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Full Length Article

Geo-environmental application of municipal solid waste incinerator ash stabilized with cement

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ABSTRACT

The behavior of soluble salts contained in the municipal solid waste incinerator (MSWI) ash significantly affects the strength development and hardening reaction when stabilized with cement. The present study focuses on the compaction and strength behavior of mixed specimens of cement and MSWI ash. A series of indices such as unconfined compressive strength, split tensile strength, California bearing ratio (CBR) and pH value was examined. Prior to this, the specimens were cured for 7 d, 14 d, and 28 d. The test results depict that the maximum dry density (MDD) decreases and the optimum moisture content (OMC) increases with the addition of cement. The test results also reveal that the cement increases the strength of the mixed specimens. Thus, the combination of MSWI ash and cement can be used as a lightweight filling material in different structures like embankment and road construction.

1. Introduction

The safe disposal of waste materials such as municipal, industrial and hazardous waste has been one of the major challenges in urban cities as well as in rural environment in recent years. Such waste poses environmental pollution problems for the surrounding disposal area because some of the part of it is not biodegradable (Muntohar et al., 2012). The incineration of municipal solid waste is a common practice to reduce its volume to be disposed in a landfill (Show et al., 2003). Some researchers have shown that the municipal solid waste incinerator (MSWI) ash can be utilized for geotechnical applications such as aggregate in road construction, embankment and landfills (Sherwood and Ryley, 1986; Poran and Ahtchi-Ali, 1989; Forteza et al., 2004; Mohamedzein et al., 2006). The other application of MSWI ash is mixed with soils, lime, cement or concrete, which improves the physical properties of finished product (Balasubramaniam et al., 1999; Kaniraj and Gayathri, 2003). The use of MSWI ash in geotechnical application can solve many geo-environmental problems and the related issues (Kamon et al., 2000; Gao et al., 2011). The addition of cement only contributes to the containment of heavy metals due to the high level of alkalinity (Show et al., 2003; Shah and Ahmad, 2008). Rahman (1986) studied the potential use of rice husk ash incorporated with lime and cement in lateritic soil stabilization and recommended the use of 7% cement for base materials, 5% lime for sub-base materials and 18% rice husk ash as a sub-base material. Prabakar et al. (2004) suggested that the addition of fly ash improves the engineering properties of soil and it is a cost-effective material for stabilization of clayey soil. Some researchers used the physico-chemical parameters as governing agents to change the properties of final product. For example, a few studies used pH value as a governing agent which significantly affects the chemical properties of both soil and fly ash (Sharma and Kalra, 2006; Cetin and Pehlivan, 2007). Davidson et al. (1965) proposed a minimum pH value of 12.4 that favors the pozzolanic reactions between soil and lime, and recommended the minimum lime requirement, regarded as a lime fixation point. The addition of lime affects the plasticity as well as increases the optimum moisture content (OMC) of mixed specimen (Bell, 1996). Simultaneously, it decreases the maximum dry density (MDD) and increases the California bearing ratio (CBR). Chauhan et al. (2008) concluded that the OMC increases and the MDD decreases with increased percentage of fly ash mixed with locally available soil. Muhunthan et al. (2004) studied the properties of incinerator fly ash, bottom ash and their blends, and recommended the use of these materials in embankment

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construction. Sharma et al. (2012) concluded that unconfined compressive strength (UCS) and CBR of soil increase substantially when 20% fly ash and 8.5% lime are mixed with each other. Ramlakhan et al. (2013) concluded that the OMC and CBR increase and the MDD decreases with increases in lime and fly ash. Gay and Schad (2000) suggested that the combination of lime and cement amplifies the strength and stiffness. Besides, the addition of cement is helpful in improvement of soil's cohesion. Some studies recommended the use of rubber tires in highway and other construction purposes (Ahmed and Lovell, 1992; Upton and Machan, 1993). The construction of buildings, roads and other civil engineering structures on weak or soft soil is generally associated with certain threats because such soil is susceptible to differential settlements due to its poor shear strength and high compressibility. Hence, there is a need to improve certain desired properties of subgrade soil, i.e. bearing capacity, shear strength and CBR.

