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Research Paper

Correlation Between Cerchar Abrasivity Index with Rock Properties in Sandstone and Tuff Samples

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Abstract: The abrasivity of materials is of vital importance in selecting an affordable excavation method in the early stages of a tunneling project. The amount of specific energy and the Mode I and Mode II stress intensity factors in the eroded disc is more than the non-eroded disc. Vickers hardness number rock (VHNR), rock abrasivity index (RAI), Cerchar abrasivity index (CAI), LCPC abrasivity coefficient, and Norwegian University of Science and Technology (NTNU) abrasion test are among the methods for estimating rock abrasivity. Correlations were proposed in this study for estimating the CAI of sandstone and tuff. To achieve reliable comprehensive results, various kinds of sandstone and tuff with different geological properties were selected. Sandstone and tuff samples were collected from different regions. Various tests were then carried out on prepared rock specimens to determine the uniaxial compressive strength (UCS), tensile strength, longitudinal waves velocity, Schmidt hammer rebound hardness, and the equivalent quartz content (EQC). Two correlations were presented by analyzing the experimental results with the help of SPSS and Excel. The first correlation estimated the CAI of sandstone based on the UCS and EQC with a coefficient of determination (R^2) of 0.81. Moreover, using data analysis in Excel, another correlation was proposed to estimate the CAI of tuff. The second correlation estimated the Schmidt hammer rebound hardness of tuff with an R^2 of 0.88.

Keywords: Sandstone, Tuff, Cerchar abrasivity index, Rock properties, Mechanized excavation.

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1- INTRODUCTION

Mechanized excavation technology has experienced great advances across the world and also in Iran in the past years, and multiple tunnels have been constructed or are under construction by this technology. Nowadays, this technology is favorably employed in tunneling projects in Iran, such that most long tunnels such as road tunnels, water transfer tunnels, highways, and subway tunnels have been constructed or are under construction by mechanized excavation methods.

Rock excavation tools (such as drilling bits and tunnel-boring machines (TBM) disc cutters) have been widely used in drilling operation and in the construction of modern tunneling and underground spaces [1-2]. The key parameters in TBM head design are head diameter, number of cutters, thrust force, rolling force, RPM, penetration depth, and cutter spacing [3].

Haeri et al. investigated the effect of the eroded disc on specific energy and the Mode I and Mode II stress intensity factors. The results showed that the amount of specific energy and the Mode I and Mode II stress intensity factors in the eroded disc is more than the non-eroded disc [3].

The effects of ground abrasion are not usually considered on the costs and scheduling of a tunneling project by design engineers. Abrasion effects are observed in the form of wear of tunnel boring machine (TBM) cutterheads and damages to this machinery in most tunneling projects around the world [4].

Wear of cutting tools is a very complex process so that its details are yet to be fully understood. These factors are dependent on the rock and geological conditions on the one hand, and machinery, including machines and more importantly excavation tools, on the other. The other important factor is the management of the construction process [5].

The most conventional methods for measuring and estimating abrasivity of rocks include [4]:

1. Cerchar abrasivity index (CAI) can be calculated from the Cerchar abrasivity test.
2. Vickers hardness number (VHN) can be calculated from the Vickers test.
3. LCPC abrasion index is calculated from the LCPC abrasion test.
4. Abrasion value of steel (AVS) is determined by the Norwegian University of Science and Technology (NTNU) abrasion test.

Cerchar abrasion test was first introduced by Cerchar Institute in France in 1980s. In this test, a 10-mm long scratch is created on the rock surface by a stylus made of vanadium-chromium steel alloy with a Rockwell hardness of 55 HRC. A 70 N force is applied on the stylus, and abrasivity is obtained by measuring the changes at the steel stylus tip. Cerchar abrasion test is performed on disc-shaped rock specimens or those without a certain geometry. The surface of rock specimens should be free of any fractures, and the rock should be placed on the horizontal clamp. A constant connection must be maintained between the steel stylus and the rock surface during Cerchar abrasion test, and the stylus should be re-sharpened after each test.

In this test, the steel stylus is fixed and the rock specimen moves for 10 s.

At the end of the test, the abrasivity of the steel stylus tip is measured in four different directions under a microscope with a magnification of 25X and an accuracy of 0.01 mm. CAI equals the arithmetic mean of the wear surface of the rock specimen measured at least 5 times [6] (Equation 1).

$$CAI = 10\frac{\sum_{i=1}^{n} d_c}{n} \tag{1}$$

Where:
n: represents the number of tests,
d_c: is the diameter of the wear of the steel stylus tip measured to an accuracy of 0.01 mm.

The CAI varies from 0.5 for soft rocks such as shale to 5 for hard rocks such as quartzite [7].

The literature on the estimation of CAI is reviewed in the following:

Daliormanli studied the effect of uniaxial compressive strength (UCS) and the direct shear strength (DSS) on the CAI. The uniaxial compressive strength and direct shear strength of 15 marble rock specimens were measured [8]. Equation 2 was presented with a correlation coefficient of 0.902.

$$CAI = 0.0410 + 0.0224 \times UCS - 0.0525 \times DSS \quad (2)$$

Where:
UCS and DSS: are in MPa [8].

