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# Utilizing Geological Properties for Predicting Cerchar Abrasiveness Index (CAI) in Sandstones

Masih Moradizadeh[1], Mohammad Ghafoori[2], Gholamreza Lashkaripour[3], Sadegh Tarigh Azali[3]
*[1]Msc student of Ferdowsi University of Mashhad*
*[2,3]Professor, Ferdowsi University of Mashhad*
*[4]phD Student, Ferdowsi University of Mashhad*

***Abstract*--Underground excavations in rock are manufactured either by drilling and blasting or by mechanical methods using roadheaders or tunnel boring machines (TBMs). Both methods employ tools which interact with the rock and this interaction leads to the fragmentation of the rock as well as to the wear of the tools. Wear may be defined as the loss of tool material while interacting with the rock. Cerchar abrasiveness test is widely used to assess the abrasiveness of rock to predict of rock cutting tool wear because it provides good information on the abrasiveness with quick and easy testing procedure. Various parameters may affect Cerchar abrasiveness index (CAI), for example, surface condition of rock, mineral contents of rock, etc. In this paper, the relations between geological properties of rock and CAI were examined for several different sandstones. The derivation of some predictive models for the engineering geological properties of sedimentary rocks will be useful due to the fact that the preparation of specimens from the rocks in depth is usually difficult and expensive in preliminary design of underground projects. To develop some predictive models for the CAI from the indirect methods including the quartz content, the cement ,grain content, EQC(Equivalent Quartz Content), $Is_{50}$ (The size-corrected Point Load Strength Index) , $Id_2$ (Slake Durability Index )and W% (Moisture content),regression analysis were applied on the data pertaining to sandstone rocks from Iran. The grain content was included to the best regression model for the prediction of CAI. It was concluded that the quartz content, the cement content, grain content, EQC, $Is_{50}$, $Id_2$ and W% are the useful physical and mechanical properties for the prediction of CAI of sandstones.**

***Keyword*-- Abrasiveness, CAI, CERCHAR test, EQC, Sandstone, TBM**

## I. INTRODUCTION

Abrasiveness of rocks is a factor that has essential impacts on abrasion and corrosion of the excavation tools. Excavation tools wear and abrasion are not only the important factors in controlling the amount of advance and excavation, but also an indispensable index in evaluating of excavation ability of an earth in tunneling projects. The primary issue concerning the cutting tools of rocks and their abrasion considers an unidentified interaction between cutting tools, excavation, geological features, kinds of rocks, and their petrography.

Cutting tools will be used excessively in case information about the abrasion of rocks is not capable of appraising the precise amount of tool abrasion, and this leads to a waste of budget and a growing economic pressure, especially in projects such as tunnelling (Yarali and et al., 2008).

CECHAR, as one of the tests for accessing the abrasiveness of different kinds of rocks, indicates the amount of abrasiveness using the Cerchar Abrasiveness Index (CAI). Because of being simple and quick and application on small-size rock samples, Cerchar test is a highly cited method (Plinninger and Restner 2008). The principles of this test were described in France in 1980 (Suana and Peters 1982). Afterwards many researchers have studied the geological impacts of rocks and their petrography as well as the effects of physical and mechanical properties of rock on the amount of abrasion (Plinninger and Restner 2008).

Rock abrasiveness is a function of quartz content and other abrasive minerals. Quartz Content is one of the important parameters of abrasivity (West 1989). Furthermore, it is approved that the effect of rock strength is less than its petrographic parameter (Yaral, 2005), because rocks with higher strength may have a lower quartz content (Schimazek and Knat 1970). However recent researches show that the amount of rock strength and its abrasivity are effective on CAI value (Deliormanl, 2011; Waller and Al-Ameen,1994).

