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Bacterial Concrete – A Review

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ABSTRACT

Concrete is the most widely used building material, in concrete cracks are inevitable due to its inherent vulnerability. Concrete has a poor tensile strength, which causes micro-cracks when the pressure applied exceeds the limit, allowing water and other salts to enter inside. This kind of damage happens early in a building's life and later in its existence. Several repairing techniques are available to repair the cracks. But they are incompatible, expensive, and need constant maintenance. In recent years, concrete bio mineralization has been developed to treat cracks. In this paper, literature study will assess the benefits and disadvantages of various methods. The scientific background that influenced the choice of microbe and metabolic pathway was also considered.

1. INTRODUCTION

Concrete is produced from natural elements like coarse and fine aggregate, with cement paste serving as a binding agent. It is considered to be only second to water in terms of consumption. Concrete is used in around 80% of all building projects throughout the globe. This chapter examines the different research studies undertaken by the scientific community as well as published work in the area of bacterial concrete.

Because of the microbial participation in carbonate precipitation, this process is being investigated for building materials. Bio-deposition was one of the earliest patented uses for protecting decorative stone. Its success prompted other research organizations to explore other methods, each defending their own bacterial strain or methodology as the best. This literature study will assess the benefits and disadvantages of various methods. The scientific background that influenced the choice of microbe and metabolic pathway was also considered.

2. LIST OF LITERATURES REVIEWS

S. Reid and S. Sedra [1]: The Pickett effect is usually associated to shrinkage-induced cracking in drying concrete (producing apparent drying creep effects). Eccentrically loaded columns showed no significant impacts of actual drying creep. However, numerical simulations have demonstrated that shrinkage-induced cracking may decrease apparent shrinkage stresses and increase apparent drying creep. However, such softening effects do not match the reported size impact for shrinkage stresses of geometrically identical materials. Using a mix of strain-softening and rapid moisture diffusion for fractured concrete would simulate the observed shrinkage size effect, but not the drying-creep effect.

Suvash Chandra Paul & Adewumi John Babafemi, 2017 [2]: SHCC dampers improve structural safety by decreasing RC shear wall response drift. SHCC lining to enhance tunnel tensile performance, SHCC overlay patch repair and link slab retrofit in bridge deck, Steel protection against carbonation, R/SHCC in tall structure construction coupling beams.

NasirZakari Muhammad, 2016 [3]: He reviewed the research, testing, and techniques of self-healing concrete. His paper suggests that microbial generated calcium carbonate precipitation may be utilised to prolong the durability of concrete through self-healing fissures. Although many studies have been done on this subject, thorough assessments of self-healing ability at macro, micro, and nano-scales are still needed. The techniques used to measure self-healing concrete are not widely established. The following are methodological flaws documented in literature: Inability to define self-healing efficiency, Inability to define self-healing efficiency, Insufficient study on healed crack length, Inadequate study on cracked healed depth, Unaddressed issue of fracture healing speed vs concrete age Absence of quantitative data on the concrete-deposit bonding strength. The above is based on the authors' observations, with more to come. While the tendency to develop new self-healing methods is growing, establishing self-healing efficiency is critical to future researchers' success.

S. A. L. de koster, 2016 [4]: Steel reinforcement strengthens the concrete's tensile strength. Concrete cracks due to excessive tensile strains. These cracks let water or other material enter into the concrete, causing damage. This causes concrete deterioration, corrosion, and permeability. Crack repairing is labour demanding and inefficient. So, early cracks should be self-healing from within, avoiding water intrusion.

Concrete may be healed by adding healing solutions including nutrients and bacterial spores. When water is present, the bacteria fill cracks with calcium carbonate. During mixing, a coating is required to preserve the water-soluble healing agent. This layer should shatter anytime a breach in the concrete develops to give bacteria access to water for activation. So it should stick to the concrete matrix effectively. This may be achieved by covering the particles with brittle geo-polymer.

C. De Nardi, S. Bullo, A. Cecchi& L. Ferrara, 2016 [5]: Traditional lime mortars may be self-healing by adding fresh chemicals and ingredients, allowing them to repair mechanical damage. Self-healing may occur at both microscopic and macroscopic levels, and can be triggered by a dispersed phase created by a mechanical damage. An impermeable covering surface protects part of the lime, making it inactive throughout the stages of setting and hardening. The mechanical properties of this material are compared to those of a normal mortar. When the material is stressed, the treated lime granules' protective covering should break, triggering another phase of setting and hardening in the material rendered dormant by the same treatment. The delayed hydration response will therefore help seal the cracks caused by the applied force. The study seeks to determine if this material can be used in structural applications due to its endurance.

