Investigation of the Physical, Mechanical and Aesthetic Characteristics of Terrazo Tiles Obtained from Different Rock Aggregates

doi:10.2478/mape-2020-0040
Date of submission to the Editor: 03/2020
Date of acceptance by the Editor: 06/2020
MAPE 2020, volume 3, issue 1, pp. 477-490

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INTRODUCTION

Concrete and cement based materials are the most used materials in the construction field today because of their longevity and durability. One of the cement-based materials is tile. Tile is a coating material obtained as a result of pressing the mortar consisting of cement or aggregate, marble powder and water, consisting of one or two layers. Tiles are generally used as paving material on pavements, indoor and outdoor buildings, floors of buildings such as parks, gardens, schools, hospitals, airports and shopping malls. Therefore, it will be inevitable that the raw material resources of the materials with such wide usage will diminish day by day. For this reason, researchers and tile manufacturers have started to search for alternative raw materials to improve the existing tiles in order to survive.
Some researchers wanted to increase the strength values of the tiles and used steel fiber in the tile, as they were exposed to more loads than the calculated loads during the service life of them (Alyamaç and ince, 2008). Some have explored the frit wastes that emerged during marble cutting in order to find an alternative raw material source to the tile body and bring the materials in waste form to the economy (Alyamaç and ince, 2007). Others have examined the changes in the physical and mechanical properties of the tiles due to the change of hydraulic pressure applied in the production of the tiles (Karam and Tabbara, 2009). In this study, it is aimed to provide alternative raw materials to the aggregates used in the production of two-layer tiles. The effects of new raw materials on products in terms of physical, mechanical and aesthetic aspects were investigated.

MATERIALS AND METHOD

Materials

As a source of raw materials, wastes in natural stone workshops in Kahramanmaraş city and rocks that have been exposed in very large areas in

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and around Kahramanmaraş-Elazığ-Antakya cities were used. Although Turkey is known to host extremely diverse geological rock types, the study area was kept limited due to the possibility of obtaining a sufficient diversity of rocks. It was possible to supply beautiful samples of igneous, metamorphic and sedimentary rocks in the mentioned cities and their surroundings. The workshops in Kahramanmaraş process the blocks from all over the country, so some samples of the geomaterials were derived from the farther distance such as Marmara island in Balıkesir region (Figure 1, Table 4). Aggregates were obtained from 15 different rock types obtained with the help of jaw crusher. A total of 30 tiles, two from each aggregate, were produced and kept in a water pool at 20°C for 28 days to achieve maximum strength of these samples. In order to determine the suitability of the samples from the pool and to get maximum performance from the experiments, surface controls of the samples were made. After determining the suitability of the samples for the experiment, unit volume weight, water absorption, bending strength, abrasion resistance and freeze-thaw resistance tests were performed on each sample. A minimum of 3 readings were made for each sample from the relevant experiments and the results are averaged of these values. In this study, the mixing ratios of the materials used in tile production were kept constant and the variable was only aggregate type. Aggregate creates a large volume of approximately 65-75% in the composition of concrete and cement-based materials. Therefore, the properties of aggregates directly affect the strength and durability of the cement-based material obtained (Postacıoğlu,1987).

Fig. 1 Regions where tile raw materials were provided

The tiles produced within the scope of the research are two-layer tiles, the substrate at the bottom of the tile is obtained by mixing 2-8 mm long sand-gravel, CEM I 42.5 N Portland cement (TSE., 2002) and water at the rates determined in Table 1. The layer that forms the surface of the tile samples and which is qualified as the top layer is obtained by mixing white CEM I 52.5 R (TSE., 1994) Portland cement, micronized marble powder, aggregate and water at the ratios specified in Table 2.

Table 1 Mixing ratios of the components forming the tile substrate

Sample No	Cement (%)	Water(%)	Sand-Gravel (%)
The substrate mixture mortar rate was kept constant in all samples.	22	3	75

Table 2 Mixing ratios of the components forming the tile top layer

Sample No	Aggregate (%)	Marble powder (%)	Cement (%)	Water (%)
The top layer mixture mortar ratios were kept constant in all samples	43.3	25.4	18.5	12.8

The physical and mechanical properties of the cements used as binding material are given in Table 3.

