Travertine as Construction and Building Material

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Abstract An experimental study was conducted to investigate physico-mechanical properties of travertines being quarried in western Turkey as construction and buildings material. Four common type of travertine, one of the most common construction materials in the world, were collected from quarries operated around the city of Denizli in south of Turkey, and related rock property tests including both dry and saturated unit weight of travertine, effective porosity, water absorption by weight, uniaxial compressive strength, P-wave velocity, slake durability test were conducted on the samples. Consequently, the results of the performed tests were evaluated according to the national and international construction stone regulations. Concluding remark is that travertine quarrying in the Denizli Basin of Turkey satisfies the relevant natural stone standards with negligible distinction to be used for construction and building purposes.

Key words: Buildings, Construction, Travertine

Introduction

Travertine that could be used in both interior and exterior of buildings is one of the most useable construction and buildings stones in the world. Travertine is a variety of calcium carbonate commonly formed around the hot and cold carbonate-bearing springs. Travertine consists predominantly of quartz grains that usually held together by cementing material with small percentages of feldspar and mica particles and clay. As silica and iron oxide provide the strongest bond for travertines, calcium carbonate gives weakest. Their color ranges from light white, yellow through dark brownish. Even though travertine is often called marble, simply a very pure and mostly porous form of limestone. The Denizli extensional basin in western Turkey has widespread travertine accumulation since Late Quaternary (Figure 1). The total area occupied by modern and old travertines is more than 100 km^2 and its thickness can reach up to 60 m (Özkul et al. 2000). Most of the studies performed on the Denizli travertines are generally focused on Pamukkale (one of the famous travertine deposite of the world) and mainly related to hydrogeology of hot waters, geothermal potential, wasting and conversation (Koçak, 1971; Eşder et al. 1991; Ekmekçi et al. 1995). Some studies have been subjected to dating, morphological classification and relations between travertine and active tectonic-seismicity of the region (Altunel and Hancock, 1993a and 1993b; Hancock et al. 1999).

The most common lithotypes presently quarried in Denizli basin are shrub, reed and crystalline crust type travertine respectively; So far, there is no attempt made to investigate physico-mechanical properties of travertine to examine the quality of them for construction purposes. In this paper, travertine types commonly quarried in the area was investigated and results of the research are discussed herein from the scope of their usability and suitability for construction and buildings.

Geological Composition of Travertine Quarried in the Denizli Basin

Thermal spring waters usually contain large amounts of calcium bicarbonate. As the spring water reaches to earth surface, the water lose most of the dissolved carbon dioxide (gases) and the calcium carbonate in solution readily precipitates as a thin layer of calcite (Demirdağ, 2007). Travertine precipitated at different depositional conditions; so they exhibit variation of color, appearance, bedding, porosity, texture, strength and chemical composition in the Basin (Yağız, 2009). Mainly quarried travertine lithotype in the basin includes; shrub type travertine represented by small bush like growths are common deposit on horizontal and sub horizontal surface (Chafetz, 1984); onyx type travertine commonly forms as a result of rapid precipitation due to fast flowing water on smooth slope; reed type travertine deposited marsh-pool, mound and self built channels (Pentecost, 1990) and noche, compact and subunit of reed type one (Guo and Riding, 1998; Akyol et al. 2005). Every travertine type has its specific texture and chemical composition because of its own depositional and environmental conditions (Figure 2).

