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Manufacturing and Characterization of Roof Tiles a Mixture of Tile Waste and Coal Fly Ash

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Abstract: The study presented in this manuscript focuses on the manufacturing of roof tiles bearing a mixture of tile waste and coal fly ash. A roof tile sample at a different composition was prepared to attain consistence in quality. The conversion factors were described to be able to convert the laboratory results for firing strength and water absorption into the industrial operating conditions. It was determined that the replacement mixture of the tile waste as well as the Tunçbilek fly ash together with the Muttalip clay as the raw material allowed the manufacturing of good quality roof tiles. Seyitömer fly ash was not suitable for use as secondary raw material due to the presence of tile waste with higher SO_3 and CaO contents and lower MgO content. In addition to this, maximum 5 % Tunçbilek fly ash samples in the composition of roof tiles provided favorable physical and mechanical characteristics of the commercial product.

Kiremit Atığı ve Kömür Uçucu Külü Karışımından Çatı Kiremiti Üretimi ve Karakterizasyonu

Anahtar Kelimeler
Çatı kiremiti,
Atık,
Kömür,
Uçucu kül,
Geri dönüşüm

Özet: Sunulan bu çalışmada kiremit atıkları ve kömür uçucu kül karışımından kiremit imalatı üzerinde durulmaktadır. Kiremit örnek kalitesinin devamlılığını sağlamak için farklı kompozisyonlar hazırlanmıştır. Laboratuvar sonuçlarının endüstriyel çalışma koşullarına dönüştürmek için mukavemet ve su emme dönüşüm faktörü tanımlanmıştır. Kiremit atığının yanı sıra hammadde olarak Muttalip kil ile birlikte Tunçbilek uçucu külünün kullanılması ile kaliteli kiremit üretiminin gerçekleştiği bulunmuştur. Seyitömer uçucu külünün, yüksek SO_3 ve CaO; ve düşük MgO içerği nedeniyle kiremit atıklarını ile beraber ikincil hammadde olarak kullanılmasının uygun olmadığı belirlenmiştir. Bununla beraber, çatı kiremiti bileşiminde maksimum %5 Tunçbilek uçucu külünün bulunması, ticari ürünün fiziksel ve mekanik özelliklerine olumlu katı sağlamıştır.

1. Introduction

Brick and tile production is an important area in industrial production worldwide. In Turkey, brick-tile industry is a branch of industry which has many production units and this industry has spread all over the country. There are 498 brick and tile factories in country. These factories centre on regions which raw material is obtained easily and annual production is 7.5 billion bricks and 700 million tiles [1]. Tile process consists of mainly of the raw material preparation, shaping, drying, and sintering. Transfer and constructions is proceeding after the tile production. Tile waste is come out during the production, transporting and construction. Approximately, in Turkey 7-10% of total production comes out as waste. The level of such waste are expected to continually increase. Generally, a part of brick and tile waste is used on sport grounds. A major part of these waste are saved in storage areas of brick and tile factories. That waste leave on rank lands without being applied any process results visual pollution and decreases storage areas [2]. Beside tile waste, coal fly ashes cause important environmental and storage problems. However, it is known that 360 million tons fly ashes have been stored all over the world. Especially in Turkey, electrical energy is produced in thermal power plants, based on coal. In

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the end of the energy production which bases on coal, approximately 15 million tons flay ashes come out. Consequently, flay ashes are seen as an important economic resources. As a result of being stored on plant grounds, it is inevitable that this type of industrial waste turns into air pollution, visual pollution and soil pollution because of meteorological factors such as; wind and rain. Together with these problems, they cause universal environment problems. For example; waste may damage agricultural products or may flow into spring waters with rain-water. In this respect, it is so important that fly ashes and contribute to economy by being recycled in sectors such as; chemistry, ceramic, glass, construction, instead of storing on plant grounds [3-12].

The utilization of the different type of wastes in brick tile, and ceramic wastes in the different industries has been investigated as: waste-brick [13], granite wastes [14], coal fly ash [15], borax waste and dewatering sieve borax waste [15, 16], ceramic roof tile [17], waste clay from gold mine [18], gneiss rock waste [19], ornamental rock-cutting waste [20], muscovite granite waste [21]. Reusing of tile waste and coal fly ash mixture has gained many features to the roof tile industry as low cost, environmentally friendly and energy efficiency raw material. Although there have been too many investigations about utilization of fly ash, there is no any detail study on manufacturing the roof tiles from mixture of tile waste and coaly fly ash. In this study, manufacturing of roof tiles from the mixture of tile waste and coal fly ash together with clay was investigated. Tile waste was mixed with Tunçbilek and Seyitömer coal fly ashes to prepare the roof tiles. The drying and firing shrinkage, drying and firing strength, and water absorption were tested to determine the properties.

