



Physical And Mechanical Properties Of Dacitic Tuff Used In The Structure Of Historical Buildings

Tarihi Yapılarda Kullanılan Dasitik Tüfün Fiziksel ve Mekanik Özellikleri

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Abstract:

Historical buildings and monuments built with natural stones have an important place in the world cultural heritage. Natural stones have been preferred as the main building material in historical buildings due to their high durability, different colors and textures. Tuffs, which have a wide geological area in our country, have been preferred in buildings because they are light due to their porous structure, can be obtained from quarries in desired sizes and can be easily processed. However, its porous structure causes it to be easily affected by environmental and atmospheric conditions and to decompose. In order to determine the factors that cause weathering, it is important to know the physical and chemical structure of tuff. One of the tuffs frequently encountered in historical buildings in our country is the dacitic tuff known as Karamürsel Od stone. While dacitic tuff is preferred in buildings due to its greenish color, light structure and easy workability, it is affected by environmental conditions and undergoes physical and chemical decomposition. In order to prevent weathering, it is necessary to determine the properties of the tuff and the factors that cause weathering. In this study, it is aimed to determine the factors that cause weathering in tuffs through researches on dacitic tuff. In this study, the properties of tuffs, the formation of dacitic tuff, the use of dacitic tuff in historical buildings and the deterioration of tuff were compiled by researching reliable databases. As a result of the researches, it was seen that the tuffs used in many historical buildings have low strength compared to other stones and therefore conservation studies are of great importance.

Keywords: Dasitic Tuff, Volcanic Tuff, Karamürsel Od Stone, Historical Structure, Physical and Mechanical Properties

Özet:

Doğal taşlarla inşa edilen tarihi yapılar ve anıtlar, dünya kültürel mirasında önemli bir yere sahiptir. Doğal taşlar, dayanıklılıklarının yüksek olması, farklı renk ve dokulara sahip olması sebebiyle tarihi yapılarda ana yapı malzemesi olarak tercih edilmiştir. Ülkemizde geniş bir jeolojik sahaya sahip olan tüfler, gözenekli yapılarından dolayı hafif olmaları, ocaklardan istenilen boyutlarda elde edilmeleri ve kolaylıkla işlenebilmeleri sebebiyle

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yapılarda tercih edilmiştir. Ancak gözenekli yapısı onun çevresel ve atmosferik koşullardan kolaylıkla etkilenmesine ve ayrışmasına yol açmaktadır. Ayrışmaya neden olan etkenlerin belirlenebilmesi için öncelikle tüfün fiziksel ve kimyasal yapısının bilinmesi önem arz etmektedir. Ülkemizde tarihi yapılarda sık karşımıza çıkan tüflerden birisi de Karamürsel Od taşı olarak bilinen dasitik tüftür. Dasitik tüf yeşilimsi rengi, hafif yapısı ve kolay işlenebilir olması sebebiyle yapılarda tercih edilirken çevresel koşullardan etkilenecek fiziksel ve kimyasal ayrışmalara uğramaktadır. Ayrışmaların önlenmesi için tüfün özelliklerinin ve ayrışmaya neden olan etkenlerin belirlenmesi gerekmektedir. Bu çalışmada dasitik tüf özelinde yapılan araştırmalar ile tüflerde ayrışmaya neden olan etkenlerin belirlenmesi amaçlanmaktadır. Bu çalışmada tüflerin özellikleri, dasitik tüfün oluşumu, tarihi yapılarda kullanımı ve tüfte meydana gelen bozulmalar güvenilir veri tabanları üzerinden araştırılarak derlenmiştir. Yapılan araştırmalar sonucu birçok tarihi yapıda kullanılan tüflerin diğer taşlara göre dayanımının düşük olduğu ve bu sebeple konservasyon çalışmalarının büyük önem arz ettiği görülmüştür.

