



# Effect of alkali release by aggregates on alkali-silica reaction



C. Drolet\*, J. Duchesne, B. Fournier

Department of Geology and Geological Engineering, Laval University, Québec G1V 0A6, Canada

## HIGHLIGHTS

- High pressure extraction was used to measure alkali content of concrete specimens.
- Alkalis can be released from aggregates into the pore solution of mortars at 1 year.
- The alkalis released in mortars did not seem to influence expansion caused by ASR.
- Potential alkali release by coarse aggregate was whether inexistent or masked by ASR.

## ARTICLE INFO

### Article history:

Received 11 March 2017  
Received in revised form 4 July 2017  
Accepted 15 September 2017

### Keywords:

Alkali-aggregate reaction  
Pore solution  
Expansion  
Alkalis

## ABSTRACT

Mortar and concrete specimens were made using one alkali-bearing reactive aggregate, one alkali-free reactive aggregate and one alkali-free non-reactive aggregate in order to determine the effect of an alkali release by an aggregate into the pore solution on the development of ASR using pore water extraction and direct expansion measurements. The fine fraction of the alkali-bearing reactive aggregate was found to be able to release up to 3 wt% of its total Na<sub>2</sub>O content (0.73 kg Na<sub>2</sub>O/m<sup>3</sup>) into the pore solution of mortar at the age of one year for specimens stored at 60 °C. However, there is no evidence that this sodium release influenced the rate of the development of the expansion. Results on mortar specimens also indicated that the amount of Na<sub>2</sub>O bounded into ASR gel is approximately proportional to the progress of expansion. The same proportionality is however not observed for potassium ion. For concrete specimens, it is clear that Na<sub>2</sub>O and K<sub>2</sub>O ions are bound into ASR reaction products, but there is no evidence that the coarse fraction of the alkali-bearing aggregate released alkalis into the pore solution of concrete after one year of testing completed in this study.

© 2017 Elsevier Ltd. All rights reserved.

## 1. Introduction

In high pH environments, some rock-forming minerals, such as poorly crystallized silicate minerals, volcanic glass, or different silica varieties, are unstable and can be dissolved into the solution. Concrete aggregates containing these mineral phases are affected by the high pH (over 12.5) of the concrete pore solution, thus resulting in a deleterious reaction known as alkali-silica reaction (ASR) [1,2]. Even though this reaction does not involve alkalis directly, contrary as its name suggests, the OH<sup>-</sup> concentration of the pore solution of concrete is predominantly controlled by its concentration in sodium and potassium ions [3].

Limiting the alkali content in the pore solution of concrete has been considered as a promising solution to inhibit ASR. Indeed, Stanton [4] demonstrated that limiting the alkali content of the

cement to 0.6 wt% Na<sub>2</sub>O<sub>eq</sub> could reduce the expansion of concrete to acceptable levels. However, this method was not equally effective with all types of reactive aggregates; Bérubé et al. [5] indeed found that the alkali threshold above which deleterious expansion occurs varies from one type of aggregate to another [6,7]. This phenomenon could be explained by the aggregate reactivity potential and also by a possible rise in the alkalinity of the pore solution over time. In that way, the hypothesis that aggregates could release alkalis into the pore solution was a matter of intensive research over the past decades [8–18]. Some studies showed that certain types of aggregates could release significant amounts of alkalis over time, when exposed to high pH environment. The rate and amount of alkalis released depends on generic exposure conditions including pH, Eh, temperature, local porosity and permeability of the (possibly already cracked) cement paste. In addition, alkali release is also affected by diverse properties of the actual aggregate, e.g. particle size, bulk lithological composition, mineral grain size, mineral (modal) content of the composing lithologies, total alkali content and bonding of mineral constituents (related to

\* Corresponding author.

E-mail addresses: [cedric.drolet.1@ulaval.ca](mailto:cedric.drolet.1@ulaval.ca) (C. Drolet), [josee.duchesne@ggl.ulaval.ca](mailto:josee.duchesne@ggl.ulaval.ca) (J. Duchesne), [benoit.fournier@ggl.ulaval.ca](mailto:benoit.fournier@ggl.ulaval.ca) (B. Fournier).

degree of alteration), and their spatial distribution in terms of microstructure, fabric/texture, as well as internal porosity and permeability of the aggregate particle [12,19–21].

In concrete, the principal source of alkalis to the pore solution is the portland cement. When the kiln is heated to manufacture clinker, alkalis are primarily bound to sulfur to form potassium sulfate ( $K_2SO_4$ ), sodium-potassium sulfate ( $(K, Na)_2SO_4$ ) and calcium-potassium sulfate ( $K_2Ca_2(SO_4)_3$ ) until there is no sulfur left. If the alkali content is greater than the sulphur content in the kiln, the remaining alkalis are distributed between  $C_3A$ ,  $C_2S$  and, in a smaller proportion, in  $C_3S$  and  $C_4AF$  [22]. When cement is in contact with batching water, alkali-bearing sulfates are considered to be readily soluble. However, the sodium and potassium incorporated in other phases of the cement are considered rather insoluble and might only reach the pore solution during the hydration of those phases [3]. On the other hand, some alkalis can also be incorporated in C-S-H gel structure. Indeed, a low Ca/Si ratio and a high alumina content fosters alkali binding in the gel [22,23]. In the 1960's, McCoy & Eshenour [25] made a clear distinction between the soluble alkalis and the total alkalis contained in the cement. Their experiments showed that, after contact with water, between 10 wt% and 60 wt% of the total alkali content of the cement is readily soluble, depending on the cement composition. Many studies were conducted over the years to evaluate the chemistry of the pore solution associated with different cements. Recently, Vollpracht et al. [26] reviewed results gathered over the years, and showed that the alkali concentration of the pore solution of concrete is highly dependent of the water-to-cement ratio and the total  $Na_2O$  and  $K_2O$  content of the cement. Typical concentration of the pore solution is approximately 500 or less mmol  $[Na^+ + K^+]/L$  for low alkali cement and 700 or more mmol  $[Na^+ + K^+]/L$  for high alkali cement when the water-to-cement ratio is near 0.5. It is also generally accepted that a significant amount of alkalis can be bound into ASR products. Indeed, using sealed mortars containing reactive opal, Diamond et al. [27] showed that approximately 35 wt% of the alkalis originally in solution was trapped into ASR products after only one month. However, the effect of an alkali release by aggregates to the pore solution on the development of the reaction is still unknown.

