Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 33(1), ss. 229-240, Mart 2018
Çukurova University Journal of the Faculty of Engineering and Architecture, 33(1), pp. 229-240, March 2018

Evaluation of Different Types of Limestones used As Marble by Nondestructive Test Methods

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Geliş tarihi: 22.12.2017 *Kabul tarihi: 14.03.2018*

Abstract

Currently, the usability of building stones is determined by direct physical and mechanical tests. Dry unit weight, water absorption by weight, post-frost weight loss, uniaxial compressive strength and post-frost uniaxial compressive strength values are compared with the limiting values as specified in TS 10449 and ASTM standards in order to be used as a building stone. This study proposes a new method that can be used to evaluate building stones to be used in construction industry by use of Vp and Vs wave velocity values gathered using a nondestructive test method. Within the scope of this study, Vp and Vs wave velocities of building stones with six different textures were measured on 144 original and weathered cube samples of 7x7x7 cm^3. The results from conventional test methods were compared with the proposed nondestructive test method results and a criteria that can be adopted to current relevant standards using Vp and Vs values was proposed. It was concluded that limestones samples with Vp higher than 5000 m/s and Vs higher than 2750 m/s can be used as building stone.

Keywords: Building stone, Limestone, Accelerated weathering test, Ultrasonic pulse velocity

Tahribatsız Yöntemlerle Farklı Kireçtaşlarının Mermer Olarak Kullanılabilirliğinin Belirlenmesi

Öz

Günümüzde, yapı taşlarının kullanılabilirliği doğrudan fiziksel ve mekanik testlerle belirlenmektedir. Yapıtaşları, kaya malzemenin kuru birim hacim ağırlığı, ağırlıkça su emme, donma sonrası ağırlık kaybı, tek eksenli basınç dayanımı ve donma sonrası tek eksenli basınç dayanımı değerlerine göre TS 10449 ve ASTM standartlarında belirtilen sınırlayıcı değerlerle karşılaştırma yapılarak kullanılmaktadır. Bu çalışmanın amacı, yapıtaşının belirlenmesinde tahribatsız bir test yöntemi olan Vp ve Vs dalga hızı değerleri ile inşaat sektöründe kullanılacak yapı taşlarının değerlendirilmesi için yeni bir parametre

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önermektedir. Bu çalışma kapsamında, 7x7x7 cm^3 boyutlarında 144 orijinal ve yıpranmış küp numunesinde altı farklı dokuya sahip yapı taşının Vp ve Vs dalga hızı ölçülmüştür. Bilinen test yöntemlerinden elde edilen sonuçlar, önerilen tahribatsız test yöntemi sonuçları ile karşılaştırılmış ve mevcut standartlara Vp ve Vs değerleri kullanılarak kabul edilebilir bir ölçüt önerilmiştir. Sonuç olarak, Vp değeri 5000 m/s'den Vs değeri de 2750 m/s'den büyük bulunan kireçtaşlarının yapı taşı olarak kullanılabileceği belirlenmiştir.

Anahtar Kelimeler: Yapıtaşı, Kireçtaşı, Yapay bozunma deneyi, Ultrasonik hız

1. INTRODUCTION

Sedimentary rocks with different mineralogy and texture are commonly used as building stone as per their physical and mechanical properties. Especially in the marble industry, the cost of a stone is related to its durability, its rarity and its appearance. Determining which rock type will be better for flooring and coating directly affects the cost and product life cycle. Less durable rocks fail in its service life because of abrasion and deterioration. Durability of building stones depend on the mineralogy, texture and strength.

Many studies were conducted to determine the physical and technomechanical properties of several type building stones found in Turkey [1-10]. Özpınar [6] found that the compressive strength of travertines increase as their water absorption values by weight and volume decreases. Akın [7] examined the deterioration mechanisms of yellow travertines in Eskipazar (Karabük) and suggested that repeated wetting-drying and freezing-thawing cycles in yellow travertines cause rock deterioration and are effective in the pores of travertines. Also, Akın [7] revealed that the yellow travertines did not completely lose their initial integrity as a result of accelerated weathering tests; however, salt crystallization caused significant cracking in the travertines.