2. Materials and Characterization

Muttalip clay (MC), tile waste (TW), Tunçbilek (TFA) fly ash and Seyitömer (SFA) fly ash were used in the manufacturing of tiles. The clay was supplied from the Muttalip region of Eskişehir in Turkey. The tile waste was collected from Güral Tile Factory in Turkey. Tunçbilek and Seyitömer fly ash specimen were supplied from the Tunçbilek and Seyitömer thermal power station located in Kütahya, Turkey. The chemical compositions of MC, TW, TFA and SFA were determined using the XRF analysis technique (Minipal4-Panalytical). Results were presented as an average of the collected data, which were obtained by fusion and press methods (Table 1). In addition, crystalline phase of the materials were determined using the XRD technique (Philips X'pert Pro, CuKα).

3. Experimental Procedure

In order to determine influence of addition of tile waste and fly ash on the physical and the mechanical properties of roof tile, three series of batches (TW, TW-TFA, TW-SFA) and one reference mixture (RS) were prepared. Each series consisted of four roof tiles at different compositions (Table 2).

Table 1. Chemical analysis result of the Muttalip clay, tile waste, Seyitömer fly ash, and Tunçbilek fly ash

Oxides (wt. %)	Muttalip clay	Tile waste	Tunçbilek fly ash	Seyitömer fly ash
SiO_2	47.8	49.1	57.4	53.6
Al_2O_3	13.7	15.9	17.1	16.3
Fe_2O_3	12.1	12.7	11.1	12.3
CaO	8.8	6.5	3.4	6.2
MgO	6.2	9.2	3.5	0.8
TiO_2	1.8	2.3	0.8	0.8
K_2O	1.2	1.6	1.6	1.9
Na_2O	0.4	1.3	0.1	0.8
P_2O_5	0.3	0.6	0.3	0.2
MnO_2	0.2	0.1	0.2	0.1
SO_3	0.2	0.1	1.7	3.0
LoI (1000°C)	7.1	0.9	2.0	2.1

Table 2. Roof tile content in each formulation (wt. %)

Sample Code		MC	TW	TFA	SFA
TW	T1	95	5	-	-
	T2	90	10	-	-
	T3	85	15	-	-
	T4	80	20	-	-
TW-TFA	T5	90	5	5	-
	T6	85	10	5	-
	T7	80	15	5	-
	T8	75	20	5	-
TW-SFA	T9	90	5	-	5
	T10	85	10	-	5
	T11	80	15	-	5
	T12	75	20	-	5

4. Results and Discussion

Drying and firing strength, drying and firing shrinkage; and water absorption are the main parameters, which are generally used for the characterization of roof tiles. The results of the drying strength and the drying shrinkage tests that were conducted after the drying process of the tablets and the stick, respectively. Various physical and mechanical properties of roof tiles obtained from the Muttalip clay, tile wastes, Tunçbilek and Seyitömer fly ash samples are given in Table 3 and Fig. 1-3.

Figure 1 shows the XRD pattern of clay, tile waste and fly ashes. Muttalip clay exhibited peaks corresponding to the characteristics of quartz (SiO_2), calcite ($CaCO_3$), hematite (Fe_2O_3) and micaceous minerals. Fe_2O_3, SiO_2 and albite ($AlNaO_8Si_3$) were the crystalline phases in the tile waste structure (Figure

1). Crystalline phases that were formed in the coal fly ash samples collected from Tunçbilek and Seyitömer thermal plants are SiO_2, Fe_2O_3 and muscovite.

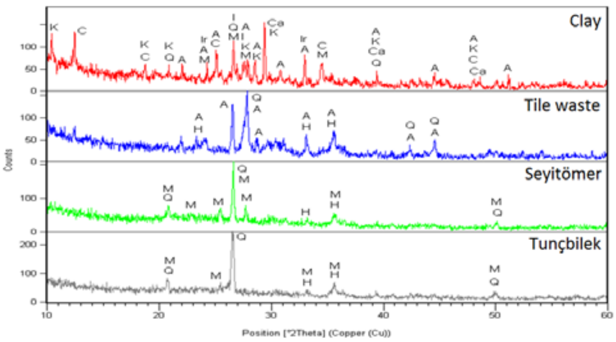

Figure 1. XRD paterns of clay, tile waste, Seyitömer, Tuçbilek (K: Potasyum Magnezyum Silikat , C: Klinoklor, Q: Kuvars, A: Albit, IR: Demir Oksit, M:Muskovit, I:İllit Ca :Kalsit, H:Hematit)