Table 3 Physical and mechanical properties of the cements used in the study

Physical and Mechanical Characteristics	CEM I 42.5 N Portland Cement	CEM I 52.5 R White Portland Cement
Compressive Strength (2 days) (MPa)	26.0	37.0
Compressive Strength (28 days) (MPa)	49.0	61.0
Density (gr/cm^3)	3.13	3.03
Surface area (cm^2/gr)	3350	4550

Source: (Çimsa, 2019)

Table 4 Types of tile samples aggregates and the regions where they are supplied

CEMENT BASED TILE MATERIAL SOURCE		
Code	**Name**	**Region**
Magmatic Rocks		
CK-1	Granodiorite	Elazığ- Baskil-SE Turkey
CK-2	Granodiorite porphyre	Elazığ-Baskil-SE Turkey
CK-3	Monzonite	Elazığ- Baskil-SE Turkey
CK-4	Diabase	Hatay -Samandağ-Çevlik-S Turkey
CK-5	Rhyodacite	Elazığ-Kömürhan-SE Turkey
CK-6	Tuff	Kayseri-Pınarbaşı-Central Turkey
CK-7	Olivine gabbro	K.Maraş- Göksun-S Turkey
CK-8	Wehrlite	Hatay -Samandağ-Çevlik-S Turkey
Metamorphic Rocks		
CK-9	Quartz-micaschist	Kahramanmaraş-S Turkey
CK-10	Amphibole-schist	Elazığ-Kömürhan-SE Turkey
CK-11	Amphibolite	Elazığ- Kömürhan-SE Turkey
CK-12	Marble	Balıkesir- Marmara Island- NW Turkey
Sedimentary Rocks		
CK-13	Limestone	K.Maraş- Andırın-S Turkey
CK-14	Dolomite	K.Maraş-Türkoğlu-S Turkey
CK-15	Travertine	Kayseri- Pınarbaşı-S Turkey

In this research, the materials used for the substrate and their mixing ratios were paid attention to using almost the same ratio in all samples, and the mixing ratios in the top layer did not change too. For the top layer, the variable type was aggregate only In the study, the aggregates used in the tile upper layer composition are given in Figure 1 and Table 4 according to the regions and rock names from which they are provided.

Method

The rock samples supplied were first broken in the laboratory with a jaw crusher, and then sieved to obtain aggregate with a size of 4.75-12 mm (Figure 2).

Fig. 2: a) Crushing, b) Sieving

During the production phase of two-layer cement-based tile samples, the top layer mortar was prepared and poured into the tile mold. Thanks to the vibrating motor located under the mold, the mixture mortar was spread homogeneously on the mold. Then, the bottom layer of the tile mixture mortar was poured into the mold and a 1000 kN hydraulic press was applied. Hydraulic press is ensured that the water in the upper layer of the tile is absorbed into the lower layer of the tile and the excess water in the environment is thrown out. Hydraulic pressed samples are kept at room temperature for at least 24 hours for freezing (Fig. 3).

Fig. 3 Preparation of tile samples a) Pouring the top layer mortar, b) Pouring the substrate layer mortar, c) Hydraulic press, d) Waiting for the samples to freze

In order to remove the roughness of the soles of the dried samples and wipe the surfaces, the process is applied in the 8-headed tile polishing machine, which serves as 4 surface thinning and wiping and 4 polishing (Figure 4).

Fig. 4 Production of tile samples a) Removal of sub-base roughness, b) Surface Thinning, c) Surface polishing, d) Final products

After the surface wiping process, the tile samples are kept in the water pool at 20 ^{0}C for 28 days to get the maximum resistance (Figure 5).

Fig. 5 Curing pool

At the end of 28 days, the suitability of the tile samples is determined by determining whether they are suitable for the tests and getting maximum performance from the tests (Table 5) (TSE, 2005).
After the surface controls, the dry unit volume weight, dry surface saturated unit volume weight and total water absorption values of the tiles that having suitable size and surface smoothness were determined (TS EN 12390-7, 2010).
In order to determine the dry, saturated unit volume weight and water absorption values, the samples were first kept in 105°C oven until the maximum dry, and their dry weights were calculated. Then, the same samples are kept in a container filled with water until they are completely saturated, and their saturated weights were calculated and unit volume weight and water absorption values were determined (Figure 6).

