ISSN:1306-3111
e-Journal of New World Sciences Academy
2011, Volume: 6, Number: 1, Article Number: 1A0124

ENGINEERING SCIENCES
Received: October 2010
Accepted: January 2011
Series : 1A
ISSN : 1308-7231

Murat Ünal
Nesrin Gündoğdu
Selcuk University
munalselcuk@hotmail.com
Konya-Turkey

THE EFFECT OF SALT CRYSTALLIZATION ON TUFF USED AS BUILDING MATERIAL

ABSTRACT

Salt crystallization is known as one of the most important degradation mechanisms effective in the rocks degradation. Degradation occurred by salt crystallization especially effects porous rocks. Beside that, it has also an important effect on fractured and micro-fractured rocks. In this study, the resistances against salt crystallization of a total of 6 different types of tuffs that are used as building materials were determined by using dry weight loss test. Furthermore, their strength changes were determined by using ultrasonic wave velocity measurements. According to the obtained data, salt crystallization has an important degree of effect on the strength of tuffs. Also, changing of the resistance of the tuffs against salt crystallization, according to the petrographic properties of the tuffs and the included alteration zones in them were reported.
Keywords: Weathering, Building Material, Salt Crystallization, Dry Weight Loss, Ultrasonic Velocity

TUZ KRİSTALLEŞMESİNİN YAPI MALZEMESİ OLARAK KULLANILAN TÜFLER ÜZERİNDEKİ ETKİSİ

ÖZET

Tuz kristalleşmesi, kayaçların bozunmasında etkin olan en önemli bozunma mekanizmalarından biri olarak bilinmektedir. Tuz kristalleşmesine bağlı bozunma, özellikle gözenekli kayaçlar üzerinde etkili olmakla birlikte çatlak ve mikroçatlaklar içeren kayaçlar üzerinde de önemli etkilere sahiptir. Bu çalışmada, farklı mevkilerden alınan ve yapı malzemesi olarak kullanılan 6 farklı tüfün tuz kristalleşmesine karşı dirençleri kuru ağırlık kaybı ve ultrasonik hız ölçümleri yapılarak belirlenmeye çalışılmıştır. Elde edilen veriler sonucunda, tüflerin dayanımlarının tuz kristalleşmesinden önemli derecede etkilendiği belirlenmiştir. Ayrıca tüflerin tuz kristalleşmesine karşı dirençlerinin tüflerin petrografik özelliklerine ve içerdikleri ayrışma zonlarına bağlı olarak değiştiği görülmüştür.
Anahtar Kelimeler: Bozunma, Yapı Malzemesi, Tuz Kristalleşmesi, Kuru Ağırlık Kaybı, Ultrasonik Hız

1. INTRODUCTION (GİRİŞ)

At the present time, salt crystallization is accepted as one of the important degradation mechanisms of porous and micro-fractured rocks [1, 2, 3, 4 and 5]. Besides, knowing that, the effect of the salts on rocks occurs as a result of crystallization and hydration, a lot of researchers have reported that, the degradation changes especially according to crystal pressure, degree of saturation of solutions and size of pores of the rocks. Furthermore crystal pressure is reported as the most important degradation mechanism [6 and 7].

Degradation occurring by salt crystallization is active in deserts, urban and polar regions [8]. Especially this degradation is more active in marine environment and mild climatic conditions and it was reported as the strongest degradation mechanism when combined with winds [9]. Salt interacts with building stones through the agency of factors as rain, humidity and fog. Salt crystallization in the porous media causes a loss of coherence between grains and matrix. Dissolution and crystallization cycle cause weight loss, a change in the size of the grains and pores, the degree splitting and visible surface deterioration [10 and 11].

