Research Status and Progress of Concrete Crack Self-Repairing Technology

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Abstract. This paper analyzes the causes of concrete cracks and discusses concrete self-healing techniques to solve concrete crack repair problems, i.e., self-healing by bacteria, self-healing by mineral admixtures, and self-healing by adhesives. Self-healing techniques can greatly reduce the economic and environmental costs of concrete production. This paper analyzes three specific self-healing methods and their advantages and disadvantages, and evaluates the effectiveness of the self-healing technology in dealing with concrete cracks, gives a method for evaluating the repair quality of cracks, and looks forward to the development prospect of the self-healing technology for concrete cracks.

Keywords: Self-healing by bacteria, Concrete cracks, Restoration evaluation.

1. Introduction

Concrete is the most extensively utilized artificial building material in the world [1]. Cracking of concrete structures is a common problem that reduces the durability and safety of structures and reduces the service life of buildings. Meanwhile, cracks in the concrete can increase over time. Cracks in concrete is a significant problem for a number of reasons. Environmental causes, material variables, or structural issues, such as heat stress, creep (a type of deformation which occurs because of sustained loading), drying shrinkage, or general loads under service-ability conditions, are commonly responsible for cracks in concrete buildings [2]. Concrete has one fundamental flaw: low tensile strength owing to load fluctuation, which invariably results in fracture formation. As a result, cracks enable liquids and corrosive chemicals to permeate, which can cause corrosion of embedded steel, lowering concrete strength and shortening its service life. It is therefore a challenge to use various methods to repair cracks to ensure their integrity over the long term. Concrete self-healing technology is a technology that can repair cracks automatically under certain conditions. It can control structural damage to a minimum and improve the durability and safety of concrete structures. This essay will discuss three kinds of self-healing techniques based on current literature survey to solve the problem of concrete crack repair: (i) self-healing based on bacteria, (ii) self-healing based on mineral admixtures, and (iii) self-healing based on adhesive agents [3]. It will argue that self-healing based on bacteria is the most innovative invention, which has good healing effect and development prospect.

2. Concrete crack self-repairing technology

2.1. Advantages and disadvantages of crack self-repairing techniques

Concrete self-healing technology is necessary and has many advantages. Concrete has the natural ability to heal cracks automatically to a certain extent by hydrating unhydrated cement particles in the presence of water, but this can only fill cracks smaller than 0.05mm and other means of repair are required [4]. The majority of procedures for mending microscopic cracks involve hand filling with chemicals such as epoxy resin, acrylic resin, and organosilicon based polymers, which are typically incompatible with concrete, expensive, and environmentally hazardous. The use of concrete self-repair technology can reduce the cost of crack repair to a certain extent, improve the sustainability of concrete structures, reduce the carbon footprint of the construction industry by reducing greenhouse gas emissions from concrete production, and contribute to sustainable development.

2.2. The self-healing technology based on mineral bacteria

One technique that has performed well in self-healing concrete research is self-healing based on bacteria. It is to use bacteria to promote the precipitation of calcium carbonate in cracks. The entering water activates the particular bacteria inserted when a crack occurs. Calcium carbonate precipitates into concrete fractures during the self-repair process due to bacterial metabolic activity. The bacteria go into dormancy once the crack is entirely filled with calcium carbonate. Bacteria operate as a long-lasting healing agent through a mechanism known as Microbiologically Induced Calcium Carbonate Precipitation (MICP) [5]. Calcium carbonate precipitation can be induced by a number of metabolic routes, including urea hydrolysis and organic acid oxidation. Urea is catalyzed by urease to breakdown into carbonate and ammonium when bacteria capable of producing urease are added, raising the pH and carbonate concentration in the bacterial environment, and precipitating into calcium carbonate in the presence of calcium ions. Bacteria were discovered to have a favorable influence on the compressive strength of Portland cement mortar pipes and concrete. Bacteria can increase the strength of rice husk ash concrete by up to 24%, while *Sporoscarcina Pasteurii bacteria* can also increase compressive strength by up to 22% by reducing porosity and permeability. According to the present findings, bacteria-based self-healing technology is cost-effective, ecologically benign, and capable of increasing the durability of building materials. However, although the concept has shown promising results in the lab, it still needs to be tested further. The added bacteria should be resistant to alkaline conditions. It is also necessary to protect bacteria from the decreasing living space during the cement hydration process to increase the life of bacteria.

Bacteria used to promote self-healing in concrete can be applied in concrete in two ways: direct application and encapsulation. The healing agent was applied by direct method to find the optimal concentration of bacteria for strength purposes, the optimal concentration being 30×10^5 cfu/mL. The direct method of adding bacterial spores to concrete is a biological activity that does not cause contamination, but requires some protection for the bacteria, and this method needs to meet many prerequisites. An example of an encapsulation approach is the encapsulation of bacterial spores in microcapsules. Once the crack ruptures the embedded microcapsule, bacterial spores are released into the crack surface by capillary movement, protecting the closure of nearby cracks. The encapsulation method shows that it has good self-healing efficiency relative to crack closure and calcium carbonate precipitation due to the uniform distribution and protection of bacteria in alkaline environment. However, this method is complex, difficult to cast, and sometimes the healing agent does not release well.