Considering all these studies, it is seen that it is important to determine the losses relevant to the deterioration of the materials used in the marble industry under atmospheric effects. Currently, the standards used for evaluation of building stones suggest use of the results of destructive and time consuming tests conducted to determine dry unit weight, water absorption by weight, post-frost weight loss, uniaxial compressive strength and post-frost uniaxial compressive strength values. These values were then compared with the limiting values specified in relevant standards. This study proposes a new method that can be used to evaluate building stones to be used in construction industry by use of Vp and Vs wave velocity values gathered using a nondestructive test method. Vp and Vs values obtained from an easy to apply nondestructive test method can be put as a criteria in the standards for evaluation of building stones that will be used in the construction industry. Therefore, in this study, limestones, which are the most commonly used building stones in the marble industry, with different texture were selected and the durability performance of these building stones were determined by conventional test methods and proposed nondestructive test method. The results from conventional test methods were compared with the proposed nondestructive test method results and a criteria that can be adopted to current relevant standards using Vp and Vs values was proposed.

2. MATERIAL and METHODS

2.1. Laboratory Studies

Laboratory studies constitute a significant part of this research and TS EN and RILEM [11-14] standards and ISRM [15, 16] criteria were used to determine the physical and durability properties of six different limestone samples within the scope of this study. Vp wave velocity values in dry and saturated condition of all surfaces of each sample and Vs shear wave velocity values of dry surfaces were measured. Thin section of each sample was also prepared and petrographic features of the limestone were determined under a polarizing microscope.

2.2. Physical Tests

Experiments were carried out according to TS 699 [11] to determine the physical properties such as dry and saturated unit weights, water absorption by weight and porosity of limestone samples. These experiments were performed on regularly shaped cube samples of 7x7x7 cm^3. Cube samples subjected to accelerated weathering test were resubjected to physical property tests to determine changes in the structural properties resulting from these experiments.

2.3. Accelerated Weathering Tests

The most important purpose of accelerated weathering test is to determine the long term durability performance of a rock material in a shorter period of time in order to be used as a building stone [7]. In this study, freezing-thawing and salt crystallization tests were applied according to TS EN 12371 [12] and RILEM [13] standards on 144 cube samples of 7x7x7 cm^3. All of these samples were subjected to freeze-thaw and salt crystallization experiments to determine the physical and mechanical properties of the material before and after the accelerated weathering tests.

2.3.1. Freeze-Thaw Test

In the freeze-thaw test applied on cube samples of 7x7x7 cm^3, the limestone samples were put under the influence of the pore water pressure by creating stress conditions in the pores of a saturated water sample as a result of freezing. The number of cycles in freeze-thaw test was selected as 30. The samples were subjected to the same tests to determine the change in physical properties by subtracting 3 samples at the end of each 10 cycle in order to examine the changes in the physical properties of the yellow travertine samples as a result of freeze-thaw cycles.

2.3.2. Salt Crystallization Test

It is known that salt crystallization plays an important role in the deterioration of the building stones [7, 17-21]. The most important aim of the salt crystallization test is to provide experimental similarity of pressures effects on building stones resulting from salt crystallization. The samples taken from the solution were washed with water and then allowed to dry for 18 hours at a temperature of 105±5 °C in an oven. 30 cycles were applied in this test. The change in physical properties was determined by testing 3 samples in every 10 cycle in the test.

2.4. Mineralogical Properties of Building Stones Tested

In this study, a total of six different limestones were collected from different parts of Turkey and Iranian. An important attention was given in selecting the limestone blocks to be free from macroscopic defects. Each limestone type used in this study was investigated mineralogically and petrographically based on thin section studies and XRF analysis. For this purpose, thin sections prepared from the collected limestones were investigated under a polarizing microscope. In addition, each sample was examined using XRF analysis. X-ray fluorescence (XRF) spectroscopy analysis was used to determine the element composition. XRF analysis was obtained using a Bruker S8 Tiger model device. The mineralogical descriptions demonstrated that all rocks mainly include calcite and dolomite minerals in different amounts (Table 1).

3. EXPERIMENTAL STUDIES

Dry (DUW) and saturated unit weight (SUW), water absorption by weight (WAW) and apparent porosity values (n) of the samples used in this study were determined according to TS 699 [11] (Table 2). When examining the classification of building stones according to porosity [22], it was seen that samples 2, 3 and 4 are compact and others are medium porous. Wave velocities of Vp and Vs of building stones were measured by the Proceq ultrasonic velocity test equipment. Using the results of Vp and Vs velocities, Poisson Ratio value was calculated according to Equation 1

(Table 2). Poisson's ratio values determined using the results of nondestructive tests are found to be close to the estimated values for limestone. A criteria that can be adopted to current relevant standards using Vp and Vs values was proposed.

$$\sigma = (0.5 * (Vp / Vs)^2 - 2) / ((Vp / Vs)^2 - 1) \qquad (1)$$

Table 1. XRF analysis, petrographic descriptions and micrographs of the samples used in the study

