# Engineering Self Healing capacity of cement based materials through crystalline admixtures

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Keywords: NSC, HPFRCC, self-healing, crystalline admixtures, chemical prestressing.

Abstract ID No:180

## ABSTRACT

In this paper aims a thorough characterization will be performed of the effects of crystalline admixtures, currently employed as porosity reducing admixtures, on the self-healing capacity of the cementitious composites, i.e. their capacity to completely or partially re-seal cracks and, in case, also exhibit recovery of mechanical properties.

The problem will be investigated with reference to both a Normal Strength Concrete (NSC) and a High Performance Fiber Reinforced Cementitious Composite (HPFRCC). In the latter case the influence of flow-induced fiber alignment will also be considered in the experimental investigation. With reference to either 3-point (for NSC) or 4-point (for HPFRCC) bending tests performed up to controlled crack opening and up to failure, respectively before and after exposure/conditioning, the recovery of stiffness and stress bearing capacity will be evaluated to assess the self-healing capacity. Moreover, in a durability-based design framework, suitable self-healing indices to quantify the recovery of mechanical properties will be defined.

## INTRODUCTION

Efforts to reduce the permeability of concrete and improve its resistance to ingress and movement of water and other water born or transported aggressive substances, thereby improving its durability, has led to the development of a class of “admixtures” referred to as Permeability Reducing Admixtures (PRAs). Crystalline admixtures are a category of PRAs, consisting of proprietary active chemicals provided in a carrier of cement and sand, which, because of their hydrophilic nature, react with water and cement particles in the concrete to form calcium silicate hydrates, increasing the density of the CSH phase, and/or pore-blocking precipitates in the existing microcracks and capillaries. The mechanism is analogous to the formation of CSH and the resulting crystals become integrally bound with the hydrated cement paste, thus contributing to a significantly increased resistance to water penetration under pressure. It can be furthermore argued that, as hairline cracks form over the life of concrete, crystalline admixtures continue to activate in the presence of moisture and seal additional gaps, even if cracks may still develop that exceed the self sealing capacity of the concrete.

The focus of this paper will be on the effectiveness of a crystalline admixture on the self sealing capacity of cementitious composites. A comprehensive experimental programme has been going on at the author’s home institution to investigate the effects of crystalline admixture on the recovery, if any, of residual load bearing capacity of different categories of cementitious composites, also addressing the beneficial effects of a synergy between the same admixture and a dispersed fibre reinforcement, as in the case of HPFRCCs. A dedicated experimental methodology has been conceived to the purpose, and the reliability of the aforementioned concept has been shown, also through the definition of suitably defined “self-healing indices”, which are instrumental to quantify the outcomes of the self-healing phenomenon. This opens challenging perspectives to the use of cement based materials intrinsically able to recover their pristine durability levels, thus guaranteeing a longer service life of the designed applications and a performance less sensitive to environmental induced degradation.

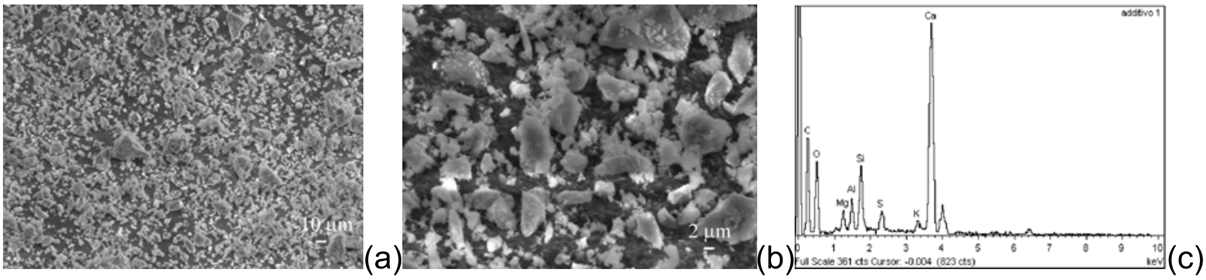

Figure 1: SEM magnification (a,b) and EDS analysis (c) of admixture particles.

## 1. MATERIALS

The employed crystalline admixture consists of a blend of cement, sand and microsilica; SEM magnified particles (Figures 1a-b) have irregular shape and size in the range of about 1-20 $\mu$m and their morphology is similar to that of cement grains; EDS analysis (Figure 1c) confirmed a spectrum is comparable with that of an Ordinary Portland Cement (OPC), except for the slightly higher peak of sulphur.
The mix composition of the employed NSC and HPFRCC is shown in Table 1.