Tripathy et al. proposed Equation 3 relating rock properties with the CAI. The rock samples of metamorphic and sedimentary origins were collected from different regions in India. In this equation, UCS (MPa), V_p (m/s) and E shows the modulus of elasticity (GPa) [9].

$$CAI = -0.05 + 0.03UCS - 8\times10^{-4}V_p + 0.08E \quad (3)$$

Moradizadeh et al. presented a correlation between the CAI and equivalent quartz content (EQC), point load index (I_{s50}), the second cycle slake durability index (I_{d2}), and porosity. A total of 36 rock samples with igneous, metamorphic, and sedimentary origins was tested and the experimental results were analyzed by univariate regression in SPSS. Equation 4, presented for all rock samples, shows the relationship between EQC and CAI [10].

$$CAI = 1.241 + 0.039EQC\% \ , \ R^2=0.77 \quad (4)$$

Ko et al. investigated the effect of rock properties such as the quartz content, uniaxial compressive strength, Brazilian tensile strength, and brittleness coefficient on the CAI. They proposed three correlations for igneous rocks (one of which is presented here in Equation 5) and three for metamorphic rocks (one presented here in Equation 6)

$$CAI = 2.6823 + 0.0192UCS - 0.1042B_3 \quad (5)$$

$$CAI = 1.607 + 0.00659UCS + 0.10618BTS \quad (6)$$

Where:
UCS (MPa), BTS (MPa), and B_3: represents brittleness index (MPa) [11].

Er and Tuğrul studied the samples collected from granite quarries in different parts of Turkey, particularly from the Marmara Region. First, petrographical, mineralogical and physical-mechanical characteristics of the collected granitic rocks were determined. Then, empirical relationships between these properties and CAI were determined using regression analysis method [12].

Capik and Yilmaz studied the effect of uniaxial compressive strength, point load index, Brazilian tensile strength, Schmidt hammer rebound hardness, and equivalent quartz content on the CAI [13]. A total of 43 rock samples collected from Cankurtaran and Salmankas tunnels in Turkey was tested. The relationship of CAI with the uniaxial compressive strength, point load index, tensile strength, Schmidt hammer (types N and L) rebound hardness, and equivalent quartz content was obtained by analyzing the results in SPSS, and Equations 7 to 11 were derived as follows:

$$CAI = 0.0189\sigma_c + 0.177 \ , \ R^2 = 0.75 \quad (7)$$

Where:
σ_c: is in terms of MPa.

$$CAI = 0.2393I_{s50} + 0.3446 \ , \ R^2 =0.68 \quad (8)$$

I_{s50} shows the point load index in terms of MPa.

$$CAI = 0.0811R_L-2.3246 \ , \ R^2 = 0.67 \quad (9)$$

$$CAI = 0.0787R_N - 2.1913 \ , \ R^2 = 0.71 \quad (10)$$

Where:
R_L and R_N: respectively show the Schmidt hammer rebound hardness for the hammer types L and N [13].

$$CAI = 0.0644EQC\% + 0.5485 \ , \ R^2 = 0.59 \quad (11)$$

Ozdogan et al. proposed a correlation for estimating the CAI of building rocks. One of the correlations estimates the CAI based on the Shore hardness, porosity, and the uniaxial compressive strength [14].

Kadkhodaei and Ghasemi estimated the CAI by gene expression programming. The CAI was estimated with the help of the rock abrasivity index (RAI) and Brazilian tensile strength of the collected rock samples [15].

According to the literature, a few correlations have been proposed for estimating the CAI for a collection of rocks with different origins. While in this study, two correlations are presented for estimating the CAI based on the properties of sandstone and tuff. Sandstone and tuff are found across Iran and thus were selected for this purpose.

Prior to statistical analysis, based on previous research, equivalent quartz content, longitudinal waves velocity, uniaxial compressive strength and Brazilian tensile strength were selected as input parameters to estimate Cerchar abrasivity index. The following tests are designed to obtain parameters that can play a role in the proposed correlation.

2- EQUIVALENT QUARTZ CONTENT

Different types of sandstone and tuff with different geological properties were selected to obtain reliable comprehensive results. The sandstone and tuff samples were collected from 12 and 10 regions, respectively. The equivalent quartz content was determined by analyzing thin sections of rock samples under a microscope. After preparing thin cross-sections, mineralogical studies were carried out by using a polarized light microscope to determine the percentage of constituting minerals of rock samples. The images of thin cross-sections were captured by a 5X lens with a magnification of 50X. The Rosiwal abrasiveness of minerals is calculated from Equation 12. The equivalent quartz content (EQC) of rock samples is then calculated from Equation 13 [16]:

$$Y = 2.12 + 1.05 \ln X \quad (12)$$

Where:

Y and X: respectively represent the Mohs hardness and Rosiwal abrasiveness of minerals.

$$EQC = \sum_{i=1}^{n} A_i X_i \quad (13)$$

Where:

EQC: represents the equivalent quartz content,

A_i: the frequency percentage of each mineral,

X_i(%): is the Rosiwal abrasiveness of minerals.

Table 1 shows the EQC of sandstone and tuff samples.

Table 1. The EQC of sandstone and tuff samples

Region number/Type of rock	EQC(%)
1/sandstone	30.66
2/sandstone	65.56
3/sandstone	37.40
4/sandstone	33.85
5/sandstone	58.98
6/sandstone	58.98
7/sandstone	72.24
8/sandstone	77.50
9/sandstone	79.36
10/sandstone	84.25
11/sandstone	89.70
12/sandstone	89.69
1/tuff	46
2/tuff	15.55
3/tuff	20
4/tuff	22
5/tuff	40
6/tuff	42
7/tuff	17.5
8/tuff	34
9/tuff	35.5
10/tuff	31.8

3- LONGITUDINAL WAVES VELOCITY

To determine the longitudinal waves velocity, the location of transducers on the end surfaces of the cylindrical specimen is marked in such a way that the deviation of the line connecting the center of transducers remains smaller than 2° from the centerline of the cylindrical specimen. The wave motion distance, i.e. the center-to-center distance of transducers, is then measured. A thin gel layer is applied where transducers are installed to avoid the reduction of energy transmitting through transducers. Transducers are installed at the previously marked locations, and the receiver is pressed to the specimen with a pressure of 10 N/cm^2 and the wave transmission time is read. The longitudinal waves velocity is calculated from Equation 14:

$$Vp = \frac{L}{T} \quad (14)$$

Where:

Vp: represents the longitudinal waves velocity (m/s),

L: the length of the cylindrical specimen (mm),

T: is the longitudinal wave transmission time (μs).

