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ABRASION RESISTANCE PREDICTION OF TRUE MARBLES USING CHEMICAL COMPOSITION DATA: A NEW APPROACH

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Keywords
Construction material, Marble, Abrasion resistance, Wide Wheel Abrasion, Böhme Abrasion.

Abstract
Natural stones are the widely used building materials in civil engineering and architectural projects. Surface abrasion resistance determination of natural stones is one of the important issues considered in flooring projects. This mechanical property is determined by performing standardized laboratory tests. In recent years, however, there has been considerable interest in its determination by means of indirect methods using the physical, mechanical, and mineralogical properties of stone materials. As a new approach, the present work was undertaken to investigate the potential usability of chemical compositions of true marbles as a guide to predict their Wide Wheel Abrasion (WWA) and Böhme Abrasion (BA) test values. By performing multiple linear regression analyses, statistically significant regression models with high prediction accuracies were derived (p-values < 0.05; R^2 = 0.98-0.99). In the established prediction models MgO, SiO_2, CaO, and (CaO/SiO_2) ratio were determined as the most significant predictor variables. These models may be updated by inclusion of data from further studies on other types of marbles.

KİMYASAL BİLEŞİMLERİ YARDIMIYLA GERÇEK MERMERLERİN AŞINMA DİRENCİ KESTİRİMİ: YENİ BİR YAKLAŞIM

Anahtar Kelimeler
Yapı malzemesi, Mermer, Aşınma dayanımı, Geniş disk aşınma, Böhme aşınma.

Öz
Doğal taşlar, inşaat mühendisliği ve mimari projelerde yaygın olarak kullanılan yapı malzemeleridir. Yer Döşemesi projelerinde kullanılacak olan doğal taşların yüzey aşınma değerlerinin belirlenmesi büyük önem taşımaktadır. Bu mekanik özellik standart laboratuvar deneyleri yardımıyla belirlenmektedir. Bununla birlikte, son yıllarda, yüzey aşınma direnci değerlerinin kayaçların fiziksel, mekanik ve mineralojik özellikleri yardımıyla dolaylı olarak kestirilmesine yönelik çok sayıda çalışma yapılmıştır. Bu çalışmada, yeni bir yaklaşım olarak, gerçek mermerlerin Geniş Disk Aşınma (GDA) ve Böhme Aşınma (BA) değerlerinin kimyasal bileşimleri yardımıyla kestirilebilirliği araştırılmıştır. Çoklu doğrusal regresyon analizleri uygulanarak, istatistiksel olarak anlamlı ve yüksek kestirim doğruluğuna sahip ($p \leq 0.05$; R^2 = 0.98-0.99) modeller elde edilmiştir. Bu modellerde MgO, SiO2, CaO ve (CaO/SiO_2) oranı en anlamlı kestirim değişkenleri olarak belirlenmiştir. Geliştirilen modeller, diğer mermer türleri üzerinde yapılacak benzer çalışmalardan elde edilen verilerle güncellenebilir.

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ABRASION RESISTANCE PREDICTION OF TRUE MARBLES USING CHEMICAL COMPOSITION DATA: A NEW APPROACH

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Highlights

- An indirect method of marble abrasion resistance prediction is presented using chemical parameters.
- Abrasion resistance values of the samples increase with increasing contents of MgO and SiO_2.
- Abrasion resistance values decrease with increasing CaO content and (CaO /SiO_2) ratio.
- Further studies are needed on other marble types to draw more sound conclusions.

Purpose and Scope

The present work was undertaken for investigating the usability of geochemical data of selected true marbles as a means of predicting their Wide Wheel Abrasion Test (WWA) and Böhme Abrasion Test (BA) values. Seemingly no attention has been paid to the influence of chemical compositions on the abrasion resistance of natural stones. This fact motivates the work reported in this contribution.

Design/Methodology/Approach

In the scope of this study, available experimental data of the two abrasion resistance test methods (WWA and BA) and chemical compositions of five different commercial marble samples were statistically evaluated. In the first part of the study, multiple linear regression (MLR) analyses were performed to select the most relevant input chemical variables for the final prediction models of the WWA and BA test values. Thereafter, using a technique known as the 'Backward Stepwise Regression (BSR)', a number of prediction models of the WWA and BA were constructed.

Findings

The presently established statistically significant models with strong prediction performances (p-values < 0.05; $R^2 = 0.98–0.99$) of the WWA and BA imply that the abrasion resistance values of the considered marble samples increase with increasing contents of MgO and SiO_2, while the opposite is valid for CaO and (CaO /SiO_2) ratio. However, the regression models derived for WWA were not found applicable for predicting the BA test values. This was attributed to the fact that abrasion resistance is not an intrinsic material property, as it depends on the measurement method.

Research limitations/implications

Due to limited number of samples used in the analyses, the presently arrived conclusions should be regarded as tentative. In this respect, it is emphasized that further studies are needed on this topic to draw more sound conclusions.

Practical implications

Information obtained by the presented method can be used in flooring projects as a preliminary guide for determining the abrasion classes of true marbles as well as their suitability for use in different foot traffic environments.

Originality

This study presents a novel approach to abrasion resistance determination of true marbles. It is thought that the practitioners and academicians working in the field of natural stone characterization may benefit from the arrived findings.

