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ORIGINAL PAPER

Modified permeability apparatus to determine the permeability of natural building stones

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Abstract Natural building stones are commonly used for a broad variety of purposes in the construction of many different types of buildings. Knowledge of the permeability of natural building stones, which are widely used in interiors, exteriors, flooring, veneering, landscaping, and walkway laying, is important for correctly determining their lifetime as well as their areas of use. The current study proposes a new test method to determine the air permeability of natural building stones, based on a previously developed method used to assess the permeability values of concrete samples. In this context, the air permeability index values of 96 natural building stone samples, belonging to 16 different types of natural stones classified into five groups, were determined using a new air permeability testing apparatus. The obtained permeability values were compared with the water absorption, open porosity, and apparent density properties of the natural building stones. Strong correlations were identified between the air permeability values of natural building stones and the open porosity and water absorption values. In contrast to other types of tests, the designed apparatus allowed information to be obtained concerning the porosity of natural building stones within a time period as short as 6 h. Based on the obtained results, the air permeability values of the natural building stones were classified into three groups as permeable, semi-permeable, and non-permeable. The study results indicated that the air permeability index can be effectively used to measure the air permeability of natural building stones within a short a period of time and by using a simple test apparatus.

Keywords Air permeability · Durability · Limestone marbles · Building stones

Introduction

Throughout history, and in many societies from ancient to modern ones, natural building stones have been used as functionally and esthetically important materials. In the present day, natural building stones are commonly employed as building materials after being dimensioned and processed through various processing techniques (Shadmon 1997). Although natural building stones are often viewed as symbols of eternity and durability, they may show severe signs of damage and decay during their service life (E.M. Winkler 1997; Blows et al. 2003). Numerous parameters from ambient conditions to stone properties play an important role in determining the decay mechanism of natural stones (Smith and Prikryl 2007; Smith et al. 2008). Regardless of the form in which natural stones are used, an effective diagnosis of usage conditions and the selection of natural building stones suitable for these applicable conditions represent the first step to ensure preservation and durability (Warke et al. 2003; Rovnanikova 2007; Urosevic et al. 2010; Török and Přikryl 2010). The service life of natural building stones is described in the literature using the concept of durability. The durability of natural stones refers to their capability to preserve their appearance, original size, resistance to degradation, and strength over a long period of time (Bell 1980; Bell 1993). At the same time, durability also determines whether a natural stone is suitable for use as a building stone (Sims 1991). The durability of natural stones is especially determined by their ambient conditions, usage conditions, and petrographic properties (such the discontinuities of their grains, the void ratio of grains, and the level of water saturation). Weathering agents, in

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particular, may rapidly alter the petrographic properties and durability of natural stones (Crewdson and Lewry 1994; Benavente et al. 2004b; Doehne and Price 2010). The service life of natural stones is directly associated not only with their area of use and their physical and mechanical properties, but also with their porosity, especially when used in exterior areas. The porosity of natural stones significantly affects their physical and mechanical properties and, by extension, their durability (Santos et al. 2012). Highly porous materials exhibit high water absorption capacities, which leads them to be less durable in the long-term. For this reason, porosity is an important parameter to be considered when selecting materials suitable for a particular area of use (Pipilikaki and Beazi-Katsioti 2009). The micro- and macro-porosity of natural stones may cause foreign materials to enter the natural stone, leading to problems with regards to their performance, hygiene, esthetic appearance, and service life. For stones with similar properties, increasing porosity is associated with decreasing durability (Plowman 1991; Karaca 2010). The porosity or porous system of natural stones is closely related to their petrography—in other words, to their mineralogy and texture. For this reason, understanding the porous systems of natural stones is of considerable importance to understanding stone decay and durability (Ordóñez et al. 1997; Fort and Ordo 2004; Maria 2010; Molina et al. 2011; Vázquez et al. 2013a).

Depending on their area of use, natural building stones are exposed to different types of environmental effects. For example, natural stones used for external veneering are subject to atmospheric effects such as rain water and acid rain. The service life of natural stones used in interior environments, on the other hand, are directly affected by water and chemicals used for cleaning, and also by contact with foreign materials (such as walking persons and vehicles). Regardless of whether natural stones are used in interior and exterior environments, all foreign materials that enter the surface or structure of these stones are conveyed into their micro- or macro-pores. When investigating the decay and durability of different natural stones, it is important to understand the aspects related to the crack and porous system, the micro- and macro-pores, the spaces within the stones, and the relationships between these aspects (Charola 2000; Siegesmund et al. 2002; Kwiatkowski and Löfvendahl 2005). Regardless of their source or nature, environmental agents that enter or move inside building stones will alter their structure. For foreign materials to be able to enter into natural stones, these stones must first have gaps or sufficient spaces that can accommodate them; in other words, these stones must have a permeability value. There are numerous studies in the literature regarding the measurement of permeability in rocks; however, these studies generally focus on large rock masses, on ore formations, and on designing underground storage areas for toxic and radioactive wastes. Nearly all of these studies employ water as flow fluid for testing permeability (Zhang et al. 1996; Shang et al. 1999; Chneider 2003; Bernabé et al. 2006; Giraud et al. 2006; Eid 2007; Rocha and Cruz 2009). Using samples, the permeability of rocks can be assessed under laboratory conditions that can even simulate the high pressures and temperatures characteristic of the conditions in the depths of the Earth's crust. However, the amount of available data concerning these types of assessments and measurements are generally limited, due to the fact that current laboratory procedures are generally lengthy and relatively difficult to perform. In addition to this, measurements of permeability performed using water tend to be somewhat relatively time-consuming (Malkovsky et al. 2009).

