AN REVIEW ARTICLE ON EFFICIENCY OF SELF HEALING CONCRETE

Abstract

Concrete is a vital component in the construction industry, and we employ a variety of materials, techniques, and processes to achieve durable and sustainable concrete. Despite taking precautions during the mixing, casting, and curing stages, cracks in concrete are an unavoidable occurrence. Numerous factors, such as temperature variations and heavy loads, can contribute to crack formation in structures. These cracks can lead to increased seepage, which in turn results in the corrosion of reinforcement, reduced durability, and shortened lifespan of the structure. Currently, epoxy systems and acrylic resins are utilized to repair cracks, but these methods are not environmentally friendly. Moreover, physical maintenance at challenging locations like high-rise buildings, basements, or underwater structures is impractical and poses significant safety risks. In such scenarios, the implementation of self-healing concrete proves to be highly beneficial.

Keywords: Self-healing concrete, Cracks in concrete, Durable and sustainable concrete, Epoxy systems, Acrylic resins, Reinforcement corrosion.

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I. INTRODUCTION

Concrete is a widely used construction material known for its strength and durability. However, it is prone to developing cracks over time due to factors like loading, temperature changes, and environmental conditions. Concrete is an incredibly adaptable building material, and as the economy and people develop, so does consumption (Miller and Moore, 2020). Structures made of concrete are prone to cracking during the course of their useful lives, whether from tensile loads or from deteriorating weather resistance. Due to their astronomically high prices, concrete structure repairs are frequently cause for anxiety, particularly in wealthy nations with extensive ageing infrastructures(Anon n.d.).These cracks compromise the structure's integrity and allow moisture and aggressive substances to seep in, leading to further damage(Kumar et al. 2020). To address this issue, researchers have developed self-healing concrete, which can autonomously repair cracks and extend its service life. Inspired by biological systems, self-healing concrete incorporates healing agents within the concrete matrix. These agents can be encapsulated polymers, bacteria, or reactive materials. When cracks form, these agents are released and fill the voids, restoring the material's strength and functionality(Kumar and Singh 2019). Microencapsulation is a key technique, where the healing agents are enclosed within microscopic capsules dispersed throughout the concrete mixture. The capsules rupture upon crack propagation, releasing the agents to initiate the healing process. Progress has been made in developing self-healing concrete, with various healing agent systems and mechanisms being explored. Extensive laboratory experiments and real-world applications have studied its mechanical properties, durability, and long-term performance. However, challenges remain in optimizing healing efficiency, ensuring compatibility, and scaling up the technology for practical use(Roy, Kumar, and Kumari 2021). Economic viability and long-term performance in real-world scenarios also need thorough assessment. Overall, self-healing concrete shows great potential in reducing maintenance costs and prolonging the service life of concrete structures by autonomously repairing cracks. Further research and development are needed to overcome challenges and fully realize its benefits in the construction industry.

II. WHY SELF HEALING CONCRETE?

Self-healing concrete has emerged as a groundbreaking technology in the construction industry, offering autonomous crack repair and enhancing the durability and sustainability of structures. By incorporating self-healing mechanisms like microencapsulation or bacterial-based systems, this innovative material can automatically repair cracks, extending the service life of concrete structures and reducing maintenance costs. Self-healing concrete saves resources, minimizes material waste, and contributes to the sustainability of the built environment(Kumar et al. 2021). It also improves structural resilience by maintaining the concrete's strength and load-bearing capacity, enhancing its ability to withstand environmental and mechanical stresses. Extensive research has been conducted to develop effective healing agents, encapsulation techniques, and activation mechanisms, while evaluating the mechanical properties and long-term performance of self-healing concrete. However, challenges remain in terms of cost-effectiveness, scalability, and long-term reliability(Roy and Kumar 2021). Ongoing efforts focus on optimizing production processes, exploring affordable healing agents, and ensuring practical application in various environmental conditions and construction scenarios. Overall, self-healing concrete holds great promise for revolutionizing the construction industry and advancing the longevity and sustainability of concrete structures.

