Study of the self-healing behavior of early-age cracks in concrete with crystalline admixtures under six environmental exposures

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ABSTRACT

The search for self-healing materials is justified by the increasing sustainability and safety needs of structures. The presence of small cracks in structural concrete, which could accelerate the degradation process and diminish its service life, is unavoidable due to the heterogeneous nature of the material. A method to enhance self-healing in concrete is the use of crystalline admixtures (CA), which are hydrophilic products formed by chemical active substances, cement and sand.

This research analyzes the self-healing properties of young concrete specimens for autogenous and CA-based healing under different exposure conditions. Two types of concrete were studied: a control mix, and a mix containing the CA (with a dosage of 4% by the weight of cement). Six exposure conditions were studied: water immersion at 15ºC, water immersion at 30ºC, water contact with a water head of 2 centimeters, wet/dry cycles, humidity chamber, and laboratory conditions.

Self-healing capability was evaluated by measuring the permeability of concrete specimens before and after the healing period. Cylindrical specimens were pre-cracked by means of splitting test at the age of 2 days, and their permeability measured at the age of 3 days and after 42 days in the healing exposure. The range of studied crack widths was limited to 300 micrometers.

From the tests, the self-healing reaction was confirmed for both mixtures for exposures in direct contact with water. Exposing just one surface to water contact increased healing rates, but only the crack in direct contact could be sealed. Finally, slight differences were measured between both mixtures, with a higher stability for concrete with CA.

To sum up, only cracks in direct contact with water could heal, achieving higher healing rates when the specimens were immersed in water. Ambient humidity was not enough to produce healing either for control concrete or concrete with CA.

1. INTRODUCTION

Cracks in concrete can permit the entrance of liquids, contaminants and aggressive agents into the structure, accelerating its degradation process, thus diminishing its service life. This research analyzes the self-healing properties of young concrete specimens with and without crystalline admixtures under six different exposure conditions. Crystalline admixtures are thought to improve closing of cracks in concrete for saturated small cracks when the conditions are of water immersion [1], [2].

2. MATERIALS AND METHODS

In this research, two concrete compositions were used: a control mix and a mix containing crystalline admixtures in a 4% by the weight of cement. Both types of concrete contained 350 kg/m^3 of cement (CEM II 42.5/ A-L) and a water/cement ratio of 0.45. The maximum size of aggregates was 12 mm. This study was performed on fibre-reinforced concrete with 40 kg/m^3 of steel fibers, since fibers control crack width during the pre-cracking process and keep its value fixed afterwards.

Self-healing capability was evaluated by measuring the permeability of concrete specimens before and after the healing period. Cylindrical specimens were pre-cracked by means of splitting test at the age of 2 days, and their permeability measured at the age of 3 days and after 42 days in the healing exposure. The range of studied crack widths was limited to 0.30 mm. The six exposure conditions compared in this study were: water immersion at 15ºC (WI_15), water immersion at 30ºC (WI_30), water contact with a water head of 2 centimeters (WC), wet/dry cycles (WD), humidity chamber at 20ºC and 95% of relative humidity (HC), and laboratory conditions at approx. 17ºC and 40% RH (AE).

The permeability of pre-cracked specimens was evaluated by a method based on the permeability test described in UNE-EN 12390-8, but measuring the water flow instead of the water depth penetration. To guarantee the impermeability of the specimen lateral surface, the zones of the lateral surface that were in contact with the machine loading platens during the pre-crack splitting tests were sealed with the epoxy resin.

3. RESULTS

The experimental results, by means of permeability tests, are expressed by means of the healing rate, defined as follows:

$$Healing\ Rate\ =\ 1 - \frac{Final\ Water\ Flow}{Initial\ Water\ Flow}$$

The results showed that for both compositions, higher healing rates were achieved when specimens were stored under water immersion (Figure 1). Wet/dry cycles and water contact of 2 cm of water layer showed similar behaviors for control specimens. In contrast, for specimens with crystalline admixtures, the WC exposure achieved better results and less dispersion than W/D conditions. In general, it is clear that specimens with CA got less dispersion for all exposures, which indicates a more reliable and predictable behavior of concrete with this admixture. It was registered that a few specimens that were stored in low humidity exposures (mostly from control

groups) had negative Healing Rates (represented as 0). This can be caused by the lack of moisture to counteract the shrinkage of specimens, thus increasing the crack opening.