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1. Introduction

Due to their durability and appealing appearances, natural stones are widely used as building materials in civil engineering and architectural projects. When intended to be used as floor coverings, building stones are subjected to abrasion resistance testing to determine if they meet the technical requirements of the project. This mechanical property is determined in the laboratory by performing standardized test methods. The information gathered by means of these tests is used for estimating the long-term surface abrasion resistance performance of a stone material under varying intensities of pedestrian foot traffic. In European countries, the two commonly used abrasion resistance test methods are the Wide Wheel Abrasion (WWA) and the Böhme Abrasion (BA) tests described in the European standard EN 14157 (2004, 2017). This standard was approved by the European Committee for Standardization (CEN) in 2004 and later revised in 2017 with minor changes.

Despite their widespread use in the field of building stone characterization, in practical applications there are some shortcomings of the WWA and BA test methods. These are mainly related to laborious and time-consuming testing procedures, difficulties in preparing specially dimensioned test specimens, and the need for specially designed test apparatus which may not be available in every laboratory. Also, regarding the WWA test method, the availability difficulties of the Boulonnaise calibration marble (Marini, 2011) and potential calibration errors due to its heterogeneous structure (Çobanoğlu, 2017) have been pointed out. For these reasons, in recent years a considerable literature has grown up around the theme of predicting WWA and BA values of stone materials by using indirect methods. These methods generally involve developing empirical prediction equations by performing statistical and/or soft computing methods on experimental data of basic rock properties. A brief summary of the research and contributions made in this field are given in the following.

In a recent study (Çelik, 2022), multivariate regression analyses and algorithms of Artificial Neural Networks (ANNs) were performed to estimate the WWA values of travertines from rock properties including porosity, uniaxial compressive strength (UCS), p-wave velocity, and unit weight values. Simple and multiple regression analyses were performed by Mohammed et al. (2021) to identify the relationships between BA test results and the physico-mechanical properties of different stone materials (basalt, tuff, travertine, andesite, and gabbro). Their findings indicated strong correlations between BA and physical rock properties, while a moderate relationship was observed between BA and uniaxial compressive strength (UCS). In another study (Çobanoğlu, 2017), abrasion resistance data (WWA and BA) were correlated to the physical and mechanical properties (Sonic velocity, Shore hardness, Schmidt hardness UCS, porosity, and density) of different rock materials. Also, abrasion resistance classification schemes based on WWA and BA data were proposed. Strzalkowski and Köken (2022) performed ANNs analyses to establish prediction models of the BA by using the density, UCS, Shore hardness, p-wave velocity, and water absorption values of different stone materials. Bayram (2020) demonstrated that the data mining techniques could be satisfactorily used to predict BA of different types of rocks from their physical and mechanical properties (Shore hardness, porosity, unit weight, UCS, modulus of elasticity, and point load strength). The relationships of the WWA and BA abrasion resistance values of different building stones to their physical and mechanical properties were investigated by Karaca et al. (2012). According to their findings, stone materials having open porosity values ≥ 1% showed stronger correlations with the results of both abrasion resistance test results. Also, the UCS was found to be a better indicator of abrasion resistance than the Brazilian tensile strength (BTS). In the same study, a statistically significant linear correlation was established between the WWA and BA test methods. Performing simple regression analyses on experimental data of different building stones, Deliormanlı (2012) demonstrated the existence of strong negative correlations between the Cerchar Abrasivity Index (CAI) and abrasion resistance values of the WWA and BA tests. The results of an experimental investigation by Güneş Yılmaz et al. (2011) indicated that a statistically significant correlation could be established between the UCS and BA of granites used as building stones. The other rock properties examined in their study (porosity, unit volume weight, water absorption, and bending strength) were not found to be reliable indicators of BA resistance of granites. Yavuz et al. (2008) observed high correlations between BA and hardness, UCS, BTS, and bulk density of carbonate rocks. They also found that the studied marbles and limestones were more abrasion resistant than the travertines. By statistically evaluating a large number of test results, Kılıç and Teymen (2008) established high correlations between the BA and physico-mechanical properties (Schmidt hammer hardness, Shore hardness, point-load index, and p-wave velocity) of igneous and metamorphic rocks. Iphar and Göktan (2006) used the Neuro-fuzzy Inference system for BA prediction of marbles by means of their porosity and UCS values. Özvan and Direk (2021) investigated the influence of deterioration on abrasion resistance values of different natural stones. They showed that the aggregate impact values (AIV) could be reliably used to predict the WWA and BA abrasion resistance values of the considered stone materials. The results of an investigation by Yılmaz et al. (2017) revealed that the WWA values of granites were more influenced by modal mineral composition than grain size. The overall Rosiwal mineral hardness was found to be highly correlated to the WWA values of the studied granites. In their study, micro-hardness of the granite samples determined by the Knoop indenter did not correlate well with the measured WWA values.