Table 3 shows the results for the drying strength tests for the waste-added sticks and the RS sample. Drying strength values for TW, TW-TFA and TW-SFA were lower than that for the RS sample. It would be observed that the increase in the tile waste content resulted in a decrease in the drying strength in comparison to that of the RS sample (84.75 kg/m^2). It may be observed that the drying strength of TW were 66.21, 54.22, 49.76 and 47.42 kg/m^2 for T1, T2, T3 and T4 respectively. Adding SFA into the tile waste was determined to be more effective than TFA in the terms of decreasing the drying strength. The minimum values of drying shrinkage were observed for T8 (42.67 kg/m^2) and T12 (32.84 kg/m^2).

Table 3. Drying strength (kg/m^2) and drying shrinkage (%) of the samples

Sample Code		Drying Strength	Drying Shrinkage
Control sample	RS	84.8	2.8
TW	T1	66.2	3.8
	T2	54.2	3.5
	T3	49.8	3.2
	T4	47.4	2.9
TW-TFA	T5	73.5	2.8
	T6	55.5	2.7
	T7	47.6	2.6
	T8	42.7	1.9
TW-SFA	T9	53.2	2.1
	T10	52.8	2.5
	T11	44.5	1.8
	T12	32.8	1.9

According to the Table 3, there is a limited increase in the drying shrinkage when only was added into the roof formulation when compared to that of the RS sample. However, the addition of 5-10% of TFA in the TW batch formulations did not result in any significant effects on the drying shrinkage values of the roof tile. If the waste concentration was increased up to a range of 15 to 20 % in the formulation, the drying shrinkage would decrease down to a value of 1.9 %. During the replacement of SFA with TFA in the roof tile formulation, although drying shrinkage values were close to that of the RS sample, the changes would not depend on the amount of waste in the roof tile composition.

Figure 2 shows the firing shrinkage of the roof tile sticks fired at different temperatures.

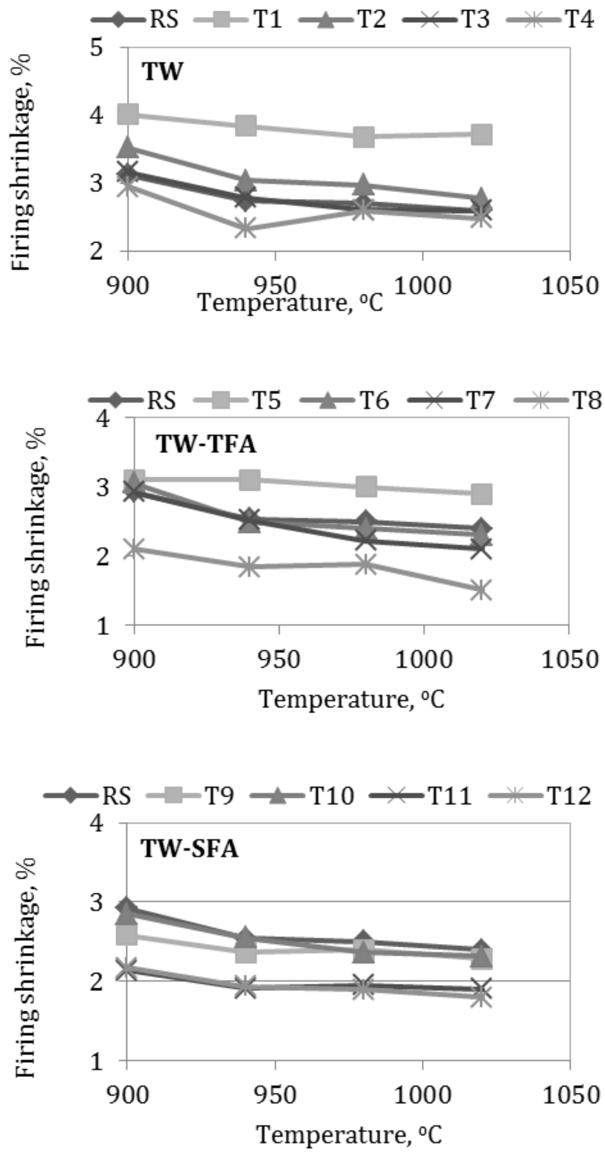

Figure 2. Firing shrinkage results for the TW, TW-TFA, and TW-SFA series

Shrinkage is an important parameter of roof tiles and the firing temperature affect the mechanical properties. Lower firing shrinkage was observed for all the samples at lower temperatures. As it may be observed, the firing shrinkage was observed to follow the same behavior as that of the dry shrinkage. The tile waste-added sticks (except for T1) were determined to possess similar firing shrinkage values with that of the RS waste-free stick. As indicated by the firing shrinkage of the TW series, the value for T3 was closer to the value for the RS waste-free stick than the other samples. If 5% TFA was added in the

