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The effect of using volcanic tuff aggregates with different grain sizes in facade cladding material on physical and mechanical properties

Cephe kaplama malzemesinde farklı tane boyutlarına sahip volkanik tüf agregalarının kullanımının fiziksel ve mekanik özelliklere etkisi

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The Effect of Using Volcanic Tuff Aggregates with Different Grain Sizes in Facade Cladding Material on Physical and Mechanical Properties

Highlights

- *Research has been carried out on the potential of raw materials for sustainable building material.*
- *The purpose of using inert aggregate areas in the production of building materials was analysed.*
- *A method on the effect of aggregate particle size on physical and mechanical properties is established,*
- *The effects of the variables in the aggregate particle size on resistance to frost action are analyzed,*
- *The effect of microporous structure on the vapour permeability value was investigated.*

Graphical Abstract

Inert aggregates were grouped into 4 granulometries with different grain sizes. For each group, 4x4x16 cm sized samples were prepared and their physical, mechanical and microstructure properties were analysed.

Figure. Sample production and test process with aggregates of different grain sizes.

Aim

It is aimed to utilise the inert volcanic tuff field as aggregate in the production of building materials.

Design & Methodology

The aggregates taken from the site were separated according to grain sizes in 4 different granulometries. For each group, 4x4x16 cm sized samples were produced. In addition, witness samples were prepared with the materials used in exterior plaster mortars for comparison. Experimental analyses were carried out on the prepared samples to determine the physical mechanical and microstructure properties.

Originality

The research is a unique study in terms of reusing the idle volcanic tuff field, contributing to the local and regional economy and contributing positively to sustainable construction processes.

Findings

According to the test results, it was concluded that the mechanical strengths were similar in all groups, but in the freeze-thaw test, one of the species showed much more strength than the other species and the witness sample.

Conclusion

It was concluded that the difference in grain size affects the physical and mechanical properties with the experiments performed on the samples prepared according to different grain sizes.

Declaration of Ethical Standards

The author of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

The Effect of Using Volcanic Tuff Aggregates with Different Grain Sizes in Facade Cladding Material on Physical and Mechanical Properties

Araştırma Makalesi / Research Article

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ABSTRACT

Pyroclastic rocks of volcanic origin formed at different stages of volcanism find widespread use in the production of building materials. The present study addressed a field that was operated for the use of volcanic tuff, one of the pyroclastic rocks, as a material but abandoned since it could not provide the expected performance. For this idle field to be a valuable raw material source in the production of building materials, changes in the physical and mechanical properties of the material produced in different particle sizes were investigated to determine the aggregate properties. Since the aggregate type was considered suitable for the building cladding material, the research topic was determined accordingly. In the study, in which white cement was used as a binder, four different sample types were obtained by classifying aggregates according to various particle sizes. In the study, in which white cement was used as a binder, four different sample types were obtained by classifying aggregates according to various particle sizes. The present study showed that differences in aggregate particle sizes affected the physical and mechanical properties of the material and a light and durable building cladding material could be produced accordingly.

Keywords: Volcanic tuff, building cladding materials, exterior plaster, physical properties, mechanical properties.

Cephe Kaplama Malzemesi Bünyesinde Farklı Tane Boyutlarında Volkanik Tüf Agrega Kullanımının Fiziksel ve Mekanik Özelliklere Etkisi

ÖZ

Volkanizmanın farklı aşamalarında meydana gelen volkanik kökenli piroklastik kayaçlar yapı malzemesi üretiminde yaygın kullanım imkanı bulurlar. Çalışmada piroklastik kayaçlardan olan volkanik tüflerin malzeme olarak kullanılması amacıyla işletilmiş ancak beklenen performansı sağlayamadığı için terkedilmiş bir saha ele alınmaktadır. Atıl haldeki bu sahanın yapı malzemesi üretiminde değerli bir hammadde kaynağı olabilmesi adına agrega özelliklerin belirlenmesi bu doğrultuda farklı tane boyutlarında üretilen malzemenin fiziksel ve mekanik özelliklerinde değişim araştırılmıştır. Agrega türü yapı cephe kaplama malzemesine uygun görüldüğünden araştırma konusu bu yönde oluşturulmuştur. Beyaz çimentonun bağlayıcı olarak kullanıldığı çalışmada agregalar çeşitli tane boyutlarına göre sınıflandırılarak dört farklı numune tipi elde edilmiştir. Araştırmada volkanik tüf agreganın özelliklerinin belirlenmesinde çimento bağlayıcılı cephe kaplama malzemesi olarak yaygın kullanımı olan dış sıva uygulamaları metot olarak kabul edilmiştir. Bu doğrultuda dış sıva standartlarında belirtilen numune hazırlama ve test metotları çalışma kapsamını oluşturmaktadır. Beyaz çimentonun bağlayıcı olarak kullanıldığı çalışmada agregalar çeşitli tane boyutlarına göre sınıflandırılarak dört farklı numune tipi elde edilmiştir. Ayrıca yaygın dış sıva üretiminde kullanılan kırma taş agregalı referans numune hazırlanarak volkanik tüf agregalı diğer türlerle sonuçları karşılaştırılmıştır. Yapılan çalışma ile agrega tane boyutlarındaki farklılıkların malzemenin fiziksel ve mekanik özelliklerini etkilediği, bu doğrultuda hafif, dayanıklı bir cephe kaplama malzemesi üretilebileceği görülmüştür.

Anahtar Kelimeler: Volkanik tüf, yapı kaplama malzemeleri, dış cephe sıvası, fiziksel özellikler, mekanik özellikler

1. INTRODUCTION

Volcanic tuffs are among the dozens of rock types, formed during volcanic activity, that differ in texture, components, and size. These different types of rocks, which are ejected as fragments from vents due to the volcanic eruption, were given the common name pyroclastic rocks. Hydroclastic fragments are formed in the parts that have water interaction with magma by steam eruption, rapid cooling, or mechanical granulation of the lava. These fragments form pyroclastic rocks arising from the eruption. Apart from these, fragments, which are the result of weathering and transport of volcanic rocks (epiclastic) [1], mechanical friction and gas eruptions during lava movement (autoclastic), are also called pyroclastic rocks [2]. Pyroclastic rocks ejected from the vent by eruption spread to the environment and form stacks in layers on the natural ground. Although pyroclasts are named according to their composition or origin, particle size is essential in general.

