Microscopical characterization of the self healing mechanisms in high performance cementitious composites reinforced with steel and natural fibres

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ABSTRACT

In this paper a thorough microscopical and chemical (by means of TGA) characterization of the cracked/healed surfaces in HPFRCCs, reinforced with different types of fibres, has been performed in order to understand the nature of the reactions governing the crack healing phenomenon. Effects of self healing on fibre matrix interface have been also investigated in order to have a deeper understanding of the mechanisms governing the phenomenon. The role of natural fibres as vehicles of the environmental moisture inside the bulk material has also been confirmed. Additional healing reaction products forming at the fibre matrix interface, in the case of natural fibres, have been clearly identified, further contributing to the enhancement of the healing capacity of cementitious composites and improved recovery of pristine levels of mechanical performance.

INTRODUCTION

Natural fibres are a waste product of food and agriculture industry to which a great potential of use as dispersed reinforcement in cementitious composites has been recognized, making them a valuable source of income for developing communities and countries, where they are abundant and can be harvested with minor investments.

A further value to the use of natural fibres in cementitious composite as promoters and facilitators of self healing phenomena has been recently hypothesized and confirmed by preliminary investigations [1]. As a matter of fact, thanks to their porous microstructure, natural fibres are able to create a porous network through which the moisture, as absorbed by the same fibres, can be distributed throughout the cementitious matrix and activate the delayed hydration reactions which, together with carbonation ones, can be responsible of the autogeneous healing of cracks [2].

High Performance Fibre Reinforced Cementitious Composites (HPFRCCs), because of their peculiar composition featuring a high binder content and a low w/b ratio, can be highly conducive to autogeneous healing, which natural fibres can further enhance.

A detailed microstructural investigation is presented in this paper with reference to two HPFRCCs reinforced with either only steel fibres or a hybrid combination of steel and sisal fibres.

1. MATERIALS AND TESTS

Two different HPFRCCs have ben used in this investigation (mix design in Table 1), either reinforced with only steel fibres (V_f = 1.28%)or with a hybrid combination of steel and sisal fibres (V_f = 1.28% equally shared between steel and sisal). With each mix double edge notched prisms were cast (geometry shown in Figure 1a) and, after one month curing in laboratory conditions, precracked in direct tension up to 0.15 mm crack opening and then exposed to wet and dry cyles for three months. Cycles consisted of one week immersion in water followed by one week in a room at controlled temperature (T = 20°C) and humidity (RH = 50%). At the end of the scheduled conditioning period specimens were tested once again in direct tension, up to failure. The obtained stress vs. Crack Opening curves (Figure 2), highlight a stress recovery capacity [3] higher for steel+sisal composite, as confirmed by a «stronger » healing of the cracks (Figure 2).

Table 1. Mix design of employed HPFRCCs

Constituent	Steel HPFRCC (kg/m^3)	Steel + sisal (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	50
Sisal fibres		7

