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# Evaluation of physicochemical and hydromechanical properties of MSWI bottom ash for road construction

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ABSTRACT

Municipal Solid Waste Incinerator (MSWI) Bottom Ash has been used as a substitute for traditional aggregates in road construction; however, this material is little understood. The work presented in this paper pursues the study on the mechanical performance of bottom ash, proven by Le et al. (2017). Using a coupling technique for the first time, the physicochemical aspects and hydromechanical resistance of bottom ash were evaluated and analyzed. Physicochemical tests were first carried out, followed by oedometer tests under a wetting path. This coupled evaluation underlined the role of principal mineralogical components of the studied bottom ash as well as the link with its hydromechanical properties. Tests results showed that the principal constituent of bottom ash is $SiO_2$, which thus affects the characteristics of bottom ash. Given the physical stability of $SiO_2$ which generated a compacted material being less sensitive to water and chemical reactions, and bottom ash's other characteristics, this demonstrates why bottom ash could be a viable material in roadworks.



## 1. Introduction

Municipal solid waste management technologies include recycling, incineration for energy recovery, and landfilling. In many countries (such as France, Sweden, Denmark, and Taiwan), Municipal Solid Waste Incinerator (MSWI) for energy recovery represents the most common waste management technology (Lin et al., 2012; Zekkos et al., 2013). Incineration reduces the mass and volume of solid waste dramatically, thus decreasing the need of landfilling (Arm, 2004; Le et al., 2010, 2015; Zekkos et al., 2013). However, there is still a considerable amount of solid incineration residues generated after combustion, including bottom ash, fly ash, boiler ash, etc., of which bottom ash accounts for about 80% (Chimenos et al., 1999; Tang et al., 2015).

In the past, MSWI bottom ash was mostly treated by sanitary landfilling. Some possibilities other than landfilling have been sought since MSWI started, and the reutilization of incinerator bottom ash has already been considered. In civil engineering, road field consumes a significant quantity of aggregates (ADEME BRGM, 2008; Kim et al., 2005; Sormunen and Kolisoja, 2016). However, the aggregate reserves are increasingly unexploitable for various reasons: inaccessibility, integration into urban areas, situated in classified or protected sites, prohibitive costs, and risks of environmental impact. In this context, the utilization of value-added bottom ash in road fields is an interesting alternative.

Since bottom ash is a granular and compactable material, it is mainly used in civil engineering for constructing embankments, road layers, and parking areas (ADEME BRGM, 2008; Forteza et al., 2004; Le et al., 2010, 2015; SETRA-LCPC, 2000; SETRA, 2012). In France, about three million tons of bottom ash is produced annually (ADEME ITOM, 2008). The use of bottom ash began in Paris in the late 1950s and was expanded throughout the country in the late 1980s and 1990s (Badreddine and François, 2008).

Physicochemical and mechanical characteristics of bottom ash have been studied in many countries. Physicochemical and geotechnical characteristics of several kinds of bottom ash were evaluated by Forteza et al. (2004), Izquierdo et al. (2001, 2002), Kim et al. (2005), Le et al. (2012), Lynn et al. (2016) and Zekkos et al. (2013). The study of mechanical characteristics of this type of material was investigated in different aspects. Arm (2004) and

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Sormunen and Kolisoja (2016) used cyclic load triaxial tests to estimate the resilient modulus of bottom ash. Becquart et al. (2008), Le et al. (2017), Pandeline et al. (1997) and Sormunen and Kolisoja (2016) used static triaxial tests to determine the secant modulus of bottom ash. Triaxial tests (Becquart et al., 2008; Le et al., 2017; Pandeline et al., 1997; Sormunen and Kolisoja, 2016) and direct shear tests (Lin et al., 2012; Weng et al., 2010; Zekkos et al., 2013) were conducted to evaluate the shear strength (cohesion and friction angle) of bottom ash.

The previous study of Le et al. (2017) underlined that bottom ash presents interesting mechanical properties similar to that of dense sand. The Poisson ratio $\nu$ and the dilation angle $\psi$ are nearly invariant, and the well graded grain size distribution of bottom ash generates a high value of effective friction angle obtained by triaxial tests.

