SELF-HEALING CONCRETE

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ABSTRAT

Tone- mending accoutrements are a class of smart accoutrements that have the structurally incorporated capability to repair damage caused by mechanical operation over time. The alleviation comes from natural systems, which have the capability to heal after being wounded. Inauguration of cracks and other types of damage on a bitsy position has been shown to change thermal, electrical, and auricular parcels, and ultimately lead to whole scale failure of the material. Generally, cracks are mended by hand, which is wrong because cracks are frequently hard to descry. A material (polymers, pottery,etc.) that can naturally correct damage caused by normal operation could lower product costs of a number of different artificial processes through longer part continuance, reduction of inefficiency over time caused by declination, as well as help costs incurred by material failure. For a material to be defined rigorously as tone- mending, it's necessary that the mending process occurs without mortal intervention. Some exemplifications shown below, still, include mending polymers that bear intervention to initiate the mending process.

A good way to enable multiple mending events is to use living (or unterminated chain- ends) polymerization catalysts. However, they may not fracture when the crack approaches, but if they're too thin, If the walls of the capsule are created toothick.In order for this process to be at room temperature, and for the reactants to remain in a monomeric state within the capsule, a catalyst is also bedded into the thermoset. The catalyst lowers the energy hedge of the response and allows the monomer to polymerize without the addition of heat. The capsules (frequently made of wax) around the monomer and the catalyst are important maintain separation until the crack facilitates the response.

Keywords: - *Healing, Synthetic, polymers, silica*

1. INTRODUCTION

Concrete is, next to steel, one of the most popular structural materials. Over the years, various modifications of concrete compositions have been proposed in order to improve its properties. Lately, the decrease of the environmental impact of concrete has been extensively studied. Lowering the carbon footprint of concrete can be done in two different ways, i.e. by the modification of the mix compositions such as replacing cement by so- called Supplementary Cementations Materials (SCM) or by lowering maintenance and repair costs. The former can be done by developing concrete with waste materials, e.g. fly ash or blast furnace slag which are industrial by-products, whereas the latter can be achieved by designing a material with self-healing properties. Possibly, it is also a combination of the two ways, by adding SCMs and improves the design

The self-repair of tissue and bones in biological materials has always been an interesting concept. Mimicking natural phenomena and mechanisms gives often the possibility to develop new materials with smart behavior. The self-healing characteristic, i.e. the ability of material to sense and repair inner damage without human intervention, is one of the most desirable properties in material science. Recently, attention has been paid to the self-healing phenomena in cementations materials. Concrete is a brittle material with low tensile strength. In order to increase the tensile strength of concrete additional reinforcement has to be implemented, usually made of steel. Concrete provides an alkaline environment, which protects the steel reinforcement from corrosion. Unfortunately, due to its brittleness, concrete is prone to cracking not only due to the external mechanical loading but also as a result of drying or autogenous shrinkage. The cracks create a passage for acidic ions to 4 reach the reinforcement leading to its corrosion and consequently to the deterioration of concrete. Consequently, the material's strength decreases, which is a serious issue.

Concrete composites have the natural ability to heal cracks (Figure 1) and to regain mechanical properties and limit the ingress of aggressive media. Many scientists aim to enhance and to control that ability. Succeeding in healing concrete cracks could lead to more sustainable construction and lowering of the maintenance costs. The potential of autogenous self-healing of concrete was already noticed over 100 years ago. Nowadays, various techniques are being investigated in order to accelerate it and to increase the potential benefits of this process

2. SELF-HEALING CONCRETE – STATE-OF-THE-ART

Following nature has always been an inspiration for development of new materials. In particular, the self-repair of tissue and bones is considered as an extremely fascinating concept. Self-healing can be described as an ability of material to sense and repair inner damage without external intervention. Biological systems can serve as an example for man- made materials (Figure 2.1). In both cases, the initiation of the mechanism is the occurrence of the "injury". The biological system initiates an inflammatory response, followed by the cell proliferation and, finally, matrix remodeling. It is a time-consuming process. The synthetic response follows similar steps (triggering, transport, chemical repair), however, the rate of healing can be adjusted by a proper design of the material (Blaiszik et al. 2015

