tile waste per year is generated in the Kaleseramik Factories. The aim of this research is to assess to the use of sintered floor tile waste and the determination of optimum usage rate in the production of ceramic body.

2. MATERIALS AND METHOD

2.1. Material Characterization

In the production of floor tile, the raw materials of kaolin, feldspar, and clay and tile waste are used. These materials are ground under the size of 45 μm sieve residue 5 %. However, the clay is reduced very fine particle in blungers. Then the mixed slurry is dried to moisture content reducing till 6 %. It is stored in silos for allowing the uniform distribution of moisture. The generalized flow chart is shown in Figure 1.

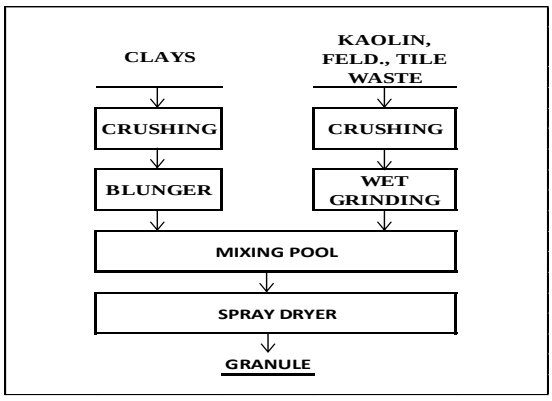


Figure 1. Flow chart of floor tile granule preparation plant

In this research, the uses of conventional ceramic raw materials together with high amount of floor tile wastes were investigated. The floor tile waste tile is ground to the finesses of 5 % residue of -45 micron sieve and the ground powder was added by 10, 15 and 20 % to the recipes of ceramic body composition.

The chemical composition of sintered floor 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 of ignition that shows the reaction of gas evolution finished.

Table 1. Chemical composition of the sintered floor tile waste

Chemical Analysis	L_OI	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O
(%)	0.37	68.55	20.6	0.76	1.33	1.51	0.44	2.82	3.36

These wastes were analyzed by X-Ray Diffraction to characterize the mineralogical structures. Figure 2 shows the X-Ray Diffraction patterns of the sintered floor tile waste. The diffraction patterns of the sintered floor tile waste gives the peaks of quartz (SiO_2), mullite ($3Al_2O_32SiO_2$), christobalite (SiO_2) and albite ($NaAlSi_3O_8$) as seen in Figure 2.

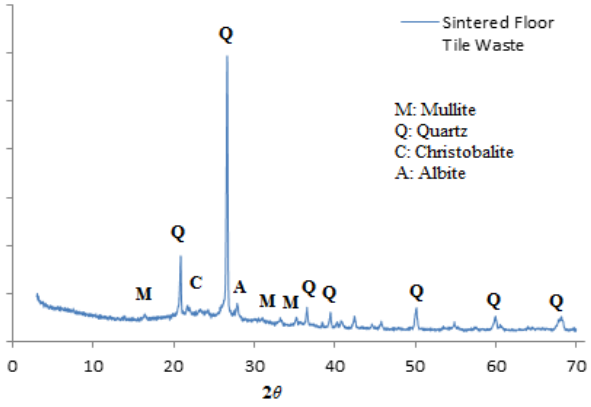


Figure 2. X-ray diffraction patterns of the sintered floor tile waste.

2.2. Methods and Technological Tests

Technological tests of floor 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 3 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 glazed porcelain floor tile that is at 1175°C, 44 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 the glazed porcelain floor tile sintering conditions. The result is given in Table 2.

Table 2. Technological properties of tile wastes

		Condition of Glazed Porcelain Floor Tile
Max. Sintering Temp.(°C)		1175
Furnace Cycle (min.)		44
Linear Shrinkage (%)		14.78
Water Absorption (%)		0
Color	L	48.47
	a	6.72
	b	14.03

The similar tests were applied to the original slurry of floor tile mixture that was prepared without addition of sintered floor tile waste. Then, the body compositions were obtained by adding 10, 15 and 20 % of dry ground sintered floor 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 glazed porcelain floor tile at 1170-1175°C, 40 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 a heating rate of 10 °C/min till 750 °C.

3. RESULTS AND DISCUSSIONS

3.1 Process Parameters

The body compositions were obtained by adding 10, 15 and 20 % dry ground sintered floor tile waste. The five 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 glazed porcelain floor tile by the additions of dry ground floor tile waste (%)

Raw Materials	**$S_{orginal}$**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**
Clay 1	10	10	10	10	10	10
Feldspar 1	22	19	16	15	14	13
Kaolin 1	17	16	15	13	13	11
Feldspar 2	21	20	19	18	23	21
Clay 2	25	25	25	24	25	25
Floor Tile Waste	5					
Dry Ground Floor Tile Waste		10	15	20	15	20

The density and flow time of glazed porcelain recipes which were prepared by adding different ratio of sintered floor tile waste and original body were given in Figure 3. It is observed that the recipe prepared by addition of 20 % sintered floor tile waste (S5) has the closest flow time value to the original one in Figure 3. Density of S5 is 1699 g/lt and its flow time value is 35 second while the density and flow time values of original recipe are 1671 g/lt and 37 second respectively. The 35 second of flow time value is a suitable value for the process.

