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Evaluation brittleness indices of rocks, implication for estimating their toughness modulus

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Abstract

Brittleness and modulus of toughness are among the most important inherent properties of rock, which are determinative for rock excavation operations. In this study, mechanical properties of granite, granodiorite, dolomite, hornfels and marble have studied in the area of Glass water supply tunnel near the Naghadeh city (NW Iran). The stress-strain curve area and rocks strength properties have applied to calculate 13 brittleness indices and modulus of toughness. Statistic relationships between brittleness indices and toughness of modulus suggest strong correlation between B_3 brittleness index (R^2= 0.83 and RMSE= 5.46 coefficients) and B_4 brittleness index (R^2= 0.83 and RMSE= 3.85) respectively with modulus of toughness. The statistical relationship between modulus of toughness and specific energy indicates a strong correlation (R^2= 0.85). The modulus of toughness and specific energy are useful parameters for calculation rock cutting. Since the modulus of toughness increases with specific energy of rock cutting, it enabled us to estimate the specific energy of rock cutting.

Keywords: *brittleness, modulus of toughness, specific energy, Glass tunnel.*

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Extended Abstract:

1. Introduction

Brittleness is a common term used in rock engineering to description the properties of rock mass failure and crack propagation. Various factors such as mineralogical composition, in situ stress and strength properties of rocks are effective in rock brittleness (Yagiz, 2009). Rock brittleness is mean the tendency to failure under low stresses without apparent deformation (Altindag, 2003). The rocks show more brittleness during fracture less deformation (Gong and Zhao, 2007). In brittleness rocks, with increasing compressive strength to tensile strength ratio and increasing difference and mean compressive strength to tensile strengths of rock increased (Ozfirat et al., 2016). Rock explosion in deep tunnels and mines are generally associated with the process of rock failure and the release of excess energy. Therefore, mining or rock drilling would not be operate without assessing the brittleness (Gong and Zhao 2007; Altindag, 2002, 2003, 2010; Yagiz, 2009; Tarasov and Potvin, 2012).

2. Materials and methods

In this investigation transferred 30 blocks with 30 × 30 × 30 dimensions to the geotechnical laboratory of Bu Ali Sina University of Hamadan without any weathering and jointing. Then, based on the ASTM D 4543 method, the cylindrical cores with a diameter of 54 mm (Nx) with length to diameter of 2.5:1 were prepared.

The uniaxial compressive strength test performed according to the standard (ASTM D7012, 2004), the Brazilian tensile strength test performed on the standard (ASTM D3967, 2008).

Database of parameters such as: uniaxial compressive strength, tensile strength, elastic and total strain values, reversible and total energy, Young's modulus, Poisson's modulus, shear modulus, post-peak modulus, lame coefficient, density were developed to calculate the brittleness indices. Then, the normality of the data statistically analyzed using Kolmogorov-Smirov, skewness and kurtosis tests.

3. Discussion

The normality of the data exanimated by using Kolmogorov-Smirov and skewness and kurtosis tests. In the Kolmogorov-Smirnov test, the significance level and Z test are more than 0.05. As a result, the null assumption that the input parameters are normal will not be rejected. Since the values of the parameters are in the interval (-2, 2) in the skewness and kurtosis test, the statistical distribution of the parameters are normal. The statistical analysis of these parameters performed after checking the normality of the parameters. The results of regressions between brittleness indices and toughness modulus shown as the best relationships (power and quadratic) and the coefficient of determinations (Table 1).