Table 5 Controls applied to tile samples

Sample No	Controls			
	Dimensions	Surface layer thickness	Deviation of the edges from the direction	Surface smoothness
CK-1	S	S	S	S
CK-2	S	S	S	S
CK-3	S	S	S	S
CK-4	S	S	S	S
CK-5	S	S	S	S
CK-6	S	S	S	S
CK-7	S	S	S	S
CK-8	S	S	S	S
CK-9	S	S	S	S
CK-10	S	S	S	S
CK-11	S	S	S	S
CK-12	S	S	S	S
CK-13	S	S	S	S
CK-14	S	S	S	S
CK-15	S	S	S	S
Açıklama	**S: Suitable**		**U:Unsuitable**	

Fig. 6 Determination of unit volume weight and water absorption values of the tiles.
a) Drying in 105 C oven, b) Dry weight determination,
c) Soaking in water for at least 24 hours, d) Determining saturated weight

Three-point bending strength test was applied to determine the bending strength of tile samples (Figure 7). The load increase rate was the same in all samples and the breakage is adjusted to occur in 45 ± 15 seconds (TSE, 2005). The average of these values was taken by reading at least 3 times for each sample in the experiment.

In order to determine the abrasion occurring on the surfaces of the tile samples, a wear abrasion test was applied (Figure 8). In this experiment, tile samples were cut to 71 ± 1.5 mm at the edge length and applied to the surface of each sample as 4 cycles and 88 cycles. The experiment was performed at least 3 times for each sample and the average of these values was given as volumetric loss (TS EN 14157., 2017, Mohammed., 2018).

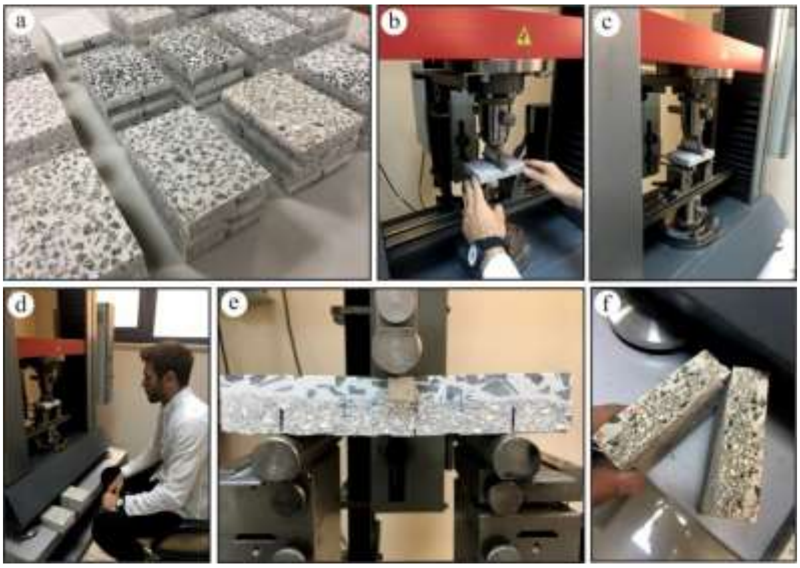

Fig. 7 Determination of bending resistance of tile samples. a) Test samples, b, c, d) Placing the sample into the device and performing the experiment, e, f) Fracture

