

Beneficiation of alunitic kaolin within the floor and wall tile angobe compositions

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Most of the kaolin in Balıkesir-Sındırgı (Turkey) region cannot be used in ceramic industry because of its high alunite content. The alunite within the composition of kaolin has to be removed in order them to be used in ceramic industry. Therefore, this research aimed at removing alunite from the kaolins of Balıkesir-Sındırgı region and investigating its possible use in ceramic industry. For this purpose, mechanical scrubbing-screening, flotation and calcination methods were applied to the kaolins of the region to remove alunite. The material obtained was then used in the floor and wall tile angobe recipes of a ceramic tile factory. The angobes, prepared using the factory's standard angobe recipes, were applied to the floor and wall tile bodies of the factory and later they were glazed. After the tests, it was understood that F2 angobe prepared by M2 kaolin, beneficiated through the flotation process and F3 angobe prepared by C3 kaolin, beneficiated through calcination could be alternatives for the commercial angobe currently used by the factory in floor tile production. Similarly, it was proven that W2 and W3 angobes prepared by using M2 and C3 kaolins, respectively, could be seen as alternatives for the angobe currently used by the factory in wall tile production.

Key words: Kaolin, Alunite, Flotation, Angobe, Ceramic tiles.

Introduction

Kaolin is one of the most important industrial clay minerals. Kaolin is comprised dominantly of mineral kaolinite and hydrated aluminium silicate [1]. Kaolin is relatively pure and white firing clay composed mainly of mineral kaolinite but it may contain other clay minerals such as halloysite, pyrophyllite, mica, illite, montmorillonite, and minor amount of impurity minerals namely; quartz (SiO_2), ilmenite (FeTiO_3), rutile (TiO_2) and hematite (Fe_2O_3) [2].

Apart from the impurities given above, there are more than 12 kaolin deposits in Turkey in which sulphur is the major impurity. The sulphur in these deposits is generally associated with pyrite and/or alunite. The physical and chemical characteristics (except sulphur content) of the kaolin extracted from these deposits are generally suitable for ceramic production. Since sulphur cause the occurrence of cracks and pores during firing at elevated temperatures, it is impossible to use such ores in ceramic production directly. Therefore, SO_3 content of such raw materials must be reduced to less than 0,5% [3, 4]. The largest kaolin deposit of Turkey is located in Balıkesir-Sındırgı region. The kaolin of the region without alunite is mainly used in ceramic industry. However, most of the kaolin reserves within the region contain alunite [5].

There have been many researches on the chemical, geochemical, mineralogical and micro-structural properties of Balıkesir-Sındırgı alunitic kaolin. According to Okut [6], chemical composition of the kaolin in this region varies depending on mineralogical compositions. Al_2O_3 content increases together with the increase in mineral kaolinite. On the other hand, K_2O within the alunitic zones varies according to the presence of mineral alunite. Kahraman *et al.*⁷, carried out mineralogical analysis on the kaolin samples from three different mines and they concluded that all sample groups contained quartz, however, two sample groups contained opal, kristobalite/tridimite together with quartz. Ekinçi *et al.* [8], determined the chemical compositions of the kaolin and alunite from the region and they concluded that silica and aluminium contents of the kaolin varied as 43-72% and 17,8-37,49%, respectively. From SEM analysis, they found that kaolin crystals had a hexagonal form while alunite crystals had an idiomorphic rhombusal form. From XRD analysis, mineralogical compositions of alunitic kaolin and kaolin were found to be comprised of mineral kaolinite, alunite, quartz; and opal, kristobalite/tridimite, quartz, halloysite (in lesser amount), respectively.

In this research, several beneficiation methods were employed to reduce SO_3 content of Balıkesir-Sındırgı kaolin to less than 0,5%, which are currently not used in ceramic industry because of its high alunite content. The beneficiated kaolin with reduced SO_3 was then used in several floor and wall tile angobe recipes to prove possible industrial utilization.

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Materials

The kaolin used in the experiments was collected from Balıkesir-Sındırgı region of Turkey. Most of the kaolin in this region contains alunite, therefore, they are called alunitic kaolin. In order to reduce SO_3 content of the alunitic kaolin samples, three different beneficiation methods namely; mechanical scrubbing-screening, flotation and calcination were used.

