ITU A|Z • Vol 16 No 2 • July 2019 2019 • 69-80

An investigation of the conservation problems of volcanic tuffs used in the facades of Dolmabahçe Palace

Seden ACUN ÖZGÜNLER[1], Elmira GÜR[2]
[1] acunsed@itu.edu.tr • Department of Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey
[2] elmiragur@itu.edu.tr • Department of Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey

Received: December 2018 • Final Acceptance: May 2019

Abstract

Historical structures resemble to historical documents that reflect the socio-cultural structures of the period which they were built in. It is our responsibility as a nation to protect these immovable documents and transfer them to future generations in a healthy manner. It is necessary to help not only experts but also users raise awareness on how to preserve these historical pieces. It is still unclear that how these buildings, built in the past periods of time when today's construction technology was not available and materials and techniques were very limited, can be still durable and in a perfect condition. Both architectural forms, materials and techniques are admirable. In order to protect these structures of cultural heritage and transfer them to future generations properly, necessary adjustment should be made in accordance with conservation principles. Protecting and repairing historic structures requires interdisciplinary collective work. Among historical works, the selection of original materials and construction techniques for the selection of the most appropriate protection and reparation interventions are among the priorities. The reparations the building has gone through can also be understood by examining the materials having been used during these procedures.

In this article, the stones used in the facades of the Dolmabahçe Palace and the environmental factors surrounding the palace are investigated. In particular, the protection problems of the volcanic tuff stones are investigated. And by the experimental studies, conservation proposals were obtained. This article is thought to be helpful for future facade preservation work.

Keywords
Dolmabahçe Palace, Volcanic tuffs, Facade damages, Stone conservation.

doi: 10.5505/itujfa.2019.33602

1. Introduction

Dolmabahçe Palace is an invaluable historical building that has been exposed to various environmental threats due to its location. One facade is located very close to the sea shore and the other side overlooks a busy road usually jammed with cars and pedestrians.

Because of being very close to sea, salt affects must be taken into consider. Salt coming from the sea is called NaCl and this affect the stone surfaces like weak acid solution. This salt is seen as white colored crusts on the stone surfaces. In general, there are many type of salts based on chloride, carbonate, sulphate and nitrate which are called water soluble salts, affect the stones. Some of them can be more destructive.

And the other facade looks through the busy road. A busy road usually jammed cars and pedestrians causes the air pollution. Especially the exhaust of cars produce and spread harmful gases to the environment. These gases (CO_2, SO_2 etc.) are called air polluting agents. The affect of air pollution on the limestones is called gypsum crusts which is seen as black coloured layer.

Therefore, considering all of these, the facades of the building coated by natural stone, the gate and garden walls around it are under the threat of the salt directly coming from the sea, the toxic gases from the air pollution and the graffiti and vandalism caused by the people. Despite the environmental factors, the fact that this structure can be taken care of in a proper way depends on the periodical maintenance and simple protection work. These environmental factors will primarily affect the materials on the facades of the building. The damage mechanism begins with the material, which is primarily a small unit, then spreads to the element, then leads to structural problems in the whole of the building at which time protection works are insufficient and larger interventions are required. For example, if the contamination layers seen on the surfaces of the stones on the exterior facades are not cleaned in time, these layers become thicker and the physico-chemical and even the mechanical properties of the stone are completely changed, which may result in inquiry of greater interventions.

In this study, the conservation problems of volcanic tuffs which were used in the facades of the Dolmabahçe Palace were investigated by theoretical and experimental studies. As the volcanic tuffs being less durable against the environmental factors, some conservation attempts have proven to be necessary. In order to minimize the damaging factors and improve the performance of these stones, required adjustments are analyzed and suggested. But before the any application of any adjustment, the importance of determination of micro and macro properties and threats deteriorating the stones are emphasized. Main purpose is to obtain a conservation methodology for these less durable stones used in historic structures in order to contribute to the protection studies of the cultural heritage.

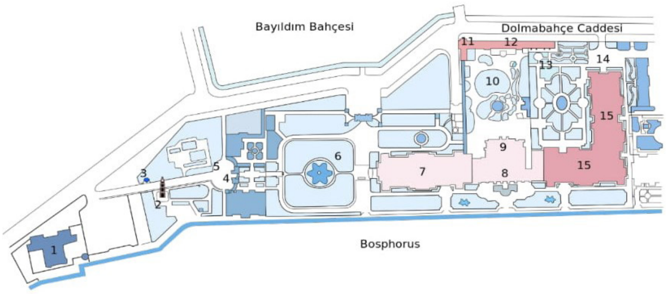
2. Dolmabahçe Palace and stones used in its construction

In this section, the history and location of Dolmabahçe Palace is mentioned primarily. Then, the stone types and locations are described. After all, the literature survey about the origins of volcanic tuffs are presented briefly in the following.

2.1. Dolmabahçe Palace and history

The Ottoman Palace, located on an area of 250.000m^2 between Dolmabahçe Street and Bosphorus from Kabataş to Beşiktaş, is located on the left bank of Bosphorus at the entrance by sea from Marmara Sea and across Üsküdar and Salacak. The area where Dolmabahçe Palace is located today was a big bay of Bosphorus, where the ships of Ottoman Empire were anchored until four centuries ago. This bay, where maritime ceremonies used to be held, became a swamp in time. Later, the place started to be filled in 17th century and was transformed into a "Hasbahçe" (fine-imperial garden) for the rest and entertainment of the Sultans. The pavilions and mansions built in various periods in this garden were called "Beşiktaş Seaside Palace" for a long time. The mansions once located in the area of Dolmabahçe Palace of today were demolished. It is also stated in old documents that the old palace was in place until 1842 and the construction of the new palace was started after that date (Url-1).