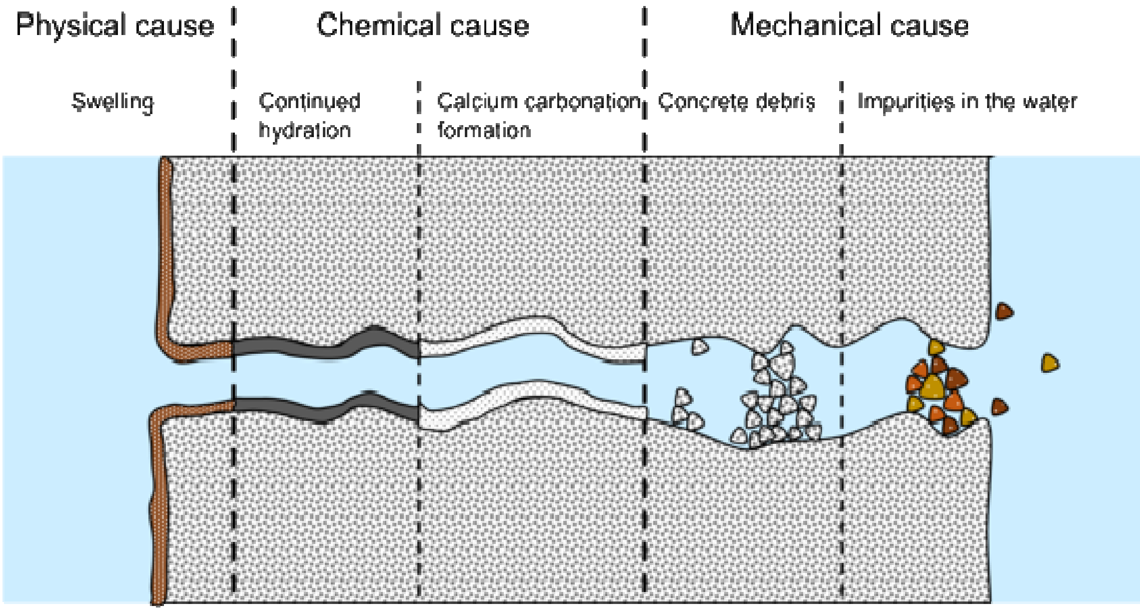

Figure 1: Autogenous self-healing mechanism
(Source: https://en.wikipedia.org/wiki/Self-healing_concrete)

III. COMPOSITION AND PROPERTIES OF SELF HEALING CONCRETE

Self-healing concrete is a groundbreaking material that can autonomously repair cracks and restore structural integrity. It consists of a cementitious matrix, healing agents, and activation mechanisms. The cementitious matrix includes cement, aggregates, and water, providing the base for the concrete. Healing agents play a vital role in self-healing concrete and can be categorized as microencapsulated or bacterial. Microencapsulated healing agents are contained within capsules dispersed in the concrete. When cracks occur, the capsules rupture, releasing the healing agents to seal and fill the cracks. Bacterial healing agents remain dormant within the concrete until cracks form. When exposed to moisture from the cracks, the bacteria become active and produce calcium carbonate, which seals the cracks and promotes healing. Activation mechanisms vary depending on the type of healing agent used.

Mechanical stress triggers the rupture of microcapsules, while moisture activates bacterial healing agents. Self-healing concrete possesses desirable mechanical and durability properties. It exhibits compressive strength comparable to traditional concrete, ensuring structural integrity and load-bearing capacity. The crack healing efficiency quantifies the percentage of successfully repaired cracks. Self-healing concrete improves durability by reducing crack propagation and preventing water and chemical ingress. It demonstrates enhanced resistance to freeze-thaw cycles, chloride penetration, and other deteriorating factors. Evaluating its long-term performance is crucial to assess its effectiveness over time, including mechanical properties, healing capacity, and sustainability. In summary, self-healing concrete is a remarkable material that offers autonomous crack repair and improved durability. Its composition, including the cementitious matrix and healing agents, along with activation mechanisms, enables the restoration of structural integrity. With favorable mechanical and durability properties, self-healing concrete has the potential to revolutionize the construction industry by extending the service life of concrete structures and reducing maintenance needs.