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Such naming includes ash (volcanic tuff) (<2 mm), lapilli (2-64 mm), bomb, or block (>64 mm) [2, 3].

With their lightness, easy accessibility, and hollow structure, pyroclastic rocks create a breathable environment within the structure where they are used. In this respect, it is known that products of volcanic origin contribute significantly to the properties of building materials [4, 5]. Pumice, basaltic pumice, and volcanic tuffs are common types of pyroclastic rocks used in the building industry [6, 7]. Depending on the movement of volcanism, they can sometimes exist intertwined. However, neither pumice nor basaltic pumice nor volcanic tuffs are products with the same physical and chemical characteristics. Color and texture differences are sometimes observed, while chemical contents often contain differences. Therefore, pumice and basaltic pumice have been able to find more widespread use in terms of their properties in the construction sector [8-12]. They are widely used in the production of lightweight concrete, especially since they have dimensions that can be concrete aggregate. Volcanic tuff, named in the same group, is not preferred as an aggregate due to its fine-grained structure. Hence, it could not find enough use in the sector. Volcanic tuffs are used more commonly in the construction sector in cement raw material [13, 14] or geopolymer [15, 16] applications by grinding.

There are many literature studies on sustainable building material production. In particular, material production with raw materials recycled from waste materials provides significant contributions to environmental protection as well as economic and sustainable construction process [17-19]. In this direction, it can be said that the u of inert volcanic tuffs in building material production will support alternative local resource utilization and a sustainable construction process with reduced economic and environmental impacts.

Due to the above-mentioned properties, building material suppliers have put pyroclastic fields into operation. While some fields containing pumice and basaltic pumice continue to work actively, some volcanic tuff fields were abandoned because they did not provide the expected performance. It is important to reclaim these idle fields. Accordingly, it was planned to produce building materials with the materials obtained from the idle field in the present study.

Building material production processes play an important role in the formation of problems such as global warming and climate change. In this regard, it is important for environmental protection that the building material contributes to issues such as sustainable raw materials that do not generate waste as much as possible and have a long service life. In line with this purpose, it can be said that producing a quality building material depends on raw material properties.

The fact that volcanic tuff is light, porous, and fine-grained indicates that it can be a breathable building cladding material made of cement. In line with this, exterior plaster applications used in the traditional method in local buildings determined the study method. The standards and literature used for exterior plaster mortars guided the creation of the method.

Within the scope of this study, the volcanic tuff field, which was put into operation for use in the production of building materials but became idle after it could not provide the expected performance, was addressed. In the study, samples were taken from the idle tuff field to be used as aggregate. Different mixture types were designed according to the particle size with the samples taken. In this way, it was revealed how differences in particle size affected the physical, mechanical, and micro internal structure of a building cladding material. Thus, the study was conducted in the direction of usability in the production of a quality building material with the understanding of sustainable raw material.

2. MATERIAL and METHOD

In the study, volcanic tuff will be used as an aggregate in a cement-bound building cladding material. Therefore, it was planned to compare it with the traditional cement-bound plaster application. Accordingly, witness samples were prepared with the aggregate obtained from crushed stone quarries, widely used as a plaster aggregate in the region. Except for all different aggregate types, white cement and mixing water were used as materials in the sample production.

2.1. Material

Aggregate, cement and mixing water were used in the preparation of the test specimens.

2.1.1. Aggregate

Volcanic tuff aggregates and crushed stone aggregates obtained from their natural environment were used in the study.

Volcanic tuff aggregates (VT): The idle volcanic tuff field located between 38º2’8.96”N latitude and 32º28’13.07”E longitude coordinates is situated in Konya province, Turkey. Aggregate was obtained from the region to be used in the experiments.

Concerning the geological structure of the region, it is seen that the area where samples were collected belongs to the Küçükmuhsine formation. Tuff, tuffite, volcanic breccia, agglomerate, and volcanogenic sandstone are the prominent rock types of the Küçükmuhsine formation. Tuff, tuffite, and volcanogenous sandstones are bedded around 20 cm. According to the microscopic characteristics, tuffs are lithic, crystal, and vitric tuff, and their components are plagioclase, amphibole crystals, biotite, quartz, and volcanic glass. Coarse-grained volcaniclastics, on the other hand, have a thick-layered and massive appearance composed of dacite and andesite fragments. Volcaniclastics bound with volcanic ash have volcanic breccia or agglomerate properties since they have round or angular components [20].

Crushed stone aggregate (CS): Crushed stone aggregate provides widespread use in exterior plaster mortars made with the traditional method. Therefore, the aggregate, which is widely used in the region, was taken from a part prepared as plastering sand from crushed stone from a private enterprise (Darbazlar Sand Pit) located between the coordinates of 38º05'25''N and 32º42'44''E in Karaömerler Neighborhood, Selçuklu District, Konya Province.

Considering the region's geological structure, it is seen to be included in the Lorasdağı formation when evaluated according to its location. The lithology of the Lorasdağı formation consists of recrystallized limestone, dolomitic limestone, and dolomites with occasional metachert interlayers, which are generally grayish but sometimes brown-red when viewed from afar. They are gray, dark gray, black, cream, and white in color on their fresh surfaces, and they are prominently bedded in their transitions with the Aladağ formation. Metacarbonates, which present a laminated interior structure in some sections, are medium-thick bedded. A common brecciated texture is occasionally encountered in these stones. Sections protected from recrystallization are generally micrite, intramicrite, and dolomicrite. At different levels of the formation, metacherts, which are generally consistent with bedding among metacarbonates, are gray, black, and white in color. Their thickness is around 15 cm at most [21]. It can be stated that the plastering sand prepared as crushed stone in the sand quarry located in the region is light gray-white in color, and in this sense, plastering sand was acquired by breaking the marble, which is the characteristic rock type of the Lorasdağı formation and contains carbonate.

2.1.2. Cement

It was produced by ÇİMSA company in accordance with EN 197-1 and "White Portland Cement" (CEM I 52,5 R), whose product name is "Super White," which is sold in 25 kg packages and whose chemical, physical, and mechanical properties are specified in Table 1, was used.