Dolmabahçe Palace was built between 1843-1855 by Garabet Amira Balyan and his son Nigoğos Balyan as a mixture of European architectural styles. The facade of the palace, which was built by Sultan Abdulmecit I, lies for 600 meters on the European shore of the Bosphorus. The palace, which was built with great costs, was used for the ceremonies held twice a year in the Grand Examination Hall for 33 years. The most important event in the palace, used by Atatürk as his residence in Istanbul during the Republican period, was the death of Atatürk in 1938, Figures 1-2.



7: Selamlık, 8-9: Muayede Salonu, 15: Harem

***Figure 1.** Dolmabahçe Palace site plan (Url-2).*

On the facades of Dolmabahçe Palace, there are different types of ornamental and plain cutting stones. The stones are embossed with floral motifs. The columns and headings, pilintus, headstones of the palace were made of Marmara marble and marble was also used in the pediments. Similarly, stairs and some architectural elements were made of marble. In addition, Trieste stone and Marseille stone, which were brought from Venice, are mentioned to have been used in various sources. One of the most important marbles used as interior decoration is the Egyptian Alabastr marble used in Hünkar Hamam. Also, it is known that Trakitic, Dacitic-Rhiodacitic tuffs, which are known as Od stone, were frequently used in the Dolmabahce fronts with the Şirinçavuş volcanic tuff.

In the 1960s, the original building blocks of Dolmabahçe Palace were renovated by the architect Lemi Merey by using Portland cement in restoration. This understanding (using cement) lasted until 1979. However, in addition to the aesthetic value loss, the structure has been damaged due to the incompatible physical properties of the artificial stone (Eren, 1998).

***Figure 2.** Dolmabahçe Palace façade seaside (Url-1).*

2.2. A literature survey about the volcanic tuffs

The volcanic tuffs used in historical buildings in Istanbul and surrounding areas show weaker performance under atmospheric conditions than other building blocks. Because of having porous fabric and feldspar minerals, the volcanic tuffs are very affected from water. Rainfall is mentioned as atmospheric effect. When the volcanic tuff stones are subjected to water for a long time, the feldspar minerals in the matrix are converted in to clay minerals which is called a chemical alteration. Moreover, in the polluted air, the water has acidic character, this water's affect is the worst. These are seen dark brown zones on the surface of the stones. These zones are turning empty holes by the time. At the end, the volcanic tuff stones are completely damaged.

In order to prevent or minimize the deterioration of these stones with a very complex and heterogeneous structure, a significant protection and reparation work are required. Success in conservation and reparation work is often dependent on many variables; In particular, certain variables such as the correct and adequate level of analysis of the original stone, the appropriateness of the methods to be used and the existing knowledge and information flow play an active role in the success of these studies.

Figure 3. Tuffs used in the external facades of Dolmabahçe Palace.

There are various types of volcanic tuff quarries in many parts of Turkey, especially the Central Anatolia Region. In particular, volcanic tuffs with various minerals are observed in cities such as Ankara, Eskişehir, Kayseri, Konya, Niğde, Nevşehir. The ones used in the buildings in Istanbul were brought from the nearest quarries in the areas located around Anadolu Kavağı, Rumeli Kavağı, and İzmit, Yalova-Karamürsel. Volcanic tuffs are in the group of stones which are solidified on the surface from magmatic stones (Erguvanlı and Sayar, 1955; Uz, 2000).

In historical buildings and monuments, the natural stones that are commonly used are; Kufeki stone (Organic limestone), Marmara marble, Kestanbol granite, Çanakkale-Montenegro, Lapseki, Biga marbles, Karamürsel Od stone, Hereke pudding, Gebze hippurite limestone, Şirincavuş volcanic tuffs, Karacabey (Mihaliç) pudding and so on (Erguvanlı et al., 1989). The volcanic rocks that are used in historical buildings in Istanbul and surrounding areas; Karamürsel Od Stone which was detected in Byzantine and Ottoman buildings, Kavaktaşı which was used in building coatings in Istanbul, Şirinçavuş tuff which was quarried in Edincik zone in Erdek, and also Camtaşı stone which was used as ornamentation stone in Marmara region. Among them, Karamürsel Od stone and Şirincavuş volcanic tuff are frequently found in historic structures in Istanbul.

Karamürsel Od stone is mentioned to have been quarried from the quarries in Dereköy /Tepeköy, in Karamürsel-Kocaeli province in various sources. The quarries of the Şirinçavuş volcanic tuffs are located on a slope overlooking the southern shore of the Marmara Sea, and the former name of the village was indeed Şirinçavuş. These tuffs were removed and used in various historic periods (Romans, Byzantines and Ottomans). These young volcanics, which are in the form of tracitic tuffs, which are in large outcrops in the north-western part of Şirinçavuş village, are generally gray, pink, coffee and sourcherry, Figure 3.

