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# Use of weathered and fresh bottom ash mix layers as a subbase in road constructions: Environmental behavior enhancement by means of a retaining barrier

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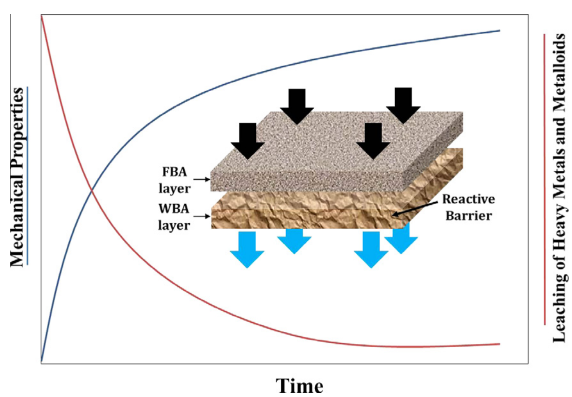
## HIGHLIGHTS

- Weathering of compacted freshly bottom (FBA) ash improves mechanical properties.
- FBA has a potential effect on the environment in the early stages of reutilisation.
- A WBA layer behaves as a reactive barrier for heavy metals and metalloids retention.
- WBA/FBA mix layers improve mechanical properties and reduce heavy metals release.

## GRAPHICAL ABSTRACT

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## ABSTRACT

The presence of neoformed cement-like phases during the weathering of non-stabilized freshly quenched bottom ash favors the development of a bound pavement material with improved mechanical properties. Use of weathered and freshly quenched bottom ash mix layers placed one over the other allowed the retention of leached heavy metals and metalloids by means of a reactive percolation barrier. The addition of 50% of weathered bottom ash to the total subbase content diminished the release of toxic species to below environmental regulatory limits. The mechanisms of retention and the different processes and factors responsible of leaching strongly depended on the contaminant under concern as well as on the chemical and physical factors. Thus, the immediate reuse of freshly quenched bottom ash as a subbase material in road constructions is possible, as both the mechanical properties and long-term leachability are enhanced.



## 1. Introduction

Bottom ash (BA) from the incineration of municipal solid waste (MSW) is composed of grate ash and grate siftings. It is a highly heterogeneous mixture of slag, ferrous and non-ferrous metals, ceramics, glass, other non-combustibles and residual organic matter (Chimenos et al., 1999). Unlike fly ash, BA is classified as non-hazardous waste by the European Waste Catalogue, as it is typically rich in calcium, aluminum, silicon and iron, resembling natural aggregate compounds but with different proportions (Chandler, 1997). However, chlorides, zinc, copper, lead and chromium are

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often present in high concentrations in BA, since they are widely used in the manufactured products that end up as waste. Consequently, a proper stabilisation process is needed in order to diminish the release of heavy metals and metalloids prior to reutilisation as secondary building material, either in road constructions or as concrete aggregate (Polettini et al., 2001; Chimenos et al., 2003; Fernández Bertos et al., 2004; Ginés et al., 2009;). However, other alternatives for their recycling and reutilisation assuring environmental safety are a major concern in order to follow the path to sustainability.

Natural weathering is the most cost-effective stabilisation treatment method, since it results in the chemical stability of BA. The early stages are characterized by strong leaching of the heavy metal content, due to the reducing conditions that favor solubility and to the steep concentration gradients between phases (Sabbas et al., 2003; Grathwohl and Susset, 2009). After a one-to-three month period, natural weathering of freshly quenched BA (FBA) causes chemical and mineralogical changes that lead to neoformed phases and minerals that are thermodynamically more stable and less reactive.

Along with a change in heavy metal and metalloid solubility, the presence of neoformed cement-like phases during weathering also exerts a special influence in mechanical properties of FBA. Chimenos et al. (2005) found that the effect of the dissolution and precipitation of metastable phases, as well as hydration and oxidation, starts immediately after quenching and becomes greater after a short period of time. The neoformed phases, as well as the elevated water content, act as a binder layer among particles that exerts a curing process with time. Because of this, the mechanical parameters have a spectacular improvement during the short-term natural weathering process. As a consequence, the freshly compacted BA progresses from behaving as an unbound material into a bound pavement material with a better performance than compacted natural weathered BA (WBA). The short-term change in mechanical properties means that FBA can be used prior to weathering as a road subbase, since its stiffness and compressive strength gradually increase over time (Chimenos et al., 2005). Accordingly, the reutilisation of FBA becomes feasible, since good mechanical behavior is assured and furthermore improved after a short period of time.

