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A new approach to rock brittleness and its usability at prediction of drillability

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ABSTRACT

Rock brittleness is one of the most important issues in rock drilling and cutting. The relations between drillability and brittleness will assist engineers in excavation works. The demand for representative rock parameters related to planning of underground excavations is increasing, as these parameters constitute fundamental input for obtaining the most reliable cost and time estimates. In rock cutting mechanics, the effects of the rock and brittleness on the efficiency of drilling and excavation are examined by many researchers. In this study, 41 different rock types were tested in laboratory to investigate the relations between the drilling rate index and different brittleness values. Firstly, the relations defined in literature are tested. Strength tests are made according to International Society for Rock Mechanics standards. In addition Norwegian University of Science and Technology standards are used to determine drilling rate index. Then, a new brittleness index is proposed which is the arithmetic average of uniaxial compressive strength and tensile strength. Considering the regression analysis carried out, it was seen that the proposed formula showed good correlation for these samples handled in this study. As a result of this study, a high correlation is obtained between the proposed index and drilling rate index values (R:0.84). The results are found to be at least reliable as well as other brittleness equations given in literature.

1. Introduction

Drilling holes in rocks at mining, tunneling and quarrying fast and economically is decisive in realizing these mining operations at lowest cost and a great capacity. Fast and economical drilling, on the other hand, is dependent on mineralogical and geomechanical features of rocks, and, on the drilling equipment used.

In order to achieve the maximum output from cutting and excavation machines like shearer-loaders, roadheaders, TBMs, all rock properties should be considered. For example; according to Alemdag et al., 2015 deformation modulus (E_m) is estimated indirectly from classification systems such as Rock Mass Rating (RMR), Rock Mass Quality (Q), Rock Mass Index (RMi) and Geological Strength Index (GSI). Therefore, prior to selecting and using a cutting/excavation machine, drillability, cuttability, and strength features of the rock should be known.

There are a number of methods, standards, and formulas proposed on drillability (Thuro, 1997; Kahraman, 2002; Dahl, 2003; Yagiz, 2009; Altindag and Guney, 2010). Considering the results obtained from tests performed, the selection of the appropriate cutting machine can be done and performance of the machine (rate of advance, bit consumption etc.) can be estimated beforehand. In case we do not have necessary laboratory facilities to determine drillability and brittleness, we can use relations defined in literature to find these values.

In this study, drillability values of a number of rocks were determined and compared to the brittleness values of rocks given in studies performed earlier. Moreover, a new relation between the drillability and brittleness of rocks is proposed. It has been found out that arithmetical mean of the uniaxial compressive strength (UCS) and tensile strength (TS) of the rock is in highly accordance with equations given in previous studies and used in excavation projects.

2. Computational brittleness

Brittleness can be measured by computing the ratio of elastic strain to plastic strain. As the value of the ratio increases, brittleness also increases and ductility decreases (Denkhaus, 2003). In other

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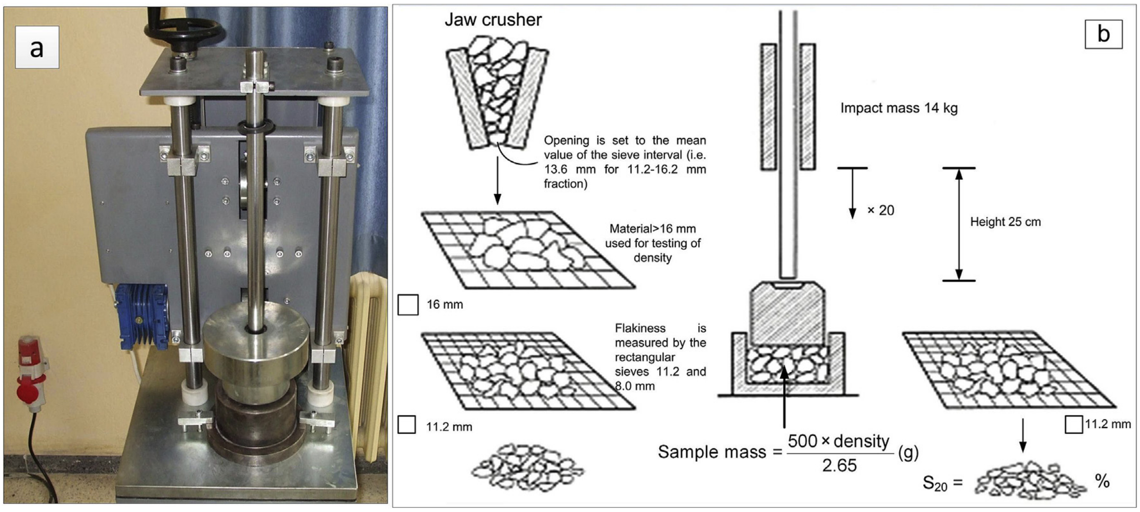

Fig. 1. Brittleness device in laboratory (a) and test apparatus (b) (Dahl, 2003).