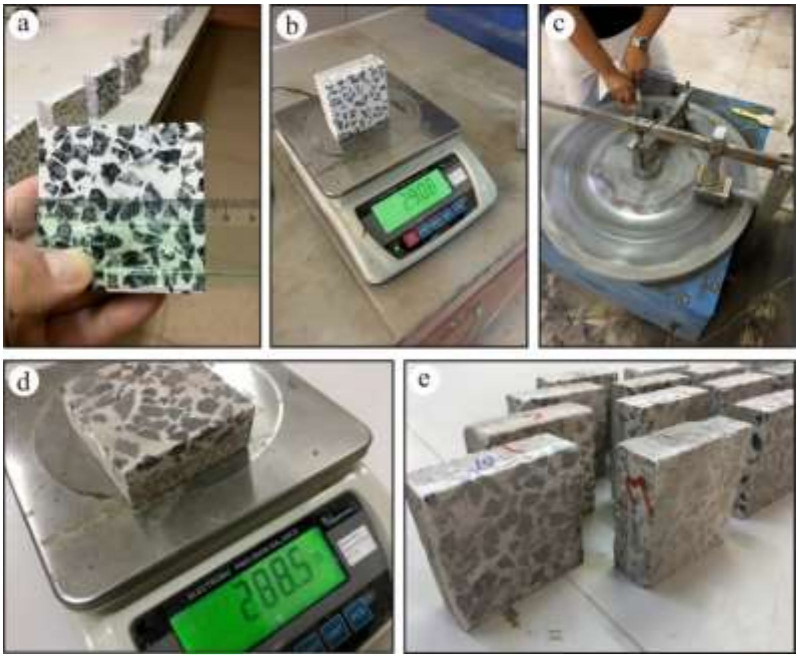

Fig. 8 Bohme Wear Test a) Test Sample, b) Weight before the test, c) Construction of the test, d) Weight after wear, e) View after wear

Freeze-thaw resistance test was applied to determine the weight losses that occur after breaking and cracking in the tile sample of the volume increase that occurs as a result of freezing of water penetrating into the cavities within the gaps in the tile samples and its composition (Tan, 2010; TS CEN/TR 15177) (Figure 9). Freezing and thawing test was performed at least 3 times for each test sample and the average value of the results obtained are given.

Fig. 9 Freeze-thaw cabinet

Marsurf M300 diamond needle scanning surface roughness measurement device was used to determine the surface roughness of the tiles produced (Figure 10). These measurements were applied taking into account the issues specified in the TS 6956 EN ISO 4287 standard, and 5 different readings were taken on each test sample and an average value was given (ISO 4287, 2004). The surface roughness measurement forms the indentation and protrusion planes on the sample surface as a result of moving the diamond needle tip with a diameter of 5 μm up and down on the surface of the test samples. The data obtained constitute the roughness parameter values on the surface of the test sample (Özdemir et al., 2018).

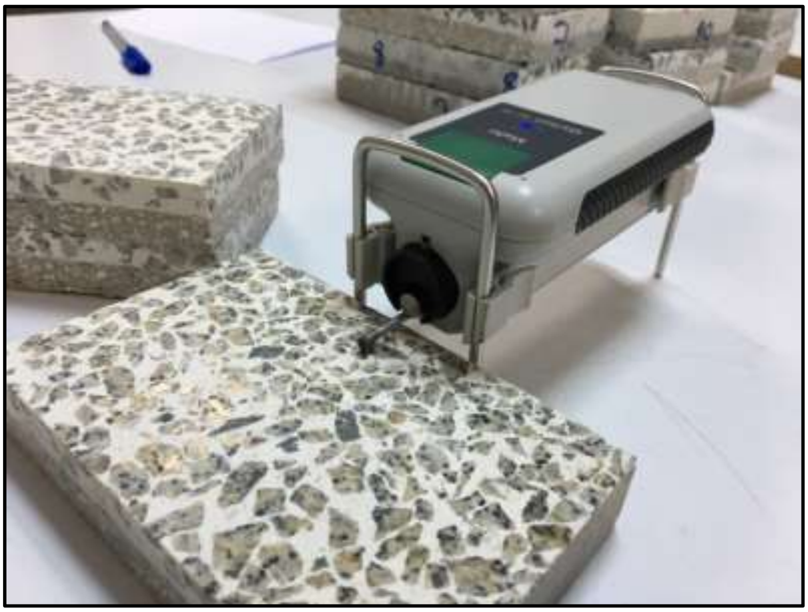

Fig. 10 Surface roughness measurement

RESULTS AND DISCUSSION

The results of the experiments applied on the tiles obtained from different geomaterials are given in the Table 6.

