Analysis on Self Healing Concrete: A Review

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Abstract: In our world, Concrete is a brittle material with a low tensile strength that is prone to breaking. Crack repairs are not only costly and time-consuming, but they also add to the carbon impact. Creating a new concrete substance with the ability to self-repair fractures would increase its durability. Self-healing refers to a material’s capacity to repair internal damage without the need for external intervention. In the case of concrete, the process can be autogenous, based on an optimum mix composition, or autonomous, including extra capsules carrying some healing agent and/or bacteria spores into the binder matrix. The first method uses unhydrated cement particles as the healing material, whereas the second employs a synthetic substance or bacteria precipitating calcite that is released into the crack from a broken capsule or activated by access to water and oxygen. The primary drawbacks of the autonomous approach are the loss of fresh concrete workability, deteriorated mechanical qualities, limited efficiency, low survival of capsules and bacteria during mixing, and the extremely expensive price. Autogenous self-healing, on the other hand, was discovered to be more efficient, cost-effective, safer, and easier to deploy in full-scale systems. There is little known about the methods and essential elements that regulate autogenous self-healing. Therefore, the aim of this research work was to better understand the autogenous self-healing process of concrete and to optimize the mix design and exposure conditions to maximize its efficiency.

Keywords: self-healing, cracks, autogenous, tension etc.

I. INTRODUCTION

Concrete, along with steel, is one of the most often used structural materials. Various adjustments to concrete compositions have been proposed throughout the years in an attempt to enhance its qualities. Concrete’s environmental impact has recently been widely researched. Cutting the carbon footprint of concrete may be accomplished in two ways: changing the mix compositions, such as substituting cement with so-called Supplementary Cementitious Materials (SCM), or lowering maintenance and repair expenses. The first may be accomplished by creating concrete from waste materials such as fly ash or blast furnace slag, which are industrial byproducts, but the latter can be accomplished by engineering a material with self-healing capabilities. Possibly, it is also a combination of the two ways, by adding SCMs and improve the design.

The idea of the self-healing of tissue and bones in biological materials has always been intriguing. Mimicking natural events and systems frequently allows for the development of novel materials with intelligent behaviour. One of the most sought features in material science is self-healing, or the capacity of a material to recognize and fix internal damage without human involvement. Recently, researchers have focused on the self-healing phenomenon in cementitious materials. Concrete has a low tensile strength and is fragile. Additional...
reinforcement, generally constructed of steel, is required to improve the tensile strength of concrete. Concrete creates an alkaline atmosphere that keeps steel reinforcement from corroding. Unfortunately, according to its brittleness, concrete is susceptible to fracture as a result of drying or autogenous shrinkage in addition to external mechanical pressure. The reinforcement is exposed to acidic ions through the fissures, which causes it to corrode and ultimately deteriorate the concrete. As a result, there is a significant problem with the material’s strength.

II. AUTONOMOUS SELF-HEALING

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.

III. 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 manmade 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). 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.

IV. LITERATURE REVIEW

Various works are given on the self healing concrete which summarized are as follows-

Waiching Tang (2015): During the last decade, self-healing of concrete has attracted so much attention in the research community as a promising tool toward more durable and sustainable infrastructures. Although various self-healing approaches have been vastly studied, employment of different assessment methods in these studies has made it difficult to compare the efficiency of various self-healing mechanisms. This paper presents a review of test methods which have been commonly utilized to assess the efficiency of self-healing mechanisms in concrete. Three broad categories of assessment methods are considered, namely visualization and determination, assessment of regained resistance and assessment of regained mechanical properties. Moreover, as a pathway toward standardized evaluation of self-healing mechanisms, various assessment techniques are evaluated against four proposed essential criteria – reliability, quality of results, operational considerations and in-situ applicability.

