Cerchar Abrasivity test in tunnelling: a modified version for evaluating the performance of conditioning agents as wear preventers

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The Cerchar Abrasivity test is used for assessing the abrasion of rock due to its simplicity and fast execution and it is considered one of the main wear indexes in tunnelling. Despite in standard condition the test is performed on a dry surface of a rock sample, this study introduces the possibility to carry out the test on a conditioned surface. In details, this work compares the Cerchar Abrasivity Index (CAI) results of rock specimens subjected to three conditions: dry, saturated with water, and saturated with a polymeric slurry.
First, dry samples were prepared according to the standard procedure while the second and the third sets have been planned in order to simulated the injection of water and polymers respectively, a practise that is nowadays accepted in construction site where rock TBMs are adopted.
Results put alight that the use of conditioning such as water and polymeric slurry on the rock leads to a reduction of the wear potential of the rock itself. Notably, the rock specimen treated with the polymer slurry exhibited the lower value of CAI (with a reduction of 34% compared to the dry sample). The potential benefits of use specific preventing-wear polymer in rock excavation is in conclusion analysed.
Keywords: *cerchar abrasivity test (CAI), wear, conditioning, anti-wear polymer.*

1. Introduction

The prediction of the TBM performances in tunnelling is not a simple issue (Cardu *et al.*, 2021), especially when wear phenomena are present. Wear is a critical issue affecting excavation projects, directly influencing productivity and operational costs irrespective of the excavation is performed in soil or in rock (Salazar *et al.*, 2016a; Salazar *et al.*, 2016b). Several different factors have to be considered when investigating the wear process, such as the excavated material proprieties, the water content, the relative quartz content, the excavation technique, the characteristics of the cutting tools, etc. (Alber, 2008; Rostami *et al.*, 2014; Kasling et. al, 2018; Plinninger *et al.*, 2004).

As concerning tunnelling in rocks, the key issue is the pressure needed on cutters to achieve the rock demolition (Peila *et al.*, 2022) but the wear phenomenon cannot be neglected. A fundamental concern in underground constructions is the capacity of tools to withstand abrasive phenomenon due to the friction between tools and rock, which can lead to premature wear and substituting cutting tools. The necessity to forecast the wear potential of a rock also in the preliminary phase of a tunnel project has led to consider this issue in the NTNU prediction model (Bruland, 1998) even if in order to be correctly applied, this model needs a specific set of test on both integer rock and powdered rock (not easy to be performed). However, a simplified approach for estimating the severity of the wear of a certain rock is available and well consolidated in the scientific literature: Cerchar Abrasivity test (Di Giovanni *et al.* 2023a). This test provides a value that permit the classification of the rock in different ranges, function of the wear severity. Thanks to its simplicity, the Cerchar Abrasivity test became a crucial tool for tunnelling engineers, providing an alert when the tested rock exhibits high value of Cerchar Abrasivity Index (CAI) and leading the project designers to foresee specific countermeasures needed for facing and reducing the wear phenomenon during the tunnel construction.

Right in the view of the countermeasures needed for preventing the wear during tunnelling, rock TBMs machines are often equipped with specific injection lines able to put on the excavation phase conditioning agent as water and/or polymeric foams sprayed with the purpose to control the wear (Grasso *et al.*, 2022).

Taking in mind these important construction details, in this paper an innovative study focused on the rock wear is proposed. Simulating the addiction of conditioning agent on the excavation phase, the Cerchar Abrasivity test (commonly carried out on dry samples of rock) has been carried out on saturated surface. The saturation has been guaranteed by a thin layer of conditioning agent i.e. the water in one case, and a polymeric slurry

(1% by volume of concentration) in the other. Outcomes, compared to those obtained performing the Cerchar test according to the standard (Alber *et al.*, 2014) highlighted the role of conditioning agents on the wear reduction. The research, confirms and expands results presented in Di Giovanni *et al.* (2023b) and adds new precious information on the possibility of limiting the rock's abrasion potential and extend the cutting tools' service life in mechanised rock tunnelling by correctly using conditioning agents.

2. Laboratory test

2.1. Testing material

Samples extracted from an exploratory tunnel known as "the Maddalena" were used to conduct the tests. This tunnel constitutes a crucial section of the Mont Cenis Base Tunnel excavation. The material was subjected to mineralogical characterization through X-ray diffraction analysis, a technique grounded in the interference of X-rays with the crystalline structure of the sample (Young, 1993; Bunaciu *et al.*, 2015). This analytical process was executed within the laboratories of Politecnico di Torino, utilizing an XRD-Rigaku SmartLab SE instrument.