Nevertheless, the high reactivity of non-stabilised FBA represents a disadvantage, because of its potential effect on the environment in the early stages of reutilisation. As it has been previously determined (Chimenos et al., 2000, 2003), the leaching of heavy metals and metalloids usually results in greater concentrations values than those established in the regulatory limits for the reuse of BA as secondary building material. However, the leached concentrations of some of these heavy metals and metalloids dramatically fall after a very short period of natural weathering. Taking into account all the above mentioned, the revalorisation of BA is only environmentally friendly once it has been stabilised by a natural weathering period. Alternatives for its immediate reuse have not yet been reported.

On the other hand, the potential environmental impact of the leachates generated by percolating water when BA is used as a secondary building material in soils and road constructions has been extensively assessed by numerous authors (Johnson et al., 1996; Kersten et al., 1998; Sabbas et al., 2003; Izquierdo et al., 2008; Olsson et al., 2009). In conclusion, it can be stated that leaching of heavy metals and metalloids is strongly controlled by pH and redox conditions, as well as by complexation effects and adsorption into neoformed phases and minerals (Chimenos et al., 2005; Grathwohl and Susset, 2009).

In the framework of this issue, the aim of this study was to carry out an environmental assessment of the use of WBA and FBA mix layers, placed one below the other, as a subbase material in road constructions. A layer of WBA at the bottom would not only grant initial mechanical support but also enhance the environmental behavior of the leachates generated in the upper layer, as it would behave as a permeable reactive barrier (PRB) for heavy metals and metalloids retention. Moreover, the ageing processes would increase the mechanical properties of the top FBA layer over time, as a consequence of the presence of neoformed oxides, aluminosilicates, gypsum and ettringite, leading to the formation of the aforementioned cement-like phases that act as a binder material (Chimenos et al., 2005). Hence, a bound pavement material with enhanced environmental behavior can be gradually obtained.

For this purpose, layers with different proportions of WBA and FBA were prepared and studied. The potential environmental impact was evaluated using percolation leaching tests.

## 2. Materials and method

### 2.1. Bottom ash sampling

Both WBA and FBA were collected from a single MSW incinerator located in Tarragona (Spain). The feed stream is commonly composed of household waste with smaller proportions of waste from commercial vendors. The facility produces 35 000 tonnes per year of BA, which is directly homogenized after quenching in a conditioned plant for the recovery of reusable metals. Afterwards, the BA is stabilised by natural weathering while stored in a stock pile in the open for up to 3 months. Sampling of both FBA and WBA was planned according to the schedule of the experiment. FBA was sampled by collecting approximately 25 kg directly from the drag conveyor following combustion and previous to the recovery of metals. The moisture content was measured immediately and then the sample was tested. Around 250 kg of WBA was taken from various stockpiles stored for at least 3 months in an open disposal environment. The characterization with respect to its moisture content was also measured. After homogenization, each sample of WBA and FBA was screened to a particle size below 25 mm and quartered by a riffle-type sample splitter.

In order to evaluate the leaching behavior and the potential impact of both types of BA, the batch leaching test was carried out according to EN 12457-4 (2004). In this test, representative samples of WBA and FBA were taken separately and reduced when necessary to a particle size below 10 mm and brought into contact with ten times the weight of water under continuous stirring for 24 h. The corresponding eluates were passed through 45 μm polypropylene membrane filters, acidified by adding a few drops of $HNO_3$ and preserved in a fridge at 4 °C for subsequent analysis. Trace metal concentrations were determined by inductive coupled argon plasma mass spectrometry (ICP-MS). The results are shown in Table 1. The threshold established by the Catalan Government for landfill disposal and the regulatory limit values for reutilization of BA as secondary building material are also displayed for their corresponding classification (DOGC 2181 and 5370).

As it can be seen in Table 1, the concentration values for all the elements analyzed were below the values established by the Catalan Legislation for the revalorisation of WBA. As for the classification prior landfill, the majority of elements can be catalogued as inert with the exception of Cu, which fall in the concentration range of non-hazardous. In contrast, the concentration value of leached Pb for all samples of FBA studied were greater than the limit established and consequently this material should not be reused as secondary building material, requiring an adequate treatment before its final management. These results are in agreement with the values found in previous research works carried out with samples of FBA from the same facility (Chimenos et al., 2000).