Anahtar Kelime: Dasitik Tüf, Volkanik tüf, Karamürsel Od Taşı, Tarihi Yapı, Fiziksel ve Mekanik Özellikler

1. INTRODUCTION

Natural stones have witnessed the developments that have occurred in the world since the existence of mankind on earth and have formed the world's cultural heritage. The caves, pyramids and many historical buildings that the first people built by shaping stones with the hand tools they invented show the importance of natural stones in construction activities and architecture. Farrelly emphasized in his study that the history of architecture and art is the history of the use of natural stones as building materials (Kazancı & Gürbüz, 2014).

Historical buildings and monuments using different natural stones were built by being influenced by the geological context of the region in which they are located. Especially in monumental structures located in ancient settlements, it is known that stones extracted from quarries close to the region were used. These stones were processed in the quarries, brought to different sizes and used in buildings for various purposes (Occhipinti, Stroschio, Maria, Barone, & Mazzoleni, 2021). The use of stones, which are preferred for structural elements, cladding or decorative purposes in historical buildings, has been restricted with the development of technology today (Gürdal & Acun Özgünler, 2016).

Today, natural stones are generally used in conservation and repair activities in historical buildings. The fact that historical buildings are damaged by environmental and atmospheric factors or human-induced damage has made the protection and repair of these structures representing cultural heritage an important issue. The protection of a building is possible with the protection of the main material that makes it up. It is important that the material to be used in repair activities is suitable for the main material, that its color and texture are similar and that its resistance to atmospheric conditions is determined in order to carry out the repair in a healthy way.

The main building materials used in historical buildings are stone and brick. Our country is located in a geography rich in natural stones due to its geological location. When the historical buildings built in different civilization periods in this geography are examined, the natural stones used are mostly limestone, sandstone, marble, granite, granite, basalt, andesite, porphyry and tuff. Volcanic tuffs, which have a wide geological area in our country, are located in many regions, especially in Central Anatolia. These tuffs are known by the names of the regions where they are mined such as Mağrap stone (Malatya - Trachyte tuff), Ayazin stone (Afyon - White colored rhyolitic tuff), Sille stone (Konya - Pink colored trachyte andesite), Karamürsel od stone (Kocaeli - dacitic, rhyodacitic tuff), Kayseri Cırlağan tuff (Acun Özgünler, 2007).

Although tuffs have a porous and lightweight structure, they have been frequently used in historical buildings because they are easy to work and durable materials. However, its porous structure causes it to be easily affected by environmental and atmospheric conditions and to decompose. The extent of weathering varies according to the minerals contained in the tuff, the void ratio and the amount of glass (Çelik & Tıgılı, 2019; Gürdal & Acun Özgünler, 2016). In order to determine the physical and mechanical weathering occurring in tuffs, the physical, chemical and mechanical properties of the tuffs should first be revealed. These properties differ according to the way the stone is formed and the region where it is located.

The main subject of this study is the dacitic tuff known as Karamürsel od stone, which is used in historical buildings in and around Istanbul, where many artifacts belonging to different civilizations are located in our country. This study aims to investigate the geological context of dacitic tuff, to examine its use in historical buildings, to investigate the causes of deterioration and to determine its physical and mechanical properties.

In the preparation of this study, books, articles, theses and dissertations on the subject were searched from libraries and reliable databases. Within the scope of the study, the geological formation of natural stones, the formation and classification of volcanic tuffs and their use in historical buildings were investigated. It was observed that the number of researches under the title of dacitic tuff is limited. Experimental studies conducted to determine the physical and mechanical properties of dacitic tuff were examined and compiled in this article.

2. GEOLOGICAL FORMATION OF VOLCANIC TUFFS AND THEIR USE IN HISTORICAL BUILDINGS

Natural stones are the rocks that make up the earth. The earth's crust consists of rocks consisting of about 1500 different minerals. Rocks formed by the accumulation of a single type of mineral

or by the combination of different minerals are analysed under 3 main headings according to their formation:

- Volcanic (igneous) rocks
- Sedimentary rocks
- Metamorphic (metamorphic) rocks

Although the rocks in these three groups have different components and properties, they all originate from magma. (Sungur, 1979). The hot solution in the depths of the earth's crust, which contains molten substances and gases in different proportions, is called 'magma'. Magmatic rocks are formed when magma cools and solidifies. Igneous rocks are also classified under 3 groups as depth (plutonic) rocks, semi-depth (vein) rocks and surface (volcanic or extrusive) rocks according to the way they are found on the earth. Igneous rocks are formed when magma rises to the surface of the earth's crust as a result of volcanism. Tuffs are volcanic rocks and are defined as pyroclastic rocks erupted by eruption during the ascent of magma to the surface. (Daloğlu, 2008; Lutgens, Tarbuck, & Tasa, 2017).