Five tests were performed on the samples collected from each region according to the ISRM standard [17]. Table 2 shows the average longitudinal waves Velocity in sandstone and tuff samples in each region.

Table 2. The longitudinal waves velocity of sandstone and tuff samples

Region number/Type of rock	Longitudinal waves (m/s) velocity
1/sandstone	3341
2/sandstone	4810
3/sandstone	2580
4/sandstone	2412
5/sandstone	3409
6/sandstone	4069
7/sandstone	3786
8/sandstone	2290
9/sandstone	5850
10/sandstone	2640
11/sandstone	4850
12/sandstone	6640
1/tuff	3545
2/tuff	3272
3/tuff	4371
4/tuff	4319
5/tuff	4103
6/tuff	4041
7/tuff	4303
8/tuff	2580
9/tuff	4750
10/tuff	4950

4- UNIAXIAL COMPRESSIVE STRENGTH

The uniaxial compressive strength is calculated based on the ISRM standard [17] by dividing the load at failure by the initial cross-sectional area (Equation 15):

$$\sigma_C = \frac{F}{A} \tag{15}$$

Where:

σ_C, F, and A: respectively represent the uniaxial compressive strength, the maximum load, and the initial cross-sectional area of rock specimens.

Five tests were conducted on the rock specimens collected from each region. Table 3 shows the average uniaxial compressive strength of sandstone and tuff collected from different regions.

Table 3. The uniaxial compressive strength of sandstone and tuff specimens

Region number/Type of rock	Uniaxial (MPa) compressive strength
1/sandstone	57.44
2/sandstone	84.18
3/sandstone	31.67
4/sandstone	42.59
5/sandstone	58.65
6/sandstone	100.19
7/sandstone	39.80
8/sandstone	41.50
9/sandstone	127.60
10/sandstone	26.73
11/sandstone	109.70
12/sandstone	61.50
1/tuff	105
2/tuff	143
3/tuff	170
4/tuff	222
5/tuff	210
6/tuff	132
7/tuff	140
8/tuff	35
9/tuff	180
10/tuff	215

5- BRAZILIAN TENSILE STRENGTH

In the Brazilian test, by applying a diagonal load on the cylindrical rock specimens, the tensile stress extends in the vertical direction on the loading axis, and the specimen eventually fails when the tensile stress exceeds its tensile strength. The tensile strength is calculated from Equation 16 based on the ISRM standard [17]:

$$\sigma_t = 0.636\frac{p}{Dt} \tag{16}$$

Where:
σ_t: represents the tensile strength (MPa),
P: the failure load (N),
D: diameter (mm),
t: is the thickness (mm).

Ten tests were conducted on the samples collected from each region. Table 4 shows the average Brazilian tensile strength of sandstone and tuff specimens collected from each region.

6- SCHMIDT HAMMER REBOUND HARDNESS

The Schmidt hammer rebound hardness test was conducted only on tuff samples based on the ISRM standard by the hammer type L [17]. Table 5 shows the average Schmidt hammer rebound hardness of tuff samples collected from different regions.

7- CERCHAR ABRASIVITY INDEX

Five tests were conducted on each specimen based on the ISRM standard [6]. The wear flatness of pin tips was determined following each 90˚ rotation and the average of four measurements was determined. The resulting number was multiplied by 10 and considered the CAI at each test.

Table 6 shows the average of 5 tests for each specimen. Figure 1 shows the used CAI apparatus. Some of the sandstone and tuff specimens are shown in Figures 2 and 3, respectively. Figure 4 shows a specimen after the two tests and Figure 5 displays the microscopic image of a pin.

The study of pins under a microscope was performed in the mechanized excavation laboratory of Tarbiat Modares University.

Table 4. The Brazilian tensile strength of sandstone and tuff specimens

Region number/type of rock	Brazilian tensile (MPa) strength
1/sandstone	4.64
2/sandstone	13.18
3/sandstone	1.65
4/sandstone	2.61
5/sandstone	5.68
6/sandstone	9.46
7/sandstone	1.85
8/sandstone	0.48
9/sandstone	6.38
10/sandstone	1.45
11/sandstone	6.03
12/sandstone	7.32
1/tuff	10.7
2/tuff	14.60
3/tuff	21.15
4/tuff	16.55
5/tuff	17.93
6/tuff	14.17
7/tuff	18.15
8/tuff	5.7
9/tuff	15.1
10/tuff	15.7

Table 5. Schmidt hammer rebound hardness of tuff samples

Region number	Schmidt hammer rebound hardness
1	38.6
2	49.5
3	53.5
4	49.8
5	45.7
6	41.9
7	43.9
8	21.7
9	51
10	53.3

Table 6. The CAI of sandstone and tuff specimens

Region number/type of rock	CAI
1/sandstone	0.76
2/sandstone	1.43
3/sandstone	0.44
4/sandstone	0.65
5/sandstone	0.41
6/sandstone	1.39
7/sandstone	1.52
8/sandstone	0.71
9/sandstone	3.24
10/sandstone	1.05
11/sandstone	2.84
12/sandstone	1.67
1/tuff	1.62
2/tuff	2.21
3/tuff	1.65
4/tuff	1.83
5/tuff	1.44
6/tuff	1.57
7/tuff	1.66
8/tuff	0.35
9/tuff	2.58
10/tuff	2.77

