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RESEARCH ARTICLE

INVESTIGATION of the THICKNESS THINNING for THE PORCELAIN TILES and THEIR APPLICABILITY

Ahmet VURAL[1], Nihal DERİN COŞKUN[2], C. Eren IŞIK[3], Fuat ÇELİK[4] , İskender IŞIK[5]

[1] Kaleseramik R&D Center, Çanakkale, ahmetvural@kale.com.tr, ORCID:0000-0003-1282-371x
[2] Ordu University, Faculty of Fine Arts, Department of Ceramic and Glass, Ordu, nihal.dcoskun@dpu.edu.tr, ORCID: 0000-0002-3024-9443
[3] Kütahya Dumlupınar University Faculty of Fine Arts, Department of Handicraft Design and Production, Kütahya, eren.isik@dpu.edu.tr, ORCID:0000-0002-1129-2497
[4] Kütahya Dumlupınar University, Faculty of Engineering, Department of Metallurgical and Material Engineering, Kütahya, fuat.celik@dpu.edu.tr, ORCID:0000-0002-8892-080x
[5]Kütahya Dumlupınar University, Faculty of Engineering, Department of Metallurgical and Material Engineering, Kütahya, iskender.isik@dpu.edu.tr, ORCID:0000-0002-9523-2837

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ABSTRACT

Porcelain tiles are building materials that offer aesthetics and advantages to the user by using ceramic raw materials and additives at high pressure. Energy and labor are spent on raw materials used for production, raw material transportation and transportation until they reach the customer after they become finished products. These high costs reduce competitiveness in the market. In this study, it has been studied on the thinning of porcelain tiles to reduce the cost and to take advantage of transportation. Two different size tiles, which are the most preferred in the market, were selected. In the study, the possibilities of making thinner and environmentally friendly tiles were investigated by characterizing the selected porcelain tile bodies. Çanakkale Saribeyli Region bentonite was used in the body instead of Istanbul clay at the rates of 0.5%, 1%, 1.5%, 2% and 2.5% by weight, respectively. The body recipes, which were prepared in standard thickness and thinned by 0.5 mm, were fired at 1185 °C temperature. Shrinkage, water absorption, color and mechanical tests of the studied compositions were carried out. As a result of the study, the tile thickness thinning process was carried out in industrial trials in accordance with TSE standards, supported by laboratory test results, and the advantages it provides for transportation cost, environment and human health were demonstrated.

Keywords: *Porcelain Tile, Bentonite, Thin Tile*

1. INTRODUCTION

Based on the data from the report published by T.R. Ministry of Industry and Technology in 2020 for the ceramic sector, Turkey exports ceramic flooring materials to 113 countries and is ranked at number 9 in the world [1]. Products that are classified as ceramic flooring materials can be divided into three sub-categories of floor tile, wall tile and porcelain tile [2]. In 2021, about ~48 million m^2 of products have been exported in this large sector in which porcelain tiles provide an advantage with regard to water absorption, colour, surface texture and dimension and are also preferred from an

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aesthetic standpoint [3]. The facts that they are especially resistant against seasonal changes especially for outdoor surfaces and that they have high strength, resistance to wear, chemicals and staining are among the primary reasons for this preference. Porcelain tiles that are defined as strong tiles with water absorption of below 0,5 % are comprised of raw materials such as clay (%30-40), feldspar (%45-50), quartz sand (%10-15) and glass-ceramic, frit and pigments [4-5].

The raw materials used in porcelain tiles should contain minimum amount of iron oxide since the impact of the colouring pigment on the body is subject to the whiteness of the body. Clays provide wet and dry strength to the bodies by providing plasticity to ceramic bodies while also giving colour to the fired product based on the impurities they contain [6]. Feldspars used as fluxing agents generate a reaction at low temperatures thus reducing the sintering temperatures. Quartz is added to the body as an actual component or as an addition component coming from clay and feldspar. The wide particle size provides resistance against cracks during drying and prevents pyro plastic deformation by generating a skeleton web during firing. It reduces dry shrinkage of the body thus controlling the thermal expansion in addition to the viscosity of the melt at high temperatures [7].

The necessity to manufacture the products based on the design recipe in the ceramic sector along with the requirement for the continuity of raw material procurement limits competitive strength. Thus, working on alternative raw materials gives an edge to the manufacturer. When the compositions of the recipes and ceramic production processes are taken into consideration, clays are the primary raw materials used in the production of ceramic coating flooring products. And it also significantly affects the end product characteristics. These raw materials mostly arrive via road transport and hence make an impact on production costs [8].

