Determining rock abrasivity in the laboratory

H. Käsling & K. Thuro
Engineering Geology, Technische Universität München, Germany

ABSTRACT: The present work light on a set of tests for the determination of abrasivity, whose results are used for the estimation of tool wear not only in TBM tunneling but also in rock drilling, in the use of road headers, in foundation constructions by pilling, etc. The Cerchar abrasivity test has to be highlighted as a widely used test especially during cost calculation in TBM tunneling. Furthermore the LCPC abrasivity test has become more and more important in rock and soil testing. Even as both tests are partly regulated by standards they are performed in multitude of variations which results in highly differing results and updating of the test recommendations is needed. For the practical use of both abrasivity tests a suggestion of a unique classification scheme has been set by the authors.

1 INTRODUCTION

The abrasivity of rock and even soil is a factor with considerable influence on the wear of tools. Hereby the wear is a question of material consumption and is in addition to the excavation speed an important indicator of rock excavation in tunnelling, underground mining or quarrying. The wear depends on the one hand on the machinery being used for excavation; that are the devices and all tools who have contact to the rock or loosened material. On the other hand the rock and the geological conditions can be specified by geotechnical parameters. The abrasivity of rocks can be described even by the petrografic composition, in particular the contribution of hard minerals like quartz. This more geological way of determination is used when the quartz or equivalent quartz content of rock is specified by microscopic examination of a thinsection. Another, more technical way is to determine the abrasivity of rocks by laboratory tests where some kind of model or index test is used. In the following paper the Cerchar abrasivity test as well as the LCPC abrasivity test are explained, some technical issues are commented and a unified classification system for both tests is presented.

2 CERCHAR ABRASIVITY TEST

2.1 *Testing principle*

The Cerchar Abrasivity Test has been introduced in the 70s by the *Centre d'Etudes et Recherches des Charbonages (CERCHAR) de France* for abrasitiy testing in coal bearing rocks. The test layout is described in Cerchar (1986) and in the French standard NF P94-430-1 in general.

The testing principle is based on a steel pin with defined geometry and hardness that is scratches the surface of a rough rock sample over a distance of 10 mm under static load of 70 N. The Cerchar-Abrasivity-Index (CAI) is then calculated from the measured diameter of the resulting wear flat on the pin (Figure 1):

$$CAI = 10 \cdot \frac{d}{c} \tag{1}$$

where *CAI* = Cerchar-Abrasivity-Index (-); *d* = diameter of wear flat (mm); *c* = unit correction factor (c=1mm).

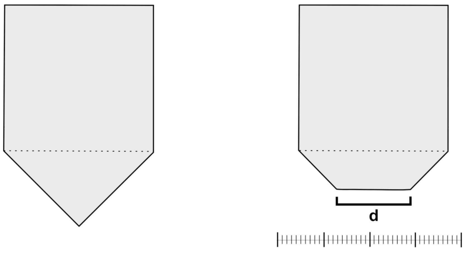

Figure 1. Sketch of the steel pin with rectangular shape before the test (left) and after the test (right) with the wear flat *d*.

As result of a worldwide survey it can be stated, that two testing devices with little modifications according to Cerchar (1986) and West (1989) are used in similar frequency (Figures 2 and 3).

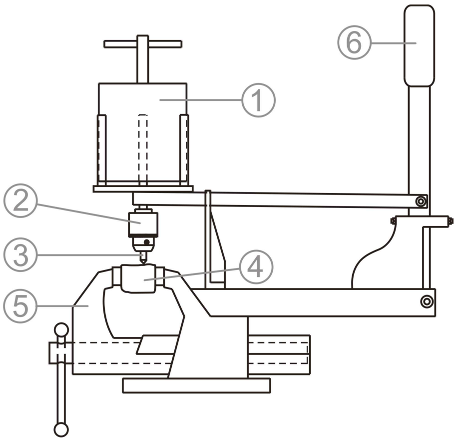

Figure 2. Setup of a modified Cerchar testing device according to Cerchar (1986). 1 – weight, 2 – pin chuck, 3 – steel pin, 4 – sample, 5 – vice , 6 – hand lever.

