Initial stress conditions influencing the Cerchar abrasiveness index

SASCHA RUEHL[1] & MICHAEL ALBER[2]

[1] *Engineering Geology, Ruhr-Universität Bochum. (e-mail: sascha.ruehl@ruhr-uni-bochum.de)*
[2] *Engineering Geology, Ruhr-Universität Bochum. (e-mail: michael.alber@ruhr-uni-bochum.de)*

Abstract: Several rock properties affect the advance rates of hard rock TBM drives. One of the most common tests used to measure rock properties assesses the abrasiveness of the rock. This is known as the Cerchar abrasiveness test. The Cerchar abrasiveness index (CAI) is a number calculated from a direct laboratory test.

Many technical and geological factors influence the CAI. This paper presents a new method to estimate the relationship between initial stress conditions and the CAI value. The increase of the CAI for the Coburg sandstone is 0.09 CAI per MPa confining pressure.

Résumé: Au total, onze échantillons de roche ont été examinés avec le test abrasif de Cerchar sous quatre différentes pressions confinées chacun.

Dans tous les essais, il y avait de l'augmentation du CAI (l'index abrasive de Cerchar) parallèlement avec l'augmentation de la pression confinée. La dépendance du CAI de la tension sur la roche peut être formulée comme une équation linéaire. L'augmentation du CAI pour le grès de Coburg est 0.09 CAI per MPa pression confinée.

Keywords: engineering geology, laboratory tests, mechanical properties, stress, substructures, tunnels.

INTRODUCTION

Cost accounting and performance calculation of hard rock TBM drives is heavily dependent on the features of the rock mass that is to be drilled through. Unlike many other geological characteristics, important rock features can be estimated accurately using laboratory tests on intact rock samples.

One of the major factors affecting TBM drives is the abrasive character of the rock. The worldwide used Cerchar abrasiveness index has been established to assess this value. Another influencing factor is the primary stress status in the rock mass, which can be well determined analogously to the Cerchar abrasiveness index (CAI), whose influence has, however, been not quantifiable so far. This paper considers the influence of different stress conditions on the CAI to generate a basis to take into account the primary stress status in the rock mass.

EXPERIMENTAL SETUP AND TEST EXECUTION

The experimental setup includes the Cerchar testing device after Cerchar (1986) and a triaxial cell after Hoek and Franklin (1968) (Figure 1), where different stress situations can be created. The diameter of the cell used is 40mm.