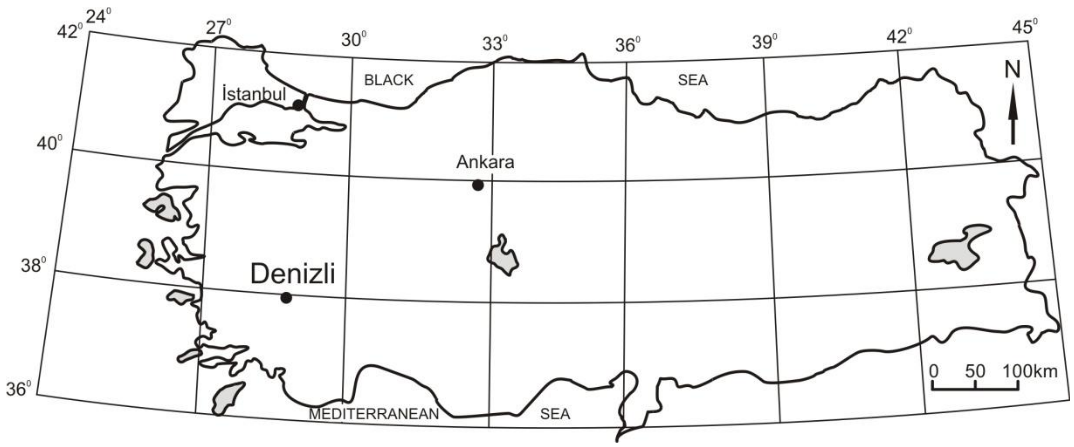

Figure 1. Location map of the sampling area, Denizli-Turkey

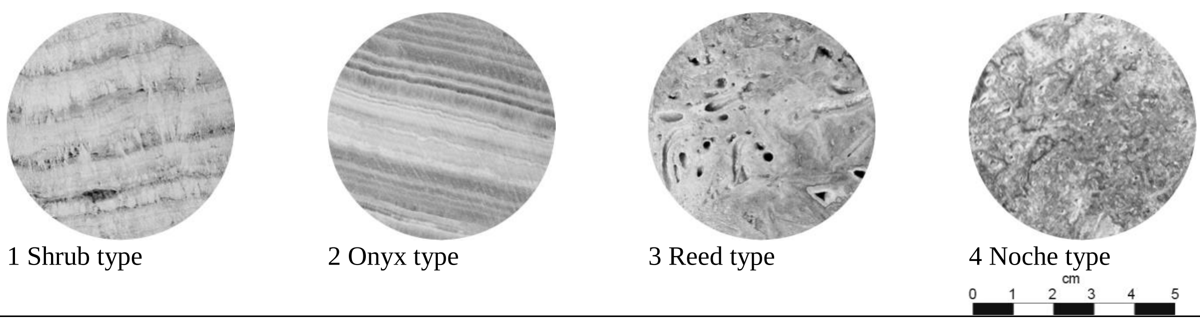

Figure 2. Macro photograph of the studied rock samples collected from quarries

Laboratory Testing Methods

Travertine blocks were obtained from quarries operating around the city of Denizli and consequently, samples were prepared to conduct laboratory tests in accordance with the specification of the International Society for Rock Mechanics (ISRM, 1981) and Turkish Standard Institute (TSE 699, 1987).

Index Properties of Travertine

The samples with 70x70x70mm dimension were used in determination of unit weight, porosity and water absorption of travertines as recommended (ISRM, 1981; TSE 699, 1987). The spacemen volume was computed from an average of several caliper readings. Dry weight of sample was obtained with a balance, capable of weighing to an accuracy of 0.01gr. Dry and saturated unit weight of travertine ($\square_{dry}$, $\square_{sat}$) was obtained from the ratio of sample weight to the volume in kg/m^3. The effective porosity (n'), pore volume and water absorption by weight (w) was determined via saturation and caliper techniques (ISRM, 1981). Rock fullness ratio (F) also computed by multiplying bulk density of rock with the ratio of water absorption by weight to void ratio. For each travertine type, the measurements were carried out on ten samples and the average values of the relevant properties with standard deviation are tabulated as in Table 5.

Uniaxial Compressive Strength Test

The uniaxial compressive strength (UCS) of rock was tested on cubical-samples (having dimension of 70x70x70mm) smoothly sawed from large size blocks in accordance with TSE 699 standards. The ends of the samples were cut parallel to each other and at right angle to the longitudinal axis and then smoothened to ensure that the samples were free from abrupt irregularities and roughness. The stress rate applied uniformly within the limits of 0.5-1.0 MPa/s. The test was conducted perpendicular to observed beddings or layers on a sample to get rid of anisotropy affect on obtained values. Ten samples were tested for each travertine type and the average values were recorded as the UCS of travertine (Table 5).