RafatSiddique [6], 2016: Concrete must be durable based on the exposure environment and desired characteristics. Compressive strength, modulus of elasticity, creep and shrinkage are all examples of technical characteristics that are required for concrete to be durable. Concrete is durable when it has strong graded aggregate, minimal contaminants such as alkalies, chlorides, sulphates, and silt, a thick structure. Concrete cracking also impacts the concrete's structural integrity and durability. The cost of repairing and maintaining concrete buildings reflects the effect of durability issues on national economies. The cost of repairing and maintaining concrete highway bridges due to reinforcing corrosion is approximately $4 billion yearly in the US. Traditionally, sealing agents like latex emulsions fill holes and fractures, reducing permeability, but they have significant drawbacks including unsuitable interfaces, UV sensitivity, unstable molecular structure, and high cost.

Chung-Chan Hung [7], 2016: Many researchers have demonstrated that young Engineering Cementations Composites (ECCs) may self-heal. This research examines the self-healing performance of ECC cracks in the medium and long term phases of material service life. Pre-cracked ECC specimens are used for this purpose. The fly ash weight fraction in ECCs (1.2, 1.6, or 2.0) and the healing time are the main experimental variables (7, 28, or 90 days). This is measured via a resonant frequency test followed by a uniaxial tensile test. SEM and energy dispersive X-ray studies are also used to examine the microstructure of the repaired crack and determine the medium-term healing product. The findings show that ECCs may partly regain their tensile mechanical characteristics as long as water is present in the environment. For ECCs with a pre-strain of less than 1%, effective medium-term self-healing performance may be obtained in 90 days.

C. De Nardi [8], 2016: Traditional lime mortars could be self-healing by adding fresh chemicals and ingredients, allowing them to repair mechanical damage. Self-healing may occur at both microscopic and macroscopic levels, and can be triggered by a dispersed phase created by a mechanical damage. An impermeable covering surface protects part of the lime, making it inactive throughout the stages of setting and hardening. The mechanical properties of this material are compared to those of a normal mortar. When the material is stressed, the treated lime granules' protective covering should break, triggering another phase of setting and hardening in the material rendered inactive by the same treatment. The delayed hydration response will therefore help seal the fractures caused by the applied force. The study seeks to determine if this material can be used in structural applications due to its endurance.

J. Feiteira [9], 2016: Self-healing concrete is designed to self-heal tiny cracks up to a few hundred micrometres wide. Due to their high stiffness and brittleness, CaCO3 and rigid polymers have been used extensively in previous studies to fill static cracks. These results show that flexible polymers may bridge repaired fractures and therefore be used to heal moving cracks. The polymers examined are the result of discharging and curing encapsulated polymer precursors, and have varied viscosity, foaming, and mechanical characteristics following hardening. The experiments identified precursors with high fracture-filling capability, leading to effective crack sealing. Despite successful sealing, mechanical stiffness recovery is restricted to 30% for crack mouth displacements up to 20 lm. The widening of healed fractures that did not affect sealing ability was between 50% and 100% of their original width owing to failure in the polymer matrix or at the crack wall interface. By increasing the endurance of fractured concrete components under cyclic loading, the sealing action may be disturbed for long term expansion of actual fractures owing to fatigue.

MianLuo [10], 2015: The fast growth of ready-mixed concrete is an essential indicator of concrete technical advancement and overall quality improvement, but it has introduced several new issues. The most serious issue is the increased likelihood of cracking induced by non-load causes such as shrinkage cracks, thermal cracks, and chemical reaction fissures as a result of the low tensile strength of concrete. Cracking increases the likelihood of hostile chemicals infiltrating the concrete, compromising its durability. Typically, cracks are repaired by hand, which is inefficient since cracks are frequently difficult to detect and maintenance and repair costs are expensive. As a result, self-healing of fractured concrete would be very useful, and much research on self-healing concrete has been conducted.

Zeynep Basaran Bundur, 2015 [11]: Microorganisms promote the production of minerals such as carbonates. The resulting precipitates from MICCP may be used to bind particles (e.g., sand and gravel) together to create a composite material and/or seal and plug cracks in concrete. A “bio-calcified” concrete would autogenously repair fractures produced in the matrix phase by precipitating carbonate minerals. Based on limited study, 1it seems that bio-mineralization may substantially decrease permeability by filling surface cracks in cement-based systems (e.g., sealing fractures, recovering toughness, and increasing compressive strength).

MianLuo, 2015 [12]: Because bacteria-based self-healing concrete is a novel technology, it is critical to collect additional data in controlled environments before using it widely. Concrete crack-healing ability has been improved by bacteria-induced mineral precipitation in recent years. Many variables affected concrete crack self-healing ability. The self-healing effect was studied in various circumstances to identify the relevant parameters. The potential of microbial healing agent was restricted for specimens with fracture width up to 0.8 mm. Moreover, the specimens' crack healing ratio decreased with increasing cracking age. The crack healing ratio was low when the cracking age was above 60 days.

