Statistical Models for Predicting the Mechanical Properties of Travertine Building Stones After Freeze-Thaw Cycles

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Abstract

Freeze-thaw is one of the most powerful weathering agents that may cause a rapid change in the mechanical properties of stones, and thus limit their durability. Consequently, determining the mechanical properties of stones after freeze-thaw is important to select the natural building stones for outdoor applications, which are exposed excessive freeze-thaw cycles. The purpose of this study is propose statistical models for predicting the mechanical properties of travertine building stones after freeze-thaw test. For this, 12 travertine samples were selected and their physical and mechanical properties including density (ρ), water absorption (Wa), uniaxial compressive strength (UCS), and P-wave velocity (V_P) were determined. Then, freeze-thaw test up to 60 cycles was carried out and mechanical properties including the UCS and V_P of the samples were measured. Using data analysis, statistical models for predicting the mechanical properties of deteriorated samples after freeze-thaw test were proposed. In these models, the mechanical property of samples after freeze-thaw was considered to be the dependent variable–dependent on the independent variables of the initial mechanical property of the samples and their water absorption. The results show that statistical models are in good accuracy for predicting the mechanical properties of samples, and thus a rapid durability assessment.

Keywords

Freeze-thaw • Statistical models • UCS • V_P

83.1 Introduction

Travertine is a chemical sedimentary rock formed mostly in tectonic areas (Pentecost 2005). Nowadays travertine with different color, texture and pattern are widely used as building materials for construction and decoration purposes especially for outdoor applications such as flooring, paving and wall cladding.

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Freeze-thaw action is one of the most powerful physical weathering agents, which may cause a rapid change in the mechanical properties of travertines, and limit their durability. Therefore, the resistance to deterioration (durability) should be evaluated before the selection of an appropriate building stone (Zappia et al. 1998).

Uniaxial compressive strength (UCS), and P-wave velocity (V_P), are one of the most important mechanical properties to assess stones durability against weathering agents (Zezza 1990; Valdeon et al. 1996; Goudie 1999; Nicholson 2001; Benavente et al. 2004). However, change in the mechanical properties of stones due to weathering agents can affect their durability in the course of time (Jamshidi et al. 2013). Thus it is necessary to understand the change of mechanical properties of stones when freeze-thaw is considered as one of the weathering agents.

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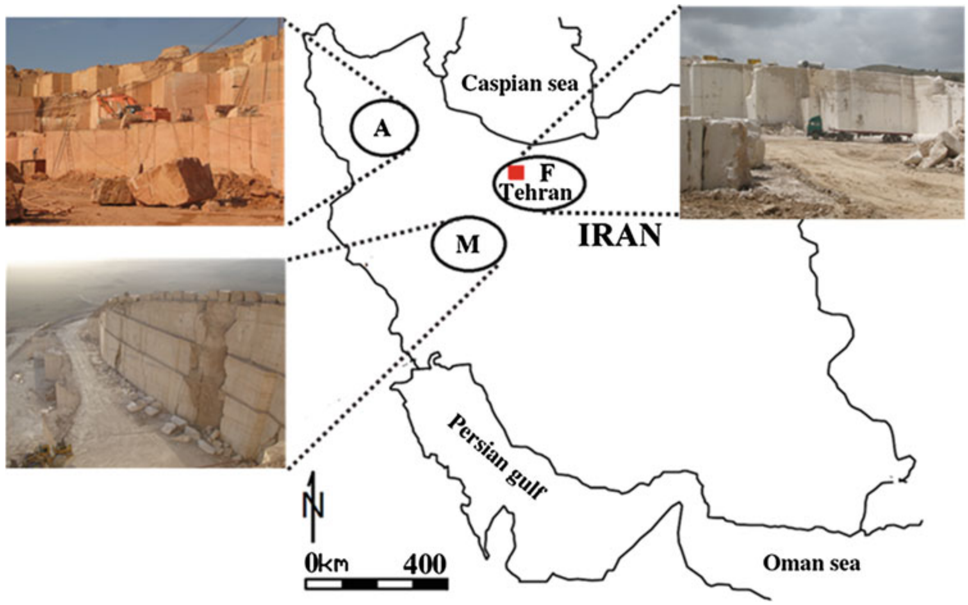