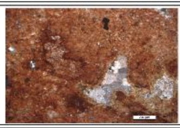
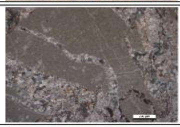
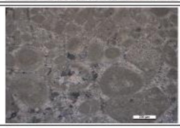
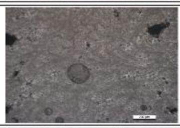
Sample No	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Rock Name		Micrograph of the rock	Petrographic description
1	9.06%	2.83%	3.69%	0.55%	45.87%	0.47%	TRAVERTINE			Microcrystalline calcite is cut by veins of coarse calsit + dolomit fillings
2	3.45%	1.12%	0.63%	0.41%	53.04%	0.32%	LIMESTONE			There are calcite and fossil fragments, calcite is cut by veins
3	1.15%	0.32%	0.28%	0.48%	54.90%	0.07%	LIMESTONE			Microcrystalline calcite ooze is cut by veins of coarse calsit + dolomit fillings
4	1.22%	0.38%	0.14%	2.96%	51.70%	0.05%	LIMESTONE			There are calcite and fossil fragments
5	0.05%	0.02%	0.06%	0.17%	55.96%		TRAVERTINE			Microcrystalline calcite ooze is cut by veins of coarse calsit + dolomit fillings
6	1.02%	0.25%	0.09%	6.61%	47.71%	0.03%	LIMESTONE			There are calcite and fossil fragments

Table 2. Physical properties and mean wave velocity of cube samples of 7x7x7 cm^3

	Limestone Samples	Number of Samples (n)	DUW (kN/m^3)	SUW (kN/m^3)	WAW (%)	Porosity n (%)	Vp (m/sn)	Vs (m/sn)	Poisson Ratio	UCS (MPa) (n=3)
1	Travertine	21	23.48	23.90	1.81	3.77	5618	3206	0.26	61.00
2	Limestone	21	25.54	25.64	0.38	0.88	5149	2750	0.30	71.31
3	Limestone	21	25.90	25.96	0.23	0.54	5841	3124	0.30	64.84
4	Limestone	21	26.24	26.28	0.14	0.33	6329	3381	0.30	122.40
5	Travertine	21	23.71	23.99	1.18	2.48	6203	3275	0.31	42.25
6	Limestone	21	24.88	25.36	1.10	2.24	5230	3019	0.25	100.98

3.1. Freeze-Thaw Test Results

The percent change in the physical properties of the samples after 30 freezing and thawing cycles on the limestone samples were determined (Table 3). No significant changes were observed in dry and saturated unit weights as a result of the 30 freezing and thawing cycles. After freeze-thaw tests, the porosity increased in all samples except sample 3. The highest increase was observed at samples 2 to 4 (Figure 1). In general, Vp wave velocity values in all samples were lower than the original samples whereas dry Vp wave velocities were approximately decreased 20% in samples of 1 and 5. As a result of the freeze-thaw tests, it has been found that, there was a partial physical alteration in the appearance and texture of the samples of 2, 3 and 4 which include calcite veins (Figure 2).

Table 3. Effect of freezing-thawing cycles on the physical properties of limestone samples

Limestone Samples	Number of Cycles	DUW (%)	SUW (%)	WAW (%)	Porosity (%)	Vp (dry) (%)	Vp (saturated) (%)
1	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	99.93	100.10	108.57	111.27	87.63	97.47
	20	99.89	100.21	118.67	126.06	80.71	99.76
	30	99.91	100.38	124.26	125.94	80.61	100.06
2	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	99.91	100.07	142.79	144.01	89.32	98.23
	20	99.88	100.11	153.81	164.33	86.18	95.42
	30	99.83	100.07	162.57	166.22	85.37	99.51
3	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	100.02	100.02	115.00	115.60	95.54	99.55
	20	99.98	99.95	86.57	92.45	94.77	99.04
	30	99.96	99.97	103.93	103.99	92.63	100.96
4	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	99.99	100.05	161.13	163.42	99.92	100.95
	20	99.98	100.03	156.69	171.34	100.88	100.40
	30	99.96	100.03	146.72	148.04	98.56	101.02
5	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	99.91	100.12	116.80	116.97	89.58	99.13
	20	99.95	100.21	124.66	134.35	83.87	99.76
	30	99.91	100.29	135.40	134.94	79.77	99.30
6	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	100.00	100.25	112.74	113.70	95.91	100.67
	20	99.98	100.25	114.47	115.92	93.15	98.60
	30	99.96	100.49	127.63	129.04	92.86	100.46

3.2. Salt Crystallization Test Results

The salt crystallization test with $MgSO_4$ solution was performed as 30 cycles and percent change rates in the physical properties of the samples were determined (Table 4). It was found that the deterioration at the end of the salt crystallization experiment using $MgSO_4$ on the samples selected for this study is much more destructive than freezing and thawing cycles. As a result of the experiment which continued 30 cycles, it was determined that the dry and saturated unit weight values generally increase due to the presence of salt crystals in the cavities (Figure 3). There was a partial physical change in appearance and texture of samples 2 and 3, which includes calcite veins whereas sample 5 had a heterogeneous structure as a result of the salt crystallization experiments (Figure 4).