TW formulation, then only the firing shrinkage of T1 would be higher than that of the RS. However, if the SFA was replaced with the TFA, then the values for all samples would be lower than that for the RS.

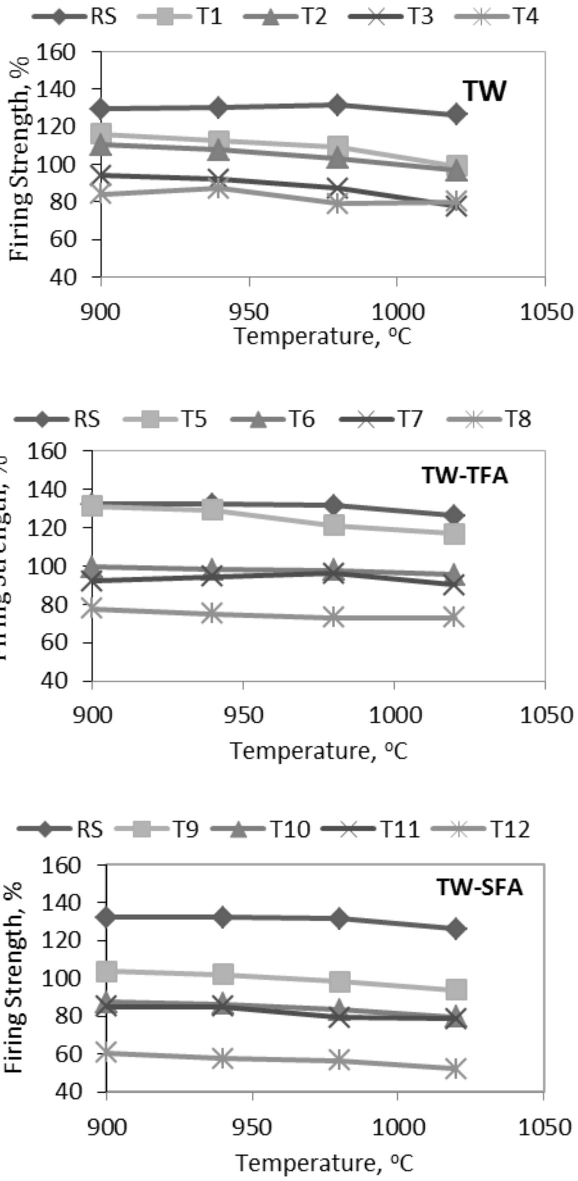

Figure 3. Firing strength results for the TW, TW-TFA, and TW-SFA series

Figure 3 shows the firing strength of the three batches at different temperatures. The firing strength of all the samples decreased with an increase in temperature. It could be observed that firing strength was determined as 129.51 %, 130.20 %, 131.51 %, and 126.28 % for the RS samples sintered at 900 °C, 940 °C, 980 °C, and 1020 °C, respectively. The results indicated that there was no significant effect of temperature on the firing strength of the RS sample. However, the addition of TFA into the TW formulation resulted in a dramatic decrease in the, firing strength of the samples consisting of 10 %, 15 % and 20 % TW with 5 % TFA. However, if the SFA was replaced with the TFA, the values for all samples would be less than that for the RS.

In the present study, a conversion factor is defined to scale the presented laboratory results into the industry operating conditions. This conversion factor was calculated as 0.301 using the firing strength for the past three years in Gurallar Tile factory Firing strength of commercial roof tiles should be 122 kg/m^2 at minimum as stated in the TSE EN 1304. It may be observed that T1 and T2 roof tile samples displayed firing strength in the range allowed in the Turkish standard (TSE EN 1304). However, the firing strength of T3 and T4 roof samples were not in the allowed range as indicated by TSE EN 1304. Firing strength of the tiles containing 15-20 % TW and 5 % TFA was lower than that for the RS sample and these samples were not suitable for use according to the TSE EN 1304 standard while only the firing strength of T9 roof tile composition was within the allowable limits of the standard. The result indicated that the firing strength was directly related to the TW, TFA and SFA contents of the roof tile composition and the presence of SFA was shown to have a negative impact on the results.