The preceding literature summary indicates that considerable research has grown up around the theme of abrasion resistance (WWA and BA) prediction by means of indirect methods. Accordingly, the relations of physical, mechanical, and mineralogical properties of stone materials to their abrasion resistance behavior have been well-documented. However, to the best of present authors' knowledge, abrasion resistance with respect to chemical compositions of stone materials has not been investigated previously. In this study, the usability of the chemical compositions of selected marble samples for their WWA and BA predictions was investigated. For this purpose, several predictive models of abrasion resistance were established by performing multiple linear regression analyses on the available experimental data. It is thought that the insights gained from this study may be of assistance to the practitioners and academicians working in this field.

2. Materials and Methods

In the scope of this study, experimental data of the two abrasion resistance test methods (WWA and BA) and chemical compositions of selected marble samples were evaluated. The presently processed experimental data have appeared as parts of two previous studies conducted with the same marble samples, but with different objectives (Karaca, 2010, 2012). Thus, selection of the considered marble samples was solely based on their available properties for the purpose of the present study.

In this study, the term marble refers to 'true' marbles which are crystalline calcareous rocks formed by the metamorphism of limestone, composed of primarily calcite ($CaCO_3$) and dolomite ($MgCO_3$) minerals in varying proportions. Commercial names of the marble samples and their corresponding code numbers as used in the present study are: *Afyon White* (S1), *Yatağan White* (S2), *Karacasu White* (S3), *Aegean Silver* (S4), and *Belevi Black* (S5). Descriptions of the two abrasion tests (WWA and BA) and the chemical compositions of the considered samples are presented in the following sections.

2.1 Wide Wheel Abrasion (WWA) Test

The WWA test is the 'reference test method' (Method-A) in the Standard EN 14157 (2004, 2017). Schematic drawing of the standard test apparatus is illustrated in Figure 1. The principle of the test is to abrade the face of a specimen with an abrasive material under specified conditions. For this purpose, a specimen with dimensions 100 mm x 100 mm x 70 mm and flat surfaces within a tolerance of ± 1 mm is prepared and fixed on a clamping trolley. Afterwards, the trolley is forced to move forwards to a steel rotating wheel by means of a counterweight having 14 kg mass. The abrasive powder (white fused alumina) is fed from the guidance hopper onto the wide wheel at a constant rate. In this way, the surface of the specimen is abraded for 60 seconds. Thereafter, the specimen is removed from the machine to measure the width of the groove formed on the contact surface. The WWA value of any stone sample is calculated (in mm) as the average of six individual tests. Before a series of abrasion tests, it is required that the preceding measurement procedures be repeated on a 'Boulonnaise Marble' for calibration of the apparatus. The lower values of WWA obtained in this test indicate higher resistance to abrasion.

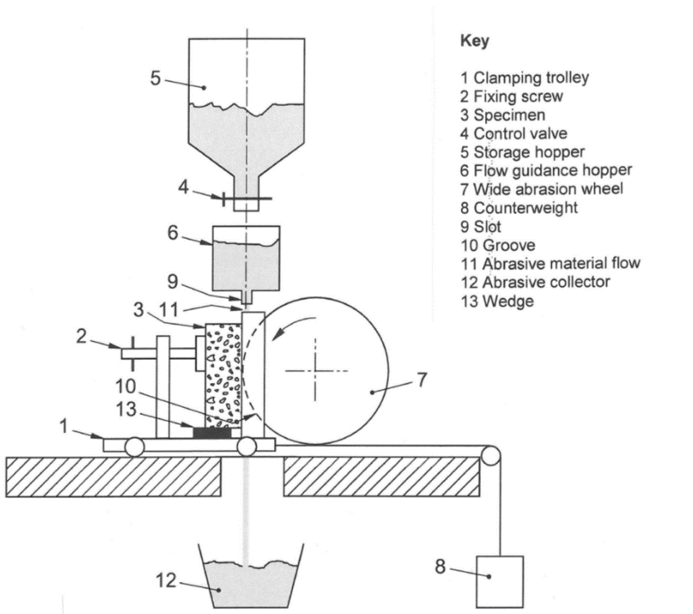

Figure 1. Wide Wheel Test apparatus (EN, 2004, 2017)

2.2 Böhme abrasion (BA) test

The Böhme method, Method-B in the Standard EN 14157 EN 14157 (2004, 2017), is performed by using the standardized test apparatus shown in Figure 2. A test specimen (71x71x71 mm) is fixed to a clamping device on the test track of a 750 mm diameter horizontal rotating disc on which a 20 g of standard abrasive sand (artificial corundum) is sprinkled. Applying a load of 294 ± 3 kN, the specimen is subjected to abrasion for 22 revolutions at 30 rev/min rotation speed. Thereafter, the surface of the test track is cleaned, and the specimen is turned 90 degrees before sprinkling another 20 g of abrasive sand. This procedure is performed for 16 cycles, each composed of 22 revolutions. After completion of the test, the volume loss of the specimen (in mm^3) is calculated. The Böhme abrasion resistance (BA) of a rock sample is expressed by averaging the results of five individual tests (EN, 2004, 2017).

