Wear Prediction in Hardrock Excavation Using the CERCHAR Abrasiveness Index (CAI)

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ABSTRACT: The Cerchar scratch test is one of the most common testing procedures used for laboratory assessment of hardrock abrasivity worldwide. The paper resumes findings on geological factors and testing conditions influencing the CAI value. Correlations are given for the CAI and other parameters related to rock abrasivity, as for example the Equivalent Quartz Content, the LCPC Abrasimetre or Rock Abrasivity Index (RAI) as well as correlations for tool wear rate estimations on drill bit lifetime, specific point attack pick wear rate and cutter disc lifetime.

1 INTRODUCING THE CERCHAR SCRATCH TEST

The choice of an economic excavation method and estimations on excavation rates and wear costs are challenging tasks in the preliminary stage of any hardrock underground project. In this stage of a project, mostly geotechnical engineers and engineering geologists are faced with various geotechnical parameters in order to estimate excavation rates and tool consumption. In addition to various other relevant parameters for predicting excavation rate and tool wear (see Thuro & Plinninger, 2002 for a compilation), the Cechar scratch test and the derived parameter, the Cerchar Abrasiveness Index (CAI), represent one of the most common testing procedures for the laboratory research of hardrock abrasivity worldwide. This paper is intended to give a current state-of-the-art overview of Cerchar testing and interpretation of CAI values.

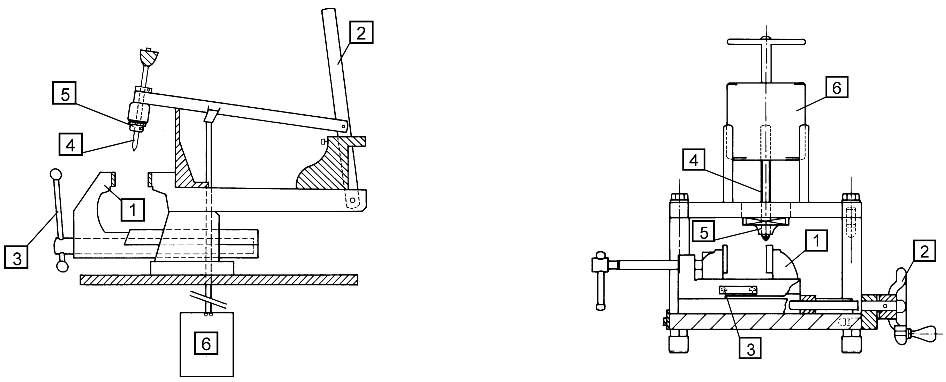
The testing principle of the Cerchar scratch was invented in France in the mid 1980s. It is based on a steel needle with defined geometry and quality that is scratched over 10 mm of a rough rock sample under a static load of 70 N. The CAI is then calculated from the measured diameter of the resulting wear flat on the testing needle. The extended use of the test by various manufacturers of tunnelling equipment as well as research institutes and consultants in the field of rock excavation has led to the CAI being a “standard” parameter for hardrock classification. The CAI is for this purpose also referred to by the Austrian ÖGG recommendations for the geomechanical design of underground structures (ÖGG, 2001).

2 TECHNICAL ASPECTS OF CERCHAR TESTING

2.1 *Testing equipment and testing velocity*

Two types of testing devices are in use today: The original “Cerchar apparatus“, according to the layout presented in the Cerchar recommendations (1986), and the “West apparatus“, according to the testing device presented in West, 1989 (Fig. 1).

The original layout (Fig. 1, left) features a vice holding the rock specimen and a testing lever that is directly connected to the steel pin. The steel pin is loaded with a static force of 70 N and scratched over the rock surface by moving the lever at a velocity of 10 mm/sec. The “West apparatus” (Fig. 1, right) also features a vice and a steel pin loaded with 70 N. In contrast to the “Cerchar apparatus”, the testing velocity is slower, taking 10 seconds for the 10 mm scratching distance. This is because of the different movement control which is done by a hand crank that moves the rock sample below the pin.



