LABORATORY TESTS FOR HARDNESS AND ABRASIVENESS : EXPLANATORY NOTES

Sklerograf Hardness :
This is measured using a Harteprufer SKLEROGRAF Modell D instrument supplied by Roell & Korthaus KG.
The reported value is the mean of 5 spot readings on the smooth polished end of a cylindrical core, clamped in a heavy V-block, with its axis vertical.
One reading is taken at the centre and 4 readings are taken at points midway between the centre and the outside edge of the core, along 4 quadrant lines.

Shore Hardness :
Not directly measured, but deduced from the Sklerograf Hardness, using data supplied by Roell & Korthaus KG.

Brinell Hardness :
Not directly measured, but deduced from the Sklerograf Hardness, using data supplied by Roell & Korthaus KG.

Rockwell Hardness :
Measured with a HR-150AI Hardness Tester supplied by Laizhou Hengguan Testing Instruments, whose measurement ranges are 20-95HRA, 10-100HRBW, or 20-702HRC.

Brinell and Rockwell Hardness are standard metallurgical test values, so measuring the equivalent values for a rock gives a useful indication of the minimum hardness which any metal surface likely to come into contact with a particular rock should have, in order to resist suffering abrasive wear by that rock.

Schmidt Hammer Hardness :
Measured with a RockSchmidt Type L, made by Proceq, having impact energy of 0.735Nm.

Goodrich Test
This test was originally suggested by Ross Goodrich, of the Joy Manufacturing Co., using similar apparatus to that used in the already-established Sievers test.
The mutual damage done by a tungsten carbide microbit (3/8" or 9.5mm wide, with a 90^{o} included angle) to the rock, and by the rock to the microbit, are measured.

Goodrich Drillability is found from the measured depth of a hole drilled under a standard thrust, by 150 revolutions of a standard tungsten carbide rotary bit. (Low values indicate tough rocks, high values indicate soft rocks.)
Goodrich Wear Number is found from the measured width of the wear flat on the bit used for the Goodrich Drillability test. (Low values indicate non-abrasive rocks, high values indicate highly abrasive rocks.)

The ratio of Goodrich Drillability to Goodrich Wear Number is correlated with the ability of a roadheader to economically cut a rock.
Ratios of greater than 10 indicate that the rock should be economically cuttable by a light machine such as an AM50 or a Mitsui-Miike S125.
Ratios of greater than 5 indicate that the rock should be economically cuttable by a medium machine such as an AM75 or a Mitsui-Miike S200.
Ratios of greater than 2 indicate that the rock should be economically cuttable by a heavy machine such as an AM105 or a Mitsui-Miike S300.

Sievers J-Value :
Uses the same test apparatus as the Goodrich Drillability Test, but the microbit has slightly different geometry (a 110^{o} included angle), and the test specimen is subjected to 200 revolutions of the microbit (rather than 150).

<u>Taber Abraser test :</u>

The mutual damage done by a carborundum (silicon carbide) disc to a disc of rock, and by the rock disc to the carborundum disc, are measured.

Taber Abradability is found from the measured loss of mass of the rock disc after it has rotated for 800 revolutions under a standard-loaded carborundum disc. (Low values indicate tough rocks, high values indicate soft rocks.)
Analysis of past decades' results of testing in this laboratory shows the following distribution of Taber Abradability values:

Lower decile	0.39
Lower quartile	4.3
Median	47.5
Upper quartile	878
Upper decile	9615

Taber Abrasiveness is found from the measured loss of mass of the carborundum disc.
(Low values indicate non-abrasive rocks, high values indicate highly abrasive rocks.)
Analysis of past decades' results of testing in this laboratory shows the following distribution of Taber Abrasiveness values:

Lower decile	0.16
Lower quartile	5.7
Median	183
Upper quartile	15586
Upper decile	551652

Abrasive Wear Index, as standardised by A.S.T.M. C-501, is calculated as 88/(Rock Disc Loss : grams)
Index of Abrasion Resistance I_w, as standardised by A.S.T.M. C-1353, is calculated as
(36.75/(Rock Disc Loss : grams)) * (bulk density : grams/cc) * (number of revolutions/1000)