2.1.3. Mixing water

Drinkable water, which is suitable for cement-bound mortars specified in EN 1008 and does not need analysis, was used as mixing water in the present study.

2.2. Method

The inert volcanic tuff deposit is considered as an alternative aggregate (raw material). In this direction, concrete or plaster etc. It has shown the idea that it can be used as aggregate in mortars. It was thought that the material would not be useful for concrete mortar in terms of grain size and mechanical strength properties. For this reason, it was deemed appropriate to be used in mortar production such as plaster etc. on building facades. As the scope of the study, it was considered to investigate whether the use of inert volcanic tuff aggregates of Konya Küçükmuhsine Forfmation in different grain sizes is effective in mortar by experimental method. Since the aggregate potential in mortar production such as plaster, which is widely used as facade cladding material, will be discussed, crushed stone aggregate, which is widely used as plaster aggregate in the region, was used to prepare a comparison (reference) sample. In this direction, the experimental method was kept in two stages. The first one is to determine the physical, chemical and mineralogical properties of the aggregates and the second one is to prepare samples for the tests and subject them to the tests. Since the aggregates will be used in the mortar, cement mortar stainless steel molds with dimensions of 4x4x16 cm will be used for sample production. Physical, mechanical and microstructural properties will be investigated on the test specimens by the methods specified in the relevant TSE and EN standards. The flowchart of the experimental method is given in Figure 1.

Table 1. Chemical, Physical, and Mechanical Properties of White Portland Cement

Chemical Properties	Çimsa Super White (%)	Physical and Mechanical Properties	Çimsa Super White
SiO_2	21.6	Specific Weight	3.06 g/cm^3
AI_2O_3	4.05	Specific Surface (Blaine)	4600 cm^2/g
Fe_2O_3	0.26	Whiteness Y	85.5%
CaO	65.7	Initial Setting	100 Minutes
MgO	1.30	Completion of Setting	130 Minutes
SO_3	3.50	Water	30.0%
Na_2O	0.30	Volume Constancy (Le Chatelier)	1.0 mm
K_2O	0.35	Residue in a 0.045 mm Sieve	1.0%
Chloride (CI)	0.01	Residue in a 0.090 mm Sieve	0.1%
Free CaO	2.20	2-day Compressive Strength	37.0 MPa
Insoluble Residue	0.18	7-day Compressive Strength	50.0 MPa
Ignition Loss	3.50	28-day Compressive Strength	60.0 MPa

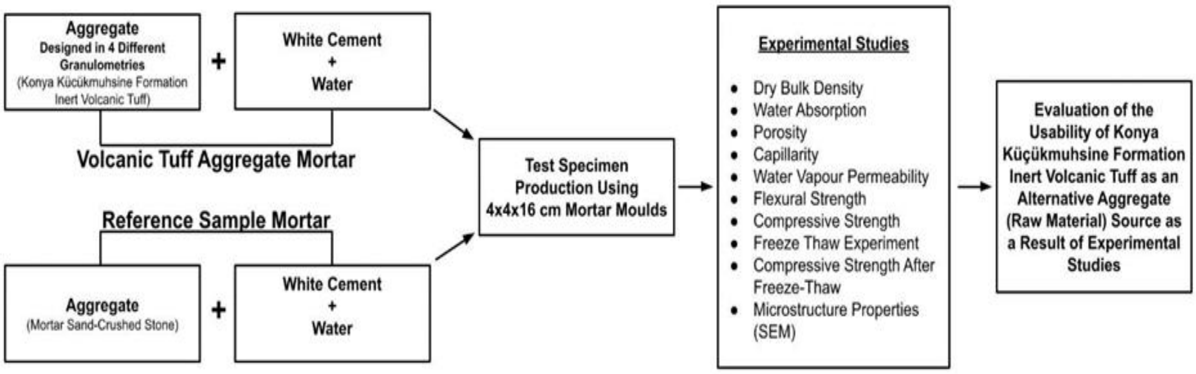


Figure 1. Experimental Method Flowchart

2.2.1. Aggregate property analysis

XRD, XRF, particle density, and particle distribution analyses were performed for the aggregates to be included in the samples used in the experiments.

X-Ray diffractometry (XRD): The Science and Technology Research and Application Center (BITAM) Laboratories at Necmettin Erbakan University (NEU) were used for X-ray diffractometry analysis. Accordingly, the ground aggregate (rock) samples were analyzed in a PANalytical EMPYREAN XRD device. Figure 2 shows the XRD analysis graph for volcanic tuff and crushed stone aggregates.

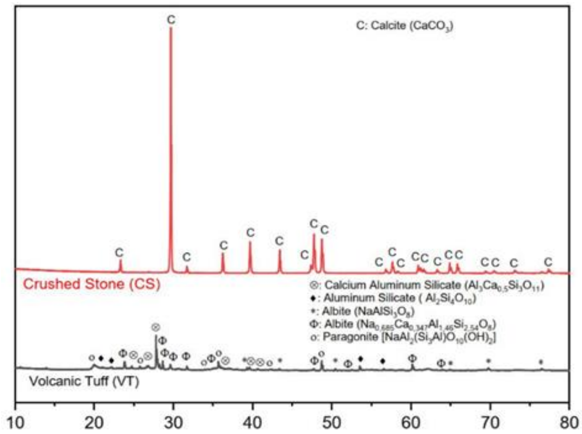


Figure 2. XRD Analysis of Volcanic Tuff (VT) and Crushed Stone (CS)

X-Ray fluorescence spectrometry (XRF): X-ray fluorescence spectrometry analysis was performed in NEU BITAM laboratories. The Rigaku – NEX-CG device was used in the analysis. The chemical analysis results for volcanic tuff (VT) and crushed stone (CS) are given in Table 2.

Table 2. The chemical analysis of Volcanic Tuff (VT) and Crushed Stone (CS)

Aggregate Type	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	Na_2O	TiO_2	ZrO_2
Volcanic Tuff (VT)	42.5	10.3	6.74	3.51	1.86	1.69	1.21	0.425	0.307
Crushed Stone (CS)	0.276	0.154	59.0	0.054	0.107	0.027	-	0.006	0.447

Particle density: The particle density test was conducted on aggregates according to EN 1097-6. The procedure was carried out with the pycnometer method described in the standard for aggregates with a particle size range from 0.063 mm to 4 mm. Table 3 contains the results of the particle density test performed on the aggregates.

