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Experimental and numerical analysis of metal leaching from fly ash-amended highway bases

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ABSTRACT

A study was conducted to evaluate the leaching potential of unpaved road materials (URM) mixed with lime activated high carbon fly ashes and to evaluate groundwater impacts of barium, boron, copper, and zinc leaching. This objective was met by a combination of batch water leach tests, column leach tests, and computer modeling. The laboratory tests were conducted on soil alone, fly ash alone, and URM–fly ash–lime kiln dust mixtures. The results indicated that an increase in fly ash and lime content has significant effects on leaching behavior of heavy metals from URM–fly ash mixture. An increase in fly ash content and a decrease in lime content promoted leaching of Ba, B and Cu whereas Zn leaching was primarily affected by the fly ash content. Numerically predicted field metal concentrations were significantly lower than the peak metal concentrations obtained in laboratory column leach tests, and field concentrations decreased with time and distance due to dispersion in soil vadose zone.

1. Introduction

Over 100 million tons of fly ash is produced in the United States as a by-product of burning coal in electric power plants (ACAA, 2009). Approximately, 39% of this fly ash is reused and majority of the remaining amount is stockpiled in landfills, thus occupying valuable land space. Benson et al. (2010) indicates that only 24% of the fly ashes generated in the United States are used in concrete production, and an increasing number of power plants are producing high carbon fly ash (HCFA) with loss on ignition (LOI) contents greater than 6%. These fly ashes can not be used as a concrete additive as unburned carbon content adsorbs the air entrainment agents that are used to prevent crack formation and propagation in the cement matrix (Cetin et al., 2010). HCFAs in the eastern parts of the United States contain very small amounts of calcium oxides and they often need to be activated with a cementitious agent for use in geotechnical applications (Baykal et al., 2004; Edil et al., 2006; Kumar et al., 2007; Yoon et al., 2009; Cetin et al., 2010).

American Society of Civil Engineers estimates that $2.2 trillion is needed over a five-year period to bring the nation's infrastructure to good condition (Cetin et al., 2010). A large portion of the earthen materials needed for these transportation infrastructure projects have the potential to use recycled materials to aid in their stabilization; however, these materials must also be safe for the environment in which they are placed. One area for their large volume reuse is highway base stabilization. Even though mechanical properties of the fly ash-amended highway base layers are deemed satisfactory, one key issue that precludes highway base layer stabilization with fly ash is the potential for groundwater impacts caused by metals in the fly ash (Jankowski et al., 2006; Wang et al., 2006; Bin-Shafique et al., 2006; Goswami and Mahanta, 2007; Li et al., 2007).

The objective of this study was to evaluate the leaching potential of HCFA-stabilized highway base layers and to assess their potential impact on groundwater through laboratory batch water leach and column leach tests, and computer modeling. One type of soil and three different HCFAs were used. The study focused on leaching of four trace metals: barium (Ba), boron (B), copper (Cu) and zinc (Zn).

2. Materials

An unpaved road material (URM) was used as the primary soil source for the highway base mixtures. URM was stockpiled in various locations in Maryland and required immediate attention for recycling. The URM was collected from a stock-pile in Caroline County, Maryland satisfied the gradation and maximum dry unit weights requirements by the Maryland State Highway Administration (SHA). The materials larger than 19-mm sieve were removed before starting any laboratory tests. Physical and chemical properties of URM are summarized in Table 1.

Three HCFAs were used as stabilizing agents in highway base layers. All fly ashes were obtained from power plants located in

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Table 1
Physical and chemical properties of the materials used in current study. Chemical compositions and metal concentrations are based on X-ray fluorescence spectroscopy and total elemental analysis, respectively.

Property	Unpaved road material	Brandon shores (BS) fly ash	Paul smith (PS) fly ash	Dickerson precipitator (DP) fly ash
Index properties				
G_s	2.64	2.17	2.2	2.37
w_{opt} (%)	13.4	26	22	36
γ_{dmax} (kN/m^3)	18.8	11.9	10	9.9
PI (%)	NP	NP	NP	NP
Chemical Properties				
Chemical Composition (%)				
LOI	NA	13.4	10.7	20.5
SiO_2	NA	45.1	50.8	35
Al_2O_3	NA	23.1	26.9	24.4
Fe_2O_3	NA	3.16	5.5	12.6
CaO	NA	7.8	0.7	3.2
Total Metal Concentration (mg/kg)				
Barium	4.62	13.7	30	19.7
Boron	2.86	17.3	45.3	24.5
Copper	1.28	74.7	25.3	58.7
Zinc	82.3	58.2	28.5	45.6
pH	6.5	9.6	7.6	8.8

Note: LOI: loss on ignition; G_s: specific gravity; w_{optm}: optimum water content; γ_{dmax}: maximum dry unit weight; NP: nonplastic; NA: not available.

