BUILDING MATERIALS AND PRODUCTS

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THE EFFECTS OF PETROGRAPHIC DIFFERENCES ON THE GEOMECHANICAL PROPERTIES AND FREEZE-THAWING (F-T) PROCESSES OF BUILDING STONES USED IN AYA HELENA CHURCH (SILLE / KONYA / TURKEY)

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Statement of the problem. Located in the very center of Anatolia, Konya houses many historical artefacts. Sille, which has an important place in the history of Christianity, is also within the borders of Konya. In this region,Volcanic rocks were formed as a result of volcanism activities that occurred thousands of years ago. These rocks have been used in many historical building in the Sille and Konya city center. One of this structures is the Aya Helena Church.
Results and conclusions. Within the scope of this study, many samples were taken from the volcanic rocks with similar petrographic properties used in the Aya Helena Church excavated from the Sille region of Konya. These stones were investigated to index and mechanical properties and the resulting loss of strength of F-T cycles. Thus, although these rocks, known as Sille rocks in the region, show similar characteristics in terms of external appearance, their index and mechanical properties seem to be significantly different from each other.

Keywords: Aya Elena Church, Sille Stone, freeze-thaw (F-T), texture, index and mechanical properties, Turkey.

Introduction. Konya is a Central Anatolian city that has hosted Hittite, Phrygian, Roman, Byzantine, Seljuk and Ottoman civilizations in history. Çatalhoyuk, one of the oldest settlements known to date(corresponding to the Neolithic Age, about 8000 years old), is within the borders of Konya [1], a remarkable city with its cultural and architectural aspects.

One of the most important building stones in Konya's cultural artefacts is the Sille Stone [2], extracted from the Sille region, 8 km north of the city centre of Konya. This area has been an active settlement since the Romans [3]. Sille stone has been used quite often in various architectural structures such as churches, mosques, bridges, fountains and schools etc. from past to present. Some of the structures built with Sille stone in the city centre of Konya are Aya Helena Church, Amber Reis Mosque, Saint Paul Church, Kadi Mursel Mosque and various fountains (Fig. 1).

