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Construction of an interim storage field using recovered municipal solid waste incineration bottom ash: Field performance study

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A B S T R A C T

The leaching of hazardous substances from municipal solid waste incineration (MSWI) bottom ash (BA) has been studied in many different scales for several years. Less attention has been given to the mechanical performance of MSWI BA in actual civil engineering structures. The durability of structures built with this waste derived material can have major influence on the functional properties of such structures and also the potential leaching of hazardous substances in the long term. Hence, it is necessary to properly evaluate in which type of structures MSWI BA can be safely used in a similar way as natural and crushed rock aggregates. In the current study, MSWI BA treated with ADR (Advance Dry Recovery) technology was used in the structural layers of an interim storage field built within a waste treatment centre. During and half a year after the construction, the development of technical and mechanical properties of BA materials and the built structures were investigated. The aim was to compare these results with the findings of laboratory studies in which the same material was previously investigated. The field results showed that the mechanical performance of recovered BA corresponds to the performance of natural aggregates in the lower structural layers of field structures. Conversely, the recovered MSWI BA cannot be recommended to be used in the base layers as such, even though its stiffness properties increased over time due to material aging and changes in moisture content. The main reason for this is that BA particles are prone for crushing and therefore inadequate to resist the higher stresses occurring in the upper parts of road and field structures. These results were in accordance with the previous laboratory findings. It can thus be concluded that the recovered MSWI BA is durable to be used as a replacement of natural aggregates especially in the lower structural layers of road and field structures, whereas if used in the base layers, an additional base layer of natural aggregate or a thicker asphalt pavement is recommended.

1. Introduction

The potential leaching of hazardous substances from municipal solid waste incineration (MSWI) bottom ash (BA) has been studied in different scales by many researchers; varying from smaller scale laboratory studies (e.g. Dijkstra et al., 2006; Ecke and Åberg, 2006; Forteza et al., 2004) into large-scale field studies (e.g. Dabo et al., 2009; De Windt et al., 2011; Hjelmar et al., 2007; Lidelöw and Lagerkvist, 2007). The technical properties of MSWI BA are also well known (e.g. Chandler et al., 1997; Hu et al., 2010; Izquierdo et al., 2002), whereas less data is available on the mechanical performance of actual civil engineering structures constructed with MSWI BA. Some researchers have investigated the stiffness and strength properties of MSWI BA in the laboratory (e.g. Arm, 2004; Becquart et al., 2009; Sweere, 1990; Wiles and Shepherd, 1999), while only a few large scale studies have been conducted on the mechanical performance of MSWI BA in actual field structures (Arm, 2003; Bendz et al., 2006; Hartlén et al., 1999; Reid et al., 2001). In general terms, the durability of structures built with this waste derived material can also have major influence on, for example, the potential leaching of hazardous substances and the functionality of civil engineering structures in the long term. Hence, it is necessary to properly evaluate in which type of structures MSWI BA can be safely used in a similar way as natural and crushed rock aggregates.

This paper describes the construction of an interim storage field within a waste treatment centre, where recovered MSWI BA was used in the different structural layers of the field, and reports the mechanical quality control measurements taken during and half a year after the construction. The MSWI BA used in this study was treated with a Dutch dry treatment technology called ADR (Advanced Dry Recovery). Up to now, no large scale field studies have been published on the mechanical performance of MSWI BA

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recovered with this particular technology. The ADR technology was developed in the Netherlands in the 2000s. It improves the recovery of especially non-ferrous metals from the BA due to removal of fines with a ballistic separator (de Vries and Rem, 2013). Therefore, the quality, and thus the properties of recovered BA can be different from what they were, for example, ten years ago when the latest studies on the mechanical performance of recovered MSWI BA in actual field structures were conducted (Arm, 2003; Bendz et al., 2006; Hartlén et al., 1999; Reid et al., 2001).

The main aim of this study was to evaluate whether the mechanical performance of structures built with this recovered BA corresponds to the performance of natural aggregates, and thus fulfils the target values set for these structures. In addition, the development of mechanical properties over time was investigated in the field scale, since recently conducted laboratory experiments have shown that the mechanical behaviour of recovered MSWI BA is greatly dependent on materials aging and the changes in materials moisture content (Sormunen and Kolisoja, 2016).

2. Materials and methods

2.1. MSWI BA and its recovery

The MSWI BA used in this study originated from a waste incineration plant in Mustasaari, Finland. The plant uses grate design for waste combustion (1000 °C). The input waste material (approximately 180 000 t/year) is source-separated waste from 50 municipalities and over 400 000 inhabitants. Approximately 30 000 t of BA is generated in the plant annually. The BA is quenched with water before transported into a waste treatment centre (Ilmajoki, Finland), where it is treated.

