Effect of Waterproofing Materials on Self-Healing Concrete

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Abstract

Improving the strength of the concrete structures and increasing the service life is an important issue. The service times of the concrete remained; external factors such as water penetrating into these micro-cracks and shorten the life of the concrete. In order to solve this problem, the idea of self-healing concrete with bacteria or other materials has been put forward and studies have shown that using CaO based materials that repair cracks in this direction by precipitating calcite. It is obvious that long-term performance of concrete will increase with to prevent water pass to concrete interior. Instead of forming a barrier on the positive or negative side of concrete, waterproofing admixture turn the concrete itself into a water barrier. Internal concrete waterproofing systems can be water repellents or crystalline admixtures. In this study, waterproofing admixture was added to concrete mixture as waterproofing material and its effect on self-healing in terms of filling the pores was investigated. Beam samples including the CaO based waterproofing powder materials were produced in size of 285x75x25 mm. The samples were cracked in the flexural machine. After some days, the cracks were investigated by microscope. Crak control was continued till 28 days. At the end of study, the cracks smaller than 0.3 mm were self-healed. However, the bigger cracks than 0.3 mm cannot be self-healed by waterproofing material. Consequently, self-healing of concrete with CaO based waterproofing powder material is very promising for the environmentally friendly and sustainable structures of the future.

Keywords: Self-healing concrete, CaO based material, micro cracks, concrete repair

Introduction

During the service life of concrete structures, internal and external effects and micro-cracks occur in the structure. These cracks cause leakage of harmful substances into the concrete, deterioration of the strength and durability properties of the concrete, structural damages and crashes, and the high cost of maintenance and repair of the concrete structure. It is known that water-dissolved CO_2 reacts with Ca^{+2} ions in the concrete and can repair the concrete by forming $CaCO_3$ (limestone) crystals with very little water solubility. However, for this type of self-repair to occur, there must be water in the environment and this repair can only be made if the cracks are too small. Recently, bacterial concrete methods which has ability to self-healing are used to overcome maintenance and repair costs. In 1994, the first study on the ability to self-healing with the extra materials that were added to the concrete during the production of concrete was published by Carolyn Dry of Illinois University. Eric Schlagen and Henk Jonkers who have been researching about self-healing concrete by adding bacterial spores and calcium lactate foods to the mixture while producing concrete have made a remarkable study in this field since 2006. Bacterial concrete, Bacillus bacterial spores in the medium of the water-activated nutrients and calcium sources in the range of appropriate pH values in the concrete due to the formation of a fibrous structure is caused by precipitation of calcite. Thus, with the precipitation of calcite, the bacteria are embedded in concrete and the concrete is provided to improve itself.

Occurring mechanism of cracks which are inevitably in concrete due to its relatively lower tensile strength and action of different load and non-load factors may be varied including plastic shrinkage, drying shrinkage, thermal stresses, external loading and rebar corrosion or coupled effect of multiple factors (Souradeep et al. 2017). These cracks cause leakage of harmful substances into the concrete, deterioration of the strength and durability properties of the concrete, structural damages and crashes, and the high cost of maintenance and repair of the concrete structure. When growth of micro-cracks reaches from the surface of concrete to the reinforcement, corrosion occurs on reinforcement due to attack of aggressive agents (water, oxygen, CO_2, chlorides, etc.) which corrodes the reinforcement reducing its service life. The rate of aggressive agents' ingress into concrete is primarily dependent on the internal pore structure of concrete (Vijay et al. 2017). Therefore, it is more important to prevent these cracks at the start or it will become a major crack, however, to repair this crack is not an easy task so some alteration is needed in the construction material (Kulthe et al. 2018).

In 1994, C. Dry was the first who proposed the intentional introduction of self-healing properties in concrete (Van Tittelboom and De Belie 2013). In recent years, there are many alternative repair mechanisms and one of them is based on the application of crystallation in concrete.