“Cerchar apparatus”			*“West apparatus”*		
1+3 sample vice		2 hand lever	1 sample vice	2 hand crank	3 vice sled
4 testing pin	5 pin chuck	6 weight	4 testing pin	5 pin guide	6 weight

Fig. 1: Testing devices to determine the CAI according to Cerchar (1986) and West (1989).

Although there is a great difference in testing velocities, the values derived from both types of testing setups are generally estimated to be equal. Nevertheless, experience has shown that testing velocity may have a major influence on the testing results of the “Cerchar apparatus”. When the testing surface is extremely rough or coarse grains force the needle to bounce, the wear flat may be deformed and testing velocities should be reduced to some seconds/mm.

2.2 *Testing needles – shape and material properties*

The geometrical features of the testing pin are precisely defined in the testing recommendations (Cerchar, 1986) and have not been varied in the past. Although the recommendations suggest the use of hardened steel with a Rockwell Hardness HRC of 54-56 and a tensile strength of about 2000 MPa, steel qualities have in the past been varied in a wider range for different reasons, as there are problems in material procurement (West, 1989) or “better” testing results while testing low abrasive rock types (Al-Ameen & Waller, 1994). The authors have suggested the use of a 115CrV4 tool steel hardened to 55 HRC in their IJRMMS Technical Note (Plinninger, Käsling, Spaun & Thuro, 2003). Special care should also be taken when resharpening used testing pins. High temperatures arising from sharpening too quickly can influence the hardness of the pin tip and may therefore have a negative impact on CAI values obtained using such pins.

Currently there seems to be a problem throughout the world with using different steel qualities. Recent discussions give rise to the supposition that the pin hardness may vary around HRC 40-43 or around HRC 54-56. Since any change in the mechanical properties of the testing pin has a significant impact on the CAI values obtained, the steel quality should be clearly defined in the testing report. Unfortunately there are currently no research available on the comparison of CAI values derived from tests with different steel qualities so that testing results with differing pin quality cannot be compared with standard tests (HRC 54-56).

2.3 *Surface conditions of rock specimen*

With reference to the Cerchar testing recommendations, the tests should be carried out on even, "broken" surfaces. Experience has shown that in many inhomogeneous rock types (such as conglomerates, course grained granite or schistous rock types), no suitable rock surfaces may be gained by breaking the rock sample with a hammer or any other splitting device. As a result of this problem, the influence of different surface conditions has been investigated by comparing samples of the same rock type that had been formatted using different methods: a) samples with "rough" surfaces, produced by splitting using a hammer and b) samples with "smooth" surfaces, after cutting using a water cooled diamond saw. The actual data shows a good correlation between both surface conditions. The flattening of the regression curve in Fig. 2 points towards an increasing influence of surface roughness with increasing CAI: In contrast with low CAI values, where tests on rough and saw-cut surfaces lead to more or less equal results, tests on very abrasive rock samples show remarkably higher CAI values on rough samples than on saw-cut surfaces.

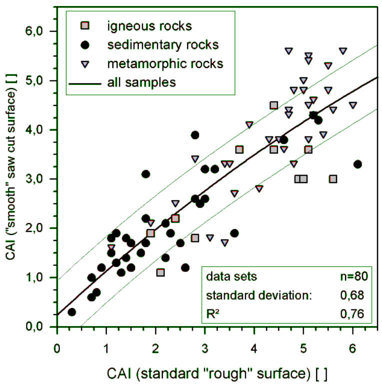


Fig. 2: Plot of CAI values gained on the same rock samples after different surface formatting.

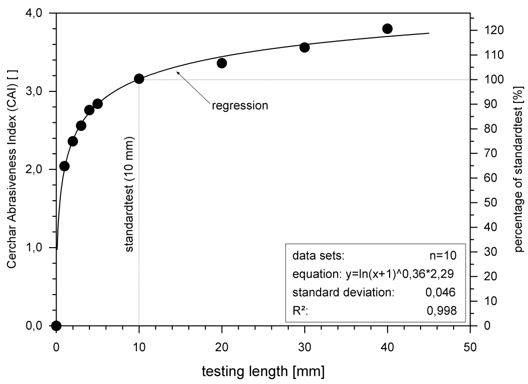


Fig. 3: Plot of CAI versus testing length.

