Mechanized tunnelling: Improving the environmental impact of chemical products without impacting technical performance

Enrico Dal Negro, Enrico Barbero & Alessandro Boscaro

*UTT – Underground Technology Team from Mapei Group*

**ABSTRACT:** Several chemical products are necessary during the mechanized tunnelling with TBM-EPB, mainly for three applications: soil conditioning (important for a fast and safe advance of the EPB), backfill grouting of the annular space that is created between the segmental concrete lining and the surrounding soil or rock mass, and tail brushes sealing (to avoid the ingress of material such as water, foam, soil, etc. into the TBM working area). Each one of these chemical products inevitably brings a certain degree of environmental impact, for example against the underground water or the excavated muck which needs to be disposed in a final destination. MAPEI have been working with its R&D laboratories to develop new products and new technologies that are able to reduce this impact, which can be measured in terms of lower eco-toxicity against terrestrial and watery organisms, quicker biodegradability, and lower emission of CO$_2$ equivalent gases, which are responsible of the global warming (Carbon Footprint). Several examples will be described where technological and environmental innovations in soil conditioning, backfill grout and tail brushes sealing have allowed a more “environmentally friendly” excavation with EPB machines, without impacting the typical technical performances in any way.

1 INTRODUCTION

Attention to environmental sustainability is becoming an increasingly more common topic within every industrial sector, including the tunnelling industry in recent years.

The amount and point of focus of the attention that is given to this topic can vary depending on which part of the world the jobsite is located in. In Italy, for example, there is a noticeable focus on soil conditioning for EPB machines and in measuring the eco-toxicologic impact which stems from the use of foaming agents and polymers, which are crucial for excavation works. If, despite the use of these products, the tunnel muck can be considered unaltered from an eco-toxicologic standpoint, it can be reused as by-product rather than being disposed as waste.

In other countries, the focus can shift to CO$_2$-equivalent gaseous masses emitted, which are deemed major culprits for global warming. In tender phases for tunnelling projects, it is no longer a rarity to find point score systems which award higher ratings to constructors proposing technological solutions which could amount to lower production of CO$_2$.

Mapei, as a global leader in the production and supply of the main chemical products which are deemed necessary for mechanized tunnelling, is adamantly committed to the development of new products and technologies aimed to improve the environmental sustainability of TBM projects, without tampering technical performances which are still considered the cornerstone of any kind of development.

This paper aims to expand on some of these innovative solutions, describing how they are being implemented in tunnelling projects throughout recent years.

DOI: 10.1201/9781003348030-146
2 SOIL CONDITIONING

Soil conditioning is closely related to the issue of environmental impact from several points of view: the conditioning agents added to the soil during the excavation phase inevitably get in contact with groundwater and will remain in part within the tunnel muck, which once extracted from the tunnel will have to be directed to a final disposal site. In addition, soil conditioning entails the use of significant amounts of water, both to generate foam and to be added to wet the soil: some solutions make it possible to reduce these amounts and consequently improve the sustainability of the work from this point of view.

2.1 What is soil conditioning?

Soil conditioning was once described as a “black art”, but nowadays it is a proven engineering technique. Its importance during TBM EPB excavation is well-understood in the global tunnelling industry: soil conditioning is a key factor for successful TBM advance, with significant influence over the machine’s performance and, more generally, over project costs. The cost of purchasing soil conditioning agents is very low compared to the overall costs of a TBM project, but their impact is not to be underestimated, since their quality and the way in which they are applied have a great influence on a machine’s productivity, speed of advance, wear to the cutterhead, torque, etc.

Furthermore, soil conditioning is also directly connected to safe tunnelling: the correct EPB pressure at tunnel face can be applied and maintained during excavation only when soil is well conditioned, otherwise several problems may occur, including water inflows and superficial subsidence.

What is perhaps less known, is its inevitable impact on the environment: chemical agents used for soil conditioning get in contact with subsurface water and end up being present inside the excavated muck.

2.2 Eco-toxicity of soil conditioning agents and of excavated muck

 Regulations covering the classification and reuse of tunnel spoil differs from country to country. What does not change is that the chemical products added to the muck influence this process: when the product is rapidly biodegradable and of low toxicity, the probability of reusing the tunnel muck increases drastically, as well as the time required to wait before the impact coming from the usage of soil conditioning products can be considered nil.

In recent years, Mapei has developed a new line of products which aim to reduce the environmental impact of soil conditioners on subsurface water and excavated muck. At the same time, the technical performance of traditional foaming agents is guaranteed, as proven by the several kilometers of tunnels already excavated using these products. These products belong to the Polyfoamer ECO and Mapedisp ECO ranges and include a series of foaming agents and polymers, each one with its own characteristics in terms of biodegradability, ecotoxicity and technical performance.

All these products have been already successfully used in several TBM projects, such as the 8km long “Santa Lucia” tunnel in Italy (with a 15.8m diameter EPB), the hydraulic tunnel “Riachuelo Lot 3” in Buenos Aires (excavated in sandy soil with a 5.2 m diameter EPB TBM), and the tunnels “Polcevera”, “Serravalle” and “Arquata” along the “Terzo Valico” railway between Milan and Genoa in Italy.