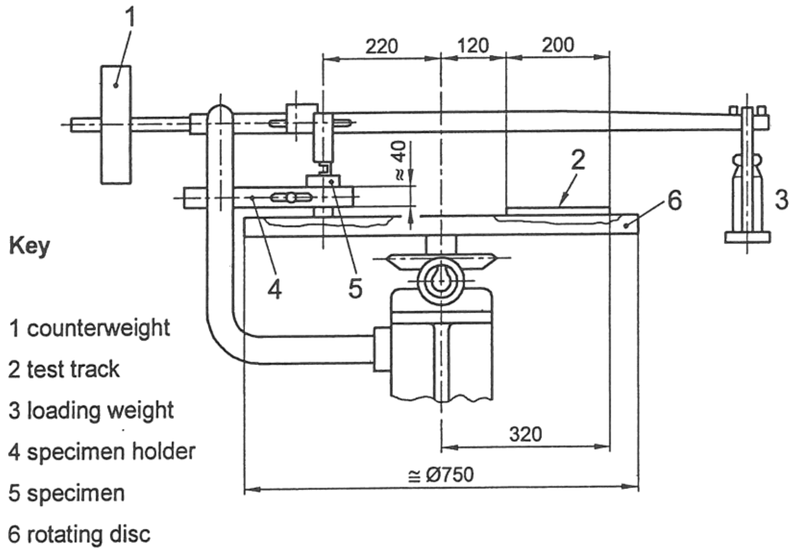

Figure 2. Böhme apparatus (EN, 2004, 2017)

The WWA and BA test results of the considered marble samples are given in Table 1 along with their mechanical properties.

Table 1. Abrasion resistance (WWA and BA) and mechanical properties of the samples (Karaca, 2012)

Sample	Wide Wheel Abrasion, WWA (mm)	Böhme Abrasion, BA (mm^3)	Uniaxial Compressive Strength, UCS (MPa)	Brazilian Tensile Strength, TS (MPa)
S1	23.5 (±0.3)	24047 (±989)	57.66 (±7.30)	6.57 (±0.68)
S2	24.6 (±0.8)	27714 (±1198)	41.02 (±3.33)	4.71 (±0.29)
S3	24.0 (±0.8)	22343 (±858)	23.43 (±3.35)	3.60 (±0.45)
S4	18.6 (±0.0)	17795 (±694)	110.3 (±19.58)	10.1 (±0.46)
S5	19.8 (±0.0)	22093 (±341)	52.74 (±22.0)	8.69 (±0.36)

2.3 Chemical compositions of the marble samples

The chemical compositions of rocks are generally reported as lists of oxides, typically including the concentrations of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), manganese oxide (MnO), magnesium oxide (MgO), calcium oxide (CaO), sodium oxide (Na_2O), potassium oxide (K_2O), titanium dioxide (TiO_2), phosphorus pentoxide (P_2O_5), and chromium oxide (Cr_2O_3) (Mason, 1990). Chemical compositions of the studied marble samples determined by using the Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) technique are illustrated in Table 2.

Table 2. Chemical compositions of the studied marble samples (in wt. %) (Karaca, 2010)

Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Cr_2O	LOI
S1	0.13	0.03	0.02	<0.01	0.17	55.52	<0.01	<0.04	<0.01	<0.01	<0.01	44.03
S2	<0.04	<0.03	0.01	<0.01	0.18	56.40	0.01	<0.04	<0.01	<0.01	<0.01	43.00
S3	0.16	0.10	0.01	0.01	0.50	55.12	0.02	<0.04	<0.01	<0.01	<0.01	44.00
S4	0.33	0.21	0.08	0.04	5.70	48.86	0.05	0.09	0.02	0.01	0.01	44.58
S5	1.42	0.16	0.03	<0.01	0.93	53.24	0.01	<0.04	0.03	0.01	0.02	44.11

The ratio of CaO to MgO is a widely applied method of quantitative geochemical classification for carbonate rocks (Grant, 1989). According to the geochemical classification system proposed by Storey and Vos (1981) cited in (Madukwe, 2016): CaO to MgO ratios >24.4 indicate Calcite Marble; 24.4-3.95 Dolomitic Calcite Marble; 3.95-1.67 Calcitic Dolomite Marble; and <1.67 Dolomite Marble. Adopting this classification system, the presently studied samples fall into the group of calcite marbles with the exception of Sample S4 which is a dolomitic calcite marble.

Referring to Table 2, the CaO contents of the considered marbles range from 48.86 to 56.40 wt%. The relatively low CaO content of Sample S4 (48.86 wt%) is mainly due to its high MgO content (5.70 wt%), indicating the presence of dolomite. The SiO_2 contents of the samples range from < 0.04 to 1.42 wt%, with Sample S5 having the highest SiO_2 content. Percentage concentration of the other silicate component Al_2O_3 is in the range <0.03-0.21, with Sample S4 displaying the highest concentration. All samples are poor in Fe_2O_3 (0.01-0.08 wt%). Alkali contents (N_2O and K_2O) are in the range of <0.01-0.05 wt% and <0.04-0.09 wt%, respectively. Concentrations of other oxides P_2O_5 (<0.01-0.01 wt%) and Cr_2O_3 (<0.001-0.002 wt%) are the lowest among all other oxides.

3. Results and Discussion

3.1 Regression Analyses

In this part of the study, multiple linear regression (MLR) analyses were performed to select the most relevant chemical variables for the final prediction models of the WWA and BA test values. For this purpose, the chemical compositions of the samples (Table 2) were used as the independent variables of the regression models. In all statistical analyses made, the less-than values in Table 2 were replaced by half the detection limits (Grant, 1989).

