



Carbonation dominates the acid intake of recycled concrete aggregate subjected to intermittent leaching



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HIGHLIGHTS

- Carbonation dominates the acidity intake of the in-situ recycled concrete aggregate (RCA).
- The volume of effluent plays a secondary role on the alkali consumption of the field RCA.
- Open-grade drainage course is efficient to delay the toxic species leaching from the RCA.

ARTICLE INFO

Article history:

Received 12 January 2015

Received in revised form 12 March 2015

Accepted 22 April 2015

Keywords:

Carbonation

pH-dependent leaching

Acid neutralization capacity

Demolished cementitious waste

Pavement

ABSTRACT

Recycled concrete aggregate (RCA) is being encouraged to use as substitute materials of the virgin aggregate for the pavement materials. RCA used in road layers is submitted to intermittent leaching. The leachant neutralizes the alkali of the RCA and the leaching intermission promotes the carbonation of the RCA's residual mortar. Both processes introduce acid to the RCA, releasing the pH-dependent toxic constituents of the RCA to the local aquifer. In this study, the acid intake caused by the leachant renewal and leachate decantation is calculated and compared with the acid intake induced by the carbonation during the leaching intermission. It is found that carbonation dominates the acid intake of the leached RCA layer while the renewal-decantation process acts only secondary role. The use of open-graded RCA base overlain by a dense pavement is recommended to reduce the carbonation rate of the RCA and to retard the leaching pH-dependent toxic elements to the local aquifer.

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1. Introduction

Recycled demolished concrete is being encouraged to use as substitute materials of the virgin aggregate for the road lower-layer materials [1–6]. The residual mortar may contain some toxic trace constituents that are possibly leached and ended up at the nearby aquifers [7–10]. As the leachability of most heavy metal elements increases with the drop of the pH [11,12], understanding how the alkali of the RCA drops during the leaching is crucial to estimate the leachability of RCA in road bases.

The alkali of the RCA is consumed by the acid intake during the leaching process, which includes the leachant renewal, leachate decantation, and drying spell. During renewal-decantation leaching process, the alkali of the RCA is diluted or consumed by the leachant and then removed when the leachate is decanted.

During the drying spell, the alkali of the RCA is consumed by the carbonation of the residual cement hydration gel at the RCA surface. These two processes alternately consume the alkali of the in-situ RCA layer, freeing the pH-dependent constituents [13–17]. It remains unknown if the consumptions of RCA alkali during these two processes are comparable or if one overwhelms the other. Understanding which of them dominating the pH drop of the RCA is important to find engineered measurements to decrease or retard the leaching of pH-dependent toxic elements to the local aquifer.

In this study, the alkali drop of the in-field RCA layers subjected to intermittent leaching is modelled and calibrated by the leaching of an in-situ RCA layer subjected to 60-week intermittent leaching in field. The acid intake induced by the leachant renewal and leachate decantation is compared with the acid intake caused by carbonation of the RCA during the leaching intermission. A practical approach is proposed to reduce the carbonation rate and thus to retard the leaching of the pH-dependent constituents in the RCA.

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2. Theoretical model the acid intake of in-situ RCA layers

In field, most building materials are stockpiled in layers, and RCA can be layered with or without an overlying cover layer. In either case, the RCA with subjected to one-dimensional leaching because the precipitation percolates through the RCA layer and then enter the underlying soil but the lateral water flow is negligible compared to the percolating water.

2.1. Acid neutral capacity and acid intake

The percolating water may be slightly acidic or neutral. This leaching adds acid to react with the alkali of the RCA and thus drops the pH of the RCA layer. The dropping degree depends on the acid neutral capacity (ANC) of the RCA, obeying Eq. (1)

$$\text{pH} = f(A) \quad (1)$$

where A (mol/kg) is the ANC of the RCA. Eq. (1) is one-to-one function because a specific acid addition consumes a unique amount of alkali.

During the leaching process, firstly the leachant enters the RCA layer and neutralizes the alkali of the RCA. The leachate then drains and leaves the RCA layer; and finally the RCA layer experiences a drying process. After these three processes, a leaching cycle completes and the next leaching cycle begins. Therefore, the acid intake during each leaching cycle can be divided into three components:

- (1) *Renewal process*: The renewal of the leachant is considered as an acid addition to neutralizing, or a solution to diluting, the alkali of the RCA. We denote this acid intake as R (mol/kg).
- (2) *Decantation process*: After the new leachant reacts with the RCA alkali, the leachate has a pH greater than the pH of the leachant. If this leachate is retained in the RCA layer, it would react with the new leachant (percolating water) that enters at the beginning of the next leaching cycle. This reaction would consume the acid of the leachant. In reality, this leachate drains from the bottom of the RCA layers, a process that is equal to remove the RCA alkali. We denote this acid intake (alkali consumption) as D (mol/kg).
- (3) *Drying process*: After the leachate is decanted, granular material interstice retains a small amount of leachate and remains wet. The retained solution promotes the carbonation of the residual mortar on the aggregate surface. This reaction promotes $[\text{H}^+]$ to neutralize the $[\text{OH}^-]$ of the RCA so that the pH of the RCA decreases. We denote this acid intake as C (mol/kg).