Yusuf Çag˘atayErsan, 2015 [13]: Self-healing concrete applications have studied utilizing bacteria that can precipitate calcium carbonate. Concrete's harsh environment (high pH, tiny pore size, and dry conditions) requires protective methods/materials to preserve bacterial agents. To assess commercial materials as alternatives, they must be thoroughly screened. When combined with either Bacillus sphaericus spores or Diaphorobacternitroreducens and their respective nutrients, diatomaceous earth (DE) and metakaolin (MET) were tested for their influence on mortar setting and compressive strength. The impact of two new self-protected bacterial agents was also studied. The results confirm that the added bacteria is capable to heal the cracks.

Yusuf Çag˘atayErsan, 2015 [14]: The interactions between concrete structures and biological beings are becoming more essential for concrete structure durability. To create self-healing concrete structures, researchers are studying bacteria that may precipitate CaCO3. Bacterial vegetative cells trapped in silica gel and polyurethane showed significant biological activity and could repair concrete cracks up to 0.4 mm. Moreover, microencapsulated bacterial spores may cause CaCO3 precipitation sufficient to fill 1 mm cracks.

Y. Zhang, H.X. Guo, 2015 [15]: MICP is the result of a sequence of metabolic processes. Microorganisms generate urease in the urea hydrolysis environment. In an alkaline environment, ammonia and carbon dioxide are transformed to ammonium and carbonate ions. The negatively charged bacteria absorb calcium ions. Carbonate ions combine with calcium ions in the environment to form calcium carbonate crystals with the cell as the nucleus. This technique has been used to restore the surface of old structures, treat heavy metals in soil, fix defects in construction materials, and enhance soil mechanical characteristics and permeability. MICP has been shown to enhance the strength and durability of damaged concrete, offering a novel technique for repairing concrete cracks.

M. Roig-Flores, 2015 [16]: The self-healing rate, derived from the results of the modified permeability test developed in this study, is a valid indication of durability property recovery. When comparing flow with the averaged crack area (Amm2) or the averaged crack width, the crack geometry parameters assessed via image analysis exhibit a clear relationship with the water flow findings (w_{avg}). These characteristics may be used as an alternative to water permeability testing. Their dispersion as healing indicators, on the other hand, is high for control specimens. Concrete has an intrinsic healing ability known as autogenously healing, which may occur in common concrete components, although its efficacy is limited and unpredictable. Neville first noted these phenomena and suggested the reasons of autogenously healing in 1981.

J.Y. Wang, 2014 [17]: To encapsulate bacterial spores for self-healing concrete, microcapsules were used. First, the viability of encapsulated spores and the effect of microcapsules on mortar specimens were examined. Scanning Electron Microscopy was used to confirm the breakage of the microcapsules during cracking. The fracture healing ratio and water permeability were used to assess self-healing capability. Microbial CaCO3 is regarded as an environmentally friendly and cost-effective material with a wide range of engineering applications, such as consolidation and protection of concrete and stone surfaces, repair of defects and flaws (specifically, cracks), cementation or consolidation of loose particles (specifically, soil and sands), and so on.

M. Guadalupe Sierra-Beltran, 2014 [18]: The bio-based agent in the SHCC is composed of bacteria as well as food for the bacteria. Oxygen profile measurements were used to track the metabolic activity of bacteria, revealing that bacteria-based samples use more oxygen than control samples. The mortar's mechanical characteristics are assesse18d (flexural behaviour, compression strength, and drying shrinkage). Pull-out tests and restricted shrinkage are used to assess the bonding behaviour with the concrete substrate.

F. Pacheco-Torgal, 2013 [19]: The degradation of reinforced concrete buildings is a frequent occurrence owing to the material's high permeability, which enables water and other aggressive media to enter, resulting in corrosion issues. Sealers are a popular method to increase the durability of concrete. The Construction Products Regulation, Regulation (EU) 305/2011, stresses the need to eliminate hazardous chemicals. As a result, new low-toxicity forms are required to improve concrete durability. Recent biotechnology research has shown the promise of bio-inspired materials in the creation of low-toxic treatments.

H.K. Kim, 2013 [20]: In this study the effect of curing of samples in bacterial medium has been studied. The samples are cured in normal water and in bacterial medium. The bacterial medium has been prepared with B. Sphaericus bacteria and S. Pasteurii bacteria. The results were compared. The SEM, XRD and ED's tests has been performed to know formation of calcite crystals. Results of this investigation confirm that the samples cured in B. sphaericus medium develops dense calcite layer than the samples cured in S. Pasteurii medium. Moreover, the concrete specimens treated by the medium with B. sphaericus showed the lowest weight increases per unit area.

