# Development of Resource-efficient and Advanced underground technologies - DRAGON

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ABSTRACT: Goal of the DRAGON project is to achieve a higher grade of resource efficiency in tunneling and other underground construction processes by turning the excavation material into a valuable resource for other processes and sectors such as the cement, steel, ceramic or glass industries. The project sets out to solve this challenge by developing a prototype system for the automated online analysis, separation and recycling of materials excavated in underground construction sites. The entire chain from characterisation to classification and processing of the excavated material will be conducted completely underground, preferably on the tunnel boring machine (TBM), thus saving natural primary resources, reducing hazardous environmental impacts and providing a high economic value.

## 1 INTRODUCTION

The European tunneling industry is flourishing. In the near future, more than 800 million tons of material will be excavated for the construction of underground infrastructures such as tunnels, metros, and power plants.

But what happens with the spoil material? Nowadays, TBM muck is considered as waste and is usually disposed of to landfills as it represents the simplest and most cost-effective method. However, this action involves environmental impacts and transport issues (landfill areas, $CO_2$ emissions, noise, and water and soil contaminations).

The last 20 years have shown that parts of the spoil can be recycled either for on-site uses (e.g., tunnel concrete, Thalmann *et al.* 2013) or as primary resource for other industrial sectors (e.g., brick industry). This requires a continuous evaluation of the raw material quality (petrographic, chemical and physical rock properties), the processing of the suitable raw material, and storage areas outside the tunnel.

A way to reduce environmental impacts and maximise the use of excavation material would be to separate TBM muck on-line, inside the tunnel, on the tunnel boring machine. These are some of the goals of the DRAGON project, which will be presented in the following chapters (Figure 1).

## 2 THE DRAGON PROJECT

The DRAGON project aimed at achieving resource efficiency in tunneling and other underground construction processes by turning the excavation material into a valuable resource for other processes and sectors such as the cement, steel, ceramic or glass industries. The project sets out to solve this challenge by developing a prototype system for the automated online analysis, separation and recycling of excavated materials in underground construction sites. The entire chain from characterisation to classification and processing of the excavated material will be conducted completely underground, when possible on the TBM. The use of excavation material for various purposes is designed to save natural primary resources while also providing a high economic value. Another important objective is to assess the resource efficiency of different usage scenarios on a quantifiable basis and thus provide a sound basis for decision making by authorities.