IV. LITERATUREREVIEW

The effectiveness of self-healing concrete has been the subject of several investigations. The list of studies that have been done in these areas is shown below.

Lala et al.(2013) Identity-healing concrete refers to paste-based materials that have the ability to repair themselves when damaged or deteriorated. This innovative technology utilizes various mechanisms such as the formation of calcium carbonate or hydroxide, particle sedimentation, continued hydration, and cement matrix swelling to achieve self-repair. The composition of self-healing concrete typically includes Portland cement, water, and additional filling materials like sand and grit. One common self-healing process involves the formation of calcium hydroxide or calcium carbonate in the presence of water and carbon dioxide. These reaction products fill the cracks in the concrete, leading to the restoration of its structural integrity. Another method involves the use of bacteria that can precipitate calcite directly or indirectly through the reaction of produced CO2 with calcium hydroxide in the cracked surface. This enhances the durability of the structure. Self-healing concrete has garnered significant interest due to its potential to extend the service life of concrete structures and prevent premature deterioration. However, the cost of self-healing concrete is typically higher than that of conventional concrete. Various techniques, such as dynamic modulus measurements, can be used to evaluate the presence and effectiveness of self-healing in concrete materials. Self-healing concrete holds immense potential for applications in everyday constructions such as bridges and buildings, offering improved durability and longevity.

Baeraet al.(2014 The idea of self-healing materials offers considerable potential in the context of sustainable infrastructure, which emphasises prevention, inexpensive maintenance, and ecological approaches. In cementitious materials, cracks are unavoidable, but they may be sealed, cured, and managed. The use of admixtures to encourage cement rehydration, microorganisms that precipitate calcite, and the creation of "intelligent materials" carrying chemical healing agent capsules are just a few of the several methods that have been studied to achieve self-healing of fractures. The spontaneous autogenic self-sealing/healing provided by Engineered Cementitious Composites (ECC) stands out as the most practical technique at this time. Wide fractures that grow beyond the boundaries where self-healing is feasible are prevented by ECC. In addition, the presence of fibre acts as a bridge over fissures where calcium carbonate may precipitate. calcite, and the development of "intelligent materials" containing chemical healing agent capsules. Among these approaches, the natural autogenic self-sealing/healing offered by Engineered Cementitious Composites (ECC) appears to be the most realistic solution at the moment. ECC prevents the formation of wide cracks that exceed the dimensions where self-healing is possible. Additionally, its fiber content provides bridges over cracks where calcium carbonate can precipitate, acting as a sealing agent. To confirm the promise of these novel materials in extending the service life of buildings and greatly lowering maintenance costs, more investigation and effective testing under genuine service circumstances, including casting, loading, curing, and retesting, are required.

Giannaros et al.(2016) The usefulness of microcapsule calculation in self-curative material was evaluated using a macroscopic measure of healing. The results indicated that the incorporation of microencapsulated healing agents led to improved strength recovery and crack sealing in solid samplings. Additionally, a large-scale concrete wall demonstrated promising indications of crack closure, further highlighting the potential of self-healing concrete with microcapsule additives.

Liu et al.(2016) An exploration was directed to evaluate the mineral self-healing performance of concrete containing 30% fly ash under various preloading conditions. The concrete specimens were subjected to damage tests under four different levels of preloading, followed by research on the self-healing capability of the concrete in a sulfate environment. The analysis of micro-tests was carried out to examine the self-healing products formed in the concrete. The degree of self-healing was assessed based on the relative dynamic modulus and compressive strength. The study examined the impact of factors such as a 5% sodium sulfate solution, the presence of 30% fly ash, the preloading level, and the age of self-healing curing on the mineral self-healing performance of the concrete. The findings revealed that the addition of 5% sulfate solution accelerated the recovery of relative dynamic modulus and compressive strength within the designated curing period. In both water and sulfate solution, the presence of 30% fly ash only improved the recovery range of relative dynamic modulus and relative compressive strength when the preloading damage was relatively high. As the preloading damage increased, the recovery capability of relative dynamic modulus and relative compressive strength after mineral self-healing decreased in a 5% sulfate solution environment. After a self-healing curing period of 28 days, the relative dynamic modulus reached a stable state. The self-healing products observed in the concrete exposed to a 5% sulfate environment were primarily composed of calcium carbonate, along with some ettringite.