Mechanical scrubbing and screening

Before the application of this method, the size of the kaolin samples was reduced to -2 mm by using a jaw and then a roller type of crusher. A sample of 500 gr was taken to prepare a suspension with a solid/liquid ratio of 50% and then it was kept in water for 1 hour in order to facilitate separation of dispersible fine particle with high kaolinite content lying on the coarse, hard and non-dispersible particles. This pulp was later mixed in a mechanical mixer at 1000 rpm for 30 minutes and screened through a $38\ \mu\text{m}$ sieve. The under sieve was removed as waste (since iron and sulphide contents were high); the over sieve was ground in a ball mill for 20 minutes and screened using a $125\ \mu\text{m}$ sieve. The

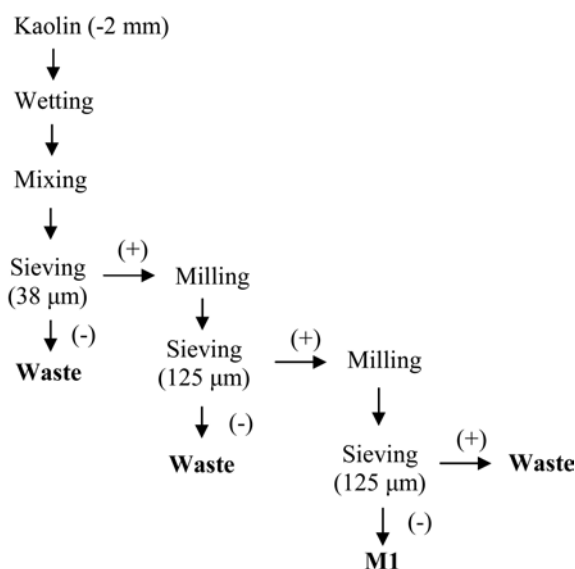


Fig. 1. Flow scheme for M1 preparation.

Table 1. Flotation conditions for M2 kaolin.

Type of collector	AERO 845
Collector dosage	3000 gr/t
Type of frother	MIBC
Frother dosage	50 gr/t
Type of depressant	Sodium silicate
Depressant dosage	400 gr/t
Flotation time	4 minutes
Agitation rate	1200 rpm
pH	8,5

under sieve was again removed as waste for the same reason and the over sieve was ground in a ball mill for 20 minutes and screened using a $125\ \mu\text{m}$ sieve. The under sieve was the kaolin used throughout the research (coded as M1) and the over sieve was removed as waste due to its high silica content and low grinding ability. The flow scheme used to prepare M1 sample was given in Fig. 1.

Flotation

For the flotation tests, M1 kaolin obtained from the mechanical scrubbing-screening method was used. In these tests, alunitic part with high sulphur content was removed as waste by flotation. The sunken part (not floated) were taken as concentrate and coded as M2. The flotation process conditions were given in Table 1.

Calcination

Before calcination, the size of the alunitic kaolin samples was reduced to -2 mm by using a jaw and then a roller type of crusher. A sample of 500 gr was taken to prepare a suspension with a solid/liquid ratio of 50% and then they were kept in water for 1 hour. This was later mixed in a mechanical mixer at 1000 rpm for 30 minutes and screened through a $38\ \mu\text{m}$ sieve. The under sieve was removed as waste (since iron and sulphide contents were high); the over sieve was ground and screened through a $38\ \mu\text{m}$ sieve. The under sieve kaolin of $38\ \mu\text{m}$ sieve was used in calcination and coded as C1. The over sieve material was removed as waste due to its high silica content and low grinding ability. The calcination of C1 sample was

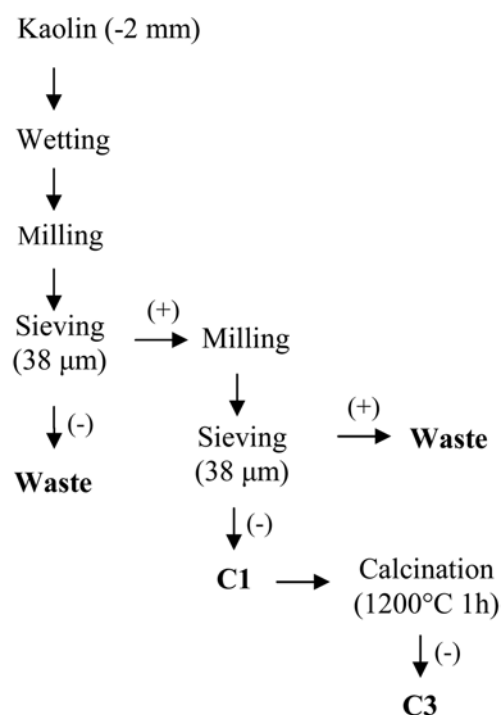


Fig. 2. Flow scheme for C1 and C3 preparation.

made using a laboratory type of oven (Protherm) at 1200 °C and for 1 hour with a temperature increment of 2,5 °C/minute. The calcined kaolin sample was coded as C3. The flow scheme used to prepare C1 and C3 samples were given in Fig. 2.