One of the places that these tuffs were used the most is the ancient city of Cyzycus (Belkız) and the famous Hadriyanus temple having been built there. Şirinçavuş tuffs were commonly used in historic structures such as in the walls of the ancient city of Cyzycus, in the castle of Erdek, from the outer courtyard of the Sultan Ahmet Mosque to the medrese street, the arch of the door and Valens arch place. It has been reported that the Şirinçavuş tuffs were used in palaces and large monumental buildings and reparations in Istanbul between 1850-1870 (Erguvanlı et al., 1989). It was used, for example, on the front walls of the Dolmabahçe Palace and on the doorway on the street, in the arch, in the feet, white-pink tuffs with large feldspar (sanidine), (Eren, 1998; Gürdal et al., 2000).

The usage of Karamürsel Od stones in historical buildings has been much more common than the Şirincavuş volcanic tuffs. The reasons for choosing these tuffs are very diverse. These tuffs are light and easy to work, requiring a small amount of energy and labor, and they can be repaired in a short time. Among the volcanic tuffs, it is known that Od stone, which is mostly green dacitic tuff, was used (Ahunbay, 1995). Generally, it was seen that the volcanic tuffs were used together with Kufeki limestone.

The characteristics of limestone and tuffs are compared in the table below (Erguvanlı et al. 1989).

In the table 1, a comparison of technical properties between the

Table 1. *The comparison of properties of volcanic tuffs with Bakırköy Kufeki stone.*

Name	Density (gr/cm^3)	Water Absorption Ratio (%)	Porosity (%)	Compressive Strength (MPa)	E-Modulus x10^3 (MPa)	Surface Abrasion Loss (%)
Karamursel Od stone	2,06	7,83	16,11	35,2	19,1	4,64
Şirinçavus tuff stone	2,10	7,29	17,30	35-41	-	9,06
Bakırköy Kufeki stone	2,15	3,11	6,63	32,5-35	7,5-11,0	-

limestone and volcanic tuffs are given. According to the table, as the physical properties; the density value of limestone is higher than the volcanic tuffs' density value. And the porosity ratio of limestone is less than the tuffs' porosity ratio. Similarly, the water absorption ratio of limestone is less than the volcanic tuff stones' absorption ratio. This means limestone is more durable than the volcanic tuffs against the water affect. But, compression strength values are similar for all off them. Consequently, as the physical properties of the limestone is better than the volcanic tuffs, this means that the limestone is more durable to physical environment conditions. Mechanical behaviour may be variable. In fact, volcanic tuff stones should not used in exterior walls but they can be used in indoor spaces without facing the water affect.

In Ottoman historic documentations, It was recorded that Od stones which were quarried from Karamürsel were brought to Langa port (Yenikapı) by ships and it was also mentioned in the records that two types of Od stone,Seng-i Nar Ocak and Seng-i Nar Köprülük, were requested to be brought. In addition, in the documents related to the construction of the Laleli Complex, it was stated that the Od stone had a resistance against fire and it is characteristically light, therefore it was chosen to be used in the furnaces and basic fillings. Od stones from Karamürsel in 1760-1762 were used in two different ways as Köprülük and Külhan, as coating material, and later as a coating system for lime in the first years of construction. It is understood from the archival documents that the stones were sent to Istanbul after kind of being processed. Od stone is divided into two as mold and bridges; and that these stones are used as reused materials have also been mentioned in similar sources (Neftçi 2002, s.62-63).

Figure 4. Pollution effects on palace's facades.

3. The deterioration problems and conservation methods in the volcanic tuffs

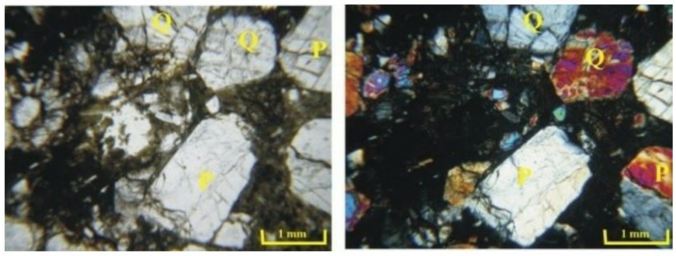
Primarily, the stone conservation principles are described and then the conservation problems of the volcanic tuffs are discussed. By the literature survey, the conservation methods for the volcanic tuffs were evaluated. This literature was be helpful for the planning of the experimental studies shown in following section.

3.1. The stone conservation principles

The stone conservation work is conducted to protect the stone against the internal and external effects such as atmospheric and environmental threats and to increase the durability of the stones (Gürdal et al., 2000).

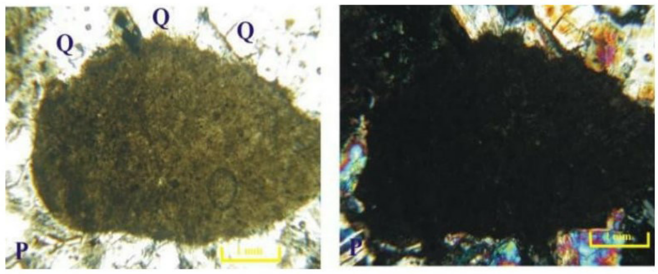
The stone conservation work first emerged as a concept which became increasingly important in Europe with the industrialization (Industry) revolution. With the development of industry, factors such as air pollution caused by toxic gases from factory chimneys, acid rain, frost events, etc. started to destroy rapidly the historical structures that had managed to survive for hundreds of years. These factors cause rapid deterioration of the natural stones, especially the ones used in the external facades, Figure 2-3.