Table 6 Karo deney sonuçları

Sample no	Total Water Absorption (%)	Bending resistance (MPa)	Abrasion Resistance ($cm^3/50cm^2$)	Mass loss after freeze-thaw (gr)
CK-1	6,34	7,73	1,37	8,37
CK-2	6,59	6,93	1,33	8,64
CK-3	6,53	7,24	1,24	8,51
CK-4	6,52	7,41	1,97	8,44
CK-5	7,16	6,07	2,06	9,59
CK-6	13,25	4,95	3,43	11,97
CK-7	5,31	8,89	1,09	8,07
CK-8	6,66	6,79	2,29	8,79
CK-9	6,93	6,68	1,99	9,06
CK-10	6,70	6,76	1,63	8,98
CK-11	6,32	7,75	1,28	8,35
CK-12	5,72	8,04	2,27	8,11
CK-13	6,19	7,93	2,26	8,22
CK-14	5,94	8,18	1,62	8,14
CK-15	9,45	5,82	2,36	10,51

Water Absorption

The first test applied on tile samples is the water absorption test. The water absorption in the tiles has a direct effect on the strength and durability of the tiles.

In Table 6 and Figure 11, it is seen that the lowest water absorption value in the tile samples is the CK-6 tuffaceous tile in the sample with the highest water absorption value in the sample of CK-7 olivine gabbro. There is a parallelism between the water absorption values in the tile samples and the aggregates in the tile composition (Figure 11).

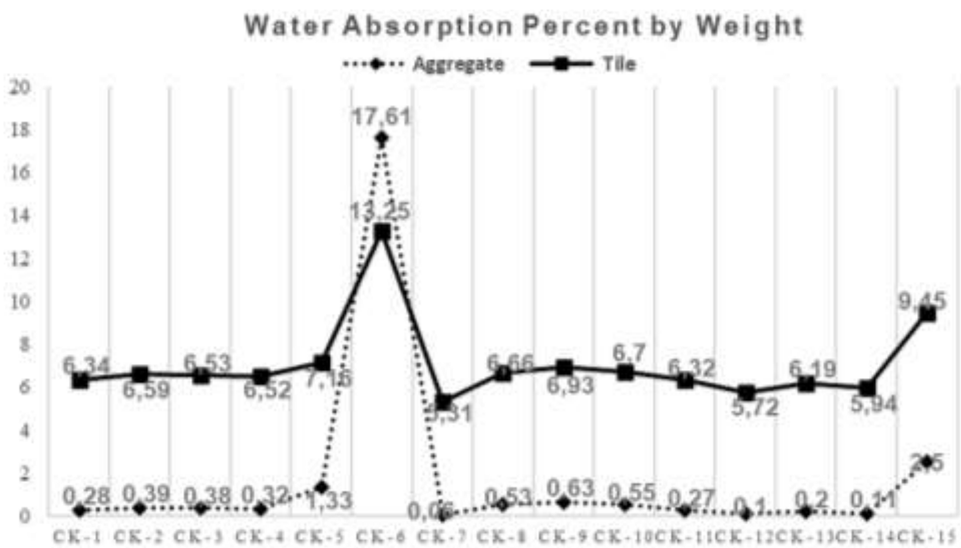

Fig. 11 Water absorption values of tile samples

Bending Resistance

According to the bending strength results, it is seen that the sample with the highest bending strength is CK-7 olivine-added gabbro tile while the lowest value is CK-6 tuff-added tile. There is an inverse proportion between the bending strength values and the water absorption value of the tile samples. Therefore, it is observed that tile samples with low water absorption capacity have high strength, and those with high water absorption capacity have low resistance (Figure 12).