Method

The kaolin samples (M1, M2 and C3) whose SO₃ contents were reduced through beneficiation methods applied were used in the floor and wall tile angobe recipes. The properties of the angobes prepared were then compared with those of commercial floor and wall tile angobes of the factory. For comparison, floor and wall tile angobe recipes of the factory were taken as reference. In the tests, quartz, kaolin and alumina within the reference angobe recipes were replaced by M1, M2 and C3 coded kaolin samples. The composition of angobe recipes prepared was given in Table 2. In this table, RF and RW stand for the reference floor and wall tile angobe recipes, respectively.

The raw materials to be used in angobe preparation were first weighted according to ratios given in Table 2 and then ground in a jet mill for 32 minutes. Milling process was carried out as wet by a solid ratio of 72%. The materials were passed through a 100 µm sieve and then applied onto the surface of wall (RWM) and floor (RFM) tiles of the factory by pouring method. The amount of angobe for each tile was determined as 20 gr. The angobed tiles were dried at 105 °C for

2 hours. The dried tiles were fired at 1195 °C for 33 minutes (floor tiles) and 1130 °C for 33 minutes (wall tiles) in a roller type of industrial kiln of the factory.

Industrial glazing process was also applied to the angobed wall and floor tiles produced. The firing process of the angobed + glazed tiles was kept similar to that of angobed tiles. The material used in glazing was similar to those, normally used for the glazing of floor and wall tiles in the factory. The glazing materials are coded as RFG and RWG for floor and wall tiles, respectively. The codes of the angobed and angobed + glazed tiles are explained in Table 3.

In order to find out whether the expansion characteristics of the floor and wall tile angobes prepared would be suitable when applied to the floor and wall tiles bodies of the factory, the thermal expansion coefficients of the angobes and the bodies were determined. Moreover, the thermal expansion coefficient of the glazes used was determined to find out the suitability to the angobes and the bodies. Thermal expansion analysis of the angobes, bodies and glazes were made using a dilatometer called NETZSCH DIL 402 PC.

Whiteness tests were carried out for the angobed and angobed + glazed tiles in order to find out the colour variations after angobing onto the surface of the floor and wall tiles produced. Laboratory colour measurements were made using a Minolta colour measuring device. Angobed and angobed + glazed tiles were compared with the reference tiles through SEM analysis using a JEOL JSM-5600 V brand scanning electron microscope. Finally, permeability and harcourt tests were conducted on the angobed + glazed tiles. While factory's standard method was used for the permeability tests, the Turkish National Standard procedure, coded TS EN ISO 10545-9 [8], was used as a method of determining thermal shock resistance of the tiles (harcourt tests).

Results and Discussion

Characterization of raw/beneficiated kaolin

Chemical analysis and whiteness measurement

Table 2. Composition of the angobes.

	Floor Tile (%)				Wall Tile (%)			
	RF	F1	F2	F3	RW	W1	W2	W3
Kaolin	23,0	–	–	–	12,0	–	–	–
Quartz	12,0	–	–	6,6	21,0	8,0	5,8	13,0
Al ₂ O ₃	4,0	–	0,8	–	–	–	–	–
M1	–	39	–	–	–	25,0	–	–
M2	–	–	38,2	–	–	–	27,2	–
C3	–	–	–	32,4	–	–	–	20,0
Others	61,0	61,0	61,0	61,0	67,0	67,0	67,0	67,0

Table 3. The codes of the tiles used.