The most important factor in the preservation and restoration of historical buildings is the preservation of the original material. Conservation of the natural stones used in these structures is also important. In particular, the conservation of natural stones, of which details the historical documents include, is of great importance given the fact that the old stonework is now disappearing. The deterioration mechanisms of the volcanic tuffs are more complex than the other stones, and the conservation process is also a matter of demanding and detailed studies. The damage given to the volcanic tuffs is mostly due to the deterioration of the chemical micro structure. Understanding the causes of deterioration is an issue that requires a detailed study. In addition to physical and mechanical property tests, detailed chemical and mineralogical-petrographic analysis is also required. Stone conservation works demands serious scientific studies. The main purpose is to improve some of its properties without removing the existing stone and keeping it in place. That is to extend the service life of the existing stone. For this purpose, first surface cleaning is conducted according to the current condition of the stone and then protection and reparation procedures are carried out with reinforcement-water repellent chemicals.



(a) (b)

Figure 5. Thin section analysis of od stone of sound core(a). The appearance of matrix in single-nicole / (b). The image of the matrix, in double-nicole.



(a) (b)

Figure 6. Thin section analysis of od stone of deteriorated part(a). The appearance of clay, single-nicole / (b). The image of the same clay, double-nicole.

3.2. The causes of deterioration for all types of volcanic tuffs

The natural stones, which have been under the exposure of atmospheric conditions for a long time in nature, begin to lose their physical and chemical properties that they have in the initial state more or less quickly or slowly depending on their mineralogical composition, tectonic history and environmental conditions. The periodic change of the stone that has undergone the process of alteration, deterioration, or aging (Weathering), continues until it becomes granulated, crumbled and shed, starting from phase of being solid and massive.

The deterioration types of stones vary depending on the affecting factors and the type of stone. For example, air pollution forms a black crust (called gypsum crust) on the surface of limestones, and brown zones are formed in volcanic tuff rocks by the cause of water (Figure 5). It has been observed that volcanic tuffs were rapidly degraded due to increasing air pollution and variable climatic conditions. In these stones, decomposition and chemical structure deterioration and some minerals such as feldspar minerals turn into clay minerals during the degradation; they basically change and show different behaviors. The most important components of these types of porous stones are; water, moisture, salt crystallization, wind and biological factors. The main minerals found in the vitreous paste are the quartz, plagioclase, alkali feldspar and zeolites, shown in Figure 5. For this reason, chemical degradation occurs in the form of quartz, feldspar and iron-magnesium minerals. The most typical alteration morphology is the brown staining of the feldspar on clay surfaces, shown in Figure 6. These stains are formed in the weakest parts of the stone and sometimes start from the surface to the inner parts of the stone until it is determined to cause fragmentation, Figure 4.

3.3. An evaluation of stone conservation methods in volcanic tuffs

Since volcanic tuffs are less durable stones against the environmental factors, conservation applications are primarily required to extend the life of these stones. Strengthening and protection applications can be conducted with chemicals that will be selected according to the structure of the stones without causing too much erosion. Stone strengthening is conducted in the case of surface damage in the stone; it is to impregnate a chemical substance in order to increase the cohesion, mechanical properties of the parts of the stone which are likely to be weakened and eroded. The protection application is carried out to increase the resistance of the stone to variable atmospheric conditions. This process is effective in improving the physical properties of the stone. What is expected from a successful reinforcement-protection application is that it does not change the mineralogical and chemical structure of the original stone, but it also improves its physical and mechanical properties., (ASTM E 2167-08). It is expected that it will not reduce the vapor permeability property of the stone while decreasing the water absorption value. In addition, the color of the stone should not change the texture. The chemicals that are used for strengthening and protection with water repellents is generally emulsions and solution based chemicals. The success of the treatment of chemicals depend on the stone structure and application techniques. Because of the presence of clays in the tuffs, problems concerning the application of chemicals start to emerge and therefore, it doesn't result in success most of the time. It has been reported that more success is achieved when solvent-based water repellents are used after solidifying with ethyl silicate in such stones. Lukaszewicz, Bruchertseifer et al. reported that more success is achieved when solvent-based water repellents are used after solidifying with ethyl silicate in such stones. And also, Özgünler Acun, reported that the same issue within the PhD thesis that consisted of conservation of volcanic tuffs, (Lukaszewicz, 1996; Bruchertseifer et al., 1996; Özgünler Acun, 2007).

Even after 8 years of resistance to atmospheric conditions, it was observed that the protection was still effective (Bruchertseifer et al., 1996). Strengthening and protective applications cannot completely prevent the effects of environmental conditions on deterioration, but the rate of deterioration can be slowed down. The information on the correct selection and use of stone-strengthening chemicals in the standard, called ASTM E 2167-01 of 2005 and 2008, prepared with the cooperation of experts in the field of stone protection, has been given in a systematic framework.

In particular, due to the heterogeneous and complex internal structures, the selection of appropriate chemical products and methods of application for protection-reparation should be conducted very carefully in volcanic tuff-type stones. Horie, Hilbert and Wendler stated that ethyl silicate type chemical products in siliceous stones were successful in strengthening processes (Horie, 1994; Hilbert ve Wendler, 1996). Also water repellents, silan/siloxanes are highly recommended in the literature.

Zezza and Garcia Pascua stated that the treatment with the strengthening chemicals were effective in the porosity, volume and specific masses of the stone and that the water repellents were effective only in the water absorption feature, because of the deep penetration (Zezza and Garcia Pascua, 1996).