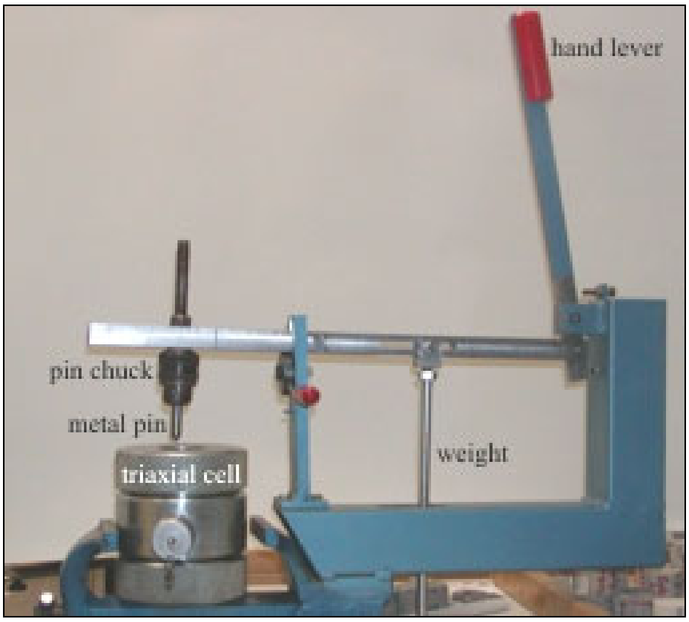

Figure 1. Testing Equipment with Cerchar apparatus and triaxial cell

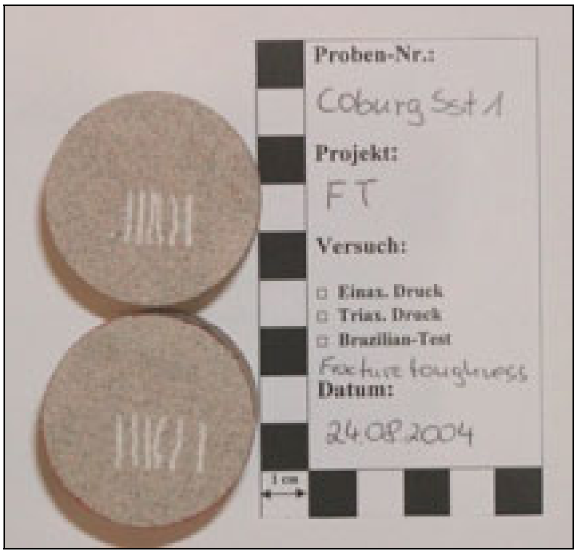

Figure 2. Tested rock specimen

The test pens are made of tempered steel with a Rockwell hardness of 54-56 and a sharp cone apex of 90°. The head of the test pen is carefully placed on the quarry-rough surface of the rock mass and axially loaded with 70 N. By pulling the hand lever the aglet is moved at a rate of 10mm/ second over the quarry-rough rock surface. The cylindrical rock samples are constrained within the triaxial cell and are loaded by the confining pressure. The abrasion of the aglet is thus determined against the restraint of the sample. The confining pressure of the triaxial cell is operated servo-hydraulically and is kept constant during the test. The result is analysed (using a microscope) by measuring the abrasion of the aglet in mm. The result is multiplied by a factor of 10 and shows the CAI of the stress condition set.

The test material was obtained from cores of fracture toughness tests, so that two equal quarry-rough rock surfaces per rock sample were available for testing. On these two surfaces, the CAI was determined under four different confining pressures. Three single tests were undertaken for each confining pressure stage (Figure 2). Eleven samples were tested; seven with the confining pressure stages 0.0-2.5-5.0-7.5 MPa and four with the confining pressure stages 0-4-8-12 MPa.

TESTED ROCK

The rock tested was the Coburg sandstone (Figure 2). Its constitution is: 50.4% of quartz, 37.6% of weathered plagioclase and 28% of Mica. This equates to an equivalent quartz content of 65.7%. The rock features determined are summarised in table 1.

Table 1. Coburg Sandstone properties

Density	2.26 g/cm^3
Compressional wave velocity	2466 m/s
Resistivity	13.9 Ωm
Uniaxial compressive strenght	49.4 MPa
Tensile strenght	3.1 MPa
Fracture toughness K_{1C}	0.22 $MPam^{1/2}$

RESULTS

For representing the stress dependency of the CAI the results were evaluated using a CAI vs. confining pressure diagram. The analysis was carried out for every single test, as well as for the averages of the single tests with each confining pressure. Every single test consisted of three scratch tests at four different confining pressures.

The CAI for the eleven tested samples of Coburg sandstone varied between 0.6 und 1.2. The median of the CAI is 1.0, with a standard deviation of 0.2 (Table 2). The CAI rises with increasing confining pressure in all tests carried out (Figure 3, 4). The increase of the CAI along with the confining pressure can be expressed as a linear equation (Figure 5).

$$CAI_\sigma = m\sigma + CAI$$

where CAI_σ is the Cerchar abrasiveness index under load where stress is σ, m is the gradient of the straight line; σ is the load of the rock in MPa.

The rise of the CAI with the confining pressure is very similar in both confining pressure stages 0.0–2.5–5.0–7.5 MPa, and 0-4-8-12 MPa and averages 0.1 CAI/MPa. The, one exception is specimen 6 where the increase of the CAI by 0.18 CAI/MPa is almost twice as large as the average for the other specimens. The correlation coefficient R^2 of the linear smoothing function is between 0.79 und 1.00 for all samples (Table 3). Standard deviation of the results is constantly 0.2 for the confining pressure stages of 0.0 – 7.5 MPa. It increases to 0.3 in the case of confining pressure of 8 MPa and to 0.4 with a confining pressure of 12 MPa. If the median of the CAI is taken as representative average for the rock tested regarding the different confining pressure stages and if it is approximated by a linear equation, the result for the Coburg Sandstone is:

$$CAI_{\sigma} = 0.1\sigma + 1.0$$

Table 2. Standard deviation of the median CAI value at the different confining pressures

Confining pressure [MPa]	0.0	2.5	4.0	5.0	7.5	8.0	12.0
Median CAI	1.0	1.3	1.5	1.6	1.8	1.7	2.2
Standard deviation	0.2	0.2	0.2	0.2	0.2	0.3	0.4