2.3. The self-healing technology based on mineral admixture

The self-healing technology based on mineral admixture is also a new method to solve the problem of concrete crack repair. During the mixing phase, mineral admixtures that might react with water are added to the concrete. When cracks form, water enters the fissures and reacts with the mineral admixtures, filling the crevices with the reaction products. Mineral admixtures for self-healing can currently be divided into two categories: expansive additive and crystalline additive . When expansive additives (e.g., calcium sulfoaluminate, anhydrite and free lime) are used, the volume of the reaction product is greater than the volume of the mixture itself, thus filling the crack. The composition of the crystallization additives can react with $Ca(OH)_2$ to form crystalline products to repair cracks. Mineral admixtures have various advantages when used as self-healing agents. Some minerals, for example, can react aggressively with water, and crack self-healing occurs quickly. However, mineral mixes employed as self-healing agents have several technical issues. Minerals that are put directly to the concrete mixture without any protection will begin to react as soon as they come into contact with water during the concrete pouring process. As a result, the additional minerals are utilized prior to breaking, a weakness that is difficult to solve. Furthermore, when utilizing expansion additives, excessive expansion may cause damage.

2.4. The self-healing technology based on adhesives

There is another self-healing technique that is based on adhesives. It means adding an adhesive to concrete. When cracks appear in the concrete, different bonding components are released and come into contact with each other, acting and hardening to repair the crack. These adhesives can be one-component or two-component, or even multi-component. However, the chemical behavior of the adhesive released is not the same as that of concrete, and the ratio of adhesive added cannot be controlled or the optimal mixing ratio can be found, which could lead to worse cracks in the future (ibid.).

The final method of repairing cracks in concrete discussed here is to use the bacteria-based concrete self-healing technique. This approach is easier to implement and more environmentally friendly. Instead of adding mineral mixes and adhesives to concrete that are not raw materials, adding bacteria to encourage the precipitation of calcium carbonate to repair cracks is the best option. In addition, bacteria in concrete can not only repair cracks, but also improve the mechanical properties of concrete such as compressive strength and tensile strength.

3. Evaluation criteria and methods for key technologies of self-repairing concrete

3.1. Detection and evaluation of crack closure rate

For self-repairing concrete, the crack closure rate, as a key evaluation index, aims to accurately reflect its ability to effectively fill and close structural cracks. First, at the microscopic level, the filling condition of repair materials inside the cracks can be clearly observed by using advanced imaging techniques such as optical microscope, scanning electron microscope (SEM) and ultrasonic inspection means, and the percentage of crack closure can be calculated by precise image analysis algorithms. At the macro level, the change in crack width during mechanical property testing of concrete specimens before and after repair or real-time monitoring of the crack closure process using high-precision measuring equipment ensures an effective measurement of the crack closure rate.

3.2. Quantitative indicators of load-carrying capacity restoration effect

The load-carrying capacity restoration effect is the core index to measure whether the self-repairing concrete can effectively restore the original load-carrying performance of the structure. The quantification of this index is mainly realized by mechanical property tests and structural performance simulations. Among them, the degree of load-bearing capacity restoration can be quantitatively analyzed by comparing the changes in the mechanical properties of concrete specimens before and after repair in terms of compressive, flexural and tensile resistance. At the same time, numerical simulation techniques, such as finite element analysis, are used to simulate the force behavior of the repaired concrete structure under actual engineering conditions, and then to determine the efficiency and reliability of its load-carrying capacity restoration.

3.3. Evaluation system for durability improvement

The durability evaluation system of self-repairing concrete is constructed with the aim of comprehensively examining its durable and stable performance under various severe environmental conditions. This system includes the assessment of the multi-dimensional performance of concrete against freeze-thaw cycles, chloride ion erosion, carbonation, and prevention of corrosion of steel reinforcement. By carrying out a series of laboratory environment simulation tests, such as rapid freeze-thaw test, salt spray corrosion test and carbonation depth determination, as well as professional tests such as chloride ion diffusion coefficient and electrical resistivity on the permeability of self-repairing concrete, the effect of durability improvement can be analyzed in depth. In addition, long-term tracking and monitoring of actual service is also an indispensable part, which helps to obtain

first-hand data on the evolution of the long-term performance of self-repairing concrete in real environments.

3.4. Consideration of Economy and Environmental Sustainability

When promoting the application of self-repairing concrete technology, its economic and environmental sustainability are also of paramount importance. The economic evaluation involves the cost analysis of the whole life cycle of self-repairing concrete, including the cost of raw materials, production process, construction difficulty, expected service life, and maintenance costs, etc., to demonstrate its economic benefits compared with traditional concrete through the whole life cycle cost analysis (LCCA). On the other hand, environmental sustainability not only focuses on energy consumption, emissions and waste management during the production process, but also examines the environmental benefits of saving maintenance frequency and extending the service life due to the self-healing function. Through the life cycle environmental impact assessment (LCA), the contribution of self-repairing concrete to environmental protection and resource saving is fully revealed, and its development towards a greener and more sustainable direction is promoted.

4. Conclusion

In conclusion, the causes of concrete cracks have been analyzed, and the self-repair technology has been discussed to solve the problem of concrete cracks repair, i.e., the self-healing based on bacteria, the self-healing based on mineral admixtures and the self-healing based on adhesives. Self-healing technology can greatly reduce the economic and environmental costs of concrete production. This essay analyzes three concrete self-healing methods and their respective advantages and disadvantages, and evaluates the effectiveness of self-healing techniques in treating concrete cracks. It is worth noting that while all self-healing mechanisms are effective to some extent, the most effective method of repairing cracks in concrete discussed here is to use the bacteria-based concrete self-healing technique. This approach is easier to implement and more environmentally friendly. Instead of adding mineral mixes and adhesives to concrete that are not raw materials, adding bacteria to encourage the precipitation of calcium carbonate to repair cracks is the best option. In addition, bacteria in concrete can not only repair cracks, but also improve the mechanical properties of concrete such as compressive strength and tensile strength. Although the technology has been extensively studied, further testing is needed to apply it to concrete production around the world.

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