Table 3. Particle Density of Volcanic Tuff (VT) and Crushed Stone (CS)

Aggregate Type	Particle Density (Mg/m^3)
Volcanic Tuff (VT)	2.63
Crushed Stone (CS)	2.71

Particle size distribution: Particle distribution analysis was carried out using the method described in EN 933-1 and sieves with nominal aperture sizes of 0.063 mm, 0.250 mm, 0.500 mm, 1 mm, 2 mm, and 4 mm specified in EN 933-2. The granulometries obtained as a result of the sieve analyses for volcanic tuff and crushed stone aggregates are given in Figure 3.

2.2.2. Sample preparation

Samples were produced as nine 40x40x160 mm samples (according to the dimensions specified in EN 1015-11) for use in the tests of physical properties (unit volume weight, water absorption, capillarity, water vapor permeability, etc.) and mechanical properties (flexural strength, compressive strength, compressive strength after freeze-thaw) of all different aggregate mixture types, one 10x10x10 mm sample to be used in SEM analysis, and one ∅65x14 mm sample (∅65 mm is the mouth width of the test container) to be used in the water vapor permeability test [22, 23].

In the sample production, the material ratios to be used in the mixture are not specified in the current EN 998-1 and EN 13914-1 standards for exterior plaster mortars. Hence, the mixture ratios were adjusted according to TS 1481, which is not in force and was replaced by the EN 13914-1 standard [24, 25]. The amount of aggregate to be used in sample production was determined according to the mold volumes. The determined section was weighed, and the proportion of cement and water was calculated according to TS 1481 in Table 4.

Table 4. Mixing Ratios for Samples

Materials	Mixing ratio (kg) according to TS 1481	Required material for all molds (kg)				
		CS* (kg)	VT-A** (kg)	VT-B** (kg)	VT-C** (kg)	VT-D** (kg)
Aggregate	1500	6.60	4.00	5.50	4.00	5.10
Cement	350-500	2.64	1.60	2.20	1.60	2.04
Water	140-170	1.36	1.74	2.58	1.24	2.62

* *CS: Crushed Stone, **VT-A-B-C-D: Volcanic Tuff*

The hypothesis 'The strength of volcanic tuff aggregate specimens depends on the grain size of the aggregate' is the main plan of the study. Therefore, this hypothesis will be tested by preparing specimens with different grain sizes. In this direction, the following algorithm was used as a method to prepare specimens with different grain distributions. Firstly, the aggregates passing below 4 mm sieve were ensured to have a grain size suitable for the ideal granulometry curve (VT-A). Therefore, in this type, the material remaining on each sieve is proportional to itself. The other type was to use the aggregate mass obtained by spalling the tuff pile as it was (VT-B), the third group was prepared without any fine grains (VT-C, without those below 2 mm sieve) and the fourth group was prepared without coarse aggregates (VT-D, without those above 0.5 mm sieve). For the locally sourced crushed stone aggregate used in the production of existing plaster mortar, all aggregates below 4 mm sieve were used as is.

Even if pyroclastic rocks are gathered under the same group name, they may exhibit different properties among themselves, according to their location and even according to their grain size when used in a building material [26]. Five different types of sample groups, named below, were formed according to the type and size of aggregate entering the mixture.

Volcanic tuff type A (VT-A): For this type, aggregate particle distribution was designed. All of the aggregate to be used was arranged to pass through a 4 mm sieve aperture size. In the other sieve numbers, planning was made in a way that the amount of material remaining on the sieve and the amount of material passing through the sieve would be equal. Figure 3 shows the granulometry curve for this type.

Volcanic tuff type B (VT-B): In this type, the disturbed material that passed through a 4 mm sieve in aggregate particle size was used. Therefore, the distribution of particle sizes was determined by sieve analysis for this type and is given as a granulometry curve in Figure 3.

Volcanic tuff type C (VT-C): To monitor the effect of using aggregates with different particle sizes on physical and mechanical properties, two more sample types with different aggregate particle sizes were prepared by determining the sieve aperture limit. The first was used from the part that passed through the 4 mm sieve and remained on the 2 mm sieve to obtain coarser grains. Accordingly, the material particle distribution is presented in Figure 3.

Volcanic tuff type D (VT-D): Considering that it is more fine-grained than volcanic tuff type C, the aggregate that

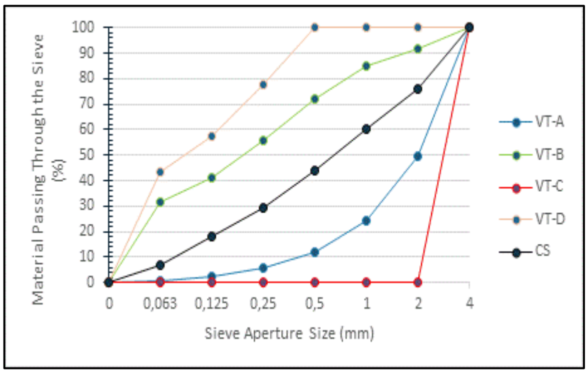


Figure 3. Aggregate Granulometries of the Sample Types

passed through a sieve with a 0.5 mm aperture size was used as the last different type. Figure 3 shows the aggregate granulometry used for this type.

Crushed stone (CS): Crushed stone plastering sand, all of which passed through a 4 mm sieve, was used to prepare the witness sample. The crushed stone aggregate granulometry used to prepare the test sample is given in Figure 3.

Optimal mixing ratios were determined by preliminary trials according to the above-mentioned granulometry and are presented in Table 4.

2.2.3. Experiments on samples

The following analyses were conducted on 5 different types of the samples prepared.

Dry bulk density: The test was performed according to EN 1015-10 [27].

Water absorption: The method specified in EN 13755 was employed to determine the Water Absorption Coefficient [28].

Open porosity: The EN 1936 standard was used to calculate the open porosity value [29].

