A device for assessing the tool wear in soft ground EPBS tunneling

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Mansour Hedayatzadeh*
Jamal Rostami**
Daniele Peila*

* Politecnico di Torino (Italy)
** The Pennsylvania State University (USA)

1. Introduction

In the recent years, Earth Pressure Balance (EPB) shields have been successfully used in many tunnels in urban areas while the range of soil types that it can handle has expanded One of the issues for the design and economical evaluation of soft tunneling project is the use of proper soil conditioning to reduce wear of metallic parts of the machine. The design assessment of the effects of abrasive ground on primary and secondary wear of tools and machine components strongly influence costs and schedule of a project. Among the parameters that can affect tool wear in EBP tunneling, soil conditioning is a relevant and not widely investigated.

In order to assess the impact of the soil conditioning on tool wear, a new test apparatus with new type of propeller has been developed and tested and a specific test procedure has been designed.

Several preliminary tests were conducted to highlight the influence of soil conditioning in the reduction of tools wear in cutter head and other parts of machine.

Modern research has established that there are four main types of wear and each process obeys its own laws (Rabinowicz, 1995): abrasive wear, corrosive wear, surface fatigue wear and erosion wear. Among them, abrasion wear is the most important issue regarding to interaction of metals and hard materials (as is the case in mechanized tunnelling) and it occurs when a rough hard surface or a soft surface containing hard particles, slides on a softer surface and ploughs a series of grooves and the material is displaced in the form of wear particles.

In EPB tunneling, the wear of the cutter head, the chamber and the screw conveyor of machine is due to interaction of soil mass-metal under pressurized condition.

Soil conditioning changes the behavior of soils and leads also to an important reduction of abrasivity and of machine torque requirement (Merit *et al.*, 2003, Thewes *et al.*, 2011 and Peila *et al.*, 2012).

Recently Nilsen *et al.*, (2006) Rostami *et al.*, (2012), Barzegari *et al.*, (2013), Peila *et al.*, (2012), Jakobsen *et al.*, (2013) and Rostami *et al.*, (2013), Alavi Gharahbagh *et al.*, (2014) have paid attention to the wear of soft ground TBMs and some laboratory devices to evaluate the weight loss and torque with using soil conditioning has been developed mainly with the goal to develop a series of parametric studies on soil conditioning to assess their impact on wear level and torque requirements for different sets.

The use of an appropriate propeller allows simulating closely the soft ground tunneling conditions and a new testing device was designed and developed in a joined collaboration between the Pennsylvania State University John and Willie Leone Family Dept. of Energy and Mineral Engineering (USA) and the Department of Environment, Land and Infrastructure Engineering at Politecnico di Torino Laboratory of Tunnels and Underground Space, to simulate the cutter head and the pressure chamber in a an EPB machine. The proposed device has been used to test different soil conditioning, water content and the results have the feasibility of the proposed device for the evaluation of wear and effectiveness of soil conditioning parameters.

2. Test Device and testing procedure

The studied device was specifically developed for this research and it consists of a cylindrical chamber, [350]

The use of mechanized excavation especially EPB shielded tunnel boring machines is growing rapidly in various soft ground tunneling projects. One of the problem to be assessed at a design stage is the wear of the tools and mechanical parts of the machine and the influence on this parameter of the conditioning agents. In the paper a new type of test procedure is presented and the preliminary results are presented and discussed.
Keywords: *soil conditioning, tool wear, shield tunneling, tunneling, soil abrasivity.*

Un'attrezzatura innovativa per prove di usura nello scavo con EPB. *Lo scavo con macchine a piena sezione ed in particolare con macchine scudate tipo EPB è in grande diffusione in tutto il mondo. Uno dei problemi che devono essere definiti già a livello di progettazione è l'usura degli utensili e delle parti metalliche della macchina e l'influenza su questo parametro degli agenti condizionanti. In questo lavoro viene presentata una attrazzatura progettata per studiare questo fenomeno ed i risultati preliminari di una campagna di prove vengono discussi.*
Parole chiave: *condizionamento dei terreni, usura, scavo meccanizzato, gallerie, abrasività del terreno.*