Table 3. Increase and correlation coefficient for the linear smoothing function

Specimen No.	1	2	3	4	5	6	7	8	9	10	11
Increase m CAI / MPa	0.08	0.10	0.08	0.13	0.08	0.18	0.14	0.12	0.10	0.08	0.07
Correlation coefficient R^2	0.79	0.90	0.93	0.97	0.79	0.78	0.98	1.00	0.96	0.98	0.98

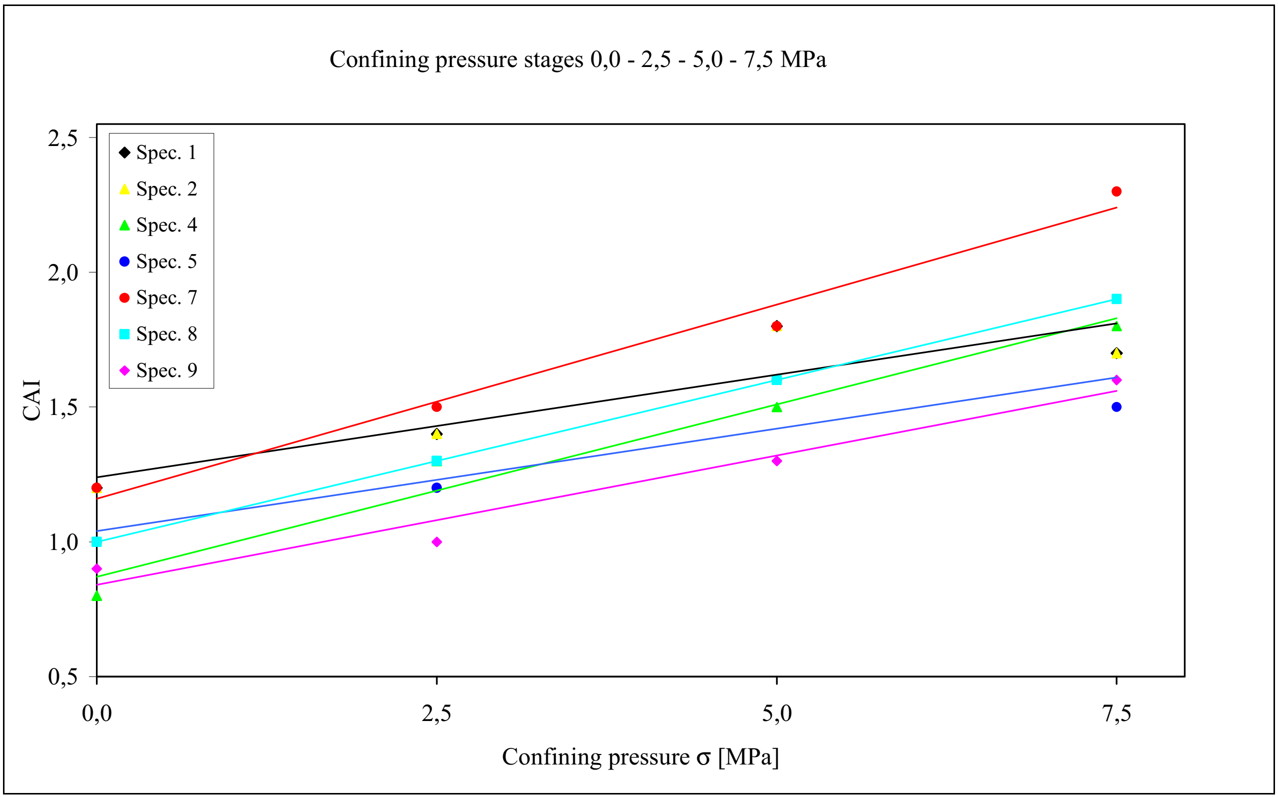

Figure 3. Increase of CAI values for single tests with confining pressure 0.0 -7.5 MPa