The annual amount of MSWI BA was treated in the year 2013, in order to recover ferrous (F) and non-ferrous (NF) metals from the BA. The treatment was performed with a Dutch dry treatment technology called the ADR. In brief, using dry screens, magnets, wind sifters, eddy current separators and a ballistic separator (i.e. the ADR), the process separates F and NF metals from the BA (Sormunen et al., 2016). The remaining fractions are BA minerals of different grain sizes (0–2 mm, 2–5 mm, 5–12 mm and 12–50 mm). They consist mainly of glass, sand, and ceramics and are the most abundant materials from the process, accounting for approximately 75–80% of the total mass of treated BA (Sormunen and Rantsi, 2015). The principle behind the ADR technology has been described in more detail in the patent of Berkhout and Rem (2009) and, for example, in de Vries and Rem (2013).

2.2. Interim storage field

2.2.1. Preparation of construction materials

The starting point for preparing construction materials from MSWI BA mineral fractions was based on their grain size distributions. The grain size distributions of different BA mineral fractions (0–2, 2–5, 5–12, 12–50 mm) reported by Sormunen and Rantsi (2015) did not, as such, fulfil the strict grain size distribution requirements for the sub-base and base layer materials that are given by the general quality criteria for infrastructure construction in Finland (RTS, 2010). Therefore, a mathematical proportioning of aggregates was used to design construction materials from recovered MSWI BA, whose grain size distributions fulfilled the aforementioned requirements for these two structural layers. A more detailed description of the material design is given in Sormunen et al. (2016). Table 1 summarizes the amounts of different BA mineral fractions (%) used in the BA aggregate mixtures for the sub-base and base layers of the interim storage field (Sormunen et al., 2016). For the filtration layer, a mixture was not necessary since the grain size distribution of 0–2 mm BA mineral fraction fulfilled the requirements given by RTS (2010) for the materials intended to be used in filtration layers (Sormunen et al., 2016).

The mixing of BA mineral fractions into aggregate mixtures was performed with a drum sieve and the grain size distributions of each BA mixture were analysed as described in Section 2.2.4. In addition, the technical and mechanical properties of these chosen BA mixtures were investigated in the laboratory before designing the interim storage field structure. The results of these analyses can be found in Sormunen et al. (2016).

2.2.2. Structural design of the interim storage field

The structural design of a flexible pavement for the interim storage field was made with the simplified (Odemark) elastic layer theory. It is commonly used theory in the structural design of road, field and street structures in Finland (Tiehallinto, 2004). The principle behind this theory is described in more detail by Ullidtz (1998) and its mathematical Eq. (1) is given as follows:

$$E_Y = \frac{E_A}{\left(1 - \frac{1}{\sqrt{1+0.81\times\left(\frac{h}{a}\right)^2}}\right)\times\frac{E_A}{E} + \frac{1}{\sqrt{1+0.81\times\left(\frac{h}{a}\right)^2\times\left(\frac{E}{E_A}\right)^{2/3}}}} \quad (1)$$

where,

E_Y = the bearing capacity on top of the upper layer (MPa).
E_A = the bearing capacity on top of the lower layer (MPa).
E = the E-modulus (stiffness) of the material in the upper layer (MPa).
h = the material thickness of the upper layer (m).
a = the radius of metallic loading plate used in the static plate load test (0.15 m).

The subsoil underneath the field structure varied from solid rock to stiff moraine. Crushed concrete, brick and glass was used as filling material below the actual structural layers. In the field design calculations, an E-modulus value of 20 MPa was used for the subgrade. This somewhat cautious estimate was considered appropriate due to the fragile nature of filling materials and since these materials would not be heavily compacted during the construction. A more detailed description of the field design process can be found in Sormunen et al. (2016). A principal cross-section of the field structure is given in Fig. 1. The bearing capacity requirements (E2) set during the structural design of the field were: 63 MPa for the MSWI BA filtration layer, 142 MPa for the MSWI BA sub-base layer, 230 MPa for the MSWI BA base layer and 260 MPa for the base layer made of crushed rock aggregate (Sormunen et al., 2016).

2.2.3. Construction of the interim storage field

The interim storage field was built between July and October in the year 2014. The size of the field was approximately 10 000 m^{-2}. As mentioned in Section 2.2.2, the BA materials were used in the filtration, sub-base and base layers. The total amount of BA minerals used in construction was approximately 15 400 t (dry weight = dw). An additional base layer of crushed rock aggregate (#0 ... 32 mm) was built on top of BA layers, since the BA mineral particles were observed to be prone for crushing (Sormunen et al., 2016). In addition, sub-surface drains and an LDPE-film (thickness 0.5 mm) was placed underneath the BA layers in order to collect and analyse the quality of leachate. The results of leachate quality are not discussed in this paper but will be reported elsewhere.

The BA structural layers were first watered in order to improve the compaction of structural layers. Each structural layer was then