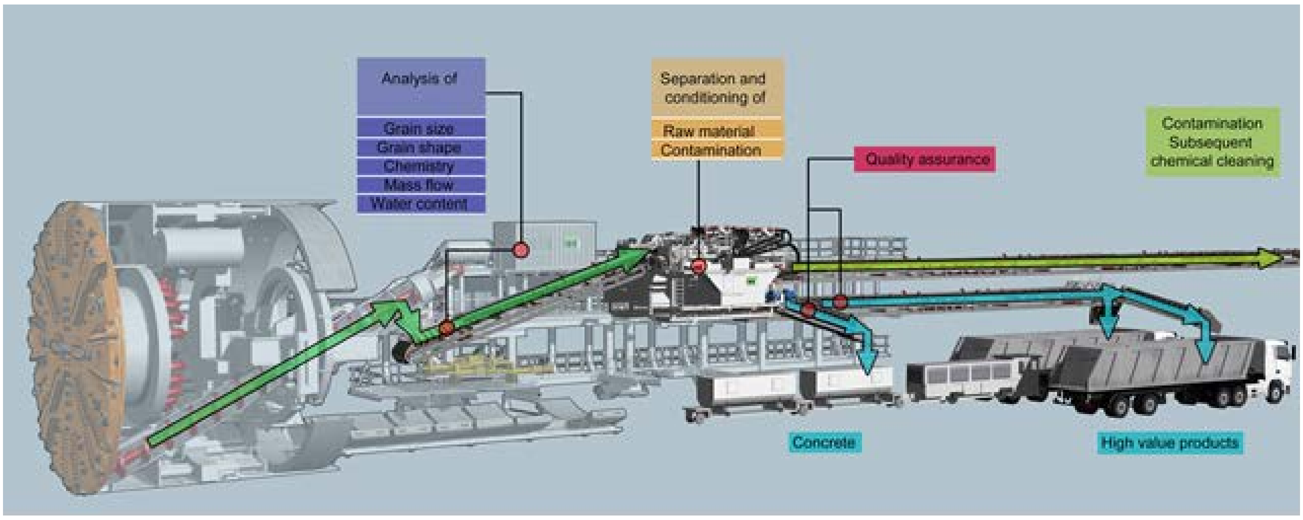


Figure 1. Overall description of the DRAGON project. After sampling from the main conveyor belt, the physical and chemical properties of the material will be analysed automatically. Based on these results, the material will then be classified into different material classes and processed automatically in order to gather various types of valuable material as output.

## 2.1 *European Funded Research Project*

DRAGON (Development of Resource-efficient and Advanced underGrOund techNologies) is a collaborative research project funded by the European Union. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 308389. It is coordinated by the Montanuniversity of Leoben (MUL), Austria and involves the following companies:

- B+ G AG Concrete Technology and Spoil Management, Switzerland
- Herrenknecht AG, Germany
- Indutech instruments GmbH, Germany
- Jacques Burdin Ingenieur Conseil, France
- PE North West Europe Limited, UK
- PORR Bau GmbH, Austria.

# 3 METHODS

Currently an on-line analysis system permitting physical and chemical measurements as well as underground processing of the material excavated is missing. DRAGON intends to develop a prototype consisting of photo-optical technologies, x-ray and microwave units to analyse the continuous mass flow of material directly behind the cutter head (Figure 2). This characterisation of physical, chemical and mineralogical properties provides the basis for assessing the suitability of the excavated material for different recycling options. A downstream underground separation plant will handle the material depending on the online test results and requirements for intended use either as concrete aggregates on site or in various other industrial sectors. All systems will be mounted directly on the back-up system of the tunnel boring machine and will thus need to be adapted to harsh environmental conditions and space restrictions underground. Methods of Life Cycle Assessment (LCA) and Mass Flow Analysis will be used to compare different scenarios of use or disposal of excavated material.

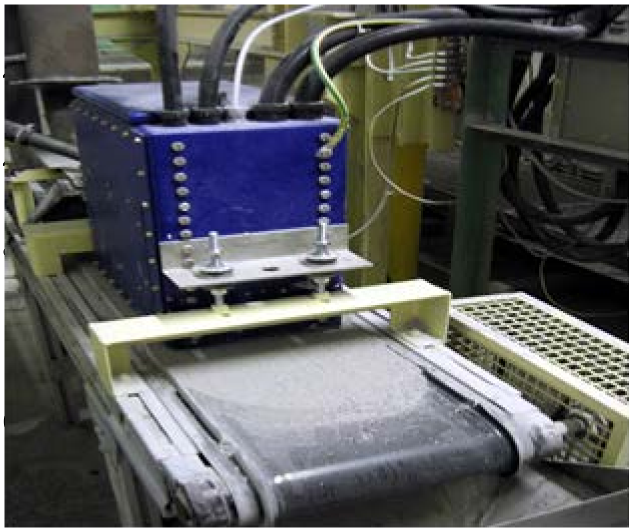

Figure 2.OXEA - Online X-ray Elemental Analyser by InduTech is based on XRF technology.

Analysis will be done on a by-pass belt parallel to the main conveyor belt. The analyser contains a microwave moisture meter, the OXEA itself and an absorption edge analyser for heavy elements.

Material will first be sampled from the main conveyor belt, before being crushed down to a grain size of < 8 mm. Since OXEA does not allow analysis of water saturated material a microwave moisture meter will also be installed on the main belt stream to stop sampling in case of very high water content.

## 4.2 *On-line Physical Analysis of Muck*

Excavated material has never undergone a natural selection process. Thus rock strength and chip form play major roles.