Volcanic tuffs are generally seen as layers in the lands. This stratification is formed by the accumulation of small particles erupted from volcanoes on the slopes or in the surrounding lakes and sea bottoms. In many volcanic areas in Turkey, there are volcanic tuffs layered with different stones and rocks. These tuffs have a porous structure, are light and soft due to the fact that they contain some moisture when extracted from the quarries. Due to these characteristics, they can be easily processed. The strong ones of the tuffs left to dry after processing are used as building stones. These stones are preferred as building materials in historical buildings because they can be extracted from the quarries in large blocks, have various colours visually and are light in weight. (Karkaş, 2020).

It has been revealed by the experiments that the characteristic properties of the tuffs in different regions of our country vary depending on the differences in their formation and the minerals they contain (Table 1) (Acun Özgünler, 2007).

Location	Compressive Strength (MPa)	Water Absorption (%)	Abrasion (mm.)
Cırlağan Tuff (red) (Kayseri)	48,6	4,7	1
Cırlağan tuff (yellow) (Kayseri)	35	1	13

Magrab stone-trachyte tuff (Malatya)	42,3	2,17	11
Poplar stone (İstanbul)	39,3	2,6	-
Ayazin Stone (Afyon) (White colour) Rhyolitic tuff	14,8	12	4,6
Köprülü Stone (Afyon) (Black purple)	40	1,5	1,16
Sille Stone (Konya) (Pink) Traki-Andezite	61,6	16,6	-
<i>Table 1: Compressive Strength, Water Absorption and Abrasion Performance of Volcanic Tuffs (Acun Özgünler, 2007)</i>			

Volcanic tuff sites are found in many different parts of the world. There are world-famous monuments and historical structures formed from volcanic rocks in the regions where they are found. The most famous of these are Easter Island, Borobudur (Java), Goreme (Turkey), Lalibela (Ethiopia) (Grissom, 1994). In our country, volcanic tuff fields are found in many provinces, especially in the cities of Central Anatolia region such as Ankara, Eskişehir, Konya, Nevşehir, Niğde, Kayseri. (Acun Özgünler, 2007).

In this study, the geological formation, physical and mechanical properties of dacitic tuff, which is frequently encountered in Early Byzantine and Ottoman period buildings in Istanbul and its surrounding regions, and which is now being experimentally studied for use in historical building conservation and repair works, will be examined.

2.1. Geological Formation Of Dacitic Tuff And Its Use In Historical Buildings

In the Marmara region of our country, there are volcanic rocks formed in different geological times. These are volcanic stones such as andesite, dacite, liparite, trachyte etc. formed close to the surface or volcanic tuffs of different colours and textures. One of the volcanic stones commonly used in historical buildings in this region is the liparitic - dacitic - vitrofirc tuffs formed in the Kocaeli - Karamürsel region (Erguvanlı, Ahunbay, & Ahunbay, 1989).

In the vicinity of Karamürsel, there are volcanic tuffs in layers 500-600 m thick. These tuffs, which are located in the Palaeocene - Eocene fliffs, are layered in some places (1 - 1.5 m) and massive in some places. They are also found in succession with sedimentary rocks. They are white, green, greenish-white, greenish-white and yellowish-white in colour, usually in thick layers. With these features, they are distinguished from the dark coloured and thin layered tuffs

found between the fisses. The stone is petrographically andesitic tuff, tuffite and agglomerate. (Acun Özgünler, 2007; Erguvanlı et al., 1989).

These tuffs, known for their fire resistance and named after the region where they were quarried, appear in historical documents as Karamürsel od stone. These stones quarried in the vicinity of Tepeköy-Dereköy and Hasandere in the south of Karamürsel district were easily processed and extracted as large blocks because they were soft in the quarries. Dacitic tuff, which was preferred because of its greenish colour, was transported to Istanbul by sea. (Kahraman & Arıkan, 2016).

