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Investigating the Effect of Specimen Diameter Size on Uniaxial Compressive Strength and Elastic Properties of Travertines

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Abstract

Uniaxial compressive strength (UCS) and elastic properties of rocks play a major and vital role for the design of any engineering structure. The specimen diameter size is one of the main factors that influencing on UCS, elasticity modulus and Poisson's ratio (E and υ). Here, an attempt has been made to investigate the effect of specimen diameter size on UCS, E and υ. Moreover, we studied the correlation between E and υ with UCS together with the effect of specimen diameter size on them. For this purpose, 9 different travertine samples were selected and core specimens with a diameters size of 38, 44, 54, 64 and 74 mm were prepared. Then, UCS, E and υ of samples in different diameter were determined. The test results were statistically analyzed using the method of least squares regression between the different specimen diameters with UCS, E and υ. The data analysis results showed that specimen diameter size significantly affects on UCS, E and υ. Moreover, it was found that the best correlation between E and UCS was for the specimen diameter of 38 mm, whereas there is not meaningful correlation between υ and UCS.

Keywords: Elasticity modulus; Poisson's ratio; Specimen diameter size; Uniaxial compressive strength.

Introduction

Strength and elastic constants are important properties to use in planning and design of engineering structures as well as in any numerical simulation of excavation. Among them, uniaxial compressive strength, elasticity modulus and Poisson's ratio are common and useful properties due to their application in tunnel design, slope stability, drilling and blasting, pillar design, support design, embankments, and many other civil and mining operations.

There are number of studies in the literature proposing correlations between E and υ with UCS. Tables 1 provide some of correlations between E and υ with UCS developed by some researchers.

Also some of researchers have investigated the effect of various factors such as the size, shape and spatial arrangement of grains, mineralogy of grains and cement, anisotropy, weathering grade, alteration,

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Table 1. Some of correlations between UCS with E and υ

References	Rock type	Equation	R or R^2
Arslan *et al.* [2]	Gypsum	E=0.2662UCS + 19.052	R^2=0.65
Arslan *et al.* [2]	Gypsum	υ=0.0043 UCS + 0.1313	R^2=0.78
Bell [3]	Sandstone, Limestone	E=0.285UCS + 12.50	R=0.35
Gupta [7]	Granite	*υ=-0.0023 UCS + 0.5175	R^2=0.49
Khandelwal & Singh [12]	Schistose rocks	*υ=-0.066 Ln (UCS) - 0.1168	R^2=0.84
Kurtulus *et al.* [13]	Serpentinized Ultrabasic Rocks	*E=2.234 Ln (UCS) – 2.817	R^2=0.80
Rohde & Feng [17]	Sandstone	$E=2.25UCS^{0.3188}$	R=0.50
Sachpazis [18]	Limestone	E=0.257UCS + 15.5	R=0.86
Tiryaki [21]	Sandstone, Limestone, Coal	*E=0.2999UCS + 5.49	R^2=0.74
Yagiz [24]	Travertine, Limestone, Schist	*E=23.99 Ln (UCS) – 56.88	R^2=0.94

R, Correlation coefficient; R^2, Determination coefficient. *Not reported equation by researchers. Data from researchers were correlated by Authors.

porosity, density, water content, confining pressure, temperature, etc. on UCS [6, 14, 16, 19, 22, 27].

Although the correlations between E and υ with UCS, and various factors affecting on them have been investigated for different rocks, the effect of specimen diameter size on UCS, E and υ [5, 8], and also the correlation between them are still poorly understood for travertines. Thus, there is a need to understand better the correlation between E and υ with UCS with emphasis the effect of specimen diameter size on them.

This study has two main purposes: to find out the effect of specimen diameter size on UCS, E and υ, and to investigate the correlation between E and υ with UCS together with the effect of specimen diameter size for 9 different travertine samples.

Materials and Methods

1.1. Rock sampling

A great number of block samples taken from travertine quarries in Azarshahr and Firuzkuh areas of Iran, and carefully checked to ensure they were homogeneous and free from visible weaknesses. The block samples varied from 0.2×0.35×0.35 to 0.30×0.40×0.40 m in size. Fig. 1 shows the location of sampling and some of the quarries. These travertines are marketed as ornamental stones and are used both in new buildings and in restoration of older ones. The name, type and location of the collected travertines are given in Table 2.

1.2. Experimental tests

To fulfill the aim of the study, some physical properties of the samples including density and effective porosity were determined in accordance with ISRM [9] (Table 3). According to the rocks classification based on density and porosity suggested by Anon [1], the samples were classified as to have moderate and high density (2.2-2.55 g/cm^3 and 2.55-2.75 g/cm^3, respectively) and low porosity (1-5%), except Azarshahr wavy red that to have medium porosity (5-15%).