Tuffs have been used as building stone material for a long time in many areas of the world as seen in the Cappadocia region settled in the central Anatolia. In the history, tuff is the most used rocks for the construction purposes by the variety of civilizations in the central Anatolia. In the present day, these rocks have commercial features in terms of building stones therefore; it is also used in widespread areas such as balustrade, wall and floor covering in every climate. In this research, a total of 6 different types of tuffs that are widely used as building stones were subjected to series of simulated salt weathering using sodium sulphate (Na_2SO_4) solution to assess the resistance of different tuffs against salt weathering by means of dry weight loss calculations and to detect the change of rock strength by means of ultrasonic wave velocity measurements.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Salt crystallization is known as one of the most important degradation mechanisms effective in the rocks degradation. Degradation due to salt crystallization is more effective, especially on porous rocks. Tuffs have high porosity value and are widely used as a building stones that reveals the importance of this study.

3. MATERIALS (MALZEME)

A total of 6 different types of tuffs were used in the tests. The samples of tuffs were provided by a company in Kayseri- Tomarza region and they are not managed and new processed blocks (30 cm x 65 cm x 15 cm). The region of Kayseri- Tomarza is settled in the east of Central Anatolia and it is a part of Cappadocia region (Figure 1). Cappadocia region includes Nevşehir, Kayseri and Nigde provinces and contains extrusives of Erciyes, Hasan and Melendiz mountains. These samples of tuffs were collected from neighborhood of Erciyes Mountain and have shown a similar property to some tuffs used as building materials and managed in other places of Cappadocia region.

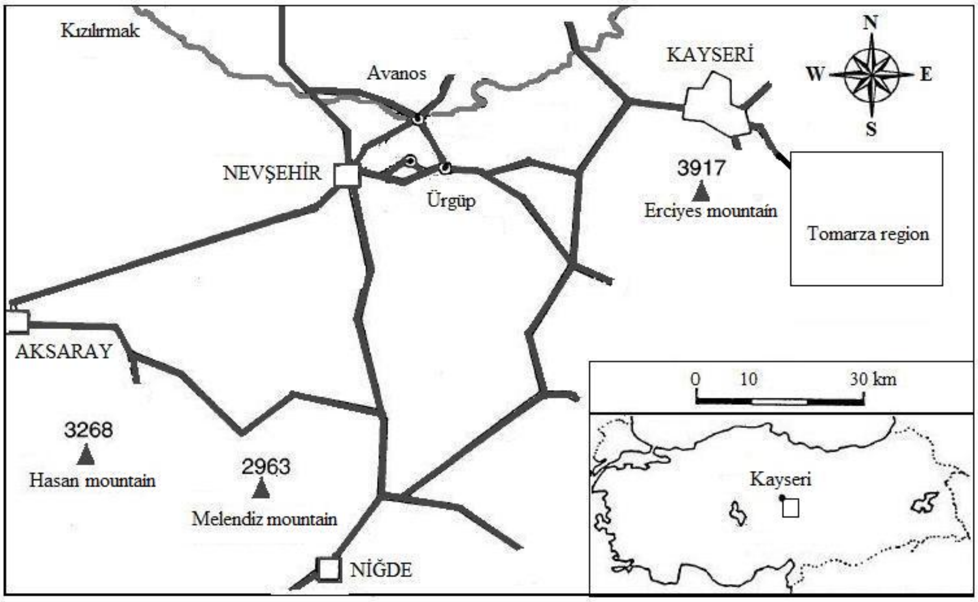

Figure 1. Location map of Kayseri - Tomarza region [After 12]
(Şekil 1. Kayseri-Tomarza bölgesinin yer bulduru haritası [12])

Samples were prepared from currently managed, used in commercial and with different petrographic, physical and mechanical properties of block tuffs. In the tests of salt crystallization, specimens of 53,7 mm diameter and 120 mm length were used.

4. METHODS (YÖNTEMLER)

4.1. Petrographic and Physical Tests (Petrografik ve Fiziksel Deneyler)

In this research, all the petrographic and physical tests were performed in the laboratory according to ISRM [13]. In order to define the petrographic properties of the different samples, thin sections were made from each sample and analyzed using petrography microscope. A summary of this analyses were given in Table 1.