Fig. 83.1 The location of sampling and some of the quarries

The aim of this study is propose the statistical models for predicting the mechanical properties (UCS and V_P), of 12 travertine building stones after freeze-thaw test. In these models, the mechanical property of stones after freeze-thaw was considered to be the dependent variable–dependent on the independent variables of the initial mechanical property of the stones and their water absorption.

83.2 Materials and Methods

To carry out the research, 12 travertine building stones were selected from various quarries in Iran (Fig. 83.1). For each travertine, some of block that varied from 0.2 × 0.35 × 0.35 to 0.30 × 0.40 × 0.40 m in size were collected. The physical and mechanical properties including density, water absorption, uniaxial compressive strength and P-wave velocity of each sample were determined. Freeze-thaw test up to 60 cycles was carried out and mechanical properties of samples after treatment were measured. Using data analysis, statistical models for predicting the mechanical properties of samples after freeze-thaw test were proposed.

83.3 Physical Properties

To fulfill the aim of the study, some of physical properties of the samples including density (ρ) and water absorption (Wa) were determined in accordance with ISRM (1981). The results of these tests are given in Table 83.1. According to the rocks classification based on ρ suggested by Anon (1979), most of the samples were classified as to have moderate ρ (2.2–2.55 g/cm^3).

83.4 Freeze-Thaw Test

For freeze-thaw test, initially, the samples were saturated by submerging in tap water and then placing in a freezer conditioned at −12 °C for 12 h. After removing the samples, they were thawed by placing in a water bath at 12 °C for 12 h. Each complete cycle of freeze–thaw lasted for 24 h, comprising 12 h for freezing and 12 h for thawing and the test procedure was repeated for 60 cycles.

Two series of samples were prepared for each stone type to identify their UCS and V_P before and after the treatment. The first series were utilized for determination of fresh stone properties (initial properties) and the second series were subjected to freeze-thaw cycles. After 60 cycles of freeze-thaw, for UCS and V_P, the measurements were made on five specimens under saturated conditions. The experimental procedure was performed according to the methods suggested by the ISRM (1981). The results of freeze-thaw test on the samples are given in Table 83.2.

83.5 Statistical Analysis of Results

In this study, the multivariate regression equations were used for predicting the mechanical properties of the deteriorated samples. In these equations, the mechanical properties of samples after 60 cycles of freeze-thaw test were considered to be the dependent variable, which dependent on the independent variables of the initial mechanical properties of the samples and their Wa. Multivariate regression equations were undertaken with 95 % confidence level and the best-fit curves were obtained using the least squares method.

Table 83.1 The statistical distribution of physical properties of the samples under study

Commercial name	ρ (g/cm[3])			Wa (%)		
	Min.	Max.	Ave.	Min.	Max.	Ave.
Azarshahr silver	2.40	2.49	2.46	1.16	1.81	1.43
Dastjerd red	2.57	2.71	2.66	0.39	0.93	0.67
Dastjerd green	2.65	2.72	2.69	0.17	0.23	0.20
Dastjerd white	2.70	2.75	2.72	0.23	0.64	0.50
Atashkooh white	2.44	2.59	2.47	1.62	1.81	1.70
Abasabad light cream	2.40	2.48	2.43	1.82	2.10	2.00
Abasabad white	2.40	2.43	2.42	1.67	1.96	1.87
Abyar white	2.33	2.47	2.41	1.33	1.62	1.47
Dareh bokhari cream	2.31	2.43	2.38	2.52	2.77	2.69
Atashkooh cream	2.39	2.50	2.46	1.38	1.89	1.72
Firuzkuh chocolate	2.32	2.46	2.38	1.09	1.53	1.27
Firuzkuh cream	2.31	2.38	2.34	1.23	2.35	1.70