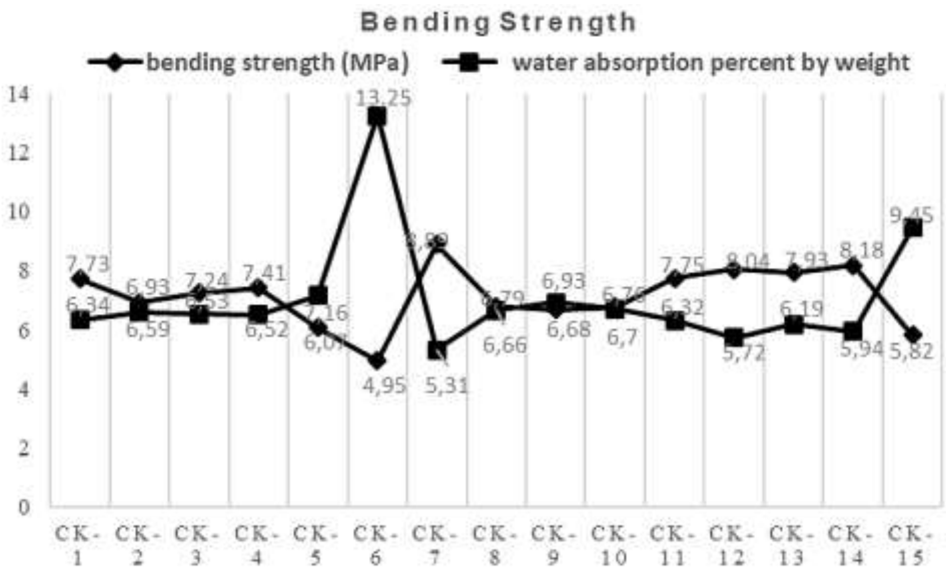

Fig. 12 Bending strength and water absorption relationship of tile samples

Böhme Wear Resistance

Wearing values vary between 1.09 and 3.43 $cm^3/50cm^2$, the sample with the least loss of wear is CK-7 olivine gabbro, while the highest sample is CK-6 tuffy tile. However, there is no parallel relation between wear loss and bending strength. It is thought that the wear loss in the tile samples depends on the mineralogical properties of the aggregates within the tiles.

Freezing and Thawing

According to the data obtained from the freeze-thaw resistance experiment applied on the tile samples, it is seen that the samples with low water absorption have the least weight loss after the freeze-thaw cycles (Figure 13).

It is seen that the water that enters the tiles and the aggregates in their composition will increase in volume when the water entering the structure increases, and the tiles with low water absorption value, which are prepared with the aggregate that does not contain any gap, and having low water absorption value have higher freeze-thaw resistance.

It is seen that the water that enters the tiles and the aggregates in their composition will increase in volume when the water entering the structure increases, and the tiles with low water absorption value, which are prepared with the aggregate that does not contain any gap, and having low water absorption value have higher freeze-thaw resistance.

