Utilization of boiler slag as fill material for geotechnical applications

Utilisation de scories de combustion du charbon comme matériau de remplissage pour des applications géotechniques

Jasna Smolar, Matej Maček & Ana Petkovšek
University of Ljubljana, Faculty of Civil and Geodetic Engineering, Chair for Soil Mechanics with Laboratory, Slovenia, jasna.smolar@fgg.uni-lj.si

ABSTRACT: The preferred management option for coal combustion by-products (CCPs) is utilization as alternative material, rather than disposal as waste. In comparison with fly ash, which presents the major share of the total annual CCPs production, the properties of boiler slag are less known.

This paper presents the results of laboratory and field investigations of mechanical and environmental properties of boiler slag, produced in boilers, where brown coal is used as fuel. From geotechnical point of view, it is recognized as alternative material for the use as structural fill and for embankments. The leaching behavior was first assessed by means of laboratory leaching and percolation tests. The potential environmental impact, which presents one of the most important limitations for the use of wastes as alternative material, was identified. A test embankment was constructed and a part of it was equipped with a lysimeter. It provides information on leaching trends under field conditions and serves for the long term monitoring of the quality and quantity of percolated water. Based on data obtained from the lysimeter the reliability of laboratory leaching and percolation test results was evaluated.

1 INTRODUCTION

Boiler slag (BS) is coarse, granular, incombustible CCP, which is collected from wet bottom boilers of furnaces that burn coal (ECOBA). In Europe, CCPs are considered as waste. For the beneficial use as alternative material in geotechnical applications, the environmental, technical, economical and legislative aspects must be considered.

Compared with other CCPs (fly ash, bottom ash and flue gas desulfurization gypsum), the geotechnical and environmental properties of BS are less known.

This study was conducted in order to determine the BS geotechnical and environmental properties intended for its use in geotechnical applications. For the evaluation of the validity and reliability of laboratory test results and for the long-term monitoring of BS in real climatic conditions, a test embankment with lysimeter was constructed.

2 EXPERIMENTAL PROGRAM

The experimental program was implemented in two phases: first, geotechnical and environmental behaviours of BS were investigated in the laboratory and second, a test embankment with lysimeter was constructed in order to determine the BS placeability and its long-term environmental impact.

2 .1 *Material*

BS samples were obtained during the period of 2012-2013 from the thermoelectric power station Trbovlje, Slovenia, where brown coal was used as fuel. In natural state BS has water content between 75%–93%. Samples for laboratory investigations were prepared by air drying of BS to the desired water content (moist preparation method). Thus, the majority of interparticle water content remained the same.

2 .2 *Testing Methods*

2.2.1 *Mineralogical Composition*

Qualitative mineralogical compositions were determined using X-ray diffraction, at a scan rate of 1°/min (Philips Norelco equipment with Cu anode). The X-rays were filtered by Ni filter.

2.2.2 *Geotechnical properties*

Index laboratory tests included the determination of water content (CEN ISO/TS 17892–1:2004), particle density (CEN ISO/TS 17892–3:2004) and grain size distribution (CEN ISO/TS 17892–4:2004).

Compaction properties of BS were investigated using standard Proctor compaction test (SPT) (DIN 18127). The results of SPT were used to evaluate the efficiency of field compaction (D_{pr}), given as ratio between the achieved dry density (ρ) and the maximum dry density (ρ_{dmax}).

The determination of properties in the compacted state includes laboratory measurements of hydraulic conductivity using a rigid wall permeameter, consolidated drained direct shear tests and unconfined compressive strength after ageing. Effectiveness of field compaction was determined by using the Drive-Cylinder Method (ASTM D2937-10) and the light weight deflectometer (ZORN Instruments).

2.2.3 *Leaching behavior tests*

Leaching depends on physical, chemical, and mechanical properties of material and local climatic conditions. In order to identify the impact of compaction, curing time and climatic conditions on the properties of eluates, the leaching tests were performed using four different methods:

1. one-stage batch test on loose BS (EN 12457-4:2004)
2. leaching test on compacted BS (EN 1744-3:2002)
3. up-flow percolation tests on compacted BS (CEN/TS 14405:2004)
4. field lysimeter test.

Chemical analyses of eluates were carried out by ICP-OES, Optima 5300DV. Perkin Elmer followed the procedures listed in Table 2.

3 RESULTS AND DISCUSSION

The main minerals in BS are gypsum, quartz, anorthite, anhydrite, calcite, hematite and gehlenite, while the amount of amorphous phase is low. Due to this composition, BS does not have hydraulic properties (Smolar et al., 2016).

Table 1 presents physical and mechanical properties of BS, relevant for further evaluation of leaching test results and field observations. More detailed data are presented in Petkovšek, (2014) and Smolar et al. (2016).

Table 1. Physical and mechanical properties of BS.

