ROCK TESTING METHODS TO DETERMINE THE CUTTABILITY OF ROCK

By Antraquip Corporation

As a leading manufacturer and supplier of specialized hydraulic and electrically driven rock cutting machines such as roadheaders and rotary drum cutting attachments it is essential for Antraquip to determine the cuttability of material prior to recommending a machine model. There are several methods in evaluating rock which are outlined below that help the experienced personnel at Antraquip ensure proper machine selection to achieve maximum production rates in a given application:

Rock- testing Procedures at geotechnical laboratory

A. "Standard" Physical Properties Tests

1. Density

2. Unconfined Compressive Strength
Measuring following ISRM suggested test methods, in a 600 kN testing machine.

3. Tensile Strength
Measured by "Brazilian" disc splitting method in a 600 kN testing machine.

4. Static Elastic Modulus & Modulus of Deformation
A load-deformation diagram is recorded during performance of the unconfined compression test. From the diagram on the X-Y plotter the E-Modulus is gained from calculating within the linear part of the curve, the modulus of deformation from the peak force and the maximum deformation.

The relation between modulus of deformation and Young's modulus was found to be a good value to judge rocks plastic-city.

This maximum deformation divided through the primary length of the specimen gives the value of specific fracture deformation.

5. Relation between Compressive Strength & Tensile Strength
This relation is used for a rough checking of toughness.

A lower value than 9 indicates tough behavior; a value between 9 and 15 indicates average behavior and a value of more than 15 shows, that the rock is brittle.

6. Relation between Normal Tensile Strength & to Parallel Bedding Planes
This relation shows the influence of rock's fabric on cut ability.

When the ratio of the two values is 1, there is no influence, but even ratios up to 6 could be found in intact rock.

7. Indentation test with Schmidt Rebound Hammer
This test is used for the purpose, which the significance of a Schmidt-rebound value decreases very much with increasing strength of rock. For this fact, mainly for testing harder rock strands, this test is used.

The Schmidt-hammer is equipped with a conical tip with a tungsten-carbide insert. The place for measuring is grounded to get a flat surface, and then the hammer is knocked ten times on one point. The depth of the crater is measured and this value can be transformed with a certainty of +/- 10 % into uneasily compressive strength.

B. Index Test for Rock Cut ability

From the results of the test subsequently describe the probable performance of a machine is calculated. This test has been developed in our laboratory.

Determination of the index values of machine ability s rund & b rund

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The reasons for determining the machining property of a rock by means of an index test are as follows:

a) The machineability/cuttability of a rock depends upon a number of mechanical values: uniaxial compressive strength, uniaxial tensile strength, shear strength, modulus of elasticity and modulus of deformation.

b) Consequence & interaction of these values differ from rock to rock.

c) The individual values show a distinct or even marked dependence on the rate of load application, which is for example in the approximate determination of strength, only a fraction of the cutting speed and force of a roadheader.

d) An index test permits an application of stress on the rock which is very similar to the stress caused by a cutterhead (thus, for instance, the pick is positioned for the index test in the same direction as on the cutter head).

Test preparations: A sample of the rock to be tested, having about the size of a fist, is put into a cubic mold 100 x 100 x 100mm, which is then filled up with a mixture of cement and water. After solidification (about $24^{h)}$ the cube is cut axially with a diamond saw in order to provide two practically identical plane rock surfaces for examination.

On this surface the index test is carried out. Subsequently the mean depth of the resulted groove, value S (mm) is measured as well as its mean width measurement B (mm) and the loss in volume V (cm3).

The values S and B are measured at 4 points within the groove, displaced by 90 degrees each in order to compensate for any small differences in the inclination of the surface.

The index value S indicates that the test data have been determined by means of a round-shaft pick (conical pick).

The obtained value S allows for the calculation of, substantially independent from the particular type of rock concerned, a correlation with production rates to be expected utilizing a roadheader. In order for these calculations to be accurate the following conditions must be met:

a) Minimum Cross-section dependent on size of machines
b) Longitudinal inclination below 4°, no transversal inclination
c) The rock represented by the sample is encountered homogeneously over the entire cross-section of the face.
d) The machine is controlled by an experienced operator.
e) Only rough profiling

The correlation between the production rate L (under normal conditions) and depth of cut S and the cutter motor power N (drum type cutterhead) is $L = 0.075 \cdot S \cdot N$

The correlation coefficient is 0.83. A correlation of the same production data with the individual uniaxal compressive strength C only shows a correlation coefficient of 0.71. This can be taken as a proof that by the index test the interaction of the individual factors influencing the machineability of a rock is perfectly well determined.