4. DISCUSSIONS

There are many standards which express the limit values of some physical and mechanical properties related to the use of natural stones as a building stone in cladding and paving [23-34]. By using limiting values dependent on physical tests from these standards, the usability of these samples as building stones has been evaluated according to TS [26, 35] and ASTM [31-34] standards.

DUW, WAW, post-frost weight loss, uniaxial compressive strength and post-frost uniaxial compressive strength results as well as proposed Vp and Vs velocity values gathered using a nondestructive test method along with the limiting values specified in [26] are shown in Table 5. It can be said that limestone samples with Vp higher than 5000 m/s and Vs higher than 2750 m/s can be used as building stone when the results are interpreted according to Vp and Vs values measured nondestructively. The correctness of the results was tested by comparing these results with the average results of uniaxial compressive strength.

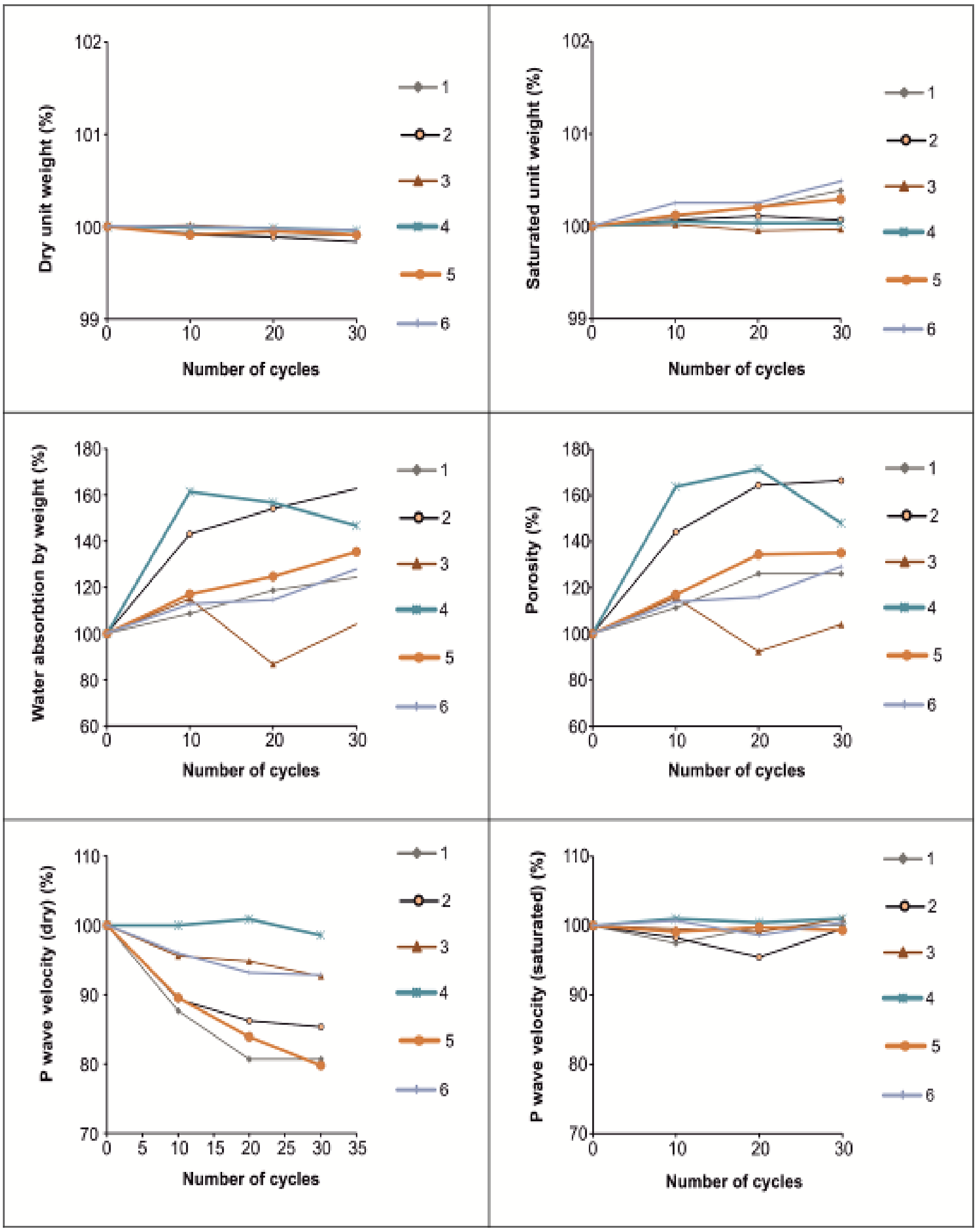


Figure 1. Effect of freezing-thawing cycles on the physical properties and Vp values of limestone samples