In the present study, bentonites of the Çanakkale Sarıbeyli Region were used at the facility in the Çanakkale Region instead of Şile clays. Bentonite is a raw material that increases plasticity and dry strength due to its alumina silicate structure, its binding characteristic in ceramic as well as temperature resistance [9]. This high water absorption characteristic of bentonites lead to high plasticity and it is observed that clays lose their plasticity at moisture levels of below 5 % [10-11]. In the light of all this data, Çanakkale bentonites were used as an alternative to the clay group of materials in the recipe for the thinning of porcelain tiles. It was aimed in the study to reduce transportation and raw material costs in addition to providing market advantage in export and import. In addition, it is known that carbonates which enter the ceramic body with the raw materials disintegrate at different temperatures based on the type of the metal oxide they are bound to leading to the transformation to metal oxide and CO_2 [12]. The reduction of CO_2 release during porcelain tile production also provided an advantage with regard to environmental friendliness in the present study.

2. GENERAL

2.1. Identification of the Properties of Clays Used in Porcelain Tile Production

Çanakkale region Sarıbeyli bentonite which is closer to Istanbul clays with regard to alternative production was used during the study with the aim of thinning the porcelain tiles and reducing costs. Bentonite tile was preferred since it has become an in-demand material used in production recipes due to its high-water absorption property and strength increasing effect. Chemical, mineralogical and physical tests were carried out. The bentonite used in the study was formed as a result of the decomposition of the volcanic ash, tuff and lava rich in calcium and magnesium and clays predominant in montmorillonite [13]. The characteristics of clays were examined in order to identify the amount of bentonite in the recipe and chemical analyses were conducted on the clays for this purpose the results of which are presented in Table 1. XRF analyses were carried out via X-ray fluorescence spectrometer using the Panalytical Axios brand device.

Table 1. XRF chemical analysis results for Sarıbeyli Bentonite and Clay 2 (By weight %).

SAMPLE NAME-INFORMATION	SARIBEYLI BENTONITE	CLAY 2
L.O. I	5,67	5,26
SiO_2	71,3	70,11
Al_2O_3	14,18	17,17
TiO_2	0,3	0,8
Fe_2O_3	1,55	2,48
CaO	2,18	0,36
MgO	2,14	0,6
Na_2O	1,43	0,26
K_2O	1,03	2,8
TOTAL	99,78	99,84

L.O.I: Lost on ignition

Rheological measurements were made following the chemical analyses which are presented in Table 2. The density, viscosity and over sieve properties were examined for the Çanakkale region Sarıbeyli bentonite in sludge form prior to granulation. The litre weight of the sludge affects the energy consumed by the spray dryer while the over sieve particle size is observed to change the particle size of the granule. Fine particle size distribution of the granule provides ease of operation during shaping. It makes an impact on the transportation of the sludge mixture prepared by taking into consideration the flow behaviour and the energy at the time of granulation.

Table 2. Rheological Properties of Sarıbeyli Bentonite and Clay 2.

RHEOLOGICAL PROPERTY	SARIBEYLİ BENTONITE	CLAY 2
Sludge Litre Weight (gr/lt)	1282	1486
Viscosity/ T ^{0}C(sn)	YOK	21
Over Sieve (63 µm) (%)	1,81	2,19
Grinding Time (min) (dk)	44	17

The mineralogical analysis of Sarıbeyli Bentonite was performed using a diffractometer device while the CuKα 1.5406^{o}A while Celerator detector was used for radiation and X'. It can be observed when Tables 3 and 4 are examined that the primary phase in Sarıbeyli bentonite is montmorillonite. In addition, the main structure is comprised of cristobalite, feldspar and quarts at various ratios [14]. High montmorillonite affects the pouring characteristic, and these values support the properties provided in Table 2.

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Table 3. Quantitative XRD mineralogical results for Sarıbeyli Bentonite.

PHASE	(%)
MONTMORILLONITE	58
CRISTOBALITE	21
FELDSPAR	9
CALCIDE	5
ZEOLITE	2
QUARTZ	2
OTHER	3
TOTAL	100

The XRD analysis results indicate that montmorillonite ratio is 5 times greater in bentonite compared with clay. Montmorillonite phase provides strength. The feldspar amount of Sarıbeyli Bentonite was observed to be about 3 times greater compared with Clay 2. The feldspar pgase helps in reducing water absorption thanks to its fluxing property. It was determined based on the phase ratios presented in Table 4 that this clay has an illitic and caolinitic with a mixed clustered structure and a 3 layered structure. These characteristics may result in the formation of anorthite at high temperatures in addition to suitability for tile production.