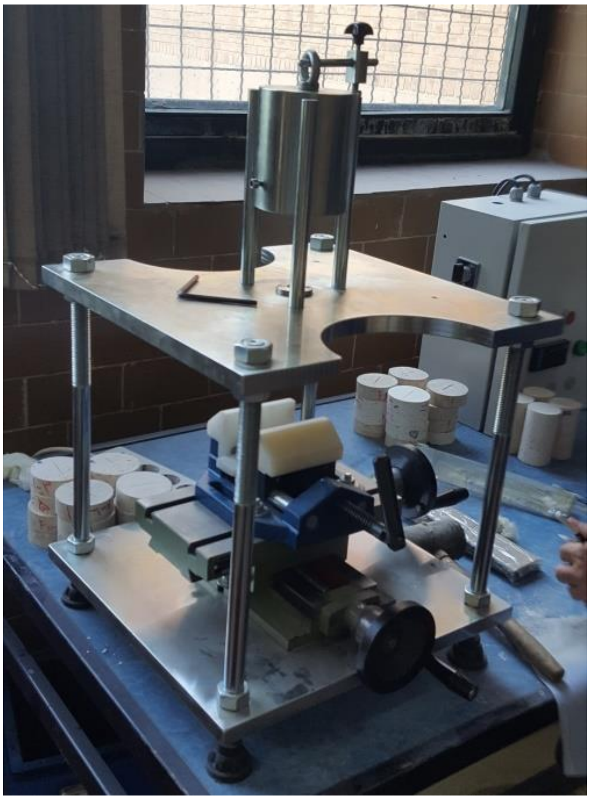


Figure 1. CAI apparatus at Rock Mechanics Lab, Imam Khomeini International University, Iran

Figure 2. A number of sandstone specimens

Figure 3. A number of tuff specimens

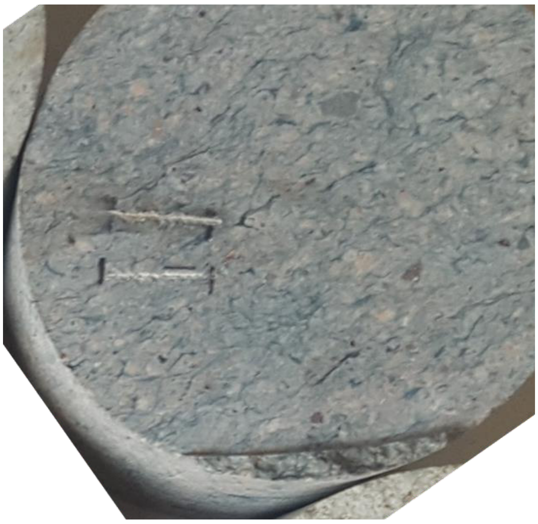


Figure 4. Two CAI tests on a tuff specimen (The Scratch directions are vertical to trace on cut surfaces.)

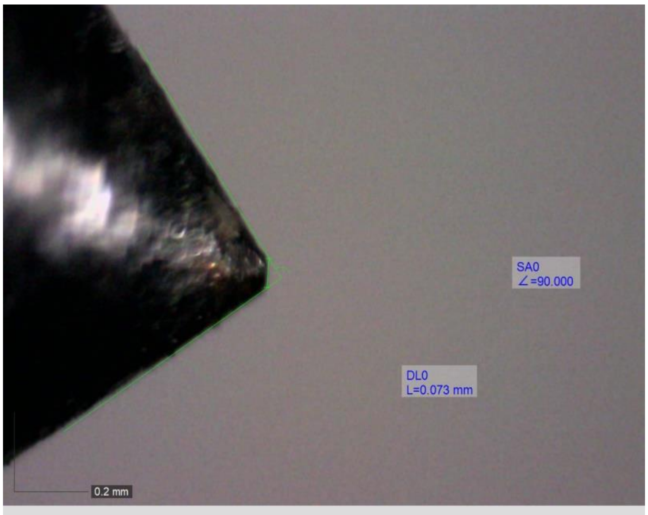


Figure 5. The microscope image of a pin (CAI=0.73, sandstone of region number 1, BTS=4.64 MPa and UCS=57.44 MPa)

8- STATISTICAL ANALYSIS

Experimental results were analyzed in SPSS and Excel softwares to obtain a correlation for estimating the CAI of sandstone samples. SPSS is among the oldest and most widely used software packages for statistical analysis. This software is used in various sciences including engineering disciplines for analyzing statistical data.

First, the relationship between Cerchar abrasivity index and other properties of sandstone and tuff is presented using univariate regression.

Figures 6 and 7 show the correlations between Cerchar abrasivity index with the equivalent quartz content, longitudinal waves velocity, Brazilian tensile strength and uniaxial compressive strength of sandstone and tuff specimens respectively.

Based on simple regression analysis and findings of literature survey the multiple linear regression was selected.