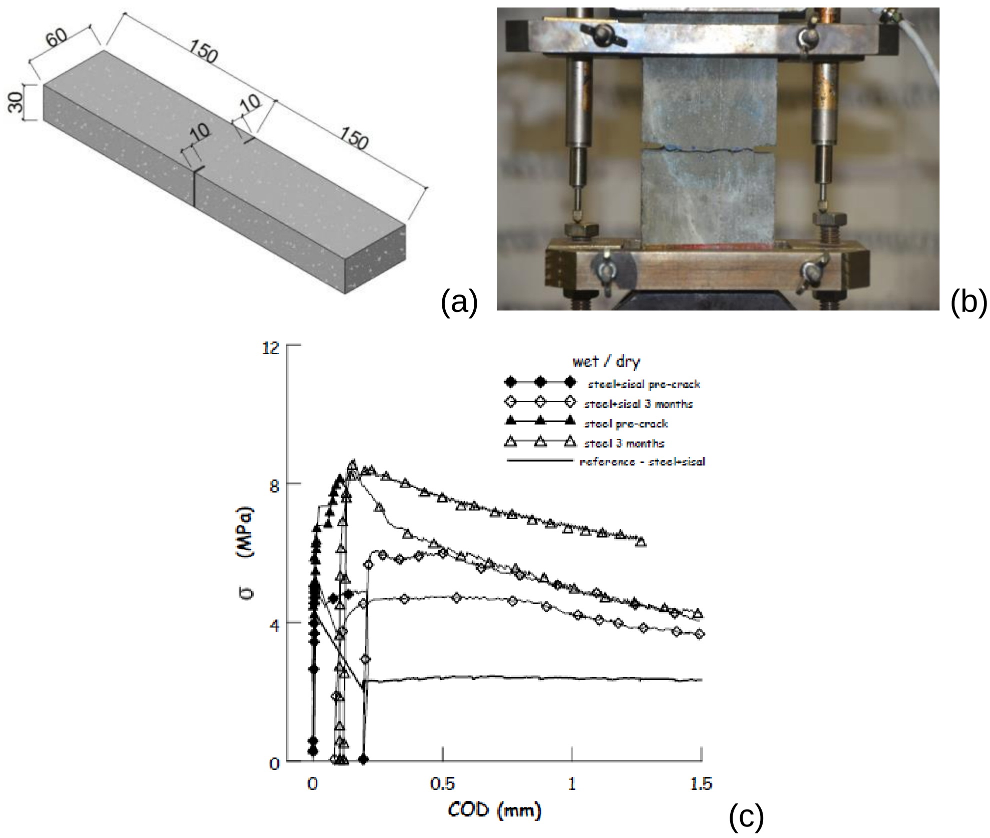
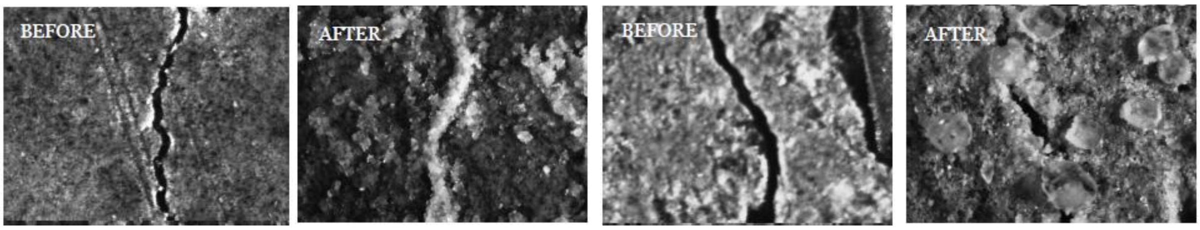
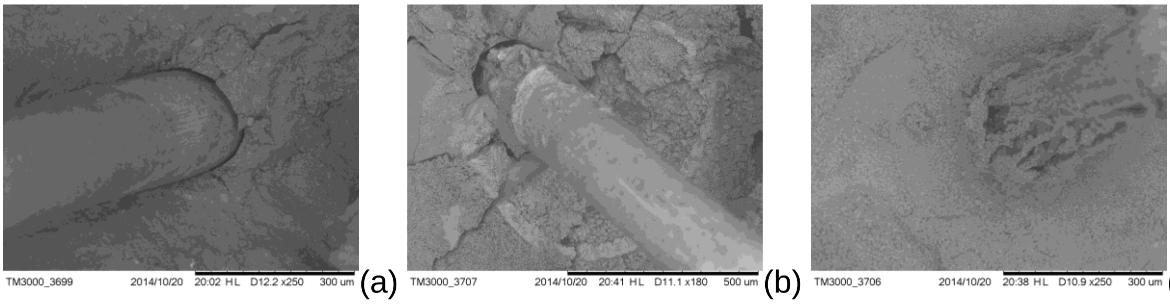


Figure 1: geometry of the double edge notched specimen for direct tension tests (DTTs) (a); specimen pre-cracking (b); results of DTTs before and after healing (c).