2.3 Reducing the amount of water for soil conditioning

Reducing the environmental impact of soil conditioning can also be linked to reducing the amount of water used in TBM tunnelling projects. As is well known, water is a very valuable resource and an increasingly rare commodity, especially in some areas of the world.

However, some soils to be excavated with EPBs require large amounts of liquid to be added, either as pure water (defined by the parameter of WIR = Water Injection Ratio) or as
water to generate the foam. In particular, high values of WIR are generally required in order to condition cohesive soils with stickiness properties, such as clays, mudstone, shale, etc. In these cases, MAPEI has developed a range of products to fluidify highly plastic soils and minimize the risk of clogging by lowering the amount of pure water (WIR) required.

In Grand Paris Express Line 11 GC01, water availability was even more of a problem because of the presence of multiple TBMs excavating simultaneously. Moreover, the soil was particularly cohesive which by itself normally requires larger amount of water to be excavated.

As shown in Figure 1, the qualities of soil encountered in the excavation were well within the risk of clogging for the TBM.

![Figure 1. In blue, the clogging risk based on the analysis of Line 11 soil samples.](image)

After analyzing the soil samples in MAPEI R&D laboratories, several combinations of foaming agents from the Polyfoamer range were tested in order to find a correct mixture that would allow an optimal excavation process this minimizing the amount of water added.

The solution with Polyfoamer FP/L was used to excavate sections with geologies with average geotechnical characteristics, while the solution using Polyfoamer FLS was used in sections with sticky soils, and finally, the combination Polyfoamer FLS and Mapedisp FLS was used for the extremely sticky sections.

More recently, Mapei R&D laboratories developed a new all in one solution capable of combining properties of both foaming agents and water dispersing agents: Mapedisp 7030 ECO. This admixture is a high-performance liquid product, which allows to reduce the cohesion and adhesion of soils during mechanized tunnelling with EPB-TBM. Mapedisp 7030 ECO can produce well-conditioned soils, reduced WIR and its environmental characteristics make it the most environmental-friendly solution available on the market among commonly used dispersing agents.

3 BACKFILL GROUT

As part of the industrial process that is a TBM excavation, the backfilling grout has some environmental impacts that must be considered. The main environmental aspects of backfilling grout are related to the ingredients used to prepare it, the type of products and their dosages. Each ingredient has an impact that must be evaluated and considered for the proper
selection of the backfilling technology. Being a water-based material, the origin of the water itself becomes an impacting factor which can influence the quality and performance of the backfill grout as well as its environmental impact. The possibility of re-using water coming from other processes at the jobsite could very well prove to be a way to optimize resources while lowering the resource requirement of the jobsite itself.

### 3.1 Backfilling grout techniques and two-components system

As a shielded TBM advances, a “gap” is created because of the difference between the TBM excavation diameter and the external lining one. During the TBM advance, the proper filling of

<table>
<thead>
<tr>
<th>Products used</th>
<th>WIR (%)</th>
<th>Polyfoamer Conc. (%)</th>
<th>Mapedisp FLS Conc. (%)</th>
<th>FER (-)</th>
<th>FIR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLYFOAMER FP/L</td>
<td>16</td>
<td>1%</td>
<td>\</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>POLYFOAMER FLS</td>
<td>12</td>
<td>1%</td>
<td>\</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>POLYFOAMER FLS + MAPE-DISP FLS</td>
<td>9</td>
<td>1%</td>
<td>0,2%</td>
<td>8</td>
<td>50</td>
</tr>
</tbody>
</table>

**Table 1. Laboratory test with Mapei products.**
this void is a key aspect to minimize the settlements of the ground, block the ring in its designated position, make the loads towards the lining homogeneous and improve the tunnel waterproofing.

Different kind of cementitious grout in soft ground tunnelling as well as pea gravel in hard rock tunnelling, have been developed in the past, but they each have their own setbacks (not homogeneous filling, long setting time, no mechanical strength at short stages, etc.) that made the two-components system the most effective choice for TBM tunnelling in every conditions.

The system is made by the A-Component, which is a super-fluid cementitious grout characterised by high volumetric stability and workability over long periods, combined with the B-Component (an accelerator admixture) to obtain a material with “gel-like” consistency and fast development of mechanical strength.

The two-components grout is the only technology which can provide the required mechanical characteristics and can be used to fill the “gap” as fast as operatively possible.

3.2 Reducing CO$_2$ quantities

Cement is the main component of the two-component backfill grout, while also being one of the materials typically used in TBM sites with the highest CO$_2$ equivalent emission rate.

The cement per cubic meter dosage of the mix can be lowered by replacing it with other binders with recovered pozzolan activity, which can produce much lower emissions than cement. As a consequence, the technical performance of the two-component grout has to be adjusted accordingly in order to meet the project requirements.