Figure 2. Images of the 30th cycle after the freeze-thaw test

Table 4. Effect of salt crystallization cycles on the physical properties of limestone samples

Limestone Samples	Number of Cycles	DUW (%)	SUW (%)	WAW (%)	Porosity (%)	Vp (dry) (%)	Vp (saturated) (%)
1	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	100.64	100.65	100.99	100.15	96.55	100.32
	20	100.86	100.80	95.99	97.76	102.34	93.33
	30	101.80	101.62	92.52	89.29	103.08	87.76
2	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	99.92	100.13	120.00	121.00	94.36	93.20
	20	99.95	99.80	53.47	53.09	96.11	90.66
	30	99.94	99.61	20.97	20.03	99.06	98.20
3	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	100.03	99.99	84.98	88.51	99.61	99.99
	20	100.08	99.97	50.62	49.89	100.48	100.47
	30	100.17	100.08	59.28	58.11	103.27	98.12
4	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	100.01	99.97	61.89	62.27	100.48	97.74
	20	100.08	100.05	71.21	72.00	98.91	99.52
	30	100.03	99.94	28.55	27.92	103.90	101.41
5	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	100.28	100.38	109.11	110.29	84.44	88.47
	20	100.54	100.54	101.12	103.43	93.10	90.56
	30	101.17	101.38	116.83	121.49	95.75	87.03
6	0	100.00	100.00	100.00	100.00	100.00	100.00
	10	100.98	100.68	89.20	90.66	91.78	92.39
	20	100.79	100.58	87.96	89.89	100.16	94.46
	30	100.92	100.73	80.92	81.64	93.09	91.88

