The soil abrasion test apparatus: a literature review

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# The soil abrasion test apparatus: a literature review

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*The wear phenomenon plays a fundamental role in excavation work, as it directly affects times and costs. While prediction models are available in the literature for rock applications, a standardized procedure for predicting wear is not yet available for soils. In this work, the Soil Abrasion Test Apparatus (SATA) is used to study the wear dependence from the moisture content. 6 different types of soils were tested by varying the moisture content and results were obtained in terms of weight loss and average torque. Considerations are presented on the potential dependence of particle size distribution, grain shape and quartz content on wear.*

**Keywords**: *wear, Soil Abrasion Test Apparatus, moisture content, grain size distribution, quartz content.*

## 1. Introduction

The wear phenomenon is a crucial issue in tunnelling application since it has a direct impact on costs and productivity. Different aspects must be considered in the wear process: properties of the medium to be excavated, water content, pressure applied on the tools and type of metal they are made of. Regardless of the excavation technique, wear always occurs when the tools come into contact with the medium to be excavated, causing the progressive change of their shape and consequently the reduction of productivity. If wear can be controlled in the excavation with demolition hammers and roadheaders by replacing the tools when necessary, the situation is more complex for tunnel boring machines, as the abrasion affects all parts of the machine directly in contact with the excavated material, i.e. tools, and also the bulk chamber and screw conveyor in the case of EPBs. Hence, studies focused on wear prediction are becoming accustomed to being performed in the preliminary phase of a tunnelling project, because the results could lead stockholders to the best choice in terms of tools material or even adaptations of machines expressly designed for the wear control.

For TBM applications in rocks, different studies available in literature are able to predict the wear and the advancement rate of the machine. The Norwegian University of Science and Technology (NTNU) has developed the model currently most used to predict feed rate, cutter wear, and excavation costs for rock TBMs by combining the rock boreability properties and TBM parameters (Macias *et al.,* 2014). The Colorado school of Mines (CSM) provided another valid method based on "full-scale" laboratory tests (Rostami *et al.,* 1993; Rostami *et al.,* 1996) although in this case the phenomenon of wear is not taken into account. Other types of prediction models are also noteworthy, which could be defined indirect, i.e. based on statistical analysis that provide predictive equations based on real case histories (Ates *et al.,* 2014; Park *et al.,* 2018; Cardu *et al.,* 2021) but even in these case the wear is not considered. A different scenario concerns excavation in soils: in fact, at present there is no recognized official approach for predicting wear. Different researchers set up different tests for the wear study. Gharahbagh *et al.* (2011) proposed a test based on a propeller equipped with 3 blades that rotates in a tank covered by the soil to be studied. This work introduces the concept of weight lost (concept taken on by Oñate Salazar *et al.,* 2018), i.e. the difference in weight of the rotating tools computed before and after the rotation in the soil. The test was implemented by Rostami *et al.* (2012) who first highlighted the relationship between weight lost and soil moisture content but, unfortunately, no relationship with soil properties has been recognized. Oñate Salazar *et al. (*2016a), and Oñate Salazar *et al. (*2016b) introduced the soil testing abrasion apparatus (SATA), developing a procedure able to provide the weight loss of an aluminium disk, after a rotation inside the soil to be studied. Although the dependence between soil moisture content and weight loss has been confirmed, parameters strictly related to the soil tested have never been taken into consideration. In this work a review of the literature related to the tests performed by SATA was considered with the addition of a new test campaign. A dataset consisting of 6 different soils was planned and observations related to the nature of the tested soil are provided.

## 2. Materials used

In this work, the results related to various studies carried out at the TUSC laboratory of the Politecnico di Torino were considered. Table 1 shows the names of the soils, images and uniformity coefficients (UC), while Fig. 1 shows the particle size distributions.