The sample was meticulously ground to create a multitude of randomly oriented crystallites. The incidence angles range covered a span from 4° (initial angle) to 84° (final angle), with a scanning speed of 0.1°/s. This analysis yielded a graphical representation of intensity angles with incidence angles. This graph permits the identification of minerals present in the sample. The analysis unveiled that the rock type corresponds to mica-schist, characterized primarily by the prominent presence of quartz (about 50%), muscovite (about 35%), and other minerals. A sample of the tested material is reported in Figure 1a.

As concerning the conditioning agent, the polymer was provided by Mapei Mapedrill SV, in a dry-powdered state. The slurry was a water solution with 99 parts of water and 1 part of polymer. It was produced by activating the polymer by mixing it in water for 5 minutes by using a rotation mixer with a fixed rotation speed of 2000 rpm. The selected amount of additives was weighed and added to the water (previously set in motion by the impeller) in the first minute. A concrete mixer was used to produce a homogenous slurry. The water was instead taken from the Turin water network.

2.2. Cerchar Abrasivity Index

The Cerchar Abrasivity Index is widely utilized for assessing the abrasiveness or wear potential of rocks and geological materials, playing a crucial role in various industries, including mining and civil engineering (Rostami *et al.*, 2012).

This index is determined through the Cerchar Abrasivity test, a standard procedure in which a steel pin (hardness rating of HRC 55) is forced against a rock surface under a specific load (70 N), and the wear flat of the stylus tip is measured (Alber *et al.*, 2014). This method provides insights into how rocks and geological materials interact with drilling equipment, excavation tools, and construction machinery, aiding engineers in project management and material selection for tunnelling, drilling, and construction applications.

The Cerchar Abrasivity Index, as introduced by Hamzaban *et al.* (2018), has proven to be a valuable tool in the field. To conduct the tests in a standardized manner, the ASTM D7625-22 protocol was followed, utilizing the test apparatus initially designed by West (1989). This standardized testing procedure ensures consistency and comparability of results across various geological and engineering projects, contributing to informed

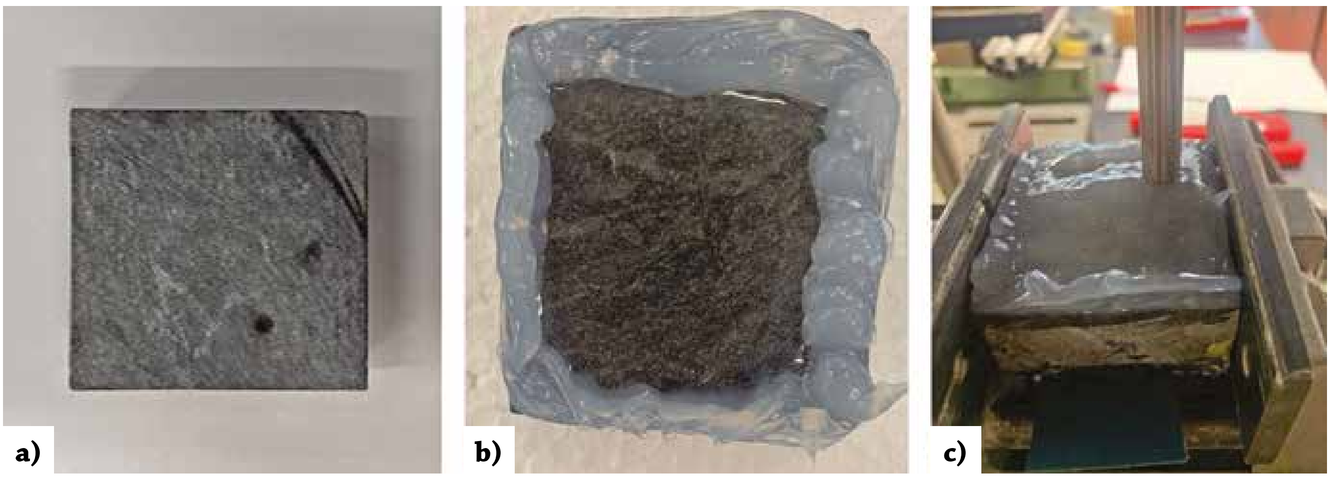

Fig. 1 – Cerchar Abrasivity test samples. a) standard sample tested under dry condition (ASTM D7625-22); b) sample saturated with water; c) sample saturated with a polymeric slurry (1% by volume).

decision-making and improved project outcomes.

The CAIs were estimated by testing three different conditioning environments. The tested conditions were dry, wet (saturated), and slurry with 1% by volume of polymer.

For the dry test, the sample underwent a preliminary drying process, where it was allowed to dry for 24 hours. Conversely, for the saturated condition, the sample was covered with water for 24 hours to ensure it reached an utterly saturated state. Equally, for the slurry condition, the sample was covered entirely with the slurry for 24 hours to achieve full saturation within the slurry medium. For both samples tested with the addiction of conditionings, the rock samples were expressly modified in order to guarantee the presence of the conditioning agents both during the saturation phase (24 hours, as previously described) and during the testing phase (the scratch of the bit on the sample surface). Special "containment banks" with a high of 10 mm have been created on the edges of the samples, by using quick-setting silicone. Modified samples for assessing the CAI on saturated surface are depicted in Figure 1b and Figure 1c.