Capillarity: To determine the capillarity coefficient, the test was carried out in accordance with the method specified in EN 1015-18 and the samples' capillarity coefficient was calculated using the formula given in the standard [30]. Two samples from a different sample group were tested, and the arithmetic average of the calculation results was taken.

Vapor permeability coefficient: Vapor permeability coefficient determination experiments were carried out with the method specified in the EN 1015-19 standard. Accordingly, the container method providing high humidity was preferred. Saturated potassium nitrate (KNO_3) solution was used for the container with high humidity. According to the experimental system, there was a change in weight that occurred with the transfer of water vapor from the sample body from the saturated solution providing high humidity (93.2% RH) to the environment with constant humidity (39% RH) in the laboratory environment. The water vapor coefficients were computed with the help of the obtained data and the formula specified in the standard.

Flexural strength: Flexural strength tests were conducted in NEU BITAM laboratory. For each type, three 4x4x16 cm prism samples produced according to EN 1015-11 were used. The samples were tested with the SHIMADZU AGS-X (100 kN) device. According to the three-point bending test method, the clear span was set to 120 mm. Constant force loading was set to 50 N per second. The test was continued until the samples were divided into two parts. The arithmetic average of the results obtained from 3 samples for each type was taken and given as the flexural strength value in the study.

Compressive strength: The EN 1015-11 standard was used as the method for compressive strength analysis. To determine compressive strength, the device of the brand specified in the flexural strength test was used. In the flexural strength test, all surfaces of the prisms divided into two were cut into 4x4x4 cm cubes. Accordingly, a total of 6 samples for each type were tested. The device was set to apply a force of 500 N per second. The test was performed until the sample completely lost its strength. The arithmetic average of the results acquired from 6 samples for each type was taken and recorded as the compressive strength value.

Resistance to frost action: Resistance to frost action was measured in the BITAM laboratory of Necmettin Erbakan University. In the experiment, a LIEBHER MEDiline GCv 4010 device set to a constant temperature of -25 ºC (±2) was used for freezing, and a water pool at the ambient temperature of 20 ºC (±2) was used for thawing. The freeze-thaw test was carried out on the samples according to the method described in the CEN/TR 15177 standard. The process of storage in the freezer for 8 hours and the water pool for at least 4 hours was accepted as a cycle. The freeze-thaw test was performed with 56 cycles. Unlike the standard, the samples that did not disintegrate during this period were subjected to the post-freeze-thaw compressive strength test.

Scanning electron microscopy (SEM): The Hitachi – SU 1510 device in NEU BITAM laboratory was used in the SEM analysis. Micropores and microcracks, which are likely to affect physical and mechanical properties, were investigated by applying 50x, 500x, and 5000x magnifications to the determined surface.

3. RESULTS and DISCUSSION

The following findings were obtained as a result of the physical and mechanical experiments on the samples.

Dry bulk density: In terms of dry bulk density, the reference sample made of crushed stone was the heaviest sample type. Whereas VT-C sample reached the highest value in terms of dry bulk density among the samples with volcanic tuff aggregates, VT-A and VT-B samples yielded almost the same value, and VT-D sample yielded the lowest value (Table 5). In a study, the dry bulk density value of mortar produced with volcanic tuff aggregates was calculated as 2170 kg/m3. This result revealed that the dry bulk density depends on the properties of volcanic tuff aggregates [31]. In the samples prepared with different grain sizes of the volcanic tuff aggregates used in our study, the highest dry bulk density value was found to be 1407 kg/m3. This result shows that the building material obtained from the inert area will be quite light, which will play an important role in reducing unwanted loads in the whole structure.

Water absorption: Concerning water absorption performance, VT-D sample had the highest water absorption value, while VT-A and VT-B samples yielded very close values to each other. Although VT-C sample was the least water-absorbing type in the volcanic tuff group, the reference sample produced from crushed stone was the least water-absorbing sample type within the scope of the study (Table 5). High water absorption potential can reduce the compressive strength. In a study conducted in this direction, it was found that the compressive strength of volcanic tuff impregnated with water for 48 hours decreased by 43.99% [32]. As a result, reducing the water absorption potential of volcanic tuff material is important for the preservation of mechanical strength. In order to maintain the strength of the building material within the mortar, it may be recommended to use water repellent materials that will reduce the water absorption rate.

Table 5. Physical and Mechanical Properties

	VT-A	VT-B	VT-C	VT-D	CS
DBD[1] (kg/m^3)	1340 (±2)	1343 (±4)	1407 (±5)	1311 (±3)	2031 (±1)
WA[2] (%)	32.44	32.61	26.23	35.15	11.05
P[3] (%)	43.59 (±0.22)	43.92 (±0.84)	37.00 (±0.36)	46.21 (±0.25)	22.50 (±0.30)
C[4] ($Kg/m^2.min^{0.5}$)	$4.69x10^{-2}$	$6.05x10^{-2}$	$2.97x10^{-2}$	$6.05x10^{-2}$	$1.75x10^{-2}$
WVP[5] (kg/m2.s.Pa)	$0.18x10^{-9}$	$0.12x10^{-9}$	$0.18x10^{-9}$	$0.18x10^{-9}$	$0.03x10^{-9}$
FS[6] (N/mm^2)	1.72 (±0.06)	1.35 (±0.33)	1.91 (±0.15)	1.02 (±0.09)	7.74 (±0.72)
CS[7] (N/mm^2)	12.75 (±0.49)	14.71 (±0.97)	10.82 (±1.09)	13.96 (±0.84)	38.68 (±0.91)
CSAFT[8] (N/mm^2)	-	-	3.94	-	-

Dry Bulk Density[1], Water Absorption[2], Porosity[3], Capillarity[4], Water Vapor Permeability[5], Flexural Strength[6], Compressive Strength[7], Compressive Strength After Freeze-Thaw[8]

Porosity: Since porosity is parallel to water absorption values, the same results are valid for porosity values. Accordingly, the sample with the highest porosity was VT-D, whereas the lowest porosity value belonged to the reference sample made of crushed stone (Table 5). In a study conducted on plaster mortar, a high porosity property was shown for types with porosity between 20-40% [33]. In another study, porosity in different samples made with quartz sand, including lime, lime-cement, and cement binder, differed between 18.1% and 41.6% according to the binder type [34]. In this study, since the binder is the same for all samples, the aggregate type determines the porosity property. Accordingly, while all types with volcanic tuff aggregates have high porosity, the sample made of crushed stone aggregate has low porosity.