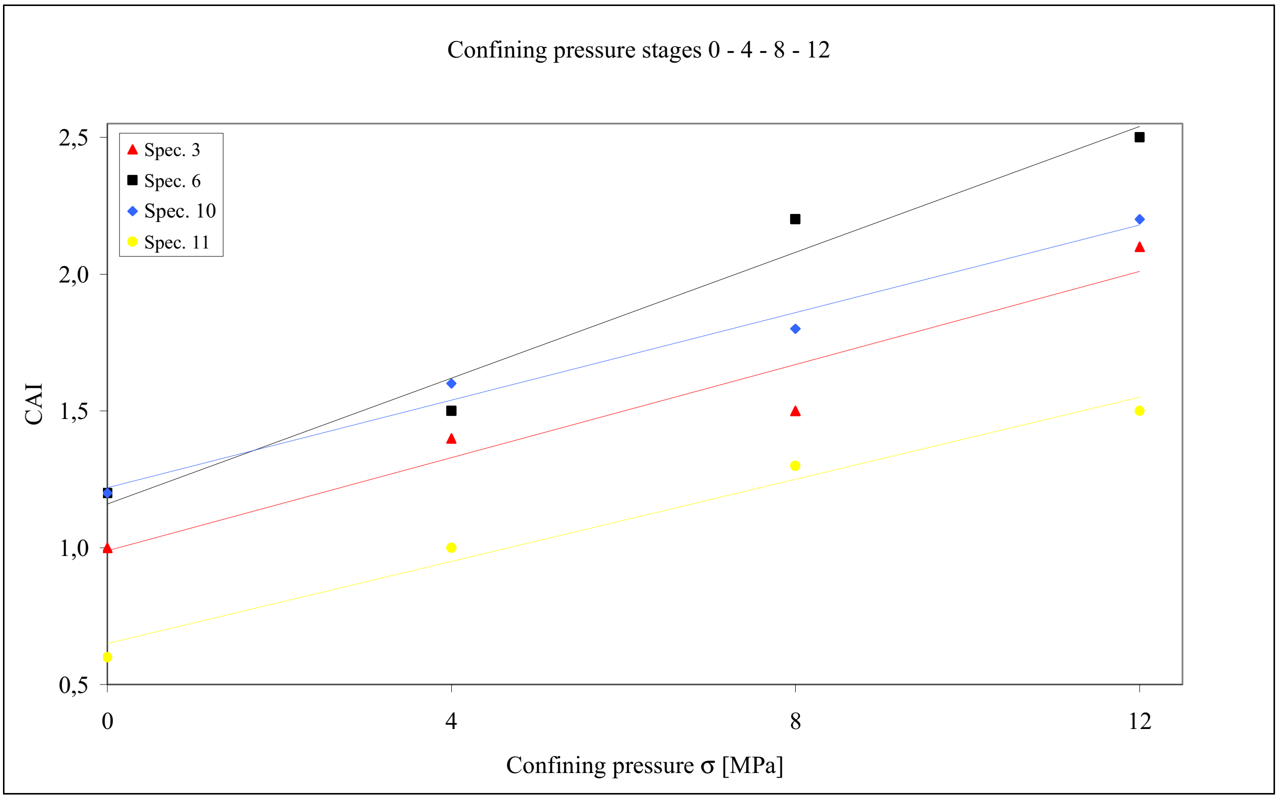

Figure 4. Increase of CAI values for single tests with confining pressure 0.0 -12.0 MPa

DISCUSSION

The uniform standard deviation of the CAI in the case of the Coburg sandstone and the highly positive correlation of linear regression between the different confining pressure stages indicate that different results are mainly due to sample variations rather than the testing procedure and apparatus. Confining pressures above 7.5 MPa, however, seems to effect the spread of the results. Due to the results, the process described could be applicable for describing stress dependency of the CAI. Compared to results for other rocks, there is a need to investigate how the influence of testing conditions and geomechanical properties on the CAI, as described by Plinninger *et al*. (2003) – (e.g. the surface conditions of the specimen), can be determined by applying a further confining pressure.