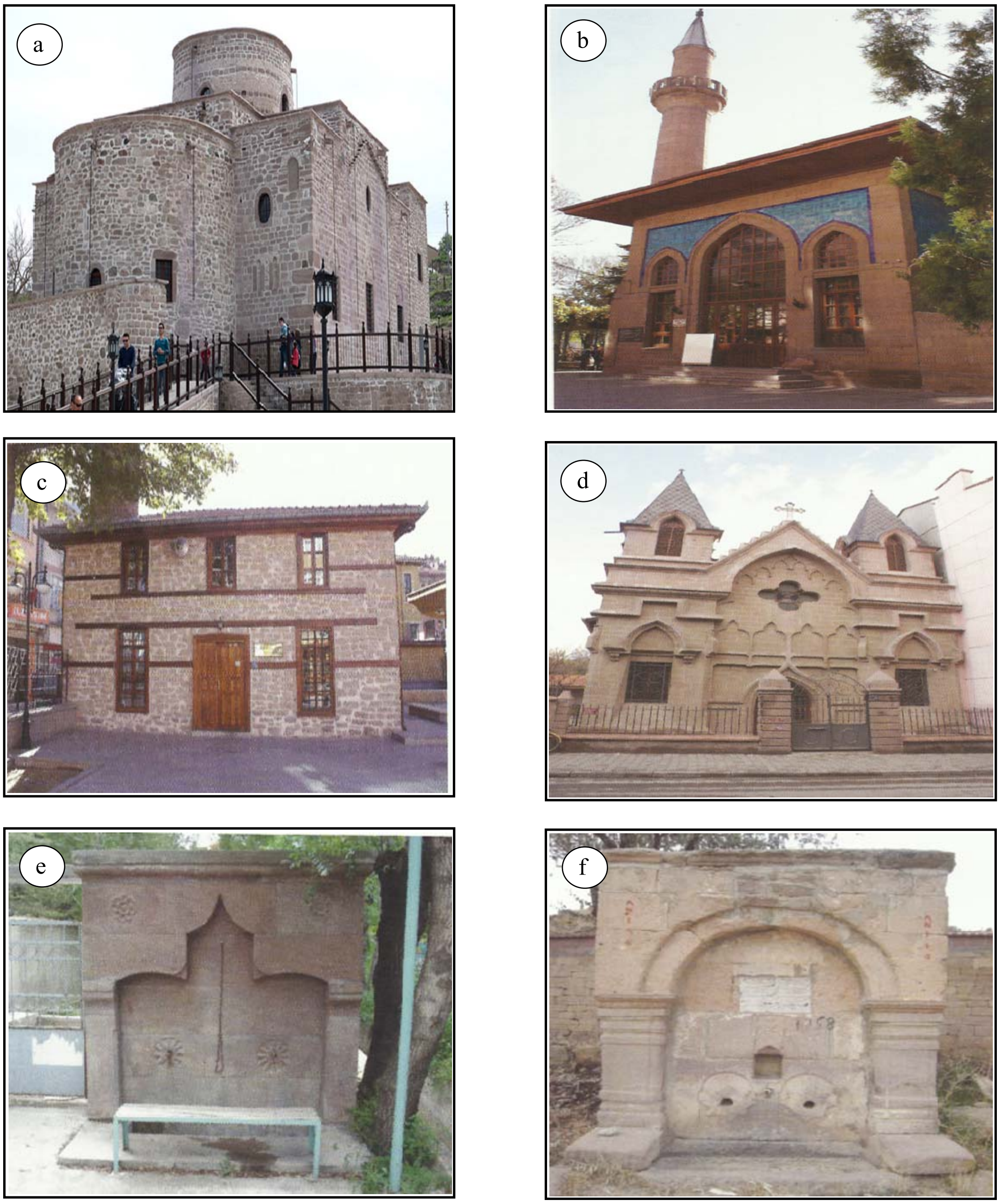

Fig. 1. Some of the structures built with Sille stone (a) Aya Helena Church, (b) Amber Reis Mosque, (c) Kadi Mursel Mosque, (d) Saint Paul Church, (e, f) Fountains [24]

Rocks are directly or indirectly affected by atmospheric events [4]. The cracked and voided structure [5, 6], texture [2] and welding degree [4] are effective in the degradation process of rocks. It has been proved many times by experimental studies that especially rocks with high porosity are more susceptible to environmental factors such as freeze-thaw (F-T), salt crystallization (SC), sulphate effect [2, 7—12]. Another factor that determines the durability of volcanic rocks against environmental impacts is water absorption capacities. The water absorption capacities of rocks are rather related to being open and total porosity than their chemical structures [13].

Volcanic rocks have been widely used as building blocks from past to present [14, 15]. The volcanic building stone commonly used in the Konya region is the Sille Stone. Considering the studies about Sille stone, it is seen that the water absorption coefficients and porosities of these rocks are particularly high due to the capillary effect [16—19]. As a natural consequence of these high cap water permeability and porosity, Sille Stones have shown to be affected by environmental events such as freezing and thawing [2, 20]. Moreover, the researchers indicated that the mineralogical, petrographic and physico-mechanical properties of andesites in this region are effective on salt crystallization, and andesite type of rocks, one of the construction rocks used in this region, are the mostly affected construction rocks of that region from SC [21—23].

Sille Stones have been observed to be highly influenced by the factors such as F-T and SC. As seen in former studies, the rates of F-T and SC exposure and other physical-mechanical values of stones vary considerably [2, 6, 20]. This is in fact an indication of the variability of the texture and mechanical properties of rocks called Sille stones in the region. In this study, petrographic, geo-mechanical and FT experiments were carried out by taking samples from various levels and locations where the Sille stone was propagated in the region. The purpose of this study is to reveal the geochemical and textural differences of the rocks used in Aya Helena Church known as Sille stones and to examine the effects of these differences on the index, mechanical and F-T processes.

Material and Method

1. Description of Aya Helena Church. Aya Helena Church (St. Hagios Mikhael according to Bell [25]), which was examined in the study, was built in 327 according to the inscription on the entrance door. However, considering the dome type of the structure, it is dated back to the early Justinian period (12^{th} century) [25, 26]. According to the inscription of the building, it was renovated 3 times and the last one was built by Sultan II. Mahmud (1785—1839) [26]. The structure has a rectangular shape and a cross plan. It is made of rough cutting sille stones by masonry technique.

As can be seen from the Figure 2, sille stones with different petrographic characteristics were used disorganized in the building. Besides that, deformations have occured due to wetting-drying and freezing-thawing effects on the parts of the structure that close to the ground (Fig. 2). In this study, sille rocks with different petrographic characteristics such as used rocks in the building were obtained from open quarries in Sille region.