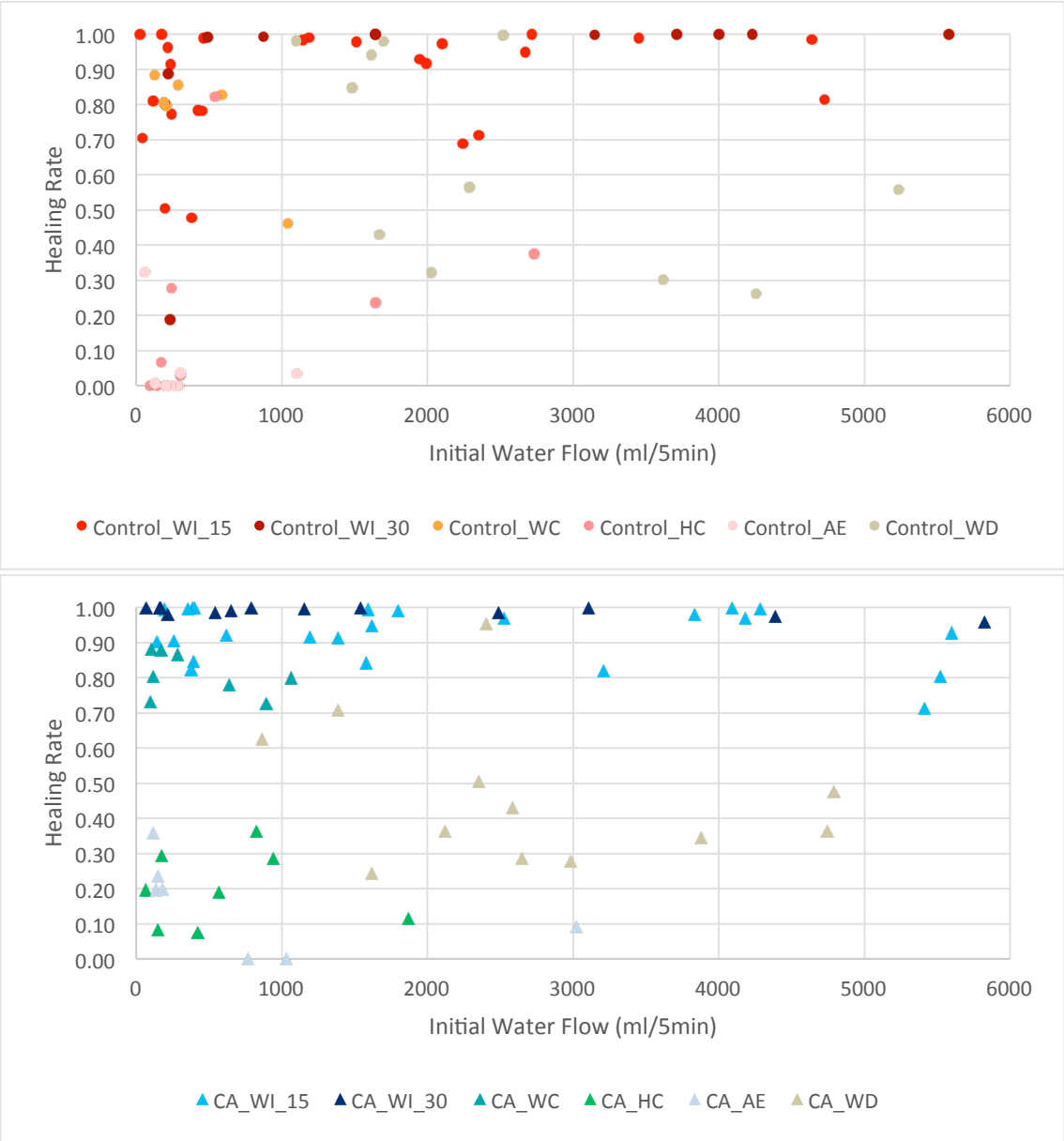

Figure 1: Healing rate for control concrete specimens (top) and concrete with crystalline admixtures (bottom)

The average healing rate and standard deviation for each group was evaluated in order to quantify the effectiveness and the differences of dispersion for each group (Figure 2). The resulting values show a clear differences of dispersion between control and CA groups, with lower deviation in the latter. It should also be noted that for exposures with continuous direct contact with water (WI_15, WI_30 and WC) the CA group achieved better results in average. These results remarks the optimal conditions for self-healing by means of crystalline admixtures and the lack of feasability for natural healing of control concrete.

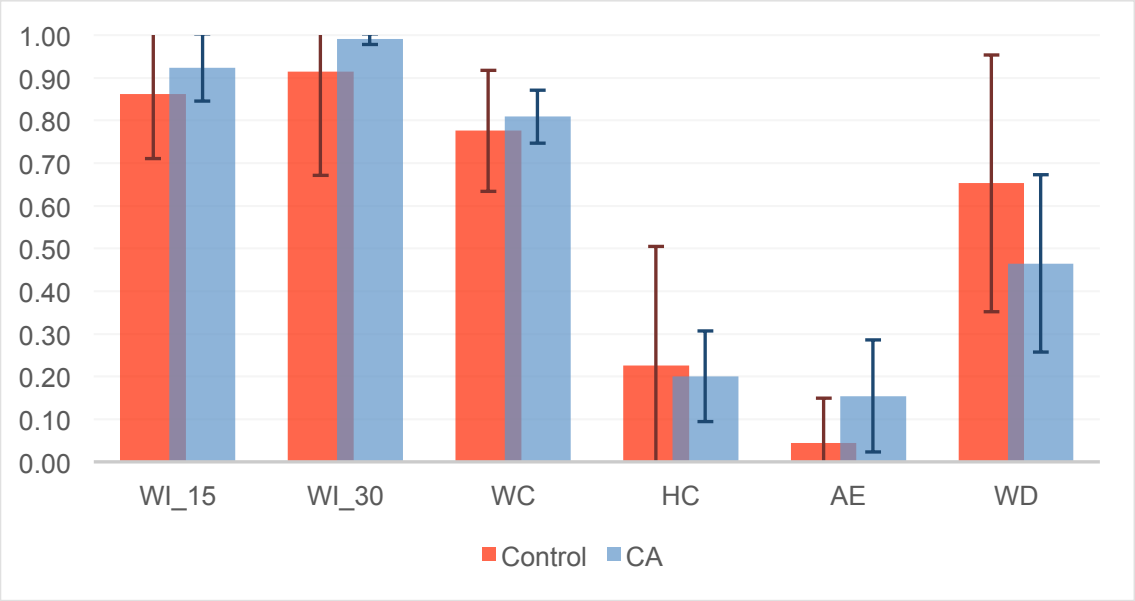

Figure 2: Average Healing Rate and Standard Deviation for cracks < 0.3 mm.

4. CONCLUSIONS

Concrete with crystalline admixtures showed a more stable behaviour in healing tests for healing cracks up to 0.30 mm, with data featuring lower dispersion. The highest Healing Rates were achieved for concrete specimens with crystalline admixtures stored under water immersion exposure at 15 and 30ºC, with values around 95%.

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