Alber (2007) studied the stress dependency of CAI and its effects on wear of the selected rock cutting tools; and Lassing et al., (2008) studied the impact of the size of grains on CAI. Mcfeact-Smith (1977) indicated that in sedimentary rocks –especially siliciclastic sedimentary rocks the abrasivity depends on cementation degree of rocks. Suana and Peters (1982) introduced quartz as an index in calibration of boring machines and an essential factor in abrasivity. Yarali (2008) studied siliciclastic sedimentary rocks and suggested a group of factors such as mineralogy of rocks, cement type, cementation degree, quartz content and the average grain sizes of quartz that affect the amount of CAI value. In siliciclastic sedimentary rocks (especially sandstones) their petrography with regard to source grains (quartz, feldspar, and etc.) and cement lead to different amounts of abrasion.

## II. METHODOLOGY

In this paper, to investigate the correlation between CAI and physical and mechanical properties parameters, we have sampled the quartz content, cement rate, amount of grains, information obtained through Cerchar and petrographic analysis of rocks of thin section. For each Cerchar test, we have also determined the following factors: a petrographic analysis of that rock, Equivalent Quartz Content (EQC), the size-corrected Point Load Strength Index ($Is_{50}$), Slake Durability Index ($Id_2$) and the amount of moisture content.

### *A. Laboratory Tests*

In order to determine the mineralogical properties of sampled sandstones, we started both microscopic researches upon rocks in thin section and the Cerchar test upon 10 siliciclastic sedimentary rocks where sampled from Isfahan and Mashhad area. We also arranged point load test and Slake Durability test to determine the $Is_{50,}$ $Id_2$ and moisture content. Additionally, using the petrographic analysis, we measured EQC, and then we used SPSS to analyze and process the data and information obtained from the tests.

### *B. The Cerchar Testing*

In the French AFNOR (NF 904-430-1) standard, the Cerchar testing is explained; similarly, in ASTM (D7625-10) standard, the method of testing Cerchar, producing pin and measuring the amount of CAI is elaborated and to some extent this method is improved. The experiment consists of a steel pin with defined quality and geometry scratching 10 mm of a rough rock at a 70 (N) static load and 1 mm/s speed (Plinninger and Restner 2008.

**Figure (1) Stages of sampling and Cerchar test.**

### *C. Petrographic Analysis*

Petrographic analysis is obtained in Rosiwal and Modal methods using optical microscope and mechanical stage (Esper et al., 1935; Chayes 1949).

The content of quartz and other minerals is determined using microscopic studies, so that the mineral amount ($A_i$) (in 100 % of quartz) is multiplied with Rosiwal abrasiveness ($R_i$) (in a 100% of quartz), and at last they are added n times, while *n* is the total number of minerals (Thuro 1997).

Therefore, EQC is measured through the following equation:

$$EQC = \sum_{i=1}^{n} Ai.Ri(\%)$$

Using figure (2), when we know the Mohs hardness, the abrasiveness of minerals can be obtained
.

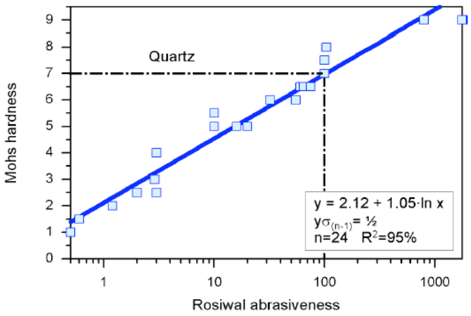

**Figure (2): Estimating Rosiwal Abrasiveness by Mohs hardness**

In fact, EQC equals the abrasivity of different kinds of minerals. When the EQC equals 0, the CAI must equal 0 too. To arrange the petrographic testing, we have collected sandstone samples from different sites, which their position is shown in Table (1). The results concerning the laboratory testing and petrographic analysis are shown in Table (2).