Fig. 2. South-West Side of the Aya Helena Church and Petrographically Different Building Stones

2. General Geology. The Sille stone is extracted from the stone quarries opened in Sulutas Volcanics in the study area (Fig. 3). Sulutas Volcanics have been formed 3—11 million years ago due to the volcanic activity occurred in the western part of Konya in the Upper Miocene-Lower Pliocene time interval [27]. These rocks were investigated as "Sulutas andesite member" in Dilekci formation by grey-brown-pink coloured plagiodasite (Quartz andesite), dacite, rhyodacite and andesitic volcanoclastic rocks [28]. Eren [29] called this unit Sulutas volcanics. These volcanics consist of dacite, andesite and rarely basalts. In the region, this unit has been passed to the region due to the cutting of proclastites with the Silurian — Cretaceous basement units and the Upper Miocene — Lower Pliocene lacustrine carbonate — rich rocks.

It is obscured by the Topraklı formation from the top (Fig. 3). According to K / Ar age determination, Keller, et al. [30] expressed the age of the unit as 11.95—3.35 million years ago. The age of Sulutas volcanic is Upper Miocene-Lower Pliocene, according to this radiometric data.

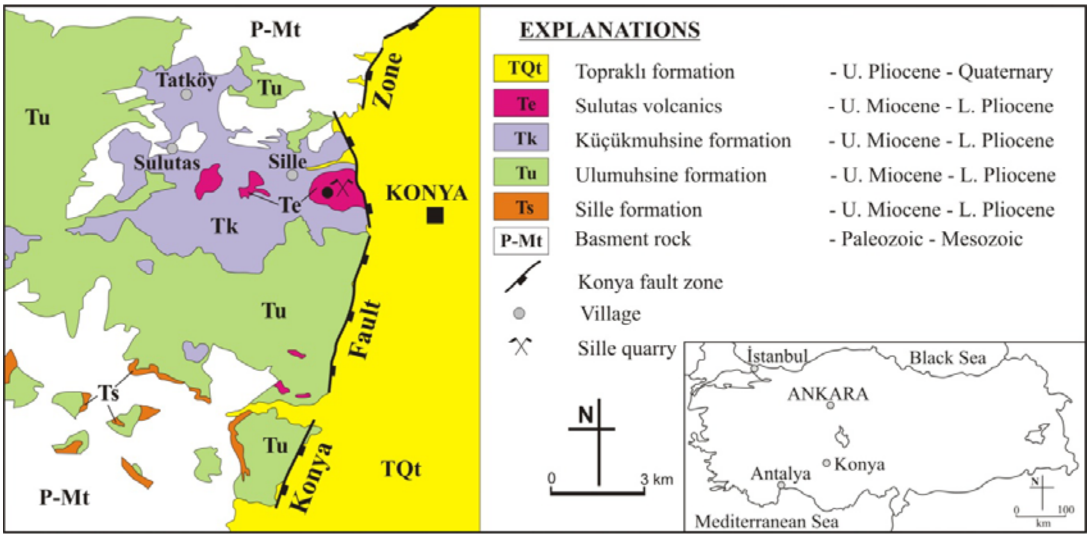

Fig. 3. Simplified geological map of the region [31]

3. Experimental Study. Petrographic analyses were carried out in the region on these rocks known as Sille Stones by taking samples from different levels before compilation. They are classified according to their various petrographic structures in Aya Helena Church. In accordance with this classification, 32 blocks of sample compositions having various petrographic structures were obtained by taking samples from different locations for Samples 1, 2, 6, 7, 8 and at 3 different elevations from same location for Samples 3, 4 and 5. The locational information of the rocks is given in Table 1.

Table 1

The sampling locations and color properties of the rocks

Sample	Location	Color
1	37.922459, 32.417578	Grayish
2	37.922545, 32.417814	Grayish
3	37.922826, 32.417706	Grayish-pink
4	37.922826, 32.417706	Grayish-pink
5	37.922826, 32.417706	Grayish-pink
6	37.921669, 32.418318	Light pink
7	37.920725, 32.415586	Black
8	37.922228, 32.419213	Light pink

3.1. Petrographic Examinations. Thin sections were prepared according to the recommendations in TS EN 12407 (2013) [33] for the determination of petrographic properties of the samples.