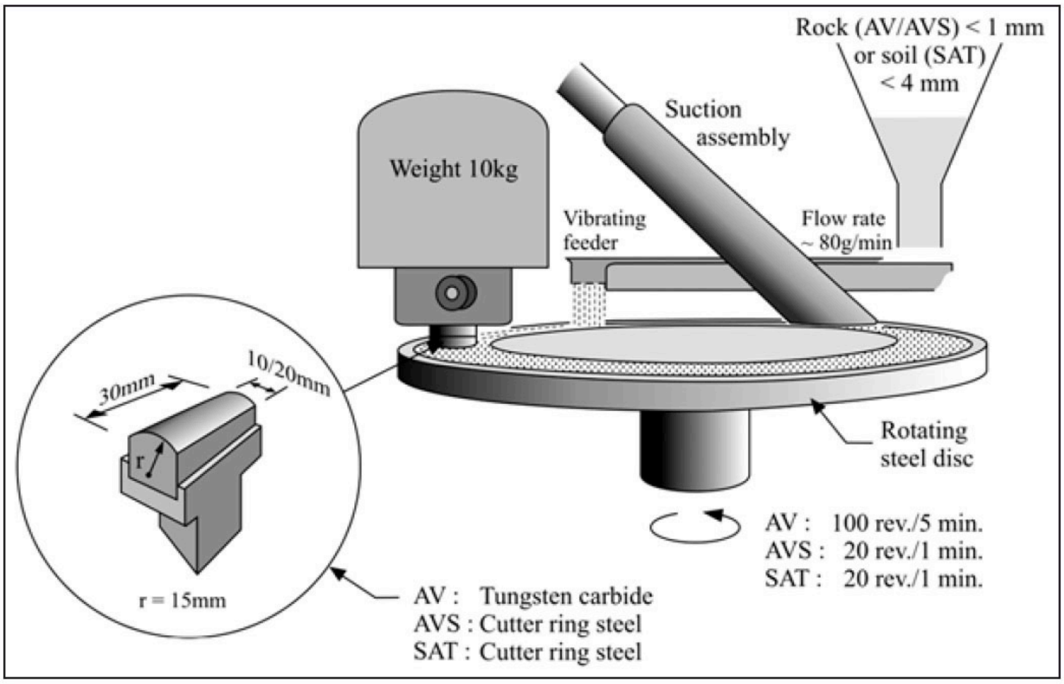
Dr. Peter Tarkoy developed a method using the same laboratory test procedure, but defining Abrasion Hardness H_A as 1/(rock disc weight loss) and Rock Abrasiveness A_R as 1/(carborundum disc weight loss).
"Total Hardness" is defined as $H_R \sqrt{H_A}$ (gms$^{-1/2}$) where H_R = Schmidt Hammer hardness.

"Total Hardness" has been correlated with, and may be used as a predictor of, the rate of advance of tunnel boring machines.

<u>The Norwegian Abrasion test (NAV/AVS/SAT)</u>

A methodology for estimating the drillability of rocks by percussive drilling was developed at the Engineering Geology Laboratory of the Norwegian Institute of Technology (NIH) in 1961.
Abrasion testing of crushed rock particles <1 mm, as illustrated in the Figure below, was then introduced together with the Swedish Brittleness test and the Sievers-J miniature drill test for estimating the drillability parameters DRI (Drilling rate index) and BWI (Bit Wear Index).

Since the early 1980's, the tests have been used mainly for predicting hard rock TBM wear
performance according to the method developed by the NTH/NTNU Department of Building and Construction Engineering (in 1996, as result of a merger, NIH changed name to NTNU - the Norwegian University of Science and Technology – and the Norwegian method now is referred to as the NTNU method).



Principle sketch of the NTNU abrasion tests

For TBM cutter wear prediction, a test piece of cutter steel is used instead of the tungsten carbide test piece used for percussive drilling estimation, and the parameter CLI (cutter life index) is calculated instead of BWI.

The Abrasion Values NAV/AVS represent time dependent abrasion of tungsten carbide / cutter steel caused by crushed rock powder. The same test equipment as for the NAV is used to measure the AVS, but instead of the tungsten carbide test pieces used for NAV, the AVS test uses test pieces of steel taken from a cutter ring.

The two tests are defined as follows:
NAV: The Norwegian Abrasion Value is the mean value of the measured weight loss in milligrams of 2 -4 tungsten carbide test work-pieces after 5 minutes, i.e. 100 revolutions of testing, by using an abrasion apparatus and crushed rock powder.
AVS: As described for NAV, but with 1 minute, i.e. 20 revolutions of testing.

For the AVS-test, the standard NTNU / SINTEF test procedure (shown in the figure above), is as follows:

- A representative rock sample consisting of approx. 2kg is used for preparation of abrasion powder.
- Crushing is done gently in several crusher steps to avoid excessive production of fines. The initial crushing is performed in a jaw crusher with the outlet opening adjusted to 10mm. Further crushing is performed using a smaller laboratory crusher in minimum 2 steps. The outlet opening is adjusted to approx 3mm-4mm prior to the first crusher step.
- The crushed material is sieved on a 1 mm quadratic mesh. The fraction < 1 mm is transferred to a suitable pan and the fraction > 1 mm is crushed again after adjustment of the outlet opening to approx. 1 mm. This process is repeated until the grain size distribution is 99% <1 mm and 70±50/ <0.5mm.
- The crushed powder is mixed thoroughly before pouring it into the funnel on the vibrating feeder connected to the abrasion apparatus. The test apparatus is set-up by starting the rotation of the steel disc together with the suction assembly and gradually adjusting the vibrating feeder until a thin and uniform layer of abrasion powder covers the track.
- 2-4 cutter steel test work-pieces are prepared by grinding them to the specified dimensions. The grinding of the test surface is a critical step and extra care is needed to avoid overheating. The edges of the test surfaces are ground, honed and visually examined to make sure that they are smooth and straight. The test bits must also be absolutely clean and dry before weighing to the nearest 0.001g.
- One of the controlled test pieces is clamped under the load and placed gently on the steel disc. The test surface should be horizontally aligned with the steel disc, as it should otherwise be adjusted by the clamping of the test piece and the suspension of the load.
- Testing time is 1 minute, i.e. 20 revolutions. The amount of abrasion powder fed onto the steel disc should be sufficient, but not excessive. It is therefore important to adjust the vibrating feeder during the test in order to avoid steel against steel abrasion or a pile of powder in front of the test piece. The operator should also make sure that the test piece runs in the middle of the track and that a single point of it does not bear directly against the steel disc.
- Test pieces from 2-4 parallel tests are rinsed and dried thoroughly before weighing. The weight loss is calculated, and the results should normally not deviate by more than 5 units (mg).

The NAV or AVS is reported in units of micrograms of mass lost from the work-piece.

AVS classification for rocks based on the NTNU/SINTEF database of 1590 rock samples

Category	% of Total	AVS
Extremely low	5	<1
Very low	10	2–3
Low	20	4–2
Medium	30	13–25
High	20	26–35
Very high	10	36–44
Extremely high	5	>44

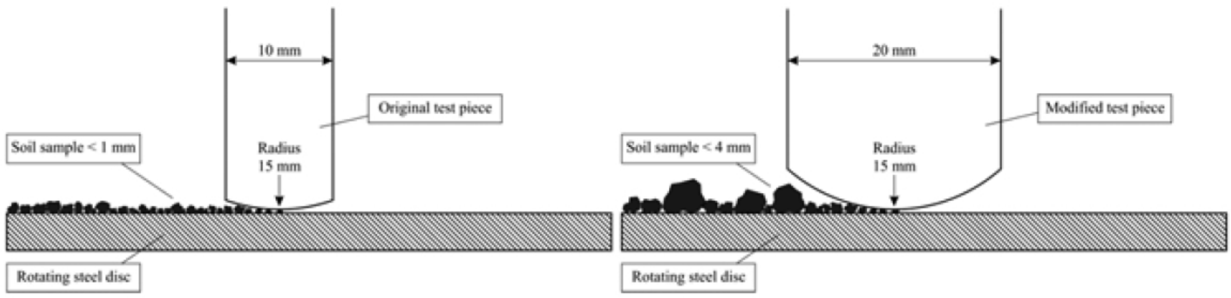
Analysis of past decades' results of testing in this laboratory shows the following distribution of Abrasion Value Steel values:

Lower decile	0.5
Lower quartile	1.6
Median	13.2
Upper quartile	23.9
Upper decile	81.3

<u>The Soil Abrasion Test (SAT)</u>

The new NTNU Soil Abrasion Test is a further development of the earlier abrasion tests for rock. Compared with the AVS test, only two details were changed :

- Instead of crushed rock powder < 1 mm a sieved soil sample with an upper grain size limit of 4mm is used in the SAT test
- the geometry of the original test pieces, as used for NAV & AVS were modified (enlarged) for the SAT



The original (left) and modified SAT test pieces (right)

Soil samples are dried gently in a ventilated oven at 30°C for 2-3 days. After drying the following techniques are used in order to disintegrate and separate the particles for the abrasion powder :

1. Disintegration by use of a soft hammer.
2. Initial disintegration with a jaw crusher of any very hard lumps of cohesive material.
3. Sieving.

SAT-testing of the sieved fraction is carried out according to the same procedures as for AVS-testing.

CERCHAR Abrasivity :

The width of the wear flat, measured in units of 0.1mm, induced on a sharpened steel needle (HRC = 55) having a 90^o conical tip, held with its axis perpendicular to a rock surface, under a load of 7 kg, slowly displaced in a direction parallel to the rock surface for a distance of 10mm, is reported as the CERCHAR Abrasivity Index.