**Table 1**
**Sampling Sites position**

| Number Of Sample | Name Of Rock | Location | Longtitude | Latitude |
|---|---|---|---|---|
| 1 | sandstone | Dizlu | E51°58′ 15″ | N33°25′21″ |
| 2 | sandstone | Dizlu | E51°58′16″ | N33°25′22″ |
| 3 | sandstone | Dizlu | E51°58′17″ | N25°23′33″ |
| 4 | sandstone | Anarak | E53°42′09″ | N33°22′15″ |
| 5 | sandstone | Shorghestan | E51°39′38″ | N33°13′29″ |
| 6 | sandstone | Meymeh | E51°21′57″ | N33°11′30″ |
| 7 | sandstone | Esfahan | E51°41′23″ | N32°34′59″ |
| 8 | sandstone | Radkan | E59°01′54″ | N36°51′20″ |
| 9 | sandstone | Radkan | E59°01′55″ | N36°51′21″ |
| 10 | sandstone | Dizlu | E51°58′17″ | N25°23′33″ |

**Table2:**
**The mineralogy and petroghraphic analysis of collected samples,(Q:Quartz , Pi:Piroksen , Mus: Muscovite , Cal:Calcite, Ir:Vein Of Iron Oxide)**

| Number Of Sample | Q% | Pi% | Mos% | Cal% | Ir% | EQC% | CAI | Kind Of Cement | Cement% | Grain% |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 32 | 0 | 0 | 52.8 | 0 | 33.58 | 2.23 | Iron oxide | 13.8 | 86.2 |
| 2 | 87 | 0 | 1.6 | 0 | 2.2 | 87.16 | 4.10 | carbonate | 7.8 | 92.2 |
| 3 | 72 | 0 | 0 | 0 | 0.2 | 72.01 | 3.75 | Carbonate | 27.8 | 72.2 |
| 4 | 28 | 3.8 | 0 | 0 | 3 | 30.68 | 1.93 | Carbonate | 55.6 | 44.2 |
| 5 | 87.20 | 0 | 0 | 0 | 0 | 87.2 | 4.18 | Carbonate+Iron oxide | 6.8 | 93.2 |
| 6 | 73.60 | 0 | 0 | 0 | 0 | 73.6 | 3.78 | Carbonate+Iron oxide | 21 | 79 |
| 7 | 85 | 0 | 2 | 0 | 0 | 85.06 | 4.31 | Iron oxide | 1.6 | 98.4 |
| 8 | 50 | 0 | 0 | 0 | 0 | 50 | 2.05 | Iron oxide | 15.6 | 84.4 |
| 9 | 57 | 0 | 0 | 0 | 0 | 57 | 2.19 | Iron oxide | 25 | 75 |
| 10 | 63.4 | 0 | 0 | 0 | 0 | 63.4 | 2.93 | Carbonate | 36.6 | 63.4 |

### *D. Physical And Mechanical Testing*

Moisture content testing for all rocks is arranged based on the ASTM D2216-10 standard. For this testing, the results are represented in Table (3).

Just as the Point Load testing is arranged for cubic and cylindrical samples to determine $Is_{50}$ based on ASTM D5731-95-10, so the Slake Durability testing is arranged to determine $Id_2$ based on ASTM D4644-04. The results are presented in Table (3).

**Table3:**
**The point load, durability and moisture content testing results**

| Number Of Sample | $IS_{50}$(MPa) | $Id_{2\%}$ | W% |
|---|---|---|---|
| 1 | 7.98 | 99.46% | 2.12% |
| 2 | 11.78 | 99.72% | 0.75% |
| 3 | 10.95 | 99.76% | 0.88% |
| 4 | 2.3 | 92.74% | 4.39 |
| 5 | 10.67 | 99.90% | 1.2% |
| 5 | 10.80 | 99.76% | 1.63% |
| 7 | 12.42 | 99.88% | 0.51% |
| 8 | 4.97 | 99.21% | 2.94% |
| 9 | 4.76 | 99.05% | 4.23% |
| 10 | 9.36 | 99.69% | 0.14% |

## III. DATA ANALYSIS

### *Statistical Analysis*

In simple regression with the variables x and y, the following equation can be represented:

$$Y = A + Bx$$

In this equation A is y-intercept and the equation constant, B is the coefficient of x that is the slope or coefficient of the straight line. So x is the independent variable and y is the dependent variable. In simple regression, the correlation coefficient R approves the correlation between variables provided that its significance is below 0.05 and the coefficient of *F* is large enough. In multiple regression that is a flexible method, there are some factors such as y, $x_1$, $x_2$, $x_3$,…that are dependent to each other. This means that the dependent variable (y) depends on the independent variables ($x_1$, $x_2$, $x_3$, …).

$$Y = A + B_1X_1 + B_2X_2 + \cdots$$

The results of the analysis is approved through correlation coefficient (R, $R^2$, and Adjusted $R^2$). In fact, $R^2$ measures the level of predictability of independent variable based on the dependent variables.