Table 83.2 The mechanical properties of fresh and deteriorated samples

Commercial name	UCS (MPa)		V_P (m/s)	
	[a]Fresh value	[b]Deteriorated value	Fresh value	Deteriorated value
Azarshahr silver	55.5	46.0	4930	4338
Dastjerd red	65.7	59.7	5260	4892
Dastjerd green	64.5	60.0	5310	4938
Dastjerd white	62.4	58.2	5450	5010
Atashkooh white	49.3	40.4	4600	3910
Abasabad light cream	41.3	32.7	4150	3445
Abasabad white	43.7	38.8	4410	3709
Abyar white	51.4	46.4	4690	4174
Dareh bokhari cream	37.4	30.1	4135	3300
Atashkooh cream	45.7	41.3	4510	3879
Firuzkuh chocolate	59.9	50.4	5010	4500
Firuzkuh cream	50.7	43.6	4470	3956

[a] Initial condition
[b] After 60 cycles of freeze-thaw test

Coefficient of multiple determinations (R^2) and standard error of estimate (SEE) were used as the numerical measures of the goodness of fit for regression equations.

The general model for predicting the mechanical property after freeze-thaw test is expressed in the following form:

$$M_{60} = \alpha_0 + \alpha_1 M_0 + \alpha_2 Wa \qquad (83.1)$$

where M_{60} is the predicted value of the mechanical property (UCS or V_P) for the samples after 60 cycles of freeze-thaw test, M_0 is the fresh mechanical property or, in other words, the initial mechanical property (initial UCS_0 or V_{P0}), Wa is the Wa of the fresh sample, α_0 is a constant, α_1 and α_2 are the regression coefficient of M_0 and Wa, respectively.

The data given in Tables 83.1 and 83.2 were analyzed using Spss® v.16 code statistical software. The results of these analyses are given in Table 83.3.

The R^2 of equations of E1and E2 given in Table 83.3 is higher than 0.978 that is at acceptable level. The SEE values for equations of E1 and E2 is 1.63 and 59.25, respectively. These measures show that equations can be accepted as a highly reliable for predicting the mechanical properties after freeze-thaw with the coefficients given in Table 83.3.

Table 83.3 Regression equations coefficients for predicting the mechanical properties of samples after freeze-thaw test from Eq. (83.1) and results of statistical tests

Equation code no.	Estimates mechanical property	Estimator	Coefficient	Coefficient of multiple determination (R^2)	Standard error of estimate (SEE)	F-ratio	Tabulated F-ratio
E1	UCS (MPa)	Constant	22.88	0.978	1.63	200.57	4.26
		UCS_0 (MPa)	0.605	–	–	–	–
		Wa (%)	−6.19	–	–	–	–
E2	V_P (m/s)	Constant	−173.68	0.991	59.25	514.85	4.26
		V_{P0} (m/s)	0.978	–	–	–	–
		Wa (%)	−206.55	–	–	–	–