P-Wave Velocity Test

P-wave velocity of travertine was measured on the UCS samples using the Portable Ultrasonic Nondestructive Digital Indicating Tester (PUNTID plus). This tester measures the time of propagation of ultrasound pulses in a sample in the range (0.1-999.9□s) with a precision of 0.1□s. The transducers used were 42mm in diameter with 54 kHz. The measurement was carried out perpendicular to visual beddings or layers by using good coupling agent necessary between rock surfaces and both receiver and transducer face for accuracy of measurement. Afterward, P-wave velocity was computed from the ratio of distance between transducer and receiver to the time that P-wave takes to travel the distance. The tests were performed on 10 samples by following ISRM methods for each travertine type and the average values were used in the dataset. As result of tests, studied travertine types show high P-wave velocity ranging from 4.5 to 5.0km/s according to P-wave classification as given in Table 1.

Vp (km/s)	Description	Shrub	Onyx	Reed	Noche
<2.5	Very low				
2.5-3.5	Low				
3.5-4.0	Moderate				
4.0-5.0	High	x	x	x	x
>5.0	Very high				

Table 1. P-wave velocity classification for studied travertine types (Anon, 1979a)

Slake Durability Test (SDI)

The slake durability test was carried out by using the standard testing method developed (Franklin and Chandra, 1972) and as suggested (ISRM 1981). To perform the test, ten rock lumps made blunt with chisel (ten pieces of about 40–60 g each) were taken and rotated in a drum half immersed in tap water about 20 ^oC for 10 min at 20rpm. Test drum was made of a standard sieve mesh of 2mm so that the products of slaking from rock samples could pass through the sieve into the water bath. The slake durability index (Id_2) corresponding to the second cycle was computed as the percentage ratio of final to initial dry weights of rock in the drum after the drying and wetting cycles. The test was performed on ten sample of each travertine type with four cycles as suggested by various researchers (Gökçeoğlu et al. 2002; Dhakal et al. 2002; Gupta et al. 2007; Yağız and Akyol, 2008). Consequently, the averaged values of slake durability indices for each travertine type with standard deviation were tabulated in Table 2. As shown in Table 2, the shrub and noche type travertine shows almost same slaking behavior while reed type gives lower durability, but onyx type demonstrates the highest durability for soaking in tap water that pH ranges from 6.75 to 7.05.

Slaking cycle	Units %	Shrub type $\bar{x} \pm SD$	Onyx type $\bar{x} \pm SD$	Reed type $\bar{x} \pm SD$	Noche type $\bar{x} \pm SD$	Number of test
Id_1	%	99.23±0.08	99.53±0.04	98.94±0.12	99.25±0.11	10
Id_2	%	98.91±0.10	99.24±0.07	98.55±0.14	98.87±0.12	10
Id_3	%	98.57±0.11	99.05±0.09	98.23±0.16	98.59±0.13	10
Id_4	%	98.34±0.12	98.86±0.10	97.95±0.19	98.32±0.16	10

Table 2. Average slake durability indices and standard deviation of travertine types

The lower value of slake durability represents the higher susceptibility for degrading. So, slake durability of travertine was classified according to first and second cycle of durability indices (Yağız, 2010) in Table 3. As mentioned previously, each test was conducted on ten samples and the average values of the results are also reported together with standard deviations herein (Table 4).