Theory

Application of traditional crack repairing systems usually contains applying a cementitious material-based mortar bonded to the damaged surface, which can be especially time consuming and expensive in concrete structures due to mostly difficult to get access to repair cracks (Rao et al. 2013). Biotechnology and nanotechnology are used to improve the properties of concrete. Consequently, bacteria-based concrete has been suggested as an alternative and sustainable crack repair technique. The conceptual idea provided by bacterial crack healing mechanism is that the bacteria should able to transform soluble organic nutrients into insoluble inorganic calcite crystals which seals the cracks (Rao et al. 2013). Concrete has a rather aggressive medium due to its high internal pH, relative dryness and lack of nutrients for common bacteria needed for growth, however, some extremophilic spore forming bacteria can survive in this medium and increase the strength and durability of concrete (Rao et al. 2013). But, the bacteria will not survive once the cells become jammed by $CaCO_3$ crystals and the bacterial activity will also come to an end once all nutrients are consumed. Therefore, it can be concluded that even the bacterial approach will not allow an endless repetition of the healing process (Van Tittelboom and De Belie 2013).

Concrete durability and permeability has a strong relationship. Bacteria-based concrete biologically produces calcium carbonate crystals to seal cracks. Calcium carbonate ($CaCO_3$) that is a common substance found in rocks exists in environments such as marine water, fresh water, and soils. There are many techniques to heal properties of concrete, among these techniques' bacteria-based concrete that special strains of bacteria capable of precipitating certain chemicals are used is a relatively new technique. According to Rao et al. (2013), autogenous healing occurs because of hydration of non-reacted cement particles present in the concrete matrix once meet leakage water resulting in in closure of micro cracks, however, due to the variability of autonomous crack healing of concrete micro cracks can still occur. The bacteria used in concrete should be able to have long-term effective crack sealing mechanism during its lifetime serviceability. Recent researches about bacteria-based concrete focus to heal cracks induced after 28-days of casting, which can be mentioned as an early age application for bacteria-based concrete (Bundur and Amiri 2016).

The mechanisms of microbially induced calcium carbonate precipitation (MICCP) can be achieved through different pathways like urea decomposition, oxidation of organic acids (aerobic process), or nitrate reduction (anaerobic process). Therefore, the effects of bacteria on concrete strength are variable. The precipitation rate of biological calcium carbonate is ideally influenced by concentration of calcium ions, pH of the solution, concentration of dissolved inorganic carbon and availability of nucleation sites. Alkali tolerant ureolytic strains, such as Sporosarcina pasteurii (Bacillus pasteurii), Sporosarcina ureae, Bacillus sphaericus, and Bacillus megaterium, that can decompose urea into ammonium/ammonia and carbonate ions (Equation 1) are the most commonly used bacteria in bacteria-based concrete. Bacterial urea hydrolysis requires oxygen to initiate bacterial activity (spore germination), which can be a restricting factor for deep crack healing. Nitrate reduction by different strains, such as Diaphorobacter nitroreducens, under oxygen limited conditions, denitrifiers use nitrate (NO_3^-) to generate $CO_3{}^{2-}$ and HCO_3^- ions, which are necessary for $CaCO_3$ precipitation (Equation 2). The alkaliphilic strains, such as Bacillus cohnii, Bacillus pseudofirmus and Bacillus alkalinitrilicus, which can degrade organic compounds into CO_2 and H_2O, and CO_2 can be easily converted to $CO_3{}^{2-}$, and with the presence of Ca^{2+}, $CaCO_3$ can be formed (Equation 3).

$$Ca^{2+} + CO_3{}^{2-} \longrightarrow CaCO_3 \qquad (1)$$
$$Ca(C_3H_5O_3) + 6O_2 \longrightarrow CaCO_3 + 5CO_2 + 5H_2O \qquad (2)$$
$$5CO_2 + 5Ca(OH)_2 \longrightarrow 5CaCO_3 + 5H_2O \qquad (3)$$

There are some basic approaches for crack healing with bacteria: direct addition of bacteria into the fresh concrete; additions in the form of spores, immobilized form onto silica gel or activated carbon, encapsulated form, or using the vascular networks (Talaiekhozan et al. 2014). Concerns about the viability of the endospores within the improper and high pH environment of cement-based materials have led researchers to suggest encapsulation for the endospores. The encapsulation methods consist of enclosing the endospores in a protective covering. Thus, some encapsulation methods such as encapsulation in porous solids, capsule based, vascular based have improved for protecting the bacteria form improper environment conditions. The most generally used method, due to its ease and low cost, is immobilization in lightweight aggregates.

The crack reparinig mechanism can be tough in concrete with crystalline water proffing material (CWPM). When the CWPM compared with water in the pores of concrete, it acts with water and produces CaO based crystalline hydration products (Fig. 1). The hydrated materials fill the pores and, they do not allow penetrating of water inside of concrete.