Maryland: Brandon Shores (BS), Paul Smith (PS), and Dickerson Precipitator (DP). The physicochemical properties and particle size distributions of all materials are presented in Table 1 and Fig. 1, respectively. The LOI and CaO contents of the ashes range from 10.7% to 20.5%, and from 0.7% to 7.8%, respectively, indicating that the fly ashes can not be classified as C or F fly ashes according to Standard Specification for Coal Fly Ash (ASTM C 618). All three ashes are slightly alkaline (pH 7.6–9.6). Due to non-cementitious nature of HCFAs, Lime Kiln Dust (LKD) with CaO content 60% obtained from Pittsburgh, Pennsylvania was used to initiate the pozzolanic reactions.

3. Methods

3.1. Batch water leach test (WLT)

Batch water leach tests were conducted on the URM, fly ashes and URM-fly ash-LKD mixtures using different percentages of fly ashes and lime kiln dusts in accordance with the Test Method for Shake Extraction of Solid Waste with Water (ASTM D 3987). Non-activated fly ashes (i.e., 100% fly ash specimens) are not used in highway base construction but the ashes, along with 100% URM, were still employed in laboratory testing for comparison purposes. Two modifications were made to the standard method. The specimens were prepared at a liquid-to-solid ratio (L:S) of 20:1. All soil materials were air-dried and sieved through the No. 4 (4.75-mm) sieve before use. The specimens were cured in plastic bags for 7 days (21 °C and 100% relative humidity) to allow pozzolanic reactions to occur. 2.4 g of URM mixture was then added to 48 mL of influent solution in 50 mL high-density polyethylene (HDPE) bottles. Next the solutions were rotated at a rate of 29 rpm at room temperature (24 °C) for 18 h in accordance with ASTM D 3987. After rotation, the samples were allowed to sit for 5 min and centrifuged at 3000 rpm for 20 min. Upon centrifugation, the suspended solids were filtered through the 0.2-μm pore size, 25 mm diameter membrane disk filters fitted in a 25-mm Easy Pressure syringe filter holder by using a 60-mL plastic syringe. pH and electrical conductivity (EC) measurements were conducted and the samples were acidified to pH < 2 with 2% HNO_3. Before use, all equipment (centrifuge tubes, filter holders syringe etc.) was washed with 2% HNO_3 acid solutions and rinsed with DI water. All samples were stored at 4 °C for chemical analysis. Triplicate WLTs were conducted on all mixtures using each soil solution.

Two different influent leaching solutions were used in water leach tests (WLTs). The influent solutions were prepared with 0.1 M NaBr solution (IS = 0.1) and 0.02 M NaBr solution (IS = 0.02) to determine the effect of ionic strength on leaching of heavy metals.

3.2. Column leach tests

The column leach test (CLTs) were conducted on URM, fly ashes alone and URM–fly ash–LKD mixtures. All specimens were compacted at optimum moisture contents in a PVC mold having 101.6 mm diameter and 116.4 mm height by using standard Proctor compaction effort with the Method of Laboratory Compaction Characteristics of Soil using Standard Effort (ASTM D 698). In the original grain size distribution of the URM, approximately 25% of the grain particles are larger than 4.75 mm in width. When placed in a mold of diameter 101.6 mm, the larger grain particles would make the specimen highly permeable and would decrease the total solid surface area in the soil matrix. Therefore, air-dried URM was sieved from a No. 4 (4.75-mm) sieve to remove these larger particles. PVC molds were preferred to minimize the outside effects on effluent metal concentrations. All mixtures were cured for 7 days

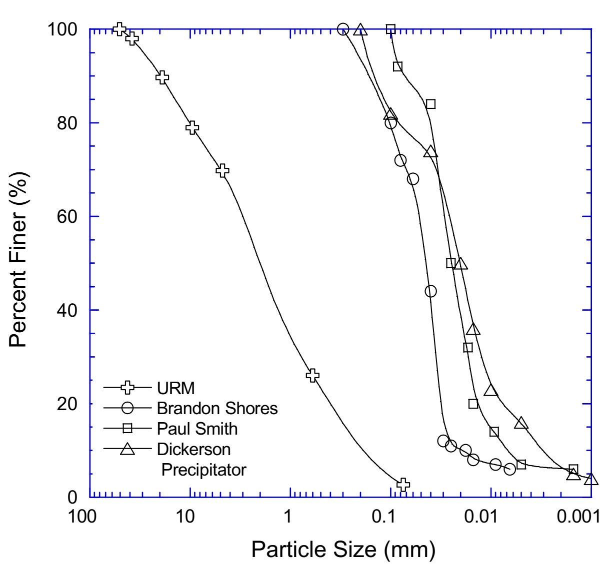

Fig. 1. Particle size distributions of unpaved road material (URM) and fly ashes.