3.2. Index Properties. The index properties of rocks were determined for BX (42 mm) core samples. Dry density and porosity were determined according to ISRM (2006) [34], while water absorption ratios by weight were determined according to the method proposed by RILEM (1994) [35].

3.3. Capillary Water Absorption Test. Water absorption values due to the capillary effect were determined according to ASTM C1794 (2015) [36]. The samples were placed in a tank filled with 3±1 mm of water for 1, 3, 5, 10, 15, 30, 60, 480, 1440 minutes according to the method specified in this standard. With the values obtained, the weight / area-time ($t^{1/2}$) diagrams were plotted. From the slopes of these graphs, the water absorption coefficients of the samples were calculated depending on the capillary effect.

3.4. Uniaxial compressive strength and flexural tensile strength tests. The uniaxial compressive strengths of these samples were made on the core samples with a length / diameter ratio of 2 according to the method recommended by ISRM (2006) [34]. The obtained results were corrected depending on the strength of the 50 mm equivalent core sample [37].

The flexural tensile strength test was performed on the samples of 25 × 100 × 125 mm rectangular prisms according to the method given in TS EN 12372 (2007) [38].

3.5. Freeze-Thawing (F-T) Test. The F-T test was carried out according to the method given in ASTM D5312 (2013) [39]. The samples were frozen at –18±2.5 ° C for 12 hours and thawed at +32±2.5 ° C. For each group, three samples were used. According to Binal [40], the annual freeze-thaw cycles for Konya and its surroundings were determined at 20 cycles. In this study, the number of F-T cycles for samples were considered as 20.

Results and Discussion

1. Petrographic properties. The results of the petrographic examinations of thin sections made from the samples taken from the Sulutas Volcanics are given in Table 2. The dough phases of the other volcanic rocks except plots 6 and 8 have been formed via plagioclase microlites and volcanic glass (Table 2, Fig. 4.a, b, c, d and g) that the plagioclase microlites are small sized and long prismatic shaped crystals. In the case of samples 6 and 8, the dough phase is entirely composed of volcanic glass (Fig. 4.f and h). Some of the hornblende and biotite crystals in the volcanic rocks studied here, sometimes presented partial and occasionally complete opacities from the edges (Fig. 4.a and e) that these mafic minerals show little oxidation. Particularly in samples 3 and 5, silicification was commonly observed under the influence of hydrothermal solutions during the dough phase of the rock (Fig. 4.c and e) that secondary quartz minerals in very small sizes appeared resulting from silicification. Also in these samples, porosity was widely obtained in micro dimensions (Fig. 4.c).