Floor tiles		Explanation	Wall tiles		Explanation
RFM	Factory's own floor tile		RWM	Factory's own wall tile	
RFA	Reference angobed tile		RWA	Reference angobed tile	
F1A	F1 angobed tile		W1A	W1 angobed tile	
F2A	F2 angobed tile		W2A	W2 angobed tile	
F3A	F3 angobed tile		W3A	W3 angobed tile	
RFG	Reference angobed + glazed tile		RWG	Reference angobed+glazed tile	
F1G	F1 angobed + reference glazed tile		W1G	W1 angobed + reference glazed tile	
F2G	F2 angobed + reference glazed tile		W2G	W2 angobed + reference glazed tile	
F3G	F3 angobed + reference glazed tile		W3G	W3 angobed + reference glazed tile	

Chemical analysis and whiteness values of raw kaolin (RK) and beneficiated kaolin (M1, M2, C1 and C3) were given in Table 4. Chemical analysis of these kaolin samples was made using an XRF instrument called Rigaku-ZSX Primus II and whiteness measurements (L) were made using a Minolta colour measuring device.

Table 4 shows that amount of SiO_2 increased considerably in M1, M2, C1 and C3 kaolin samples compared to that of RK. The amount of Al_2O_3 decreased except for C3 kaolin sample. The amount of SiO_2 increased, while the amount of Al_2O_3 decreased in M1 and C1 kaolins, since the under sieve of 38 μm and 125 μm sieves after mechanical scrubbing-sieving processes was removed as waste in obtaining these kaolins (Fig. 1 and Fig. 2). In fact, there are lots of fine kaolin and alunite in the waste removed. On the other hand, the over sieve parts of both sieves were rich in quartz, therefore, it is difficult to grind and dissolve them in water, which in turn, increased the amount of SiO_2 . In M2 kaolin, the amount of SiO_2 was the highest while Al_2O_3 was the lowest since M1 kaolin with high SiO_2 and low Al_2O_3 content was used to obtain M2 kaolin. M1 kaolin was then taken to the flotation process and mineral alunite within the kaolin was removed by flotation. As a result, the amount of Al_2O_3 was further reduced while the amount of SiO_2 was further increased in M2 kaolin. Since calcination burned organic matters and removed SO_3 within C1 kaolin, the amount of Al_2O_3 was reduced whereas the amount of SiO_2 increased in the calcined C3 kaolin.

Table 4 shows that the amount of SO_3 was reduced considerably in M1, M2, C1 and C3 kaolin samples compared to that of raw kaolin (RK). The decrease in SO_3 content led to the reduction in loss of ignition (LOI) for kaolins tested. Table 4 also shows that the amount of K_2O was reduced considerably in M1, M2, C1 and C3 kaolin samples compared to that of RK. K_2O within the kaolin composition was originated from the mineral alunite [10, 11]. The reason of K_2O reduction in M1 and C1 kaolins was the removal of

fine alunite particles as waste after mechanical scrubbing-screening (Fig. 1, Fig. 2). However, K_2O content in C3 kaolin almost remained the same with C1, since calcination did not remove alunitic parts in C1. Fe_2O_3 and TiO_2 contents which affect whiteness of kaolin were reduced [12, 13], therefore, whiteness values of M1, M2, C1 and C3 increased compared to that of RK (Table 4). The reduction of Fe_2O_3 and TiO_2 within the beneficiated kaolins was caused by the removal of under sieve parts with fine iron and anatase minerals after mechanical scrubbing-screening (Fig. 1, Fig. 2).

Mineralogical analysis

Mineralogical analysis of RK, M1 and M2 kaolin was given in Fig. 3; XRD patterns of C1 and C3 kaolin were given in Fig. 4. Mineralogical analysis of the kaolin was made using an XRD instrument (Rigaku Miniflex ZD13113 series) using $\text{CuK}\alpha$ X-rays ($\lambda = 1,54056 \text{ \AA}$) in the range of $5\text{--}50^\circ$ at a rate of $2^\circ/\text{minute}$. When XRD pattern of RK kaolin is examined (Fig. 3), it is seen that SO_3 and K_2O in the chemical composition are originated from alunite ($\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$). Alunite peak in M1 kaolin is much lower and there is no alunite peak in M2 kaolin. This result proves that alunite was removed from raw kaolin (RK)

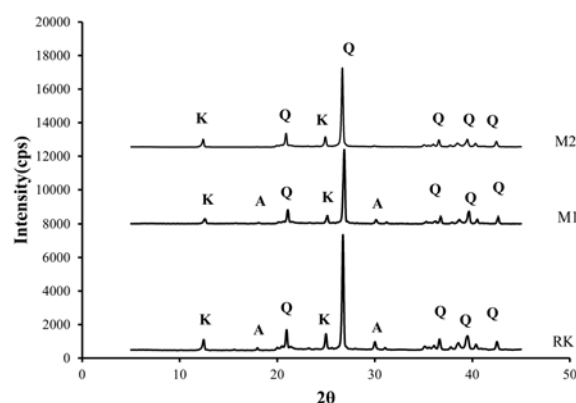


Fig. 3. XRD patterns of RK, M1 and M2 kaolins (K: kaolinite, A: alunite, Q: quartz).