Parameter	BS
USCS classification	SP – SM
particle density, ρ_s (t/m^3)	2.26 – 2.35
fines content, < 0.063 mm (%)	6.20 – 14.4
maximum dry density (SPT), ρ_{dmax} (t/m^3)	0.80 – 0.92
optimum water content (SPT), w_{opt} (%)	50 – 56
apparent cohesion ($D_{pr} \approx 99\%$), c´ (kPa)	41 – 44
effective shear angle ($D_{pr} \approx 99\%$), $\varphi´$ (°)	39 – 42
hydraulic conductivity ($D_{pr} \approx 95\%$), k (m/s)	10^{-4} – 10^{-5}

3 .1 *Test Embankment and Lysimeter*

Figure 1 shows a plan view and cross section of the test embankment with lysimeter built from BS. It was compacted in app. 0.4 m thick layers using vibratory roller with a smooth drum (static weight of 8.9 t). The efficiency of rolling was controlled and optimized during construction. The compaction of layers was finished when no increase in stiffness after two successive passes had been observed.

Lysimeter was constructed as part of the test embankment, separated from its surrounding. A pipe connects the sealed bottom of the lysimeter to a collecting barrel where an automatic tipping counter was installed. Seasonal changes in suction, temperature and water content are measured with 6 tensiometers (T4e, UMS) and 8 time-domain reflectometers (PICO 32, IMKO), installed at different depths. Meteorological data for the calculation of the lysimeter water balance were measured with tipping bucket rain gauge installed near the lysimeter and collected from a nearby meteo station.

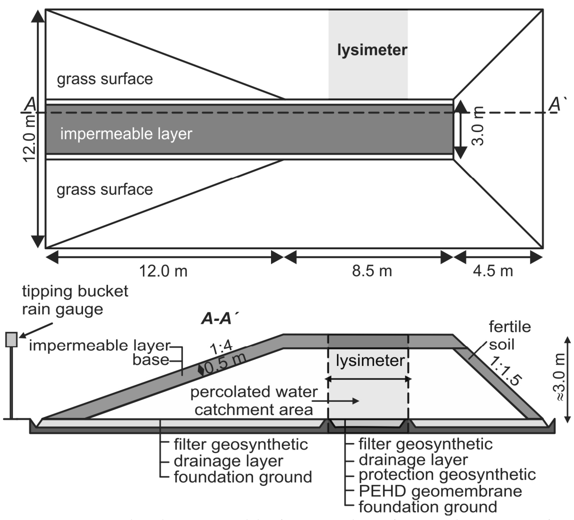

Figure 1. Test embankment and lysimeter plan view and cross section.

3.1.1 *Effectiveness of field compaction*

Figure 2, left, shows the average degree of compaction achieved at separate layers of BS at water content of about 54%. The average layer stiffness (E_{VD}) was 8 MPa (Figure 2, right).

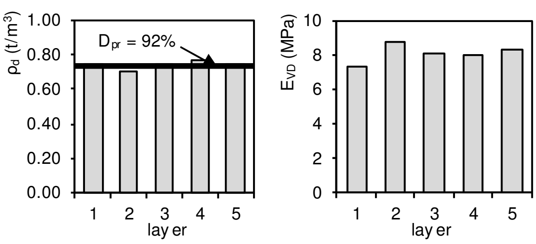

Figure 2. Effectiveness of field compaction.

For the effective compaction of BS, four vibratory roller passes were needed. Regardless of the number of passes and the roller operation mode, it was not possible to achieve $D_{pr} > 95\%$ and $E_{VD} > 15$ MPa (Smolar et al., 2016).

3 .2 *Laboratory and field leaching test results*

Chemical composition of eluates obtained with laboratory leaching tests is presented in Smolar et al. (2016). Selenium, sulphates and fluorides exceeded the limit values for inert wastes (2003/33/EC) in all eluates, regardless of the test method. Percolation test shows also excessive concentration of Molybdenum, regardless of the L/S ratio.

Water balance of the test embankment with lysimeter shows that in 10 months, 19% of rainwater percolated through the embankment and in the same period the L/S ratio of about 1.11 was achieved. In comparison with lysimeter test, laboratory leaching tests are rapid and aggressive. L/S 10 is achieved in a short period of time.

Table 2 presents the results of chemical analysis of eluates from the up-flow percolation test and from the lysimeter. In the eluates, collected from the lysimeter, only the parameters which exceeded the limit values for inert wastes in laboratory leachates were analysed. With the exception of Se, concentrations of constituents at the same L/S ratio were lower in eluates from the lysimeter than those from the up-flow percolation test. Generally, results obtained on eluates from the lysimeter confirmed the laboratory leaching test results.

Table 2. Chemical composition of eluates.

Parameter	Up-flow percolation test			Lysimeter		
L/S	0.2	2.0	10	0.59	0.80	1.11
pH[a]	7.60	7.60	7.70	8.10	7.70	8.00
Mo[b] (mg/L)	0.262	0.130	0.073	–	–	0.075
Se[b] (mg/L)	0.036	0.034	0.025	0.01	0.02	0.046
SO_4[d] (mg/L)	2652	1966	1477	1047	2660	1605
F[c] (mg/L)	1.98	2.24	2.45	0.78	0.84	0.86

[a]EN ISO 10523:2012, [b]EN ISO 11885:2009, [c] ISO 10359-1:1996, [d] In-house method

4 CONCLUSION

The outcomes of the present study are:

- The physical and mechanical properties, as well as the ability for field compaction indicate that the investigated BS may be beneficially used as fill material in geotechnical applications.
- According to the present environmental regulation in Slovenia, BS is classified as non-hazardous waste and cannot be placed on the market as a construction product. Further investigation for the improvement of the environmental behaviour of BS with pre-treatment is still ongoing.

5 ACKNOWLEDGEMENTS

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