As the first step of the analyses, major oxides CaO, MgO, SiO_2, Fe_2O_3, Al_2O_3, Na_2O, and K_2O were selected as the candidate independent variables. Using the correlation tool in the Excel software, a correlation matrix was constructed to determine the strength and direction of the correlations between pairs of independent variables (Table 3).

Table 3. Correlation matrix of the independent variables

	CaO	MgO	SiO_2	Fe_2O_3	Al_2O_3	Na_2O	K_2O
CaO	1						
MgO	-0.96331	1					
SiO_2	-0.28895	0.414150	1				
Fe_2O_3	-0.97690	0.975620	0.173188	1			
Al_2O_3	-0.91657	0.801284	0.545924	0.812871	1		
Na_2O	-0.88899	0.956949	-0.10519	0.873263	0.762112	1	
K_2O	-0.92350	0.991419	-0.07981	0.958706	0.717749	0.953959	1

The presently constructed MLR models were based on a technique known as the 'Backward Stepwise Regression, (BSR)'. Application of this method starts with fitting the model with all candidates independent variables. Thereafter, variables that do not have a statistically significant effect on the dependent variable are gradually removed one-by-one. This is done by considering the probability value (p-value) of each independent variable. In this study, a 5% significance level (p-value ≤ 0.05) was selected as statistically significant. After removing the least significant variable, the model is refitted, and the p-values of the remaining variables are re-examined. This approach is repeated until the remaining independent variables are statistically significant. Prediction performances of the constructed regression models were determined by considering the test statistics coefficient of determination (R^2). The R^2 is used as a measure of model accuracy, which explains the proportion of variance in the dependent variable that can be estimated from the independent variable. The R^2 values range from 0 to 1, with values close to 1 suggesting higher prediction performance.

Following the regression procedures outlined above, prediction models of the WWA and BA abrasion resistance values were derived using the Excel software. The two models that best estimate the WWA values of the considered marble samples are given by Eqn. 1 and Eqn. 2:

$$WWA = 24.5702 - 0.8818\ MgO - 2.7936\ SiO_2 \qquad (R^2 = 0.98) \qquad (1)$$
$$WWA = -16.2951 + 0.7274\ CaO - 1.8438\ SiO_2 \qquad (R^2 = 0.99) \qquad (2)$$

where WWA is in mm and MgO, SiO_2, and CaO are in wt%.

Regarding Eqn. 1, the coefficient of determination ($R^2 = 0.98$) for the model indicates that 98% of the variation in WWA values can be explained by the independent variables MgO (p-value = 0.01) and SiO_2 (p-value = 0.02). According to Eqn. 1, increasing values of MgO and SiO_2 correspond to lower WWA values, implying higher resistance to abrasion. The R^2 value (0.99) determined for Eqn. 2 suggests that the 99% of the variance in WWA values can be explained by the independent variables CaO ($p = 0.01$) and SiO_2 ($p = 0.04$). The same equation signifies that the increasing values of CaO are associated with higher values of WWA (implying lower resistance to abrasion), while the opposite is valid for SiO_2.

As might be expected, the regression models given in Eqn. 1 and Eqn. 2 were not found applicable for predicting Böhme abrasion (BA) test values. This is probably due to the fact that abrasion resistance is not an intrinsic material property, as it depends on the measurement method. In the case of currently considered marbles, the following relationship was found between BA and WWA test results:

$$BA = 1100.3\ WWA - 1519.2 \qquad (R^2 \approx 0.70) \qquad (3)$$

A separate regression analysis performed on the chemical variables for predicting BA values yielded the following model:

$$BA = 22853.98 - 939.75\ MgO + 1.787\ (CaO/(SiO_2) \qquad (R^2 = 0.98) \qquad (4)$$

where BA is in mm^3 and MgO, CaO, and SiO_2 are in wt%.

The $R^2 = 0.99$ determined for this model (Eqn. 4) suggests that 99% of the variance in BA can be explained by the independent variables MgO (p-value = 0.02) and the ratio of CaO to SiO_2 (p-value = 0.02). According to Eqn. 4, the BA values of the considered marble samples decrease with increasing values of MgO (implying higher resistance to abrasion), while the opposite is valid for CaO to SiO_2 ratio.

To visually illustrate the accuracies of the presently derived regression models, the predicted and laboratory-measured values are plotted in Figures 3-5.