Then the core specimens were taken at five different

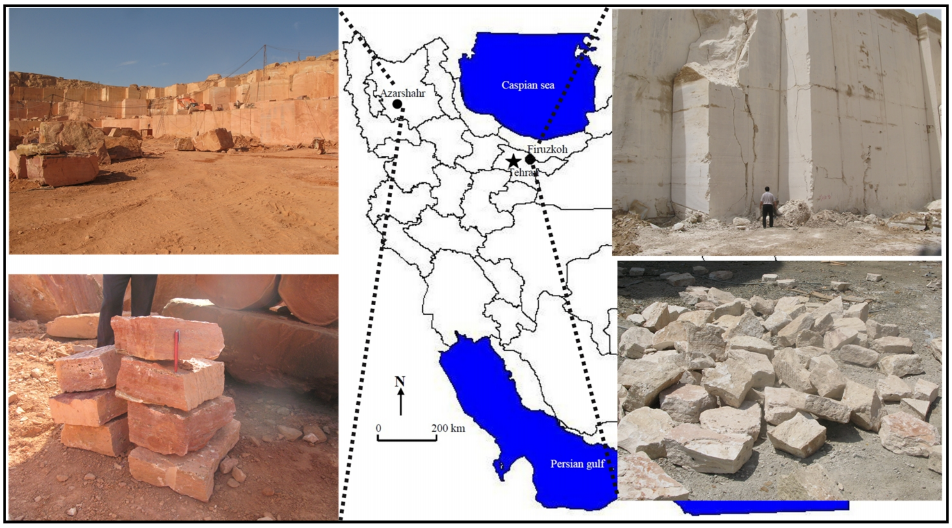

Figure 1. The location of sampling and some of the quarries.

Table 2. Name, type and location of the samples under study

Rock code	Commercial name	Rock type	Rock class	Location	
A1	Azarshahr wavy red	Travertine	Sedimentary	Azarshahr	05 78 835-41 75 768
A2	Azarshahr walnut	Travertine	Sedimentary	Azarshahr	05 82 940-41 77 150
A3	Azarshahr yellow	Travertine	Sedimentary	Azarshahr	05 79 962-41 78 232
A4	Azarshahr silver	Travertine	Sedimentary	Azarshahr	05 75 086-41 72 118
A5	Dastjerd red	Onyx travertine	Sedimentary	Azarshahr	05 79 419-41 77 952
A6	Dastjerd green	Onyx travertine	Sedimentary	Azarshahr	05 79 714-41 78 401
A7	Dastjerd white	Onyx travertine	Sedimentary	Azarshahr	05 78 893-41 75 830
F8	Firuzkuh chocolate	Travertine	Sedimentary	Firuzkuh	06 36 414-39 49 491
F9	Firuzkuh cream	Travertine	Sedimentary	Firuzkuh	06 34 361-39 49 023

Rock code; A, Azarshahr samples; F, Firuzkuh samples.

Table 3. Physical properties of the samples under study

Rock code	Commercial name	Dry density (g/cm^3)	Saturated density (g/cm^3)	Effective porosity (%)
A1	Azarshahr wavy red	2.48	2.55	7.41
A2	Azarshahr walnut	2.55	2.58	3.10
A3	Azarshahr yellow	2.51	2.55	4.65
A4	Azarshahr silver	2.46	2.49	3.17
A5	Dastjerd red	2.66	2.67	1.77
A6	Dastjerd green	2.69	2.70	0.54
A7	Dastjerd white	2.72	2.73	1.39
F8	Firuzkuh chocolate	2.38	2.41	3.00
F9	Firuzkuh cream	2.34	2.40	4.10

diameters from all travertines. These diameters are 38, 44, 54, 64 and 74, with the length to diameter ratio of 2 (Fig. 2).

The ends of the specimens were cut to be at right angles to the long axis within 0.05 mm in 50 mm. For each diameter, 5 specimens were prepared and their UCS, E and υ were determined according to ISRM [9]. All of the core specimens used for UCS measurement were also used in the determination of E and υ. Fig. 3 show UCS apparatus utilized in this study. Fully bridged strain gauges that were pasted in lateral and longitudinal directions to measures the strain in respective directions. According to the stress-strain curves, tangential E and υ were calculated. The mean values of these tests are given in Table 4.