To study the subject, Constantiner & Diamond [28] created mortars using an ASR reactive calcined flint as main aggregate with 25 wt% replacement of finely ground microcline, an alkali-bearing feldspar. Also, for comparison, three different series of similar mortars were made: the first, with an alkali-free, almost pure limestone with the same 25 wt% replacement of finely ground microcline; the second, with the same ASR reactive aggregate (flint), but without replacement; and the third, acting as control specimens, with the above limestone, but without replacement. Results obtained showed that the alkali concentration in the pore solution is constant over time for specimens without ASR reactive or alkali-bearing aggregates. In the presence of ASR reactive aggregates, the alkali concentration is significantly lower than the control and decreases over time. On the contrary, the alkali concentration in the specimens containing the limestone with microcline is increasing constantly over time. For specimens containing both reactive and alkali-bearing aggregates, the alkalis released by microcline outweighed the removal of alkalis by the formation of ASR products.

However, even though the results of Constantiner & Diamond [28] confirm that some aggregates do release alkalis into the pore solution over time, it is impossible to transpose these results to real concrete, as the alkali-bearing aggregate was finely ground in order to foster alkali release. Also, very low alkali cement was used and mortars were placed in sealed containers. These two conditions limit ASR development since the alkalis and humidity are necessary for the reaction.

The methods currently used in North America to assess the reactivity potential of an aggregate, e.g. CSA A23.2-14A and ASTM C1293, specify that concrete specimens must be kept in high moisture conditions in order to promote the development of the ASR reaction. However, the condensation of water on the surface of concrete specimens can promote alkali leaching from the specimens. Even if concrete specimens exposed to humidity will always suffer from that phenomenon, Rogers & Hooton [29] showed that the alkali leaching can be minimized with appropriate conservation conditions. Rivard et al. [30] performed an alkali mass balance on concrete prisms submitted to CSA A23.2-14A test. They found that the alkali leaching can account for up to 25 wt% of the total alkali content of cement, which emphasizes the importance of considering this phenomenon in the alkali balance of concrete. Lindgård et al. [31] found a correlation between the amount of alkali leaching during the first weeks of exposure and the final expansion of concrete prisms, particularly at high temperature. They also found that the cement type and the water-to-binder ratio are having different effects on the rate and extent of alkali leaching, depending on the diffusion properties of the hardened paste and initial alkali concentration of the pore solution. Multon & Sellier [32] showed that if the amount of alkali leached from the concrete specimens is known, it is even possible to calculate a theoretical expansion.

The measurement of the alkali concentration of the pore solution of concrete is thus a complex task, as the conservation conditions can lead to a diminution of the alkalinity through leaching, which is why this phenomenon needs to be minimized as much as possible. Also, linking a possible alkali release from aggregates with the development of ASR is also complex, as a notable amount of alkalis are bound in the formation of reaction products such as ASR gel. This binding could likely mask the potential alkali release from aggregates. Even though previous studies confirmed that aggregates release alkali through time in high pH environment, very few data is currently available on the possible impact of such a release on the rate and extent of ASR.

## 2. Objective and scope of work

The understanding of the evolution of the alkalinity in the pore solution of ASR-affected concrete structures is nowadays very important to determine the appropriate timing and approaches for maximizing their lifetime. Moreover, the alkali release by aggregates can influence the development of ASR, and it is thus critical to understand the influence of this phenomenon on the rate and extent of the expansion caused by ASR over time.

In this context, the objective of the present study is to evaluate the influence of a possible alkali release by aggregates into the pore solution, as they are used in concrete and mortar, on the development of expansion due to ASR. In order to do so, the alkali content in the pore solution was measured over time for a number of mortar and concrete specimens made with two types of reactive aggregates with different alkali contents and one non-reactive, alkali-free aggregate. The comparison between the alkali concentrations of the specimens containing the different aggregate should allow to isolate the alkali binding in ASR products along with the alkali release by aggregates and to evaluate the influence of such a release on the rate and extent of ASR development.

## 3. Materials and experimental procedures

### 3.1. Materials

Three different aggregates from Canada, two reactive and one non-reactive, were chosen for this study. The non-reactive

Download English Version:

<https://daneshyari.com/en/article/4912871>

Download Persian Version:

<https://daneshyari.com/article/4912871>

[Daneshyari.com](https://daneshyari.com)