Despite numerous studies in the literature regarding the measurement of permeability values for different types of rocks, and there are only a few studies investigating the permeability values of natural building stones.

This study proposes a new method to determine the permeability value of natural stones, which is closely associated with the durability of natural stones.

In applications where natural stones are used as building stones, the thickness of decorative natural stones is generally between 2 and 3 cm. Depending on where they are used, these stones will be held in place by using either mortar or metal fasteners. For this reason, it is considerably important to determine the permeability values of these natural stones, which are generally used at fixed thickness values. Knowledge of natural stone permeability values facilitates the development of approaches suitable for these stones' porosity and durability.

The objective of this study was to propose a new test to measure the permeability values of natural stones used in interiors, exteriors, flooring, veneering, landscaping, and walkway laying. To this end, we tested 16 different types of natural stones commonly used and traded in Turkey and around the world.

In practice, natural stone permeability can be determined based on water absorption and porosity values. However, tests involving the determination of water absorption and porosity not only require very sensitive measurements and weighing, but are also very time-consuming (requiring a minimum of 7 days, although the actual time may vary depending on the amount of water).

This study first presents the adapted version of a test apparatus previously used for measuring the permeability values of concrete samples and then evaluates the results obtained with this apparatus. The mentioned apparatus, which was adapted specifically for the measurement of natural stone air permeability, was used for the first time in this field. The dimensions of the original test apparatus, as well as its sample placement area and its joint design to ensure airtightness, were all modified as necessary.

Sixteen different types of natural building stones were selected for use in the measurements of the test apparatus. These stones differed from one another both in terms of mineralogy and texture. The selected stones were building stones commonly used in Turkey and around the world, and were obtained from four different regions in Turkey. Comparisons were performed between the permeability results of natural stones and their water absorption at atmospheric pressure, apparent density, and open porosity values.

Experimental work

The principles of air permeability testing and the characteristics of the testing apparatus

The original test method used to determine the air permeability value of concrete samples was first developed by Alexander et al. (Alexander and Beushausen 2009). The samples used in the original test method were cylindrically shaped, with diameters and thicknesses of 70 and 25 mm, respectively. In addition, low permeability values in the original test method were associated with high concrete durability.

The general working principle of this test method consisted of placing a sample inside an airtight tank, and then determining the amount of air passing through the sample. A higher amount of air being removed from the tank was associated with greater porosity in the sample. Figure 1 provides a diagram illustrating this test apparatus.

The test apparatus simply consists of a vessel, a rubber collar, covers, a pressure transmitter, a data logger connecting the pressure transmitter to a computer, and a software allowing data to be monitored on the computer. The vessel of the apparatus is manufactured from stainless steel. From its vessel to its upper cover, the internal volume of the apparatus is 5 l.

In the new design that we developed and used, the height and diameter of the vessel was selected as 377 and 130 mm, respectively. The main reason for the selection of these dimensions was the size of the samples. The dimensions of the apparatus' upper cover was determined according to the size of the samples and the diameter of the rubber collar. As the sample size used in this study was 70x70x20 mm, the diameter of the upper cover was 200 mm. Another important factor to obtain accurate measurements with the apparatus was the sensitivity of the pressure transmitter. To be able to accurately read the pressure changes/decreases within the system, a pressure transmitter with 0.25 % sensitivity capable of performing measurements between 0 and 2 bars was employed. Data conveyed from the pressure transmitter through a data logger was recorded onto a computer using a software.

Based on the measurements that were performed, the permeability coefficient's negative log was accepted as the samples' air permeability index.

In the air permeability index test, the natural stone sample is placed inside the rubber collar. This rubber collar with the natural stone sample is, in turn, placed on the main vessel. Testing procedures can be initiated after the rubber collar is fixed onto the main vessel with the aid of the upper cover.