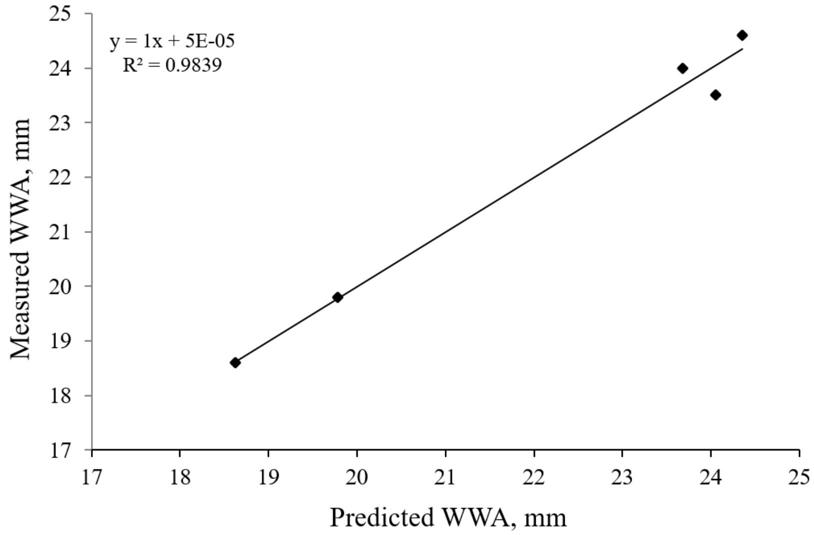

Figure 3. Predicted (Eqn.1) versus laboratory-measured WWA values

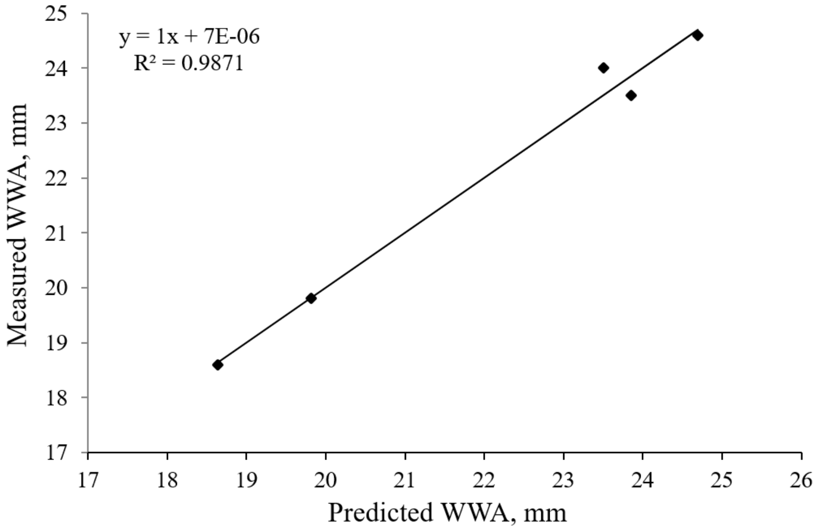

Figure 4. Predicted (Eqn. 2) versus laboratory-measured WWA values

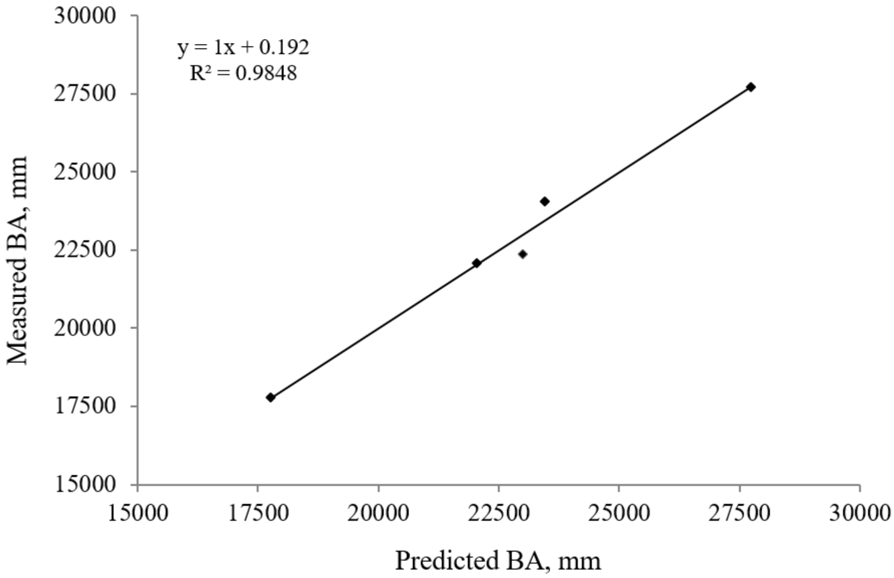

Figure 5. Predicted (Eqn. 4) versus laboratory-measured BA values

3.2 Discussion

The preceding findings indicate that abrasion resistance values of the marbles determined by the WWA and BA tests are closely related to their chemical compositions. The chemical compositions of carbonate rocks are also of particular interest in many industrial applications. In the stone processing industry, for example, the presence of SiO_2 and/or MgO results in lower cutting and grinding performance, higher specific tool consumption, and higher power consumption (Sidorko, 2008; Güneş, 2010; Almasi, 2017). On the other hand, the study of chemical compositions is a key issue when investigating the potential use of marble as a filler material in products such as floor tiles, paints, and glass (Grant, 1989). For these reasons, the chemical compositions of marbles are often reported together with their physical and mechanical properties.