In this context, various cement stabilization techniques including jet grouting and deep cement mixing have been used worldwide for stability and deformation control of land reclamation and road construction (Fatahi et al., 2012). These techniques are based on mixing cement with soil due to which the soil becomes more resistant. The soil can be stabilized using different sorts of binders, i.e. lime or cement, as the strength characteristics are reached faster with their addition. However, the soil or ash treated with cement is more prone to shrinkage and may be associated with certain ruptures when used as a base material (Gray et al., 1994). On the basis of outcomes suggested by various researchers, the MSWI ash stabilized with cement was supposed to be a promising application and it may change the characteristics of finished product. Thus, the study aims to evaluate the effects of cement stabilization on the geotechnical properties of MSWI ash mixtures, such as compressibility, UCS, split tensile strength (STS), CBR and pH value.

2. Materials and methods

2.1. Cement stabilization

During experimentation, the cement content in MSWI ash varied from 0% to 8%. After this, the mixed specimens were cured for 7 d, 14 d and 28 d.

2.2. Experimental design

2.2.1. MSWI ash

The MSWI ash used in present study was obtained from the Municipal Solid Waste Incineration Plant, Chandigarh, India. The physical and engineering properties and chemical compositions of the MSWI ash are summarized in Tables 1 and 2, respectively. The particle size distribution curve for MSWI ash was obtained by wet sieve analysis (ASTM D6913-04, 2004). The sieve analysis results reveal that 84.6% of the particles exist within the range of 75 μm to 1.18 mm, implying that the MSWI ash consists of coarse sand particles. The grain size of the ash falls within the typical range for poorly graded sand with silt (SP-SM). Table 2 shows that the MSWI ash used in the present study consists largely of calcium and silicon with considerable amount of potassium, iron, aluminum, magnesium and sodium. The high contents of Ca and Si are the main strength-contributing agents in Portland cement. It is likely that the MSWI ash can also be used as a cement admixture or pozzolanic material.

Table 1
Physical and engineering properties of MSWI ash.

Specific gravity	Loss on ignition (%)	MDD (kN/m^3)	OMC (%)	Angle of internal friction ϕ (°)	Cohesion (Pa)
2.05	8.67	16.8	11	36.5	0

2.2.2. Physical properties of cement

An ordinary Portland cement of 43 grades was used for the study. It was bought from the local market of institutional area. The physical properties of cement are listed in Table 3.

2.2.3. Compaction test

The compaction test was performed as per ASTM D1557-78 (1978) to determine the MDD and OMC of the MSWI ash. The heavy compaction test was carried out on the MSWI ash alone and mixed specimens at various moisture contents and allowed to equilibrate for 24 h prior to compaction. A specimen weighing 3 kg passing through 4.75 mm sieve was taken for conducting the compaction test in a standard Proctor mold with capacity of 0.001 m^3. The water was added to MSWI ash and mixed thoroughly without formation of any lumps. Thereafter, the specimen was poured in standard mold in five layers and compacted by applying 25 blows per layer using a standard rammer weighing 4.89 kg and falling through a height of 300 mm.

2.2.4. Unconfined compression test

The unconfined compression test was carried out on cylindrical specimens of 38 mm in diameter and 76 mm in height according to ASTM D2166-98 (1998). The MSWI ash–cement mixtures were compacted to MDD at OMC in standard molds. The mixture was compacted in five layers and each layer was compacted using rammer under a free fall of 450 mm. Then the specimens were extracted from the molds and stored in desiccators partially filled with water at room temperature for curing. After that, the specimens were tested after 7 d, 14 d and 28 d of curing. The UCS was determined at a loading rate of 1.14 mm/min. The average of test results on three specimens was considered as the UCS value.

2.2.5. Split tension test

For conducting split tension test, the cylindrical specimens of 38 mm in diameter and 76 mm in height were prepared and compacted to MDD at OMC in the same manner as the unconfined compression test. The STS was calculated according to ASTM C496-96 (1996) as follows:

$$T = \frac{2P}{\pi dL}$$

where P is the failure load; and L and d are the length and diameter of specimen, respectively.

2.2.6. CBR test

The CBR test was carried out according to ASTM D1883-05 (2005) on specimens of 152 mm in diameter and 170 mm in height and compacted by applying 56 blows per layer using a standard rammer weighing 4.89 kg and falling through a height of 300 mm to MDD at OMC. The soaked CBR test was conducted after soaking the specimens for 96 h in water. A metal plunger of 50 mm in diameter and 100 mm in length was allowed to penetrate the specimens at strain rate of 1.25 mm/min using CBR testing machine. The CBR value was determined corresponding to 2.5 mm and 5 mm settlements.

2.2.7. pH test

The pH test was performed according to ASTM D4972-13 (2013) to determine the optimum combination of mixed specimens. For