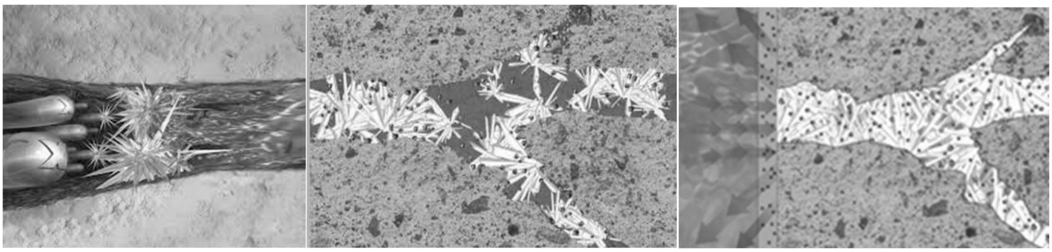

Figure 1. The crack filling mechanism of CWPM.

Therefore, the objective of this study is investigation of repairing effect of crystallation waterproofing materials as self-healing in concrete cracks. The crystalline products can be healed the crack of concrete (Van Tittelboom and De Belie 2013).

3. Experimental study

Plain control specimens and CWPM containing specimens in size of 285x75x25 mm were prepared and tested. Plain mortar specimens were used as reference. Plain control mixture was composed of river sand (1350 g), CEM I 42.5R cement (350 g) and, tap water (227,5 g). As repairing material, liquid CWPM and powder CWPM were used as 0%, 10%, 20% and 30% of cement dosage. Following demoulding, specimens were cured for one day at room temperature inside a tightly sealed bag. Cured specimens were cracked by applying flexural load with four point test. Multiple cracks were achieved in all mortar specimens (Fig. 2).

Figure 2. Small mortar beams for self-healing measurement

The obtained mulitple cracks were viewed under 1000X magnification microscope. The crack width measured and healing of cracks was investigated at 7 and 28 days aged samples. Also, water absorption test was carried out on the specimens.

Results and Discussion

Crystalline based powder and liquid material containing concrete cracks was experimentally conrolled by water absorption test. Almost, some cracks were checked for several days as self-healing. Fig. 3 shows the same crack with different magnification. It would be clearly seen that crack was filled with CWPM.

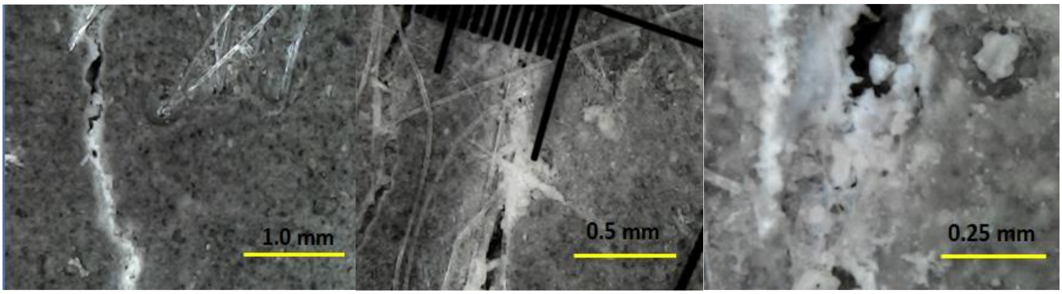

Figure 3. Crack filling with CWPM

Repairing of cracks in concrete structure occurs mostly early age, Souradeep et al. (2017) observed that bacteria repairs early age cracks more efficiently than later age cracks. Additionally, the crack healing ratio decreased remarkably along with the increasing of cracking age (Lou et al. 2015). It was reported by Rao et al. (2013), life-time of bacteria added directly into concrete mixture is restricted due to continue cement hydration resulting in reduction of cement sand matrix pore-diameter. Moreover, for effective crack healing both bacteria and nutrients mixed into concrete should sustain to continue the integrity of concrete mixture (Rao et al. 2013). According to Vijay et al. (2017), it was observed that encapsulation method protects bacteria from improper environment of concrete so that self-healing efficiency about crack closer and the amount of calcium carbonate precipitation. Bundur and Amiri (2016) mentioned that the chemical admixtures studied herein have no significant influence over the performance of the MICCP applications in bacteria-based concrete. However, CWPM is cement based material, and it is not live. Therefore, it has not a life-time problem.