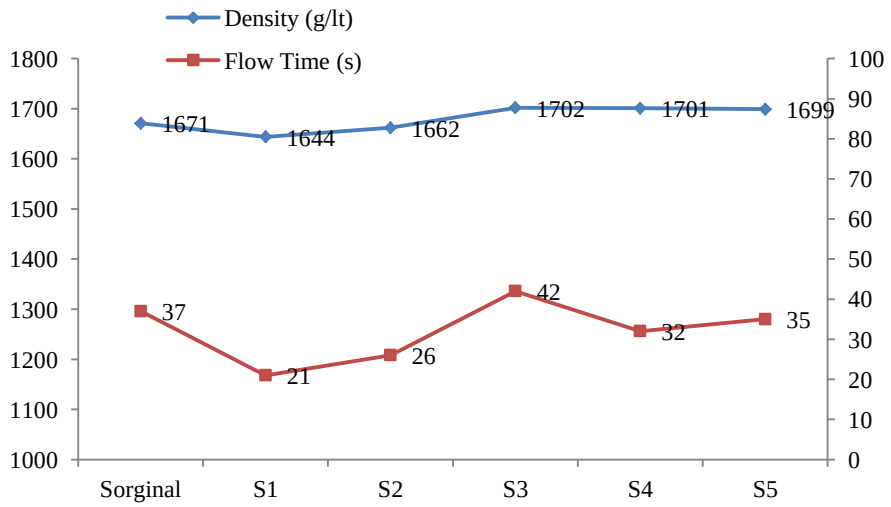


Figure 3. Density and flow time changes of glazed porcelain floor tile mixing slurry.

3.2 Product Parameters

Changes of water absorption and linear shrinkage of added sintered floor tile waste recipes and original recipes for glazed porcelain were given Figure 4. In Figure 4, 0.22 % water absorption and 7.83 % linear shrinkage were found on the original floor tile body sintered at 1175°C, while 20 % sintered floor tile waste body (S5) has 7.71% and linear shrinkage and 0.39 % water absorption values, respectively. The measured linear shrinkage and water absorption values are similar with values of the original body.

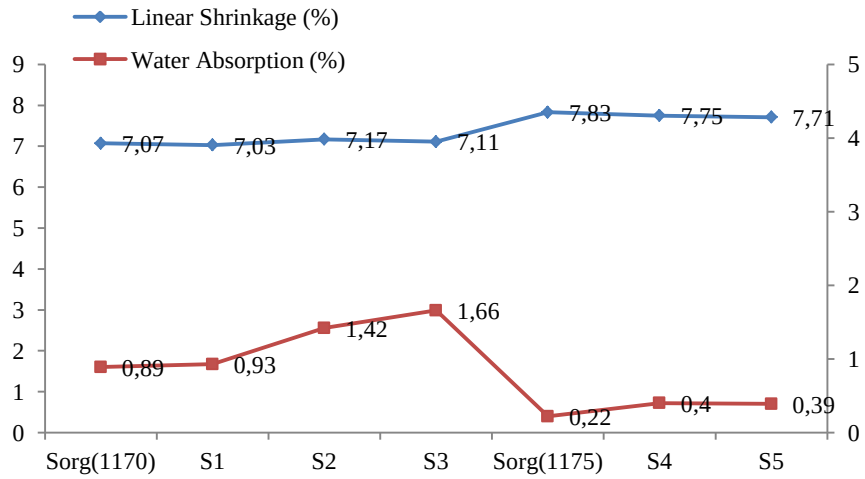


Figure 4. Linear shrinkage and water absorption changes of the original glazed porcelain bodies (sintered at 1170℃ and at 1175℃) and recipes including waste

Figure 5 shows the color values of glazed porcelain bodies which were prepared by adding different ratio of sintered floor tile waste and the original body. Color values of S5 are L: 55.08, a: 5.04, b: 14.22 when the color values of original glazed porcelain body, at 1175 °C, are L: 54.80, a: 5.31, b: 13.48. Both have the similar color values.

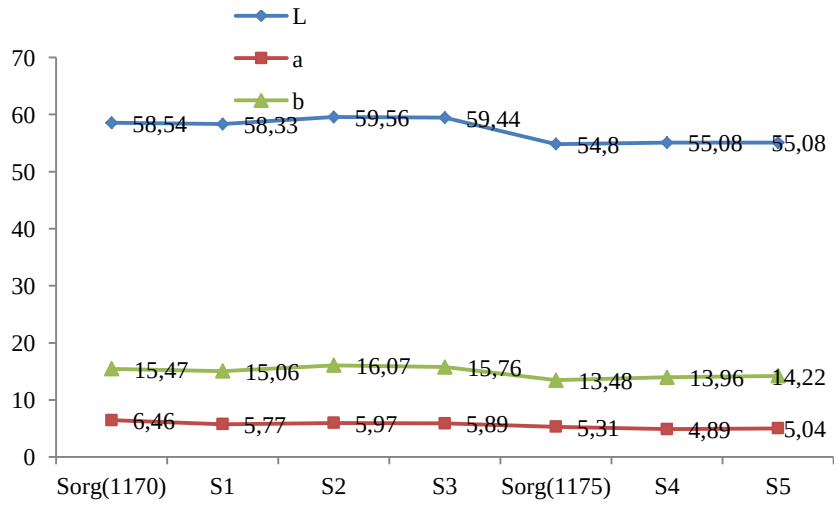


Figure 5. Changes of sintered color values of the original glazed porcelain bodies (sintered at 1170℃ and at 1175℃) and recipes including waste