Meharie et al.(2017) Several significant conclusions may be made based on the effectiveness of self-healing smart concrete in self-repairing. The creation of CaCO3 or Ca(OH)2 in natural processes, the dose and type of healing agent in chemical processes, and the kind of bacteria and precipitation of CaCO3 in biological processes are important parameters that have a substantial influence on the ability of cracked concrete structures to mend on their own. To sum up, an increase in the number of capsules, a shorter fracture width, an early onset of the crack, ideal water content, a thin capsule shell, and a greater concentration of Ca2+ ions all help the self-healing effectiveness. To sum up, an increase in the number of capsules, a shorter fracture width, an early onset of the crack, ideal water content, a thin capsule shell, and a greater concentration of Ca2+ ions all help the self-healing effectiveness. Selecting an appropriate healing agent and approach for a specific application is crucial to achieve self-healing efficiency and reliability. However, there is a lack of standardization and a common optimum point for practical application, as well as insufficient research on the causes of cracks and ensuring long-term efficiency throughout the lifespan of the structure. This highlights the need for further work in these areas. The information presented in this paper is relevant for professionals in civil engineering, biotechnology, and bioprocess engineering, providing insights into the critical factors involved in the practical application of self-healing concrete in real-world scenarios.

Zhukova et al.(2020) Concrete, being the primary man-made structural material, is subjected to significant loads and undergoes processes like freezing and thawing that can compromise its integrity, resulting in cracking. To enhance the performance properties of concrete, the use of self-healing elastic concrete has emerged as a promising development. This technology aims to increase the strength of concrete structures and prevent corrosion of reinforcement elements. The article explores the production process of self-healing concrete, outlines the necessary conditions for self-healing, and highlights its application features. Additionally, the article includes a cost analysis and calculates the economic benefits of implementing self-healing concrete production. Through correlation analysis, the relationship between service life and cost is determined. The results confirm the potential of the self-healing method, particularly in situations where repair work and regular inspections are impractical, such as in underground and underwater construction, high-rise buildings, and bridge-type structures. The use of self-healing concrete ensures the structural integrity and extends the service life of concrete and reinforced concrete structures, thus reducing the need for additional maintenance expenses. Furthermore, the research indicates that bio-concrete incorporating Bacillus subtilis bacteria helps reduce environmental pollution by minimizing hydrocarbon emissions during the concrete preparation process. This highlights the eco-friendly aspect of using self-healing concrete in construction projects.

Hermawan et al.(2021) This learning wishes to investigate the effect of curative managers on the comportment of concrete in both fresh and hardened states, with a focus on self-healing capacity. Three potential self-healing materials, namely calcium aluminate (CA), bacteria, and captured healing mediators, are explored for their ability to repair cracks and enhance the self-healing efficiency of concrete. The findings from literature studies reveal several important conclusions. First, there is still uncertainty regarding the impact of healing agents on the workability of concrete, as some studies suggest no negative effects while others indicate changes such as longer setting time, reduced plasticity, increased air content, and decreased slump value. Further research is needed to understand the consistency and workability of self-healing concrete and address any observed changes. Second, the addition of CA and microbes, along with suitable nutrients, generally improves the compressive strength of concrete composites. This can be attributed to factors such as the filling and water-barrier effects of CA, its role as a hydration activator, microbial calcite precipitation leading to densification, and the influence of nutritional admixtures in producing more calcium carbonate-based materials. Third, the inclusion of microcapsules can cause a significant decrease in strength due to the high pore volume they introduce. The impact of macrocapsules on hardened concrete properties is not well understood, and their presence may disrupt aggregate packing. Overall, this research highlights the need for further investigation, particularly in understanding the workability, strength effects, and long-term efficiency of self-healing concrete for practical applications.