Many researches and Figure 2 support that cracks in bacteria-based concrete specimens fully filled with calcium carbonate provided by crack width up to 0.8 mm (Lou et al. 2015) or 100–200 μm (Souradeep et al. 2017), although it depends on several factors. When the average crack width increases, repairing of cracks are difficult and limited for bacteria repair agent (Figure 1b). To use crack area instead of crack width as measuring cracks was suggested by Souradeep et al. (2017).

To evaluate the crystalline waterproofing products efficiency, the most commonly used tests are those which measure water absorption and chloride penetration. Upon crack healing tests, cracks presented in Figure 4 were tested for water absorption. Water absorption through the healed cracks of specimens were less than the control specimens (Figure 4). As reported previously, CWPM self-healing of concrete cracks occurs at the crack mouth and provides a sealing effect. The absorption increase in the concrete with the liquid crystalline waterproofing admixture (in high volume, 30%) can be justified by a possible hygroscopicity generated by the use of this product may be a result of increase amount of evenly distributed small pores, or by the product may be hygroscopic and contribute to this increase absorption.

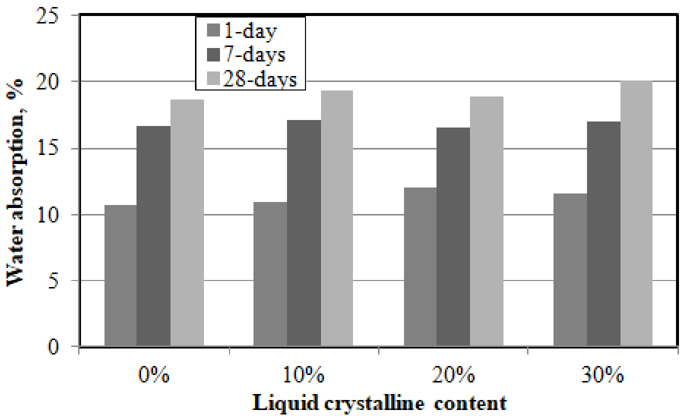

Figure 4. Water absortion of liquid CWPM containing samples

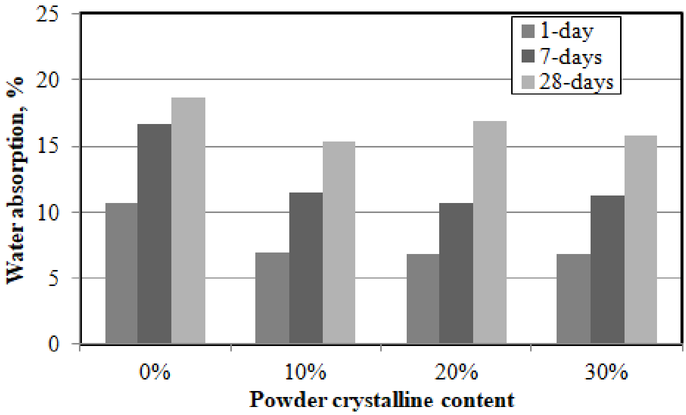

Figure 5. Water absortion of powder CWPM containing samples

It is observed that the use of powder crystalline waterproofing coating is more efficient compared with the concrete with liquid waterproofing admixture. The powder crystalline waterproofing coating system is a form of surface protection and has little dependence on the distribution of concrete voids, because it was expected to have better performance than the reference concrete. Thus, the powder crystalline waterproofing in most cases performed better than reference concrete. The crystalline waterproofing is to prevent the water penetration and allow the steam passage into the concrete (Capellesso, 2016).

Conclusion

This paper focused on ability of the healing of cracks in concrete with crystalline based materials. In the study, two types of crystalline cement based materials were used as self-healing in the concrete. The concrete samples were cracked after production, and they were cured till 28 days. The use of powder crystalline waterproofing material contributes filling of cracs that smaller than 0.8 mm, and it reduces the water absorption ratio. The use of powder waterproofing materials in 10% shows better self-healing and water absorption reducing performance than concretes which are including liquid waterproofing materials. If concretes are built with CWPM that is designed to perform under multiple damages, very low cost may be obtained over the life-time though initial cost may be higher than normal concrete. Also, we can obtain durable and sustainable concrete structures by their self-healing properties.

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