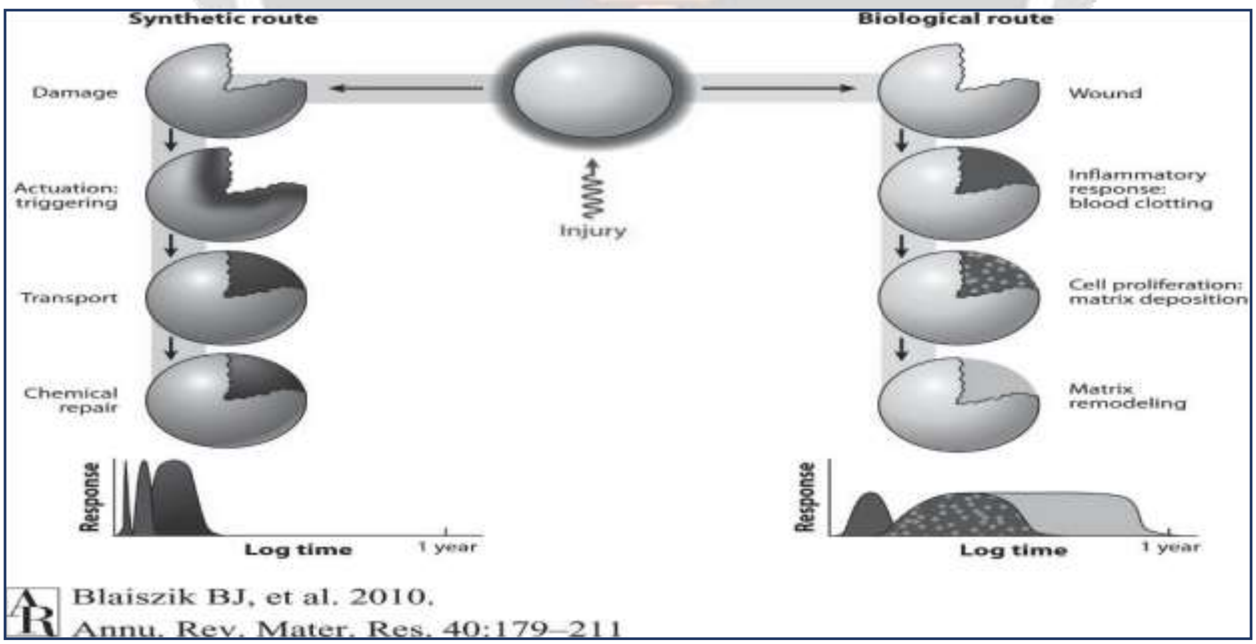

Fig: Synthetic and biological route of self-healing, from (Blaiszik et al. 2010).

This concept of materials with self-healing properties has been widely studied in polymer science (e.g. White et al., 2001; Thakur & Kessler, 2015; Zheng & McCarthy, 2012). Various autonomic self-healing strategies have been implemented including, e.g. the application of microcapsules.

Concrete is the most frequently applied structural material. The binder used for concrete production is primarily ordinary Portland cement (OPC). Over the recent years, the annual world cement production has reached around 1.7 billion tons (Yang et al 2015, Gartner, 2004). At the same time, it was estimated that the worldwide production of OPC contributes to emission of as much as 7% of the total global CO2. Therefore, design of a more environmentally friendly material is urgently required. 12

In addition, concrete exhibits brittle behaviour and very limited tensile strength. This makes it prone to cracking which provides a way for acidic ions to reach the reinforcement leading to its corrosion and deterioration of concrete microstructure. Cracking severely contributes to shorter life-time of concrete structures and high maintenance costs. Concrete composite having the ability to heal cracks and to regain mechanical properties is a scientific goal for many researchers. It could not only lead to a reduction of the cost of structural repairs but also, possibly by proper alternative mix design, help to reduce the CO2 emissions.

There are two types of self-healing processes in cement-based composites, i.e. autogenous (Figure 2.2a) and autonomous (Figure 2.2bc). The autogenous self-healing involves only the original concrete ingredients, which promote the crack repair due to their specific chemical composition and under favorable environmental conditions (De Rooij et al. 2013). On the other hand, the autonomous self-healing uses external components, such as microcapsules or bacteria to facilitate the damage restoration (Cailleux and Pollet 2009; Da Silva et al. 2015; Jonkers 2007).

3.Autonomous self-healing

3.1. Bacteria-based approach

One of the first applications of bacteria to seal cracks in concrete was mentioned by Gollapudi et al. (1995). The use of bacteria-modified mortars, which could be applied externally for concrete repair was the topic of many research projects (Orial et al., 2002; De Muynck et al., 2008; Van Tittelboom et al., 2010; Ramakrishnan et al., 2013). Recently, the use of bacteria for self-healing concrete was also studied.