It is known that Karamürsel dacitic tuff was used in the Late Roman, Early Byzantine and Ottoman periods. Especially in the Ottoman period, it is revealed in the archive documents that it was preferred in the buildings and repair activities built in the 19th and 20th centuries.

It was used as beams on the eastern façade, entrance jambs and arches of Hagia Sophia, one of the most important architectural works of the early Byzantine buildings of its period, and on the main bearing walls of Little Hagia Sophia.

During the Ottoman period, there are archive documents requesting the transport of od stone from the Karamürsel region. According to these documents, wood stone was requested from the Karamürsel region to be used in the repair and reconstruction of the furnaces of the Tophane-i Amire Foundry, in the construction of the cannon casting furnaces of the Hasköy Foundry, in the construction of the Humbara Foundry Furnace of the Tersane-i Amire, in the tomb and imaret buildings built by Valide Sultan in Eyüp, in the repair of Eyüp Mosque, Fatih Mosque and other selatin mosques, in the construction of Süleymaniye Complex and Laleli Complex. (Baş, 2017).

In the 1766 earthquake damaged Fatih and Eyüp mosques, Ahi Çelebi Mosque, Adile Sultan Palace, Ragıp Paşa Library, Grand Bazaar and Taşkışla building window jambs, Sepetçiler Pavilion's water basin, Bahçekapı almshouse, Topkapı Palace's Harem bath and palace kitchen, od stone was used. In addition, the use of od stone is found in 90% of the buildings in the Fener-Balat region and in many other historical buildings (Baş, 2017).

3. FINDINGS

It has been observed that Karamürsel dacitic tuff was used together with limestone known as Küfeki stone in historical buildings. In this context, the properties of the dacitic tuff were revealed by comparing it with limestone. When the technical properties of dacitic tuff and

limestone are compared with each other, the density value and porosity ratio of dacitic tuff are greater than limestone. In parallel with this, the water absorption rate is also higher. However, it is said that the compressive strength value is low for both. (Table 2) (Acun Özgünler & Gür, 2019).

Stone	Density (gr/cm ³)	Water Absorption Rate (%)	Porosity (%)	Compressive Strength (MPa)	Surface Abrasion (%)
Dasitic Tuff (Karamursel Od Stone)	2,06	7,83	16,11	35,2	4,64
Limestone (Bakirkoy Kufeki Stone)	2,15	3,11	6,63	32,5 – 35	-

Table 2: Comparison of the properties of limestone and dacitic tuff used in historical buildings in Istanbul (Acun Özgünler & Gür, 2019)

As can be understood from the table above, tuffs, which have a porous structure, are easily affected by climatic conditions and atmospheric events due to the voids they contain and deterioration occurs. In these deteriorations, the feldspar minerals in the content of the tuff generally turn into clay minerals by chemical change with the penetration of water into the tuff. With the effect of the acidic character of the water penetrating into the stone, dark brown regions are formed on the surface and these regions turn into empty holes after a while. In addition, as a result of water absorption in the stone, organisms develop in the tuff, salt is transported through capillary gaps and crystallisation occurs and deterioration accelerates (Acun Özgünler & Gür, 2019; Çelik & Tıǧlı, 2019).

Protection and repair activities are needed to minimise or completely prevent the deterioration of these stones. In repair activities; the building stone to be used should have suitable properties for the original stone, its colour and texture should be compatible and most importantly, its resistance to atmospheric conditions should be high. For this reason, the existing stone should be analysed well, the methods to be used should be determined correctly and the necessary physical and mechanical strength tests should be performed on the stone.

In the determination of the characteristic properties of the stone, firstly, tests are carried out in accordance with the standards to find values such as water absorption rate, unit volume weight and specific gravity to determine the physical properties. Additional tests may be required according to the results of these tests. For example, frost resistance tests should be performed on stones with a water absorption rate of more than 0.5%. As a result of these tests, compressive strength tests are also performed on the stones that are found to be durable and the initial and final results are compared. When the difference is less than 15%, it is decided that the stone is durable.