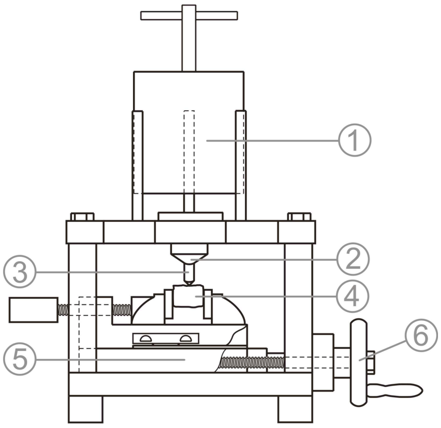

Figure 3. Setup of a testing device according to West (1989). 1 – weight, 2 – pin guide, 3 – steel pin, 4 – sample, 5 – vice sled, 6 – hand crank.

2.2 *Variations and influencing factors*

The Cerchar-Abrasivity-Index is used as a key parameter in prediction models for TBM tunneling (Gehring 1995, Rostami et al. 2005) and for roadheader excavations. Therefore reliable test results are needed to ensure the practicability of this index test as a quick and easy way to gain information about abrasivity of rocks worldwide.

Modifications of the test setup (Al-Ameen & Waller 1993, West 1989), who are partly not in familiar with the French standard headed to a multitude of testing variations and highly differing testing results all over the world. This leads to inadequate prediction of tool wear and often in unexpected cost over-runs. This inaccuracy could have been observed during several tunneling projects in Europe, North America and Australia in the last decade. Highly varying testing results from different laboratories have also been shown by Rostami (2005) and Rostami et al. (2005).

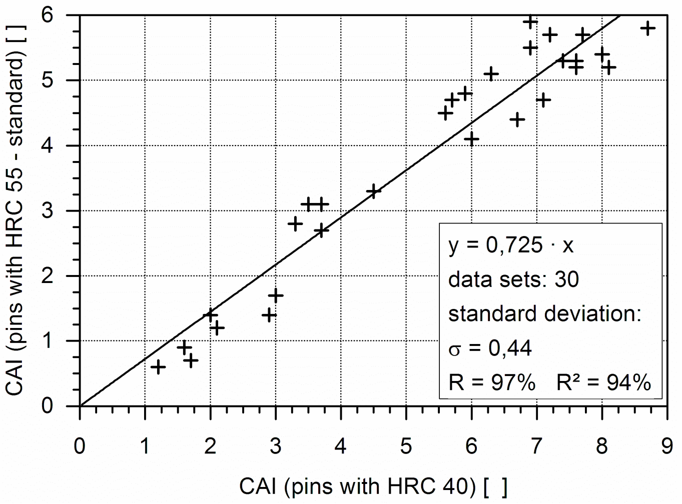

Figure 4. Results of Cerchar abrasitity tests carried out with steel pins of different hardness HRC 54-56, according to the French standard NF P94-430-1, and HRC 40 according to Al-Ameen & Waller (1993) or West (1989).

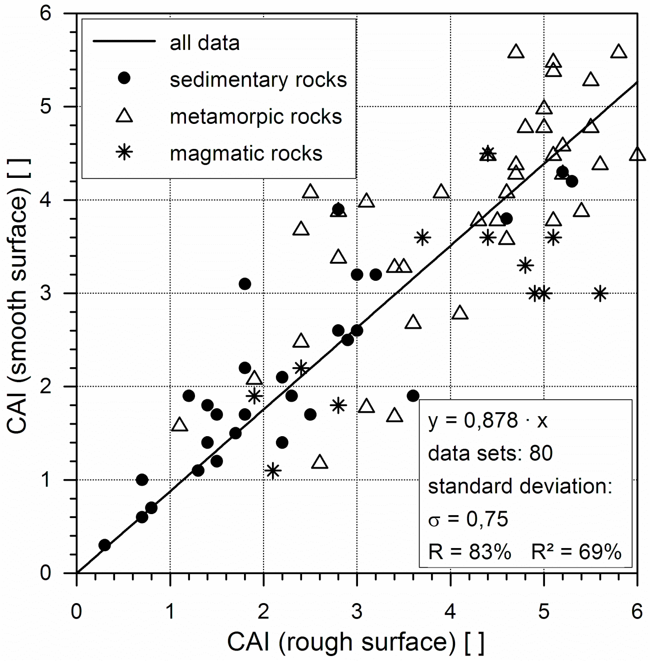

Figure 5. Results of Cerchar abrasitity tests carried out on rough rock surfaces and smooth, saw cut surfaces in Käsling (in prep.).