In principle, accurate measurement of the amount of air passing through the sample, or of decreases in the system's pressure, requires that the system remains strictly airtight. In this study, the natural stone sample was placed inside a rubber collar beneath the upper cover. For this test, this collar was specifically produced using polyurethane. To ensure complete airtightness and firmly fix the sample, we decided, following a number of trials, to prepare this collar designed according to the dimensions of the sample by using a semi-flexible material with a Shore hardness of 45.

To test the airtightness of the system as a whole, a steel sample with dimensions similar to the stone samples to be measured was prepared and placed inside the rubber collar. Measurements with this steel sample indicated a pressure decrease of zero over a period of 24 h.

Testing

Natural building stones are generally cut with a thickness of 10–60 mm. Slabs, on the other hand, are generally cut with 2–3-cm thickness, although this thickness may vary depending on their area of use. Thus, for the test, the specimen size to be used was modified and selected as

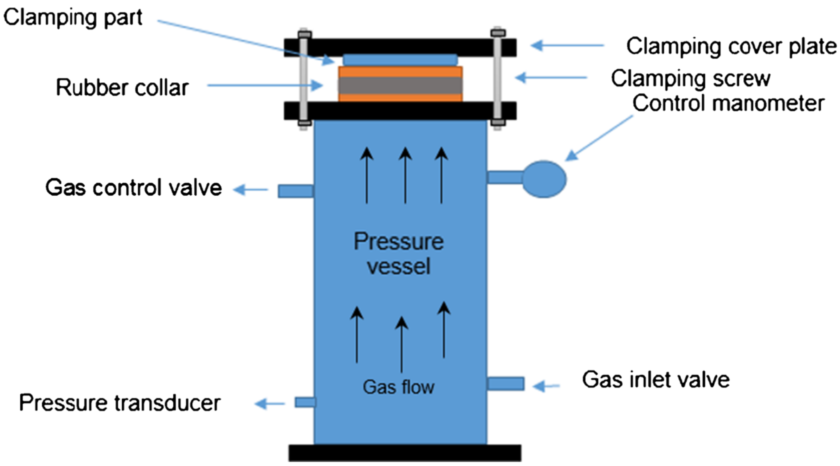


Fig. 1 Diagram of the modified permeameter and its details

70x70x20 mm, as a 20-mm thickness is very close to the thickness generally used in natural building stones. The 70 × 70 mm dimension, on the other hand, was selected because tests such as the uniaxial compressive strength, water absorption, and porosity tests are generally performed with 70x70x70 mm samples. For this reason, the preparation of the samples for our test does not require special preparations, and samples prepared for other tests can be readily used. In addition to this, cutting 70 × 70 mm rectangles from natural stones cut as slabs or tiles is relatively easier.

Prior to testing, the samples were pre-prepared by drying in an oven for 7 days at 50 °C. After drying, the samples were cooled in a desiccator to 23 ± 2 °C for 2–4 h (if preferred, the cooling of the samples can also be performed by maintaining them on a still tray at <60 % relative humidity and 23 ± 2 °C). Following this step, the sample was placed inside an airtight pressure vessel. The design of this setup is shown in Fig. 2. Three pressure vessels were used at the same time within the scope of this test. Data was recorded automatically through the pressure transmitter; the pressure vessel was also equipped with its own analog pressure reader.

After the natural stone sample to be tested was placed inside the rubber collar situated between the upper cover and vessel, the rubber collar was fixed—together with the upper cover—onto the main vessel with the aid of clamping screws.

After an overpressure 1 bar above the atmospheric pressure was appliedin the cylinder, the air cylinder conection and the main vessel was sealed. Consequently, air could escape the vessel only through the sample of natural stone placed inside the rubber collar. During the test performed on the sample, internal pressure data of the system was recorded either for a period of 6 h or until the pressure dropped to 0.5 bars. The changes that occurred in pressure over time were evaluated based on this recorded data, and the best curve was determined between "ln (P_0/P_t)" and "t". In this expression, "P_0" represents the initial pressure at the beginning of the test (approximated to nearest 0.5 kPa); "P_t" represents the ensuing pressure readings (also approximated to the nearest 0.5 kPa) at time "t"; and "t" represents time in seconds. In the determined curve, the correlation coefficient between "ln (P_0/P_t)" and time should have values greater than 0.99. In case a correlation coefficient value of 0.99 was obtained, the test was repeated with the same sample; if a value of 0.99 was obtained once again during the repeat test, the test was repeated with a different sample. If the correlation coefficient is less than 0.99, there is no linear relationship between pressure drop and time, suggesting that either the sample was cracked before the test or it is cracked or fractured during the test. In this case, the test should be repeated. After the curve was established, Eq. 1 was used to calculate the Darcy permeability coefficient.