The statistical model used in this study aims at finding a relationship between the CAI and rock properties through multivariate linear regression. In general, multivariate regression can be expressed as follows:

$$Y = B_O + B_1X_1 + \ldots + B_iX_i + \varepsilon_i \tag{17}$$

Where:

Y: is the dependent variable,

ε_i: error,

X_i: independent variable,

B_O: the intercept of the regression equation,

i: the number of independent variables,

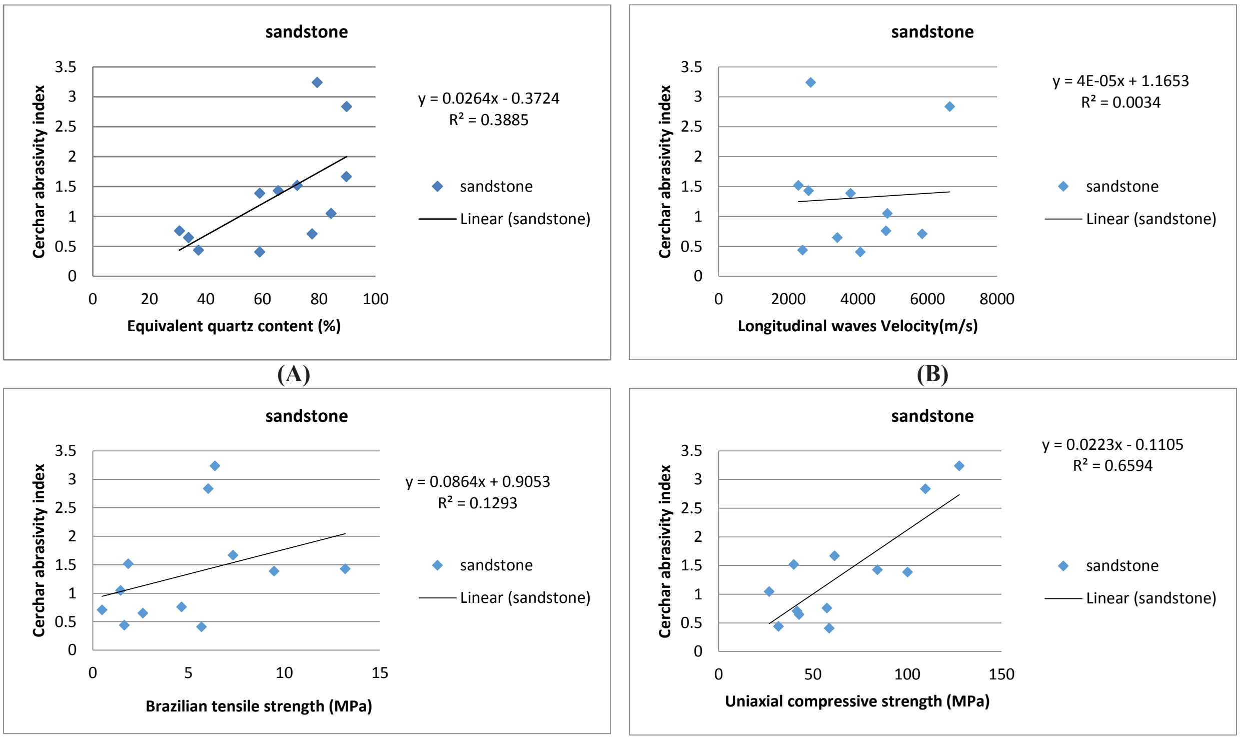
B_i: the slope of the regression equation [18].

First, the statistical analyses for deriving a relation for estimation of CAI of sandstone specimens are discussed.

For this purpose, the correlation between independent variables in the statistical model is investigated as the first step. In the case of a linear correlation between two variables, one of them can be used in statistical and regression analyses. The uniaxial compressive strength and the equivalent quartz content were used in this regard.

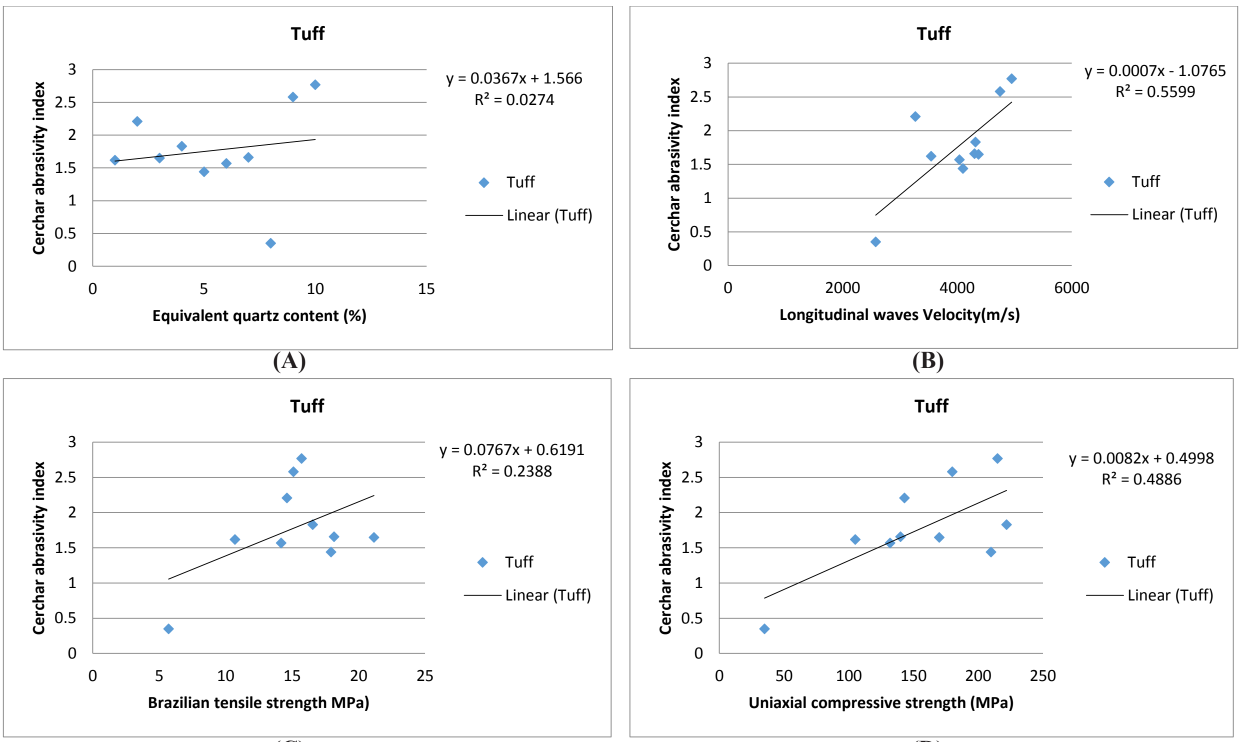
Table 7 summarizes the statistical model. The correlation coefficient of independent and dependent variables equals 0.9 with a coefficient of determination (R^2) of 0.81. In other words, independent variables explain 81% of variations in the dependent variable. This indicates that 81% of CAI variations can be predicted by this regression equation.