Table 1. Mix composition of investigated NSC and HFRCC.

| Constituent NSC | W/out admixture (kg/m$^3$) | With admixture (kg/m$^3$) |
|---|---|---|
| Cement type II 42.5 | 300 | 300 |
| Water | 190 | 190 |
| Superplasticizer (lt/m$^3$) | 3 | 3 |
| Fine aggregate 0-4 mm | 1078 | 1080 |
| Coarse aggregate 4-16 mm | 880 | 880 |
| Crystalline admixture | = | 3 |

| Constituent HPFRCC | W/out admixture (kg/m$^3$) | With admixture (kg/m3) |
|---|---|---|
| Cement type I 52.5 | 600 | 600 |
| Slag | 500 | 500 |
| Water | 200 | 200 |
| Superplasticizer (lt/m$^3$) | 33 | 33 |
| Fine aggregate 0-2 mm | 982 | 982 |
| steel fibres $l_f/d_f$ = 13/0.16 | 100 | 100 |
| Crystalline additive | = | 3 |

## 2. METHODS

Beam specimens, 500 mm long x 100 mm wide x 50 mm (NSC) or 25 mm (HPFRCC) thick, were cut from larger slabs (1m x 0.5 m) cast with each mix and, after 35 to 42 days curing in a fog room at 20°C and 95% relative humidity, were pre-cracked by means of a COD-controlled 3-point (NSC) or 4-point (HPFRCC) bending set-up. For NSC two different values of crack opening were set (about 130 and 250 $\mu$m). For HPFRCC, the behaviour of which could be deflection softening or hardening depending on the matching between the flow induced alignment of fibers to direction of the applied bending stress [1], different levels of crack openings were employed, namely 0.5 mm for deflection softening and up to 0.5 mm beyond the peak for deflection hardening. Specimens were then immersed in water at 20°C and, for NSC only, also exposed to open air. After scheduled exposure times (1, 3, 6 and, for NSC only, 12 months) bending tests were performed again on the same specimens and results between the pre- and post-conditioning response were compared, in order to evaluate the recovery of mechanical performance and calculate related "self-healing indices" ([2]).

## 3. RESULTS

In Figure 2a the results of a typical test, in terms of nominal stress $\sigma_N$ vs. Crack opening displacement (COD) curves, are shown, for the same specimen in the pre-cracking and post-conditioning failure tests. By comparing the peak stress attained in the post conditioning test, with respect to the unloading value in the pre-cracking test, to the amount of stress lost from the peak up to the unloading in the same pre-cracking stage, an Index of Load Recovery (ILR) was quantified (Figure 2b). Beneficial effects of crystalline admixtures as catalysts of self healing are evident. Through a dedicated methodology [2] crack closure was also estimated and correlated to ILR (Figure 2c). Pictures in Figures 3 a-d confirm the aforementioned statement.

HPFRCC deflection softening specimens always exhibited some recovery of the post-cracking stress, as witnessed by the new "cracking peak" detected in post-immersion tests, and, in the case with the crystalline admixture, by the new cracking strength even higher than that of the virgin specimen. This is confirmed also in the case of deflection hardening specimens, leading to hypothesize that, because of the expansive reaction by the crystalline admixture, some sort of "internal chemical prestressing" of fibres may have occurred, enhanced by the favourable alignment of fibres.

## 4. CONCLUSIONS

In this study the effects of crystalline admixtures as catalysts of self healing in cement based materials have been investigated, with reference to a NSC and a HPFRCC. A methodology has been conceived and validate to measure and quantify the effects of self-healing on the mechanical properties of cement based materials. In both cases the crystalline admixture enhances and makes more reliable the autogeneous healing capacity of cementitious composites. In the case of HPFRCCs, the measured performance of the healed material containing crystalline admixture, can result significantly better than the one of virgin specimens: it can be argued that some kind of internal chemical pre-stressing of fibers may be triggered by the expansive reactions of the admixtures, which needs to be further and more systematically investigated.

## ACKNOWLEDGEMENTS

The author thanks Mr. Robert Revera, Penetron Intl. Ltd. and MsArch. Enrico Maria Gastaldo Brac, Penetron Itaia Ltd. for their enthusiastic support. The support of the Young Researchers grant 2011- Politecnico di Milano is also gratefully acknowledged.