Fig. 2 The setup of the modified permeameter test apparatus

$$k = \frac{\omega \mathrm{Vgdz}}{RA\varnothing} \tag{1}$$

In Eq. 1, "k" represents the permeability coefficient of the test sample (m/s); "ω" represents the molecular mass of air (28.96 g/mol); "V" represents the volume of pressured air within the permeameter (m^3), approximated to the nearest 0.01 l or 0.00001 m^3; "g" represents gravitational acceleration (9.81 m/s^2); "R" represents the universal gas constant (8.313 Nm/K mol); "d" represents the average thickness of the samples (m); "A" represents cross-sectional area of specimen in m^2, "Ø" represents temperature (K); and "z" represents the slope of the line determined by regression analysis.

The value for "z" was calculated with Eq. 2:

$$z = \frac{\sum \left[\ln\left(\frac{P_0}{P_t}\right) \right]^2}{\left[\ln\left(\frac{P_0}{P_t}\right) t \right]} \tag{2}$$

After the "z" and "k" values were calculated, the permeability coefficient was determined for each test sample. The air permeability index (API) was determined using the negative logarithm value of the samples' average permeability coefficient (Alexander and Beushausen 2009). Equation 3 was used to calculate the API value of the four samples;

$$\mathrm{API} = -\log 10[1/4(k_1 + k_2 + k_3 + k_4 \ldots . + k_n)] \tag{3}$$

The equation above can be rearranged as the number of samples increases.

The permeability index test method can be described as a procedure that involves determining the decrease in a system's pressure caused by air passing through the sample placed in the vessel's output head.

The major limitation of the study is that the difference between inlet and outlet pressures has to be small, and the sensitivity of the pressure transmitter should be increased accordingly.

In this study, to ensure that the relatively small building stone samples would be more representative of their respective building stones, measurements were performed with a total six samples for each stone. The average of the values obtained for these six samples was used in calculating the air permeability value.

Results

Physical characteristics of the rocks

In this study, we determined the API values of natural stones along with some of their physical characteristics associated with porosity. In this context, we determined the apparent density, open porosity, and water absorption level at atmospheric pressure for each sample of natural stone being investigated.

Water absorption at atmospheric pressure

Tests to determine water absorption at atmospheric pressure (A_b) were performed in accordance with the specifications of TS EN 13755 (Türk Standartları Enstitüsü 2003). These tests were performed using cube-shaped samples with an edge length of 70 mm, prepared through the cutting of larger stone blocks.

The water absorption values (A_b) were calculated using Eq. 4.

$$A_b = \frac{m_s - m_d}{m_d} \times 100 \tag{4}$$

In this equation:

A_bWater absorption at atmospheric pressure (%)
m_sMass of the water saturated sample (gr)
m_dMass of the dry sample (gr)

Apparent density and open porosity

The apparent density (ρ_b) and open porosity (ρ_o) of natural stone samples were determined in accordance with the TS EN 1926's specifications (Türk Standartları Enstitüsü 2001).

As required by the TS EN 1926 standard, a total of six cube-shaped samples with edge lengths of 70 ± 5 mm were used in the experiments. The samples were dried at 70 ± 5 °C until they reached a constant mass (m_d). Following the drying process, the samples were weighed using balances with a sensitivity of 0.01 g and then left within a container of water at atmospheric pressure. After being held in water for 48 h, the samples were weighed using an Archimedes balance with a sensitivity of 0.01 g in order to determine their water saturated mass. After this step, the samples were rapidly dried and weighed once again (m_s). The apparent density and open porosity were calculated using Eqs. (5) and (6), respectively:

$$\rho_b = \frac{m_d}{m_s - m_h} \times \rho_{rh} \tag{5}$$

$$\rho_o = \frac{m_s - m_d}{m_s - m_h} \times 100 \tag{6}$$

In these equations;

ρ_bThe apparent density of the sample, g/mm^3
ρ_{rh}The density of water, g/mm^3
m_dMass of the dry sample, g
m_sMass of the water saturated sample, g
m_hMass of the sample immersed in water, g
ρ_oOpen porosity of the sample, %

Table 1 lists the physical characteristics of the natural stones evaluated within the context of this study.

Air permeability index values

In this study, API values were measured after the re-designed test apparatus was prepared and the necessary airtightness tests were performed.

When measuring API values, samples with visible crack and fracture systems were discarded. In case the pressure decrease observed within the first 5 min from the start of the experiment/test was greater than 0.5 bar, the sample was considered as being cracked and excluded from the study evaluations.

Changes in pressure values were controlled through a computer and with the aid of a software for approximately first 10 min following the placement of the samples in the permeability cells. When determining the air permeability index of a natural stone sample, the first step consisted of observing the time-dependent decrease in pressure. By evaluating the time-dependent pressure change curve, it was possible to observe any unexpected changes in the permeability cell. In case of a leak within the system, or in case a crack or fracture is identified within the sample, the sample was changed and the test was repeated. An example of time-dependent pressure decrease curves are provided in Fig. 3 for each one of the natural stone groups used in this experiment (marble, limestone, breccia, dolomite). The slopes of the straight lines in Fig. 3 were used to calculate the API values.