Table 1. Results of calculation brittleness indices with toughness modulus

Equation number	Equation	Equation type	(R^2)
a	$B_1= 1.3931T_m^{0.2873}$	power	0.45
b	$B_2= 0.3777T_m^{0.1208}$	power	0.38
c	$B_3= -0.0018T_m^2+3.4472T_m – 77.661$	quadratic	0.83
d	$B_4= - 0.0001T_m^2+0.1076T_m+5.1198$	quadratic	0.83
e	$B_6=0.0463 T_m^{0.4786}$	power	0.65
f	$B_9= - 7E\text{-}07T_m^2+0.0004T_m+0.8024$	quadratic	0.12
j	$B_{10}= 4E\text{-}07T_m^2 – 0.0005T_m+0.3917$	quadratic	0.13
h	$B_{11}= - 4E\text{-}07T_m^2+0.0005T_m+0.6083$	quadratic	0.13
i	$B_{25}= - 1E\text{-}05T_m^2+0.0102 T_m+2.9488$	quadratic	0.32
g	$B_{26}= 36.141T_m^{0.3632}$	power	0.23
k	$B_{27}= - 0.0024T_m^2+1.9548T_m+458.51$	quadratic	0.20
l	$B_{28}= - 6E\text{-}05T_m^2+0.0439T_m+16.481$	quadratic	0.18
m	$B_{29}= - 5E\text{-}05T_m^2+ 0.0598T_m+13.443$	quadratic	0.35

According to Table 1, the equations (c and d) show the highest coefficient of determination between the rocks brittleness index and their toughness modulus. Therefore, in this study, brittleness indices B3 and B4 can consider as the most acceptable indices in comparison with other indices for evaluation of rock toughness modulus.

Different statistical indicators using for investigated the ability and accuracy of the equations and their performance. Statistical indicators calculated to predict the performance of the brittleness indices (Table 2). The values of the statistical indicators represent the significance and efficiency of the presented statistical equations.

Table 2. Performance of statistical indicators for prediction brittleness indices

Brittleness index	Equation number	R^2 adjusted	VAF (%)	RMSE	F fisher	Tabulated F Values
B_3	C	0.83	73.01	5.46	74.26	2.69
B_4	d	0.83	73.10	3.85	67.31	2.69

The relationship between B3 and SE (Specific energy) has showed in Equation (1) (Comakli et al, 2016, Altindag, 2003).

$$SE = 0.2389\, B_3{}^2 - 5.0069\, B_3 + 93.092 \qquad R^2 = 0.866 \qquad RMSE=4.28 \qquad (1)$$

The values of specific energy obtained by using equation (1), it show in Table 3. The relationship between toughness modulus and specific energy has showed in fig 1. Such as the toughness modulus of rock and special energy are increased the volume of excavation material and advance rate of rock improvement. Brittleness indices and rock toughness modulus help to estimate the specific energy for cutting the rock at a laboratory scale.

Table 3. Specific energy values obtained for cutting rocks

Sample	SE (Mj/m^3)	Sample	SE (Mj/m^3)
1	212.0	9	143.8
2	407.3	10	440.6
3	251.8	11	15.3
4	314.5	12	22.9
5	2.9	13	85.3
6	225.9	14	109.1
7	6.1	15	153.7
8	17.5	16	191.3

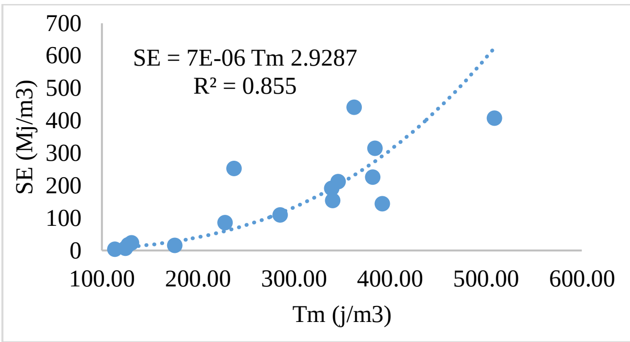

Fig 1. The relationship between toughness modulus and specific energy

4. Conclusion

In this study, the results of uniaxial compressive strength and tensile strength tests, the area under the stress-strain curve and rock toughness modulus were calculated. The normality of the data exanimated by using Kolmogorov-Smirov and skewness and kurtosis tests. The brittleness indices B3 and B4 calculated against the toughness modulus showed the highest coefficient of determination of 0.83. The relationship between B3 and specific energy was calculated. This relationship used for calculation specific energy of rock cutting. Brittleness indices and rock toughness modulus help to estimate the specific energy for cutting the rock at a laboratory scale.

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