When there is no change or a slight change occurs in the stone, the salt crystal resistance test is carried out in accordance with the standards. If there is no damage to the stone in these test results, it is considered to be resistant to atmospheric conditions. These tests provide information about the usability and lifetime of natural stones used in buildings (Gürdal & Acun Özgünler, 2016).

Acun Özgünler (2007) carried out experiments to determine the physical and mechanical properties of dacitic tuff samples obtained from three different buildings in Istanbul. In the physical properties experiments, 6 samples were used for each structure and averages were taken. The physical properties of the samples obtained from three different structures were close to each other and the average values of the physical properties of these three are given in Table 3. According to the data obtained as a result of porosimetry analysis, it was determined that the voids in the tuff were up to 20,000 nm, but the voids with a diameter of 100 - 500 nm occupied more space. The fact that the voids with a diameter of 10.000 - 20.000 nm are more in the damaged samples taken from the buildings shows that the void diameter and ratio are proportional to the deterioration (Acun Özgünler, 2007).

Stone	Water Absorption by Mass (Sk-%)	Water Absorption by Volume (Sh-%)	Unit Volume Weight (Dh-g/cm ³)	Specific Mass (do-g/cm ³)	Porosity (P-%)
Dasitic Tuff	% 7 – 9	% 16 – 18	2,05 – 2,12	2,40 – 2,50	% 16 – 18

Table 3: Comp Average Physical Property Test Results of the Samples Taken from the Structures (Acun Özgünler, 2007).

In the results of the mechanical strength tests performed in the continuation of the study, the results of the samples obtained from the three structures were close to each other and the average values are given in Table 4 (Acun Özgünler, 2007).

Stone	Flexural Strength (N/mm ²)	Compressive Strength (N/mm ²)	Ultrasound velocity (km/sn)	Modulus of Elasticity (N/mm ²)
Dasitic Tuff	5 – 10	35 – 40	2,20 – 2,70	12,1 – 19x10 ³
<i>Table 4: Average Mechanical Strength of Samples Taken from Structures (Acun Özgünler, 2007).</i>				

structure. When the physical and mechanical properties revealed by the experimental studies are examined, it is determined that the resistance to atmospheric events is low due to the porous structure of the stone.

For this reason, conservation studies of these tuffs used in historical buildings, especially in facades and exterior spaces, are important. The success of the works depends on the type of stone, the type and properties of the strengthening or water repellent chemicals to be used and the application technique. (Acun Özgünler, 2007).

4. CONCLUSION

Natural stones forming the earth's crust have been preferred as building materials in many historical buildings from past to present. Natural stones, which appear as different building elements in these buildings, have been preferred because they are durable and have different colours and textures.

The structures in which natural stones have been used throughout history have been built by being affected by the geological context of the regions where they are located. The fact that our country has large volcanic areas has also increased the use of tuffs in buildings. Tuffs have been preferred in buildings because they are light due to their porous structure, they can be easily processed due to their dampness when extracted from the quarry, they can be obtained in large blocks and they have different colours. The colour, texture and properties of the tuffs vary according to the regions where they are found and they are generally known by the names of the regions where they are quarried.

In the history, Karamürsel wood stone was generally preferred in furnace construction due to its fire resistance and used in different building elements such as foundations, walls and window

jamb. It was concluded that deterioration occurred in the stone when they were preferred in outdoor areas and studies should be carried out to repair these stones.

When the experimental studies in the articles and theses researched within the scope of the study were examined, it was determined that the factor that initiated the degradation of tuffs was water. It was concluded that with the entry of water into the structure of these stones, which have a porous structure, the gaps expand, the minerals contained in the tuff change and the stone deteriorates with salt crystallisation.

Due to the low strength of volcanic tuffs used in many historical buildings in our country compared to other stones, conservation studies are of great importance. In this study, the role of the physical and mechanical properties of dacitic tuff in the repair of historical buildings by compiling the existing studies, in this context, the use of regional volcanic rocks in the repair of our cultural heritage located in different geographies, determination of their properties, etc. It is suggested that the issues such as the need to investigate the issues.