Table 8 shows the analysis of variance (ANOVA) for the CAI of sandstone specimens in this model.



(C) (D)

Figure 6: The correlations between Cerchar abrasivity index with A: the equivalent quartz content, B: longitudinal waves velocity, C: Brazilian tensile strength and D: uniaxial compressive strength of sandstone



(C) (D)

Figure 7: The correlations between Cerchar abrasivity index with A: the equivalent quartz content, B: longitudinal waves velocity, C: Brazilian tensile strength and D: uniaxial compressive strength of tuff

The F test is confirmed since the significance level of this model (0.001) is less than 0.05, and the statistical model can be used for linear regression.

The table of coefficients shows the main output of the regression test. The coefficient for each variable is shown by B. Table 9 lists the regression coefficients of the statistical model. Only variables with a significance level less than 0.05 can be used in the regression equation [18].

Equation 18 was obtained from this model for estimating the CAI of sandstone specimens:

$$CAI = -1.005 + 0.019(UCS) + 0.017(EQC) \quad (18)$$

The most important tests for controlling the regression equation include [18]:

1. Distribution of residuals should be normal.

The normal distribution of residuals is controlled by the Kolmogorov-Smirnov and Shapiro-Wilk tests and diagrams.

Given that the significance level for the Kolmogorov-Smirnov and Shapiro-Wilk tests is greater than 0.05, the normal distribution of residuals for the CAI in this model is confirmed (Table 10).

The histogram of residuals for the CAI (Figure 8) shows the normal distribution of residuals in this model.

As seen in Figure 9, the residuals are scattered around a straight line, indicating the normal distribution of residuals.

Table 7. A summary of the statistical model for the CAI of sandstone specimen

Model Summary[b]					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.900[a]	0.810	0.768	0.43546	2.563

a. Predictors: (Constant), EQC, UCS
b. Dependent Variable: CAI

Table 8. Analysis of variance (ANOVA) for the CAI of sandstone specimens

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.274	2	3.637	19.179	0.001[b]
	Residual	1.707	9	0.190		
	Total	8.980	11			

a. Dependent Variable: CAI
b. Predictors: (Constant), EQC, UCS

Table 9. Regression coefficients for the CAI of sandstone specimens

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.005	0.442		-2.272	0.049
	UCS	0.019	0.004	0.684	4.468	0.002
	EQC	0.017	0.006	0.409	2.670	0.026

a. Dependent Variable: CAI

2. The average of residuals should be zero.

Table 11 shows the average residuals for this model. As seen, the average of residuals is zero in this model, indicating the accuracy of the regression equation.

The statistical analysis of experimental results (based on EQC, Vp, BTS and UCS) for tuff was carried based on multivariate regression correlation. The results showed regression coefficients of all variables for the estimating CAI of tuff specimens had a significance level with P

Table 10. Normal distribution of residuals

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
UCS	0.211	12	0.148	0.907	12	0.197
EQC	0.151	12	0.200*	0.901	12	0.162
CAI	0.192	12	0.200*	0.865	12	0.057

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

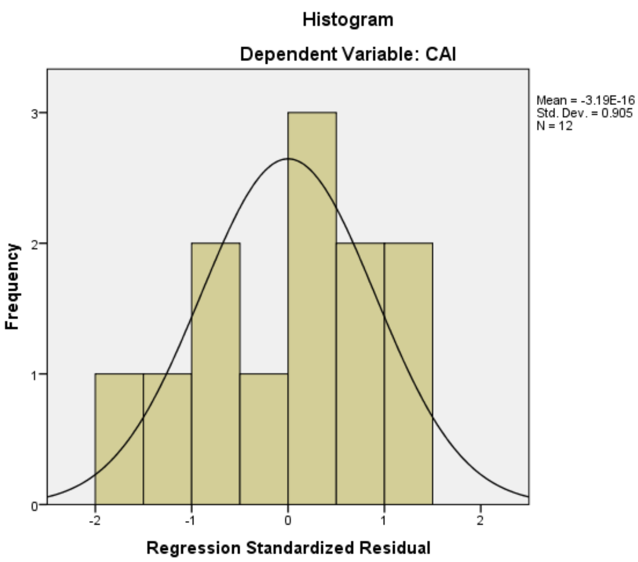


Figure 8. The residual histogram for the CAI

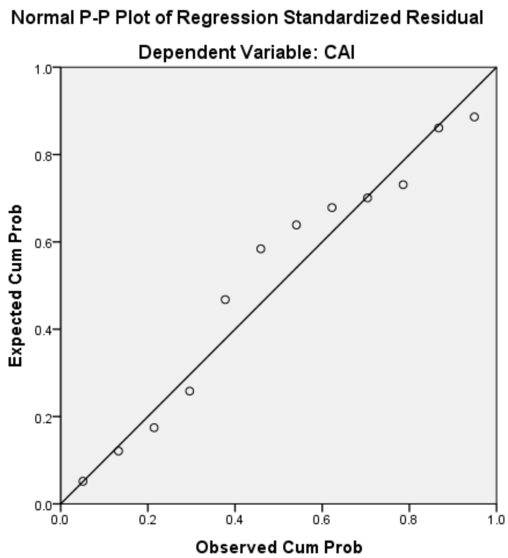


Figure 9. Residual normality test for the CAI

Table 11. Residuals

Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	0.2381	2.7677	1.3425	0.81317	12
Residual	-0.70906	0.52515	0.00000	0.39389	12
Std. Predicted Value	-1.358	1.753	0.000	1.000	12
Std. Residual	-1.628	1.206	0.000	0.905	12