Wang et al.(2021) This paper focuses on evaluating In order to evaluate the ability of microcapsule self-healing concrete to repair damage, we looked at its strength recovery and acoustic performance. To identify the ideal combination of components and the appropriate mix percentage for the concrete, an orthogonal experimental design with three factors was used. The results show that the microencapsulated self-healing concrete performs better at self-healing than regular concrete. greater pre-damage loads result in a reduction in the healing effect, whereas greater damage levels result in an increase in the sound speed recovery rate. Although the proportion of sodium silicate and sodium flu silicate dose had little effect on the sound speed recovery rate at greater damage degrees, all three elements taken into account in the study have an impact on the healing rate. The microcapsule content was also shown to be maximum under high damage loads and vice versa. Overall, the results highlight the enhanced performance of microcapsule self-healing concrete and provide insights into the factors influencing its healing capabilities.

Uddin et al.(2022) This article provides an overview of the use of bacteria-based concrete for self-healing applications in the construction industry. The review highlights the need for more data to simulate real-world conditions before implementing these technologies on a larger scale. Chemical and polymer treatments, commonly used to reduce crack formation in concrete, pose risks to human health and the environment, making bacteria-based concrete an environmentally friendly alternative. However, there are limitations regarding crack width and large-scale application. The review presents various nutrients and bacteria that have been studied for enhancing the durability performance of self-healing concrete. Bacillus subtilis, Bacillus pasteurii, and Sporosarcinapasteurii, among others, have shown promising results in filling cracks and improving compressive strength. Optimal conditions for bacteria growth, such as pH levels and temperature ranges, are also discussed. The study demonstrates the effectiveness of bacteria in healing concrete cracks when combined with specific nutrients, varying time durations, oxygen presence, temperature, and pH factors.

Hadhinata et al.(2022) Concrete is a common building material known for its strength and durability. However, cracks in concrete can reduce its lifespan and require costly repairs. To address this issue, researchers have developed self-healing concrete, which has the ability to repair cracks through various mechanisms. Self-healing concrete exhibits superior mechanical properties compared to regular concrete. There are two types of self-healing mechanisms: autogenic, which involves the formation of calcium carbonate crystals, and autonomic, which utilizes encapsulated healing agents. Self-healing concrete has been applied in various macro-scale structures such as panel walls, roof slabs, and floodgates.

Medeiros et al.(2022) By using low-carbon concrete with a bacterial self-healing agent, this article suggests a greener and more sustainable method of building. The goal of the study is to determine the effects of a bacterial self-healing agent on the mechanical characteristics of low-carbon concrete, specifically by substituting ground granulated blast-furnace slag (GGBS) for 50% of ordinary Portland cement (OPC).In order to evaluate how mechanical qualities, change throughout 7, 14, and 28 days of curing, several experiments are carried out at various curing phases. The findings show that GGBS mixes initially have a lower compressive capacity but have the potential to outperform control mix values after 28 days. Early in the curing process, the self-healing ingredient only minimally improves the mechanical characteristics; but, by 28 days, GGBS mixtures show a noticeable improvement. In addition, using GGBS in place of OPC lowers carbon emissions and increases the structural durability and design life. According to laboratory testing, the created concrete can successfully address broader gaps and can seal cracks as small as 0.3 millimeters (or as large as 0.8 millimeters with the maximum dose).

Jaf et al.(2023) Concrete is a common building material because of its durability and strength. But fractures are a typical issue in concrete constructions, resulting in a shorter lifespan and higher maintenance expenditures. As a result of these fissures, the concrete is more susceptible to corrosion, sulphate attack, carbonation, alkali-aggregate interaction, and other problems. While completely preventing fracture formation is impossible, they may be controlled or repaired using a number of techniques. A proposed method to increase the long-term durability of concrete is self-healing. In this method, healing agents like as microorganisms, chemicals, and polymers are used to allow fractures to self-heal as they occur. Particularly, the use of bacteria has led to the development of names like "bacterial-concrete" or "bioconcrete" for self-healing concrete. This article gives a general overview of self-healing concrete and explains its system, procedure, durability, and mechanical qualities.