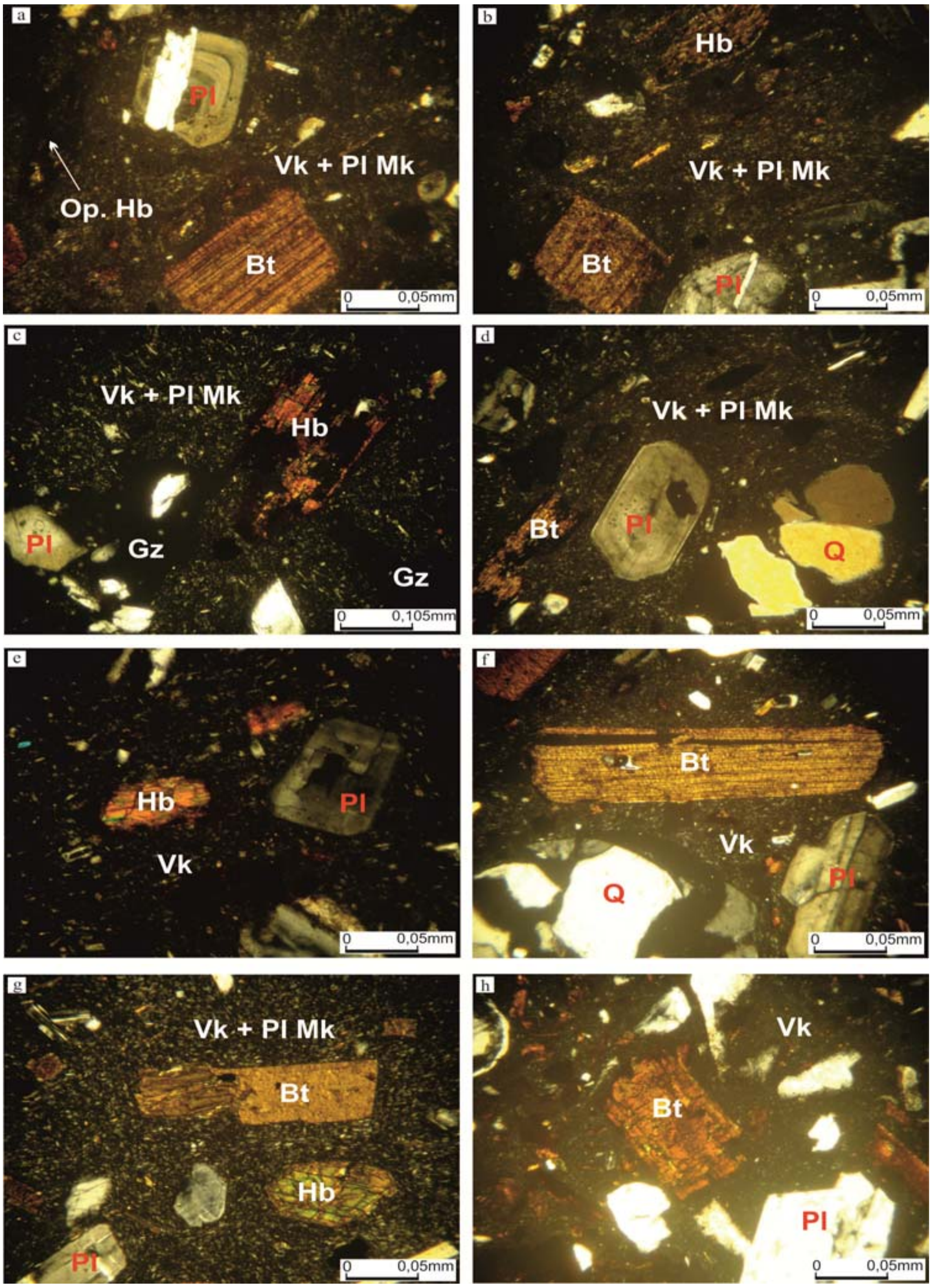

Fig. 4. Plagiodacites (a, b, c, d, e ve h) and dacites (f ve h).
Pl: Plagioclase, Hb: Hornblende, Op. Hb: Opacified hornblende, Bt: Biotite, Q: Quartz, Vk: Volcanic Glass, Pl Mk: Plagioclase Microlites, Gz: Pore. (a): Sample 1, (b): Sample 2, (c): Sample 3, (d): Sample 4, (e): Sample 5, (f): Sample 6, (g): Sample 7, (h): Sample 8 (Cross Nikol)

Considering their mineralogical composition, Streckeisen [41] classified the samples 6 and 8 as "dacite" and the other samples as "plagiodacite" according to their classification (Table 2).

Table 2

The minerals, % values and rock names of the samples taken from Sulutas Volcanites

Minerale	Samples (%)							
	1	2	3	4	5	6	7	8
Plagioclase	25	23	27	23	28	26	23	28
Amphibole (Hornblende)	10	12	14	12	11	10	11	12
Biotite	15	15	9	8	9	17	13	13
Quartz	9	9	10	10	10	9	12	10
Sanidine	—	—	—	—	—	5	—	6
Plagioclase microlites	10	12	7	15	12	—	23	—
Volcanic Glass	30	28	31	30	30	32	16	30
Apatite	—	—	1	1	—	—	1	—
Opaque Mineral	1	1	1	1	1	1	1	1
Rock Name	Plagio-dacite	Plagio-dacite	Plagio-dacite	Plagio-dacite	Plagio-dacite	Dacite	Plagio-dacite	Dacite

2. Index and Geomechanical properties. The index properties of dry density, porosity, water absorption and capillarity are given in Table 3.

Table 3

Index properties of the samples

Index properties	1	2	3	4	5	6	7	8
ρd-g/cm^3	2.187	2.132	2.076	2.211	2.238	2.269	2.448	2.215
n-%	7.721	8.853	15.591	9.983	10.892	8.384	1.552	7.676
Wa-%	3.554	4.146	7.499	4.508	4.857	3.688	0.633	3.500
C-(g/m^{2}min$^{1/2}$)	15.50	17.12	83.67	74.01	77.39	69.13	2.01	48.25

ρd: Dry density, n:Porosity, Wa:Water absorption by weight, C: Capilarity.