The more the amount of $R^2$ is, the more successful and closer to reality the model would be, provided that its significance is below 0.05 and F is large enough (Cohen et al., 2003).

In fact, F and $R^2$ approve that the correlation is significant. Additionally, the original criterion is in choosing kinds of R and Adjusted $R^2$.

In this paper, according to the results obtained, first seven simple regressions are calculated to estimate the correlation between CAI and the percentage of quartz, percentage of cement, percentage of the entire grain size rocks, EQC, $Is_{50}$, $Id_2$ and w%. Afterwards two multiple linear regressions are calculated to estimate the correlation primarily between the CAI and the percentage of quartz, percentage of cement and percentage of the entire grain sizes, and secondarily between the CAI and EQC, $Is_{50}$, $Id_2$, w%. In fact, in the second multiple regression calculated, the EQC is a means of petrography in statistical evaluations. In simple regression, the Linear, Logarithmic, Inverse, Quadratic, Cubic and Exponential models are used. The model which has both a significance (sig) less than 0.05 and a larger coefficient Adjusted $R^2$ and F would be selected as the most appropriate model. In Table (5) the regression analysis results for seven independent variables (percentage of quartz, percentage of cement, percentage of the entire grain sizes, EQC, $Is_{50}$, $Id_2$, w%) correlated with the independent variable (CAI) is presented.

### *A. Simple Regression*

According to Table (4), the best model for Q is Cubic; for EQC, Exponential; for $Is_{50}$, Exponential; and for w%, Exponential. The Tables (5), (6), (7), and (8) consecutively show coefficient for each of the models mentioned. In addition, for the percentage of cement, grain size rocks and $Id_2$ variables, no special correlation was observed.