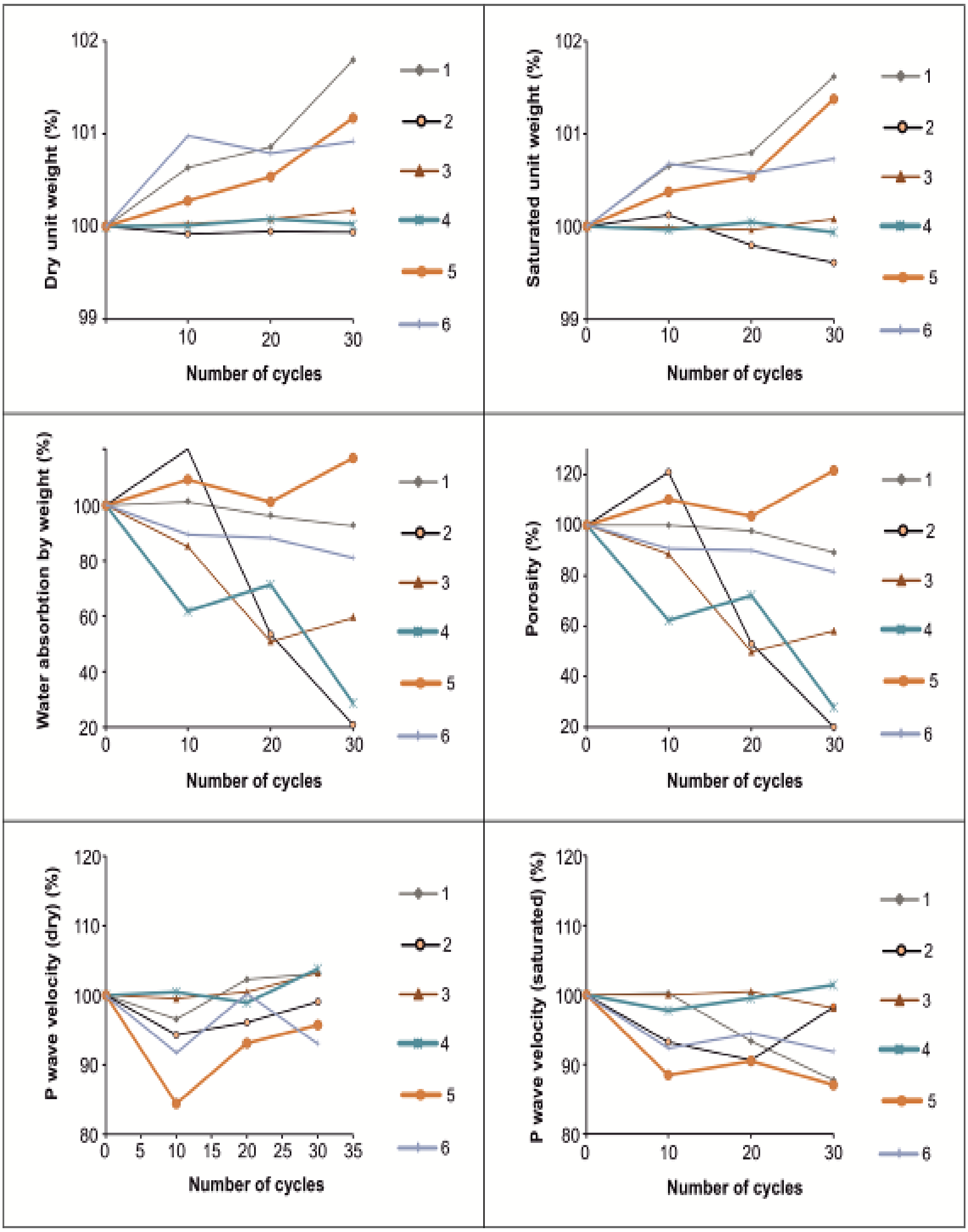


Figure 3. Effect of the salt crystallization test cycles on the physical properties and Vp values of limestone samples

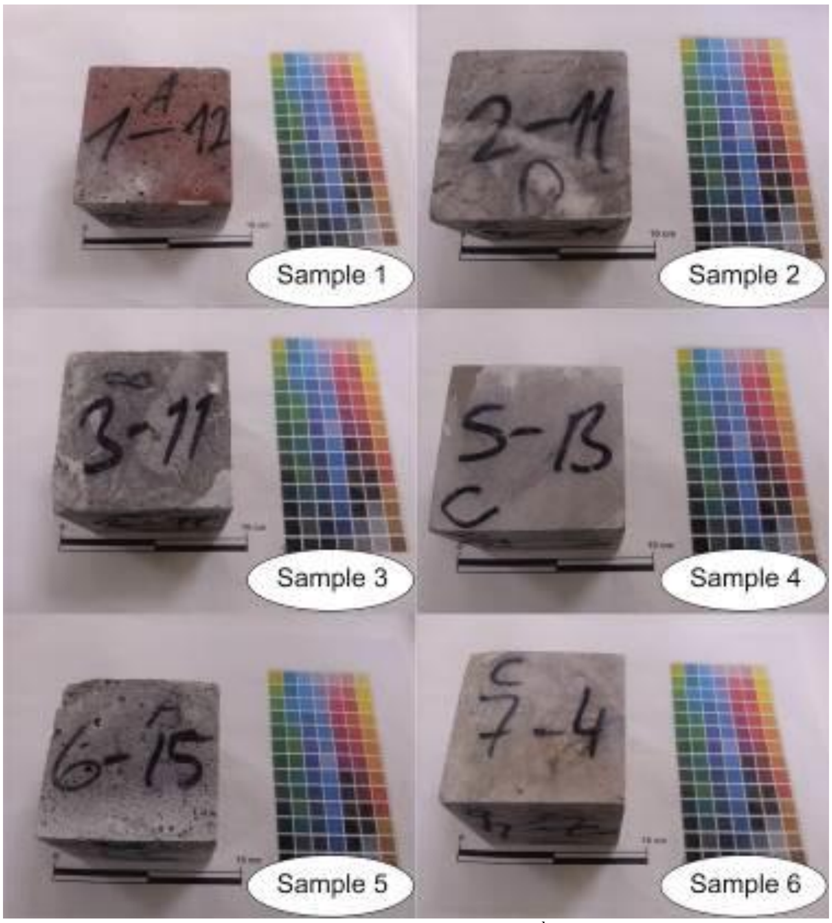


Figure 4. Amount of deteriorations occurred in samples after 30th cycle of salt crystallization test

Table 5. Comparison of Vp and Vs values with limiting values of currently used standards

