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Geotechnical characterization of a Municipal Solid Waste Incineration Ash from a Michigan monofill

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ABSTRACT

A field and laboratory geotechnical characterization study of a Municipal Solid Waste Incineration Ash disposed of at the Carleton Farms monofill in Michigan was performed. Field characterization consisted of field observations, collection of four bulk samples and performance of shear wave velocity measurements at two locations. Laboratory characterization consisted of basic geotechnical characterization, i.e., grain size distribution, Atterberg limits, specific gravity tests, compaction tests as well as moisture and organic content assessment followed by direct shear and triaxial shear testing. The test results of this investigation are compared to results in the literature. The grain size distribution of the samples was found to be very similar and consistent with the grain size distribution data available in the literature, but the compaction characteristics were found to vary significantly. Specific gravities were also lower than specific gravities of silicic soils. Shear strengths were higher than typically reported for sandy soils, even for MSWI ash specimens at a loose state. Strain rate was not found to impact the shear resistance. Significant differences in triaxial shear were observed between a dry and a saturated specimen not only in terms of peak shear resistance, but also in terms of stress–strain response. In situ shear wave velocities ranged from 500 to 800 m/s at a depth of about 8 m, to 1100–1200 m/s at a depth of 50 m. These high shear wave velocities are consistent with field observations indicating the formation of cemented blocks of ash with time, but this "ageing" process in MSWI ash is still not well understood and additional research is needed. An improved understanding of the long-term behavior of MSWI ash, including the effects of moisture and ash chemical composition on the ageing process, as well as the leaching characteristics of the material, may promote unbound utilization of the ash in civil infrastructure.

1. Introduction

Municipal Solid Waste (MSW) management technologies include landfilling, recycling/recovery and incineration for energy recovery, also known as Waste-to-Energy (WTE). The amount of waste managed by each technology varies significantly between nations, regions, and even locally. In many countries, such as Sweden and Denmark, waste incineration for energy recovery represents the most common waste management technology (Michaels, 2010). In the United States, in 2010, waste incineration in 86 plants managed 96,164 tonnes per day, which is equal to only 11.7% of the total MSW stream (EPA, 2011). However, significant variations in this percentage are observed among different states. Only 24 states have WTE facilities. In the State of Connecticut and Massachusetts 64.9% and 37% respectively of generated MSW is handled by WTE facilities. In other states the majority of waste is landfilled (Columbia University, 2012). Modern WTE facilities have improved energy recoveries during the incineration process compared to older WTE technologies. Due to the growing energy demand, WTE is expected to play a larger role globally in managing the increasing amounts of generated MSW.

WTE has important advantages. Energy recovery can be significant. Existing WTE facilities in the US generate 2720 MW of power per year. The process can be well controlled and modern air pollution control systems are reported to effectively capture hazardous constituents, such as dioxins (Psomopoulos et al., 2009). A by-product of the incineration process is the MSW Incineration Ash (MSWI ash). The volume of MSWI ash generated by the incineration process is approximately only 10% of the volume of the MSW before incineration and the weight of the MSWI ash is only 20–30% of the weight of the MSW before incineration (Ahmed, 1991). Thus, there is a significant reduction in the volume and weight of the residuals, reducing the amount of material that needs to be disposed of, or reused. MSWI ash consists of fly ash and bottom ash. Fly ash (FA) represents approximately 20% of the total weight of the ash, and is reported to have elevated concentrations of metals and salts. As a consequence, it may classify as hazardous (Chang and Wey, 2006; Hjelmar, 1996). Bottom ash (BA) is typically classified as non-hazardous (NREL, 1999; Roffman,

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1998; Stegemann and Schneider, 1991). The mixture of the two ashes, referred to as combined ash (CA), is also typically considered a non-hazardous waste material. Although MSWI ash is reused in many countries, in the United States, MSWI ash is almost exclusively disposed of in landfills, known as monofills, and is occasionally used as fill material for access roads within the landfill footprint. Brown (1997) reports that only 7% of the MSWI ash generated in the US is reused, primarily in bounded or "contained" applications.

A number of studies have been published on the reuse of MSWI ash in "contained" applications such as asphalt or concrete mixes and bricks (Berg and Neal, 1998; Rachid and Frantz, 1992; Tay et al., 1982; Tay, 1988, Tyrrell and Field, 1970, Abrahams, 1970; Malisch et al., 1970, and as an admixture in stabilization of soils (Goh and Tay, 1993; Show et al., 2003). These studies focus on characterization data such as grain size distribution, fines content, and in some cases, compaction characteristics. However, far more limited data, particularly in the United States, is available in the literature on geotechnical properties of MSWI ash, such as the shear strength and the stiffness or shear wave velocity of the material. Improved characterization of the geotechnical properties of MSWI ash will lead to improved and more efficient landfilling of the material and may lead to increased reuse in civil infrastructure in unbounded (or "open") applications, i.e., applications where ash is used instead of natural soils.