Id_2	Id_1	Durability	Shrub	Onyx	Reed	Noche
>30	<60	Very low				
30–60	60–85	Low				
60–85	85–95	Medium				
85–95	95–98	Medium high				
95–98	*98–99*	High				
>98	>99	Very high				
Class of travertine according to Id_1			V. High	V. High	V. High	High
Class of travertine according to Id_2			V. High	V. High	V. High	V. High

Table 3. Durability of travertine types according to slake durability classification (Frank and Chandra, 1972)

Travertine type	UCS $\bar{x} \pm SD$ (MPa)	V_p $\bar{x} \pm SD$ (km/s)	n' $\bar{x} \pm SD$ (%)	w $\bar{x} \pm SD$ (%)	Fullness $\bar{x} \pm SD$ (%)	$\square_{dry}$ $\bar{x} \pm SD$ (kg/m^3)	$\square_{sat}$ $\bar{x} \pm SD$ (kg/m^3)
Shrub	61±20.6	4.8±0.12	1.35±0.46	0.55±0.19	98.65±0.46	2427±25.2	2440±22.2
Onyx	58±15	4.7±0.19	2.05±0.88	0.76±0.34	97.95±0.88	2664±46	2683±38.1
Reed	41±16.6	4.5±0.11	1.89±0.50	0.80±0.22	98.11±0.50	2317±56.3	2336±54.0
Noche	64±10.9	5.0±0.08	1.59±0.89	0.66±0.38	98.41±0.89	2373±48.1	2389±42.1

$\bar{x}$ =average values and SD=Standard deviation

Table 4. Engineering properties of travertine type based on average values of ten tested samples

Properties of travertine	Shrub	Onyx	Reed	Noche	TSE11143 (1987)	TSE2513 (1987)	ASTMC97 (1990)	ASTMC170 (1990)
UCS (MPa) (tile flooring)	61	58	41	64	>50	-	-	>52
(for wall covering)	61	58	41	64	>30	-	-	-
ρ_{dry} (kg/m^3)	2427	2663	2318	2373	>2300	-	>2305	-
w (%)	0.55	0.76	0.80	0.66	<3	<7.5	<0.2	-
n'(%)	1.35	2.05	1.89	1.59	-	<12	-	-
V_p Class	High	High	High	High	-	-	-	-
SDI Class (Id_1 and Id_2)	High	High	High	High	-	-	-	-

Table 5. Suitability of investigated travertine types for construction and buildings

Discussions

The uniaxial strength, P-wave velocity, effective porosity, slake durability index, fullness ratio, water absorption by weight and both dry and saturated unit weight of travertine that were quarried around the city of Denizli were investigated. 10 samples were prepared and the tests were performed for each type of travertine in order to obtain the best representative value for each rock property. TSE and ASTM standards were used to investigate quality of travertine types as construction materials. Further, P-wave velocity and slake durability classification were performed according to the scientific classifications recommended by various researchers (Anon, 1979a; Frank and Chandra, 1972) as represented in Table 5. Properties of investigated travertine types are very good and acceptable except effective porosity in ASTM standards that counts travertine as marble. The ASTM standard stated that the effective porosity of travertine should be more than three percent (Table 5). In fact, this range is actually impossible for travertine that is more porous and weaker than marble. In TSE, natural stone were categorized in detail according to their origin (TSE 11143, 1993; TSE2513, 1977); on the other hand, the stone were categorized as general in the ASTM standard (ASTM C97, 1996; ASTM C170, 1990); however, such a variation between two different standards is likely.

Conclusions

In this study, several type of travertine was investigated according to their physic-mechanical properties and usability for modern civil construction and buildings. It is fact that the travertine is categorized as sedimentary origin, porous and weak rocks; therefore, the important issue is not only its properties but also where to be used. Investigated travertine types quarried in the Denizli Basin of Turkey have reasonably good quality to be used for construction and buildings purposes in accordance with national and international standards. Further, P-wave velocity of travertine types is high meaning is that they do not have much micro crack and alteration. The slake durability of those travertine is very high according to the relevant durability classification. So, these travertine types could be used for the purposes without thinking of annual precipitation or humid environments. Concluding remark is that even though reed type travertine being porous has low density and the uniaxial compressive strength is the lowest in comparison with others, type of travertine quarried in the area have acceptable stone quality to be used for developing and constructing building and recreation environments in the modern cities.

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