Applied Tests	**Samples**						**TS 10449 / 11137**	**ASTM C**
	1	**2**	**3**	**4**	**5**	**6**		
Density (g/cm^3) [11]	2.39	2.60	2.64	2.67	2.42	2.56	>2.3	>2.5
Water Absorption By Weight (%) [11]	1.81	0.38	0.23	0.14	1.18	1.10	<0.4	
Post-Frost Weight Loss (%) [12]	0.09	0.17	0.04	0.04	0.08	0.04	<1	
Uniaxial Compressive Strength (MPa) [14]	61.00	71.31	64.84	122.40	42.25	100.98	>50	>50
Post-Frost Uniaxial Compressive Strength (MPa) [14]	58.23	68.99	75.43	110.54	54.16	92.89	>30	
Usability according to [35]	√	√	√	√	√	√		
Vp (m/s) [16]	5618	5149	5841	6329	6203	5230	***>5000***	***Suggestible***
Vs (m/s) [16]	3206	2750	3124	3381	3275	3019	***>2750***	

According to TS [35], limestone that will be used as marble should have a calcite mineral content less than 95% whereas the density (of limestone that will be used as marble) should be less than 2.16 g/cm^3 and the water absorption should not be more than 0.4% under atmospheric pressure. The weight loss after freezing and thawing cycles should not exceed 1%. It is also desirable that the UCS value should be at least 50 MPa in the load bearing elements and should not be less than 30 MPa in the coverings. The limestones examined in this study fulfill all of these requirements.

5. CONCLUSION

Travertine, limestone, granite and basalt are industrially used in many buildings as decorative stone due to their appearance and pattern features. Apart from these two uses, these rocks are in demand in the marble industry as cladding and paving stone.

Within the scope of this study, the use of limestones as a building stone was investigated by carrying out conventionally used physical tests and proposed nondestructive test method on original and deteriorated samples after accelerated weathering tests.

By using limiting values dependent on physical experiments from these standards, the usability of these samples as building stones has been evaluated according to TS 11143 [26] and ASTM [31-34] standards. A correlation between P-wave and physical and mechanical value has been seen in this study. The results from conventional test methods were compared with the proposed nondestructive test method results and a criteria using Vp and Vs values was proposed.

It is concluded that limestone samples with Vp higher than 5000 m/s and Vs higher than 2750 m/s can be used as building stone. However, it is necessary to increase the number of samples in order to determine the lower limit of these values.

Since, the wave velocity values are easily and quickly obtained under all conditions, Vp and Vs limiting values are recommended to be added to the relevant standards used for evaluation of building stones.

6. REFERENCES

1. Ayaz, M.E., Karacan, E. 2000. Sivas Batısındaki Traverten Oluşumlarının Yapı ve Yüzey Kaplama Taşı Olarak Kullanılabilirliklerinin İncelenmesi. Jeoloji Mühendisliği Dergisi, 23-24(1), 87-99.
2. Kahraman, S., 2001. Evaluation of Simple Methods for Assessing the Uniaxial Compressive Strength of Rock. Int. J. Rock Mec. Min. Sci, 38, 981-994.
3. Altaş, Z., 2006. Üçtepe (Bünyamin-Kayseri) Traverten Ocağının İncelenmesi. Yüksek Lisans Tezi, Çukurova Üniv. Fen Bilimleri Enstitüsü. Adana, 82.
4. Şen, S., 2006. Baltaşı - Palu (Elazığ) Travertenlerinin Tekno-Mekanik Özelliklerinin Belirlenmesi. Yüksek Lisans Tezi, Çukurova Üniv. Fen Bilimleri Enstitüsü, Adana, 93.
5. Kaya, T., 2007. Ulumuhsin (Konya) Civarındaki Traverten Yataklarının Jeolojisi ve Fiziksel Özellikleri. Yüksek Lisans Tezi, Selçuk Üniv. Fen Bilimleri Enstitüsü, Konya, 47.
6. Özpınar, Y., Heybeli, H., Semiz, B., Baran, H.A., Kocan, B., 2001. Kocabaş (Denizli) Travertenlerinin ve Kömürcüoğlu (Kocabaş) Travertenlerinin Jeolojik ve Petrografik Olarak İncelenmesi ve Bunların Teknolojik Açıdan Değerlendirilmesi. PÜ Mühendislik Fakültesi Jeoloji Mühendisliği Bölümü. Türkiye 3. Mermer sempozyumu (Mersem'2001) Bildiriler Kitabı. Afyon.
7. Akın, M., 2008. Eskipazar Karabük Travertenlerinin Bozunmasının Araştırılması. Doktora Tezi, Ankara Üniv. Fen Bilimleri Enstitüsü. Ankara, 280.
8. Kılıç, A.M., Kahraman, E., Kılıç, Ö., 2017. The use of Ultrasonic Mesaurements Determining the Quality of the Dimension Stone Blocks, International Journal of Natural and Engineering Sciences. 11(1), 28-33.