Table 4. Minerological Results for Clay 2 via Quantitative XRD (By weight %).

PHASE	%	PHASE	%
MONTMORILLONITE	10,38	**ILLITE**	9,76
CAOLENITE	36,28	**QUARTZ**	36,43
FELDSPAR	2,55	**OTHER**	4,6
		TOTAL	100

2.2. Porcelain tile recipe studies prepared using Sarıbeyli Bentonite

Çanakkale region Sarıbeyli Bentonite was used in place of the Istanbul clay used in porcelain tile recipes at the Çanakkale Ceramic tile factories at ratios of 0,5-1-1,5-2 and 2,5 % by weight. Table 5 shows the raw materials used by weight % and their ratios.

Table 5. Porcelain tile recipes prepared using Sarıbeyli Bentonite (by weight %).

Recipe Name-Information	STANDART RECIPE %	RECIPE 1 (R1) %	RECIPE 2 (R2) %	RECIPE 3 (R3) %	RECIPE 4 (R4) %	RECIPE5 (R5) %
FIRED GROG	6,20	6,20	6,20	6,20	6,20	6,20
KAOLINE 1	7,00	7,00	7,00	7,00	7,00	7,00
CLAY 1	0,80	0,80	0,80	0,80	0,80	0,80
KAOLINE 2	10,00	10,00	10,00	10,00	10,00	10,00
FELDSPAR	30,00	30,00	30,00	30,00	30,00	30,00
KAOLINE 3	7,00	7,00	7,00	7,00	7,00	7,00
CLAY 2	18,00	17,50	17,00	16,50	16,00	15,50
CLAY 3	21,00	21,00	21,00	21,00	21,00	21,00
SARIBEYLİ BENTONITE	0	0,50	1,00	1,50	2,00	2,50

TOTAL	100	100	100	100	100	100

Table 6. Rheological properties of the porcelain tile recipe prepared using Sarıbeyli Bentonite.

Recipe Name-Information	**UNIT**	**STANDART RECIPE**	**R 1**	**R 2**	**R 3**	**R 4**	**R 5**
ieve Balance + 45 µm)	(%)	4,37	4,31	4,31	4,32	4,3	3,28
)ensity	(gr/lt)	1685	1685	1685	1678	1670	1665
'low Time	(sec)	20	45	45	58	62	69
;rinding Time	(min)	28	31	32	34	36	38

The mixtures were prepared by grinding in ball mills with at laboratory scale with a 45 µm over sieve balance of 4-4,5 %. Sludges close to the standard recipe with a density of ~1685 g/lt were dried at 120ºC in the stove and after which they were reground in agate mortar with the granule having a humidity ratio of 5 % shaped in laboratory presses under a pressure of 450 kg/cm^2. All samples were sintered at the Çanakkale Ceramic tile factories for a period of 45 minutes in ovens working with dimensions of 45x45 at 1185ºC. As can be seen in Figure 1, the prepared samples were obtained in the laboratory environment, however Recipe 2 with 1 % additive that had the best result was manufactured in two dimensions of 60x60 cm and 15x60 cm which have the greatest customer demand and the cost and thickness calculations were made for these samples.

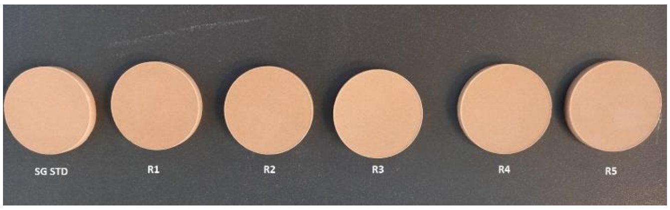

Figure 1 Fired porcelain tile tablets at 1185ºC

Konika Minolta brand device for CIALab colour system and colour identification was used in the study in addition to the Gabrielli brand vacuum device used in water absorption vacuum method. The properties that the porcelain tile bodies should have in accordance with ISO 10545 standards were used and the values were measured based on these standards [15].

3. RESULTS AND DISCUSSION

Adverse impacts on rheology were observed in the recipe behaviours of the montmorillonite structure in the quantitative XRD results of bentonite. Since montmorillonite structure which has an adverse impact on rheology displays a positive behaviour with regard to strength in construction, it enables tile thinning and the reduction of clay use in the recipes.