H.M. Jonkers (2016): The innovative technology of self-healing concrete allows the material to repair the open micro-cracks that can endanger the durability of the structure, due to ingress of aggressive gasses and liquids. Various concepts of self-healing concrete have been developed, with target on the recovery of water tightness after cracking. Among those, bacteria-based self-healing concrete has shown promising results regarding the improvement of crack sealing performance. In this study, the bacteria-based healing agents incorporated into lightweight aggregates and mixed with fresh mortar. By this means, autogenous healing of concrete is enhanced and upon cracking the material is capable to recover water tightness. The study focuses on the investigation of the effect of healing agent when incorporated into the mortar matrix and the evaluation of the recovery of liquid tightness after cracking and exposure to two different healing regimes (water immersion and wet-dry cycles) through water permeability tests. It was found that the compressive strength of the mortar containing lightweight aggregates is not affected by the presence of the healing agent. The study also reveals that the recovery of water tightness does not differ substantially either for specimens with or without healing agent when immersed continuously in water. Conversely, the recovery of water tightness increases significantly for specimens containing the healing agent compared to specimens without it, when subjected to wet-dry cycles. Oxygen concentration measurements and bacterial traces on calcite formations confirmed the bacterial activity on specimens containing the healing agent.

J.Y. Wang (2014): Microcapsules were applied to encapsulate bacterial spores for self-healing concrete. The viability of encapsulated spores and the influence of microcapsules on mortar specimens were investigated first. Breakage of the microcapsules upon cracking was verified by Scanning Electron Microscopy. Self-healing capacity was evaluated by crack healing ratio and the water permeability. The results indicated that the healing ratio in the specimens with bio-microcapsules was higher (48%–80%) than in those without bacteria (18%–50%). The maximum crack width healed in the specimens of the bacteria series was 970 μm, about 4 times that of the non-bacteria series (max 250 μm). The overall water permeability in the bacteria series was about 10 times lower than that in non-bacteria series. Wet-
dry cycles were found to stimulate self-healing in mortar specimens with encapsulated bacteria. No self-healing was observed in all specimens stored at 95%RH, indicating that the presence of liquid water is an essential component for self-healing.

Rajesh Talluri (2015) : Concrete, a strong, durable material composed of cement, aggregate and water, is the most used building material in the world. Concrete has an ultimate load bearing capacity under compression but the material is weak in tension. So, it cracks under loading. That is why steel bars are embedded in the concrete for the structure to carry tensile loads. Steel bars take the load when concrete fails under tension. The concrete protects the steel reinforced bars from the environment and prevents corrosion. However, the cracks in the concrete form a major problem which affects the durability of the structures. Water and other salts seep through these cracks, corrosion initiates, and thus reduce life of concrete. So there was a need to develop a bio material, a self-repairing material which can remediate the cracks and fissures in the concrete. The goal of our study is to apply bacterially precipitated CaCO3 to heal the cracks in concrete. This technique is highly desirable because microbial activities are pollution free and natural. In this study, a Bacillus bacterium (Bacillus pasteuriior Bacillus subtilis) has been used to induce CaCO3 precipitation. This phenomenon is called Microbiologically Induced Calcite Precipitation (MICP). Use of these bio mineralogy concepts in concrete leads to invention of new material called-Bacterial concrete. Bacterial concrete is a material, which can successfully remediate cracks in concrete.

Ravindranatha : The requirement of high durability for structures exposed to harsh environment such as seafloor, offshore, tunnels, highways, bridges, sewage pipes and structures for solid, liquid wastes containing toxic chemicals and radioactive elements may not be achieved using today’s ordinary portland cement (OPC). This research gives information about the aims at increasing the strength and the total durability of the concrete used in the present day by introducing bacteria (Bacillus pasteuri). This microorganism is a soil bacterium. Bacillus pasteuri exhibits a phenomenon known as bio-calcification as a part of its metabolic activity. Bio-calcification is a process through which the micro-organism externally secretes calcium precipitate, which in the presence of a carbonate ion forms CaCO3 which fills up the voids in the concrete texture thus making it more compact. This inturn improves the strength in concrete due to growth of the filler material within the pores of the concrete mixer. A comparison study was made with concrete cubes and beams subjected to compressive and flexural strength tests with and without the bacterium. It was found that there was high increase in strength and healing of cracks subjected to loading on the concrete specimens.