9. Erdoğan O., Özvan A., 2015. Evaluation of Strength Parameters and Quality Assessment of Different Lithotype Levels of Edremit (Van) Travertine (Eastern Turkey). Journal of African Earth Science, 106, 108-117.

10. Celik, M.Y., 2017. Water Absorption and P-Wave Velocity Changes During Freeze-thaw Weathering Process of Crosscut Travertine Rocks. Environ Earth Sci.76:409. DOI 10.1007/s12665-017-6632-7

11. TS 699, 2009. Doğal Yapı Taşları. İnceleme ve Deney Metotları. Türk Standartları Enstitüsü. ICS91.100.01; 91.100.15. Ankara.

12. TS EN 12371, 2002. Doğal Taşlar-Deney Metotları-Dona Dayanım Tayini. Türk Standartları Enstitüsü, Ankara.

13. RILEM, 1980. Recommended Tests to Measure the Deterioration of Stone and to Assess the Effectiveness of Treatment Methods. Commission 25-PEM. Material and Structures. 13, 175-253.

14. TS EN 1926, 2007. Doğal taşlar-Deney yöntemleri -Tek eksenli basınç dayanımı tayini, Ankara.

15. ISRM, 2007. The Complete ISRM Suggested Methods for Rock Characterization. Testing and Monitoring: 1974-2006. Eds. R. Ulusay and J.A. Hudson. ISRM Turkish National Group. Ankara.

16. ISRM, 2014. The ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 2007–2014, R. Ulusay (ed.), DOI: 10.1007/978-3-319-07713-0, _ Springer-Verlag Wien 2013.

17. Cooke, R.U., 1994. Salt Weathering and the Urban Water Table in Deserts. Rock Weathering and Landform Evolution. Robinson. D.A. and Williams. R.B.G.(eds.). Chp. 12, 193-205.

18. Benavente, D., Del Cura, M.A.G., Fort, R., Ordonez, S., 2004. Durability Estimation of Porous Building Stones from Pore Structure and Strength. Engineering Geology. 74, 113-127.

19. Ruiz Agudo, E.. Mees, F.. Jacobs, P., Rodriguez Navarro, C., 2007. The Role of Saline Solution Properties on Porous Limestone Salt Weathering by Magnesium and Sodium Sulfates. Environmental Geology. 52, 305-317.

20. Fereidooni, D., Khajevand, R., 2017. Correlations Between Slake-Durability Index and Engineering Properties of Some Travertine Samples Under Wetting–Drying Cycles. Geotech Geol Eng DOI 10.1007/s10706-017-0376-8

21. Zalooli, A., Khamehchiyan, M., Nikudel, M.R., 2018. Durability Assessment of Gerdoi and Red Travertines from Azarshahr, East Azerbaijan Province, Iran. Bulletin of Engineering Geology and the Environment https://doi.org/10.1007/s10064-018-1249-y

22. Tarhan, F., 1989. Mühendislik Jeolojisi Prensipleri, K.T.Ü. Basımevi, Trabzon.

23. TS 2513, 1977. Doğal Yapı Taşları, TSE, Ankara.

24. TS 10449, 1992. Mermer–Kalsiyum Karbonata Esaslı–Yapı ve Kaplama Taşı Olarak Kullanılan. Ankara.

25. TS 6234, 1988. Granit Yapı ve Kaplama Taşı Olarak Kullanılan, TSE, Ankara.

26. TS 11143, 1993. Traverten Yapı ve Kaplama Taşı Olarak Kullanılan, TSE, Ankara.

27. ASTM C 616, 1989. Standard Specification for Quartz-Based Dimension Stone, Annual Book of ASTM Standards.

28. ASTM C 568, 1990. Standard Specification for Limestone Dimension Stone, Annual Book of ASTM Standards.

29. ASTM C 615, 1992. Standard Specification for Granite Dimension Stone, Annual Book of ASTM Standards.

30. ASTM C 503, 1989.Standard Specification for Marble Dimension Stone, Annual Book of ASTM Standards.

31. ASTM C 97, 1996. Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone, Annual Book of ASTM Standards.

32. ASTM C 170, 1990. Standard Test Method for Compressive Strength of Dimension Stone, Annual Book of ASTM Standards.

33. ASTM C 99, 1987. Standard Test Method for Modulus of Rupture of Dimension Stone, Annual Book of ASTM Standards.

34. ASTM C 241, 1990. Standard Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic, Annual Book of ASTM Standards.
35. TS 10449, 2009. Mermer-Kalsiyum Karbonat Esaslı-Yapı ve Kaplama Taşı Olarak Kullanılan, Ankara.