Table 1. The petrographic properties of tuff samples
(Tablo 1. Tüf numunelerinin petrografik özellikleri)

S.code	Texture (cement type)	Components	Grain size distribution	Desription
SR	Vitrophyric porphyric	Volcanic glass, Plagioclase, Volcanic rocks, Quartz, Amphiboles, Apatite, Opaque	0.06 - 5 mm	Vitric tuff
KV	Vitrophyric porphyric	Volcanic glass, Volcanic rocks, Plagioclase, Biotite Clinopyroxenes, Orthopyroxenes Quartz, Opaque, Apatite	0.06 - 8 mm	Crystal tuff
PB	Vitrophyric porphyric	Volcanic glass, Volcanic rocks, Plagioclase, Clinopyroxenes, Amphiboles, Opaque	0.06 - 6 mm	Vitric tuff
KR	Vitrophyric porphyric	Volcanic rocks, Volcanic glass, Plagioclase, Amphiboles, Clinopyroxenes, Quartz, Opaque	0.06 - 15 mm	Litik tuff
SY	Vitrophyric porphyric	Volcanic glass, Volcanic rocks, Plagioclase, Biyotite, Clinopyroxenes, Opaque, Quartz	0.06 - 8 mm	Crystal tuff
GR	Vitrophyric porphyric	Volcanic glass, Plagioclase, Volcanic rocks, Amphiboles, Orthopyroxenes, Opaque	0.06 - 4 mm	Vitric tuff

According to the specified standards in the laboratory environment, some physical properties of tuffs were determined and were presented in Table 2. The porosity of tuffs, water content, saturated and dry densities were carried out by using saturation and caliper method. The hardness index values of tuffs were determined be taking 40 data on blocks with dimensions of 30 cm x 65 cm x 15 cm using LD (L Digital) type Schmidt hardness hammer test.

Table 2. Some physical properties of tuff specimens [5]
(Tablo 2. Tüf numunelerinin bazı fiziksel özellikleri[5])

Specimens code	*SHV*	ρ_g *(g/cm³)*	ρ_w *(g/cm³)*	*W (%)*	*P (%)*
SR	48.25 ± 2.36	1.73	1.94	21.30	12.31
KV	40.67 ± 3.26	1.63	1.87	14.70	23.91
PB	38.27 ± 2.32	1.63	1.93	18.52	30.23
KR	43.85 ± 6.08	1.83	2.03	10.83	19.83
SY	35.40 ± 3.39	1.47	1.73	17.85	26.24
GR	57.70 ± 1.70	1.88	2.05	8.72	16.41

SHV: Schmidt hardness, ρ_g: Dry density, ρ_w: Saturated density, W: Water content, P: Porosity,

4.2. The Salt Testing Procedure (Tuz Testi Yöntemi)

There are many standard tests based on total immersion of sample in a salt solution. All standard tests consist of three stages: immersion, drying and cooling [10]. Also this test studies, generally consist of three stages; immersion, drying and cooling as in TS EN 12370 and UNE EN 12370 [10] standards. In this paper, salt crystallization tests were carried out according to TS EN 12370 and UNE EN 12370 standards that are mentioned in literature as baseline. The testing procedure was involved the following steps:

- At first, specimens were dried in oven at temperature of (105 ± 5) °C until have a constant mass. After that the specimens were left in the room temperature until cooled, then they were marked and weight according to 0.01 g.
- %14 Na_2SO_4 solutions were used in the test. Solution is changed after every five periods. The container were filled with Na_2SO_4 solution to cover the specimen with height of (8 ± 2) mm.
- Specimens were settled into Na_2SO_4 solution at 20°C for 4 hours. Later, specimens were taken out of the solution and settled into the oven at 60 ± 5 °C for 16 hours. Before immersing into sodium sulfate solution, the specimens were weighed after they were cooled at 20 ± 5 °C for 4 hours.
- Except situation like dispersion and disintegration of specimens, tests were carried out in 5, 10 and 15 cycles. After this procedure, specimens were taken from oven and weight. The samples were washed with pure water at 23 ± 5 °C until they release all the salt. Samples were dried again and weight for the last time.

