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Classifications of properties influencing the drillability of rocks, based on the NTNU/SINTEF test method

Filip Dahl [a,*], Amund Bruland [b], Pål Drevland Jakobsen [b], Bjørn Nilsen [c], Eivind Grøv [a]

[a] SINTEF Building and Infrastructure, Rock Engineering, N-7465 Trondheim, Norway
[b] Department of Civil and Transport Engineering, NTNU, N-7491 Trondheim, Norway
[c] Department of Geology and Mineral Resources Engineering, NTNU, N-7491 Trondheim, Norway

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ABSTRACT

The demand for representative rock property parameters related to planning of underground excavations is increasing, as these parameters constitute fundamental input for obtaining the most reliable cost and time estimates. The Brittleness Value (S_{20}), Sievers' J-Value (SJ), Abrasion Value (AV) and Abrasion Value Cutter Steel (AVS) have been used extensively at NTNU/SINTEF since the 1960s in connection with drillability testing of rock samples. Nearly 3200 samples originating from projects in 50 countries have so far been tested, and the method and associated prognosis model are internationally recognised for giving reliable estimates of time and cost for tunnelling. A classification of the NTNU/SINTEF drillability indices Drilling Rate Index™ (DRI), Bit Wear Index™ (BWI) and Cutter Life Index™ (CLI) has been available since 1998, but until now no official classification has been available for the individual tests used to calculate these indices. In this paper, classifications of the NTNU/SINTEF drillability test methods Brittleness Value (S_{20}), Sievers' J-Value (SJ), Abrasion Value (AV) and Abrasion Value Cutter Steel (AVS) tests will be described in detail. The presented classifications of the individual tests are based on statistical analysis and evaluations of the existing test results recorded in the NTNU/SINTEF database.

1. Introduction

Producing reliable and robust prognoses on cutter wear, drilling progress and related costs is becoming an increasingly sensitive issue for machine manufacturers and contractors dealing with operation of mechanical excavation systems in mining, tunnelling, and underground construction. Equally important for the clients and owners; cost and time estimates must have adequate quality. Representative and trustworthy parameters describing various rock properties, along with rock mass properties, are crucial as these constitute the fundamental input for obtaining the most reliable cost estimates. This is equally important when it comes to risk assessments described by terms such as "low" and "good" in tender documents, and situations where claims are filed during or following the construction period (Dahl et al., 2010).

The original NTNU/SINTEF drillability test method, formerly known as the NTH test (Selmer-Olsen and Lien, 1960), was developed in 1958–1961 for evaluation of the drillability of rocks by percussive drilling. The Drilling Rate Index™ (DRI) (Selmer-Olsen and Blindheim, 1970) is assessed on the basis of two laboratory tests, the Brittleness Value (S_{20}) test (Matern and Hjelmer, 1943) and the Sievers' J-Value (SJ) miniature drill test (Sievers, 1950). The DRI™ may be described as the S_{20} of rocks, also defined as the ability to be crushed by repeated impacts, corrected for the surface hardness determined by the SJ. The Bit Wear Index™ (BWI), which is used to estimate the wear rate of drill bits, is assessed on the basis of the DRI™ and the Abrasion Value (AV) (Selmer-Olsen and Lien, 1960). The AV is a measure of time dependent abrasion on tungsten carbide by crushed rock powder. The development of the Cutter Life Index™ (CLI) (NTH, 1983), which took place in the years 1980–1983, was based on the original NTH test method. The CLI™ has since the 1980s provided the possibility of estimating cutter life in connection with rock excavation by use of TBM. The CLI™ is assessed on the basis of SJ and the Abrasion Value Cutter Steel (AVS). The AVS test uses test pieces of steel from TBM disc cutter rings with specific properties, and it is regarded as a measure of time dependent abrasion on cutter ring steel.

Performance prediction and cost evaluation models for drill- and blast tunnelling, TBM tunnelling and rock quarrying have been developed by correlating laboratory tests and in situ geological data with production data from tunnelling projects. The models are continuously updated and revised as new tunnelling data become available (Dahl et al., 2010). In recent years the NTNU/SINTEF method has been used extensively in connection with cost/time estimates and planning of major international underground

* Corresponding author. Tel.: +47 73 59 48 35; fax: +47 73 59 71 36.
E-mail address: filip.e.dahl@sintef.no (F. Dahl).

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projects, and it is gaining acceptance as a recognised and widely used method for TBM performance prediction testing.

The NTNU/SINTEF drillability indices have recently been registered as trademarks (Dahl et al., 2010). NTNU/SINTEF is committed to ensure that all end users have confidence in these quantitative methods for describing drillability characteristics of rock by performing consistent and repetitive testing. Quality assured and reliable drillability test results is of vital importance in order to obtain the best possible time and cost estimates, which is the main reason for labelling the NTNU/SINTEF indices as trademarks.

A classification of the NTNU/SINTEF drillability indices DRI™, BW I™ and CLI™ has been available since 1998 (Bruland, 1998), but there has until now not been any officially published classification available for the individual test values used to calculate these indices. The increasing use of the NTNU/SINTEF drillability test method has generated a demand for a classification of the individual tests, in addition to the existing classification of the drillability indices. This paper presents classifications of the S_{20} test, SJ-Value test, AV test and AVS test, based on the existing test results, recorded in the NTNU/SINTEF database.