Capillarity: In terms of capillary pressure results, the lowest value belongs to the reference sample made of crushed stone, whereas VT-B and VT-D have the highest capillary pressure value together. Among the samples prepared with volcanic tuffs, the lowest capillary pressure value belongs to VT-C sample (Table 5). In a study performed on traditional lime-based plaster mortars, capillary pressure results were 0.25 $Kg/m^2.min^{0.5}$ for coarse mortar and 0.40 $Kg/m^2.min^{0.5}$ for fine mortar [35]. Considering this, capillary pressure is lower in cement-based samples compared to lime-based plaster mortar and the white cement-bound plaster mortars used in the present study.

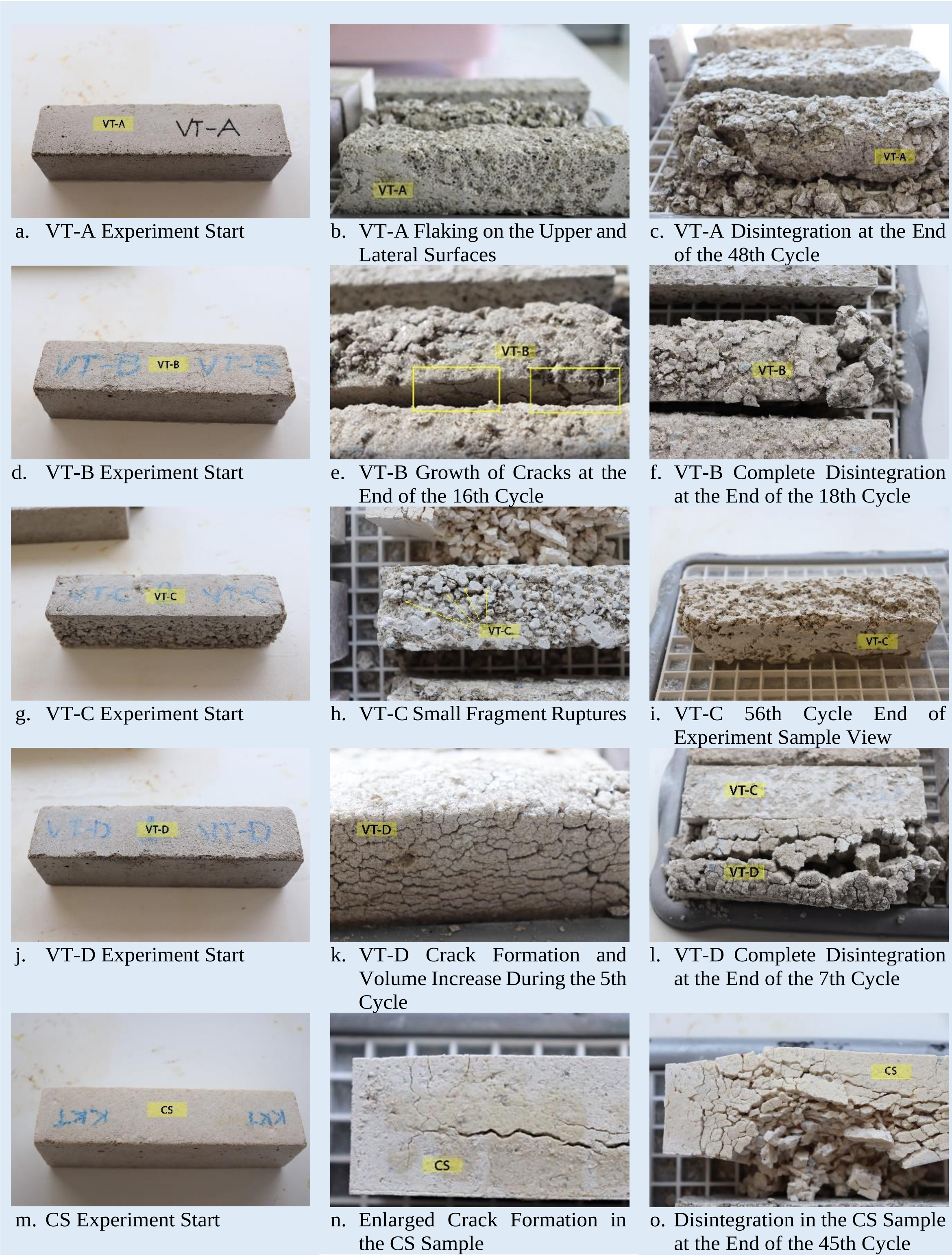
Water vapor permeability: Water vapor transfer occurs in the same way as heat transfer. As heat moves from the hot environment to the cold environment, the water vapor also moves in parallel. However, the condensation of water vapor within the structure of the building envelope and its transformation into water can cause damage in which water is effective. Hence, it is important to evacuate the water vapor before it condenses within the material. In materials with high water vapor permeability, this evacuation process will be quick, and the risks that cause damage will be eliminated. In addition, in a study that investigated nanocomposite systems to reduce this effect, it was concluded that water repellency can be provided and thus volcine tuff aggregate can be protected [36]. While VT-A, VT-C, and VT-D samples with volcanic tuff aggregates used in the study had the same values, VT-B sample displayed less water vapor permeability. The reference sample produced from crushed stone, on the other hand, displayed six times less water vapor permeability than VT-A, VT-C, and VT-D samples and four times less water vapor permeability than VT-B sample (Table 5).

Flexural strength: Flexural strength is the type of mechanical strength that a wall cladding is likely to encounter according to its compressive strength. Accordingly, it was observed that the flexural strength of the reference sample with crushed stone aggregate yielded a higher strength value compared to the types with volcanic tuff aggregates. In a study conducted by replacing volcanic tuff aggregates with normal mortar aggregate at 0%, 25%, 50% and 75%, the specimen with 50% aggregate replacement gave the highest flexural strength [37]. In line with this result, it was revealed that it can be used with displacement in normal mortar. Using the entire mortar from volcanic tuff aggregates will mean re-processing the idle area. According to the flexural strength results of the types with volcanic tuff aggregates, the highest strength value was observed in VT-C sample, and the lowest strength value was observed in VT-D sample. It is seen that there is little difference between the flexural strength values of volcanic tuffs (Table 5).