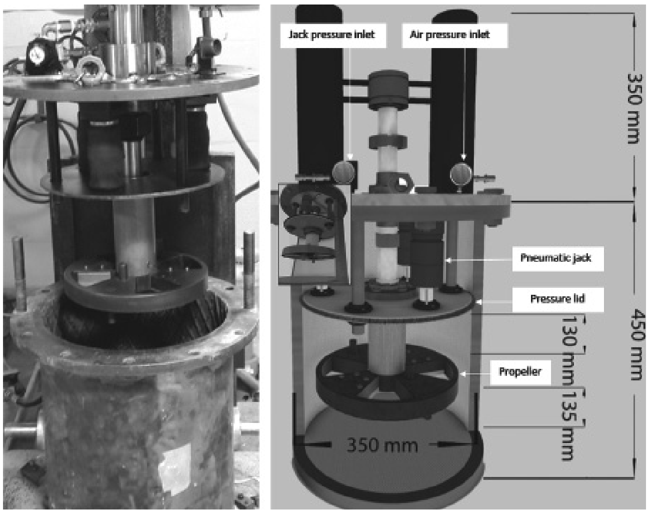

Fig. 1. General view of the device and construction details of the developed device.
Vista generale dell'attrezzatura e dettagli costruttivi dell'utensile.

mm in diameter and 450 [mm] in lengths, which is filled with selected soil under desired test conditions (i.e. dry, moist, saturated, conditioned etc.). Thanks to its size it is possible to test soils which contains gravel.

The rotation speed of propeller can be adjusted in desired speed. In the presents tests a rotational speed of 60 [rpm] was set up.

The test device and the testing system have a capability to apply a pressure on the soil with expansion of three pneumatic jacks together with air pressure in the upper chamber for the simulation of soil mass-tool interaction that is close to the working conditions in the chamber of EPB tunneling machines where the soil particles are pressed against the tools.

The load pressure exerted by jacks can be controlled and ranged from 3 kPa to 11 kPa while the air pressure can exert an air pressure ranging from 1 bar to 10 bar.

The whole system is assembled on a drill press with a 3.7 kilowatt drive unit.

Fig. 1 shows the general view of testing device. In order to take into account both type of wear happened in soft ground excavation, the specially propeller was designed and installed by two sets of blades, including surface and lateral blades. The blades assembled on propeller are made of aluminum with a tensile strength of 440 MPa and an elastic modulus of 3.3 GPa.

Four pins were designed to mix the conditioned soil during the test to have always fresh contact with soil as occur in the real situation. The detail of the developed device and the propeller are shown in figs. 1 and 2.

In order to examine the developed soil abrasion test device, several tests were performed to evaluate the effect of conditioned soil parameters on tool wear.

For each test, the soil samples were dried, without altering the samples original grain size distribution, and mixed with the conditioning agent at the defined conditioning set (defined by Cf: Concentration ratio, FIR: Foam Injection Ratio, FER: Foam Expansion Ratio and WC: Water content) in a concrete bowl.

After mixing a slump test was conducted to capture the optimal conditioning parameters for the studied soil, based on procedure suggested by Peila *et al.*, (2009).

After the rotation of the propeller inside the chamber for 30 min the surface and lateral blade are carefully cleaned and then weighed using a high-precision scale (resolution of up to of 0.0001 g) to measure the lost weight.

For evaluation of device under pressure load, the pneumatic jack pressure together with air pressure are applied to the chamber by connecting the chamber to pressurized air through a high pressure hose.

In order to measure the torque value on the propeller, a computer data acquisition system is installed on the control box of the drill press drive unit.

3. *Carried out test*

The preliminary tests were carried out in a sample of silica sand with 97.6% quartz and 2.4% of kaolinite. The sieve analysis gave the following results: USCS class: SP (poorly graded sand) with D60 equal to 1[mm], D10 equal to 0.2 [mm] and an Uniformity Coefficient of 5.