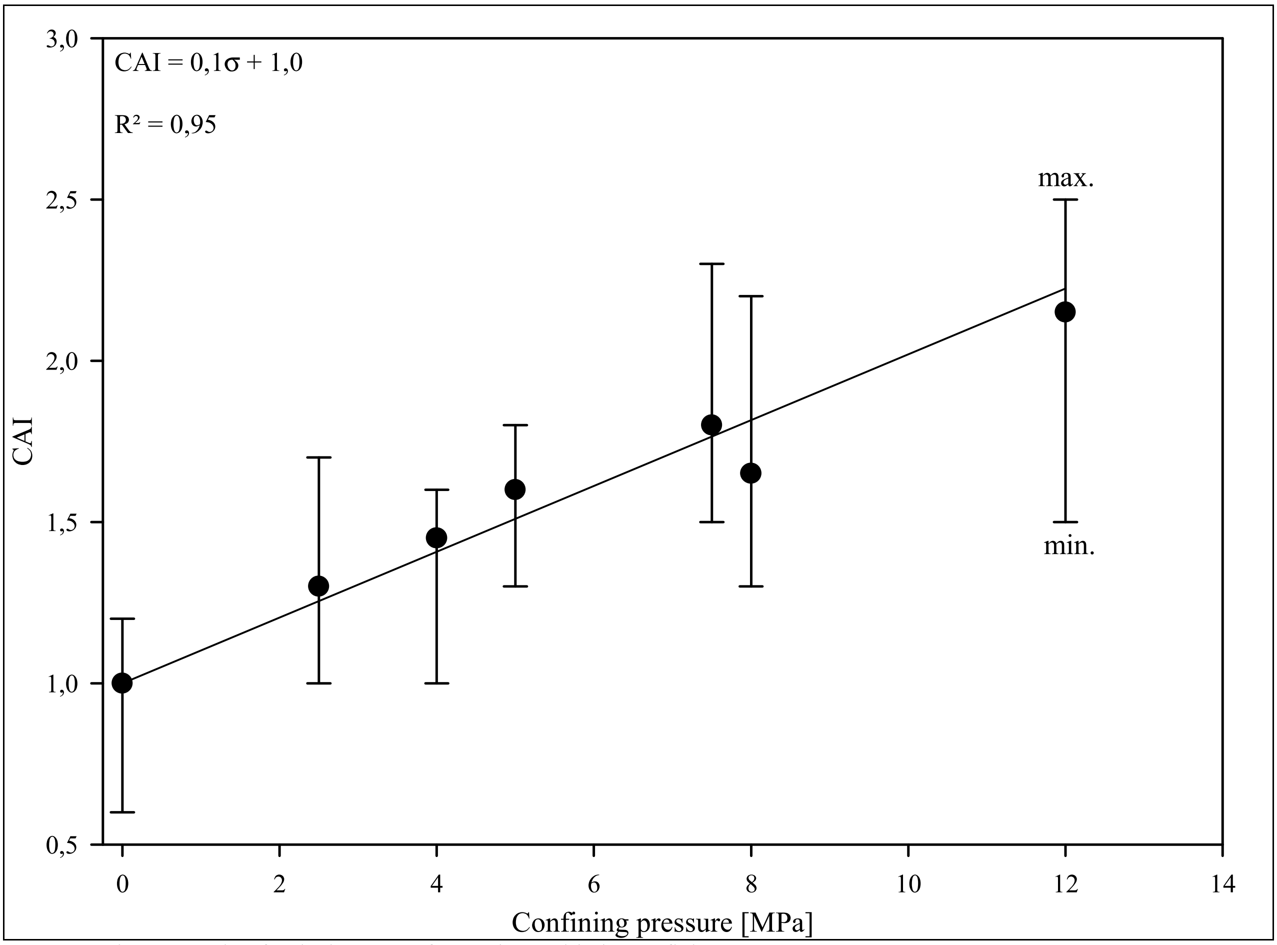

Figure 5. Linear equation for the increase of CAI along with the confining pressure

The dependency of the CAI as function of the calculated quartz equivalence, as formulated by Suana and Peters (1982), cannot be confirmed for the Coburg sandstone. However, the relation of the CAI to the quartz content supports that reported by West (1989). According to Büchi, Mathier and Wyss (1995) the combination of the CAI with other rock characteristic values provides significant results regarding abrasive features of a rock mass in the case of mechanical excavation. Therefore, the combination of the stress dependent CAI_{σ} in combination with other rock characteristic values, especially in the case of deep undergrounds spaces, seems to be rather promising as a method for evaluating the abrasion in the case of mechanical advance rates.

SUMMARY

Cerchar abrasiveness tests have been carried out on eleven rock samples at four different confining pressures for each sample. All tests resulted in the increase of the CAI with rising confining pressure. Dependency of the CAI of the pressure on the rock can be presented as a linear equation. The increase of the CAI for the Coburg sandstone is 0.09 CAI per MPa confining pressure.

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