Influence of moisture on the development of Delayed Ettringite Formation

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Alkali Aggregate Reaction (AAR) and Delayed Ettringite Formation (DEF) are both Internal Swelling Reactions leading to expansion of the affected materials, cracking and decrease of the mechanical properties, which induce concerns regarding serviceability and structural integrity of the affected structures. These two reactions are highly influenced by the water supply conditions. AAR has deserved many research efforts regarding the influence of moisture, even in realistic conditions, so that a minimum moisture threshold and coupling laws have been established and validated against field data, documenting the critical relevance of external water supply due to rain exposure [1, 2]. Meanwhile, DEF still deserves investigations to complete existing results available in the literature and confirm a possible higher moisture threshold (e.g. [3–5]).

This presentation is focused on the design of an experimental programme aiming at quantifying the effect of water supply conditions on the development of DEF at the material scale. Two concrete mixes are investigated, one being highly reactive (using a cement with high aluminate, sulphate and alkali contents), the other one being moderately reactive (with corresponding lower contents). Using these materials, prismatic specimens (11x11x22 cm^3) are fabricated and exposed to different moisture conditions (fixed temperature of 20°C):

- Either constant conditions, to quantify the influence of water supply on magnitude and kinetics of expansion: specimens are stored in reactors with a regulated Relative Humidity (RH) ranging from 88% RH to 100% RH. In addition, some specimens are immersed in water to investigate the effect of liquid water supply and increased alkali leaching. These tests with simple stationary exposure conditions are used to establish coupling laws aiming at predicting expansion characteristics as a function of the water content of the materials.
- Or variable but controlled conditions: specimens are exposed alternatively to immersion and drying cycles (called wetting-drying cycles hereafter) to reproduce more realistic water supply conditions. They are believed to represent exposure conditions more representative of the ones experienced *in situ* but remain simple enough to assess the effect of moisture solely (e.g. no temperature variations). The final objective of these more-complex cases is to benchmark the coupling laws established with the previous simplified tests: the prediction of the expansive behaviour based on these relations will be compared to the experimental results.

In this programme, RH has been controlled using salt solutions placed in reactors specifically designed for these tests (Figure 1); in particular, they include fans to homogenize RH around the specimens. Moreover, to avoid periodic perturbations of the exposure conditions due to manual operations, specific devices have been used for automated monitoring of expansion (as described in [6]) and water content (using load cells) during the whole testing procedure (duration of about 2 years in the initial design).

A challenging issue to design this programme has been the determination of the wetting-drying cycles:

- on the one hand, they had to be as representative as possible of concretes exposed to natural weathering (e.g. rain exposure), i.e. with relatively short but repeated exposures to liquid water;
- on the other hand, they had to allow significant expansion for the planned monitoring duration (about 2 years).

These two contradictory criteria implied a compromise between the duration and frequency of the wetting and drying periods. The optimization process developed to reach this objective is detailed in the presentation.

First of all, the results of trial tests performed for the highly reactive concrete are presented: they were based on rather long wetting and drying phases (one or two weeks for each) but with different relative durations for these two conditions. These results allowed not only a preliminary assessment of the effect of wetting-drying conditions on the development of DEF for the concrete mixes considered, but also were used to calibrate a finite-element non-linear diffusion model in order to simulate exposure conditions with much shorter (but more repeated) immersion phases.

Multiple calculations were performed to determine a wetting-drying-cycles sequence satisfying the criteria listed above. The corresponding exposure conditions have finally been applied to both concrete mixes studied in this programme. The expansive behaviour is presented to confirm the prediction of the finite-element simulations.

The programme has been launched in 2018 and specimens have been monitored for over 40 months. Under conditions of permanent water supply, specimens have reached their expansion potential, while several specimens are still slowly expanding due to reduced water supply.

As a first-approach interpretation, DEF expansion appears to result as the sum of DEF-induced expansion increments which take place as soon as the moisture content threshold has been locally exceeded.

Figure 1: experimental setup

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***Keywords**: Delayed Ettringite Formation, moisture, coupling, experimental.*

This article was selected to be published in special issue of ICE Magazine of Concrete Research devoted to 16th ICAAR (https://www.icevirtuallibrary.com/toc/jmacr/current)