According to standards, aggregate hardness is determined by the Los Angeles test. However, the latter cannot be used on raw material. A precise evaluation of the TBM muck hardness is gained using the point load index and the breakability tests (AFNOR P 18-579). Their results linearly correlate with those of the Los Angeles test as shown by Thalmann (1996).

The shape of the raw material is determined by the flakiness index. Different automatic devices are already available on the market. However, there are no methods existing to assess rock hardness online. Its automation is a central part of the DRAGON project.

### 4.2.1 *Disc Cutter Load Monitoring Systems*

Herrenknecht AG and the Montanuniversity of Leoben are working on two different Disc Cutter Load Monitoring systems (DCLM-system). The sensors should permit a better understanding of the relation between wear, rock hardness and the load on disc cutters.

The Herrenknecht system is based on direct load measurement by thin film technology (piezo-element). The MUL system is based on indirect load measurement by deformation (strain gauges). First tests delivered positive results in both cases. The most effective technique will be chosen in a further step. Figure 3 presents the different alternatives.

### 4.2.2 *Correlation Between TBM Data and Rock Quality*

It has been shown in several papers that the uniaxial compressive strength and the point load strength strongly correlate with the TBM penetration rate in hard rock (e.g., Kahraman *et al.* 2003).

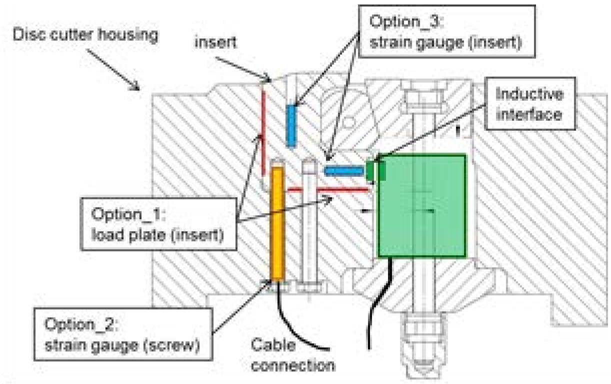


Figure 3. Three different options of disk cutter load monitoring systems developed by Herrenknecht AG (load plate) and Montanuniversity of Leoben (strain gauge).

B+ G AG currently works on finding new correlations between additional physical properties of the raw material (grain size, grain shape, point load, LCPC) and TBM data (speed of excavation and contact pressure) to evaluate rock quality. This would enable a better understanding of relations between geology and mechanical driving.

## 4.3 *On-line Analysis of Muck Quality*

Before being upgraded into aggregates, the TBM muck has to meet different quality criteria, which were published by Thalmann (1996). Besides its physical and chemical properties (discussed in the last chapter), rock petrography plays a crucial role.

Nowadays, the type and amount of unsuitable minerals are inferred from thin section analysis. No automatic methods exist yet. A breakthrough innovation of the DRAGON project will be to automatise the precise detection and selective removal of lithologies with high mica content directly on the TBM.