This paper presents the results of a limited field and laboratory investigation on the physical and geotechnical characteristics of MSWI combined ash disposed of in Carleton Farms monofill in southeast Michigan. The results are compared to data available in the literature, in an effort to draw more generic conclusions with regards to the variability of the MSWI ash and its physical and geotechnical characteristics.

2. Approach

The testing site is the Carleton Farms monofill located in southeast Michigan. The site receives MSWI ash from a local WTE Facility. A total of 800,000 tons per year is handled by this WTE facility and the generated combined ash is disposed of in the monofill. Field activities included bulk sample collection at four locations and the performance of surface wave measurements at two locations with the objective to characterize the shear wave velocity variation with depth. Laboratory testing activities included grain size distribution analyses, Atterberg limit tests, moisture and organic content tests, specific gravity, particle morphology evaluations using Scanning Electron Microscopy (SEM), and compaction tests. In addition, direct shear and triaxial tests were performed to assess the shear strength of the MSWI ash. The results of this study are integrated with test data available in the literature in an effort to assess the variability of the material and generalize conclusions on the physical and geotechnical characteristics of the MSWI ash.

3. Results and discussion

3.1. Grain size distribution

Grain size distribution analyses were performed per ASTM D-422-63 using the dry method. The grain size distributions for the four samples collected are presented in Fig. 1. The grain size distributions for the four samples are very similar, despite the fact that the samples were collected from different locations at the monofill. All four samples classify as poorly or well graded sand with silt and/or gravel, and the fines content varied from 3.1% to 7.5%. The coefficient of uniformity was 12.5–32 and the coefficient of variation was 0.56–1.46.

Grain size distribution results available in the literature are also shown in Fig. 1. A total of twenty-six additional grain size distributions are shown from thirteen different studies worldwide (Tay and Goh, 1991; Forrester and Goodwin, 1990; Shieh, 1991; Gress et al., 1992; Goh and Tay, 1993; Demars, 1994; Pandeline et al., 1997; Berg and Neal, 1998; Zhang et al., 2009; Zwahr, 2004; Izquierdo et al., 2001; Chang and Wey, 2006; Travar et al., 2009). Although there is expected variation in the data, the results are generally consistent. Bottom ash samples are systematically coarser than fly ash and combined ash samples and have low fines content. The variability among samples is not as significant, when one considers that the database includes samples from a large number of sites worldwide. Fly ash samples appear to be more variable and finer with fines content ranging from 5% to 70%. This data is consistent with the observation by Blaisdell et al. (1990) who suggested that the constituents of the fly ash are a function of the air pollution control system in use at each facility. Grain size distributions for combined ash samples from the literature and this study fall generally between the fly ash and bottom ash grain size distribution data, as expected.

3.2. Plasticity

Plasticity tests were performed in the material passing the No. 200 sieve according to ASTM D-4318-05 to evaluate the liquid limit, plastic limit and plasticity index. The results are presented in Table 1. Two of the samples were non-plastic and two other samples had low plasticity with liquid limits of 33 and 37 and plasticity index of 6 and 14, respectively.

3.3. Organic content

An assessment of the organic content was performed according to ASTM D 2974-07a. The samples exhibited low organic contents ranging from 1.1% to 2.6%. Although MSWI ash samples are byproducts of an incineration process and would be expected to have no organic constituents, small amounts of organic matter may still be present due to incomplete incineration. Organic content and LOI values in the literature range from 2% to 7% for bottom ash. Lower values are observed in upgraded/modern facilities that are efficient in the incineration process (National Renewable Energy Laboratory, 1999). Higher values (as high as 17%) have been reported in older facilities (IAWG, 1997). Aburatani et al. (1998) also reports 5% organic content on fill material consisting primarily of MSWI ash used in reclamation sites of Osaka Bay Phoenix project.

3.4. Specific gravity

Approximately 150 gr of the ash fraction passing the No. 4 sieve were used to determine each sample's specific gravity per ASTM D-854-06. Overall, specific gravity values were around 2.6 for three of the samples. Sample 2 had a lower specific gravity of 2.10–2.11. These values confirm that the MSWI ash has lower specific gravities than silicates and are consistent with values reported in the literature that indicate specific gravity values of 1.5–2.5 for bottom ashes and 1.9–2.2 for fly ashes, as shown in Table 2. Gress et al. (1992) reported the lowest specific gravity value of 1.90 for the finer fraction of a bottom ash. Goh and Tay (1993) reported specific gravity equal to 1.71 for a fly ash.

3.5. Surface morphology

All samples were similar in appearance. Thus, the surface morphology of one sample (Sample 2) was investigated using Scanning