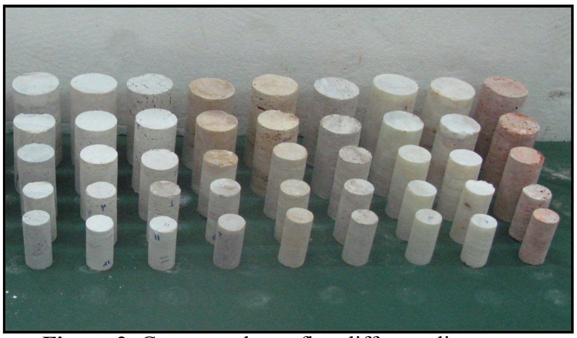

Figure 2. Core samples at five different diameters.

Figure 3. Uniaxial compressive strength apparatus for determination of UCS, E and υ.

Results and Discussion

1.1. The effect of specimen diameter size on UCS, E and υ

Figs. 4-6 graphically illustrate the UCS, E and υ samples at different diameter sizes. It can be seen from Fig. 4 that for all samples, except onyx travertines (rock codes; A5, A6 and A7), with the increase of the specimen diameter, the values of UCS are decreased. For instance, the highest and lowest UCS values for the Dastjerd red (Rock code; A5) were obtained for the specimens having 38 (65.7 MPa) and 74 mm (54.8 MPa) diameters, with a pronounced reduction of 10.9 MPa between these diameters.

Fig. 5 shows that, although the trend of data shows a decrease in E with the increase in specimen diameter, but in some of samples there is an anomaly. For instance, the highest E for Azarshahr yellow, Dastjerd

Table 4. UCS, E and υ values of the samples with different diameter sizes

Properties	Diameter	Rock code								
		A1	A2	A3	A4	A5	A6	A7	F8	F9
UCS (MPa)	38 mm	33.6	60.7	42.5	55.5	65.7	64.5	62.4	59.9	50.7
	44 mm	32.0	58.1	40.1	53.2	61.7	62.0	60.1	56.9	50.1
	54 mm	30.1	56.0	39.2	51.0	63.0	60.1	53.9	55.0	49.3
	64 mm	27.7	54.2	37.4	50.0	59.9	63.8	56.0	52.1	46.0
	74 mm	24.0	50.1	36.1	45.9	54.8	61.9	58.2	50.0	42.2
E (GPa)	38 mm	4.40	8.71	4.66	7.21	12.81	12.20	13.45	10.15	9.16
	44 mm	4.05	8.20	4.95	6.55	11.73	11.50	14.35	10.70	8.35
	54 mm	4.67	8.00	4.56	6.16	12.22	10.89	13.00	9.50	7.80
	64 mm	4.21	8.55	3.95	6.38	11.49	11.33	12.38	10.05	8.10
	74 mm	3.66	7.75	3.50	6.00	10.53	10.02	11.17	9.05	7.50
υ	38 mm	0.2630	0.2930	0.3210	0.3550	0.1950	0.3440	0.1780	0.2750	0.2987
	44 mm	0.2330	0.2650	0.3330	0.3690	0.1780	0.3540	0.1870	0.2900	0.3030
	54 mm	0.2540	0.2550	0.3010	0.3210	0.2000	0.3210	0.2010	O.2620	0.3210
	64 mm	0.2710	0.2870	0.3670	0.3710	0.2110	0.3670	0.1800	0.3000	0.3100
	74 mm	0.2200	0.2430	0.3550	0.3600	0.1980	0.3090	0.1910	0.2820	0.2900

white and Firuzkuh chocolate (Rock codes; A3, A7 and F8) were recorded in 44 mm diameter specimen. Although, variation in UCS and E shows a decreasing trend with the increase in specimen diameter but υ variation had no meaningful pattern with diameter size of specimens. In fact, the specimens with different diameter sizes show different υ values when compared with each other (Fig. 6).

However, with the increase of the specimen diameter, the amount of inherent weakness agents such