Another advantage provided by this procedure is the small size of the samples required. In case that the uniaxial compressive strength values and the uniaxial tensile strength values are also required (the latter for determination of the F-value) a rough determination on the basis of the short-term test result is possible.

C. The for Evaluation of Abrasivity

1. The coefficient fo wear “F” according the Schimazek

The coefficient of wear "F" is determined on the basic of the petrol graphical structure of the rock concerned. To attain this measure an examination of the rock in the form of a thin section by means of a polarizing microscope is necessary.

In this examination the following values are determined:

a) Percentage (by volume) of the different minerals. These minerals are usually grouped by their chemical structures and bye approximate hardness. The individual groups indicated are the following:

- Quartz
- Feldspar
- Other hard silicates (for ex: augite, hornblende etc.)
- Argillaceous minerals
- Mica (including chlorite)
- Other soft silicates (for ex: zeolite or other hydrous silicates)
- Carbonates
- Organic matter (carbonaceous, bituminous)
- Other minerals components (all minerals not yet represented in as far as they occur in the single grain)
- Poly minerals grains: Fragments of poly minerals rocks in the form of grain components in sedimentary rocks.
- Accessories: All mineral components that would belong to one of the above indicated groups, the total share of which, however falls below 2 % in volume.

These components are determined by an estimate of the mineral proportions in strips having a width equal to the mean diameter of grain and formation of the mean value of these strips in order to compensate for any errors in estimation. Depending on the size of grain, this estimate is carried out on at least 10 (very coarse grain) up to a maximum of 50 (very fine grain) adjacent strips.

In case of a very irregular distribution of the mineral components a mean value of 2 or 3 thin sections may be used.

b) The second value to be determined is the mean diameter of the quartz grains included in the rock. This value is determined by examination of 50 grains by means of an ocular microscope. In cases where the grains distinctly vary from the cubic form and are part of a structural order, the diameter of the quartz grain is determined on the basis of two diameters displayed by 90°, one of them being the greatest diameter of the grain. Where the size of the grain falls below 0.025mm (this is clearly discernible by some experience) only the biggest ascertainable grains are subject to a check measurement. If their diameters do not exceed 0.035mm, a mean diameter of the quartz grain of < 0.025 is entered into the report.

In rock where little or no quartz is found but another relatively hard mineral exists with a higher percentage (for ex: hard silicates, pyrite) the mean diameter of these minerals components is determined in the same way as described in the above paragraph.

c) In addition to the aforementioned values, the following parameters are examined and described in terms of quality.

Bond of grain: Type & intensity of bond

Homogeneity: This parameter includes characteristics such as type and degree of structural order, alternating layers of different minerals, typical inclusions.

Secondary factors: Influencing the machineability of a rock: These might be solidification (for ex: porous sandstone is solidified by carbonate solution) or softening (for ex: by weathering); a beginning metamorphic transformation of a rock would also constitute such a factor.

The quantitative description of the bond of grain is provided with sufficient accuracy by the tensile strength according to the Brazilian test, unless big single grains with distinct cleavage property (for ex: feldspar, calcite etc) are occurring with a relatively important share in the total volume, in the latter case, the bond at the grain boundary does no longer constitute the weakest spot. As however, such grains do mainly occur in plutonites, pegmatite's, and occasionally in volcanic and metamorphic rocks, where an economic use of cutting with picks is not yet possible, the tensile strength according to Brazilian test may well be applied as a suitable measurement for the density of the bond.

On the basis of these values, the coefficient of wear "F" is calculated according to the following formula:

$$F = \frac{V * d * t}{100}$$

Where V = percentage of hard minerals related to quartz (in volume)

d = mean diameter of the contained quartz grain (mm) or, alternatively, in case of very low or no quartz contents at all, the diameter of the main hard mineral contained (this diameter must be multiplied by a reducing factor if the hardness of this mineral is below that of quartz)

t = tensile strength according to Brazilian test (Mpa)

The factor V must be calculated from the mineral components of the rock. For this calculation each mineral group is multiplied by a factor corresponding with their hardness according to Rossival's scale.