2.4 *Testing length*

The scratching distance on the rock sample is defined with a length of 10 mm. At the beginning of the research work at TU München (TUM), a longer testing length was taken into consideration for a greater wear flat and therefore better evaluation of the CAI value. A series of tests were carried out on identical rock samples with differing testing lengths (Fig. 3) which confirmed observations presented a few years earlier by Al-Ameen & Waller (1994): About 70 % of the pin wear occurs during the first millimeter of the testing length and only 15 % of the change in CAI are achieved on the last 8 mm of the testing path. According to these findings, the testing length would have to be extended to some 5-10 cm to achieve noticeable greater wear flat on the testing pin. Based on these results, lengthening the scratch distance was considered to be useless. As a positive impact of this effect, deviations in the CAI value coming from the variation of scratch length will not be very significant when the variation in testing length is kept between ± 0.5 mm in length.

2.5 *Number of tests*

Cerchar (1986) considers 2-3 single tests as sufficient for fine-grained, homogenous rock samples and suggests 5 or more tests only for samples with a grain size of more than 1 mm. Based on testing experience, the authors suggest 5 individual tests for every rock sample to achieve a better defined mean value.

2.6 *Evaluation of test results*

The original Cerchar paper (1986) recommends a "microscopic reading method" of the pin wear flat diameter which is not described in detail. The authors suggest the use of a reflected light microscope and evaluation of the wear flat with 50x magnification and a measuring ocular. The error of this method is at about 0,02 mm (=0,2 CAI). In addition to this, the wear form of the pin should be considered: Two measurements should be carried out at a 90° angle to each other and a mean value should be used for further interpretation, which gives a representative reading, even when the wear flat is too asymmetrical for simple and proper reading of the wear flat diameter.

3 CORRELATING CAI AND OTHER WEAR-RELEVANT PARAMETERS

3.1 *CAI vs. Quartz Content*

West (1989) proposed the Quartz Content being the main geomechanical parameter influencing the CAI value and found a fair correlation for 29 data sets with low abrasiveness (Fig, 4, left). Focussing on this proposal, a research program at TU München was conducted by Käsling (2000). 109 different rock samples with a broad range of abrasiveness (CAI=0.3 to CAI=5.6) were investigated using the Cerchar Test and some additional "standard" hardrock parameters, such as UCS, Young´s Modulus and Brazilian Tensile Strength as well as petrographical thin section analysis. In contrast with West´s proposal, these records, presented in Fig. 4 (right), show that the (Equivalent) Quartz Content alone is not suited to interpret the abrasion values of the Cerchar Scratch Test. Similar correlations presented for the CAI and the Abrasive Mineral Content by Al-Ameen & Waller (1994) could also not be confirmed.

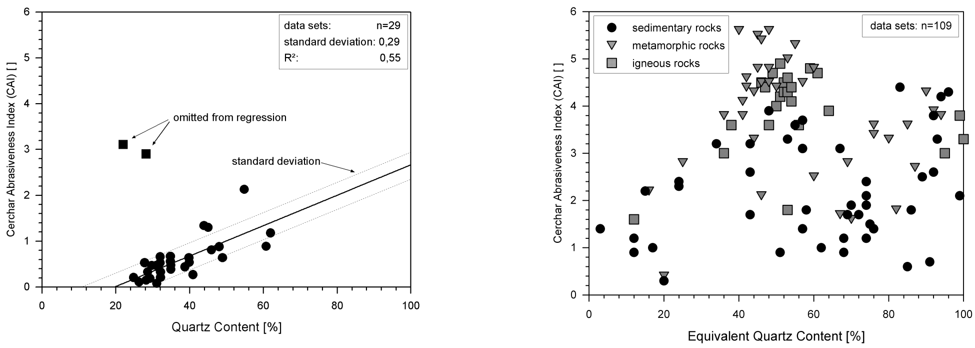


Fig. 4: Cerchar Abrasiveness Index (CAI) plotted against the Equivalent Quartz Content. On the left the results by West [2], on the right the results of the TUM research program.