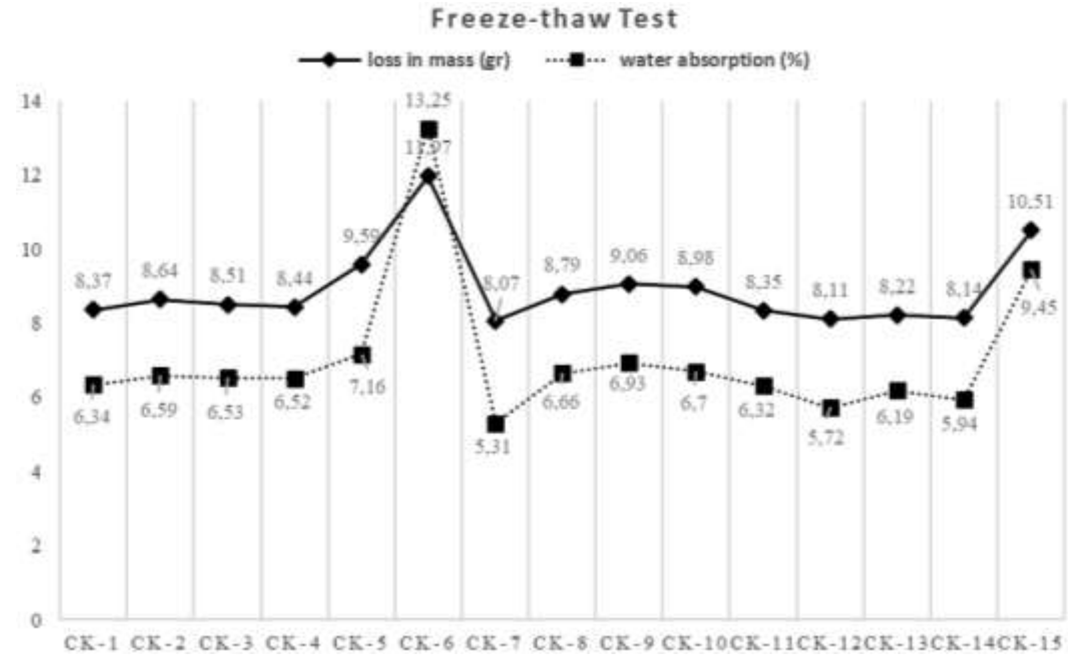

Fig. 13 The relationship between freeze-thaw and water absorption

Aesthetics in Tile Samples

As a result of the production process, it has been observed that the tiles obtained from the igneous rocks showing granular texture (Granodiorite, granodiorite porphyry, monzonite and olivine gabbro) and metamorphic rock (Amphibole-schist and quartz-mica-schist) aggregates with a foliation plane were found to be aesthetically superior.

Fig. 14 Aesthetics in tile samples

Surface roughness

The surface roughness test results applied on the Tile Samples are given in Table 7 and Figure 15. Here Ra means the average surface roughness, Rz Ten point roughness mean value Rmax is the largest roughness value.

Table 7 Surface roughness test results

Sample No	Ra(µm)	Rz(µm)	Rmax(µm)
CK-1	0.872	7.088	10.44
CK-2	0.674	5.554	8.22
CK-3	0.834	6.015	10.30
CK-4	3.004	17.112	37.15
CK-5	4.115	28.063	53.54
CK-6	5.534	32.734	85.00
CK-7	0.440	4.291	5.719
CK-8	1.455	10.554	14.35
CK-9	2.048	13.501	30.49
CK-10	1.636	13.443	27.14
CK-11	1.565	12.694	22.60
CK-12	1.158	10.197	14.32
CK-13	3.523	27.498	39.91
CK-14	2.452	15.156	30.51
CK-15	4.409	28.192	55.54

When the results obtained in the surface roughness test are examined, the average surface roughness values (Ra) in olivine gabbro, granodiorite porphyry, monzonite and granodiorite aggregates are 0.440, 0.674, 0.834 and 0.872 µm, respectively, while diabase, basalt, travertine and tuff In tile samples 3.004, 4.115, 4.409 and 5.584 µm, respectively (Table 7, Figure 15). Therefore, the surface roughness of the tiles prepared with coarse rock aggregates was found to be relatively lower than the tile samples obtained with fine grained rock aggregates.