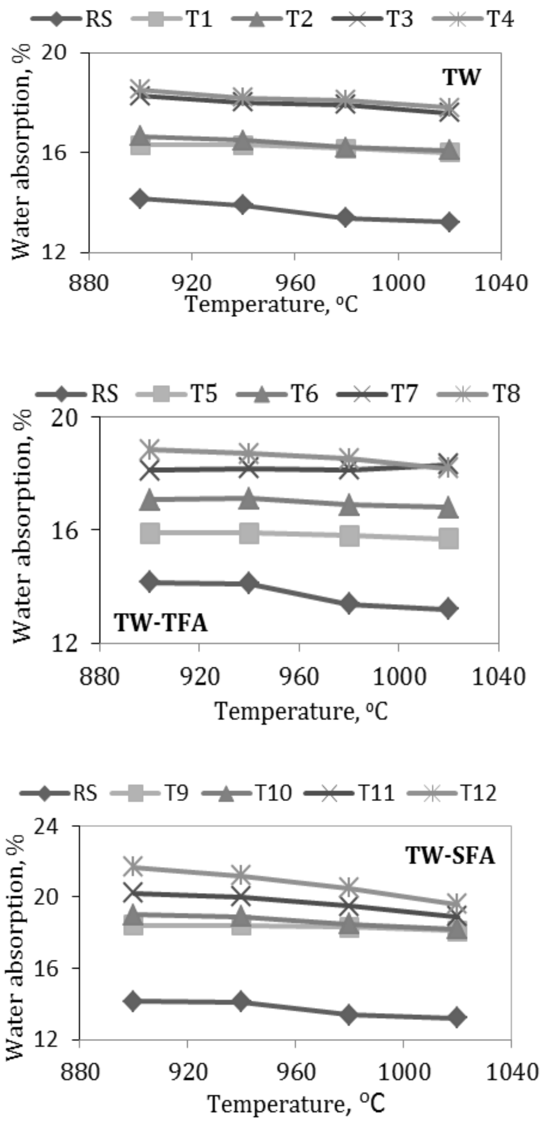

Figure 4. Water absorption results for the f TW, TW-TFA, and TW-SFA series

Figure 4 shows the water absorption values for the fired roof tile upon production at different firing temperatures. It was observed that water absorption values of all three batches were higher than that of the RS sample. In addition, water absorption values increased with increasing waste content. Furthermore, as the firing temperature increased, the water absorption values of TW, TW-TFA and TW-STA all decreased when compared to the values obtained for the RS samples. Water absorption values of T1, T2, and T5 were closer to that of the RS sample. As stated in the Turkish standard TS 562, each water absorption value should not be lower than 13 % of the arithmetic mean for the samples under the condition that they are not larger than 16 % of the tile content. A water absorption conversion factor was defined in order to convert the laboratory results into suitable industrial operating conditions and it was determined as 0.290. Water absorption values were converted into suitable numbers for industrial operating conditions through multiplication by the conversion factor. Figure 4 shows the converted water absorption values of the fired roof tiles at different firing temperatures. As indicated by the converted water absorption values for the samples T1, T2 and T5 were in compliance with the TS 562 standard. In addition, the presence of SFA was observed to have a negative impact on the results and none of the samples containing SFA were in compliance with the standard.

5. Conclusion

Physical and mechanical tests were performed in order to investigate the effect of the addition of tile waste and coal fly ash on the physical and the mechanical characteristics of roof tile samples. The drying and firing shrinkage, the drying and firing strength and; water absorption; were determined for samples in the shape of tablets and sticks. Tile body would be subjected to "lime pops" if the tile waste composition in the roof tile formulation was increased. Lime pops are small craters on the tile surface with a white spot at the bottom. The use of the mixture of tile waste and the Tunçbilek fly ash sample in roof tile compositions did not have a considerable effect on the physical and the mechanical properties. It was also determined that the Seyitömer coal fly ash samples were not suitable to be used as a raw secondary raw material due to its higher contents of SO_3 and CaO as well as the lower content of MgO. Furthermore, high Al_2O_3 content of the Tunçbilek fly ash samples caused an increase in the plasticity level of the roof tiles when compared to that of the Seyitömer formulation. As a conclusion, a formulation with 5 % tile waste and 5 % Tunçbilek fly ash samples in the composition of roof tiles displayed favorable physical and mechanical characteristics that would possess the consistent quality for industrial manufacturing.

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