The CAI values reported in Table 1 are the average of the tests performed (at least 5), while SD is the standard deviation. The classification of the wear potential was drawn up according to ASTM D7625-22 which ranges are reported in Table 2. The CAI reduction (%) is computed on the dry condition values.

The resulting mean CAI values fall within the range of 1.28 to 1.93, indicating a medium level of abrasiveness for the three distinct conditions of the surface.

In Figure 2, the analysis carried out using an electronic microscope is reported. In detail, a bit used for testing a rock sample covered by a layer of polymeric slurry is depicted. The value of the worn bit equal to 0.092 mm is reported, equal to a CAI value of 0.92 (slightly under the average value reported in Table 1).

Tab. 1 – Cerchar Abrasivity test results.

Surface condition	CAI	SD	CAI reduction (%)
Dry	1.93	0.25	/
Wet	1.44	0.08	25
Slurry 1%	1.28	0.05	34

3. Discussion

Results show that the conditioning of the samples tends to decrease the wear severity compared to the dry condition. They confirm that the use of polymers expressly designed to reduce the wear phenomenon can successfully leads to a reduction of the wear magnitude of a certain type of rock. As possible to observe, CAI classification according to ASTM D7625-22 for the three different surface condition is the same, i.e., medium abrasiveness. However, it can be inferred that the obtained values cover all the medium abrasiveness class (1.00-2.00); for the slurry, the CAI value is in the first third part, the wet case is in the middle position and, the dry one instead fall on the highest third sector. For completeness, it should however be reported that the highest CAI registered in the dry condition was 2.16 that corresponds to a high abrasiveness classification.

Tab. 2 – Criteria for the Cerchar Abrasiveness Index (ASTM D7625-22).

Classification	Average CAI (HRC = 55)
Very low abrasiveness	0.30-0.50
Low abrasiveness	0.50-1.00
Medium abrasiveness	1.00-2.00
High abrasiveness	2.00-4.00
Extreme abrasiveness	4.00-6.00
Quartzite	6.00-7.00

The decrease in CAI values, particularly amplified with the slurry, can be attributed to the lubricating effect resulting from the solution between the stylus tip and the rock surface, thus reducing the friction between the two surfaces (Bakar *et al.*, 2016). In particular, the water and slurry saturated conditions registered a reduction in wear compared to the dry state of 25% and 34%, respectively.

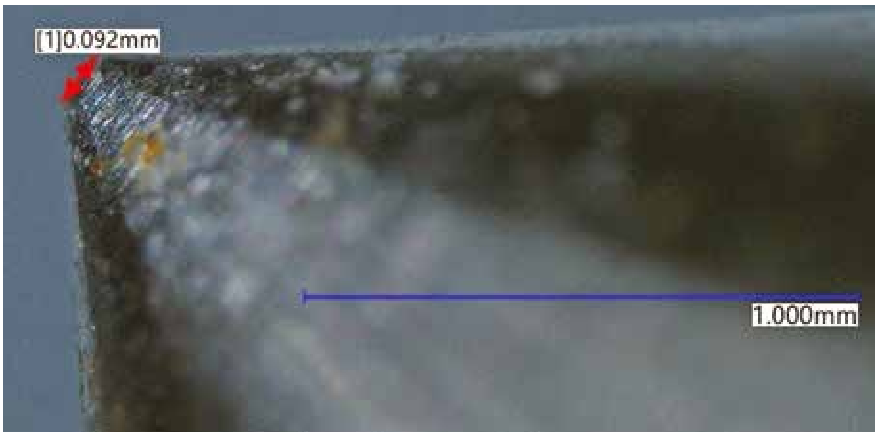

Fig. 2 – Bit after the execution of a Cerchar Abrasivity test performed on a sample covered by a layer of polymeric slurry.

4. Conclusion

Predicting the wear of excavation tools is a multifaceted and intricate area of investigation. Due to its profound implications in excavation projects, impacting costs and time, this phenomenon is a worldwide challenge to establish a standardized predictive model that nowadays is not unique. Furthermore, prediction models that can take into account the action of anti-wear conditioning agent are nowadays not available in scientific literature.

Tests carried out in slurry polymer conditioning sample have shown a noteworthy reduction in wear potential, while the simple use of the water also should be taken into account since a wear reduction is also appreciable. Although this research has provided promising results, it should be considered as a preliminary testing phase since a series of further tests on various rock types (with different quartz content) are necessary. However, evidences reported in this work can be taken as reference for construction sites where TBM machines are facing wear problems since water or polymeric slurry addiction could lead to unneglectable benefits.

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