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Recycled concrete aggregate as road base: Leaching constituents and neutralization by soil Interactions and dilution

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ABSTRACT

Recycled Concrete Aggregate (RCA) is often used as a replacement for natural aggregate in road construction activities because of its excellent mechanical properties, and this trend should increase as more transportation departments include RCA in specifications and design manuals. Concerns raised by some engineers and contractors include impacts from leachate generated by RCA, both from transport of metals to water sources and the impact of a high pH leachate on corrosion of underlying metal drainage pipes. In this study, RCA collected from various regions of Florida exhibited pH ranging from 10.5 to 12.3. Concentrations of Al, Ba, Cr, Fe, Mo, Na, Ni, Sb, and Sr measured using batch leaching tests exceeded applicable risk-based thresholds on at least some occasions, but the concentrations measured suggest that risk to water supplies should be controlled because of dilution and attenuation. Two mechanisms of pH neutralization were evaluated. Soil acidity plays a role, but laboratory testing and chemical modeling found that at higher liquid-to-solid ratios the acidity is exhausted. If high pH leachate did reach groundwater, chemical modeling indicated that groundwater dilution and carbonation would mitigate groundwater pH effects.

1. Introduction

The US Federal Highway Administration (FHWA) defines recycled concrete aggregate (RCA) as reclaimed portland cement concrete (PCC) produced by crushing concrete pavement, bridges, sidewalks, curbing, and other concrete structures (FHWA, 2007). RCA is produced at mobile and fixed crushing operations, where crushed concrete is screened to produce products of desired size gradation. The aggregate retained on the 4.75 mm (No. 4) screen is typically referred to as “coarse aggregate” and the material passing that screen is referred to as “fine aggregate” (FHWA, 2004). RCA has been shown an effective alternative to natural aggregate to meet the increasing demand for road construction materials such as concrete and asphalt pavement aggregate, and for use as road base or subbase, as it provides necessary mechanical and performance properties including bearing capacity, resilient modulus, and specific gravity (Bennert & Maher, 2008; Bozyurt et al., 2012; Wen et al., 2015). The US Geological Survey (USGS) reported that about 21.8 million tons of RCA were sold in the US in 2014 (USGS, 2016). Road base has been reported as the most common RCA construction application, with uses such as asphalt pavement aggregate, concrete aggregate, rip-rap, and general fill providing lesser markets (USGS, 2000).

Since RCA is a waste-derived product and has been in contact with possible contaminants during its life cycle, some environmental concerns from using RCA as unencapsulated road base have been raised (FHWA, 2004; Reiner, 2008). Percolation of rain water through an RCA road base (which should be small in the case of well-maintained paved roads) results in leachate, and the transport of inorganic pollutants to the surrounding environment has been reported as a potential environmental risk. Heavy metals occur in relatively small amounts in RCA, a result of their occurrence in natural aggregates and waste products added during the production of concrete (e.g., fly ash, slag; Aydilek, 2015; Mullauer et al., 2015), as well as contact with chemicals during the life of the concrete. Total elemental analysis of RCA has shown the presence of aluminum (Al), arsenic (As), antimony (Sb), barium (Ba), calcium (Ca), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), molybdenum (Mo), nickel (Ni), potassium (K), selenium (Se), sodium (Na), strontium (Sr), vanadium (V), and zinc (Zn) (Aydilek, 2015; Chen et al., 2012, 2013; Engelsen et al., 2006; Garrabrants et al., 2004). The magnitude of RCA metal concentrations (mg/kg) differs depending on the RCA source and the demolition and recycling process utilized to produce the crushed aggregates. Total element concentrations are less of a concern than leachable concentrations as direct exposure should

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not be a significant pathway for road base aggregate. Inorganic element concentrations in RCA leachate have been reported by a number of investigators (Aydilek, 2015; Chen et al., 2012, 2013; Engelsen et al., 2006, 2017; Garrabrants et al., 2004), with concentrations heavily controlled by pH-dependent chemical processes such as sorption to iron and aluminum hydroxides, mineral precipitation and complex formation with humic substances (Engelsen et al., 2017).

RCA leachate is typically alkaline with pH values reported as high as 12.5; pH varies according to the age of concrete and the resulting degree of carbonation (Garrabrants et al., 2004; Mulugeta et al., 2011). The hydration process of calcium compounds from cement results in the release of hydroxyl ions (OH^-) from the cement paste residues in crushed concrete (Aydilek, 2015; Kuo et al., 2001; Reiner, 2008; Chen et al., 2013). Several researchers have examined RCA pH as a function of age, and it has been reported to decrease from above 12.5 to approximately 8 over time (Engelsen et al. 2012, 2017). Aydilek (2015) observed a relation between the amount of calcium present in an RCA sample and the resulting pH; higher pH measurements were observed in samples with greater calcium oxide (CaO) content. An RCA sample with a 17% CaO content (by weight) yielded leachate with a pH of 11.8 and a sample with 13% CaO content exhibited a pH of 10.4.