It is important to recognize 2 kinds of soils studied. More in depth, soils 1,2 and 3 can be defined as "sharp soils", obtained by means of a crashing process which involved a grain size distribution where the maximum size was 20 mm. Soils 5 and 6, instead, have been obtained after a sieving process where the passing at 20 mm were saved for testing. Soil 4 was the only one tested in its natural state, i.e. no grinding or sieving operations were performed. It can be said that soils 4, 5 and 6 do not have sharp edges, therefore they can be grouped in another type, called "rounded soils". According to the uniformity coefficient, soils 1 and 2 can be defined as non-uniform whereas soils 3, 4, 5 and 6 can be named very varied.

Wear tests were performed by using the SATA on soils conditioned only with water, i.e. no foaming agent or chemicals were added to the samples to be tested. SATA results consist of the weight lost by the tool used to test wear during a single test and the average torque, recorded.

Tab. 1 – Studied soils, pictures and uniformity coefficients.

| ID | Soil name | Picture | UC |
|---|---|---|---|
| 1 | Vagli marble |  | 8 |
| 2 | Quartzite sand |  | 7 |
| 3 | Palombini clay |  | 17 |
| 4 | Etna volcanic sand |  | 19 |
| 5 | Gneiss |  | 13 |
| 6 | Moraine |  | 77 |

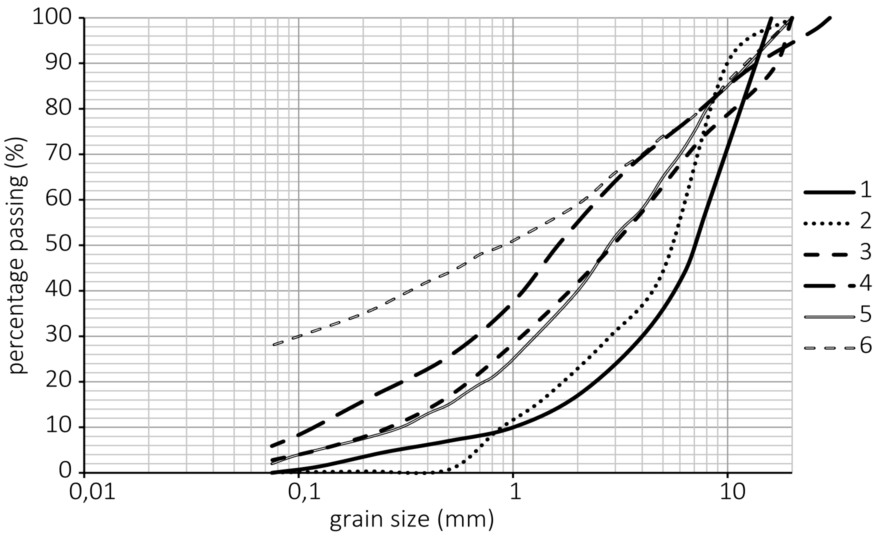

Fig. 1 – Grain size distributions of the studied soils.

## 3. Soil abrasion test apparatus (SATA)

The soil abrasion test apparatus (SATA) has been described in Barbero *et al.* (2012), Oñate Salazar *et al.,* (2016a) and Di Giovanni *et al.* (2022). The scheme of the test is given in Fig. 2.

A steel tank (inner diameter 308 mm; height: 310 mm) is the container for the soil to be tested. An aluminium disc (Vickers hardness = 115.6 MPa) of 120 mm in diameter is fixed on a boom and positioned in the centre of the tank, where it can rotate around its own axis but all translations are constrained. The distance