It is important to note that the presently established prediction models are valid only for the considered 'calcite' and 'dolomitic calcite' type marbles with certain chemical compositional ranges. These models may be updated and expanded by further studies with the inclusion of data from other types of marbles. If confirmed by other studies, the strong prediction capabilities of the presently established statistical models suggest that they may be used as practical tools for preliminary *abrasion class* and *usage class* determinations of similar marble types. While the abrasion class of a stone material is a comparative measure of its abradability (i.e. low, moderate, high), the usage class describes its suitability for use in a particular location of a building (i.e. fast foot areas, stairs, light foot areas). The abrasion classes and usage classes of natural stones have not been defined by the European Committee for Standardization. However, guidance in this field has been provided by several authors and institutions (Marradi, 2008; TFCGG, 2013; Çobanoğlu, 2017).

As already mentioned in the literature review section, the relations between basic rock properties and abrasion resistance values determined by the WWA and BA test methods have been investigated by many authors. Accordingly, different correlative relations have been developed with varying degrees of correlations depending on the rock type and the employed test method. For the completeness of this study, an additional consideration was addressed to evaluate the influence of some mechanical rock properties on WWA and BA test results. For this purpose, simple linear regression analyses were performed using the individual uniaxial compressive strength (UCS) and indirect tensile strength (TS) values of the marble samples (Table 1). To represent these relations the following regression equations were derived and illustrated in Figures 6-9:

$$WWA = -0.0659\ UCS + 25.857 \quad (R^2 = 0.63) \quad (5)$$
$$BA = -76.8\ UCS + 27182 \quad (R^2 = 0.49) \quad (6)$$
$$WWA = -0.9375\ TS + 27.452 \quad (R^2 = 0.88) \quad (7)$$
$$BA = -0.0005\ TS + 18.673 \quad (R^2 = 0.48) \quad (8)$$

where WWA is in mm, BA in mm^3, UCS in MPa, and TS in (MPa).