Numerous influences that have been evaluated during the last years are described in Käsling et al. (2007) and Käsling (in prep.).

Some influencing factors are shortly described in the following. At first the used testing equipment has to be stiff enough that the steel pin is accurately guided over the rock surface. Secondly and maybe the core point is the steel. Not only an adequate steel grade has to be used but also the required hardness of the pin has to be ensured. A worldwide survey at rock laboratories showed that steel pins of Rockwell hardness HRC54-56 like in the original literature and the French standard NF P94-430-1 are used as well as steel pins of a much lower hardness (HRC 40). Figure 4 shows a correlation of testing results by both hard and soft steel pins. On the face of it, the results can not be compared as easy, as stated by Michalakopoulos et at. (2005). In addition some laboratories carry out the test on plain, saw cut rock surfaces. As Figure 5 shows the CAI derived at this smooth, saw-cut surface is bit lower than the CAI derived on the rough, freshly broken rock surface recommended in the French standard. Again a reliable conversion from a saw-cut surface CAI in a rough-surface CAI and vice versa is difficult due to the high deviation at high CAI values. Furthermore the orientation of the test using anisotropic rocks and the precise reading of the wear flat of the steel pin using a microscope are relevant for comprehensible results.

3 LCPC ABRASIVITY TEST

3.1 *Testing principle*

The LCPC abrasivity testing device (Figure 6) is described in the French standard P18-579 and has been developed by the *Laboratoire Central des Ponts et Chausées (LCPC)* in France for testing rock and aggregates. The “abrasimeter” is built of a 750 W strong motor holding a metal impeller rotating in a cylindrical vessel which contains the granular sample. The rectangular impeller is made of standardized steel with a Rockwell hardness of HRB 60-75. The grain size of the sample has to be in a range between 4 to 6.3 mm; rock accordingly has to be crushed before the test accordingly.

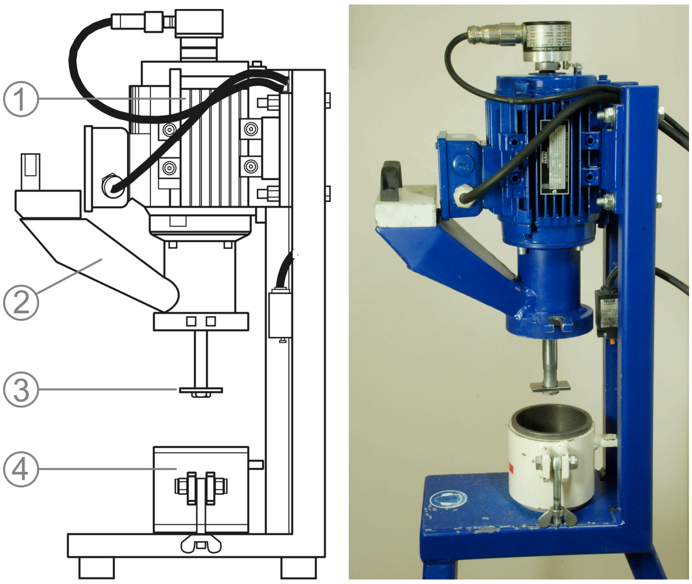

Figure 6. LCPC abrasivity testing device according the French standard P18-579 (1990). 1 – motor, 2 – funnel tube, 3 – steel impeller, 4 – sample container.

The LCPC-Abrasivity-Coefficient (LAC) is calculated as the mass loss of the impeller divided by the sample mass (500 g):

$$LAC = \frac{(m_0 - m)}{M} \quad (2)$$

where LAC = LCPC-Abrasivity-Coefficient (g/t); m_0 = mass of impeller before test (g); m = mass of impeller after test (g); M = mass of the sample material (=0.0005t).