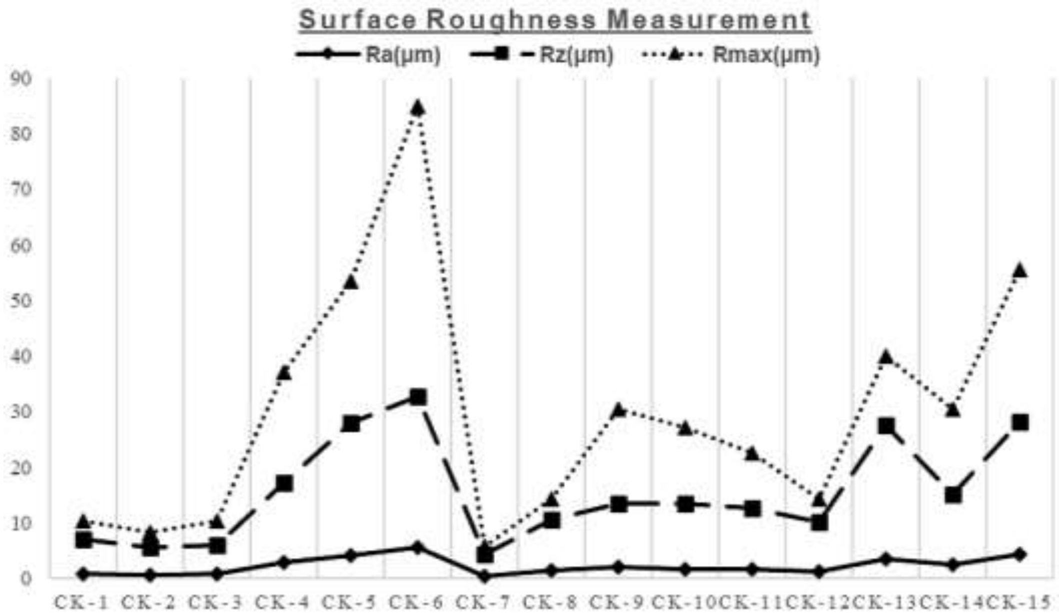

Fig. 15 Surface roughness test results

CONCLUSIONS

1. Water absorption values of the tile samples are in the range of 5.31-13.25 (%). It is observed that rock aggregates without voids have low water absorption value, and this value increases in rock aggregates with voids and discontinuities such as foliation.
2. The bending strength values of tiles produced from different geomaterials have been measured between 4.95-8.89 MPa and it is recommended to use products with high bending strength in order to survive the products applied in areas subject to excessive loads according to the tiles usage areas.
3. The wear losses were found to be between 1.09-3.43 $cm^3/50\ cm^2$, and the tiles obtained with plutonic igneous rocks are exposed to less wear.
4. It is observed that the mass loss that occurs as a result of freeze-thaw cycles applied to the tile samples is 8.07-11.97 g and these values are parallel to the water absorption value of the tiles. Therefore, it is recommended to use tiles with low water absorption value and more resistant to freeze-thaw, which will be used in areas where frost is frequently experienced.
5. The tiles obtained from the aggregates with the granular texture and foliation plane increaseed the visual diversity and offer a superior aesthetic feature.
6. The mineral grain size in the aggregates used in the tile samples directly affects the surface roughness value.

ACKNOWLEDGEMENTS

This work is a part of MSc study of Canberk ÇOŞKUN. Financial support from Kahramanmaraş Sütçü İmam University Research Foundation (Project Number: 2017/7-169 YLS) is greatly acknowledged. We would like to thank Assoc. Prof. Dr. Yağız Ferhat ÖZDEMİR for allowing us to use his laboratory facilities for testing surface roughness of the tiles.

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Abstract: Throughout history, people have covered the floors of the buildings with materials such as carpet, rock pieces, wood, mosaic, ceramic and tile according to the conditions of the day due to their desire to protect them from moisture, make them hygienic environment easy to clean and give an aesthetic appearance. The merging of mechanization with cement based materials with the industrial revolution in the 19th century has brought along the development of diversity and different production methods in these floor covering materials. One of these coating materials is terrazo tiles that form the subject of the current paper. Terrazo tiles are materials obtained by pressing the mortar obtained by mixing water, cement, marble powder and aggregate in certain proportions. Within the scope of this research, it was aimed to provide alternative raw materials to the tile body and to transform the rock pieces, which are found in waste form in natural stone workshops, into the economy. For this purpose, geomaterials collected from magmatic, metamorphic and sedimentary rocks cropped in the Kahramanmaraş-Antakya-Elazığ regions and natural stone workshops operating in Kahramanmaraş city, were classified according to their geological origins and aggregates of 4.75-12 mm were obtained with the help of jaw crushers and sieves. Tiles have been produced in accordance with the method of tile production from sized aggregates. The produced tiles were kept in the water pool for 28 days and surface controls were made. According to the physical and mechanical test results applied to the tile samples, water absorption by weight is 5.31-13.25%, bending strength 4.95-8.89 MPa, Böhme abrasion resistance 1.09-3.43 $cm^3/50cm^2$, mass loss after freeze-thaw is observed to be in the range of 0.97-1.59%. On the other hand, the surface roughness of the tiles prepared with coarse rock aggregates was found to be relatively lower than the tile samples obtained with fine grained rock aggregates. The obtained results indicate that the geomaterials subject to the research can be used as an alternative raw material source in tile production and these raw materials will provide new benefits to the construction field.

Keywords: tile, geomaterial, physico-mechanical test, aesthetic property