a. Dependent Variable: CAI

values more than 0.05. Therefore, a valid model cannot be obtained.

In order to obtain an equation with high coefficient of determination using univariate regression, Schmidt hammer rebound hardness was used (Equation 19). As can be seen, the coefficient of determination between CAI and Schmidt hammer rebound hardness is much higher than the coefficient of determination between CAI and UCS.

Figure 10 displays the CAI as a function of the Schmidt hammer rebound hardness.

$$CAI = 0.0008.\ R_L^{2.0205}\ ,\ R^2=0.88 \qquad (19)$$

9- DISCUSSION

Figures 6 and 7 show that as the equivalent quartz content, longitudinal waves velocity, Brazilian tensile strength and uniaxial compressive strength increase, Cerchar abrasivity index increases. The correlation coefficient in the sandstone is low. The correlation results of index with equivalent quartz content, longitudinal waves velocity, Brazilian tensile Cerchar abrasivity strength and uniaxial compressive strength is consistent with Er and Tuğrul's research [12]. The results of Er and Tuğrul research show that Cerchar abrasivity index has a direct linear relationship with the mentioned properties.

Gharahbagh et al. [19] investigated correlation between Cerchar abrasivity index with rock properties. These researchers presented an equation using multivariate linear regression.

$$CAI = -0.127+ 0.0148\ (UCS) + 0.0411\ (EQC)\% \qquad (20)$$

This equation (Equation 20) is a linear equation. Cerchar abrasivity index is also directly related to equivalent quartz content and uniaxial compressive strength.

10- CONCLUSION

Some correlations were proposed for estimating the CAI of sandstone and tuff using their physical and mechanical properties. In order to presenting correlations, the equivalent quartz content, the longitudinal waves velocity, the uniaxial compressive strength, the Brazilian tensile strength, the Schmidt hammer rebound hardness, and Cerchar abrasivity index of rock specimens were also determined. A correlation was proposed for determining the CAI through statistical analysis of experimental results in SPSS. This correlation estimated the CAI of sandstone based on the uniaxial compressive strength and EQC with a coefficient of determination of 0.81. Statistical analyses of experimental results for tuff samples did not lead to a valid multivariate regression correlation. A univariate correlation was obtained for estimating the CAI of tuff samples by analyzing data in Excel. The resulting

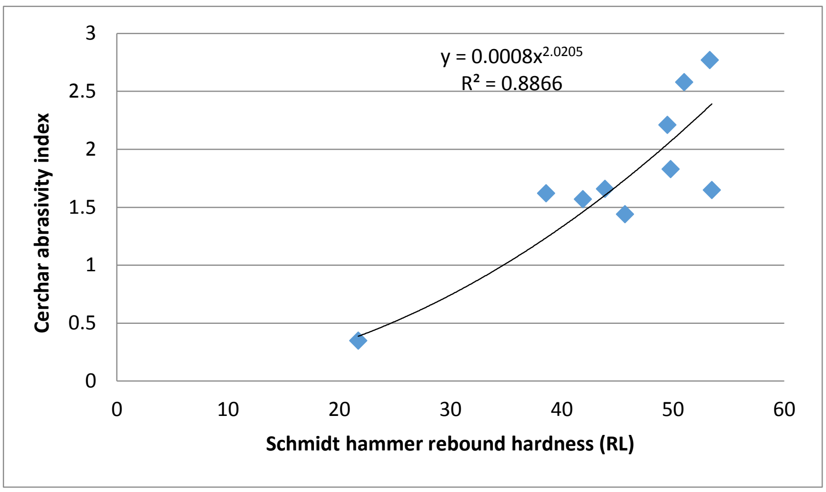


Figure 10: CAI as a function of Schmidt hammer rebound hardness

correlation estimated the CAI of tuff samples based on the Schmidt hammer rebound hardness with a coefficient of determination of 0.88.

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12- REFERENCES

[1] Marji, M. F. (2015). *"Simulation of crack coalescence mechanism underneath single and double disc cutters by higher order displacement discontinuity method"*. Journal of Central South University, 22(3): 1045-1054.

[2] Haeri, H., and Marji, M. F. (2016). *"Simulating the crack propagation and cracks coalescence underneath TBM disc cutters"*. Arabian Journal of Geosciences, 9(2): 124.

[3] Haeri, H., Shahriar, K., Marji, M. F., and Moarefvand, P. (2013). *"Simulating the bluntness of TBM disc cutters in rocks using displacement discontinuity method"*. In Proceedings of 13th International Conference on Fracture, China.

[4] Nilsen, B., Dahl, F., Holzhäuser, J., and Raleigh, P. (2007, June). *"New test methodology for estimating the abrasiveness of soils for TBM tunneling"*. In Proceedings of the Rapid Excavation and Tunneling Conference (RETC), 104-106.