Nwaubani et al. stated that, with the penetration of water repellents (protectives), the micro cavities of the building stone were changed. On the other hand, the macro cavities were changed by impregnation of the stone strengtheners. This success was measured as 90% in porous stones, 60% in dense stones (Nwaubani et al., 2000).

The results of the literature research given above, the selection of information and the selection of stone strengthening and water repellent chemicals, application method and evaluation of the results will be released. It is thought that it will be guiding on such issues.

4. The experimental studies conducted for the conservation of volcanic tuffs used in Dolmabahçe Palace

In this section, the experimental studies which were conducted for the conservation of volcanic tuffs are presented. Before the studies, the stone samples were taken from the building and then the experimental studies were planned respectively. The results of all the tests were shown in tables and figures in the following. By this study, a general evaluation could be obtained.

4.1. Sampling

In order to conduct the conservation studies of Şirinçavuş and Karamürsel volcanic tuffs used on the facades of Dolmabahçe Palace, experimental studies were carried out on the stone samples taken from the façades, in the building material laboratory in Department of Architecture in ITU. The samples were taken from Muayede building and Musahiban building, Figure 7. These samples are chosen because they are the ones which are exposed to sea water and air pollution the most. For these reasons, experiments have been carried out to determine the morphology of degradation in the degraded outer shell and characterization of the intact samples taken from the inner parts.

For choosing the appropriate chemicals; the micro structures, the macro properties of the volcanic tuff samples as well as the deterioration problems were determined primarily.

4.2. The experimental studies and the results

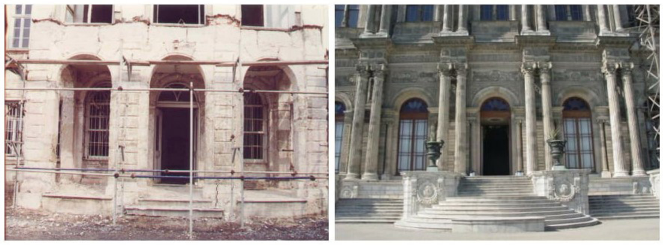
The experimental studies were planned to determine the characteristics of the volcanic tuffs, to compare the physical properties of the samples treated with chemicals and samples untreated with chemicals and to evaluate the effectiveness of the chemicals used, since the durability of the stones against the environmental factors can be evaluated according to the physical properties of the stones. If the results of the tests are found satisfactory, treatment with chemicals will be successful for the volcanic tuffs, and this means the longer period sustainability of these stones can be achieved.

The volcanic tuff samples were cut as prismatic in 4x4x16 cm dimensions and dried in 105° C oven and prepared for experiments for 20 minutes at a temperature of 20 ± 2 °C and a humidity of 60 ± 5%. At least three samples were prepared for each test. Physical property tests were carried out in the samples treated with chemicals and the ones untreated with any chemicals.

In the light of the literature studies, Wacker 1311 siloxane based emulsion water repellent application which is a protective chemical was tested and the experiments were repeated in the samples treated and untreated with chemicals.

The Wacker SMK 1311 emulsion was diluted with water at a ratio of 1:10 and was applied to the surfaces by brush. The implementation time was 40 minutes, and 8 cycles were applied at equal intervals until the saturation level, Figure 8. The depth of the water repellents used was 2-3 mm. The samples were kept under constant ambient conditions for 4 weeks because of the polymerization time and then the experiments were initiated.

In order to determine the physical properties; water absorption (weight-by volume), water absorption and drying rates (%), unit weight, specific gravity tests were carried out by capillary water absorption, immersion



(a) (b)

Figure 7. *(a). The facade of Musahiban Building , (b). The facade of Muayede Building.*

Figure 8. *Application of chemicals in laboratory conditions.*

Table 2. *The results of physical property tests of volcanic tuff samples comparatively.*

ŞİRİNÇAVUŞ TUFFS / WACKER SMK 1311													
C		Wa (m/m)		Wa (v/v)		D (g/cm³)		SG (g/cm³)		k (%)		p (%)	
Un	Tr	Un	Tr	Un	Tr	Un	Tr	Un	Tr	Un	Tr	Un	Tr
17.10^{-3}	$1.4.10^{-3}$	7.14	1.80	15.28	3.92	2.14	2.18	2.64	2.57	81.06	84.82	18.9	15.2
KARAMÜRSEL TUFFS / WACKER SMK 1311													
C		Wa (m/m)		Wa (v/v)		D		SG		k		p	
Un	Tr	Un	Tr	Un	Tr	Un	Tr	Un	Tr	Un	Tr	Un	Tr
19.10^{-3}	$1.7.10^{-3}$	8,7	1,1	18,28	2,42	2,11	2,14	2.67	2.58	79	80	21	17

(*) Un : Untreated sample - Tr : Treated sample - C: Coefficient of capillary ($g/cm^2\sqrt{dak}$) - Wa (m/m): Water absrption (by mass %) - Wa (v/v) : Water absorption (by volume %) - D : Density (g/cm^3) – SG : Specific gravity (g/cm^3) - k : Compasity (%) - p: Porosity (%)