Water absorption test was conducted for these composition studies using the vacuumed water

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absorption test method. It was observed when bentonite was used at ratios of 0,5 % and 1 % that the maximum 0,5 % water absorption target is reached for glazed granite porcelain tiles. It was also observed that the shrinkage is increased due to its magnesium content when used at ratios of above 1,5 %.

Table 7. Tablet shrinkage, size, water absorption characteristics of the prepared porcelain tile recipes.

Recipe Name-Information	**UNIT**	**STANDART RECIPE**	**R 1**	**R 2**	**R 3**	**R 4**	**R 5**
Tablet Biscuit Size average	mm	46,36	46,32	46,32	46,25	46,23	46,19
Shrinkage average	%	7,63	7,71	7,71	7,85	7,89	7,97
Vacuum method Biscuit Water Absorption	%	0,02	0	0	0,02	0	0

As is shown in Table 8, bentonite was added to the glazed granite recipes at various different ratios and firing process was carried out. Afterwards, colour value measurements were taken for the fired tablets and the L*, a*, b* values were compared. Based on the colour value results for the Standard Recipe and the recipes including bentonite, it can be seen from Table 8 and Figure 1 that ; (L+) whiteness values changed at very small ratios such as <%0,4, (a+) redness value increased slightly, that the highest change was observed in the shift from yellowness (b+) to blueness (b-) but that these changes did not reach 1 % and hence they cannot affect production.

Table 8. L*, a*, b* measurement values for the prepared porcelain tile tablet samples .

	SG STD	**R 1**	**R 2**	**R 3**	**R 4**	**R 5**
L	49,77	49,72	49,57	49,41	49,36	49,34
a	4,05	4,09	4,13	4,24	4,25	4,31
b	14,17	13,37	13,38	13,65	13,59	13,57

Bentonite was tested at different ratios in glazed granite recipes under laboratory conditions. It was observed based on the acquired results that 1 % Bentonite results were positive for the glazed granite masse Recipe. Operation with 1 % bentonite was continued based on the evaluation of the shrinkage, water absorption and colour results. Glazed granite masse mixture was prepared with 1 % bentonite.

Table 9. Thinning goals for 60x60 and 15x60 tiles.

DIMENSION (cm)	60 x 60		15 x 60	
WORKING GOAL	STANDARD THICKNESS	AIMED THICKNESS	STANDARD THICKNESS	AIMED THICKNESS
THICKNESS (mm)	9,1	8,6	9	8,5

Table 10. Dry and fired strength values for the prepared recipes.

	STANDARD 60 x 60	R 2 60 x 60	STANDARD 15 x 60	R 2 15 x 60
DRY STRENGTH (kg/cm^2)	16,22	15,12	18,12	17,95
FIRED STRENGTH (kg/cm^2)	549,36	578,79	598,00	597,9

The dry and fired strength measurements were conducted for the prepared 1 % bentonite containing masse tiles and the standard tiles. While dry strength was measured as 16,22 kg/cm^2 at 60 x 60 dimension and standard thickness, fired strength was measured as 549,36 kg/cm^2. Dry strength decreased to 15,12 compared with the standard for the 1 % bentonite containing tile at 60 x 60 dimension subject to thinning. Fired strength increased in comparison with the standard fired strength reaching a value of 578,79 kg/cm^2. While dry strength was measured as 18,12 kg/cm^2 for 15 x 60 dimension at standard thickness, fired strength was measured as 598 kg/cm^2. Dry strength was measured as 17.95 kg/cm^2 for 15 x 60 dimension with 1 % bentonite whereas fired strength was measured as 597,9.

Table 11. Water absorption results for the prepared 1 % bentonite Recipe 2 and standard recipes.

	60X60 Standard	**60X60 R 2**	**15X60 Standard**	**15X60 R 2**
VACUUM WATER ABS. AVERAGE (%)	0,43	0,29	0,23	0,08

The vacuum water absorption results are presented for the tile samples of 1 % bentonite masse at dimensions of 60 x 60 and 15 x 60 after firing with the standard masse. Vacuum water absorption for 60 x 60 dimension was measured for the standard tile as 0,43. Vacuum water absorption for thinned 1 % bentonite 60 x 60 tile was measured as 0,29 which is lower than that of the standard. Whereas standard vacuum water absorption value was measured as 0,23 for the tile with dimensions of 15 x 60. Vacuum water absorption was measured as 0,08 for the 15 x 60 tile with 1 % bentonite.

Figures 2 and 3 show the phase analyses for the standard porcelain tile and the samples with the best results with regard to thickness, water absorption, strength, shrinkage, colour values and cost. These results indicated that there is illite, kaolinite, albite, quartz, orthoclase and bentonite in the structure. The quartz, albite and anorthite phase formations differ in the structure, while a slight decrease takes place in the quartz ratio intensity, it is observed in Recipe 2 that the formation of multiple phases has increased [16].