Compressive strength: According to compressive strength, the reference sample acquired from crushed stone gave the highest strength. Although there were no high range differences in compressive strength depending on particle size in other samples with volcanic tuff aggregates, VT-B yielded the highest strength among samples with volcanic tuff aggregates, while VT-C gave the lowest strength (Table 5). In a study conducted on using expanded perlite as a plaster mortar and evaluating its performance, the standard values and the commonly applied plaster mortar were compared with the samples with expanded perlite aggregate. Accordingly, ordinary Portland cement, slag cement and ordinary Portland cement + fly ash types were used as binders, and sepiolite, expanded pearlite, and diatomite were used as aggregates. The study showed that the traditional plaster mortar strength was 19.6 MPa, while it was 10.91 MPa in the sample type with Ordinary Portland cement-bound sepiolite aggregate, and the compressive strength of the expanded perlite aggregate sample was 1.31 MPa [38]. According to the results, the compressive strength of the samples with volcanic tuff aggregates is either close to or higher than the expanded perlite types.

Freeze and thaw: Frost action within the building cladding material mostly occurs when the material becomes saturated with water through surface wetting or capillary route. The frost action can cause significant damage due to the pressure it creates within the material [39]. The freeze thaw test is carried out by the method specified in the standard. During the test process, which is carried out by an observational method, cracked and disintegrated specimens are recorded as specimens that cannot withstand frost effects. Specimens that retain their integrity even if they have partially small fragment breaks are considered to be resistant to frost effects and are weighed at the end of the test to obtain quantitative data and are also subjected to compressive strength test for the difference in mechanical strength [40]. Within the scope of the study, according to the observations made on the samples at the end of the freeze-thaw experiment, which was continued for 56 cycles, to determine how water-saturated samples were affected by the frost action, the following was determined:

At the end of the 4th cycle, flaking was observed on the upper part of VT-A sample, whose experiment start is given in Figure 4.a. During the 16th cycle, spalling occurred on the upper and lateral surfaces of VT-A sample. At the end of the 18th cycle in VT-A sample, it



a. VT-A Experiment Start
b. VT-A Flaking on the Upper and Lateral Surfaces
c. VT-A Disintegration at the End of the 48th Cycle
d. VT-B Experiment Start
e. VT-B Growth of Cracks at the End of the 16th Cycle
f. VT-B Complete Disintegration at the End of the 18th Cycle
g. VT-C Experiment Start
h. VT-C Small Fragment Ruptures
i. VT-C 56th Cycle End of Experiment Sample View
j. VT-D Experiment Start
k. VT-D Crack Formation and Volume Increase During the 5th Cycle
l. VT-D Complete Disintegration at the End of the 7th Cycle
m. CS Experiment Start
n. Enlarged Crack Formation in the CS Sample
o. Disintegration in the CS Sample at the End of the 45th Cycle

Figure 4. Freeze-Thaw Effects on Samples

was seen that flaking on the upper and lateral surfaces progressed (Figure 4.b). Detachment occurred in the sample at the end of the 26th cycle. Detachment also occurred at other corners of the sample with the 31st cycle. With the 35th cycle, the cracks that became prominent in the corners started to be observed. During the 37th cycle, the cracks became very wide. It was determined that the integrity of the sample was impaired as a result of small ruptures and growing cracks until the 41st cycle. At the end of the 48th cycle, the sample was completely disintegrated (Figure 4.c). Since VT-A sample was damaged later than VT-B, VT-D, and CS samples, it was the second type after VT-C sample in terms of resistance to frost action.

At the end of the 4th cycle, flaking was observed on the upper part of VT-B sample, whose experiment start is given in Figure 4.d. During the 7th cycle, small detachments occurred at the corners of the sample. During the 11th cycle, cracks began to appear in the upper part and at the corners of the sample. During the 16th cycle, the form of VT-B sample was distorted, and cracks grew (Figure 4.e). At the end of the 18th cycle, VT-B sample was completely disintegrated (Figure 4.f). VT-B sample was the second last sample type that displayed the least strength after VT-D sample.

VT-C sample, whose experiment start is given in Figure 4.g, was damaged in the form of small detachments from the surfaces during the 28th cycle. At the end of the 33rd cycle, damage to the sample was determined in the form of detachment from one corner. At the end of the 42nd cycle, small detachments from the corners and vertical surfaces occurred (Figure 4.h). Small detachments continued during the 46th cycle. At the end of the 48th cycle, geometry defects occurred in some corners and vertical edges as a result of small detachments. The sample retained this form until the end of the 56th cycle. At the end of the experiment, it was the most durable sample compared to other sample types in terms of resistance to frost action, maintaining its general integrity (Figure 4.i) despite detachments from the corners and edges.

At the end of the 4th cycle, more significant spalling was observed in the crusty layer in VT-D sample, whose experiment start is given in Figure 4.j. At the end of the 5th cycle, a significant increase in volume occurred on the upper surface of VT-D, and many cracks were formed on all the lateral surfaces (Figure 4.k). At the end of the7th cycle, VT-D was completely disintegrated during thawing (Figure 4.l). It was concluded to be the most nondurable type compared to other samples subjected to the frost resistance test. At the end of the 24th cycle, capillary cracks were observed in the upper part of the CS sample, whose experiment start is given in Figure 4.m. Due to the experimental process, it is necessary to rotate samples at certain times. In line with this, the samples were rotated at the end of the 28th cycle thawing process. During the said process, the crack that was formed in the lower part of the CS sample began to be observed (Figure 4.n). At the end of the 32nd cycle, it was observed that the observed crack grew. It was determined that the crack widened considerably during the 36th cycle thawing. At the end of the 40th cycle, an increase in volume was observed around the crack while the crack continued to grow. It can be stated that the sample was completely split off during the 43rd cycle. At the end of the 45th cycle, the sample was completely disintegrated (Figure 4.o.). Since it was disintegrated after VT-D and VT-B samples, the CS sample ranked third among the samples subjected to the frost resistance test.