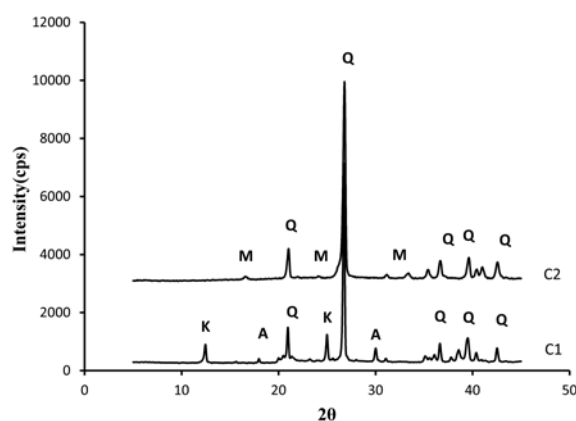


Fig. 4. XRD patterns of C1 and C3 kaolins (K:kaolinite, A:alunite, Q:quartz, M:mullite).

Table 4. Chemical composition and whiteness of the kaolins used.

Parameters	RK	M1	M2	C1	C3
SiO_2	58,42	69,46	75,52	65,57	74,96
Al_2O_3	21,71	17,73	16,34	19,41	22,83
K_2O	1,34	0,86	0,25	1,10	1,12
Fe_2O_3	0,49	0,33	0,31	0,38	0,29
CaO	0,12	0,12	0,08	0,11	0,11
MgO	0,05	0,05	0,00	0,04	0,04
Na_2O	0,17	0,13	0,00	0,10	0,10
TiO_2	0,32	0,29	0,23	0,27	0,28
SO_3	4,46	2,65	0,53	3,02	0,12
L.O.I.	12,92	8,37	6,74	10,18	0,15
L value	74,87	91,09	92,58	83,60	91,01

by the mechanical scrubbing-screening and flotation processes applied. When Fig. 4 is examined, it is seen that there are some alunite together with kaolin and quartz in C1 kaolin. In the calcined C3 kaolin, kaolin was completely decomposed and mullite begun to develop. One of the reasons of mullite development was alunite. Because Al_2O_3 within the kaolin and alunite is transformed to mullite above 1000°C [14, 15]. However, there was no phase transition started, therefore, quartz peak was still noticed.

Thermal gravimetric analysis

Thermal gravimetric and differential thermal analysis (TG/DTA) of RK sample is seen in Fig. 5. In thermal behaviour of kaolin, a strong endothermic peak occurs as a remark of degraded crystal structure by the removal of crystal water at $550\text{--}700^\circ\text{C}$ [14, 16, 17, 18]. As seen from Fig. 5, similar effect, in other words, endothermic reaction peak due to the removal of crystal water from RK kaolin at 553°C can be seen. There is another endothermic peak at 749°C which was caused by the removal of sulphur from the alunite body [14, 19]. In kaolin, a strong exothermic peak due to the re-crystallization of alumina and mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) at $925\text{--}1200^\circ\text{C}$ is generally observed. During the transition of kaolin to mullite, silica is first progressed into a spinel phase when it is in metakaolin and then Al-Si spinel phase is occurred from metakaolin. Finally, mullite is occurred together with alumina. Mullite is the most important phase that occurs from kaolin at elevated temperatures. This occurrence which initiates above 950°C , increases together with the temperature. This phase which is caused by the reactions between alumina and silica is observed until 1400°C [14, 16, 17, 18]. As seen from Fig. 5, in RK kaolin, the first exothermic peak due to the occurrence of primary mullite phase at $1024\text{--}1028^\circ\text{C}$ can easily be observed. The second exothermic peak due to the occurrence of secondary mullite phase at 1145°C is also seen.