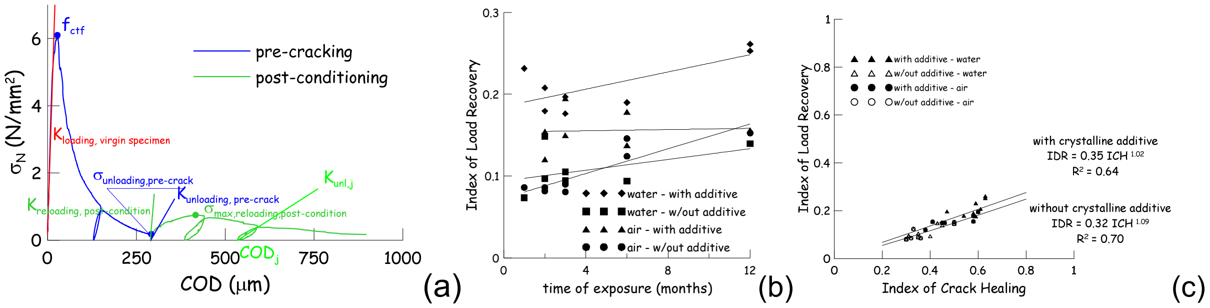

Figure 2: example of pre-cracking and post-conditioning $\sigma_N$ vs. COD curves for NSC specimens (a); Index of Load Recovery ILR (b); correlation ILR vs. crack healing (c).

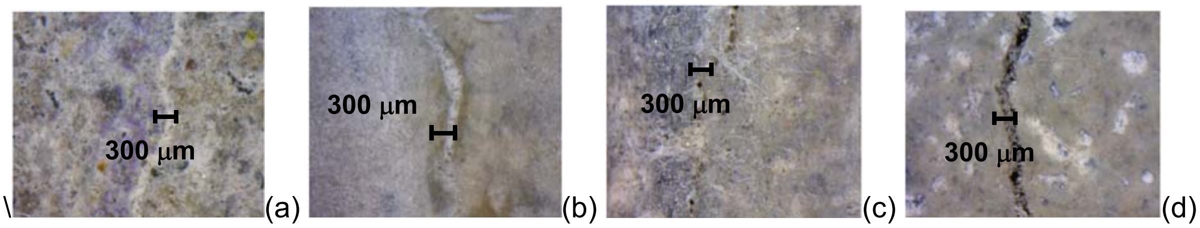

Figure 3: healed/healing cracks for specimens with (a,c) and without (b,c) crystalline additive after six months of immersion in water (a,b) and exposure to air (c,d).

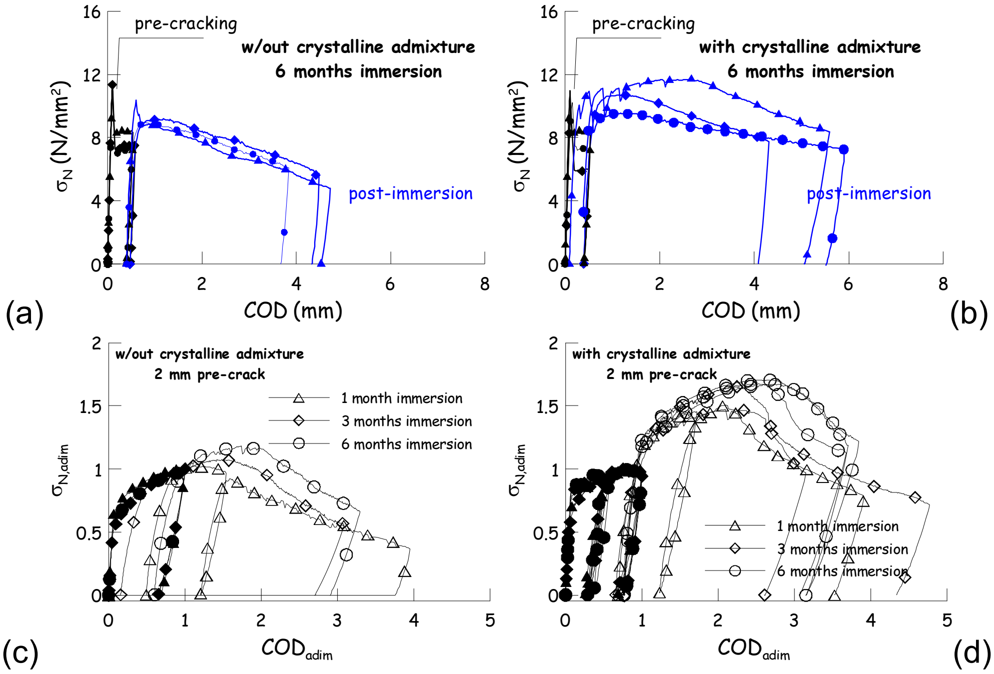

Figure 4: nominal stress vs. COD curves for deflection softening (a,b) and hardening (c,d) HPFRCC specimens without (a,c) and with the crystalline admixture (b,d).

## REFERENCES

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