(a) (b) (c) (d)

Figure 2 : healing of cracks in steel+sisal (a,b) and steel (c,d) HPFRCC specimens-



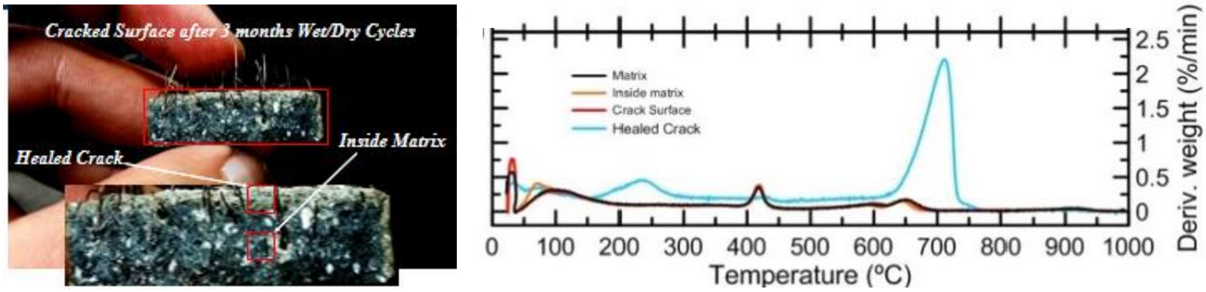
(a) (b) (c)

Figure 3 : detail of fibre-matrix interface in : (a) non healed steel HPFRCC; (b) healed steel HPFRCC and (c) healed sisal+steel HPFRCC.

2. MICROSCOPICAL CHARACTERIZATION

After the post-conditioning failure tests the crack surface, and in particular the fibre matrix interface, was inspected with a SEM. In Figure 3a a steel fibre clearly and neatly pulled out from the matrix in a reference non healed specimen is shown, while a pre-cracked/healed specimen is shown in Figure 3b. The deposit of new products on the fiber can be observed, as a further proof of the occurred healing. Moreover the matrix around the fibre appears to be, upon pull-out of the same fibre, heavily cracked, as a result of an increased pull-out work. In Figure 3c a sisal fibre completely covered by delayed hydration/healing productsis shown, with a visible stronger concentration of the same products at the fibre matrix interface, since the fibre act as a vehicle of the water, which is the prominent healing promoting agent. This could support the assumption that the observed recovery of mechanical properties exhibited upon crack healing is the outcome of the re-established matrix connection between the crack faces but also of an improved fibre matrix bond, resulting in an enhanced pull-out energy.

In order to further clarify the different processes and mechanisms characterizing and governing the healing process, TGA analyses have been performed on four samples extracted from both non-healed and healed specimens and in the bulk matrix or on the crack surface. The results for the bulk matrix from non-healed and healed specimens, as well as for the crack surface of non-healed specimens, hyghlight, all in a similar way, mass loss peaks related to typical hydration products, such as ettringite (80 °C), CSH (104-140°C) and CH (460°C). This similarity corroborates the assumption that the observed post-conditioning macroscopical recovery of the mechanical performance is attributable not to a generalized prolonged hydration of th binder. As a matter of fact, because of the high compactness of the hardened matrix, water, which is necessary to promote the delayed hydration, can hardly penetrate into the matrix but through a crack, even in a completely immersed specimen. On the other hand, the TGA curve of the healed crack sample, shows peaks in correspondance of the dehydroxylation of CSH (230-240 °C) and of the decarbonation (620-645 °C). The presence is hence confirmed of the aforementioned substances, respectively products of the delayed hydration and carbonation reactions, which are the cause of the crack healing, respectively produced during the wet and the dry stage of the cycles.



(a) (b)

Figure 3 : detail of a cracked specimen surface with located samples fotr TGA (a); TGA results for matrix and crack surfaces of non healed and healed specimens (b).

3. CONCLUSIONS

This paper has presented the results of a microscopical and microstructural characterization of the crack self healing mechanisms in HPFRCCs reinforced with either steel and steel+sisal fibres. The role of natural fibres as vehicles of the healing water inside the material has been confirmed. The healing reactions are the outcome, also as a function of the exposure conditions, of delayed hydration of unhydrated binder and carbonation. Cracking is essential for water and air to penetrate inside the material, reaching the unhydrated binder clusters and active the aforementioned reactions. The compactness of the matrix would otherwise prevent any ingress of any fluid in the specimen. Healing reactions promote, beside the crack closure and the “re-establishment” of the load bearing links across the crack faces, also an improvement of the fibre-matrix bond, through the growth and deposit of the healing products. Both the mechanisms contribute to the observed macroscopical recovery of the mechanical performance.

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