Examples of the ln (P_0/P_t)-time curves used for each one of the natural stone samples used in this study are provided in Fig. 4. As 96 different measurements were performed, each stone group was illustrated as a single line/curve on Fig. 4 to avoid any confusion.

Table 1 Physical characteristics of the evaluated natural stones

Commercial name	Stone type	A_b (%)	ρ_b (g/mm3)	ρ_o (%)
Rosso Galiano	Fossiliferous limestone	0.03	2.71	0.10
Royal beige	Fossiliferous limestone	0.04	2.62	0.13
Sogut cappucino	Dolomitic intraclast limestone	0.18	2.71	0.41
Goksu beige	Lacustrine micritic limestone	0.06	2.69	0.21
Denizli travertine	Limestone	1.99	2.39	4.75
Golden travertine	Dolomitic limestone	0.99	2.64	2.71
Aksehir black	Recrystalized limestone	0.06	2.72	0.14
Burdur beige	Micritic intraclast limestone	0.34	2.69	1.04
Afyon sugar	Marble	0.08	2.74	0.18
Reis white	Marble	0.02	2.73	0.03
Mugla white	Marble	0.05	2.70	0.13
Tiger skin	Marble	0.03	2.71	0.10
Usak white	Marble	0.02	2.7	0.04
Afyon yellow trv.	Travertine	1.82	2.47	4.49
Karakaya beige	Breccia	0.23	2.58	0.61
Golden tobacco	Dolomite	0.66	2.45	1.80

The travertines used as natural building stones are characteristically highly porous. Although some of the fissures and pores in natural stones can be seen by the unaided eye, precise measurements are necessary to identify the nature and complexity of natural stone porosity (e.g., size, geometry, specific surface area, and grade of connection) (Hall and Hoff 2009). As such, determining whether pores are interconnected with one another (in other words, determining whether pores are interconnected with each other along the natural stone's thickness in its area of application) is important with respect to both durability and life service (Siegesmund and Dürrast 2011; Molina et al. 2011; Vázquez et al. 2013b).

Figure 5 shows a pressure-time curve for a travertine sample used in this study. In samples with high air permeability values, the test was stopped when the pressure decreased to approximately 0.5 bar. Due to the highly visible pores as well as the extensive interconnectedness of pores in this travertine, pressure decreased to 0.5 bar within 55 min in all six samples of this stone. During the tests, it was also noted that the pores of the travertine samples released air. However, the same

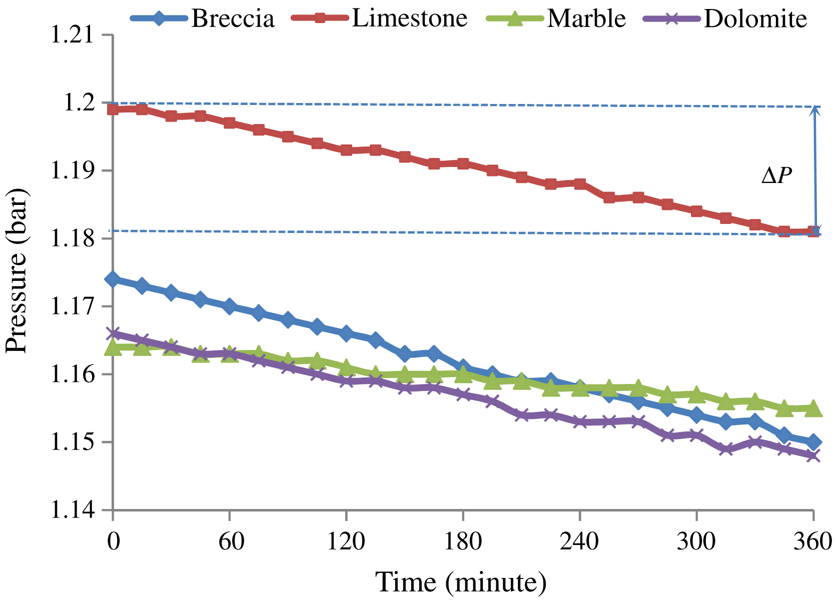
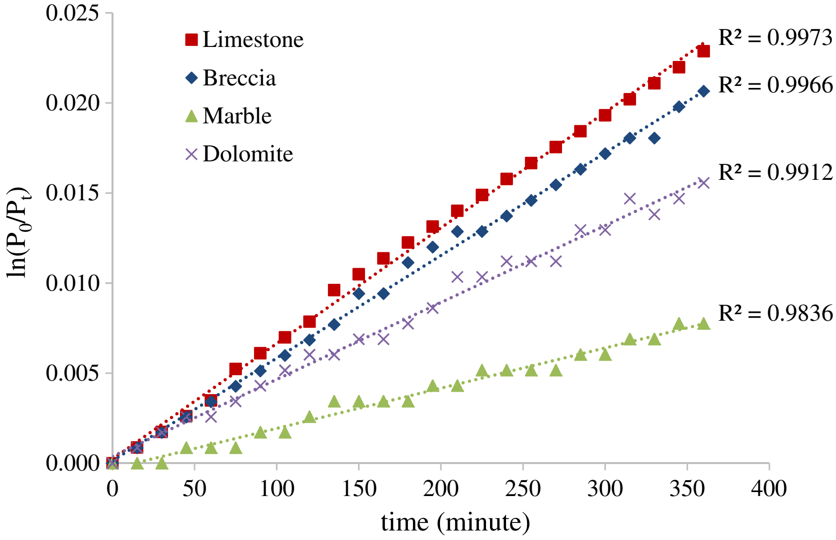