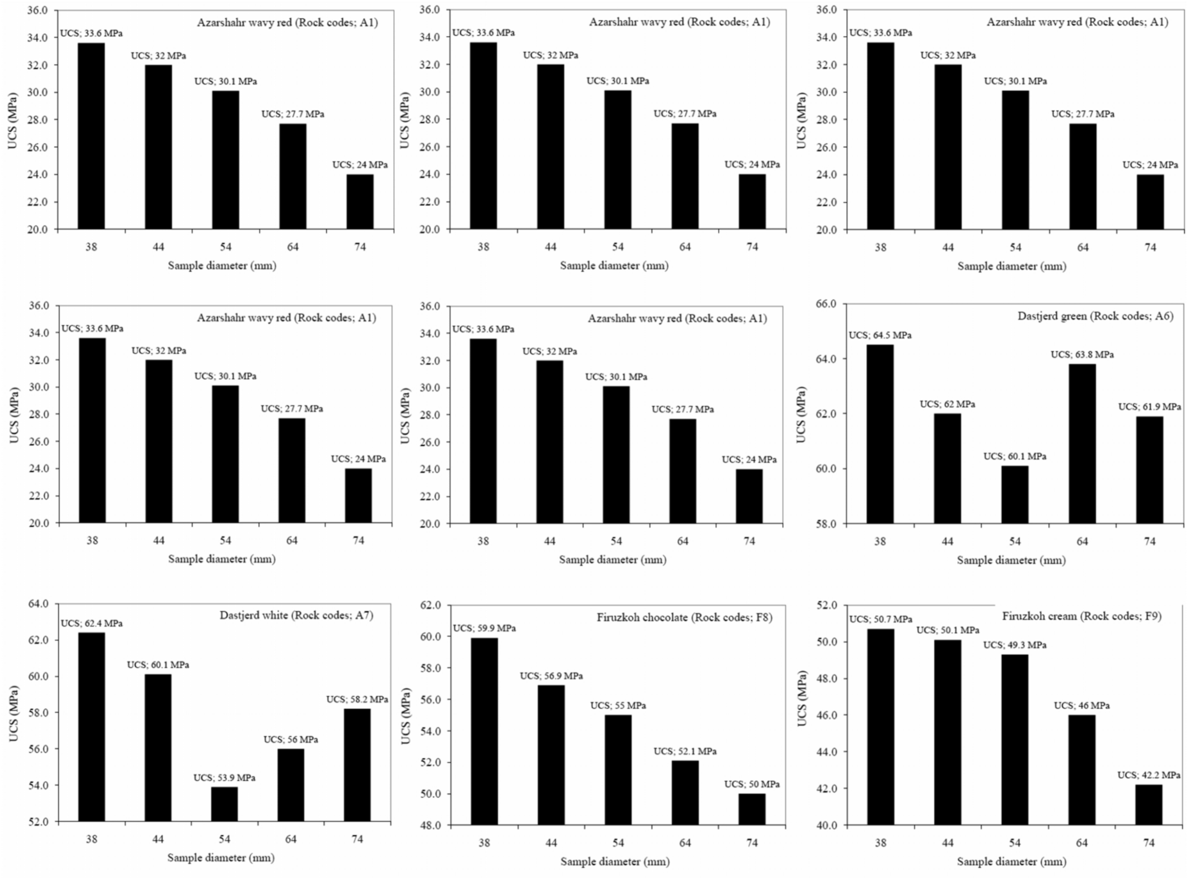

Figure 4. Uniaxial compressive strength versus specimens' diameter.

