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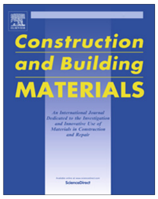

Minimizing alkali leaching in the concrete prism expansion test at 38 °C

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HIGHLIGHTS

- Alkali leaching reduces the reliability of concrete expansion tests for ASR evaluation.
- Alkali leaching depends on water vapour-concrete interactions in the test container.
- A relationship between alkali leaching and vapour mass/concrete volume is developed.
- Low leaching is obtained using a low net container volume/concrete volume ratio.
- This ratio may be used for designing reliable concrete ASR expansion tests.

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ABSTRACT

Unwrapped concrete prisms (70 × 70 × 260 mm in size; three prisms for each concrete mix) made with two different alkali-reactive aggregates and four different alkali contents were subjected to expansion tests at 38 °C and RH >95% (CPT-38 °C tests). Appositely designed storage containers with reduced net container volume/concrete volume ratio ($V_{nc}/V_{concrete} = 2.32$; one prism per container) were used. Alkali leaching was found to be very low (8–10% Na_2Oeq leached) and little affected by concrete alkali content. A good correlation between alkali leaching and $V_{nc}/V_{concrete}$ ratio was obtained using both the data of the present study and the results of two other studies available in the literature. This suggests the suitability of the $V_{nc}/V_{concrete}$ ratio as a key parameter for designing reliable CPT-38 °C tests.

1. Introduction

Alkali leaching from cementitious specimens containing ASR (alkali-silica reaction)-susceptible aggregates and vertically stored over water in sealed containers is a problem known since 1946 [1].

Alkali leaching may lead to reduced expansions of specimens during laboratory concrete prism expansion tests and, in some cases, to misleading conclusions about the alkali-reactivity of certain aggregates (false-negative results). This is the case of aggregates exhibiting Threshold Alkali Level (TAL) values slightly lower than the concrete alkali content of the test method used for ASR assessment. The TAL is defined as the alkali content of the concrete mix of standard composition and containing the test aggregate, above which deleterious ASR expansion will develop [2].

However, little attention has been dedicated to alkali leaching when developing ASR performance test methods based on the expansion of concrete prisms vertically stored over water in sealed containers.

Among the wide variety of such test methods, the concrete prism expansion test performed at 38 °C and Relative Humidity (RH) above 95%, here briefly indicated as CPT-38 °C test, is certainly the most frequently used worldwide. This test has been standardized in many countries or proposed by scientific organizations, like RILEM. The most widely diffuse versions of the CPT-38 °C test are those published by CSA (CSA A23.2-14A) [3] and ASTM (ASTM C 1293) [4] for unwrapped concrete prisms, or by RILEM (RILEM B – TC 106-3) [5] for wrapped concrete prisms. The CPT-38 °C test is currently used for evaluating the alkali-reactivity of aggregates and/or for assessing the efficacy of ASR inhibitors in concrete. This test is often taken as a reference test for calibrating other ultra-accelerated concrete prism test methods.

However, a study by Thomas et al. [6] reported that, due to significant alkali leaching (about 35% of the alkalis originally in the concrete), the CSA A23.2-14A test (similar to ASTM C 1293) is not appropriate for evaluating the critical alkali content for

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deleterious expansion of aggregates, nor for determining the minimum dose level of a mineral addition needed to prevent ASR development in concrete mixes made with different alkali contents.

Wrapping concrete prisms with a wet cotton cloth according to RILEM AAR-3 procedure (cotton cloth soaked with deionized water) does appear to be an effective measure for reducing alkali leaching only if wrapped prisms are stored within polyethylene bags. However, at early age of exposure, wrapped prisms with or without polyethylene bags were found to leach out considerably more alkalis than unwrapped prisms [7].

According to Lindgård et al. [7,8], one effective measure to reduce the rate and amount of alkali leaching is to increase the cross section of the concrete specimens from 75 × 75 mm^2 (CSA, ASTM or RILEM) to 100 × 100 mm^2 (Norwegian CPT-38 °C test [9]).

Alkali leaching may be regarded as a two-step process: the first step is the transport of the alkalis to the prism surface; the second step is the external reception of alkalis, also indicated as "sink capacity" [7].

As suggested by several Authors [1,6,7,10,11], in the case of concrete specimens vertically stored over water in sealed containers, the "sink capacity" is attributable to the condensation of water vapour on prism surfaces and running down the prism surfaces into the water reservoir below. Condensation of water vapour is ascribed to small temperature variations during the expansion tests [11]. However, capillary condensation of water vapour occurs even in the absence of temperature variations. The latter phenomenon is related to the porosity and pore size distribution of the concrete mass exposed to the storage environment.