MAPEI has developed on the possibility of producing a totally cement-free two-component mixture, where cement is completely replaced by Mapequick CBS System CF binder. In this case, the emitted CO$_2$ can be reduced by 70% compared to a cementitious mix with the same performance: considering the amounts of backfill mix involved in a mechanized excavation site, the raw difference in raw CO$_2$ volumes emitted can be astounding.

3.3 Recycling water

TBM tunnelling, like many other industrial processes, requires a massive amount of water to be performed. The machines currently in use in the Brenner Tunnel Project are using a mixed backfill system comprised by two components grout, plus pea gravel. The cleaning operations of the two-component backfill grout batching plant require great amounts of water every day.

Such large quantity of water could be re-employed in the TBM tunnelling process by using it to produce the two-component backfill grout’s A-component. Several tests were carried out to explore this possibility, but the recycled water caused performance issues to the grout itself, such as excessive bleeding and lower viscosity, which were incompatible with the jobsite requirements.

In order to obtain an A-component with the desired mechanical performance, MAPEI R&D Laboratories developed a stabilizing polymer, Mapedrill FR10, which was then included into the mix design.

The addition of a low amount of this additive into the A-component allows to minimize the bleeding even when recycled water is used. This change in the two-component grout production procedure was implemented without impacting the plant in any meaningful way.

In future developments, a better implemented re-use of by-product water coming from other processes in mechanized tunnelling could lead to downsizing of one or more steps of the water treatment plants, which will inevitably result in cost reduction (coming from less intensive treatment operations) and reduction of environmental impact due to a decrease of water to be reintroduced in nature.

4 SEALANT AND LUBRICANTS

Tunnel Boring Machines make extensive use of sealants and lubricants during their operational phase. With these chemical products come the possibilities to improve their degree of environmental impact, hereunder are some examples.
4.1 Tail sealants

Tail sealants are continuously injected during the TBM advance in order to seal the tail brushes, thus avoiding any ingress of grout, water, soil, etc. into the TBM working area. Tail sealants need to be easy to pump and, at the same time, very sticky to metal surfaces and with great sealing properties against water and cement-based grouts.

Typically, among their main constituents there are hydrocarbons-based materials, which have a high degree of CO₂ emission (GWP<sub>100</sub> = Global Warming Power). Mapei has developed a special type of tail sealant, called Mapeblox/T LCF, which can ensure the same technical performance of commonly used tail sealants, while also being completely hydro-carbons free. This characteristic allows to drastically improve the carbon footprint, thus helping reduce the CO₂-equivalent quantities for the TBM operational phase.

4.2 Lubricant greases

EP (Extreme Pressure) greases are used in TBMs mainly to lubricate the main bearing. Different EP greases are available in the market: all the traditional materials are based on mineral oils, and they are slowly biodegradable since it will inevitably come in contact with the environment during the machine’s operational phases.

In the last years, the cooperation between Mapei and ENI (one of the largest oil companies in the world) has led to the formulation of Mapeblox EP ECO, an EP lubricant grease characterized by great technical properties in terms of lubrication, water resistance, etc., and at the same time by a much faster biodegradability than traditional mineral-based EP greases: Mapeblox EP ECO is readily biodegradable according to the EOCD 301 guideline, thus further minimizing the impact of chemical products used in excavation to the environment.

5 CONCLUSIONS

A different and conscious approach to the TBM tunnelling is nowadays possible. The development of innovative chemical products allows to provide ECO solutions for many technologies related to the mechanized excavation. Innovative agents with specific properties can minimize the use of water for the soil conditioning saving this precious resource. Furthermore, these groundbreaking products have a minimal environmental impact guaranteeing the re-use of spoil as by-product in accordance with the up-to-date spoil management approaches.

The reduction of greenhouse gases emission is another aspect on which the modern TBM consumables can play a key role: a backfilling grout with reduced CO₂ emissions can now be formulated thanks to the R&D activity carried out at Mapei laboratory as well as the use of a new kind of tail sealant whose carbon footprint is drastically reduced.

Finally, being the water one of the most important sources on earth, the re-use of it within TBM jobsite is a crucial sustainable step forward that is now possible thanks to the selection of the proper admixture.

We anticipate that proper implementations of these solutions could very well be suitable options into reducing the environmental impact of TBM tunnelling projects. Still, the increasing focus towards environmental sustainability of large-scale project does not mean that technical performances of products can be considered of less importance. R&D activity will prove increasingly fundamental in ensuring top performing products are also compatible with the project’s environmental requirements, in an increasingly environmental-aware world.

REFERENCES


OECD 301, Biodegradability testing, Organization for economic co-operation and development, Paris 1995, OECD/GD(95)43.


André, L.; Bacquié, C.; Comin, G.; Ploton, R.; Achat, D.; Frouin, L.; Cyr, M. Improvement of two-component grouts by the use of ground granulated blast furnace slag. Tunnelling and Underground Space Technology 2022, 122, 104369