Vidhya Lakshmi : The service life of the structure have reduced in today’s construction field due to the low durability, strength factors and various other properties of concrete structures exposed to the environment. A novel strategy to restore or remediate cracks formed in the structures is bio-mineralization of Calcium Carbonate using microbes such as Bacillus. This research gives the information about increasing the durability of the concrete structure by introducing bacterial cell and other required nutrients for the process of bio-calcification where the micro-organisms secrete Calcium Precipitate which in the presence of Carbonate ion forms Calcium Carbonate(Calcite) layer thus self-healing the cracks. Thus the durability of the concrete structure will increase and a study has to be carried out with concrete cubes subjected to bacterium.

Subham Ajay Puranik (2019) : Cracks formed in concrete are inescapable and are one of the major reasons for the weaknesses of concrete. Majorly water along with other components penetrate through these cracks resulting in corrosion thereby reducing the strength of concrete directly hampering its life. The objective of present research work is to promote sustainable development and to identify sustainable materials for treating cracks formed in concrete. Various researches have shown positive results by adding calcite precipitating bacteria in concrete, also known as bacterial concrete or self-healing concrete. This research is dedicated to check the suitability of mixing these self-healing calcite depositing bacteria with concrete in order to increase the compressive strength of concrete, reduce its permeability and seepage of water by bio-mineralization process. Substantial increase in strength is observed in concrete specimens when casted with bacterial solution. The study has devised methods or ways to test the effect of use of bacteria in concrete. Tests on concrete slab with various combinations of bacterial solution as well as varied percentage of bacterial solution have been conducted. Use of bacterial solution for surface application on slab to test the sealing capacity is done. Results have been compared with conventional concrete. Biological modifications of construction materials are the need of the hour for strength improvement and long term sustainability. The present study proposes a promising sustainable repair method for concrete.

Dr.K.ChandraMaouli (2018) : This experiment was conducted to investigate the properties of Bacterial concrete for constructional purposes. In addition to concrete, bacteria named BACILLUS SUBTILIS (along with its nutrients) is added to attain more strength than conventional concrete and to improve properties of concrete. Aim of the study is to test and analyse compressive strength of concrete cubes, optimum dosage of bacteria used and to study properties of cracked specimens by introducing Bacillus Subtilis, which is ureolytic, gram positive (spore forming bacteria), and facultative aerobic.

S.S.Lucas(2018) : Preparation process and life service solicitations can cause damage on concrete’s internal structure, creating cracks that tend to propagate and increase with time. This poses a risk of failure as water penetrates, corroding the rebar reducing concrete’s life span. Cement can exhibit up to a certain extent a natural ability to self-heal, consequence of the long-term hydration phenomenon. Some initial cracks can be spontaneously closed if the right conditions are met (humidity). However, it will not be enough to repair major cracks
formed internally over a long period of use, so strategies need to be developed to achieve an efficient level of self-healing. This need lead
to a new concept – self-healing. The biological approach is a suitable alternative to achieve healing in concrete. In this work, bacteria were
immobilised in expanded clay and added to concrete by aggregate replacement.