Fig. 3 Example of the measured pressure decreases for four stone specimens

Fig. 4 Example of the pressure decrease observed in four stone samples. The slope of the straight line was used to calculate the API



situation is not observed in all samples with visible pores. Certain natural stones have relatively low air permeability despite visible porosity. This situation can be explained by the lack of interconnectedness between the pores of the natural stone. Thus, it is possible to determine through the API test whether the pores are actually interconnected with one another.

The results are provided in Table 2.

A simple regression analysis was employed to demonstrate the relationship between the measured API values and the physical characteristics of the natural stones. The relationship of API values with water absorption at atmospheric pressure, apparent density, and open porosity values were investigated using linear functions (Figs. 6, 7, and 8).

These characteristics were particularly selected since they are informative about the porosity of natural stones and can be easily accessed through experimentation. They are commonly used when selecting areas for the use of natural stones and for assessing the general properties of natural stones.

The amount of water permeating a natural stone—in other words, its water absorption value—is a considerably important engineering parameter for determining the durability of the relevant stone (Xeidakis and Samaras 1980; Aboushook et al. 1999; Camuffo 2000; Benavente et al. 2004a). Regardless of the standard used when determining the water absorption value of a natural stone, it is necessary to have the stone absorb water until it is saturated. However, lengthy hydration periods during tests will result in an interaction between the stone and the absorbed water, causing alterations in the stones' properties such as its permeability and pore structure. Just as water may alter the structure of the natural stone sample, it may also lead to algae formation on the