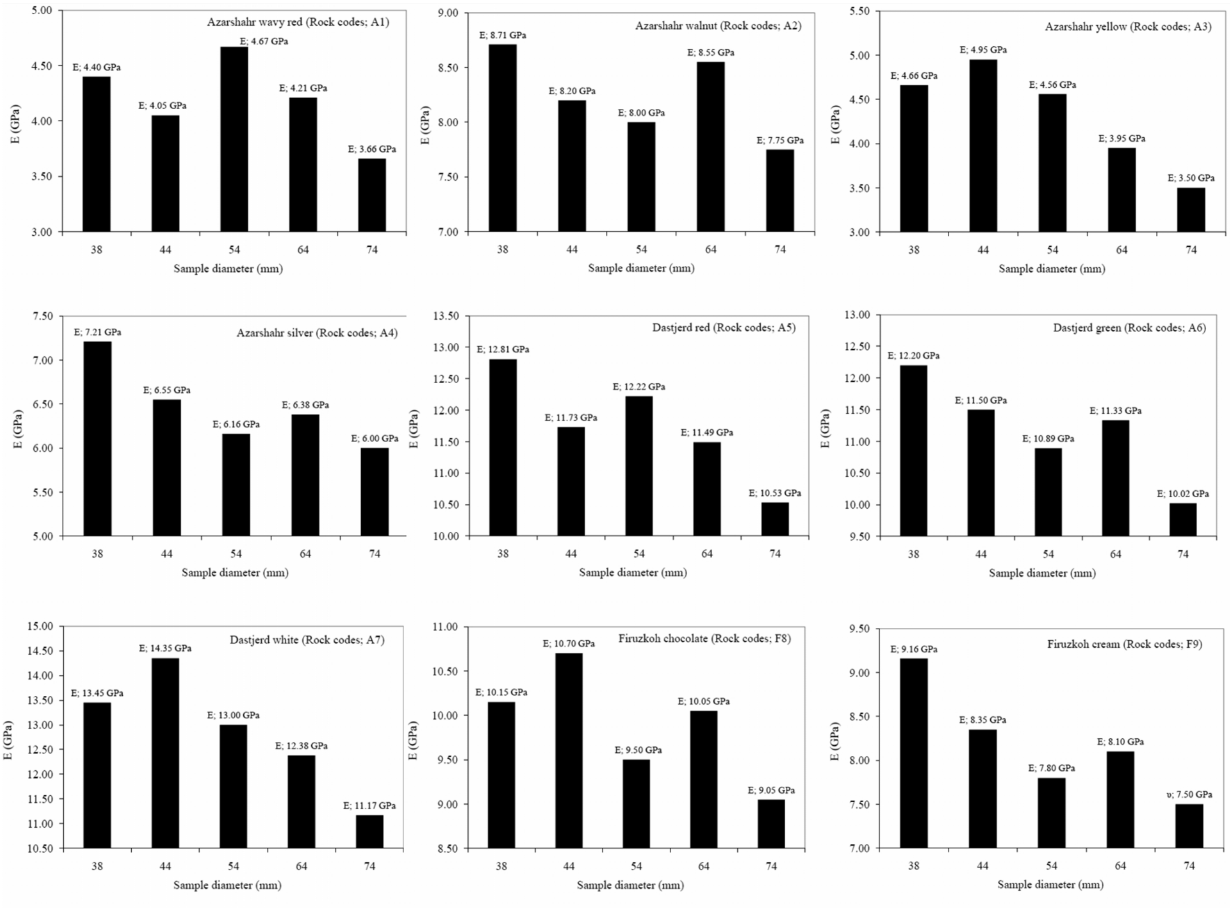

Figure 5. Elasticity modulus versus specimens' diameter.

as porosity, microfissure, etc. is increased; these, in turn, influence on the UCS, E and υ values.

The derived results in this study were compared with those available in the literature. Cobanoglu & Celik [5] investigated the change in UCS for limestone, sandstone and cement mortar samples at diameters 21, 30, 42, 48 and 54 mm. They identified a significant decrease in UCS with increase in the diameter size of limestone but the sandstone and cement mortar had no meaningful pattern with diameter size.

The rocks classification based on UCS by ISRM [10] is shown in Fig. 7 (dashed lines). Fig. 7 shows that specimens with respect to the diameter sizes of 38, 44, 54, 64 and 74 fall into the different rocks class with low or medium strength. For instance, Firuzkuh cream (Rock code; F9) at the diameter sizes of 54, 64 and 74 mm fall into the rocks class with low strength (UCS 25-50 MPa), whereas at a diameter sizes of 38 and 44 mm it goes into the rocks class with medium strength (UCS 50-100 MPa).

1.2. The effect of specimen diameter size on correlation between E and υ with UCS

Using the linear and nonlinear regression techniques including simple or multiple analysis for estimating the unknown from known variables are commonly encountered in the previous studies [4, 11, 20, 23, 26, 27]. The authors this work attempted to develop the best correlation between E and υ with UCS among the different diameters of specimens to attain the most reliable empirical equation. The equation of the best fit line, the 95% confidence limits and the determination coefficients (R^2) were determined for each regression.

In Figs. 8 and 9, the correlations between E and υ with UCS in different diameters are presented, respectively. Also, the results of regression analyses and the determination coefficients are summarized in Table 5.

The results of the regression analysis indicate that E has reliable correlation with the UCS in accordance with the result of statistical analysis (Fig. 8). On the other hand, the correlation between υ and UCS is not strong enough and meaningful to rely on (R^2<0.072) as given in Fig. 9.

