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New self-healing techniques for cement-based materials

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Abstract

In recent years, researches concerning cement-based materials has been focused not only on the strength and the toughness but also on the durability. In fact, the interest on concrete's self-healing process is increasing, due to the rapidly deterioration of that material which tends to crack and thus quickly deteriorate.
In this paper, a new self-healing technology for cement-based materials is proposed. This technology is based on the encapsulation method of repairing agent inserted in randomly distributed *shell* inside the material during its preparation. Two different kind of *shells* were used: glass spheres and pharmaceutical capsules. The material the shells are made of has to be endowed with a series of fundamental characteristics. That material has to be inert with respect to the repair agent so that it doesn't react with it, resisting to the severe stress condition that the shells undergo during the mixing, and at the same time being capable of breaking down when the crack intercept them, having a good compatibility with the cement mixture.
The results demonstrate that it is possible to use this kind of shell to encapsulate the repairing agent: the crack breaks them and they release the healing agent, which allows patching up the crack.

Keywords: innovative techniques; encapsulation; sodium silicate; self-healing; cement-based materials;

1. Introduction

Concrete is the most used construction material on Earth but it is susceptible to crack formation due to its limited tensile strength. Moreover, damage repair tends to be difficult when cracks are not visible or not easily accessible.

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Consequently, durability reduces and maintenance costs increase (Fregonara, E, 2016). Therefore, self-repair of fractures in concrete is of the highest interest: Turner, back in 1937, (Turner, L. 1937) observing damaged tanks and water pipelines, noticed that water was the key to the occurrence of self-repairing. After cracks formation, the delayed hydration of the mix along the interface of the cracks occurred: by reacting with water, the width of the crack was reduced, and, in some cases, the complete filling of the damaged zone was evidenced.

Crystals of calcium hydroxide and of calcium carbonate, produced by the reaction between the former and carbon dioxide, allowed cracks sealing. Hearn and Morley (Hearn, N., Morley, C.T. 1997) sixty years later, continued to support the thesis of Turner and confirmed that the presence of water was mandatory to activate the self-healing process in not fully hydrated cementitious materials. Neville (Neville, A.M. 2002) states that, in addition to water and carbon dioxide, the phenomenon is influenced by water temperature and relative humidity.

Nowadays there are other approaches than the autogenous healing of concrete previously described (Van Tittelboom, 2013): self-healing with mineral additives, self-healing by means of bacteria and self-healing based on encapsulated adhesives.

The self-healing process can be attributed to the reaction of the mineral additives dispersed in cementitious materials too (Ahn, T-H. 2010, Roig-Flores, M. 2016). These minerals are added to the concrete mixture during preparation. When a crack occurs, the additives are located on the surface of the break, when the water penetrates inside, these mineral additions react with water and the slit is filled with the reaction products.

In the 90s, Gollapudi (Gollapudi, U.K. 1995) suggested to use bacteria to induce the precipitation of calcium carbonate ($CaCO_3$) to repair the cracks. The calcium carbonate precipitation can be caused by various phenomena, such as hydrolysis of urea and the oxidation of organic acids. Jonkers (Jonkers, H.M. 2010) claims that the bacteria spores that have a life of about fifty years, when inserted directly into the concrete mix, undergo a drastic decrease in life expectancy. Wiktor shows that the immobilization of bacteria in porous clay aggregates, before the conglomerate mixing, can greatly extend their life (Wiktor, V. 2011). In this way, the self-healing process is activated when the crack intersects one of these clay particles.

In many works, hollow glass tubes were used as encapsulation devices (Van Tittelboom, K. 2013) and the release of the healing agent is activated by the breakage of the brittle glass tubes during concrete damaging. The internal diameter of these tubes usually ranges from 0.8 mm to 4 mm. However, glass capsules may lead to the possible onset of alkali-silica reactions. To limit this drawback, ceramic capsules were therefore successfully experimented (Van Tittelboom, K. 2011), in addition to spherical or cylindrical polymeric capsules (Van Tittelboom, K. 2013). In the case of spherical capsules, the capsule diameters range from 5 μm up to 5 mm, while for cylindrical capsules, the diameters range from 0.8 mm up to 5 mm (Van Tittelboom, K. 2013).

In general, the above described healing agents such as bacteria, mineral additives and adhesive agents, markedly improves the ability of self-healing of concrete, but they increase its cost too. Therefore, in this work, more than the investigation of new repairing agents, materials already present on the market for other purposes were assessed, with the aim of reducing as much as possible their incidence on final costs of self-healing concrete. After several hypothesis, small glass spheres (commonly used for jewelry) and pharmaceutical capsules were retained and used. Though the volume of healing agent they contain is limited, respect to glass or extruded tubes, these capsules can be randomly dispersed all throughout the cementitious matrix, and are not only ideally located in the sample center of prisms for three-point bending tests, as previously experimented (Formia, A. 2015; Formia, A. 2016).

2. Materials and methods

2.1. Sodium silicate as healing agent

After careful analysis, it was concluded to use the sodium silicate ($Na_2Si\ O_3$). Commonly known as liquid glass, this compound is widely used in the building sector, for example as an additive for concrete waterproofing. It starred in several previous trials in the field of self-healing cementitious materials, allowing to get pretty good results (Brough, A. R. 2002; Chang, J. J. 2003; Yang, K. H. 2008; Huang, H. 2011; Gilford, 2013; Van Tittelboom, K. 2013; Formia, A. 2015; Formia, A. 2016; Alghamri, R. 2016). Sodium silicate has the ability to repair cracks because of its adhesive capacity and of its reaction with Portlandite $Ca(OH)_2$ and calcium silicate hydrates (CSH), two hydration products of Portland cement.