5.REFERENCES

- Acun Özgünler, S. (2007). Tarihi Yapılarda Kullanılan Volkanik Tüflerin Konservasyonu Üzerine Bir Araştırma: Od Taşı Örneği. In.
- Acun Özgünler, S., & Gür, E. (2019). An investigation of the conservation problems of volcanic tuffs used in the facades of dolmabahçe palace. *A/Z ITU Journal of the Faculty of Architecture*, 16(2), 69-80. doi:10.5505/itujfa.2019.33602
- Baş, Y. (2017). İstanbul Yapılarında Karamürsel Od Taşının Kullanımına Dair Tespitler. *Bingöl Üniversitesi Sosyal Bilimler Enstitüsü Dergisi(BUSBED)*, 7(14), 45-56. doi:10.29029/busbed.331373
- Çelik, M. Y., & Tıgılı, R. (2019). Afyonkarahisar Yöresinde Yapı Taşı Olarak Kullanılan Tüflerin Karakterizasyonu ve Tuz Kristallenmesine Dirençlerinin İncelenmesi. *Bilimsel Madencilik Dergisi*, 58(3), 197-209.
- Daloğlu, G. (2008). Eskişehir-Derbent Tüflerinin Doğal Yapı Taşı Olarak Değerlendirilebilirliği. In.
- Erguvanlı, K., Ahunbay, M., & Ahunbay, Z. (1989). Marmara Bölgesi Eski Taş Ocaklarının İşletilebilmesi ve Taşların Restorasyonda Kullanılabilme Olanaklarının Araştırılması. Retrieved from
- Grissom, C. A. (1994). The Deterioration And Treatment Of Volcanic Stone: A Review Of The Literature. In A. E. Charola, R. J. Koestler, & G. Lombardi (Eds.), *Lavas and volcanic tuffs* (pp. 3-32). Rome: ICCROM.
- Gürdal, E., & Acun Özgünler, S. (2016). Tarihi Yapıların Onarımında Doğal Taş Seçimi ve Kullanımı. *Restorasyon ve Konservasyon Çalışmaları Dergisi*(16), 27-35. Retrieved from <https://dergipark.org.tr/en/pub/restorasyon/issue/48726/619961>

Kahraman, N., & Arıkan, R. (2016). Başbakanlık Osmanlı Arşivi Belgelerinde Karamürsel Taşı ve İzmit Bölgesi Diğer Taş Ocakları. Kocaeli Tarihi ve Karamürsel Alp Sempozyumu Bildiri Kitabı, 3. Retrieved from https://www.academia.edu/40911350/BA%C5%9EBAKANLIK_OSMANLI_AR%C5%9E%C4%B0V%C4%B0_BELGELER%C4%B0NDE_KARAM%C3%9CRSEL_TA%C5%9EI_VE_%C4%B0ZM%C4%B0T_B%C3%96LGES%C4%B0_D%C4%B0%C4%9EER_TA%C5%9E_OCAKLARI

Karkaş, Z. S. (2020). Tarihi Yapıların Cephelelerinde Kullanılan Kagir Yapı Malzemelerinde Konservasyon Çalışmalarının İrdelenmesi ve Sistemik Bir Yöntem Önerisi. In.

Kazancı, N., & Gürbüz, A. (2014). Jeolojik Miras Nitelikli Türkiye Doğal Taşları. Türkiye Jeoloji Bülteni, 57(1). Retrieved from www.progeo.se

Lutgens, F., Tarbuck, E. J., & Tasa, D. (2017). Essentials Of Geology (11 ed. Vol. 1).

Occhipinti, R., Stroschio, A., Maria, C., Barone, G., & Mazzoleni, P. (2021). Chemical and colorimetric analysis for the characterization of degradation forms and surface colour modification of building stone materials. Construction and Building Materials, 302. doi:10.1016/J.CONBUILDMAT.2021.124356

Sungur, K. A. (1979). Kayalar ve Ayırışma. İstanbul: Edebiyat Fakültesi Matbaası.