With the aid of the LCPC abrasivity test, the breakability or brittleness of the sample material can be quantified too and a modified classification is given in Table 1. The LCPC-Breakability-Coefficient (LBC) is defined as the fraction below 1.6 mm of the sample material after the test:

$$LBC = \frac{(M_{1.6} \cdot 100)}{M} \quad (3)$$

where LBC = LCPC-Breakability-Coefficient (%); $M_{1.6}$ = mass fraction < 1.6 mm after LCPC test (g); M = mass of the sample material (=0.0005t).

Table 2. Classification of the LCPC-Breakability-Coefficient (LBC) according to Käsling (in prep.), modified from Büchi et al. (1995).

LBC [%]	Breakability classification
0-25	low
25-50	medium
50-75	high
75-100	very high

4 CLASSIFICATION SCHEME

The common rock samples, the Cerchar-Abrasivity-Index varies between 0 and 6 and the LCPC-Abrasivity-Coefficient varies between 0 and 2000 g/t. As shown in Figure 7, there is a close linear correlation between the LAC and the CAI for the tested rock samples. Therefore the well-known Cerchar-Abrasivity-Index is used as a basis for a combined classification scheme as shown in Table 3 instead of the classification given in Büchi et al. (1995).

Table 3. Classification of the LCPC-Abrasivity-Coefficient (LAC) in connection with the CERCHAR-Abrasivity-Index (CAI) according to Thuro et al. (2007).

LAC [g/t]	CAI [0.1]	Abrasivity classification	Examples
0-50	0.0-0.3	not abrasive	organic material
50-100	0.3-0.5	not very abrasive	mudstone, marl
100-250	0.5-1.0	slightly abrasive	slate, limestone
250-500	1.0-2.0	(medium) abrasive	schist, sandstone
500-1250	2.0-4.0	very abrasive	basalt, quartzitic sdst.
1250-2000	4.0-6.0	extremely abrasive	amphibolite, quartzite

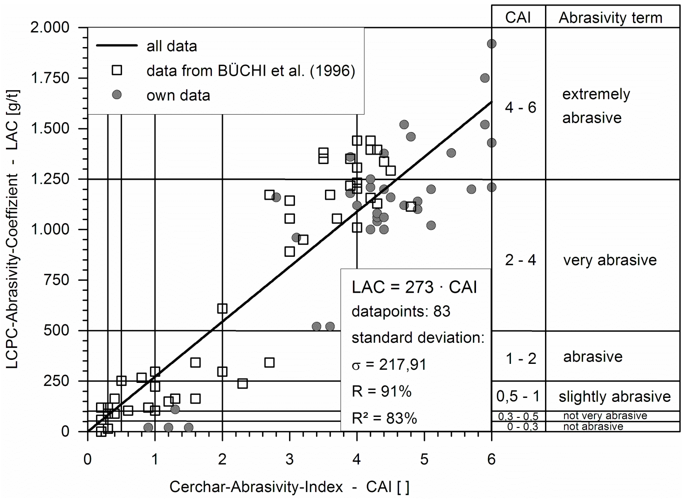

Figure 7. Correlation between CAI and LCPC abrasivity testing results using data in Büchi et al (1995) and results from own studies (modified from Thuro & Käsling 2009).

5 CONCLUSIONS

The Cerchar abrasivity test is in worldwide use for abrasivity assessment of rocks and wear prediction. His results are directly linked with the prediction model of the Colorado School of Mines for TBM cutter wear (Rostami et al 2005) and is used for wear predictions of roadheaders too. Due to variations of the test occuring in the last decades, reliable and comparable testing results are occasionally non-existent. Revised testing recommendations for the Cerchar abrasivity test are in preparation by the DGGT working party 3.3 Versuchstechnik Fels (rock testing technology) and will include the main influencing factors that have been evaluated during the last years.