According to Table (5):$CAI=9.748-0.482Q+0.009Q^2-4.676E-005Q^3$

According to Table (6): $CAI= 1.178e^{0.015\ EQC}$

According to Table (7):$CAI=1.393\ e^{0.089\ Is50}$

According to Table (8):$CAI= 4/174-e^{-0.176\ w\%}$

**Table 4**
**Significant statistical coefficients for kinds of independent variables in simple regression**

| variables | coefficient | Linear | Logarithmic | Inverse | Quadratic | Cubic | Exponential |
|---|---|---|---|---|---|---|---|
| Quartz | $R^2$ | 0.859 | 0.765 | 0.647 | 0.916 | 0.964 | 0.862 |
| | Adjusted $R^2$ | 0.842 | 0.736 | 0.603 | 0.892 | 0.946 | 0.844 |
| | F | 48.828 | 26.044 | 14.667 | 38.074 | 53.267 | 49.773 |
| | Sig | 0.252 | .012 | 0 | 0.394 | 0.03 | 0 |
| Cement | $R^2$ | 0.34 | 0.406 | 0.283 | 0.363 | 0.524 | 0.323 |
| | Adjusted $R^2$ | 0.257 | 0.331 | 0.194 | 0.181 | 0.286 | 0.238 |
| | F | 4.14 | 0.5463 | 3.162 | 1.993 | 2.199 | 3.818 |
| | Sig | 0.077 | 0.048 | 0.113 | 0.630 | 0.204 | 0.086 |
| Grain | $R^2$ | 0.340 | 0.318 | 0.294 | 0.363 | 0.372 | 0.323 |
| | Adjusted $R^2$ | 0.257 | 0.233 | 0.206 | 0.181 | 0.193 | 0.238 |
| | F | 4.114 | 3.738 | 3.335 | 1.993 | 2.078 | 3.818 |
| | Sig | 0.803 | 0.219 | 0.105 | 0.797 | 0.843 | 0.086 |
| EQC | $R^2$ | 0.872 | 0.792 | 0.685 | 0.916 | 0.916 | 0.873 |
| | Adjusted $R^2$ | 0.856 | 0.766 | 0.646 | 0.892 | 0.892 | 0.857 |
| | F | 54.694 | 30.385 | 17.40 | 38.217 | 38.217 | 54.759 |
| | Sig | 0.385 | 0.007 | 0.003 | 0.493 | 0.493 | 0 |
| $Is_{50}$ | $R^2$ | 0.856 | 0.717 | 0.527 | 0.933 | 0.934 | 0.887 |
| | Adjusted $R^2$ | 0.838 | 0.683 | 0.467 | 0.914 | 0.901 | 0.873 |
| | F | 47.410 | 20.366 | 8.899 | 48.622 | 28.202 | 62.794 |
| | Sig | 0.032 | 0.951 | 0.018 | 0.255 | 0.782 | 0 |
| $Id_2$ | $R^2$ | 0.289 | 0.286 | 0.282 | 0.293 | 0.297 | 0.328 |
| | Adjusted $R^2$ | 0.201 | 0.197 | 0.193 | 0.205 | 0.209 | 0.244 |
| | F | 3.257 | 3.202 | 3.149 | 3.314 | 3.372 | 3.90 |
| | Sig | 0.156 | 0.121 | 0.114 | 0.213 | 0.282 | 0.822 |
| W% | $R^2$ | 0.614 | 0.318 | 0.021 | 0.615 | 0.859 | 0.659 |
| | Adjusted $R^2$ | 0.565 | 0.233 | -0.101 | 0.505 | 0.789 | 0.616 |
| | F | 12.709 | 3.734 | 0.172 | 5.592 | 12.201 | 15.442 |
| | Sig | 0.007 | 0.089 | 0.689 | 0.880 | 0.041 | 0.004 |

**Table 5**
**Coefficients for independent variable (*Q*), Cubic model in SPSS**

| | Unstandardized Coefficients | | Standardized coefficients | T | Sig |
|---|---|---|---|---|---|
| | B | Std.Error | Beta | | |
| Q | -.482 | .162 | -10.696 | -2.980 | .025 |
| Q ** 2 | .009 | .003 | 23.365 | 3.025 | .023 |
| Q ** 3 | -4.676E-005 | .000 | -11.925 | -2.821 | .030 |
| (Constant) | 9.748 | 2.704 | | 3.605 | .011 |

**Table 6**
**Coefficients for independent variable (EQC), Linear model in SPSS**

| | Unstandardized Coefficients | | Standardized Coefficients | T | Sig |
|---|---|---|---|---|---|
| | B | Std.Error | Beta | | |
| EQC | .015 | .002 | .934 | 7.400 | .000 |
| (Constant) | 1.178 | .156 | | 7.555 | .000 |

The dependent variable is In (CAI).

**Table 7**
**Coefficients for independent variable ($Is_{50}$), Exponential model in SPSS**

| | Unstandardized Coefficients | | Standardized Coefficients | T | Sig |
|---|---|---|---|---|---|
| | B | Std.Error | Beta | | |
| Is50 | .089 | .011 | .942 | 7.924 | .000 |
| (Constant) | 1.393 | .144 | | 9.645 | .000 |

The dependent variable is In (CAI).

**Table 8**
**Coefficients for independent variable (w%), Exponential model in SPSS**
**Coefficients**

| | Unstandardized Coefficients | | Standardized Coefficients | T | Sig |
|---|---|---|---|---|---|
| | B | Std.Error | Beta | | |
| W | -.176 | .045 | -.812 | -3.930 | .004 |
| (Constant) | 4.174 | .441 | | 9.456 | .000 |

The dependent variable is In (CAI).

Moreover, Figures (3), (4), (5), and (6) consecutively show CAI diagram against percentage of quartz, EQC, $Is_{50}$ and w%.