3.2 *CAI vs. Young´s modulus and Equivalent Quartz content*

As a conclusion of the TUM testing program combination of all available rock parameters lead to the finding that a product of Young's Modulus and the Equivalent Quartz Content of a rock sample was best suited to interpret the CAI by means of "classical" rock mechanical parameters. The fair correlation presented in Fig. 5 gives rise to the supposition that the rock´s abrasiveness determined using the Cerchar Scratch Test is mainly influenced by its deformability and the content of abrasive minerals.

3.3 *CAI vs. LCPC Abrasimetre(Abroy index)*

Büchi, Mathier & Wyss (1995) have presented a fairly good linear correlation between the CAI Value and another rather often used index test, the LCPC Abroy Index ABR, which is measured as material loss of a defined steel plate after rotating through a sample of crushed rock material (Fig. 6).

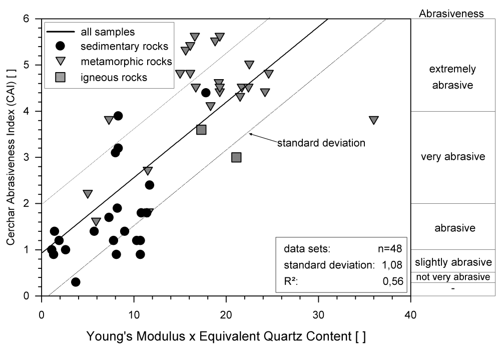


Fig. 5: Cerchar Abrasiveness Index (CAI) plotted against a product of Young's Modulus and Equivalent Quartz Content.

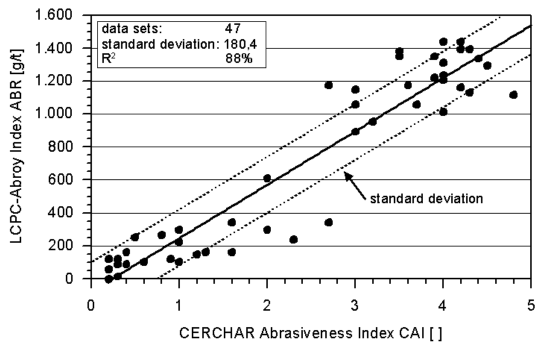


Fig. 6: Cerchar Abrasiveness Index (CAI) plotted against the LCPC Abroy Index (Büchi, Mathier & Wyss, 1995).

3.4 *CAI vs. Rock Abrasivity Index (RAI)*

The Rock Abrasivity Index, RAI is a new geotechnical wear index presented by Plinninger (2002). The RAI is easily calculated by multiplying the rock´s Unconfined Compressive Strength and Equivalent Quarz content. From the current data available, a fair logarithmic correlation between CAI and RAI can be proposed (Fig. 7).

4 TOOL WEAR PREDICTION USING THE CAI

The CAI is primariliy used to investigate and classify hardrock abrasivity. For that purpose a classification scheme is available from the testing recommendations of Cerchar (1986).

Another main application of the CAI is the estimation of tool wear rates in hardrock operations. For this task, empirical equations and correlations have to be used. Unfortunately such data is rare, since used machines and tools vary in a wide range and more detailed case studies are rather expensive in respect to time and cost. Figures 8 to 10 resume the current level of knowledge for tool wear rate estimation based on the CAI or a combination of CAI and and other additional rock parameters as the rocks Unconfined Compressive Strength (UCS).

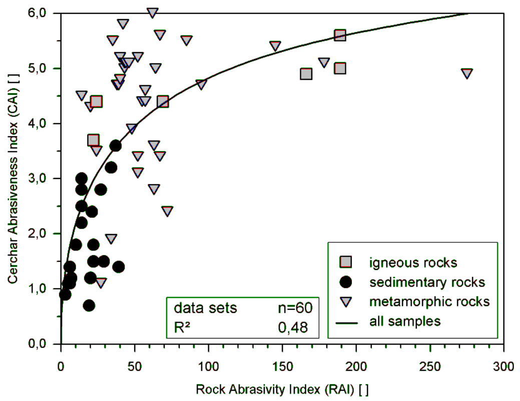


Fig. 7: Cerchar Abrasiveness Index (CAI) plotted against the Rock Abrasivity Index (RAI).