Results for floor tiles

Thermal expansion characteristics of the angobe,

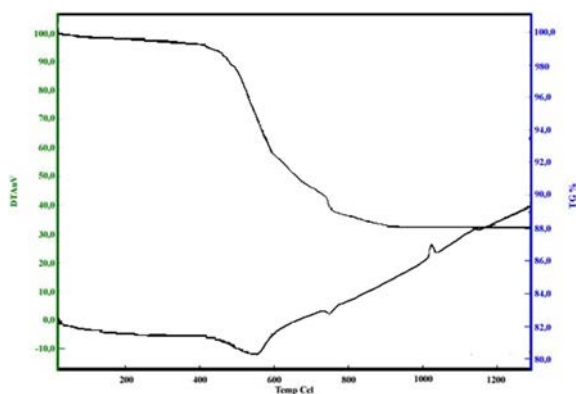


Fig. 5. Thermal gravimetric and differential thermal analysis (TG/DTA) of RK sample.

body and glaze

The thermal expansion coefficients of the floor tile angobes obtained by the use of beneficiated kaolins and the commercial floor tile angobe (RF) were given in Table 5. The thermal expansion coefficient of the body (RFM) to which these angobes were applied and the glaze used (RFG) were also given in Table 5. Table 5 reveals that thermal expansion coefficient of the commercial floor tile angobe (RF) is much lower than that of the glaze used (RFG). Thermal expansion coefficients of the floor tile angobes using beneficiated alunitic kaolin (F1, F2 and F3) were increased compared to that of RF. Therefore, thermal expansion coefficients of the glaze and the angobe will exhibit better conformity if F1, F2 and F3 are used in place of RF in the recipes.

Results of angobed and angobed + glazed floor tiles

The L values for the reference angobed tile (RFA) and the reference angobed + glazed tile (RFG) were given in Table 6. The L values for the angobes prepared by the beneficiated kaolin (F1, F2, F3), tiles angobed with the prepared angobes (F1A, F2A, F3A) and the glazed angobed tiles (angobed+glazed tiles) (F1G, F2G, F3G) were also given in Table 6. From Table 6, it is seen that whiteness values of F1A, F2A and F3A are slightly lower than that of RFA. The reason why whiteness values of F1A and F2A are lower can be explained by the lower coating ability of F1 and F2 angobes. This claim is well supported by the SEM pictures of these angobed tile surfaces too (Fig. 6). Fig. 6 shows that the angobed body of F1A, F2A have more porous structure than RFA body. The whiteness of F3A is slightly lower than that of RFA. The reason is explained by the fact that melting was higher in F3 angobe which causes the pores on the surface of the body to be filled out, resulting in a better coating ability of the angobe. This explanation can well be supported by Fig. 6.d. The increased melting of the angobe also led to a more transparent tile surfaces angobed. The increased melting was thought to be caused by the high amount of K_2O within the C3 kaolin which was used to prepare F3 angobe.

When whiteness values of angobed + glazed tiles are

Table 5. Thermal expansion coefficients (TEC) of the angobes, body and glaze (floor tiles).

TEC	RF	F1	F2	F3	RFM	RFG
$\alpha(1/\text{K}) \cdot 10^{-6}$	5,64	6,25	6,30	6,26	6,80	6,40

Table 6. Whiteness (L) of the angobed and angobed+glazed floor tiles.

Tiles	RFA	F1A	F2A	F3A	RFG	F1G	F2G	F3G
L value	82,94	81,96	82,01	82,58	86,54	87,77	87,97	87,29

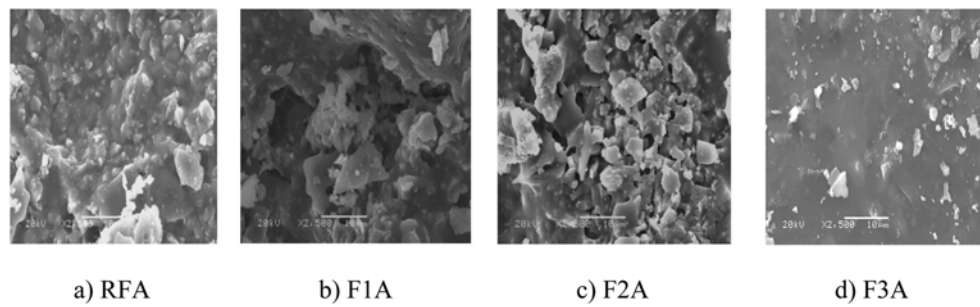


Fig. 6. SEM pictures of the angobed surfaces of floor tiles.