Kumar et al.(2023) A comparison was conducted between concrete made with manufactured sand and concrete made with conventional sand. The results indicated that the manufactured sand concrete exhibited superior properties in terms of water absorption, permeability, and durability. It showed lower water absorption and permeability, suggesting improved resistance to deterioration. The manufactured sand concrete also demonstrated enhanced resistance to chloride ion penetration and acid-alkaline attacks, resulting in reduced weight loss. Furthermore, it displayed increased impact and abrasion resistance compared to traditional sand concrete. These findings highlight the potential of manufactured sand as a viable alternative to conventional sand in concrete construction, aligning with sustainable development goals and offering the possibility of complete substitution.

Hermawan et al.(2023) It can be difficult, expensive, and time-consuming to manually repair fractures in concrete buildings. Technology for accelerated autogenous and autonomous self-healing offers a viable remedy, nevertheless. In these technologies, the concrete is cast with healing ingredients added. Traditional concrete has some autogenous mending capacity; however, this ability is not very strong. In this work, crystalline admixtures (CA) and bacteria-based healing agents (BAC) were used to develop self-healing concretes. When the concrete's mechanical and fresh characteristics were first assessed, the addition of healing agents led to a 4% improvement in CA's 28-day compressive strength and a 16% rise in BAC's. Optical microscopy measurements of fracture closure and permeability setup tests of water flow were used to evaluate the self-healing capabilities. The findings showed that the presence of healing agents promoted fracture closure over time, and that the permeability rate dramatically decreased as a result of the healing products' clogging of the cracks. In comparison to conventional autogenous self-healing in concrete, the self-healing concretes demonstrated improved healing and sealing efficiency, showing intriguing possibilities for practical applications.

Chandanaet al.(2023) Concrete is a widely used building material, but it is prone to cracking, which compromises its strength and durability. These cracks can lead to water seepage, corrosion, and structural failure. To address this issue, bio mineralization in concrete has emerged as a promising approach. By introducing calcite precipitating bacteria into the concrete, the cracks can be filled with calcium carbonate precipitates, resulting in crack-free concrete. This type of concrete, known as bacterial concrete, has shown positive results in various studies. In this project, we aim to investigate the mechanical properties of self-healing bacterial concrete by varying the quantities of bacteria and calcium lactate. Previous research has indicated that the optimal results were achieved with 0.5% and 2.5% calcium lactate along with 10ml and 15ml of bacteria. Therefore, we plan to conduct an experimental study using self-healing bacterial concrete with the addition of 10ml bacteria to 0.5% and 2.5% calcium lactate, as well as 15ml bacteria to 0.5% and 2.5% calcium lactate.

V. SUMMARY

The effectiveness of self-healing concrete, a potential strategy to increase the sturdiness and longevity of concrete structures, is the main topic of the review study. Concrete that can self-heal cracks and regain structural integrity eliminates the need for expensive and time-consuming human repairs. An overview of several self-healing methods used in concrete, including autogenous and autonomous healing, is given in this article. While autonomous healing requires the insertion of healing agents such as bacteria, chemicals, or polymers into the concrete matrix, autonomous healing makes use of the intrinsic capabilities of concrete to mend micro cracks through the creation of calcium carbonate crystals. Through several metrics, including crack closure measures, water flow testing, and mechanical property evaluations, the effectiveness of self-healing concrete is evaluated. The findings show that the inclusion of healing agents boosts fracture closure over time and increases concrete's compressive strength. As cracks are sealed by healing materials, self-healing concrete loses some of its permeability. The review also analyses the drawbacks and constraints of self-healing concrete, such as fracture width restrictions and the viability of large-scale use. It emphasizes the significance of additional research and development to enhance self-healing concrete systems and boost their durability. Overall, the review paper highlights how self-healing concrete has the potential to improve the resilience and durability of concrete buildings in a sustainable way. Self-healing technology can support eco-friendlier and economical construction methods by lowering the need for frequent repairs and prolonging the lifespan of concrete.

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