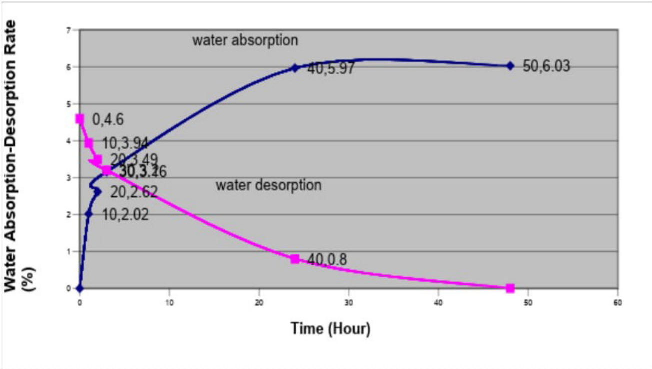


Figure 9. *The graph of water absorption-desorption rate of untreated samples.*

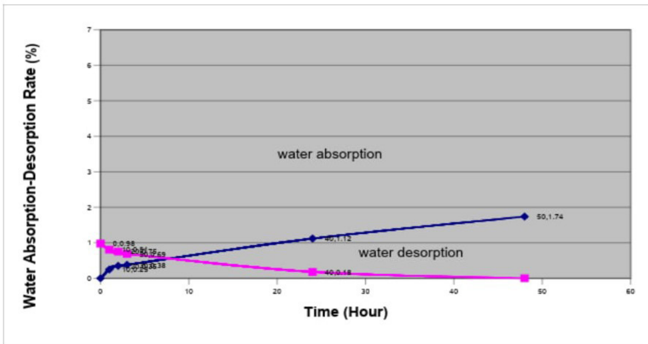


Figure 10. *The graph of water absorption-desorption rate of treated samples.*

under atmospheric pressure. In the experiments, TS 699, Natural Stone Experiment Methods and TS EN 1925 standards were used. At least 3 samples were used and averaged for each test. The results are given in the following Table 2.

In the table above, it was seen that the decrease in capillary water absorption ratio and the ratio of water absorption in atmospheric pressure was found 88% and 70% respectively. As these results are seen promising, the further studies were continued (Figure 9-10, Table 3).

The results of physical property tests and the aging/weathering tests (durability tests) which were conducted on the same samples in order to detect the long-term success of the chemical applications were found to be satisfactory (Acun Özgünler, 2007).

4.3. The durability of treatment applications

The salt resistance test was known as the most damaging durability test that simulate the atmospheric affect. So, this salt resistance test was conducted in order to determine the durability of the chemicals used for water repellent treatment. Succes in this test means this chemical treatment is appropriate and making sure that the water repellency performance will be long enough.

Salt resistance test was conducted according to TS EN 12370 standard. During test, treated and untreated samples were immersed in 14% $Na_2SO_4.10\ H_2O$ salt solution for 6 hours at first, then dried in oven at 60ºC for 16 hours in each cycle. This test included 20 cycles until the samples were destroyed. The untreated samples were able to withstand the 15th cycle. But the treated samples were not so much affected from the salt exposure.

During the salt crystallisation test, the changes in physical appearence of the samples were observed day by day. At the end of the test, physical and mechanical property tests were repeated in order to determine the long term performance of treatment. Untreated samples absorbed much more salty water (behave like acidic agent) than the treated samples. Repeating the cycles consisted of immersion of salt solution and drying in oven made the samples damaged in different levels. The mass of untreated samples were increased first, then the mass is decreased critically. The brown zones were seen increasing then these zones turned in to empty holes. Empty holes were enlarged and then the untreated samples were broken into pieces. And moreover an evident change in the color of untreated samples were observed. In the other case, as absorbing less salty water, the brown zones were not enlarged in treated samples. At the end of the durability test, a minimal change in the mass of the treated samples was detected. And also, the change of water repellency performance was measured as acceptable degree. The results were preferred to be shown in bar chart graphs in order to present the property change, shown in Figure 11-12.

As seen in the figures, treated samples were not so much affected from the salt resistance test. The water absorption ratios of the treated samples were only approx. 30% increased. This means the treatment with the water repellent chemicals was found successful.

4.4. General evaluation of the results

An experimental pilot study was carried out to increase the durability of the volcanic tuff type of stones, used in Dolmabahçe Palace and in many historical buildings, toward atmospheric effects. In the study, the effectiveness of the protective chemicals applied in the laboratory in the tuff samples taken from the structure was examined. In addition, not only the short-term performances of protective chemicals, but also the long-term performances were determined by the aging test. As the aging test, salt resistance test was preferred because the structure is located on the seashore. According to the type of stones, which chemicals would be suitable were decided with the help of the previous studies conducted before. Studies for the selection of the appropriate chemical have concluded that siloxane based water repellents do not harm the color and texture of the stone, but improve its physical properties and make it more resistant to environmental effects. Extending the life of the original material prevents the loss of value of the structures which bear a value of being like historical documents. Such applications are highly recommended, especially in volcanic tuff-type stones.