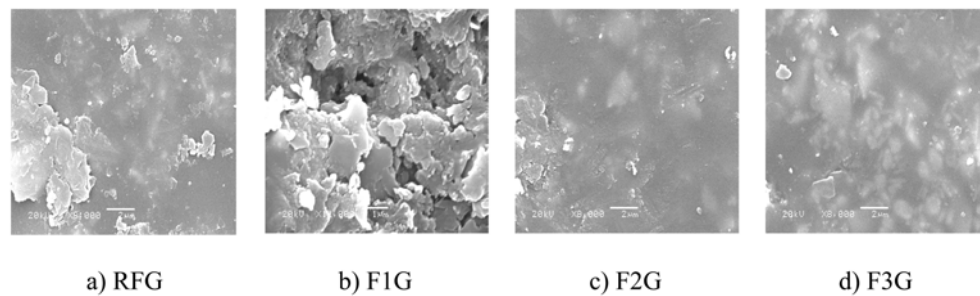


Fig. 7. SEM pictures of the angobed + glazed surfaces of floor tiles.

examined from Table 6, it is seen that the whiteness of F1G, F2G and F3G tiles are higher than that of RFG, although their coating abilities are lower. The reason was explained by the fact that glazing materials filled up the pores which resulted in a better coated surface. In other words, the coating ability of F1, F2 and F3 angobes was increased by the glazing done (Fig. 7). When glazed surfaces in Fig. 7 are examined, it is seen that there are some defects occurred by the removal of sulphur at F1G surface during firing. Surface features of F2G and F3G are seen to be similar to those of RFG.

Permeability tests were carried out on the angobed + glazed floor tiles to find out whether they would release any water absorbed when used. After the tests it was found that the tiles tested were impermeable which means the tiles did not release any water absorbed to the surfaces. This result ensures that decorative paintings on the surface of the tiles will be stable and not fade. The thermal shock resistance of the angobed+glazed floor tiles were also determined using the Turkish Standard TS EN ISO 10545-9. The tests were conducted up to 200 °C and it was understood that the tiles were resistant to thermal shocks, producing no cracks at all.

The most important criteria in determining the suitable angobe is that the surfaces glazed should be white and defectless. This is very important especially for the appearance of ceramic tiles, since the colour becomes dark and the surface is not smooth if angobing is not applied. As well known, glazing without angobing cannot overcome this problem, since glazing itself is transparent and it only reflects the colour of the surfaces beneath.

When all the test results for floor tiles were evaluated together, it was concluded that F2 and F3 angobes prepared by using the beneficiated kaolin of Balıkesir-Sındırgı region can be convenient alternatives for the commercial angobe (RF) currently used by the factory.

Results for wall tiles

Thermal expansion characteristics of the angobe, glaze and body

The thermal expansion coefficients of the wall tile angobes obtained by the use of beneficiated kaolins and commercial wall tile angobe (RW) were given in Table 7. The thermal expansion coefficients of the body (RWM) to which these angobes were applied and the glaze (RWG) were also given in Table 7. When angobes of RW, W1, W2 and W3 are examined, it is seen that thermal expansion coefficients of these angobes are very similar to each other. Although thermal expansion coefficient of the body (RWM) is slightly lower than that of angobes, no negative result was obtained from the harcort test.

Table 7. Thermal expansion coefficients (TEC) of the angobes, body and glaze (wall tiles).

TEC	RW	W1	W2	W3	RWM	RWG
$\alpha(1/K)*E-06$	6,92	7,30	7,16	7,30	6,90	5,90

Table 8. Whiteness (L) of the angobed and angobed + glazed wall tiles.

Tiles	RWA	W1A	W2A	W3A	RWG	W1G	W2G	W3G
L value	91,75	90,72	91,25	91,29	90,10	89,61	89,71	90,02

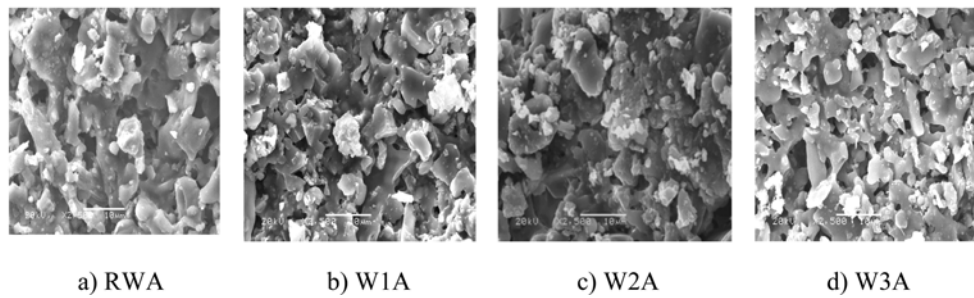


Fig. 8. SEM pictures of the angobed surfaces of wall tiles.