From the results of the index tests, the dry density values of the samples ranged from 2.08 g/cm^3 to 2.44 g/cm^3 and the porosity values varied from 1.55 % to 15.59 %. According to Norwegian Group for Rock Mechanics (NBG) (2000) [42], the porosity value of the Sille stone varies from “low” to “high”. The value of capilarity is “very low” to “low”. The capilarity values of the samples were obtained between 2.01 and 83.67 g/m^{2}min$^{1/2}$.

The uniaxial compressive strength and flexural tensile strength values for each sample group are given in Table 4. It is seen that Sample 7 presented the highest strength among the tested rocks. However, the strength values of Samples 6 and 8 used in this region and called as Sille Stone with their characteristic pink color were the lowest values of all rocks. After sorting the sample rocks according to their compressive strength values by considering their colors; the pink colored rocks had the lowest and the black colored rocks had the highest compressive strength values, and it is also observed that the compressive strength values of the sample rocks increased from pink color to gray color, and gray color to black color. The highest tensile strength is determined for sample 7 and the lowest for sample 3.

Table 4

Result of uniaxial compressive strength and flexural tensile strength tests

Geomechanical Properties	1	2	3	4	5	6	7	8
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
σ_u-Mpa	31.49±0.93	21.20±2.63	11.18±2.44	27.10±2.44	25.63±2.20	19.65±2.78	39.07±4.10	16.72±1.29
τ_u-Mpa	11.52±1.19	6.23 ±0.96	4.29 ±0.78	8.42 ±1.16	9.57 ±1.03	4.93 ±0.97	13.45±1.57	6.84 ±0.81

σ_u: Compressive Strength, τ_u: Flexural Tensile Strength.

3.3. The strength loss of the samples as a result of F-T test. The UCS values before and after the F-T tests and the strength loss values are given in Table 5.

Table 5

The strength loss of the samples as a result of F-T

Sample	UCS before F-T test (MPa)	UCS after F-T test (MPa)	Percentage loss in UCS, %
1	31.49±0.93	31.30±4.87	0.60
2	21.20±2.63	21.08±1.31	0.56
3	11.18±2.44	*	100
4	27.10±2.44	23.84±4.17	12.07
5	25.63±2.20	*	100
6	19.65±2.78	19.29±2.48	1.86
7	39.07±4.10	37.74±7.68	3.38
8	16.72±1.29	16.48±0.77	1.47

UCS: Uniaxial compressive strength.

(*) the test could not be performed since the samples were broken.

The least loss of strength is seen in sample 2. The highest loss appeared in sample 4. In samples 3 and 5, the UCS test could not have been performed due to the cracks occurred after the F-T process (Fig. 5). Due to the fact that the samples 3 and 5 were exposed to hydrothermal alteration, their influence on the F-T process was accelerated. As many researchers [2, 20] indicated, there is a strong relationship between the F-T process and porosity. When the loss of strength was examined, the highest values were observed in samples with high porosity (Samples 3—5).

Fig. 5. Macro cracks as a result of F-T test (a) Sample 3 (b, c,d), Sample 5

Conclusion. Volcanic rocks are widely used building materials due to their easy processing properties. Sille Stone is a building material of volcanic origin, which is widely used in historical constructions especially in Konya region.

Based on the analyses, the following main conclusions were drawn.

— When the Aya Helena Church and sample collection area is examined, it has been determined that the color, texture, petrographic and index-mechanical properties of the building stone, spreading in a very confined space, also known as the Sille stone, show quite many differences.

— The porosity of the Sille Stones are between 1.552 % and 15.591 %, while the dry density values are between 2.076 and 2.448 g/cm^3.

— The capillarity values range from 2.01 to 83.67 g/m^{2}min$^{1/2}$.

— The uniaxial compressive strength values of the samples widely vary depending on the textural properties of the rock, such as 11.18 and 39.07 MPa.

The main factors in determining the effects of F-T process on the rocks are the textural properties, porosity and capillarity values of rocks.

As appeared from the results, it is seen that the rocks used in Aya Helena Church having characteristic pink and pinkish grey colour, have quite different petrographic, index and mechanical properties, although they are taken from a narrow region. It is thought that the correct selection of the rock, especially considering the restoration and renovation of historical structures built with this stone in the region, is considered to be an important factor to determine the life of these constructions.

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