2.2. Computation of acid intake

According to the leaching processes in Section 2.1, the acid intake during an individual leaching cycle i includes three components: R_i , D_i , and C_i . Acid intake by the leachant, R_i , is a function of the leachant volume and leaching acidity. At a specific precipitation i , the ratio of the leachant volume to the RCA weight is denoted as V_i (L/kg); the infiltration rate, θ (the infiltration is deemed unchanged so it does not have a subscript); and the precipitation acidity-alkalinity, $\text{pH}_{in,i}$. The acid intake at the i th precipitation event is

$$R_i = V_i \cdot \theta \cdot 10^{-\text{pH}_{in,i}} \quad (2)$$

where the operator $10^{-\text{pH}_{in,i}}$ denotes that the leachant with $\text{pH}_{in,i}$ contains $10^{-\text{pH}_{in,i}}$ $[\text{H}^+]$ in each unit volume.

After the leachant enters the RCA layer, it reacts with the RCA and becomes alkaline so its pH rises to $\text{pH}_{out,i}$. The $\text{pH}_{out,i}$ can be computed by interpolating the ANC curve in Eq. (1). The decanted

leachate, in volume, is assumed equal to the entered leachant (neglecting the evaporation). Therefore, D_i can be computed by Eq. (3)

$$D_i = V_i \cdot \theta \cdot 10^{14-\text{pH}_{out,i}} \quad (3)$$

The acid intake due to the carbonation during the leaching intermission is time-dependent but hard to be computed. We leave it un-calculated and denote it as C_i . Therefore, the total acid intake, A_i (mol/kg), from the 1st leaching cycle to the n th leaching cycle can be computed in Eq. (4):

$$A_i = \sum_{i=1}^n V_i \cdot \theta \cdot 10^{-\text{pH}_{in,i}} + \sum_{i=1}^n V_i \cdot \theta \cdot 10^{14-\text{pH}_{out,i}} + \sum_{i=1}^n C_i \quad (4)$$

If the function of C_i is known, the acid intake to the RCA layer at each precipitation event is computable.

Because C_i is unknown at each leaching cycle, the acid intake (A_i) in Eq. (4) cannot be computed directly. But when the pH of the leachate is known, we can calculate the acid intake in Eq. (4) by using the inverse function

$$A = f^{-1}(\text{pH}) \quad (5)$$

The pH of the leachate from a RCA layer during a leaching cycle is usually collected by a designed catchment. The leachate is then submitted for further chemical analysis, in which the pH of the leachate $\text{pH}_{out,i}$ can be recorded. Substituting $\text{pH}_{out,i}$ as the pH into the Eq. (5), one gets the remaining ANC in the RCA layer. The acid intake A_i is the difference between the initial ANC, A_0 , and the remaining ANC, $f^{-1}(\text{pH}_{out,i})$.

2.3. Parameterizations

To calculate the acid intake, we need to parameterize the inverse function f^{-1} in Eq. (5). This study uses the ANC curve (Fig. 1) that was experimentally observed by [12]. This RCA has an initial pH value of 12.6, i.e., $A_0 = f^{-1}(12.6)$. Adding acid to the RCA drops the pH while extracting the acid from it increases the pH. As shown in Fig. 1, the pH and ANC is one-to-one function so the functions f^{-1} and f are computable.

To know the acid intake caused by the leachant renewal R_i , the leachate decantation D_i , and the carbonation C_i , we have to parameterize the variable of V_i , $\text{pH}_{out,i}$, θ , and $\text{pH}_{in,i}$ so that the first two terms (R_i and D_i) in Eq. (4) can be computed respectively. The value of $\sum_{i=1}^n C_i$ can be computed by subtracting $\sum_{i=1}^n R_i + \sum_{i=1}^n D_i$ from the total acid intake A_i .

The cumulative infiltration volume documented in Engelsen et al. experiment [18] is used to compute the ratio of the leachant volume to the RCA weight is denoted as V_i , which is the ratio of this

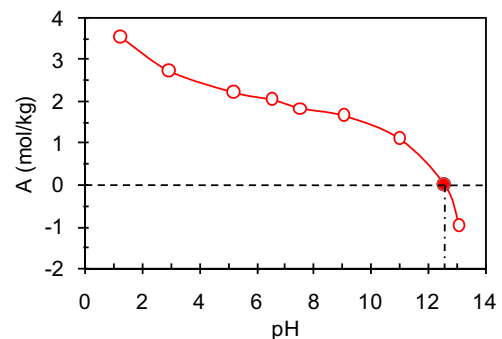


Fig. 1. The pH and the typical ANC curve for RCA. Data adopted from [18] with permission.

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