Note the criteria for abrasiveness published by CERCHAR(1986), and modified by Sandvik Mining & Construction (2007) :

0.3 - 0.5	"*not very abrasive*"	<0.5	"not abrasive"
0.5 - 1.0	"*slightly abrasive*"	0.5-1.0	*"little abrasive"*
1.0 - 2.0	"*medium abrasiveness to abrasive*"	1.0-1.3	*"moderately abrasive"*
2.0 - 4.0	"*very abrasive*"	1.3-1.8	*"considerably abrasive"*
4.0 - 6.0	"*extremely abrasive*"	1.8-2.3	*"abrasive"*
6.0 - 7.0	"*quartzitic*"	2.3-3.0	*"very abrasive"*
		3.0-4.5	*"highly abrasive"*
		>4.5	*"extremely abrasive"*

CERCHAR (Dureté*Abrasivity)

CERCHAR Dureté (or Toughness) is not directly measured, but is deduced from published correlations between Uniaxial Compressive Strength and CERCHAR Dureté.
The product of CERCHAR Abrasivity and CERCHAR Dureté is a measure of the difficulty of cutting a rock.
Hughes (1986) was of the opinion that a value of 18 was the desirable upper limit for the use of light-duty roadheaders.
Recent observations indicate that rocks with a value of up to 60 or 80 can be cut by heavy roadheaders.

Schimazek's Wear Index "F"

$F = (V.d.T_o)/100$

Where V = Percentage of hard minerals, standardized against quartz
d = Mean diameter of the contained quartz grains (or of the other dominant hard minerals, multiplied by a reduction factor)
T_o = Brazilian tensile strength

The measured percentage of each mineral is multiplied by a conversion factor based on Mohs hardness e.g.

Mohs hardness	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	1.0

Collective conversion factors can be used e.g.

Hornblende -	0.31
Feldspars -	0.3
Argillaceous minerals -	0.04
Carbonates -	0.03

Correlations by several authors between CERCHAR Abrasivity Index and the Schimazek Wear Index allow the qualitative descriptive terms to be applied to the latter :

CERCHAR Abrasivity Index		Schimazek Wear Index
0.3 - 0.5	"*not very abrasive*"	0.001 – 0.01
0.5 - 1.0	"*slightly abrasive*"	0.01 – 0.1
1.0 - 2.0	"*medium abrasiveness to abrasive*"	0.1 – 0.4
2.0 - 4.0	"*very abrasive*"	0.4 – 1.8
4.0 - 6.0	"*extremely abrasive*"	1.8 – 4.9
6.0 - 7.0	"*quartzitic*"	4.9 – 7.3

Paddle Abrasiveness :
This test was originally developed by the Allis Chalmers Company to describe the abrasiveness of rock fragments, for the specification of materials with which to face the jaws of rock crushers, to resist abrasive wear by the crushed rock.
The test was later standardised by the U.S. Bureau of Mines.
Each test material consists of 400 grams of rock fragments, passing through a 3/4 inch (19mm) screen and retained on a 3/8 inch (9.5mm) screen.
A steel paddle is rapidly stirred through the rock fragments for 15 minutes, and the resulting weight loss is measured.
The total weight loss caused by 4 test runs, in tenths of a milligram, is reported as the Paddle Abrasiveness.

This is a useful test for indicating whether a crushed and fragmented rock might be expected to cause undue wear to metal wear surfaces, in applications like loaders, scrapers, pipes, etc.

Analysis of past decades' results of testing in this laboratory shows the following distribution of Paddle Abrasiveness values:

Lower decile	37
Lower quartile	88
Median	200
Upper quartile	590
Upper decile	1393

Approximate CERCHAR Abrasivity values deduced from Paddle Abrasiveness:

Compilation of test data indicate a trend line of the form
CERCHAR Abrasivity Index = 0.29*(Paddle Abrasiveness $^{0.40}$)

On this basis, Paddle Abrasiveness values may be assigned the following tentative descriptions:

1-4	"*not very abrasive*"
4-22	"*slightly abrasive*"
22-128	"*medium abrasiveness to abrasive*"
128-738	"*very abrasive*"
738-2056	"*extremely abrasive*"
2056-3036	"*quartzitic*"

<u>The Abroy (LCPC) Abrasimètre</u>

The Abroy abrasimètre is used to investigate the abrasiveness of rocks under varied testing conditions typical of the various types of wear encountered, in accordance with standard NF P 18-579. This abrasimètre was designed at the Laboratoire Centrale des Ponts et Chaussees (LCPC) in France, and the commercial version is sold by IGM.
The equipment has a cylindrical steel receptacle into which is inserted a steel vane (50mm * 25mm * 5mm thick) that rotates in a horizontal plane. A mass of crushed rock is put into the receptacle. The standard mass is 500 g, with a specified material granularity of 4/6.3mm
The stirring action, as the vane rotates through the crushed rock at a speed of 4,500 rpm, subjects the vane to wear, and the rock to breakage.
The abrasivity index is expressed as grams of steel worn off the vane per tonne of material treated, reaching as high as 2500g/t for extremely abrasive rocks.
The breakability index is expressed as the percentage of the original mass which will pass through a 1.6 mm aperture sieve at the conclusion of the test.

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