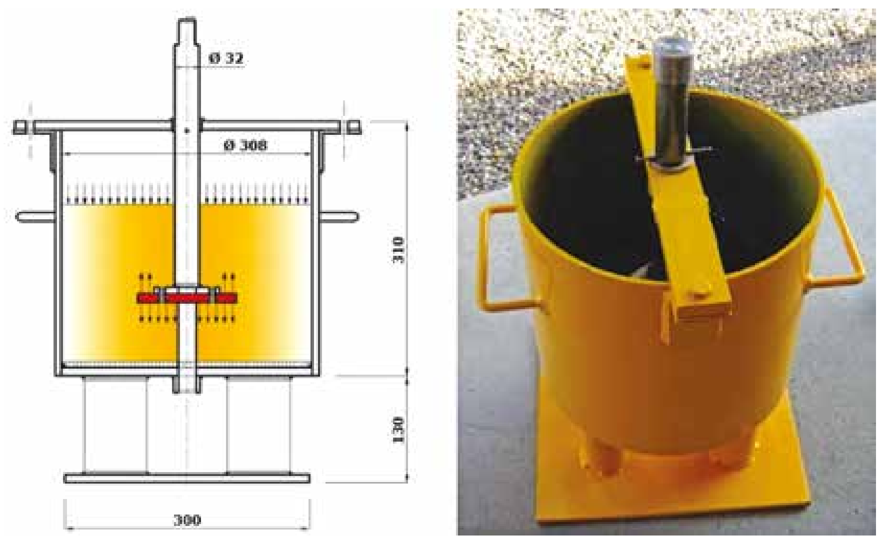

Fig. 2 – SATA scheme.

between the disc and the bottom of the tank is about 75 mm.

The testing procedure is as follows:

1) sample preparation: 20-25 kg of granular soil is mixed with water, previously dosed to reach the expected water content;
2) weighing of the disc: $w_1$ is measured, i.e. the initial weight of the disc;
3) mounting the disc on the drive shaft: the disc is coupled to the drive shaft. The assembled piece is put into the tank and locked with two bolts;
4) filling of the first layer of soil: the tank is filled with conditioned soil from below up to the height of the disc. Correct contact between the soil particles and the bottom surface of the disc is checked manually;
5) filling of the chamber: the tank is filled and a confinement pressure of 2 kPa is applied;
6) test starting: a torque is constantly applied to the drive shaft for a duration of 10 minutes. The rotation speed is kept constant for the entire duration of the test, equal to 160 rpm. An automatic recording of the torque measurement is performed by using a torque meter;
7) weighing of the disc: $w_2$ is measured, i.e. the final weight of the disc.
8) calculation of the weight lost ($\Delta w$).

## 4. Results

Fig. 3 shows the weight lost as a function of the moisture content. At least 3 different tests were carried out for each moisture content considered. The results relating to the average torque are reported as a function of the moisture content in Fig. 4. Also in this case, each datum reported in Fig. 4 is the average of at least 3 values.

## 5. Final remarks

Taking into account Fig. 3, it can be said that almost all soils tested by SATA exhibit a curvilinear bell-like pattern. The wear bells obtained are aligned with the research carried out by Rostami *et al.* (2012) and Jakobsen *et al.* (2013). Considering the magnitude of the wear in terms of weight loss, it can be stated that sharp soils exhibit the more severe wear. Soils 1, 2 and 3 (sharp soils) show very similar peaks with weight loss values close to 0.6 grams. It should however be highlighted that these 3 soils are also very reach in quartz: in fact, the quartz contents are respectively 11%, 98% and more than 50% for soils 1, 2 and 3. It is evident that, despite the presence of quartz, the percentages are very different, and consequently it can be deduced that the shape of the grains, together with the quartz content, play a significant role in the wear phenomenon. Other considerations related to the position of the peaks on the moisture content axis can be deduced. In fact, for these 3 soils, the position of the peak is closely linked to the grain size distribution: the coarser the soil, the coarser the soil, the lower the moisture content where the wear peak is recognizable.