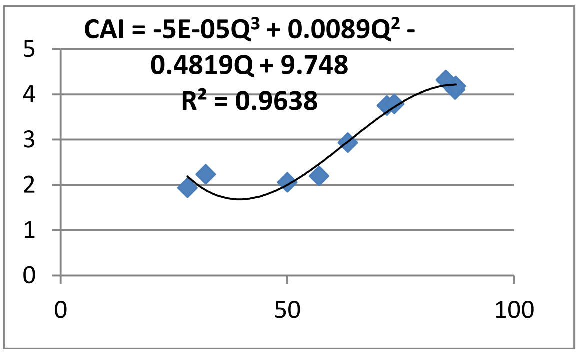

**Figure (3): the curve in cubic model for percentage of quartz and CAI, in which Adjusted $R^2$= 0.946**

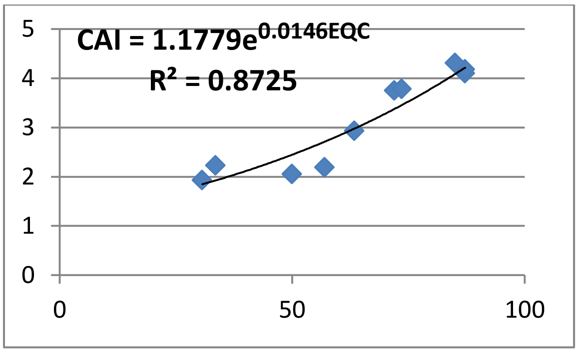

**Figure (4): the Curve in Exponential model for the independent variable (*EQC)* and *CAI*, in which Adjusted $R^2$ = 0.857**

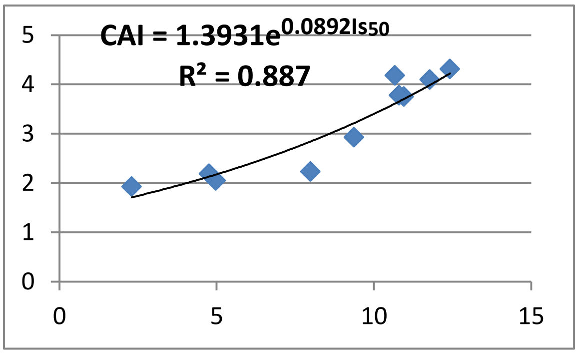

**Figure (5): the Curve in Exponential model for variables Is$_{50}$ and CAI, in which *Adjusted $R^2$ = 0.873***

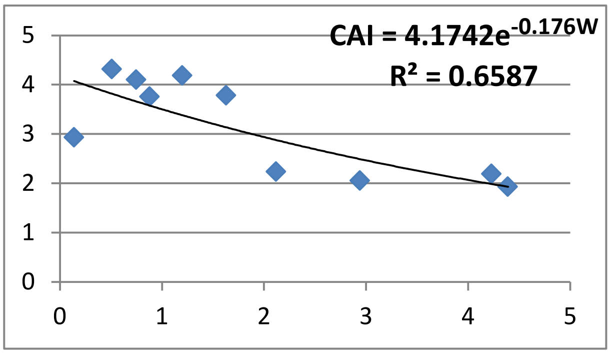

**Figure (6): the Curve in Exponential model for variables *w%* and CAI, in which: *Adjusted $R^2$= 0.616***

### *B. Multiple Regression Analysis*

Multiple linear regression analysis was calculated based on Stepwise method, which in the first analysis the dependent variable was CAI; and independent variables, percentage of quartz, percentage of cement and percentage of main grains. In this regression analysis, we have tried to investigate the dominant petrographic effects of sandstones on CAI.

This dominant petrography equals the percentage of quartz, percentage of cement upon percentage of its grains. Table (9) indicates this method. It shows that for this method, we have selected three models which we have consecutively entered Q, the percentage of cement, and the percentage of original grains for 1st, 2nd and 3rd models. According to Table (10), we observe that in 1st and 3rd model, the amount of $R^2$ and Adjusted $R^2$ is larger than their amount in other models. According to Table (11), the coefficient of F in the 1st and 3rd is larger than in other models, but in Table (12), Table for coefficients, the significance of y-intercept or the constant in all three models is more than 0.05, consequently, no significant correlation is observed in this method. Therefore, in the next regression analysis, we have used EQC as a substitute for petrography.