Fig. 5 Example of a pressure decrease-time curve for a travertine sample

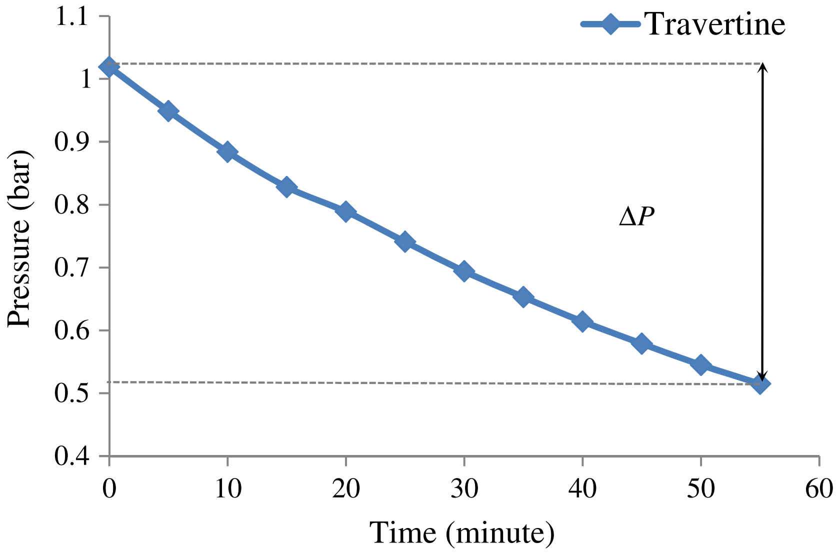


Table 2 The API values of the evaluated natural stones

Sample	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	API
Rosso Galiano	11.674	10.461	11.114	11.048	12.128	10.604	11.172
Royal beige	11.322	11.630	11.503	10.647	11.525	11.934	11.427
Cappucino	11.502	11.384	11.401	12.026	11.229	11.448	11.498
Goksu beige	11.474	11.182	11.085	10.778	11.228	10.709	11.076
Denizli travertine	8.382	8.465	7.834	9.073	8.550	8.355	8.443
Golden travertine	8.090	8.010	8.051	7.862	7.845	7.815	7.946
Aksehir black	10.974	10.453	10.080	10.649	11.102	10.740	10.666
Burdur beige	11.057	11.065	11.161	11.632	11.583	10.548	11.174
Afyon sugar	11.010	10.571	10.661	10.725	11.326	10.684	10.830
Reis white	10.642	10.518	11.055	10.140	10.808	11.624	10.798
Mugla white	11.827	10.777	10.790	11.561	11.352	10.983	11.215
Tiger skin	10.467	12.143	10.444	11.729	10.679	11.098	11.093
Usak white	11.150	11.520	10.387	11.465	10.354	10.229	10.851
Afyon yellow trv.	8.989	8.417	9.395	9.215	8.453	8.137	8.768
Karakaya beige	11.251	11.113	11.136	10.497	11.234	11.115	11.058
Golden tobacco	10.656	11.647	11.778	11.015	9.591	10.918	10.934

sample's surface. Moreover, waiting for a natural stone sample to become water saturated is quite time-consuming. Since the air permeability index test proposed in this study uses air to determine the permeability value, no interaction is expected between the stone and air. The entire test is completed with 6 h. An increase in pore diameter and in the number of interconnected pores might further decrease the test period.

The study results indicated a relatively good relationship (i.e., $R^2 = 0.731$) between API values and water absorption at atmospheric pressure (Fig. 6). This observation can be explained by the relationship between porosity and API values.

In addition, API values showed a very limited correlation with apparent densities ($R^2 = 0.3$) (Fig. 7). Many different parameters can be responsible for this. Especially in natural stones with high porosity values, apparent density may be low despite high air permeability. The opposite may also hold true; although natural stones containing clay have relatively higher apparent densities compared to porous stones, their air permeability values may be high as well. In addition to this, Fig. 7 indicates that the ten different samples of natural stone had relatively close apparent density values. At the same time, the measurement sensitivity used when determining apparent density values is also quite important. In this study, a level of sensitivity of up to two decimals was used for apparent density values. If the measurements were performed with a higher level of sensitivity, it might have been possible to identify a relationship between apparent density and the API values. Between the API and the open porosity values, the value of the determination coefficient was calculated as 0.69. This result indicated that API values from natural stone samples can be effectively used to describe natural stone porosity.