Weight loss and compressive strength tests were conducted on the VT-C sample, which was not completely disintegrated despite the intense damage from the vertical corners and edges at the end of the freeze-thaw test. Accordingly, at the end of the frost resistance test, its mechanical strength decreased by 63%. Despite this result, it was the most resistant sample type to frost action within the scope of the study.

Scanning electron microscopy (SEM): The pore structure of the aggregates of volcanic origin, which can be noticed even through macro-observation, will provide lightness in the building material to be made with this type of aggregate. However, SEM analysis was performed to observe the effect of this pore structure on freeze-thaw and mechanical strength properties in micro dimensions. Micropores and microcracks were identified on the surfaces of the samples, which were magnified 500 and 5000 times.

While cracks occurring in all other sample types except VT-C sample were seen as cracking as a whole (Figure 5.), the crack in VT-C sample (Figure 5.f) was thought to be a crack of the gap between the materials coming together rather than a crack divided into two sides. It can be said that this micro-sized natural crack in VT-C sample can tolerate the increase in volume during freezing of water, thus making it the best type in terms of resistance to frost action in the current study.

4. CONCLUSION

In this study, which was conducted to use an idle volcanic tuff field in building material production again,

It was concluded that volcanic aggregate particle distribution could be variable even if there was no big difference between all types in terms of dry bulk density, they were very light materials compared to the reference sample widely used as a plaster aggregate, and accordingly, the load reflected on the structure would be reduced by using all types with volcanic tuff aggregates having different particle sizes.

The high water absorption potential and porosity of all types with volcanic tuff aggregates having different particle sizes caused the reference sample to be adversely affected in terms of resistance to frost action, except for one type, despite its low water absorption and porosity. In line with this, it was concluded that it could withstand frost action with different particle sizes.

It was found that the volcanic tuff group would provide high water vapor permeability and breathing feature in all different types, and it could prevent the formation of condensation in the material.

Compressive and flexural strengths that vary depending on different particle sizes were observed in all types with volcanic tuff aggregates, which are expected to have low mechanical strength due to porosity and dry bulk density. When compared to other studies in the literature, it was

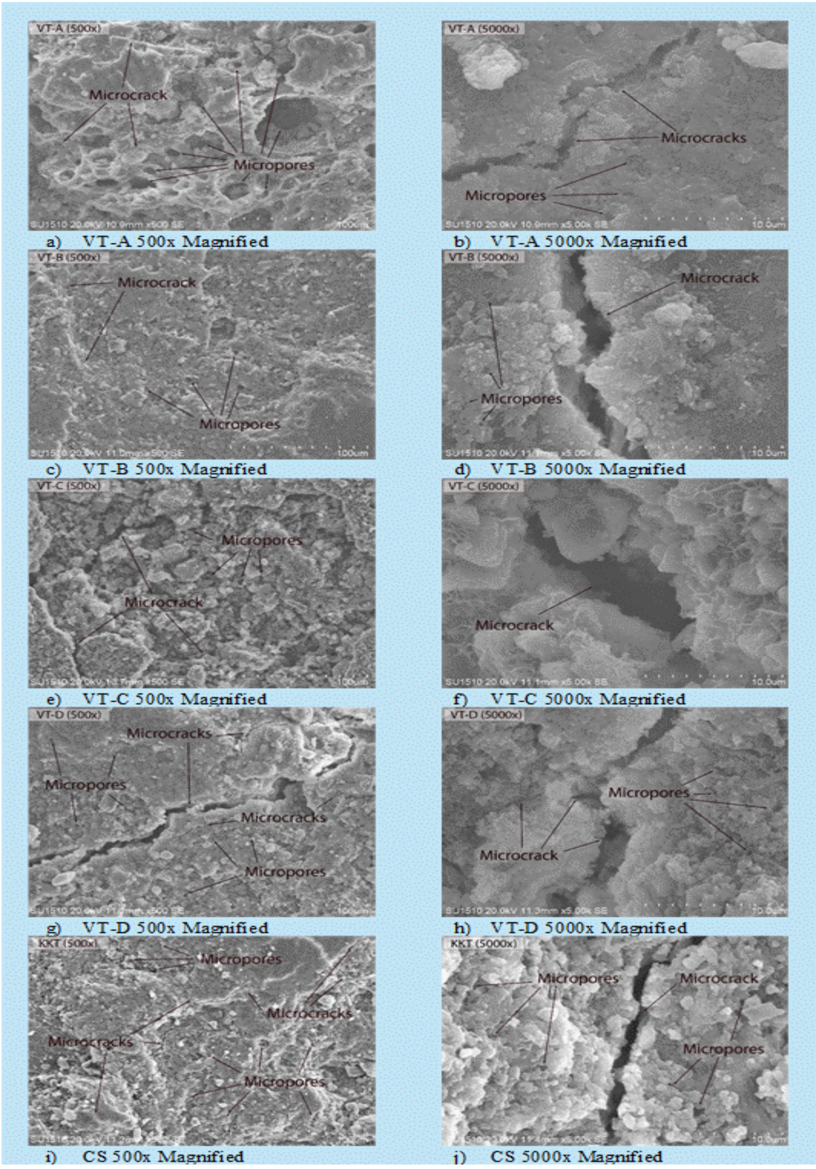


Figure 5. SEM Images at 500x and 5000x Magnification

seen that all types achieved sufficient mechanical strength.

In conclusion, in the present study, the physical and mechanical properties of the aggregate can change due to different particle sizes, and accordingly, it will be possible to produce a light, frost-proof facade cladding material having sufficient strength with the volcanic tuff obtained from the idle tuff field.

Although the study has shown that it is possible to produce coating materials such as plaster etc. with suitable grain size aggregates obtained from the inert volcanic tuff field, it will not be possible to actively use the entire field due to aggregates with unsuitable grain size. For this reason, it is recommended to carry out research on the use of other grain sizes in different building materials. For example, the fact that the site is volcanic tuff may show pozzolanic properties and can be used as cement raw material since the grinding cost of fine-grained aggregates will be low.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mustafa DERELİ: Determining the research issue, planning, conducting the experiments, analyzing the results and writing the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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