Prior to usage, bottom ash must be in accordance with environmental requirements set by state regulatory agencies (Kim et al., 2005). Physicochemical characteristics are important for the reuse of bottom ash because these characteristics are taken to evaluate the leaching potential or the retention potential of pollutant by bottom ash. Otherwise, bottom ash physicochemical characteristics affect mechanical properties which is one of the major concerns in engineering design (Arm, 2004; Sormunen and Kolisoja, 2016; Weng et al., 2010). Usually, mechanical and chemical performances are considered separately. This study aimed to combine both approaches and give a new explanation of the macroscopic behavior (mechanical performance) by an additional microscopic (grain and mineral phases level) point of view. The long-lasting mechanical behavior of MSWI bottom ash under the wetting path and the link with its chemical properties were an interesting challenge to be investigated. The first part of this study analyzed the physicochemical properties of the tested bottom ash to determine chemical content in accordance with the French regulation authorities. Physicochemical characteristics were identified and analyzed by using X-ray fluorescence, X-ray diffraction (XRD), loss on ignition, and a leaching test. Furthermore, mechanical and hydromechanical tests involving fragmentability, degradability, and the use of an oedometer performed in immersed and non-immersed conditions, respectively, were evaluated to assess the long-lasting performance of the material used in road construction.

## 2. Material and methodology

### 2.1. Material

The MSWI bottom ash used in this study originated from the recycling platform of PréFerNord Company located in Fretin, France (Le et al., 2017). PréFerNord recovers "slag" resulting from the combustion of five incineration plants.

To calibrate the materials, a pre-treatment of the bottom ash, including sifting, removal of ferrous, and non-ferrous elements, was carried out on site. Additionally, it was allowed to mature for three months. A range of particle sizes from 0 to 20 mm was chosen to approach the size range of natural aggregates which is usually used in the road field.

### 2.2. Methodology

Loss on ignition, leaching and mineralogy tests were used to classify bottom ash according to the governmental specifications issued by French Ministry of Environment in 1994 and the updated SETRA technical guide in 2012. Oedometer, fragmentability, degradability and additional geotechnical tests were used to assess the stability of bottom ash under different conditions.

#### 2.2.1. Loss on ignition

The loss on ignition was used to assess the fraction of organic matter content inside the tested material. The loss in ignition is determined by the loss of mass, expressed as a percentage of dry weight of the initial sample after four hours of calcinations at 500 °C of a sample previously dried at 105 °C and crushed to 4 mm.

#### 2.2.2. Leaching test

In addition, the pollution potential of the material is characterized by a leaching test performed with the French standard NF X 31-210 in accordance with the European standard EN 12457-2 (2002). This test was based on repeated contact of a representative sample of 100 g of bottom ash with one liter of water, under standardized conditions, to evaluate the amount of solubilized pollutants.

#### 2.2.3. Mineralogy characterization

To anticipate difficulties which may appear in the process of adding value to bottom ash, the mineralogical composition of bottom ash needs to be identified. The elementary mineral component of bottom ash is a significant parameter in the comprehension of its physicochemical behavior (Kim et al., 2005; Pecqueur et al., 2001). To determine the elementary mineral component of bottom ash, measurements using a Siemens SRS 300 spectrometer with X-ray fluorescence had to be carried out.

The XRD analysis specifies the mineralogical phases presented in the material and results are summarized in Fig. 1. The XRD was performed with Siemens D5000 diffractometer destined for the qualitative identification of the mineral crystallized phases in a given compound.

#### 2.2.4. Additional geotechnical test

In addition to the geotechnical identification tests performed in Le et al. (2017), the abrasiveness and brittleness of bottom ash and its long-term evolution were tested: degradability (NF P 94-067, 1992) and fragmentability (NF P 94-066, 1992). The degradability and fragmentability coefficients are representative of the behavior of certain materials that change over time. Although these coefficients are much more suitable for rock material, it seemed appropriate to conduct such tests to obtain a complete characterization of bottom ash.

The degradability coefficient is used to study the behavior of a material subjected to weathering agents. The test consists of determining the reduction of $D_{10}$ (the diameter of particles for 10% of cumulative passing ones) of a 10/20 mm granularity sample subjected to four cycles of imbibition-drying (degradability).

The fragmentability coefficient is used to study the behavior of a material subjected to mechanical agents. The test consists of determining the reduction of $D_{10}$ (the diameter of particles for 10% of cumulative passing ones) of a 10/20 mm granularity sample subjected to four cycles of pounding (fragmentability).

#### 2.2.5. Oedometer test

Oedometer tests had been performed in addition to the triaxial tests of Le et al. (2017), according to French standard XP P 94-090-1 (1997). It enables the monitoring of settlement of the sample submitted to uniaxial loading path. The vertical deformation is measured while the lateral displacement is inhibited. This test allows the analysis of the mechanical behavior of a material under different loads, similar to that of road traffic. In the present study, the oedometer test was used to assess the collapse potential of bottom ash during loading followed by imbibition along the wetting path.

A protocol was developed to study the mechanical behavior of bottom ash at different states of compaction and saturation. Since bottom ash is made of materials of high caliber (0/20 mm), conventional oedometer molds are not suitable. A new protocol method of