Taking into account soils 4, 5 and 6 (rounded soils) the results are more chaotic. Only soil 5 shows a high peak (about 0.45 grams). This could be always linked to the quartz content, as gneiss is also commonly composed of quartz grains. Soils 4 and 6 show different trends, in fact the wear bells are not recognizable. Anyway, also for these two soils the peaks of the

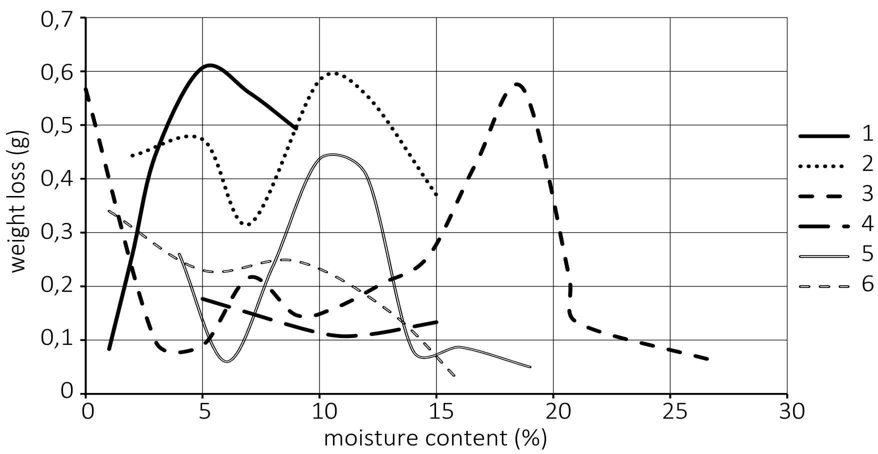


Fig. 3 – Weight lost in function of the moisture content.

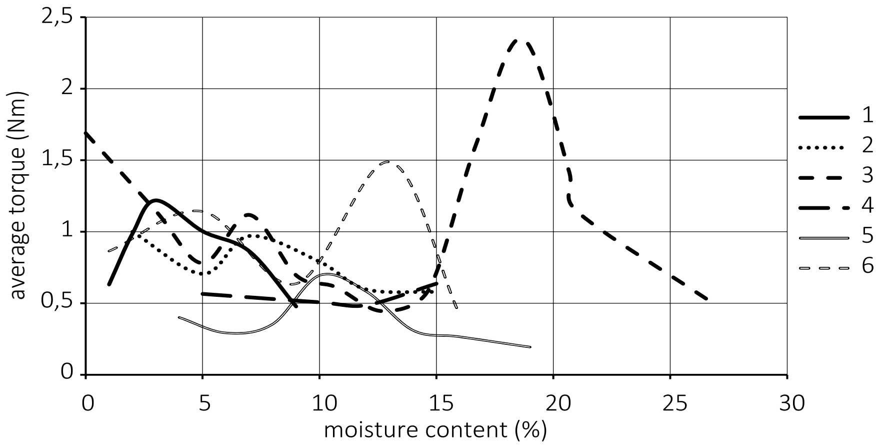


Fig. 4 – Average torque in function of the moisture content.

weight loss can be spotted but, unlike others, they correspond to the lowest moisture content tested. Worthy of note is the Palombini clay wear bell (3): this soil is the only one characterized by two peaks of similar magnitude (about 0.6 g), one for the dry condition and the other for a high moisture content (close to 18%). It can be hypothesized that for the second peak, a sort of "abrasive paste" mad up of quartz grain trapped inside the clay paste operated on the tool. Indeed, as soon as this critical moisture content is exceeded, wear abruptly decreases.

Taking into account Fig. 4, the torque peaks not always correspond of those of weight loss. In fact, this correspondence is recognizable only for soils 3 and 5. For soil 4, the wear bell and the torque have the same trend even if peaks do not match.

## 6. Conclusions

The wear phenomenon is a complex issue, not fully understood at present. In excavation works, wear plays an important role in terms of costs and time and for this reason it is currently studied in various research centres, even if a standardized method for predicting the wear is not available in literature yet. In this work, 6 different soils were studied, divided between sharp and rounded soils. Regardless of the soil considered, the dependence between wear and moisture content was confirmed. However, the expected wear bell was not always obtained, in fact soils 4 and 6 showed a different trend. The quartz content and the sharp shape of the soil particles play a crucial role in the extent of wear. To predict the wear pick as a function of the moisture content, for sharp soils the grain size distribution can be taken as a reference, since coarser soils will probably have the wear peak for a lower water content.

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