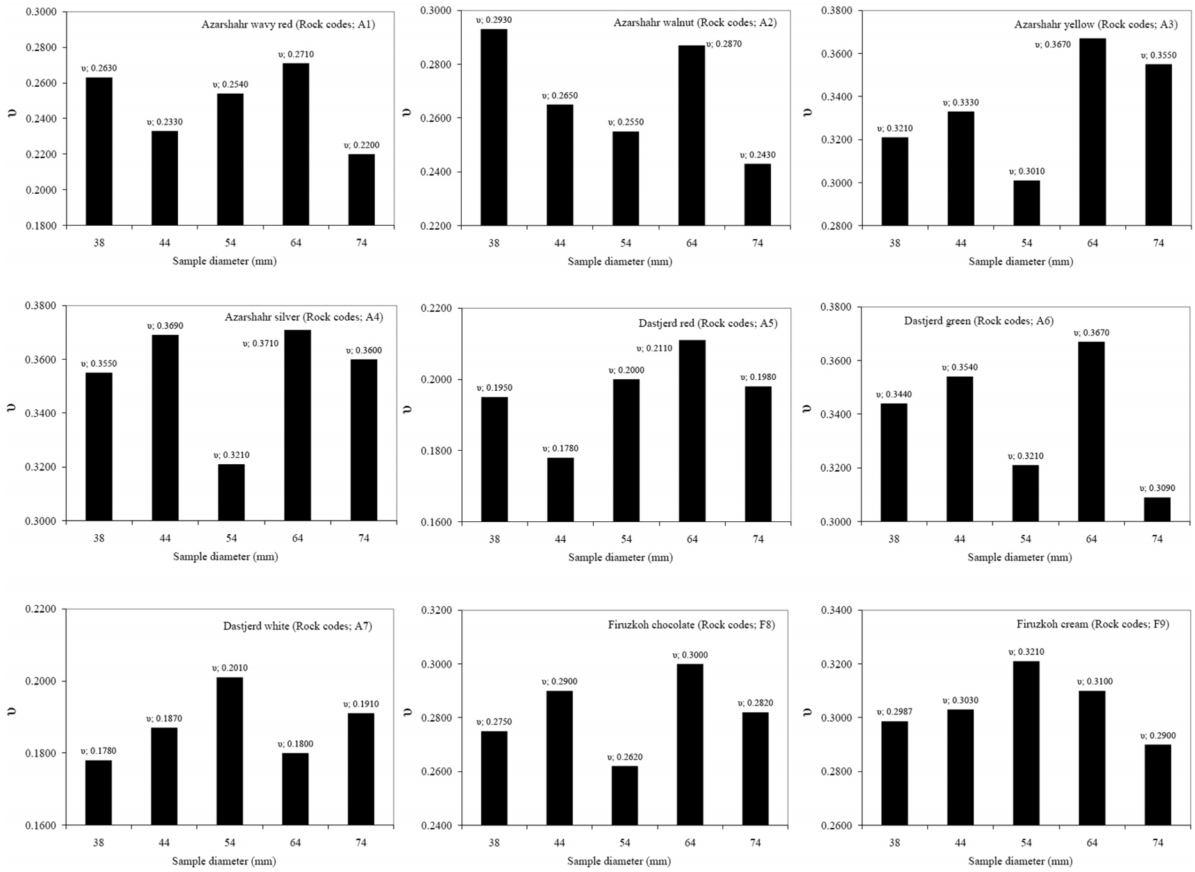

Figure 6. Poisson's ratio versus specimens' diameter.

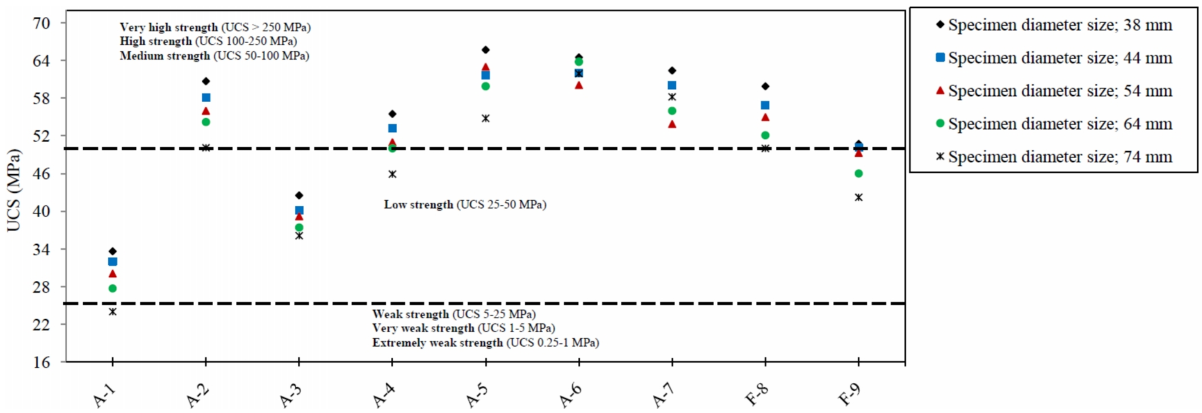

Figure 7. Samples classification based on UCS by ISRM [10] at different diameter sizes.