Figure 6 shows the X-ray diffraction patterns of the original sintered glazed porcelain body (at *1175℃)* and the sintered glazed porcelain body contained 15% and 20% sintered tile wastes (S4 and S5) respectively. The diffraction patterns of the original sintered glazed porcelain body gives the peaks of quartz (SiO_2), mullite ($3Al_2O_32SiO_2$) and albite ($NaAlSi_3O_8$). Also, the diffraction patterns of sintered glazed porcelain body containing wastes give the same peaks of quartz (SiO_2), mullite ($3Al_2O_32SiO_2$) and albite ($NaAlSi_3O_8$). This indicates that the body included floor tile waste is similar to the original body in terms of the mineralogical structure to the original body.

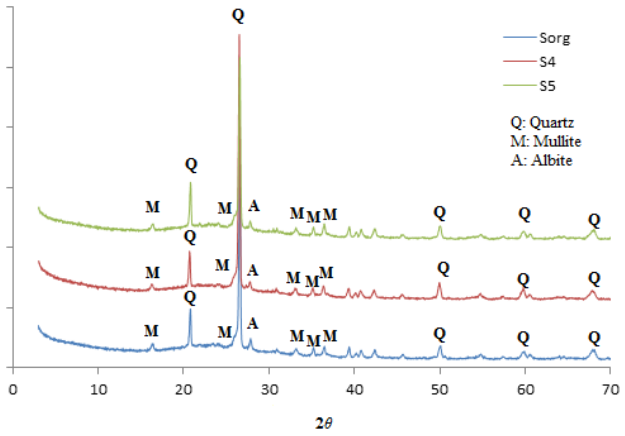


Figure 6. X-ray diffraction patterns of original sintered glazed porcelain body at 1175 C˚ and sintered glazed porcelain body contained 15 % and % 20 wastes (S4 and S5).

After standard glazed porcelain body and floor tile waste added glazed porcelain 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 (sintered at 1170°C) is 71.63 x10-7.K^{-1}, the body of 20 % floor tile waste added (S3) is 70.57 x10-7.K^{-1}. Thermal expansion value (α_{400}) of original body (sintered at 1175°C) is 72.58 x10-7.K^{-1}, body of 20 % floor tile waste added (S5) is 71.92 x10-7.K^{-1}. It can be concluded that there are no significant differences between the thermal expansion of the original body and the 20% floor tile waste added body.

Table 4. Thermal expansion values and mineralogical compositions of the recipes of glazed porcelain floor tile by adding dry ground floor tile waste.

		$S_{orginal}$ (sintered 1170°C)	S_1	S_2	S_3	$S_{orginal}$ (sintered 1175°C)	S_4	S_5
Sintered DLM	α300 x 10 $^{-7}$ K^{-1}	68.39	68.46	66.93	67.24	69.29	70.84	68.82
	α400 x 10 $^{-7}$ K^{-1}	71.63	71.74	70.37	70.57	72.58	73.28	71.92
	α500 x 10 $^{-7}$ K^{-1}	74.88	75.12	73.86	73.97	75.94	76.50	75.28
	α600 x 10 $^{-7}$ K^{-1}	82.26	82.87	81.65	81.60	83.09	83.91	82.37

The slurry densities of the compositions with the addition of the dry ground floor 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 mining costs of raw material in current production and at the case of 20% use of tile wastes were given in Table 5.

The optimum recipe is obtained by the use of 20% of waste according to the technological and economic criteria that is the formula of S5. This recipe reduces the raw materials costs of glazed porcelain floor tile from 64.45 TL/ton to 56.53 TL/ton. Also the natural gas consumption costs of glazed porcelain floor tile decreases from 36.06 TL/ton to 33.12 TL/ton.

Table 5. Costs of natural gas and mining costs of raw material in current production and at the case of 20 % added tile waste

	Glazed Porcelain Floor Tile
Cost of raw materials in current production (TL/Ton)	64.45
Cost of raw materials in the case of using 20 % of tile waste (TL/Ton)	56.53
The cost of natural gas in current production (TL/Ton)	36.06 (1671 g/lt)
The cost of natural gas in the case of using 20% tile waste (TL/Ton)	33.121699 g/lt)

4. CONCLUSIONS

In the experimental study; the slurry of original mixture of glazed porcelain floor tile was prepared without sintered floor tile waste. Then, the body compositions were obtained by addition of dry ground sintered floor tile waste. Technological and mineralogical properties of original body and the bodies that include different amount of sintered floor 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 20% of waste for glazed porcelain composition that is given in formula of S5. 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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