[5] Thuro, K., and Käsling, H. (2009). *"Classification of the abrasiveness of soil and rock"*. Geomechanics and Tunneling, 2(2): 179-188. DOI:10.1002/geot.200900012.

[6] Alber, M., Yaralı, O., Dahl, F., Bruland, A., Käsling, H., Michalakopoulos, T. N., and Özarslan, A. (2013). *"ISRM suggested method for determining the abrasivity of rock by the CERCHAR abrasivity test"*. In The ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 2007-2014, Springer International Publishing, 101-106. DOI: 10.1007/978-3-319-07713-0_7.

[7] Plinninger, R. J., and Restner, U. (2008). *"Abrasiveness testing, quo vadis?–a commented overview of abrasiveness testing methods"*. Geomechanik und Tunnelbau: Geomechanik und Tunnelbau, 1(1): 61-70. DOI: 10.1002/geot.200800007.

[8] Deliormanlı, A. H. (2012). *"Cerchar abrasivity index (CAI) and its relation to strength and abrasion test methods for marble stones"*. Construction and Building Materials, 30: 16-21. DOI: 10.1016/j.conbuildmat.2011.11.023.

[9] Tripathy, A., Singh, T. N., and Kundu, J. (2015). *"Prediction of abrasiveness index of some Indian rocks using soft computing methods"*. Measurement, 68: 302-309. DOI: 10.1016/j.measurement.2015.03.009.

[10] Moradizadeh, M., Cheshomi, A., Ghafoori, M. and TrighAzali, S. (2016) *"Correlation of equivalent quartz content, Slake durability index and Is50 with Cerchar abrasiveness index for different types of rock"*. International Journal of Rock Mechanics & Mining Sciences, 86: 42-47.

[11] Ko, T. Y., Kim, T. K., Son, Y., and Jeon, S. (2016). *"Effect of geomechanical properties on Cerchar Abrasivity Index (CAI)"*. Tunnelling and Space Technology, 57: 99-111. DOI: 10.1016/j.tust.2016.02.006.

[12] Er, S., and Tuğrul, A. (2016). *"Correlation of physico-mechanical properties of granitic rocks with Cerchar Abrasivity Index in Turkey"*.Measurement,91: 114-123.

[13] Capik, M., and Yilmaz, O. (2017). *"Correlation between Cerchar abrasivity index, rock properties, and drill bit lifetime"*. Arabian Journal of Geosciences, 10: 15. DOI: 10.1007/s12517-016-2798-7.

[14] Ozdogan, M. V., Deliormanli, A. H., and Yenice, H. (2018). *"The correlations between the Cerchar abrasivity index and the geomechanical properties of building stones"*. Arabian Journal of Geosciences, 11(20): 604.

[15] Kadkhodaei, M. H., and Ghasemi, E. (2019). *"Development of a GEP model to assess CERCHAR abrasivity index of rocks based on geomechanical properties"*. Journal of Mining and Environment, 10(4): 917-928. DOI: 10.22044/JME.2019.8141.1684.

[16] Thuro, K. (1997). *"Drillability predictiongeological influence in hard rock drill and blasttunneling"*. Geologische Rundschau, 86(2): 426-438. DOI: 10.1007/s005310050.

[17] Ulusay, R., and Hudson, J. A. (2007). *"The complete ISRM suggested methods for rock characterization, testing and monitoring"*. ISRM Turkish National Group, Ankara, Turkey.

[18] Esmaelian, M., and Rabie, M. (2015). "*SPSS Comprehensive Manual"*. Dibaragan Artistic and Cultural Institute Publications.

[19] Gharahbagh, A. E., Rostami, J., Ghasemi, A. R., and Tonon, F. (2011). *"Review of rock abrasion testing"*. In: 45th US Rock Mechanics/Geomechanics Symposium, American Rock Mechanics Association.

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علمی-پژوهشی

همبستگی بین اندیس سایندگی سرشار با خواص سنگ در نمونه‌های ماسه‌سنگ و توف

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چکیده

در مراحل مقدماتی یک پروژه تونلسازی دانستن میزان سایندگی مصالح برای انتخاب یک روش حفاری مقرون به صرفه بسیار تاثیرگذار است. در این پژوهش روابطی برای تخمین سایندگی سرشار ماسه‌سنگ و توف ارایه شد. برای این منظور انواع ماسه‌سنگ و توف با ویژگی‌های زمین‌شناسی گوناگون انتخاب شده است تا نتایج جامع و قابل استناد به دست آید. پس از جمع‌آوری نمونه‌های ماسه‌سنگ و توف از نقاط مختلف و آماده‌سازی آن‌ها، آزمایش‌های گوناگونی برای تعیین مقاومت فشاری تک محوری، مقاومت کششی، سرعت امواج طولی، سختی واجهشی چکش اشمیت و محتوای کوارتز معادل انجام شد، سپس با توجه به نتایج حاصل از آزمایش‌ها با استفاده از نرم‌افزار آماری SPSS و Excel دو رابطه ارایه شد. اولین رابطه بر اساس مقاومت فشاری تک محوری و میزان کوارتز معادل با ضریب تعیین ۰٫۸۱ شاخص سایندگی سرشار ماسه‌سنگ را تخمین می‌زند. برای تخمین شاخص سایندگی سرشار توف رابطه‌ای بر اساس تحلیل داده‌ها به کمک نرم‌افزار اکسل ارایه شد. این رابطه بر اساس سختی واجهشی چکش اشمیت با ضریب تعیین ۰٫۸۸ شاخص سایندگی توف را تخمین می‌زند.

کلمات کلیدی

ماسه‌سنگ، توف، شاخص سایندگی سرشار، خواص سنگ، سایندگی.

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