As seen from the Fig. 8, in all cases, the best-fitted correlation between E and UCS has been represented by power regression curves. The highest determination coefficient, R^2=0.86, was obtained for the specimen diameter of 38 mm and the lowest was for the diameter of 54 mm with R^2=0.75. The equations of these correlations are as below:

$$\mathbf{E_{38}}=1.234\ e^{0.0352\mathbf{UCS38}} \qquad R^2=0.86 \qquad (1)$$

$$\mathbf{E_{54}}=1.522\ e^{0.0326\mathbf{UCS54}} \qquad R^2=0.75 \qquad (2)$$

The determination coefficients showed that the diameter of 38 mm is the most reliable for estimating E from UCS than other diameters. In fact, with the decrease of the specimen diameter size, the amount of its heterogeneity is decreased. As a result, the highest of

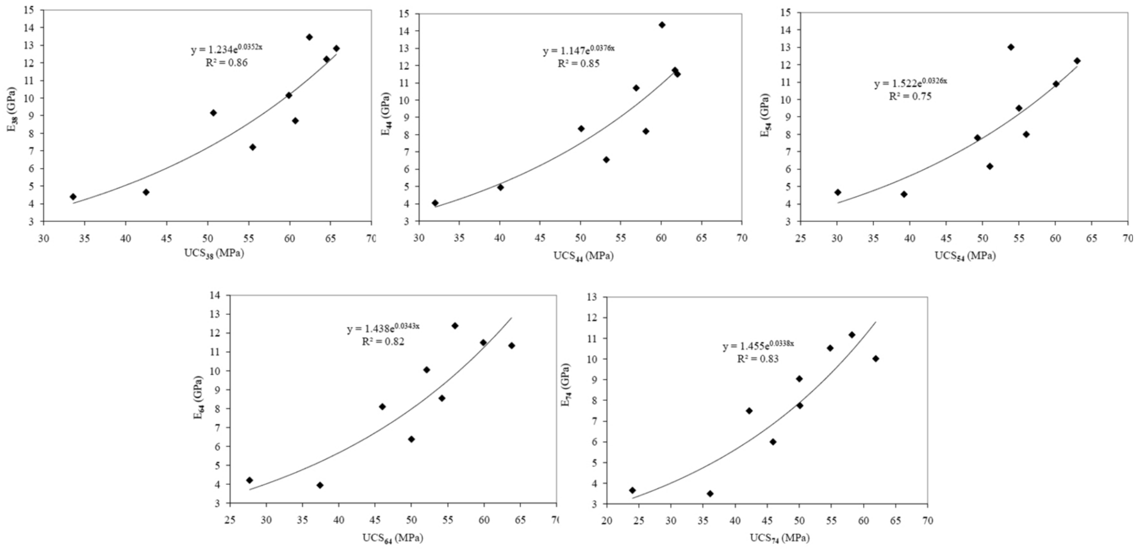

Figure 8. Correlation between UCS and E at different diameter sizes.

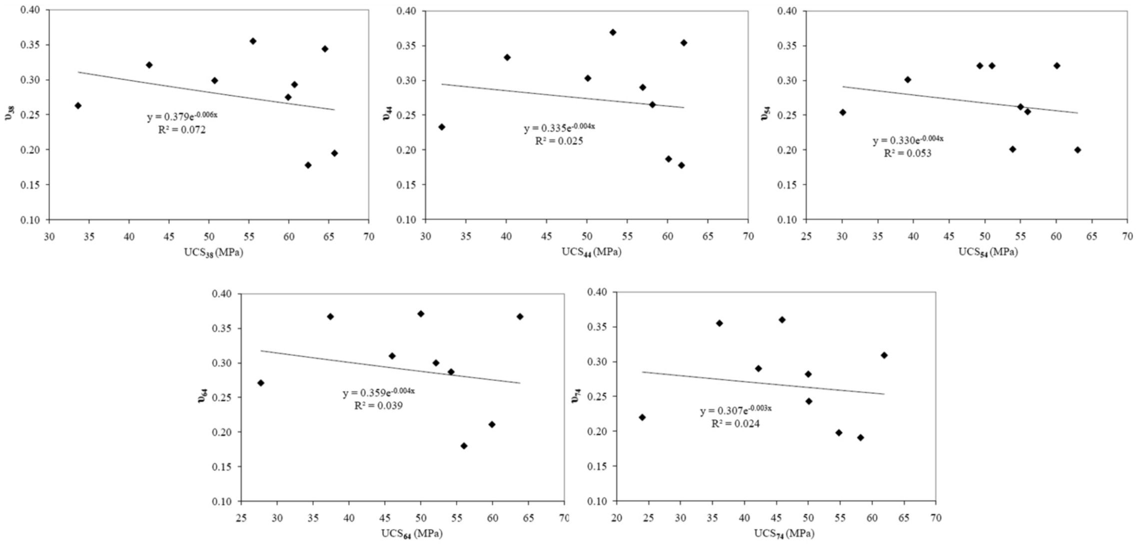

Figure 9. Correlation between UCS and υ at different diameter sizes.