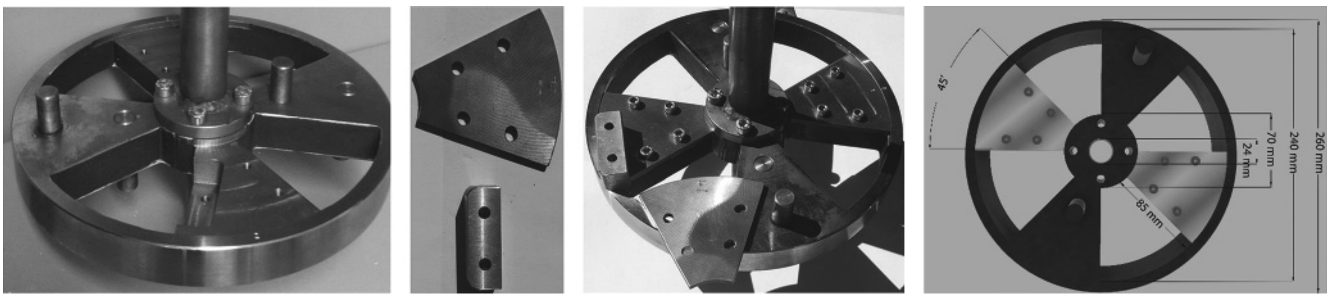

Fig. 2. a:) A general view of the propeller, b) Surface blade and Lateral blade, c) detail of the propeller and of the blades, d) geometrilac characteristics of the developed propeller.
a) Vista generale dell'utensile; b) parti di usure superficiali e laterali; c) dettaglio dell'utensile che supporta le parti di usura; d) caratteristiche geometriche dell'utensile.

The friction angle of the sand is 40°.

For the test, dried soil mixed by appropriate conditioning set parameters is placed in the test chamber and the propeller is rotated inside it.

The soil mass needed for each test is of about 40 kg.

In order examine the impact of various ground pressure on tools wear, five set of tests (20 tests) were conducted using a different set conditioning parameters.

The results are summarized in fig. 3 while fig. 6 shows that the weight loss increases with increasing the amount of normal load on the soil.

These results are as expected since there is a reduction in the volume of pore spaces between soil particles and an increase of solid-solid contact and friction.

Fig. 3 also indicates that the torque also increases with increasing applied load. The described trends can be observed with all the conditioning sets.

Figg. 4 and 5 show the examples of the measured torque diagram by varying the applied pressure for two set of tests.

In order to determine the effect of soil conditioning on wear, the soil was conditioned using 47 different conditioning sets (by changing FIR, FER, WC and Cf). With the use of slump tests it was assessed the optimal conditioning parameters (Peila *et al.*, 2009) that is defined by FIR=20%, FER=15 and WC=15% by weight.

Fig. 6 shows the amount of weight loss and torque with two different types of studied foaming agents. The results clearly points to better performance of stabilized foam versus the non-stabilized foam: with stabilized foam the bubbles are more "robust" and they remains in contact with the soil over longer time and can support more load.

In order to study the effect of Foam Injection Ratio (FIR), several tests were conducted and fig. 7 illustrates the influence of FIR vs the weight loss and the torque.