Therefore, an important operational parameter affecting alkali leaching should be the ratio between the available mass of water vapour in the sealed container (M_{vapour}) and the total volume of concrete exposed to the storage environment ($V_{concrete}$). This parameter should significantly affect both the "sink capacity" by condensed water vapour and the rate of water absorption by forming ASR gels during the expansion tests. The higher the value of $M_{vapour}/V_{concrete}$ ratio, the greater the rate and amount of alkali leaching.

On the basis of the above considerations, an experimental study was undertaken in order to minimize the alkali leaching and, hence, to improve the reliability of the CPT-38 °C test. Unwrapped concrete prisms with sizes of 70 × 70 × 260 mm were tested and appositely designed storage containers were used to "minimize" the $M_{vapour}/V_{concrete}$ ratio. Two different alkali-reactive aggregates were used for the preparation of concrete mixes with different alkali contents. The leaching data thus obtained were also compared with those reported by other Authors [6,7].

The present paper reports the results of this study that was a part of the research programme sponsored by UNICEMENTO and aimed at developing the Italian version of the concrete prism expansion test at 38 °C [12].

2. Water vapour – concrete interaction and alkali leaching

When each sealed container including one, or more than one concrete prism is placed inside the oven kept at 38 °C, there is a transient period of heating where the temperature of water vapour is higher than that of concrete prisms, and this is due to the different thermal conductivities of water and concrete. As a result, condensation of water vapour occurs on the surface of concrete prisms and the amount of condensed water is absorbed by the concrete and/or run down the prism surface into the water reservoir below.

On the other hand, when the sealed container is removed from the oven and the concrete prisms are cooled to ambient temperature inside the sealed container, prior to prism length measurement, there is a transient cooling period where the temperature of concrete is higher than that of condensed vapour. As a result, there is water evaporation from concrete prisms that may also lead to formation of surface deposits (efflorescence).

The above considerations suggest that, in order to minimize alkali leaching from concrete prisms during the expansion tests, it would be desirable to omit the intermediate length measurements of the concrete prisms. However, during the expansion tests, condensation of water vapour occurs even if there is no difference between the temperatures of water vapour and concrete prism, as is the case of the most exposure period of prisms to storage environment.

This phenomenon is known as capillary condensation and can be described by means of the equations of Halsey (modified) and Kelvin-Wheeler [13,14] that correlate, respectively, the thickness of the water layer condensed on the pore surface and the radius of pore in which condensation occurs, with the partial pressure of water vapour in the environment.

Capillary condensation takes place because the equilibrium pressure of water vapour inside the pores of concrete (p'_s) is less than the equilibrium pressure of water vapour in the storage environment (p_s): the smaller the value of pore radius, the lower the vapour pressure p'_s. A pressure difference $\Delta p = (p_s - p'_s)$ is established and, consequently, water vapour can flow through the concrete pores, where it condenses. Even if concrete is water-saturated after preliminary curing, vapour condensation will occur because the water in the pores is combined in the cement hydration products and, eventually, in the ASR gels, so that the pores can accommodate further water. It is likely to think that the capillary condensation phenomenon can happen predominantly in the cortical layer of the specimen, more porous than the bulk and affected by micro cracks formation.

The alkali release from the concrete specimen is the result of alkali concentration gradient: alkali concentration of pore solution in the bulk is higher than in the cortical layer owing to water condensation. Considering that, under the test conditions, the concrete specimen is placed in a vertical position, the running down of surface water transfers alkalis into the water reservoir present in the bottom of the sealed container.

Based on such a leaching mechanism, a direct relationship between alkali leaching and specific surface area (surface area/volume) (S_{sp}), of concrete prisms should be expected, with S_{sp} being inversely proportional to prism sizes. Moreover, alkali leaching should be directly proportional to the mass of water vapour available per unit surface area of the concrete prisms stored in the sealed container, M^*_{vapour}.

The rate of alkali release from concrete prisms was assumed to follow a kinetic equation of first order with respect to the concentration of alkalis in concrete (Lac, kg Na_2Oeq/m^3). Thus, at an established testing time (365 days in the CPT-38 °C test), alkali leaching in terms of percentage release of Lac, D_a (% Na_2Oeq leached), should be independent of Lac.

With the above assumptions, D_a was related to M^*_{vapour} and S_{sp} through the equation:

$$D_a = k(M^*_{vapour})^m (S_{sp})^q \tag{1}$$

with:

$$M^*_{vapour} = \frac{M_{vapour}}{n_p A_p} \tag{2}$$

and:

$$S_{sp} = \frac{A_p}{V_p} \tag{3}$$