For the water repellent chemical, water based emulsion type was selected. Although solvent-based chemicals are considered to be longer lasting in the literature, solvent-based chemicals indeed cause darkening of the stone color and are not suitable for ecological requirements. On the other hand, the use of siloxane-based emulsion water repellents is preferred in this study since emulsions are not considered to make a significant change in the color of the stone and their environmental effects are considered to be in the minimal level. According to the results of the experimental studies, the water repellents decreased the water absorption rates of the chemical tuff-type of stones by about 80%. As a result of long-term aging test, it is thought that the application could be considered as being successful since it has been observed that this feature was reduced by only 30%. For the erosion depth which is less than 5 cm, it is possible to protect the stone by using treatment method with protective chemicals. And also, these chemicals can prevent the dirt deposits

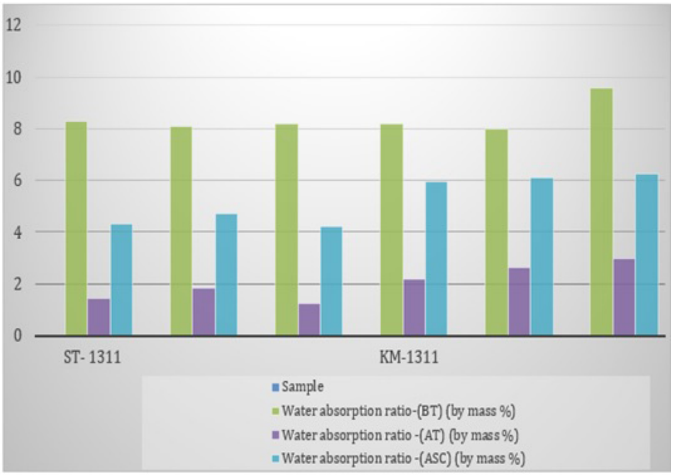


Figure 11. *Changes in Water Absorption by Mass Ratio Values of ST and KT stone samples.*

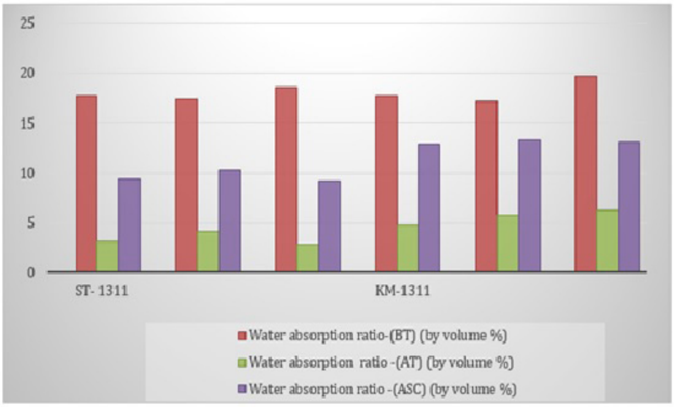


Figure 12. *Changes in Water Absorption by Volume Ratio Values of ST and KT stone samples.*

ST: Şirinçavuş tuff, **KM:** Karamursel tuff

BT : Before chemical treatment / **AT:** After chemical treatment / **ASC:** After Salt resistance

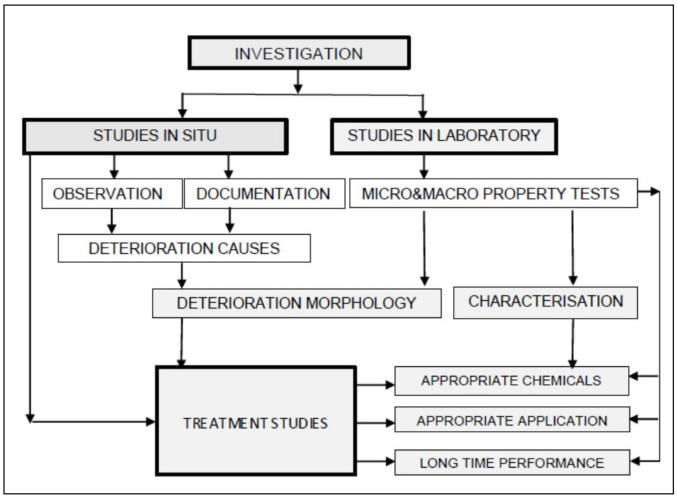


Figure 13. *A flow diagram shows the required studies before the treatment decisions.*

on the facades caused by air pollution. Especially, for the stones which are less durable against the atmospheric conditions, this application is highly recommended in all over the world. But some factors must be taken into consideration before the treatment is applied. Some studies should be conducted before the decision of treatment application as seen in this paper. These factors are mentioned below respectively. This flow diagram can be guideline before the decision of treatment application for all type of stones Figure 12.

5. Conclusions

The natural stones used on the exterior facades are deteriorated due to various internal and external factors. In order to prevent this deterioration, it is important that the conservation works are well planned and under the supervision of the relevant experts, otherwise irreversible results will be obtained. The history of stone conservation practices in historical buildings in our country is not very long and it is being tried to develop chemicals to be used by many experts at national and international level. Scientists and academicians all over the world are doing research on chemicals that can be used safely in stone protection. Because, depending on the structure of each stone and the morphology of degradation, the type of protective chemicals may vary. In addition, the choice of the right application technique with the right chemical selection is required for successful applications. As a result, the success in stone conservation studies depends on many variables and is a subject area that requires interdisciplinary collective work. In addition, long-term monitoring of the application and follow-up of the problems that may arise is necessary. Therefore, stone protection decision and chemical application should not be seen as an easy decision. Experimental studies conducted in the laboratory environment, although positive results are obtained, it is possible to encounter unexpected surprises in in situ applications. For this reason, documenting the studies and results on this subject and sharing the experiences will shed light on successful applications. In particular, conservation studies of volcanic tuffs are very difficult due to their very heterogeneous structure and due to a wide variety of degradation mechanisms. Because of their complex nature, the correct chemicals and application methods to be selected for conservation studies should be considered separately for each volcanic tuff and detailed studies should be carried out for reliable results.