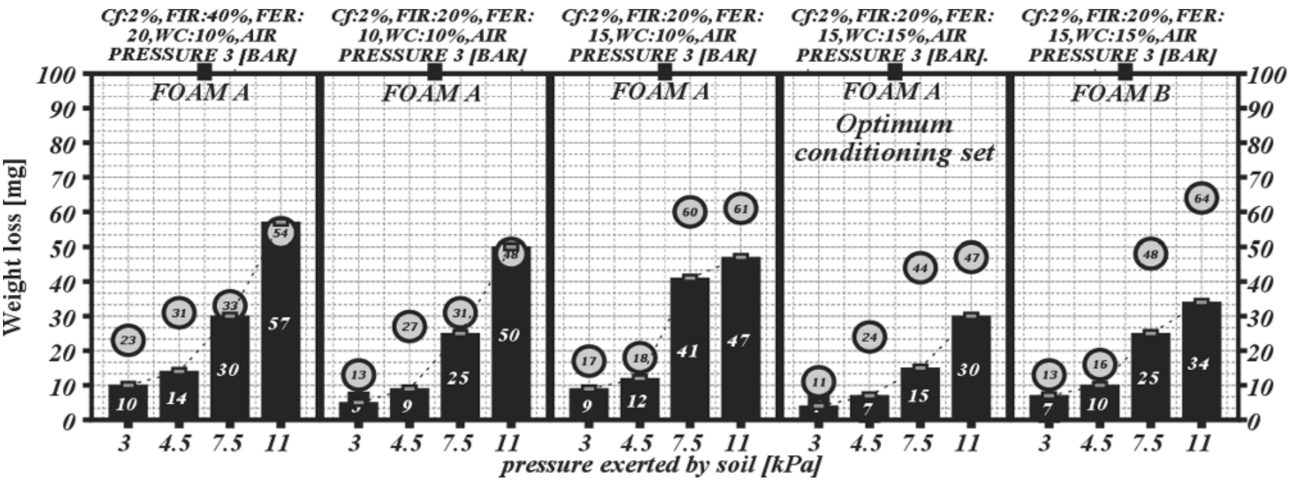

Fig. 3. Comparative relationships between weight loss and torque rate at different pressures based on different set of conditioning sets. Bar charts represent weight loss and circle points represent torque value.

Abachi comparativi tra la perdita di peso e la coppia torcente a differenti pressioni per differenti livelli di condizionamento. Il diagramma a barre rappresenta la perdita di peso, i punti (cerchi) indicano i valori di coppia.

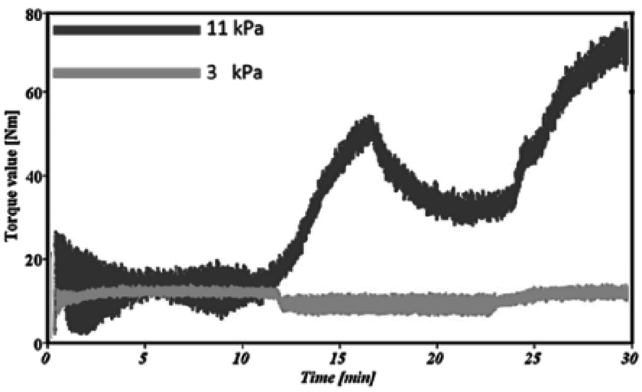

Fig. 4. Comparison of torque requirement in different tests as a function of time for 3 kPa and 11 kPa of applied pressure (Cf: 2%, FIR: 20%, FER: 15, WC: 15%, air pressure: 3 bar).

Confronto tra la coppia richiesta per differenti prove in funzione del tempo per una pressione sul terreno di 3 bar ed 11 bar (Cf = 2%; FIR: 20%; FER: 15; WC = 15%, pressione dell'aria pari a 3 bar).

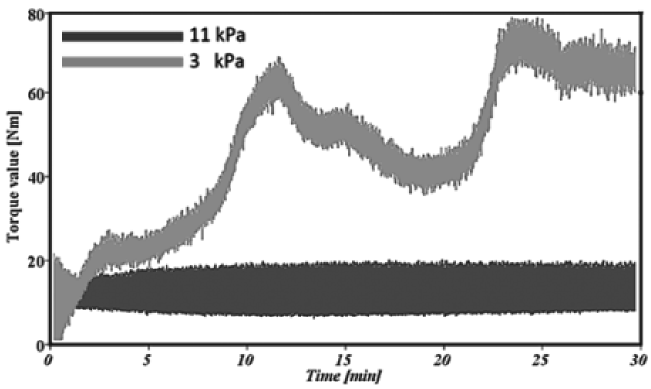

Fig. 5. Comparison of torque requirement in different tests as a function of time for 3 kPa and 11 kPa of applied pressure (Cf: 2%, FIR: 20%, FER: 15, WC: 10%, Air pressure: 3 bar).

Confronto tra la coppia richiesta per differenti prove in funzione del tempo per una pressione sul terreno di 3 bar ed 11 bar (Cf=2%; FIR: 20%; FER: 15; WC=10%, pressione dell'aria pari a 3 bar).