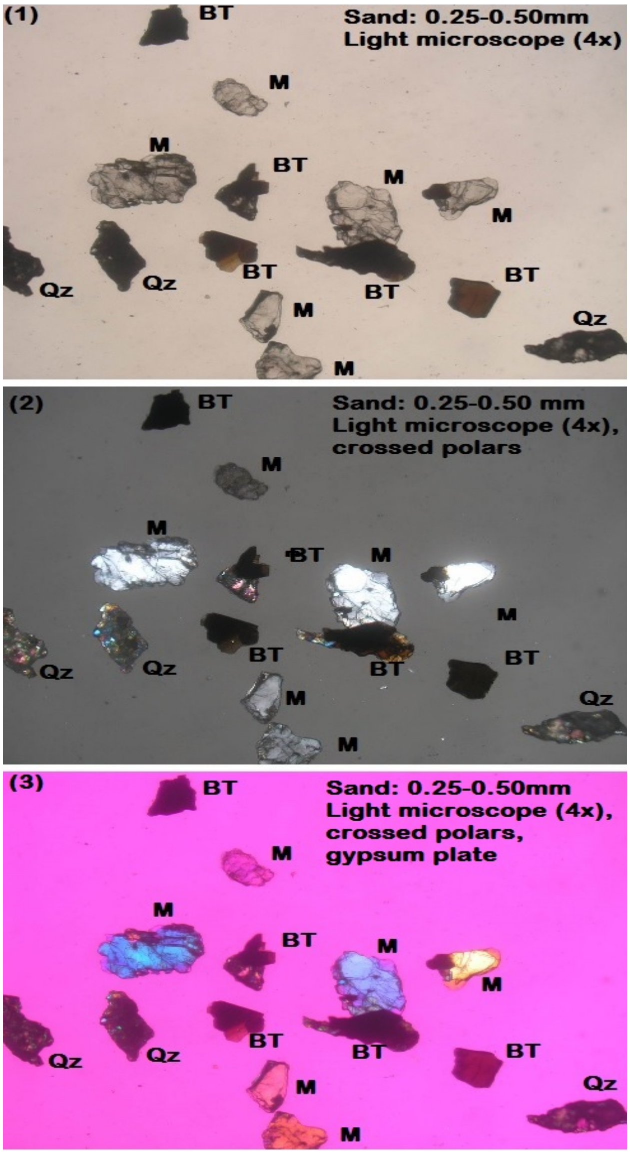


Figure 4. Microscopic analysis of the 0.25-0.50 mm fraction of crushed sand containing mica (biotite (BT) and muscovite (M)) and quarz (Qz). The automatic detection of mica will be possible by analysing a sample with different filters or filter arrangements (1,2,3) and juxtaposing the different results one over the other.

### 4.3.1 *Online Mica Recognition System*

Mica represents one of the most annoying mineral groups regarding concrete production. If present, it forms platelets during raw material crushing. These accumulate in the sand fraction and change the properties of fresh concrete.

Today, the mica content present in the crushed sand is counted under a microscope. Based on the different optical properties of mica minerals, B+ G AG is developing a mica detection technique based principally on microscopic image processing.

First results have shown that two different mica minerals can be separated from each other and from other minerals when observed under different optical filters (Figure 4). Available microscopes on the market will make this process completely automatic.

In parallel, B+ G AG has also obtained a linear correlation between the mineralogical composition (XRD; weight-%) and the microscopic counting (particle-%) of the same samples having different origins and mica contents. This indicates that XRD measurements are an accurate way to determine mica content in a given sample (Figure 5).

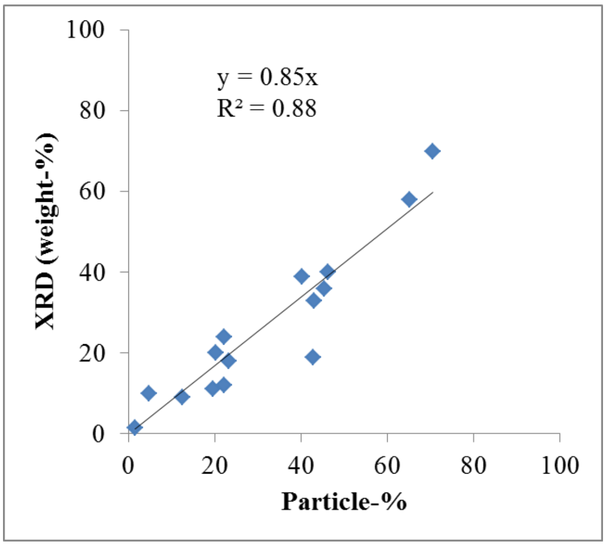


Figure 5. Linear correlation XRD (weigth-%) vs countings (particle-%).

The Montanuniversity of Leoben is developing a shape separation system to isolate phyllosilicates, which embrace mica minerals as well as chlorites, and determine the weight-% of harmful minerals in crushed sand (Figure 6). The aim is to have a practical system on construction site providing fast results for the decision if certain materials are suitable for concrete production.