Potential negative consequences of a high pH RCA leachate as a result of RCA in road base include deleterious impact on underlying groundwater and ecosystem impact at surface water drainage locations. One particular concern to road construction engineers is the possible effect on metal pipes buried under the road (e.g., drainage pipes). For example, in Florida, US, engineers specify a variety of pipe materials, including concrete, aluminum, aluminized steel, polypropylene, high density polyethylene and polyvinyl chloride, and galvanized steel (FDOT, 2017). Contact with a high pH environment may cause corrosion problems with zinc-galvanized and particularly aluminized pipe. High pH conditions can breakdown the protective coating of aluminum oxide of the aluminized steel pipes to form hydroxyl aluminate ions, thus exposing the aluminum and steel for further corrosion (Setiadi et al., 2006; Akhoondan & Sagüés, 2013). Damage of the metal pipes will lead to increased cost by premature pipe replacement, road demolition, and service outage.

Alkaline RCA leachate will be neutralized to some extent while passing through the soil below a road base as a result of its reaction with soil acidity and carbon dioxide in the soil pore space (CO_2 resulting from biological activity). Once this leachate reaches the groundwater table, the pH will further be affected as a result of mixing with the lower-pH groundwater and the reaction of hydroxide with the acidity of the groundwater. The Ohio Department of Transportation, US, observed a slight decrease in leachate pH after mixing with different types of soil. However, after few days the pH of RCA-soil mixture leveled off reaching a pH of the RCA leachate itself (ODOT, 2000).

The research presented here was motivated by recent changes in the Florida Department of Transportation (FDOT) design manual allowing RCA to be used as road base at an equivalent thickness as the prevailing base coarse aggregate (limerock) (FDOT, 2015, 2016). The possible increase in RCA utilization has raised concerns over an increase in pH of rain water infiltrating through the road base and subsequent environmental effects and corrosion potential for underlying metal pipes. Similar to other locations, questions regarding the pollutant leaching potential of Florida RCA were raised. The research described herein makes two contributions to the existing literature on RCA chemical leaching and environmental risk. First, quantitative results of the leaching of inorganic elements from Florida RCA are added to the existing literature database, including results from US Environment Protection Agency (EPA) Method 1316 leaching procedure, which examines the release of elements as a function of liquid-to-solid ratio (L/S). Second, the potential for soil acidity to neutralize the high pH solution resulting from RCA is examined by testing the ability of a range of soils to neutralize the pH and the potential for groundwater dilution to reduce the pH in underlying aquifer units.

2. Methods

2.1. Experimental approach

RCA samples were collected from recycling facilities throughout Florida and different soils were used with a range of acidities. US EPA Method 1316, a batch test examining leaching as a function of L/S, was conducted on all the RCA samples to assess constituent leaching. Method 1316 simulates the accelerated condition of years of water infiltration through the road and its interaction with the base material. The ability of a range of soil acidities to neutralize the alkaline RCA leachate was examined through both batch and column tests where RCA leachate was placed in contact with soil. The potential for a high pH RCA leachate to be neutralized by soil acidity and through dilution in the groundwater was also modeled.

2.2. Materials

Eight RCA samples and two limerock samples were collected from various recycling facilities in Florida; details of the samples are provided in Table S1. Crushed concrete was processed at each recycling facility to make aggregates. Samples were collected from existing stockpiles at the facilities. RCA samples were free from glass, wood, and other debris when inspected visually. For each facility, eight random sampling points across the target pile were selected to collect the subsamples. All collected subsamples were homogenized on a plastic tarp in the laboratory with clean stainless-steel shovels to make a representative sample for each facility. Two 19 L buckets were filled with the mixed material to make duplicates. Samples were labeled and sealed to avoid any contamination and moisture loss. Limerock samples were collected from FDOT stockpiles and were analyzed as control samples.

To analyze the potential for soil to neutralize high pH leachate from RCA, nine soil samples were collected with a varied range of acidities. FS1, FS2, and FS3 samples were collected from FDOT stockpiles. FS1 and FS2 were classified as A-3 materials based on the AASHTO soil classification system, and FS3 was an A-2-4 type (AASHTO, 2008). Other samples were collected from a site near a lake in Alachua County, Florida, and one from an agricultural farm in Marion County, Florida. Soil pH was measured using 2:1 water-soil ratio in the suspensions (Hendershot et al., 1993).

RCA must meet specific particle size requirements to be used as an approved road base material in Florida. Sieve analysis of RCA was performed on approximately 1000 g oven-dried RCA samples, using sieves of 50 mm, 19.1 mm, 9.52 mm, 4.75 mm, 2 mm, 0.3 mm, and 0.075 mm, in accordance with Florida method FM 1-T027 to check for gradation requirement by FDOT.

2.3. Leaching procedures

Leaching tests were performed on the RCA and limerock samples using EPA Method 1316 (US EPA, 2012). Method 1316 determines the liquid-solid partitioning between water and the sample material under equilibrium conditions in five parallel batch tests per sample using reagent water at L/S of 10, 5, 2, 1, and 0.5 L/kg. All extractions were filtered through a polypropylene 0.45 μm membrane. The filtered samples were measured for pH according to EPA standard procedure 9040C (US EPA, 2004). The extractions were then digested and analyzed for element concentrations.