The dry weight loss (*DWL*) of samples was then calculated at the end of these stages with the following equations:

$$DWL = \frac{M_w - M_{uw}}{M_{uw}} * 100 \quad (1)$$

Where, *DWL*: Percentage of dry weight loss
M_w : Dry weight of weathered specimens

M_{uw} : Dry weight of unweathered specimens

Salt crystallization tests were carried out in three serials (5 cycle, 10 cycles and 15 cycles). Every serial have been repeated for two times. In the tests, from every tuff type for every serial, 3 number and totally 6 specimens were used. Before and after every serial, the ultrasonic wave velocity measurements were accomplished.

5. FINDINGS AND DISCUSSION (BULGULAR VE TARTIŞMALAR)

5.1. Visual Appearance of Specimens Before and After Salt Tests (Numunelerin Tuz Testi Öncesi ve Sonrasının Görsel Görünümü)

After the tests of salt crystallization, a significant physical dispersion of the specimens was not observed. Generally, weathering happened in surfaces, corners and alteration zones of the specimen (Figure 2). When the cycle number increased, roughness in the surfaces of the specimen occurred because of increasing of degradation and speed degradation in alteration zones in the specimens were observed.

Figure 2. Visual appearance of specimens before and after salt test
(Şekil 2. Numunelerin tuz testi öncesi ve sonrası görünümü)

5.2. Dry Weight Loss by Salt Crystallization (Tuz Kristalleşmesi Nedeniyle Kuru Ağırlık Kaybı)

Dry weight loss (DWL) data obtained from the tests is shown in Table 3. Changes dependent to cycle numbers occurred after degradation DWL were observed significantly. When data obtained from salts crystallization test is evaluated, it is observed that specimens with code PB is the most effected and specimens with KV code is the lowest effected sample by salt crystallization. Also, it is observed that vitric tuffs were more affected in the first 5 cycles. As mentioned previously, this situation is originated from the speed degradation of alteration zones. Generally, it is said that crystallized tuffs is less affected from salt crystallization.

Table 3. The dry weight loss value of tuffs [After 5]
(Tablo 3. Tüflerin kuru ağırlık kaybı verileri [5])

Specimens code	*Mean dry weigth loss (%)*		
	5 cycle	*10 cycle*	*15 cycle*
SR	-0.83 ± 1.94	-0.93 ± 0.89	-1.13 ± 0.24
KV	-0.21 ± 0.35	-0.28 ± 0.13	-0.82 ± 0.01
PB	-1.08 ± 0.47	-5.72 ± 5.28	-6.88 ± 4.32
KR	-0.75 ± 0.84	-0.83 ± 0.80	-1.21 ± 0.44
SY	-0.30 ± 0.73	-0.52 ± 0.63	-1.42 ± 0.94
GR	-0.39 ± 0.42	-1.22 ± 0.40	-1.36 ± 0.63

During 15 cycles, the percentages amounts of salt were taken by structure of specimens were given in Figure 3 as graphics. As seen in Figure 3, when salt amounts were taken by structure of specimens with similar structure compared, it is observed that, specimens give the same behavior. For example, it is observed that percentages of salt amounts were taken by structure of specimens with codes SY-KV and SR-GR have an important similarity. The percentage weight loss of specimens with code PB is originated from the significant degradation of the specimens. According to general evaluation, observation of no important changes in weight of tuffs after the first 6 cycle was recorded (Figure 3).