3.2 Capsule-based approach

The encapsulation of the healing agent is one of the most studied approaches. In contrast to autogenous healing, the healing component is contained in microcapsules, which are added to the concrete mix. After hardening, the repair occurs when the forming crack propagates through the capsule, breaking it and releasing the healing agent, (Figure 2.2c). As a result, not only the crack propagation is blocked but also the material is repaired by filling the crack with the healing agent. The permeability is usually decreased and some regain of strength can occur (Wang et al., 2017). This method was initially applied for structural polymers (White et al., 2001). The proposed system consisted of a microcapsule with the healing agent and a catalytic chemical trigger (Figure 2.4).

4. Autogenous self-healing

According to RILEM's definition, the autogenous self-healing is a process, which occurs when the recovery of a material from damage involves only its original components (De Rooij et al., 2011). In other words, the self-healing ability of concrete and other cementitious materials is possible only due to their specific chemical composition and, in addition, under favorable environmental conditions. This phenomenon has been studied since the beginning of the nineteenth century. The healing of cracks in water retaining structures, culverts and pipes was noticed by the French Academy of Science in 1836 (Wu et al., 2012). Afterwards, many researchers not only observed the presence of autogenous healing products in the cracks of concrete but also tried to verify its physicochemical background.

5. Conclusions

The following conclusions can be formulated:

• A large amount of cement in the concrete mix does not ensure the efficient autogenous self-healing of cracks;

• A dense and impermeable binder matrix microstructure having, e.g., a low water-to-cement ratio or a high amount of silica fume, limits the transport of calcium and silicone ions to the crack thus diminishing the precipitation of healing products;

• Fly ash supports the formation of a thick layer of calcite over the crack mouth. It does not support the flexural strength recovery due to the lack (or limited) formation of healing products inside the crack, in particular the load bearing phase C-S-H;

• Calcium carbonate (cuboid crystals) forms close to the surface of the sample, at the crack mouth, whereas C-S-H and ettringite (needle-like products) develop deeper inside the crack. The formation of C-S-H and ettringite is presumably connected to the flexural strength regain. On the other hand, calcite, which does not support the recovery of the mechanical properties, is possibly responsible for the control of conditions inside the crack, e.g. helping to obtain a higher calcium and silicone ion concentration inside the crack;

• Water alone is inefficient in promoting self-healing;

• A phosphate-based retarding admixture promotes the self-healing by crack closure at the crack mouth as well as internally; the self-healing mechanism is presumably based on two processes, i.e. inhibiting the formation of a dense hydration shell on the surface of hydrated cement grains and the precipitation of calcium phosphate compounds inside the crack. Unfortunately, this exposure did not lead to the recovery of strength regain, suggesting that satisfactory internal crack closure does not necessarily contribute to the regain in mechanical parameters;

• Water mixed with microsilica particles supports an external crack closure as well as induces flexural strength regain. The silica particles possible act as nucleation sites for the formation of self-healing products.

6. FUTURE RESEARCH

The preliminary experimental results presented in this licentiate thesis, combined with previous research, demonstrated that the logical pattern of self-healing behavior of cementitious materials exists. However, several mechanisms are to be determined in order to describe fully the phenomenon under different conditions. The verification of those mechanisms requires further experimental studies, in particular:

- Fly ash appeared to have a positive influence on the efficiency of the external crack closure, therefore different mix compositions should be tested in order to confirm the effect of fly ash and slag on the external self-healing. As the strength recovery was not successful in case of fly ash blended cement, the internal self-healing should be also investigated. A systematic experimental setup should be designed which takes into consideration the effect of the amount of SCMs as well as their chemical compositions. Self-healing products’ elemental and possibly mineralogical compositions together with the spatial distribution of the precipitates inside the crack would give an insight into the self-healing mechanism;

- The density and the pore structure of the binder matrix, were hypothesized to have a significant influence on the availability of ions, e.g., calcium and silicate, inside the crack and, as a consequence, the precipitation of the self-healing products. Hence, mix compositions with varied water-to-cement ratios should be investigated. In addition, the effect of the porous network, both at micro and nano scale as well as particular types of porosity, e.g., capillary porosity, on the self-healing mechanism should be tested. Measurements of the ion concentrations inside the crack could give a deeper understanding of the process.

- Exposures containing a retarding admixture and micro silica particles significantly enhanced the self-healing efficiency, therefore more detailed studies on those exposures should be performed. Different kinds of chemical compositions and dosages of retarders could be compared. The effect of volume fractions in the exposure solution as well as micro silica grading on the self-healing efficiency should be studied. The mineralogical composition, solubility, durability and other physical properties of the calcium phosphate phase should be verified with respect to its full-scale applicability. A combination of different exposures, could be tested, e.g., a retarding admixture together with micro silica particles.

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