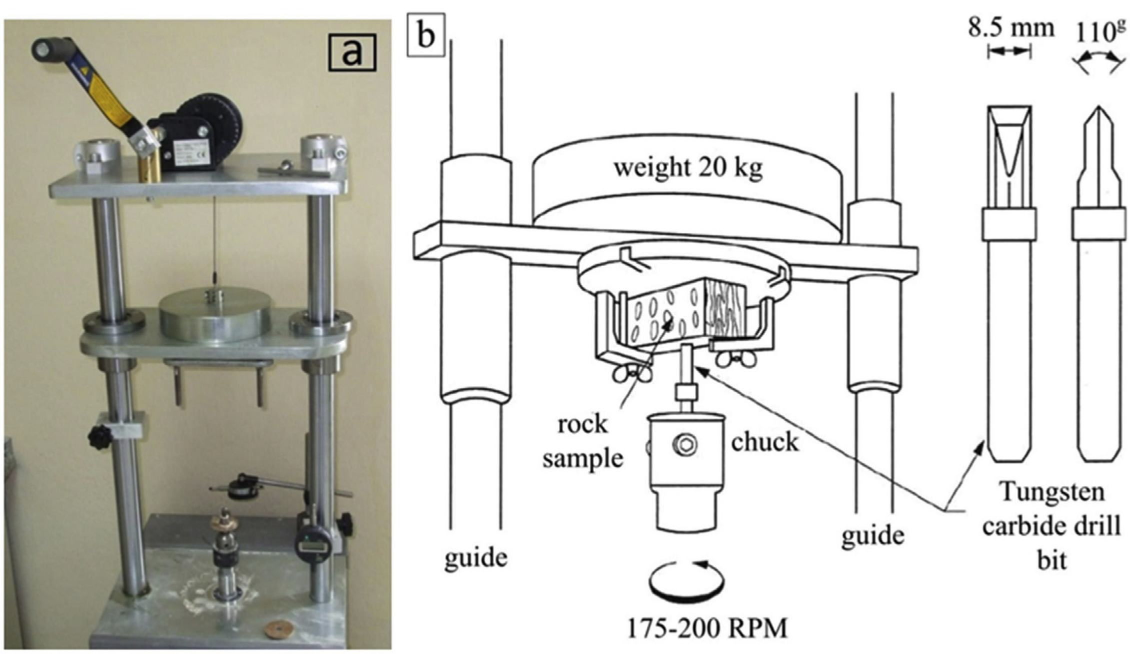

Fig. 2. The Sievers'J miniature drill test: laboratory (a), apparatus (b) (NTNU, 1998).

words, brittleness can be defined as the lack of ductility or its inverse. Rock brittleness is one of the most studied research areas in rock engineering. Many researchers emphasized the importance of brittleness in mining, tunneling and drilling operations. Generally, brittleness index values were used at drilling operations and in previous studies (Goktan, 1992; Bilgin et al., 1993; Thuro, 1996, 1997). To determine brittleness (B_1), Hucka and Das (1975) presented the equation;

$$B_1 = \varepsilon_r/\varepsilon_t \tag{1}$$

where ε_r is the reversible strain and ε_t is total strain.

The brittleness of B_2 is widely used in previous studies (Inyang and Pitt, 1990; Gong and Zhao, 2007).

To determine brittleness (B_2);

$$B_2 = \sigma_c/\sigma_t \tag{2}$$

where σ_c is the UCS of the rock and σ_t is TS of the rock.

Hucka and Das (1975) stated that the brittleness of B_3 is suitable even for friable substances like coal. To determine brittleness (B_3);

$$B_3 = (\sigma_c - \sigma_t)/(\sigma_c + \sigma_t) \tag{3}$$

where σ_c is the UCS of the rock and σ_t is TS of the rock.

B_4 is the brittleness determined from Mohr's envelope (at $\sigma_n = 0$). To determine brittleness (B_4);

$$B_4 = \sin\theta \tag{4}$$

where θ is the angle of internal friction.

B_5 is the brittleness from the Protodyakonov (1962) impact test.