**Table 9**
**Entering data in the STEPWISE method.**
**Variables Entered /Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | Q[b] | . | Enter |
| 2 | Cement[b] | . | Enter |
| 3 | Grain[b] | . | Enter |

*a. Dependent Variable :CAI*
*b. All Requested Variables Entered.*

**Table 10**
**The Coefficient R For The Three Selected Models**

| Model | R | R Square | Adjusted R Square | Std.Error of the Estimate |
|---|---|---|---|---|
| 1 | .927[a] | .859 | .842 | .38857 |
| 2 | .927[b] | .859 | .819 | .41536 |
| 3 | .927[a] | .859 | .842 | .38857 |

*a. Predictors: (constant),Q*
*b. Predictors: (constant),Q , cement*

**Table 11**
**ANOVA coefficient for the three assumed models. (ANOVA)[a]**

| Model | | Sum Of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 7.37 | 1 | 7.37 | 48.82 | .000[b] |
| | Residual | 1.20 | 8 | .15 | | |
| | Total | 8.58 | 9 | | | |
| 2 | Regression | 7.37 | 2 | 3.68 | 21.36 | .001[c] |
| | Residual | 1.20 | 7 | .17 | | |
| | Total | 8.58 | 9 | | | |
| 3 | Regression | 7.37 | 1 | 7.37 | 48.82 | .000[b] |
| | Residual | 1.20 | 8 | .15 | | |
| | Total | 8.58 | 9 | | | |

*a. Dependent Variable: CAI*
*b. Predictors: (Constant),Q*
*c. Predictors: (Constant),Q*

**Table 12**
**Multiple Regression Coefficients For The Three Selected Models (Coefficients)[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | T | Sig |
|---|---|---|---|---|---|---|
| | | B | Std.Error | Beta | | |
| 1 | (Constant) | .492 | .399 | | 1.234 | .252 |
| | Q | .042 | .006 | .927 | 6.988 | .000 |
| 2 | (Constant) | .512 | .702 | | .730 | .489 |
| | Q | .042 | .008 | .923 | 5.084 | .001 |
| | cement | .000 | .011 | -.006 | -.036 | .973 |
| 3 | (Constant) | .492 | .399 | | 1.234 | .252 |
| | Q | .042 | .006 | .927 | 6.988 | .000 |

*a. Dependent Variable :CAI.*

In the second multiple regression analysis, we have predicted CAI based on the appearance of mechanical features in $Is_{50}$ and $Id_2$ templates; physical features in w% template; and petrographic features in EQC template. In this evaluation, CAI is the dependent variable, and EQC, $Is_{50}$ , $Id_2$ and w% are the independent variables. Table (13) shows that we have entered the EQC variable, then $Is_{50}$, then $Id_2$, and at last we have added w% to the model, warning that for w% , it is not considered an entering row, because it is not significantly correlated to other variables. In Table (17), the significance (sig) of coefficient for w% is more than 0.05, therefore it is automatically excluded from the models.

According to Table (14), Adjusted $R^2$ in the 3rd model equals 0.978 which is larger than its amount in other models. Moreover, according to Table (14), ANOVA coefficients, the coefficient of F in the 3rd model equals 137.465 which is larger than its amount in other models. According to Table (15) –the sig coefficients –among these three models, the 3rd model is the best and the most appropriate model, and accordingly we can obtain the following equation:

$CAI= 13/62+0/026EQC+0/194\ Is_{50}\ -0/139\ Id_2$

**Table 13**
**Entering data in STEPWISE method**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | $EQC^b$ | . | Enter |
| 2 | $Is_{50}{}^b$ | . | Enter |
| 3 | $Id_2{}^b$ | . | Enter |

*a. Dependent Variable :CAI*
*b. All Requested Variables Entered*

**Table 14**
**The coefficient *R* for the three selected models**
**Model Summary**

| Model | R | R Square | Adjusted R Square | Std.Error of the Estimate |
|---|---|---|---|---|
| 1 | .934[a] | .872 | .856 | .36995 |
| 2 | .970[b] | .940 | .923 | .27133 |
| 3 | .993[c] | .986 | .978 | .14321 |