Varenyam Achal, 2013 [21]: Biologically precipitated calcite is a natural process that technique was widely utilized to remediate the cracks in concrete. In study the effect of Bacillus sp. Bacteria on performance of concrete has been evaluated. Findings of this investigation confirm that there is a 50% of diminution porosity of concrete. Also, the chloride ion permeability test results of concrete are changed from moderate to very low. The durability of concrete considerably improves by the addition of Bacillus sp. Bacteria in concrete.

Navneet Chahal, 2012 [22]: The effect of S. Pasteurii bacteria on performance of concrete has been investigated in this study. The experimental work involves compressive strength, water absorption, and chloride ion permeability of concrete. The results of the bacterial concrete are compared with the normal concrete. The findings of this investigation suggests that the addition of bacteria in concrete. The bacteria modified concrete increases the strength of concrete as compared to control mix. Also, the water absorption and chloride ion permeability results also confirm the use of bacteria in concrete.

Jochen Stark, 2011 [23]: Hydration of cement is the result of chemical and physical reactions that occur when anhydrous cement is mixed with water. Whereas clinker mineral and admixture chemical reactions are important, the other aspects like agglomeration, adsorption, evaporation, and thermal energy release are also significant. The majority of knowledge about these processes comes from experimental research, with some theoretical modelling studies assisting to clarify the underlying concepts.

Afifudin, H, 2011 [24]: The silicate precipitation was produced when the untreated Bacillus subtilis was incubated in the silica solution for 10 days. There seemed to be no difference in the quantity of Si adsorbed by untreated Bacillus subtilis versus chemically manipulated Bacillus subtilis (CMBS). It has been discovered that incorporating Bacillus subtilis into concrete improves compressive strength. The improvement was discovered to be noticeable for those made of 106 cells/ml. When a concentration of 10^6 cells/ml of Bacillus subtilis was added, the compressive strength increased by about 28% when compared to that without the addition of Bacillus subtilis.

Jianyun Wang, 2011 [25]: Concrete cracks are the primary cause of concrete structure failure. It is thus better and cheaper to prevent micro-cracks from occurring than to fix them after they have grown into large cracks. A potential method is to pre-add healing chemicals to the concrete to repair early age cracks as they develop. In addition to polymeric healing materials, bacterial CaCO3 precipitation may be utilized for self-healing. It is more environmentally friendly and compatible with concrete. The pH of concrete environment increases with the bacterial activity. The findings of this investigation suggest using the bacteria in concrete.

Kim Van Tittelboom, 2010 [26]: Cracking is a frequent occurrence in concrete owing to its low tensile strength. External loads, forced deformations, plastic shrinkage, plastic settlement, and expansive reactions cause high tensile stresses. The cracks may likely to expand further if not treated properly. These fractures also reduce the durability of concrete because they offer an easy path for the passage of liquids and gases that may contain hazardous chemicals. If micro-cracks extend to the reinforcement, not only will the concrete be damaged, but the reinforcement will also corrode when exposed to water, oxygen, and potentially carbon dioxide. As a result, micro-cracks are precursors to structural collapse.

Séverine Anne, 2010 [27]: The major cause of historical building degradation is water infiltration through micro-cracks. To prevent or reduce this impact, several surface treatment methods have been suggested. The utilization of certain bacteria's carbonatogenesis technique as an alternative to chemical treatments is one option. In an aqueous environment, this bacterial technique has been shown promising results. However, carbonate production was assessed indirectly, and the experimental methodology was distant from realistic usage circumstances. In this work, authors demonstrated the structural and morphological development of the carbonate coating generated on model plaster samples utilizing the same procedure as an industrial one and a surface selective research technique, grazing incidence X-ray diffraction. This substrate was selected to detect bacterial carbonate production clearly.

Willem De Muynck, 2008 [28]: Surface treatments are critical in protecting building materials from the intrusion of water and other harsh chemicals. Because of the undesirable side effects of certain traditional methods, bacterial driven carbonate mineralization has been suggested as a new and environmentally acceptable approach for stone and mortar protection.

3. SUMMERY

The objective of this summary of literature review is to provide in-depth overview of the different micro-organisms used to repair cracks in concrete also, the method of application of bacteria in concrete. Alternative methods of obtaining a protective coating of calcium carbonate on the surface of building materials have been investigated by various research groups are also briefly discussed. Until recently, most of the work on bio-deposition has been done in Europe, whereas much of the work on concrete crack repair has been done in the United States. Researchers in China are looking into using microbially generated carbonate precipitation for the repair of old masonry structures and the preservation of concrete surfaces. There is a need to develop alternate bacteria to use in concrete to heal the cracks in buildings exposed to Indian atmosphere.

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