M. Monisha (2017): In this paper an overview of new development obtained in experimental study on self-healing concrete. Strength and
durability of concrete is mainly affected due to the formation of cracks. Micro cracks are the main cause for structural failure. While larger
cracks affect structural integrity, micro cracks result in durability problems. Ingress of water and chemicals can cause premature matrix
degradation and corrosion of embedded steel reinforcement. Also concrete fails due to insufficient tensile strength. In order to overcome
this, an attempt is made in Bacterial concrete with non-pathogenic, spore forming, calcite mineral precipitating bacterium “Bacillus
subtilis”. M20 grade concrete is prepared with different bacterial cell concentration of 104, 105 and 106 cells per millilitre of water and
polyethylene fibre kept at constant as 0.4%. The overall development of strength and durability of self-healing concrete using Bacillus
subtilis and polyethylene fibre has investigated and compared with control concrete. The optimum strength is obtained at 105 cells
concentration and polyethylene fibre were bridging over the crack and crystallization products became easy to be attached to a large
number of polyethylene fibre. The optimum strength is obtained at 105 cells concentration, which increases the compressive strength by
13.2%, split tensile strength by 21.4% and flexural strength by 16.04%. The percentage of increment in strength clearly shows that the self-
healing concrete is advantageous.

Er. Chetan Kumar (2020): In recent years, researches concerning the strength, toughness and the durability of cement based concrete
structures. 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. Crack formation is very common phenomenon in concrete structure which allows the water and different type
of chemical into the concrete through the cracks and decreases their durability, strength and which also affect the reinforcement when it
comes in contact with water, CO2 and other chemicals. It is costly to maintain or repair concrete based structures time to time. For
resolving this problem self-healing concrete mechanism is introduced in the concrete which helps to repair the cracks by producing
calcium carbonate crystals which block the micro cracks and pores in the concrete. Self-healing concrete is classified into two parts:

Ishraq Mohammad Ali Khattab (2019): The most popular treatment for concrete structure is self-healing method to enhance the
durability of concrete. The relevance between cracks and conceivable self-healing method is sophisticated and environmentally considered.
This current paper a review on biological, natural and chemical mechanism of self-healing concrete was deeply evaluated from past journal
was published about them and the main purposed of this paper as focuses on biological processes of self-healing concrete. The data
introduced in current study as huge substantial for bioprocess and biotechnologists engineer to provide useful details on present condition
of self-healing concrete.

Ali Keyvanfar (2014): Self-healing concrete technologies were completely reviewed. The main
focus of the study is for the biological processes. The review presents a new insight into the research for the treatment of unexpected
cracking of concrete. The information presented in this paper can be considered significant for biotechnologists and bioprocess engineers
to have comprehensive updates on the current status-quo of self-healing concrete.

Salmabanu Luhar (2015): Crack formation is a very common phenomenon in concrete structure which allows the water and different type
of chemical into the concrete through the cracks and decreases their durability, strength and which also affect the reinforcement when it
comes in contact with water, CO2 and other chemicals. For repairing the cracks developed in the concrete, it requires regular maintenance
and special type of treatment which will be very expansive. So, to overcome from this problem autonomous self-healing mechanism is
introduced in the concrete which helps to repair the cracks by producing calcium carbonate crystals which block the micro cracks and
pores in the concrete. The selection of the bacteria was according to their survival in the alkaline environment such as B. pasteurii, Bacillus
subtilis and B. sphaericus which are mainly used for the experiments by different researchers for their study. The condition of growth is
different for different types of bacteria. For the growth, bacteria were put in a medium containing different chemical at a particular
temperature and for a particular time period. Bacteria improves the structural properties such as tensile strength, water permeability,
durability and compressive strength of the normal concrete which was found by the performing different type of experiment on too many
specimens had varying sizes used by different researchers for their study of bacterial concrete in comparison with the conventional
concrete and from the experiment it was also found that use of light weight aggregate along with bacteria helps in self healing property of
concrete. For gaining the best result a mathematical model was also introduced to study the stress-strain behavior of bacteria which was
used to improve the strength of concrete.
V. CONCLUSION

Overall, it is recommended to conduct the research mentioned above to see if the encouraging outcomes related to self-healing mortar that have been described in the literature correlate with concrete proportionately. Additionally, it is necessary to investigate the elements that, whether by a different encapsulation process, nutrient choice, curing regimen, or bacterial strain, may enhance the self-healing mechanism of bio concrete through direct application of bacteria.

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