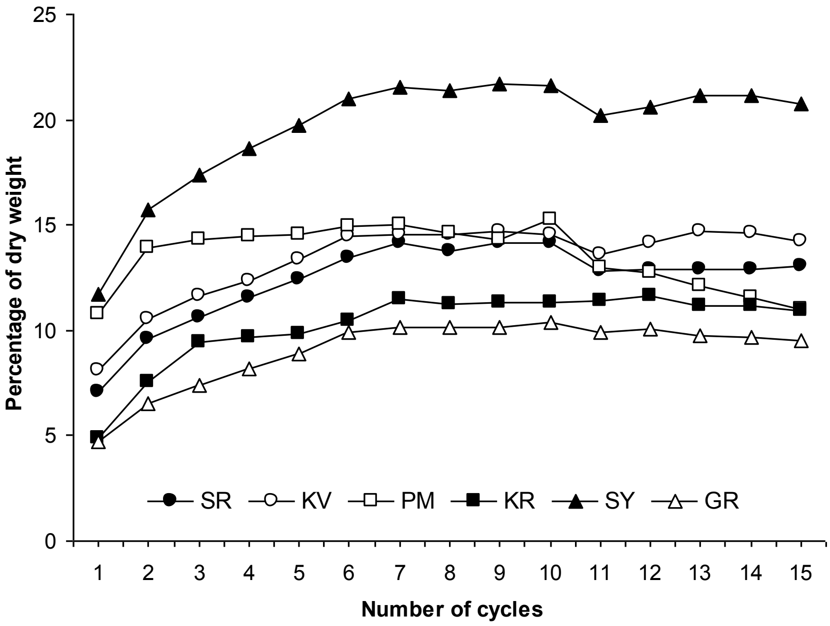

Figure 3. The percentage weight change of the tuff depends on the number of cycle[After 5]
(Şekil 3. Tüflerde döngü sayısına bağlı yüzde ağırlık değişimi[5])

When the relation between porosity properties of samples (Table 2) and degradation properties is evaluated (Table 3), it is observed that generally, increasing of porosity lead to increasing in degradation. This situation is more significant in the tuffs having similar petrographic structure. For example, it is observed that tuffs with the same petrographic properties and with codes SR, PB and GR were broken down according to their porosity values.

5.3. Estimation of The Changes After Salt Tests Using Ultrasonic Velocity (Tuz Testleri Sonrası Değişimin Ultrasonic Hız Kullanılarak Tahmin Edilmesi)

Ultrasonic method is a non-destructive testing technique. it is a method that just reveals the cracks. alterations without destroying the sample. In this study, the ultrasonic wave velocity before and after salt crystallization was measured by using PUNDIT plus. Weathering of building stones was tried to observe by this measurement method. 1MHz transducers were used at measuring. To observe the weathering rate on specimens, 3 measurements were made. Ultrasonic measurements were taken in 5. 10. 15 cycles after the washing and drying processes of prepared samples. The P wave and S wave velocity of the rock specimens was measured on the core specimens in accordance with ISRM [13]. The obtained measures data were summarized in Table 4.

Table 4. The average values of ultrasonic velocity after and before weathering [5]
(Tablo 4. Bozunma öncesi ve sonrası ortalama ultrasonik hız değerleri [5])

Specimens code	*Ultrasonic wave type*	*Ultrasonic velocity of unweathered tuff (m/s)*	*Ultrasonic velocity of weathered tuff (m/s)*		
			5 cycle	*10 cycle*	*15 cycle*
SR	P	2197.4	2158.3	2119.4	743.6
	S	2074.9	1950.2	1749.1	986.3
KV	P	2496.5	2452.4	2366.8	2362.2
	S	2247.5	1975.0	1967.7	1915.3
PB	P	1998.9	1979.2	1507.3	983.2
	S	1785.7	1297.1	1112.4	1084.0
KR	P	2859.6	2843.9	2812.5	2585.0
	S	2572.5	2533.9	1972.3	1860.6
SY	P	3007.8	2963.2	2885.1	2871.9
	S	2614.2	2051.4	2039.2	1960.9
GR	P	1891.0	1731.0	1710.0	919.6
	S	1730.8	1729.3	1592.4	1062.5

In ultrasonic measurements, increasing of wave velocity is evaluated as increase of steady of sample and decreasing of it is evaluated as increase of degradation. As seen, the increase in cycle number decreased ultrasonic velocity of the samples (Table 4).

When data of not damaged ultrasonic velocity values (Table 4), resistance (Table 3) and porosity (Table 2) compared. Generally, significant accordance is not determined. Consequently, it is seen that ultrasonic wave velocity always dose not give true information about resistance of rocks and their porosity properties. Evaluations of the previously made ultrasonic measurements [14] shown that, comparing of measures were carried out on the rocks with the same petrographic properties and estimating of changes after degradation were given more harmonious results.