## 4.4 *Tunnel Related Raw Material Database*

Another important goal of the DRAGON Project is to find new economic ways to exploit excavated material. For the enhancement of muck material usage a web-based database system is being developed, providing access for the client, construction companies and companies from the mineral industry. The system combines the results obtained from the online material analysis with a raw material database that contains all information concerning the excavated material, of a certain project. This architecture allows an immediate classification of the excavated material into usage groups and a pre-selection of potential industries that can use the penetrated rocks as a base for their products. The implementation of the raw material database within the tunneling and mineral industry is an important step towards a modern, web-based trade of mineral resources.

## 4.5 *Prototype Conception*

The company Herrenknecht is responsible for the prototype design, assemblage and testing. This highly innovative system will be used to analyse and classify the excavated material up-on its physical (e.g. grain size) and chemical properties (e.g. mineralogy).

This challenge is supported by the special-ised know-how of InduTech (chemical anal-yses), Jacques Burdin and B+ G (spoil man-agement, physical parameters).

### 4.5.1 *Hard Rock TBMs*

Generally, the material excavated by hard rock TBMs is fine-grained and platy. This material cannot directly be used for the production of concrete, but has to be washed first, then broken and finally separated into several groups of stones (0 – 4mm; 4 – 8mm; 8 – 16mm; 16 – 22 to 32mm) in a sand and gravel plant. This is often very complex, costly and sometimes leads to large material loss. Hence, a breakthrough innovation of the DRAGON project is the direct use of the TBM raw material for the production of shotcrete, mortar and subsidiary structural while the TBM is still running.

### 4.5.2 *Earth Pressure Balanced TBMs (EPBs)*

The raw material excavated by earth pressure balanced machines is usually not used on the jobsite itself. This explains why no technology exists for its automatic processing close to the tunnel face.

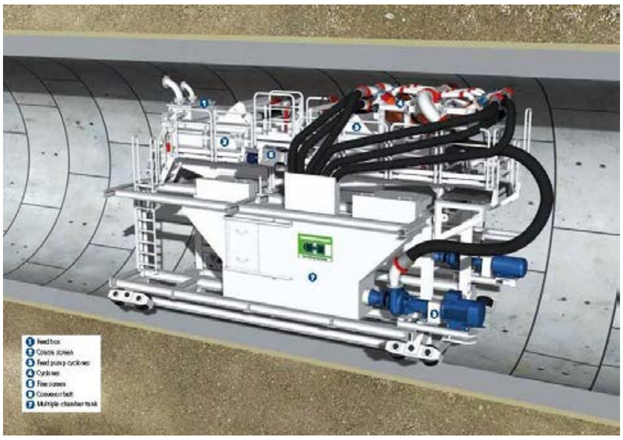

Figure 6: EPB Underground processing unit

DRAGON will develop a prototype to process the excavated EPB material, automatically, in a way that any end user – depending on the boundary conditions of the project – is able to use the processed material easily for their purpose. Moreover, a technique will be created for separating water from the excavated muck on EPB - TBMs, which will take place on the TBM back-up (Figure 6).

## 5 CONCLUSION

The primary results show some analytic automation potentials for the back-up system of a TBM.

The chemical characteristics of the rock will be determined by OXEA (InduTech Gmbh), a XRF analyser.

Physical properties of the rock will be pre-cisely measured by disk cutter load monitoring systems (Herrenknecht AG and Montanuniver-sity of Leoben) and/ or assessed by correlating TBM vs rock quality data (hard rock; B+ G AG). Geometric and other physical parameters (grain size, grain size distribution, hardness, LPCP) will be assessed using up-to-date and al-ready existing technologies.

Chemical and physical results monitoring will be important tools to document the encoun-tered geology and prepare prognoses for the project. At the same time, results will allow a better understanding of the relation between wear and geology/mineralogy.

Lithologies containing a too high content of mica minerals for concrete production will be automatically quantified and recognised. In a further step, they will be removed by already existing and accepted technologies within the tunnel, thus enhancing aggregate and sand quality.

After adding and placing all the infrastructures needed for aggregate processing on the TBM back-up, suitable concrete aggregates will be produced during excavation on the machine itself.

## 6 ACKNOWLEDGEMENTS

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