*a. Predictors: (Constant),EQC*
*b. Predictors: (Constant),EQC , $Is_{50}$*
*c. Predictors: (Constant),EQC , $Is_{50}$,$Id_2$*

**Table 15**
**ANOVA coefficient for the three assumed models ANOVA[a]**

| Model | | Sum Of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 7.48 | 1 | 7.48 | 54.69 | .000[b] |
| | Residual | 1.09 | 8 | .13 | | |
| | Total | 8.58 | 9 | | | |
| 2 | Regression | 8.06 | 2 | 4.03 | 54.77 | .001[c] |
| | Residual | .51 | 7 | .07 | | |
| | Total | 8.58 | 9 | | | |
| 3 | Regression | 8.45 | 3 | 2.81 | 137.46 | .000[d] |
| | Residual | .12 | 6 | .02 | | |
| | Total | 8.58 | 9 | | | |

*a. Dependent variable:CAI*
*b. Predictors: (Constant),EQC*
*c. Predictors: (Constant),EQC, $Is_{50}$*
*d. Predictors: (Constant),EQC, $Is_{50}$,Id2*

**Table 16**
**Multiple Regression Coefficients For The Three Selected Models**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | T | Sig |
|---|---|---|---|---|---|---|
| | | B | Std.Error | Beta | | |
| 1 | (Constant) | .362 | .394 | | .919 | .385 |
| | EQC | .044 | .006 | .934 | 7.396 | .000 |
| 2 | (Constant) | .398 | .289 | | 1.375 | .211 |
| | EQC | .025 | .008 | .533 | 3.135 | .016 |
| | Is50 | .135 | .048 | .477 | 2.806 | .026 |
| 3 | (Constant) | 13.620 | 3.027 | | 4.500 | .004 |
| | EQC | .026 | .004 | .554 | 6.158 | .001 |
| | Is50 | .194 | .029 | .688 | 6.752 | .001 |
| | Id$_2$ | -.139 | .032 | -.313 | -4.374 | .005 |

*a. Dependent variable : CAI*

**Table 17**
**The excluded variables from the selected models**

| Model | | Beta In | T | Sig. | Partial Correlation | Collinearity Statistic |
|---|---|---|---|---|---|---|
| | | | | | | Tolerance |
| 1 | Is50 | .477$^b$ | 2.806 | .026 | .728 | .296 |
| | Id2 | -.085$^b$ | -.494 | .636 | -.184 | .603 |
| | w | -.246$^b$ | -1.473 | .184 | -.487 | .500 |
| 2 | Id2 | -.313$^c$ | -4.374 | .005 | -.872 | .468 |
| | w | .209$^c$ | .852 | .427 | .328 | .149 |
| 3 | w | .193$^d$ | 1.769 | .137 | .620 | .149 |

*a. dependent variable :CAI*
*b. Predictors: (Constant),EQC*
*c. Predictors: (Constant),EQC , Is*$_{50}$
*d. Predictors: (Constant),EQC , Is*$_{50,Id2}$

## IV. CONCLUSION

To estimate the amount of CAI of sandstones using all their features, two kinds of simple and multiple regression analyses are calculated. The best feature of sandstones in linear regression analysis of CAI is the percentage of quartz in rocks. Furthermore, w% which is a physical feature of sandstones, has the least amount of $R^2$ and Adjusted $R^2$ and is not an appropriate criterion for determining CAI.

Moreover, no special correlation was observed for the percentage of cement, percentage of grains of rocks and Id$_2$, consequently, these three variables are not appropriate factors for estimating CAI. According to multiple regression analysis, it was observed that the percentage of cement and grain rocks do not affect the amount of CAI, while an EQC template, show their effects.

Furthermore, EQC, $Is_{50}$ and $Id_2$ are good criterion for determining CAI in sandstones, therefore, adjusted $R^2$ equals 0.978 which is large. Lastly, w% is not correlated to other variables significantly to determine CAI.

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