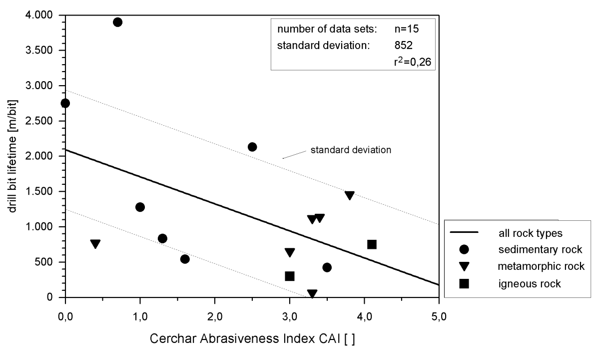


Fig. 8: Correlation of 45mm button bit lifetime [m/bit] and CAI (Plinninger, Spaun & Thuro, 2002)

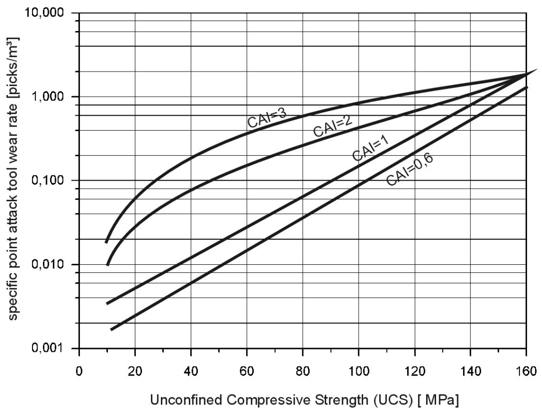


Fig. 9: Correlation of point attack pick consumption [picks/m³] and CAI (Voest Alpine)

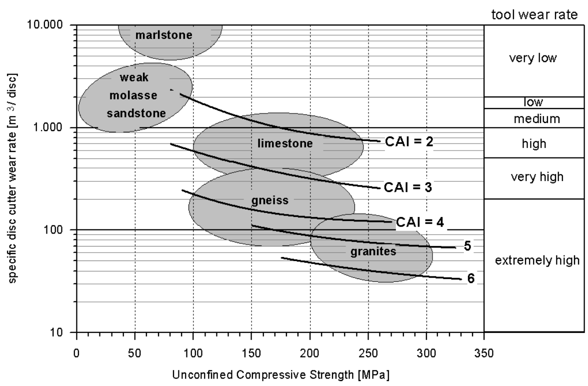


Fig. 10: Correlation of TBM cutter life [m³/disc], UCS and CAI for some common rock types (Maidl, Schmid, Ritz & Herrenknecht, 2001)

5 CONCLUSIONS

The Cerchar Scratch test and the derived Cerchar Abrasiveness Index represent one of the most common geotechnical parameters for describing and classifying hardrock abrasivity. Technical aspects of Cerchar testing have in the past been studied extensively by research institutes worldwide. As a summary of the presented data, the authors evaluate the Cerchar Test as a very quick and simple testing method for rock abrasivity classification. Rough estimations on tool wear rates, like drill bit lifetime, point attack pick consumption or disc cutter wear based on empirical correlations are possible.

Nevertheless comparisons between different geotechnical wear prediction procedures (for example Deketh, 1995; Plinninger, 2002) show that simple model tests, like the Cerchar test have some weaknesses that give rise to the supposition that even with more and better data sets tool wear predictions that exceed rough estimations will never be possible with these tests. Geotechnical research programs including the whole range of scale from mineral to rock and rock mass parameters promise a more reliable prediction. Geotechnical indexes such as the Schimazek index, Equivalent Quarz Content or Rock Abrasivity Index used in the course of such research programs may also offer a better understanding of what causes a rock´s abrasiveness, than a simple scratch test.

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