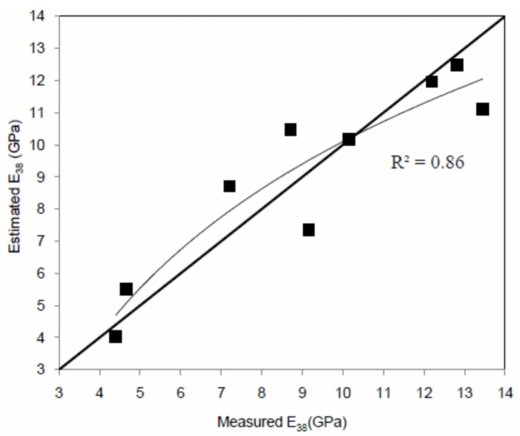

Figure 10. Measured the E_{38} values versus the E_{38} values

consistency between E and UCS is obtained from the specimens with the diameter of 38 mm.

To investigate the validity of the proposed empirical equations in this study (Table 5), t-test was conducted among the achieved equations using the SPSS statistical package version 16.

The significance of the r-values can be determined by t-test, assuming that both variables are normally distributed and the observations are chosen randomly. The test compares the computed t-value with a tabulated t-value using the null hypothesis. In this study, a 95% level of confidence was chosen. If the computed t-value is greater than the tabulated t-value, the null hypothesis is rejected. This means that R^2 is significant. If the

Table 5. Correlation equations between E and υ with UCS at different diameters and the analyses results by t-test

Specimen diameter size (mm)	Regression equation	Determination coefficient (R^2)	t test	
			Calculated value	Tabulated value
38	$E_{38}=1.234\ e^{0.0352UCS38}$	0.86	-17.07	±2.306
44	$E_{44}=1.147\ e^{0.0376UCS44}$	0.85	-17.16	±2.306
54	$E_{54}=1.522\ e^{0.0326UCS54}$	0.75	-15.83	±2.306
64	$E_{64}=1.438\ e^{0.0343UCS64}$	0.82	-14.32	±2.306
74	$E_{74}=1.455\ e^{0.0338UCS74}$	0.83	-12.79	±2.306
38	$\upsilon_{38}=0.379\ e^{-0.006UCS38}$	0.072	-15.07	±2.306
44	$\upsilon_{44}=0.335\ e^{-0.004UCS44}$	0.025	-15.12	±2.306
54	$\upsilon_{54}=0.330\ e^{-0.004UCS54}$	0.053	-14.66	±2.306
64	$\upsilon_{64}=0.359\ e^{-0.004UCS64}$	0.039	-13.12	±2.306
74	$\upsilon_{74}=0.307\ e^{-0.003UCS74}$	0.024	-11.96	±2.306

computed t-value is less than the tabulated t-value, the null hypothesis is not rejected. In this case, R^2 is not significant. It can be seen from Table 5 that for correlation between E and υ with UCS all of the computed t-values are greater than the tabulated t-values. So it is concluded that there are real correlations between E and UCS, which can be used at least for preliminary investigations.

Although the determination coefficients of the correlation equations between E and UCS is in reliable level and this is very good value, it does not identify the valid equations necessarily. For this, the equation (1) proposed in this study for the diameter of 38 mm was evaluated by comparing their results with each other. The estimated values of E by correlation equation (1) was then plotted versus the measured values for the specimen diameter size of 38 mm using 1:1 slope line (Fig. 10). A point lying on the line indicates an exact estimation. The figure indicates that for the specimen diameter size of 38 mm, the data points fall closer around the 1:1 slope line. This suggests that for estimating the E by UCS, a specimen diameter size of 38 mm is the reliable.

Conclusions

In this study, core specimens were taken from 9 different travertine samples at 5 different diameters (38, 44, 54, 64 and 74 mm). Then, the laboratory tests were performed to investigate the effect of specimen diameter size on UCS, E and υ. Also the correlation between E and υ with UCS were researched when specimen diameter size is considered as a factor that can affect on them.

The results of this study indicated a significant decrease in UCS, except onyx travertines (rock codes; A5, A6 and A7), with increase in the specimen diameter size. Although, variation in E shows a decreasing trend with the increase in specimen diameter but in some samples there is an anomalies. For υ, the specimens with different diameter sizes show different values when compared with each other. In fact, υ variation had no meaningful pattern with diameter size of specimens.

The correlations between E and UCS showed that specimen diameter size has significant influence on their determination coefficient (R^2). The highest (0.86) and lowest (0.75) of determination coefficients were for the diameters of 38 and 54 mm, respectively. Accordingly, it is concluded that the specimen diameter size of 38 mm is the most appropriate for establishing the best reliable correlation between E and UCS. On the other hand, the correlation between υ and UCS is not strong enough and meaningful to rely on (R^2 <0.072).

Acknowledgments

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