These conversion factors (in dependence upon the usually indicated Mohs hardness) are shown in the following table:

Figure 1

Hardness according to Mohs scale	Factor for conversion to Quartz
1	0
1.5	0
2	0.0021
2.5	0.015
3	0.036
3.5	0.038
4	0.042
4.5	0.047
5	0.055
5.5	0.16
6	0.31
6.5	0.55
7	1

For the groups according to (a), where the hardness values show a certain degree of scattering, a collective conversion factor is used for simplicity, for instance:

Feldspars	0.3
Argillaceous minerals	0.04
Carbonates	0.03

Poly mineral grains are put in, depending upon their composition, with a factor of 0.3 up to 0.5

The following example shows the calculation of the value "V" in case of a rock with a composition as indicated below:

Figure 2

	Percentage (by volume)	Conversion Factor	Percentage (by volume related to quartz
Quartz	42	1	42
Feldspar	31	0.3	9.30
Divers hard silicates (hornblende)	6	0.31	1.86
Argillaceous minerals	8	0.04	0.32
Carbonates	4	0.03	0.12
Poly mineral grains	9	0.5	4.50

V= 58.10 %

The coefficient of wear of a rock varies between 0 (ash-free coal) and 80 (coarse-grained granite). Initially developed for use in coal mining, the use of the "F" value is also most advantageous in sedimentary rock. Comparative studies by means of index test procedures have shown that there is a definite connection between the "F" value according to Schimazek and the index value of wear, in case of sedimentary rock. For other rocks, however, (in particular for metamorphic rocks) distinct and even extreme deviations of the comparative value have been ascertained.

From these "F" values and the respective compressive strength of rock the pick consumption can be estimated.

2. Abrasivity- testing of rocks with the VVUU-Radvanice-method

As the determination of abrasivity with the Schimazek-method is limited both with regards to the results as well as to the testing-technique, an alternative is offered with the Index-testing method as described below. Particular disadvantages of the F-value determination according to Schimazek are the following:

a) Considerable loss in time because of the necessity of a petrography thin-section examination as well as of a determination of the tensile strength (for this determination an adequate size of the rock samples is required).

b) Inexact or wrong results if quartz is missing or only represented in little quantities, but proportions of hard minerals (hard-silicate, pyrite, etc.) are considerable.

The abrasivity-testing according to Radvanice is carried out on samples which are prepared in the same way as the samples for the determination of the Index-values S and B rund. Therefore, approx. fist-sized samples would be sufficient.

The test is carried out by wear of the lower surfaces of a steel-pin of 20(+/-5) mm in length and 3.5 (+/-0.3) mm in diameter. The tensile strength of the steel must range between 800 and 850 Mpa.

The test is carried out with 5 steel-pins, total weight of which has to be determined with an accuracy of 0.lmg, before the tests are started.

The steel-pins are clamped separately in a testing device and loaded with a force of 100N. The head of the testing device is provided with 5 different diameters, which are used one after the other by one steel-pin each. The largest diameter is 50mm. On each circular path the steel-pin accomplishes the same number of turns so as to provide that the total distance that all 5 steel-pins traverse in 15m.

After completion of the test, the testing-steel-pins are cleaned and by means of weighting the loss is substance (^ M) is determined with an accuracy of 0.lmg.

The coefficient of wear according to Radvanice is calculated by using the following formula:

$$F_{Radv.} = \frac{AM}{15} \quad (mg/m)$$

As comparative tests showed, in carboniferous rocks as well as in other sediments with a quartz content of more than 10% a very good, almost linear correlation with the coefficient of wear "F" according to Schimazek could be found:

$$F_{Radv.} \sim 8,3 \; Fschim$$

For all rocks that are not sedimentary as well as for all sediments with low quartz content, the above calculation is not valid. However, as the determination of F_{Radv}, is a direct one, hypothetical values for F_{Schim} can be calculated based on the above relationship.