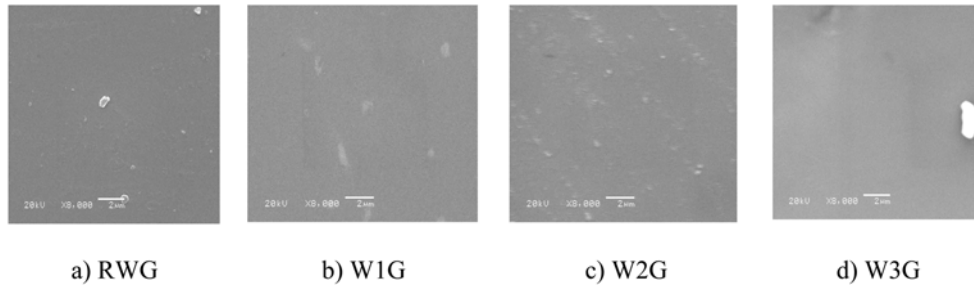


Fig. 9. SEM pictures of the angobed + glazed surfaces of wall tiles.

Results for the angobed and angobed + glazed wall tiles

The L values for the reference angobed tile (RWA) and the reference angobed + glazed tile (RWG) were given in Table 8. The L values for the angobes prepared by the beneficiated kaolin (W1, W2, W3), the tiles angobed with the prepared angobes (W1A, W2A, W3A) and the glazed angobed tiles (W1G, W2G, W3G) were also given in Table 8. From Table 8, it is seen that whiteness of W1A, W2A and W3A angobed surfaces are almost similar to that of RWA.

When SEM figures of the tiles were examined (Fig. 8), it was noticed that the microstructure of W1A was more porous than that of RWA. The microstructure of W2A and W3A are almost similar to that of RWA. However, W2A is more heterogeneous than RWA. As seen, melting has not yet started at the boundary of particles which can be explained by the lack of melting agent, K_2O , in M2 kaolin used to prepare W2 angobe. When SEM pictures of angobed + glazed surfaces are considered (Fig. 9), it can be said that there are some defects in W1G body due to the removal of sulphur during firing. The microstructures of W2G and W3G are seen to be similar to that of RWG.

The thermal shock resistance of the angobed + glazed wall tiles were also determined (harcort tests) using the Turkish Standard TS EN ISO 10545-9. The thermal shock resistance tests were conducted up to 200 °C and it was understood that all the tiles tested were resistant to thermal shocks, producing no cracks at all. Permeability tests (as applied by the factory) were carried out on the angobed + glazed wall tiles in order to find out whether they would release any water absorbed to the surface when used. After the tests it was found that tile samples tested were impermeable

which means they did not release any water absorbed to the surfaces.

When the results of wall tiles tested were considered, it was seen that W2 and W3 angobes prepared by the beneficiated kaolin produced similar results as RW angobe did. Therefore, they can be alternatives for the commercial angobe (RW) currently used by the factory.

Conclusions

In this research, sulphide and iron contents of Balıkesir-Sındırgı kaolins were reduced by employing various processing methods. SO_3 contents of the alunitic kaolin were reduced from 4,46% to 2,65%, 0,53% and 0,12% by the processes of mechanical scrubbing-screening, flotation and calcination, respectively. The whiteness of the kaolins after beneficiation were increased. When the entire test results for the angobes (prepared by the beneficiated kaolin with reduced SO_3), bodies, glazes, as well as the tiles angobed and angobed + glazed were considered, the following conclusions could be derived:

- F2 angobe prepared by the use of M2 kaolin beneficiated by flotation and F3 angobe prepared by the use of C3 kaolin beneficiated by calcination can be used as alternatives for the commercial angobe (RF), used by the factory in floor tile production.
- W2 and W3 angobes prepared by the use of M2 and C3 kaolin, respectively, can be used as alternatives for the reference angobe (RW), used by the factory in wall tile production.

Finally, the use of Balıkesir-Sındırgı kaolin which have no economic value at present because of the high

alunite content in ceramic industry was made possible in angobe preparation after its SO_3 content was reduced through the beneficiation methods. By the helps of the research, not only the kaolin reserves of the region will gain economic value but also the people of the region will benefit of the created employment.

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