References

Acun, S., Güleç, A. and Ersen, A., (2003). *Efficacy o the consolidants and the water repellents for the conservation of Şirinçavuş volcanic tuff, Proceedings of the Industrial Minerals and Building Stones,* International Symposium, Istanbul, Turkey, September 2003, 363-370.

Ahunbay, Z., (1995). *Osmanlı mimarlığında od taşı,* 9. Milletlerarası Türk Sanatları Kongresi, Ankara.

ASTM E-2167, (2008). *Standard guide for selection and use of stone consolidants,* American Standards Institute, USA.

Bruchertseifer, C., Brüggerhoff, S., Grobe, J. and Götze, H.J., (1996). *DRIFT investigation of silylated natural stone, Proceedings of the 8th.* International Congress on Deterioration and Conservation of Stone, Berlin, 1223-1227.

Charola, A.E., (2001). *Water repellents and other protective treatments: A critical review, Proceedings of the 3rd.* International Conference on Surface Technology with Water Repellent Agents, Aedificatio Publishers, 4-10.

Eren, E., (1998). *Dolmabahçe Sarayı yapı taşlarının bozulma nedenlerinin saptanması ve korunması üzerine bir araştırma,* Doktora Tezi, Y.T.Ü. Fen Bilimleri Enstitüsü, İstanbul.

Erguvanlı, K. ve Sayar, M., (1955). *Türkiye Mermerleri ve İnşaat Taşları,* İTÜ, Maden Fakültesi, Kurtulmuş Matbaası, s. 115, İstanbul.

Erguvanlı, K., Ahunbay, M., Ahunbay, Z., Eriş, I., Erdoğan, M., Onak, A. ve Eyüboğlu, R., (1989), *Marmara bölgesi taş ocaklarının işletilebilme ve taşlarının restorasyonda kullanılabilme* *olanaklarının araştırılması,* Tübitak Projesi, 681, İstanbul, s.173.

Ersen A., Özgünler Acun, S., (2006). *A research about consolidation of natural stones used in the facades of Dolmabahçe Palace,* 150 Years Old International Symposium, 23-26 November, İstanbul.

Grissom, C.A., (1990). *The determination and treatment of volcanic stone: A review of the literature, Proceedings of the International Meeting About Lavas and Volcanic Tuffs,* Easter Island, Chile, 3-10.

Gürdal, E., Yüzer E., Ersen, A., Güleç, A., Eyüboğlu R., Eriş, İ., Görür, N., Vardar, M., Suner, F., Mahmutoğlu, Y. ve Pehlivanoğlu, C., (2000). *Dolmabahçe Sarayı Kullanılan Taşların Korunmuşluk Durumlarının ve Ayrışma Nedenlerinin Belirlenmesi Koruma ve Onarım Yöntemlerinin Saptanması Sonuç Raporu,* İTÜ Geliştirme Vakfı Araştırma Projesi Raporu, İstanbul.

Horie, C.V., (1994). *Materials for Conservation, Organic Consolidants, Adhesives and Coatings,* s.77, Butterworth Heinemann, Cornwall.

Hilbert, G. and Wendler, E., (1996). *Influence of different consolidating agents on the water vapour diffusion properties of selected stones, Proceedings of the 8th.* International Congress on Deterioration and Conservation of Stone, Berlin, 1345.

Kober, H., Wittman, F.H., Siemes, A.J.M. and Verhoef, L.G.W., (1995). *Water thinnable silicon impragnating agents for masonry protection, Proceedings of the 1th.* International Symposium on Surface Treatment of Building Materials with Water Repellent Agents, Delft, Netherlands, 1-3/13.

Lukaszewicz, J.W., (1996). *The influence of stone pre-consolidation with ethyl silicate on deep consolidation, Proceedings of the 8th.* International Congress on Deterioration and Conservation of Stone, Berlin, 1210.

Neftçi, A., (2002). *Laleli Külliyesi'nin inşaat süreci,* Doktora Tezi, İ.T.Ü. Sosyal Bilimler Enstitüsü, s.62-63, İstanbul.

Nwaubani, S.O., Mulheron, M., Tilly, G.P. and Schwamborn, B., (2000). *Pore-structure and water transport* properties of surface treated building stones, Materials and Structures, Vol.33, pp.198-206.

Özgünler Acun S., (2007). *Tarihi Yapılarda Kullanılan Volkanik Tüflerin Konservasyonu Üzerine Bir Araştırma: Od Taşı Örneği,* İTÜ, Fen Bilimleri Enstitüsü, Doktora Tezi.

Rossi-Manaresi, R., (1993). *Stone protection from Antiquity to the beginning of the Industrial Revolution,* Science and Technology for Cultural Heritage, 2, pp. 149–159.

Zezza, F. and Gacia Pascua, N., (1996). *Experimantal physico-chemical methods fort he identification of previous intervention in porous stone, Proceedings of the 8th.* International Congress on Deterioration and Conservation of Stone, Berlin, 801.

Url-1:<https://en.wikipedia.org/wiki/Dolmabahçe_Palace>, erişim:30.06.2019.

Url-2:<https://commons.wikimedia.org/wiki/File:Dolmabahce_Palace_plan.svg>, erişim:30.06.2019.