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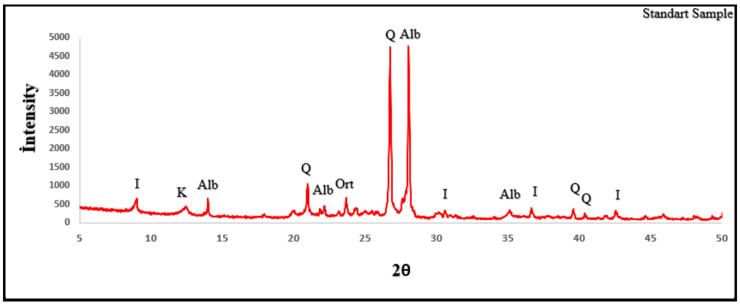

Figure 2. Standard porcelain tile masse XRD results (I: Illite, K: Kaolinite, Alb: Albite, Q: Quartz, Ort: Orthoclase B: Bentonite).

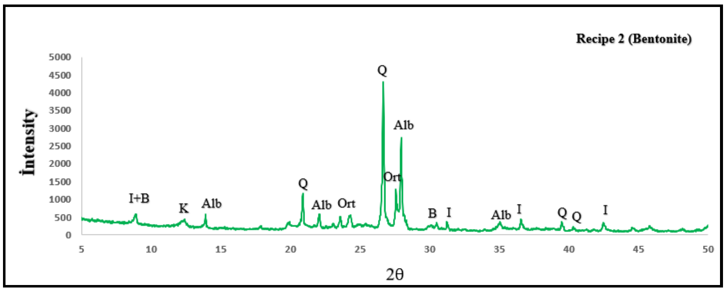

Figure 3. XRD results for Recipe 2 prepared using Sarıbeyli bentonite (I: Illite, K: Kaolinite, Alb: Albite, Q: Quartz, Ort: Orthoclase B: Bentonite).

Table 12 presents the thermal expansion analysis results which indicates that the data obtained from the XRD analyses have been met and that thermal changes have occurred in the structure following the formation of the change in the feldspars and multiple albite, orthoclase and quartz peaks. Moreover, it can also be seen from Table 12 that thermal expansion has decreased subject to the increase in the anorthite formation at high temperatures due to the greater montmorillonite ratio compared with clay 2 in bentonite use [17-18].

Table 12. Thermal expansion results for the prepared 1 % bentonite Recipe 2 and the standard recipes.

	STD	R 2
DLMα400(kg/cm^2)	75,14	74,83
DLMα500(kg/cm^2)	78,31	77,81
DLMα600(kg/cm^2)	86,15	85,56

4. CONCLUSION

It was determined in the present study that tile thinning can be conducted in glazed porcelain tiles using bentonite. It was observed that the use of bentonite at ratios of over 1 % have various adverse impacts on flow and shrinkage behaviours. Whereas it was observed for bentonite use of 1 % and below that values such as strength and water absorption have been met.

A total of 120 tiles of 60 x 60 and 43,2 m^2 can be carried in one palette whereas this number increased up to 128 tiles of 46,08 m^2 after the present study. Carrying about 22-25 palette tiles in an average transportation vehicle, it thus provides an opportunity to carry 72 m^2 more tiles which correspond to 6 % on average. Sales advantage is thus attained by reducing costs per m^2 through transporting more tiles. By increasing the quantity shipped at one time, the goods will reach the consumer more quickly and in a timely manner**.** 6 % less masse is required by reducing the masse amount through decreasing thickness and thus reducing the amount of masse used per 1 m^2. By using in the Sarıbeyli Bentonite Recipe instead of 1%, Clay 2 the distance will be reduced by about 8 times. In addition, transportation labour will decrease as well as the exhaust gases from the vehicles thereby reducing pollution. It was determined that it is possible to reduce the porcelain tile thickness by 5 % through the utilization of 1 % by weight bentonite instead of Istanbul clays. A decrease of about 8,1 % obtained for the recipe prepared using Sarıbeyli bentonite instead of Istanbul clay through the reduction of tile-thickness by 5 %.

Savings in both transportation and raw material cost will provide significant market advantages to the manufacturing company. Moreover, the fact that bentonite raw material is transported from a distance that is about ten times shorter will reduce CO_2 emissions thus providing a more superior contribution for human health compared with the reduction in costs.

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