In this type of studies, besides the advantages of ultrasonic measurements as non-destructive procedure, presence of wrong measurements were recorded. In the degradation studies, because of changing of material measured, providing the conditions that measured (because of the changes of material surface) is not possible. Because of that, it is thought that it is more suitable to evaluate this type of ultrasonic measurement methods as an estimation method not as properties determination method.

6. CONCLUSIONS (SONUÇLAR)

The strengths of 6 different tuffs used as building stones against salt crystallization were determined by using dry weight loss, uniaxial compressive test, indirect tensile test, point load index test and ultrasonic wave velocity measurements and the obtained data shown that strength of tuffs was affected by salt crystallization. The results obtained from the experimental studies are represented as following.

- Significant physical disintegration in specimens was not observed in salt crystallization tests. Weatherings were happened in surfaces. corners and alteration zones of the sample. It is seen that. resistances of tuffs against salt crystallization is changed according to their petrographic properties and alteration zones present in them. Changes dependent on cycle numbers after degradation were seen significantly. It was determined that vitric tuffs were more affected in the first 5 cycles. .
- Changes in degradation of rocks depends on salt crystallization can be estimated by ultrasonic measurements of the samples. When the obtained data was compared, approximately decreasing in all ultrasonic velocity of samples was shown. Although the advantage of ultrasonic measurements as a non destructive procedure was known, the presence of wrong measurements was recorded, because of physical changes were occurred by degradation.

REFERENCES (KAYNAKLAR)

1. Bell, FG., (1993). Durability of carbonate rock as building stone with comments on its preservation. Environmental Geology,Vol: 21,pp: 187-200.
2. Benavente, D., García-Del Cura MA., Bernabéu, A., and Ordóñez, S., (1999). Thermodynamic modeling of changes induced by salt pressure crystallization in porous media of stone. Journal of Crystal Growth,Vol: 204,pp:168-178.
3. Goudie, A.S., (1999). Experimental salt weathering of limestones in relation to rock properties. Earth Surface Processes and Landforms, Vol: 24,pp:715-724.
4. Unal, M., Oksuzoglu, C., and Berber, H., (2006). Salt- induced decay of the building stone. VIth International Scientific Conference, SGEM 2006, Bulgaria, Varna, pp:75-82.
5. Gundogdu, N., (2008). Investigation of the salt induced decay of the some tuffs used as building Stone, MS Thesis, Department of Mining Engineering, Selcuk University (in Turkish).
6. Navarro, C.R. and Doehne, E., (1999). Salt weathering: influence of evaporation rate supersaturation and crystallization pattern. Earth Surface Processes and Landforms,Vol: 24,pp:191-209.
7. Flatt, RJ., (2002). Salt damage in porous materials: how high supersaturations are generated. Journal of Crystal Growth, Vol:242, pp: 435-454.
8. Goudie, A.S. and Miles, H.A., (1997). Salt Weathering Hazards, Chichester, Wiley, p:241.
9. Jefferson, D.P., (1993). Building Stone: The Geological Dimension. Quarterly Journal of Engineering Geology,Vol: 26,pp:305-319.
10. Benavente, D., García-Del, Cura, M.A., Bernabéu, A., and Ordóñez, S., (2001). Quantification of salt weathering in porous stones using an experimental continuous partial immersion method. Engineering Geology, Vol:59,pp:313-325.
11. Benavente, D., García-Del, Cura, A., and Ordóñez, S., (2003). Salt influence on evaporation from porous rocks. Construction and Building Materials, Vol:17,pp:113-122.

12. Topal, T. and Doyuran, V., (1998). Analyses of deterioration of the Cappadocian tuff, Turkey. Environmental Geology, Vol:34(1),pp:5-20.
13. ISRM, (1981). Rock Characterization, Testing and Monitoring, ISRM Suggested Methods, Pergamon, Oxford, p:211.
14. Unal, M., Ozkan, I. and Kekec, B., (2006). An estimation of the salt weathering in building stone by using ultrasonic velocity measurements. MERSEM 2006, Afyon (in Turkish).