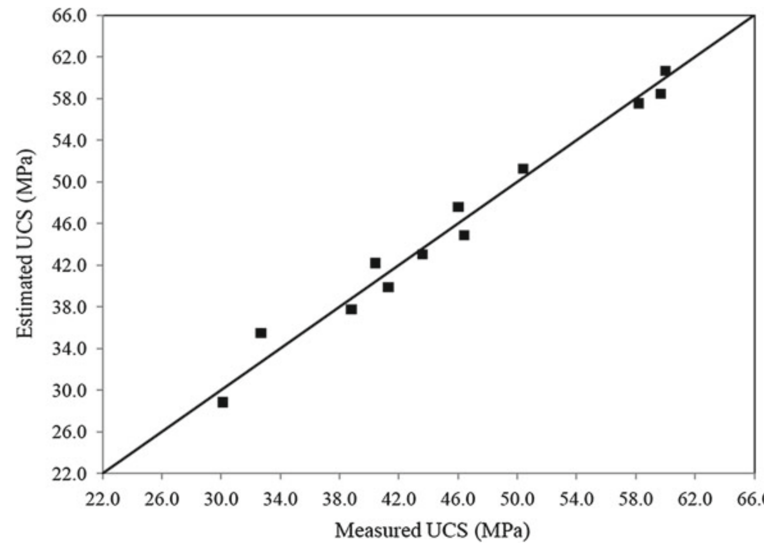

Fig. 83.2 Measured UCS versus estimated UCS from Eq. (E1) given in Table 83.3

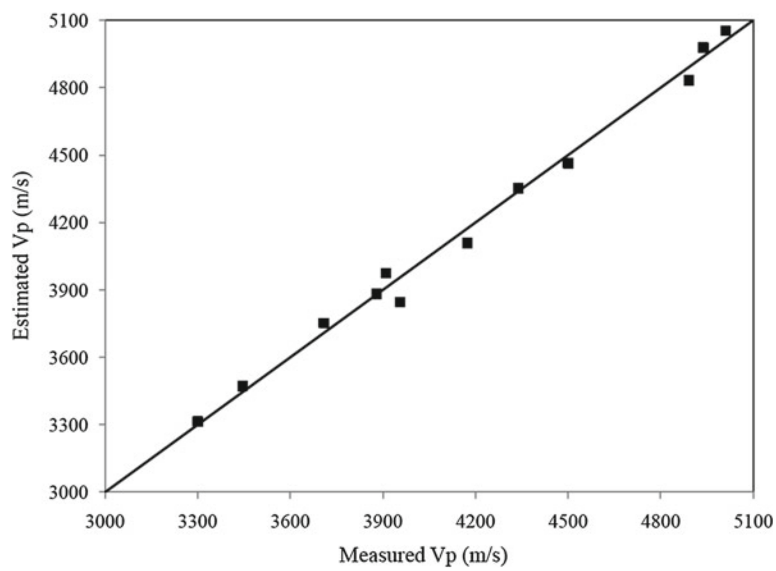

Fig. 3 Measured V_P versus estimated V_P from Eq. (E2) given in Table 83.3

To test the global usefulness and the significance of equations, analysis of variance for the regressions were also performed. F statistics test is widely used in regression and analysis of variance. The null hypothesis for this test is H_0: $\alpha_1 = \alpha_2 = 0$, against alternative hypothesis H_1: at least one of α_1, α_2 is not equal to zero. Analysis of variance for the regressions is given Table 83.3. For a significance level of 5 %, the tabulated F-ratio with degree of freedom $\upsilon_1 = 2$ and $\upsilon_2 = 9$ is 4.26. Since all the computed F-ratios for the equations are quite larger than tabulated F-ratio, the null hypothesis is rejected. So, it can be concluded that the equations given in Table 83.3 are appropriate for predicting the mechanical properties of samples after freeze-thaw test.

The relationship between the measured the mechanical properties and estimated values from equations given in Table 83.3 using 1:1 slope line is shown in Figs. 83.2 and 83.3. A point lying on the line indicates an exact estimation. The Figs. 83.2 and 83.3 indicate that the data points fall close to the 1:1 slope line and are scattered uniformly around it, suggesting that equations with the suggested coefficients are appropriate for predicting the mechanical properties after freeze-thaw test.

83.6 Conclusions

The freeze-thaw test is a well-known test for mechanical properties and durability assessment of building stones and construction materials. However, performing freeze-thaw test is a very laborious and time-consuming. In this paper, statistical models for predicting the UCS and V_P of 12 travertine samples after freeze-thaw were proposed.

The results show that statistical models are in good accuracy for predicting the UCS and V_P, and thus a rapid durability assessment. As a result, these models avoiding from performing freeze-thaw test, which is laborious and time-consuming.

However, it must be pointed out that travertine are notoriously variable and heterogeneous in their properties such as mechanical properties and porosity due to the nature of its porous media. As a result, these models can be used with care for rocks with the range of initial properties (fresh properties) of samples studied here.

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