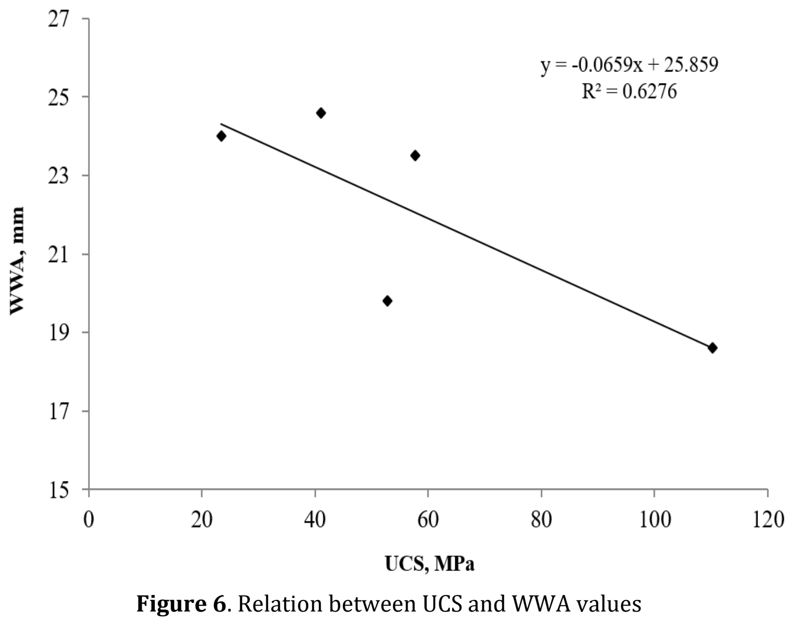

Figure 6. Relation between UCS and WWA values

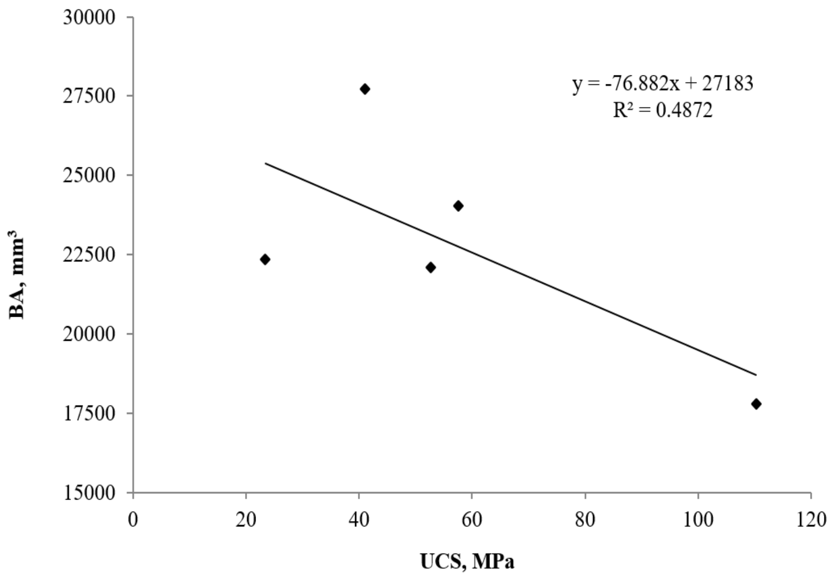

Figure 7. Relation between UCS and BA values

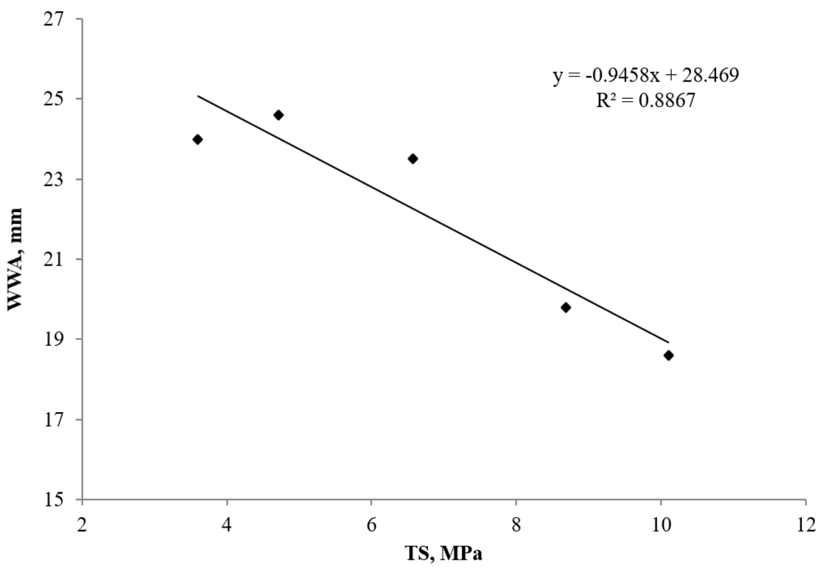

Figure 8. Relation between TS and WWA values

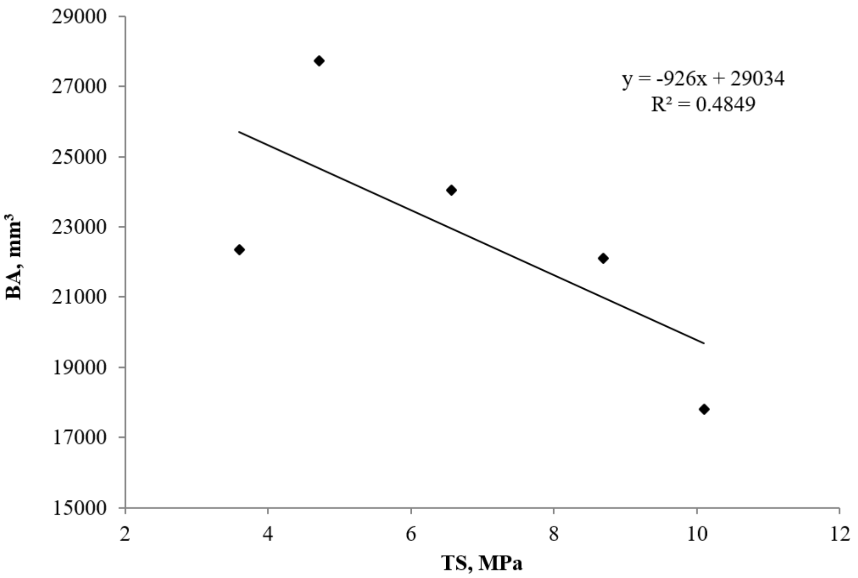

Figure 9. Relation between TS and BA values

As seen from Eqns. (5-8), in all cases there are inverse linear correlations between both abrasion resistance test results and mechanical rock properties, implying higher resistance to abrasion with increasing UCS and TS values. The WWA and BA prediction performances of Eqns. (5-8) can be compared with those based on chemical compositions (Eqns.1, 2, and 4).

4. Conclusions

Knowledge of the abrasion resistance of building stones is required for flooring applications. This mechanical property is determined in the laboratory by conducting standardized tests. However, in the literature, a great amount of work has been devoted to its indirect determination by means of physical, mechanical and mineralogical properties of rocks. The objective of this work was to investigate the possibility of using chemical compositions of marbles as a means of their abrasion resistance prediction. For this purpose, available chemical data and abrasion resistance values (WWA and BA) of five different commercial marbles were evaluated by performing multiple linear analyses.

Based on evidence made from the analyses, the general conclusion is that evaluating chemical parameters of true marbles might be one efficient way of predicting their WWA and BA values. The presently established statistically significant models with strong prediction performances (p-values < 0.05; $R^2 = 0.98–0.99$) imply that the abrasion resistance values of the considered marble samples increase with increasing contents of MgO and SiO_2, while the opposite is valid for CaO and (CaO /SiO_2) ratio. It is thought that the currently developed models may be used in practice for preliminary predictions of the WWA and BA values of marbles having similar chemical compositions. In this way, their abrasion classes and suitability for use in different environments (i.e. domestic, commercial, or industrial spaces) can be determined.

Despite strong statistical significances and prediction accuracies of the presently established regression models, this study has some limitations that need to be acknowledged. It is possible that the restricted number of samples used in the analyses can be mentioned as a weakness of the present contribution. This limitation suggests that the currently reached findings should be interpreted cautiously. Nonetheless, notwithstanding this limitation, insights gained from this study could serve as a first step towards a better understanding of the influence of chemical parameters on abrasion resistance of marbles. In this respect, further studies are needed on this topic to draw more sound conclusions.

Conflict of Interest

No conflict of interest was declared by the authors.

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