It is essential for everyone involved in planning of underground excavations to gain a proper understanding of how various individual rock properties can influence the drillability of rock and hence time and cost. The classifications are intended to act as an important aid in that respect.

2. Principle and specifications of the NTNU/SINTEF test methods

2.1. Rock brittleness determined by the Brittleness Value (S_{20}) test

There are several different methods used for determination of rock brittleness (Yarali and Kahraman, 2011). The brittleness test method, utilised by NTNU/SINTEF, was originally developed in Sweden by Matern and Hjelmer (1943). The original test was initially intended for determination of strength properties of aggregates, but several modified versions of the test have later been developed for various purposes. The version of the S_{20} test developed for determination of rock drillability has been used since the end of the 1950s (Fig. 1).

S_{20} constitutes a measure of the rock brittleness or ability to be crushed by repeated impacts, and it is determined by use of an impact apparatus. S_{20} is defined as the percentage of a pre-sieved fraction that passes through the finer sieve after 20 impacts. The S_{20} test is normally performed on three extractions from one representative and homogenised sample of crushed and sieved rock material. The reported S_{20} is hence the mean value of three parallel tests. A screening of tests performed at the NTNU/SINTEF laboratory indicates that this test, correctly performed, normally will show a standard deviation of three parallel tests on homogenised material (homogenised through the crushing and sieving process), less than 2 units (i.e. 4% for a mean S_{20} of 50). Local variations in the lithology and texture of the sample would most likely provide larger differences, if the sample material not was homogenised prior to the testing.

The lowest and the highest S_{20} of the 3002 values recorded in the NTNU/SINTEF database are 15.0 (*amphibolite*) and 95.1 (*limestone*). The measuring range and the distribution of the recorded test results are shown in Fig. 2.

2.2. Rock surface hardness determined by the Sievers' J-Value (SJ) test

The Sievers' J-miniature drill test (Sievers, 1950) was originally developed by Sievers (1950s). SJ constitutes a measure of the rock surface hardness or resistance to indentation. SJ is defined as the mean value of the measured drillhole depths in 1/10 mm, after 200 revolutions of the 8.5 mm miniature drill bit, see Fig. 3. The standard procedure is to use a pre-cut surface of the sample which is perpendicular to the foliation of the rock. SJ is hence measured parallel to the foliation. The SJ test is normally performed as 4–8 drillings, depending on variations in the texture of the sample. The SJ values may however in some specific cases show a variability, which necessitates more than 8 drillings in order to achieve a representative average value.

SJ is reported as the mean value of the performed drillings. Foliated rocks like gneiss or schist can often show a texture with distinct bands of minerals with different hardness. This can result in significant variations in penetration depth. It should therefore always be aimed at placing the drillholes in soft and hard layers

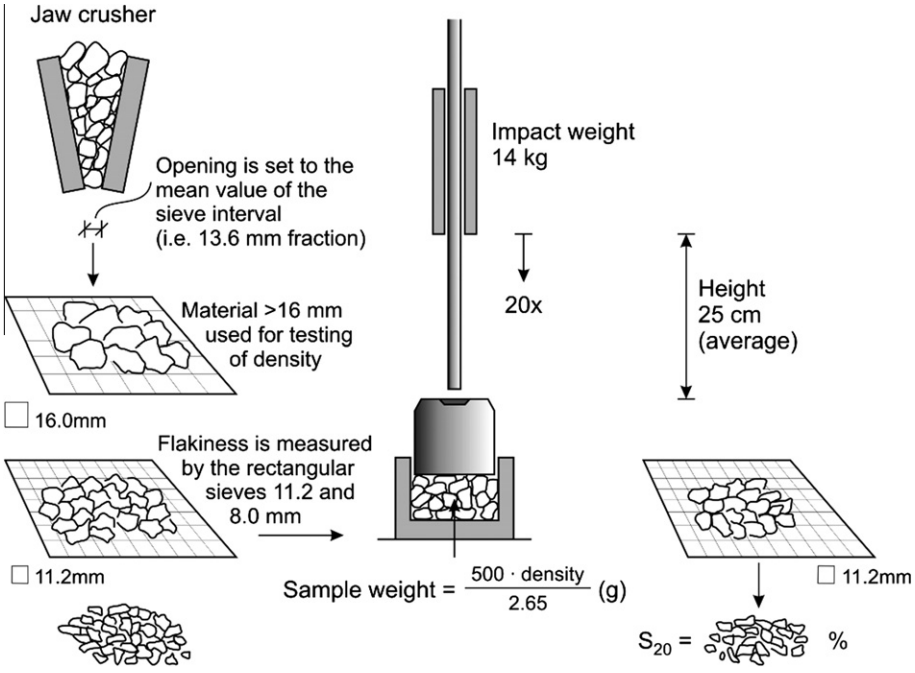

Fig. 1. Outline of the Brittleness Value (S_{20}) test (www.drillability.com, 2003).