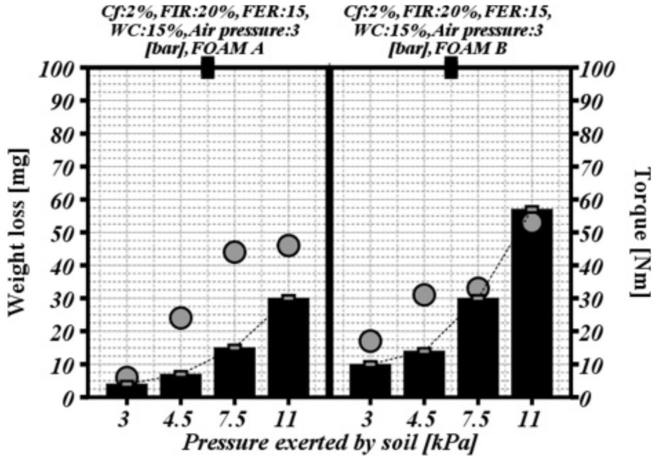

Fig. 6. Comparison of weight loss and torque at different pressures for different soil conditioning types (Foam A, stabilized, and Foam B un-stabilized), bar charts represent the weight loss and the circle points represent the torque.

Confronto tra il peso perso e la coppia per differenti pressioni applicate e per differenti schiume per il condizionamento (Schiuma A stabilizzata – Schiuma B non stabilizzata) il diagramma a barre rappresenta il peso perso mentre i punti rappresentano la coppia.

As expected, increasing FIR would enhance lubrication between soil particles and reduce the solid–solid interactions. More examination were done to evaluate the impacts of water content, FER on tool wear fig. 9 shows the influence on wear by changing the water content of soil while fig. 9 shows the changing of weight loss in relation with FER.

Fig. 10 shows the trend variations of weight loss by changing the amount of Cf. the results show that for Cf: 2% and 3.5%, the weight losses are the same but for Cf: 5%, it decreases.

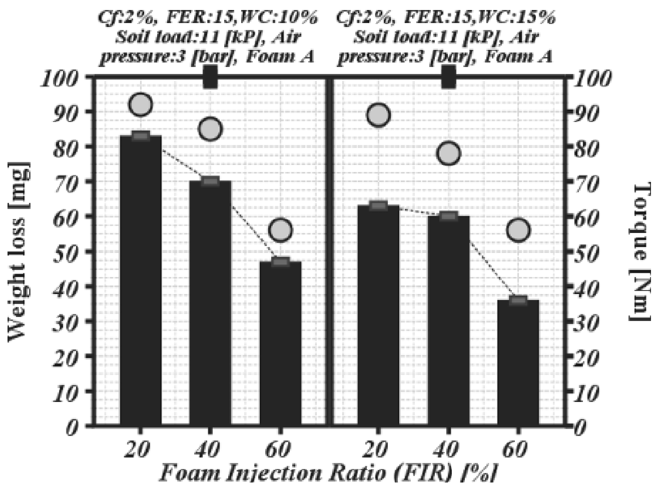

Fig. 7. Comparison of weight loss and torque at different Foam Injection Ratio (FIR) and for different soil conditioning sets, bar charts represent the weight loss and the circle points represent the torque value.

Confronto tra il peso perso e la coppia per differenti valori di FIR e differenti condizionamenti. Il diagramma a barre rappresenta il peso perso mentre i punti rappresentano la coppia.

4. Conclusion

The proposed soil abrasion and wear testing device with an improved propeller and test methodology have allowed to observe the impacts of various soil conditioning parameters on wear and torque requirements of a soft ground tunneling machines.

The testing unit is able to simulate the condition of various parts in the cutting chamber of EPB tunneling machine.