The LCPC abrasivity test becomes more and more common for rock and soil testing in Europe. A French standard describes the testing facility in detail but ongoing work has to be done to implement testing of soil and aggregates satisfying. Also for this test, testing recommendations are in preparation by the DGGT working party

In addition a unified abrasivity classification for the Cerchar Abrasivity Index and the LCPC Abrasivity Coefficient as shown in Table 3 could have been presented. It is based on the classification of Cerchar (1986) and has successfully been proven in construction practice with the CAI for years.

By the use of the presented laboratory tests, in some cases unusual test results have occurred. They can be caused by the specific test style and impact when testing a certain rock type; (e.g. very inhomogeneous or anisotropic rocks). Therefore it is helpful to combine the model or index test with additional petrographic respectively thin section analyses. This reinsurance can help to avoid bad surprises and disputes during tunneling works.

REFERENCES

Al-Ameen & Waller 1993. The influence of rock strength and abrasive mineral content on the Cerchar Abrasive Index. *Engineering Geology* 36: 293-301.

Büchi, E., Mathier J.-F. & Wyss, Ch. 1995. Gesteinsabrasivität – ein bedeutender Kostenfaktor beim mechanischen Abbau von Fest- und Lockergestein. Rock abrasivity – a significant cost factor for mechanical tunnelling in loose and hard rock. *Tunnel* 5: 38-44.

Cerchar - Centre d´Études et des Recherches des Charbonages de France. 1986. *The Cerchar abrasiveness index*. Verneuil.

Gehring, K.-H. 2005. Leistungs- und Verschleißprognosen im maschinellen Tunnelbau. *Felsbau* 16 (6): 439-448.

Käsling, H., Thiele, I. & Thuro, K. 2007. Abrasivitätsuntersuchungen mit dem Cerchar-Test – eine Evaluierung der Versuchsbedingungen. In Otto (ed.) *Veröffentlichungen von der 16. Tagung für Ingenieurgeologie, 7.-10. März 2007.* Bochum: Technische Fachhochschule Georg Acricola.

Käsling, H. (in prep.). Bestimmung der Gesteinsabrasivität – Grundlagen, Anwendung und Einsatzgrenzen bei maschinellen Tunnelvortrieben. *Münchner Geowissenschaftliche Abhandlungen,* (B) 19, München: Verlag Dr. Friedrich Pfeil.

Michalakopoulos, T. N., Anagnostou, V. G., Bassanou, M. E. & Panagiotou, G. N. 2005. The influence of steel styli hardness on the Cerchar abrasiveness index value. *Int. J. Rock Mech. Min Sci. & Geomech. Abstr.* 43: 321-327.

Normalisation Française P18-579. 1990. *Granulats: Essai d'abrasivité et de broyabilité*. Paris: AFNOR Association française de normalisation.

Normalisation Française P94-430-1. 2000. Roches - Détérmination du pouvoir abrasive d'une roche. Partie 1: Essai de rayure avec une pointe. Paris: AFNOR Association française de normalisation.

Rostami, J. 2005. CAI testing and its implications. *Tunnels & Tunnelling International*, 37 (10): 43-46.

Rostami, J., Ozdemir, L., Bruland, A. & Dahl, F. 2005. Review of Issues related to Cerchar Abrasivity testing and Their Implications on Geotechnical Investigations and Cutter Cost Estimates. In J. D. Hutton, & W. D Rogstad (eds) *Proceedings of the 2005 Rapid Excavation and Tunnelling Conference (RETC) in Seatle.* Littleton: Society for Mining, Metallurgy and Exploration.

Thuro, K. & Käsling, H. 2009. Classification of the abrasiveness of soil and rock. *Geomechanics & Tunnelling* 2: 179-188.

Thuro, K., Singer, J., Käsling, H. & Bauer, M. 2007. Determining abrasivity with the LCPC Test. In E. Eberhardt, D. Stead & T. Morrison (eds.). *Proceedings of the 1st Canada – U.S. Rock Mechanics Symposium, 27.-31.05.2007, Vancouver B.C.,* London: Taylor & Francis.

West 1989. Rock abrasiveness testing for tunnelling. *Int. J. Rock Mech. Min Sci. & Geomech. Abstr.* 26: 321-327.