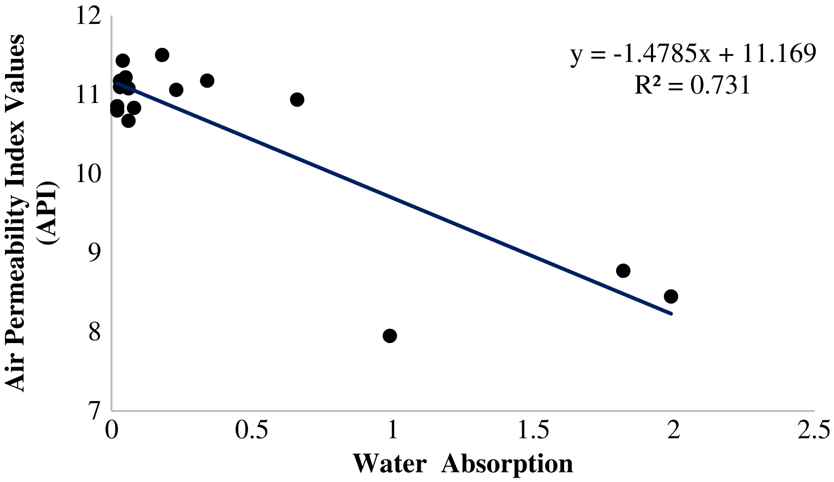


Fig. 6 The relation of API values with A_b

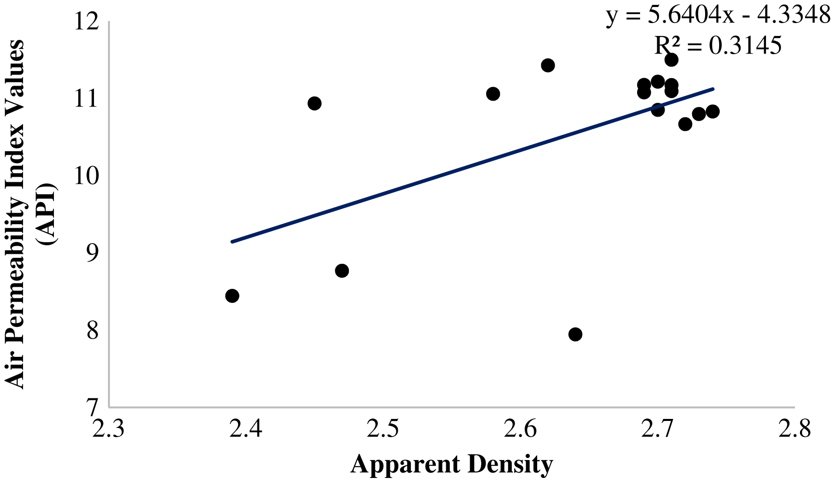


Fig. 7 The relation of API values with apparent density

Conclusions

The 16 natural building stones belonging to five different groups that were investigated within the context of this study possessed different textures, colors, and characteristics. The porosity of these commercially traded stones ranged between 0.01 and 4.75 %, while their water absorption values varied between 0.02 and 1.99 %, and their density was generally around 2.7 g/mm^3. All these parameters and values are quite useful in providing an opinion regarding the porosity, the permeability, and hence the durability of natural stones. Within the scope of this study, a modified and new permeability test method was presented, along with the test results associated with this method, in order to provide a new approach to determine the durability values of natural building stones. In this context, 96 tests were performed on 16 different types of natural stones. Based on the obtained results, it was determined that the air permeability index test can be successfully used to determine the permeability values of natural stones; however, the number of samples should be increased in order to obtain more reliable results. The study results have also shown that air permeability values have a relatively strong correlation with the water absorption and porosity values of natural stones. The literature describes many different methods to determine natural stone porosity. The API test method is quite fast like other methods. The experiment lasts for a maximum of 6 h, and as the sensitivity of the pressure transmitter is increased, very precise results can be obtained. Increasing stone porosity has the effect of further reducing the duration of the test. The air permeability test can also be effectively used to determine whether the pores in natural stone samples are interconnected with one another. For limestone, which is one of the natural building stones, the API values obtained using the air permeability test varied between 10 and 12. In both the natural building stone literature and this study, limestone marbles generally have fairly close physicomechanical properties. In agreement with the literature, the API values of the limestone marbles in this study were found to be quite similar. Based on the general observations we made regarding natural stones, it is possible to state that the API values of

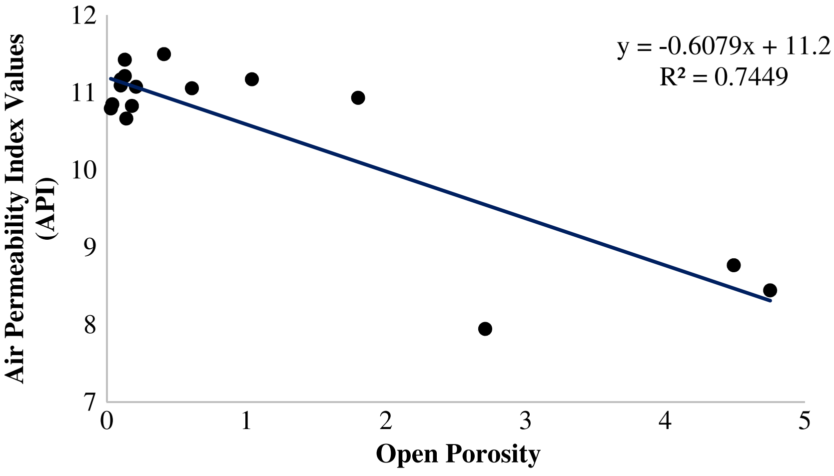


Fig. 8 The relation of API values with open porosity

limestones without visible porosity was generally between 10 and 12. However, the stones with the commercial names of Denizli Travertine and Golden Travertine, which are geologically described as limestones, represented exceptions to this. Of these two stones, the Denizli Travertine had easily visible pores (API value 8.392). This situation serves to explain why its API values were low. However, the situation with the Golden Travertine natural stones is quite different. This stone has no visible pores, and although it is defined as a limestone, it is noteworthy that its name mentions the word "travertines." Despite its lack of visible pores, the passage of air inside the Golden Travertine stone takes place within a very short period of time. This observation can be explained by the presence of numerous and interconnected pores within the stone that cannot be perceived by the unaided eye. An interesting observation regarding these two stones is that although the Denizli Travertine had highly visible porosity with pore diameters of 2–6 mm, the Denizli Travertine had higher API values than the Golden Travertine. This observation can be explained by the superficiality of the pores on the surface of the Denizli travertine, or their lack of interconnectedness. The API test thus provided meaningful and promising results concerning the interconnectedness of the pores along the surface on which the natural stone will be applied. According to the API test values, limestone marbles had relatively low permeability values. In practice, natural stones with high API values are used in exteriors. Thus, knowledge of surface permeability is of considerable importance for determining/selecting areas of use for natural stones. The API test has the potential to bring a new, low cost, rapid, and reliable approach in determining the surface permeability of natural stone samples.

This study may be further extended by including other decorative natural building stone types in order to produce additional and more comprehensive data, and also to better identify the relationships between a broader range of stone-related characteristics and properties.

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