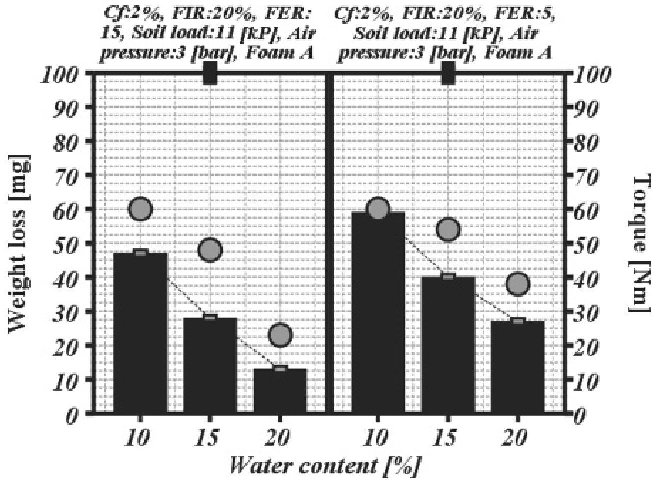

Fig. 8. Comparison of weight loss and torque at different water content (WC) and for different soil conditioning sets, bar chart represent the weight loss and the circle points represent the torque value.

Confronto tra il peso perso e la coppia per differenti valori di contenuto d'acqua e differenti condizionamenti. Il diagramma a barre rappresenta il peso perso mentre i punti rappresentano la coppia.

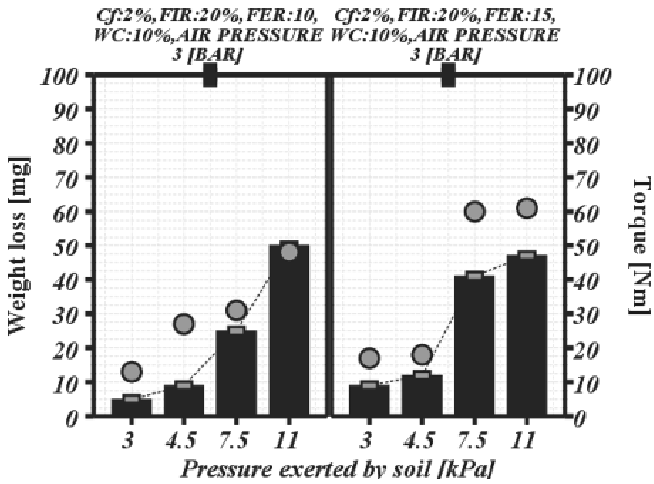

Fig. 9. Comparison of weight loss and torque for different Foam Expansion Ratio (FER), different soil conditioning sets and different pressure, bar chart represent the weight loss and the circle points represent the torque value.

Confronto tra il peso perso e la coppia per differenti valori di FER, differenti condizionamenti e differente pressione applicata. Il diagramma a barre rappresenta il peso perso mentre i punti rappresentano la coppia.

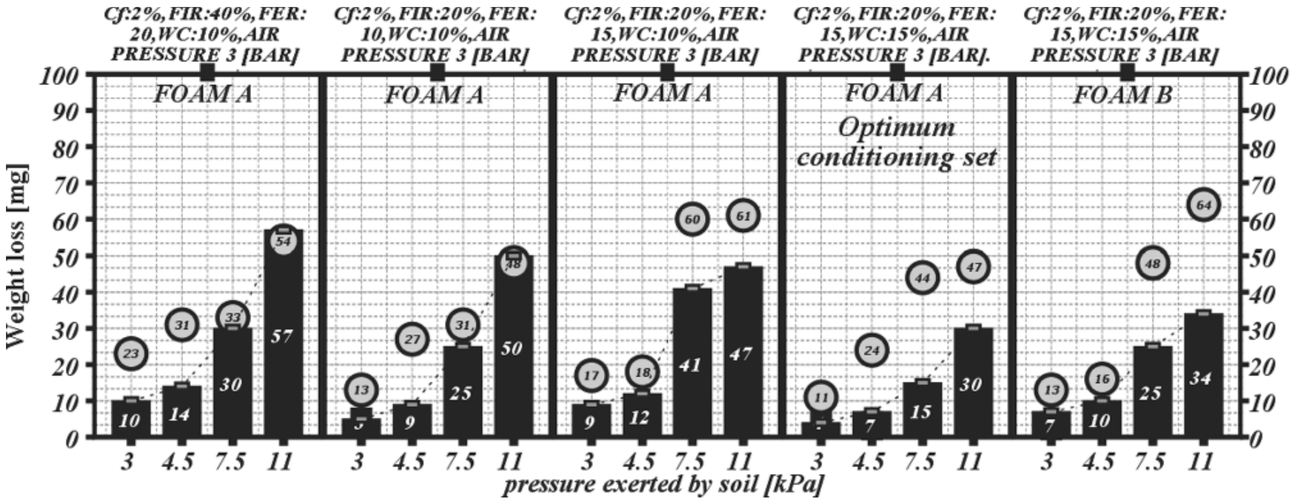

Fig. 10. Comparison of weight loss and torque for different concentration ratio (Cf)at different load pressure, bar chart represent the weight loss and the circle points represent the torque value.
Confronto tra il peso perso e la coppia per differenti valori di concentrazione di agente schiumogeno (Cf) a differenti pressioni. Il diagramma a barre rappresenta il peso perso mentre i punti rappresentano la coppia.

The results of preliminary testing of a silica based sand sample with different soil conditioning under changing conditioning set and soil pressures show that the soil pressure has a significant impact on wear and torque requirement of the machine.

The results show also that suitable soil conditioning can substantially reduce both wear and friction of the soil that is directly linked to the torque on the test propeller. Also, the use of stabilized foam has proved to reduce wear and torque, especially if long life cycles and circulation in the pressure chamber is expected. Further studies are underway to evaluate the effect of conditioning parameters on wear.

References

Alavi Gharahbagh, E., Rostami, J. and Talebi, K. (2014). Experimental study of the effect of conditioning on abrasive wear and torque requirement of full face tunneling machines, Tunnelling and Underground Space Technology, 41, pp. 127-136.

Barzegari, G., Uromeihy, A. and Zhao, J. (2013). A newly developed soil abrasion testing method for tunneling using shield machines, Quarterly Journal of Engineering Geology and Hydrogeology, 46, PP. 63-74.

Jacobsen, P. D., Langmaack, L., Dahl, F. and Breivik, T. (2013). Development of the Soft Ground Abrasion Tester (SGAT) to predict TBM tool wear, torque and thrust. Tunneling and Underground Space Technology, 38, PP. 398-408.

Mair, R.J., Merrit, A.S., Borghi, F.X., Yamazaki, H. and Minami, T. (2003). Soil conditioning for clay soils. Tunnels and Tunneling International, April, pp. 29-32.

Nilsen, B., Dahl, F., Holzhaser, J. and Raleigh, P. (2006a). Abrasivity of soils in TBM tunneling, Tunnels and Tunneling International, March, pp. 47-49.

Peila, D., Oggeri, C. and Borio, L. (2009) Using the slump test to assess the behavior of conditioned soil for EPB tunneling'', Environmental & Engineering Geoscience, (2009), Vol. XV, No. 3, pp. 167-174, DOI: 10.2113/gseegeosci.15.3.16.

Peila, D., Picchio, A., Chieregato, A., Barbero, M., Dal Negro, E. and Boscaro, A. (2012). Test Procedure for Assessing the Influence of Soil Conditioning for EPB Tunneling on the Tool Wear, World Tunneling Congress, Bangkok.

Rabinowitz, E. (1995). Friction and wear of materials. New York: Wiley. 315 p.

Rostami, J., Alavi Gharahbagh, E., Palomino, A.M. and Mosleh, M. (2012). Development of soil abrasivity testing for soft ground tunneling using shield machines, Tunneling and Underground Space Technology Journal, 28, pp. 245-256.

Thewes, M., Budach, C. (2011). Soil Conditioning for EPB Shields: New Results from Research on Foams and Soil-Foam-Mixtures, Proceedings of the ITA-AITES World Tunnel Congress, Helsinki.

Zum Gahr, K.H. (1987) Microstructure and wear of materials. Elsevier, 1987.

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