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A Review - Experimental Investigation of a Self-Healing Concrete

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Abstract:

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, and versatility; however, its low tensile strength makes it vulnerable to cracking. The formation of micro-cracks and macro-cracks permits the penetration of water, oxygen, and aggressive chemicals, resulting in reinforcement corrosion, reduced structural integrity, increased maintenance costs, and shortened service life. Self-healing concrete has emerged as an innovative and sustainable solution to overcome these limitations by enabling autonomous crack repair without extensive external intervention. This review presents an overview of experimental investigations conducted on self-healing concrete technologies, including biological healing through bacteria, encapsulated healing agents, chemical admixtures, mineral precipitation, and microcapsule-based systems. The study discusses healing mechanisms, crack-closing efficiency, compressive and tensile strength recovery, water permeability reduction, and durability enhancement. Experimental findings reported in various studies indicate that self-healing concrete significantly improves crack sealing capability, restores mechanical performance, and enhances resistance against environmental deterioration. Furthermore, self-healing technology contributes to sustainability by reducing repair frequency, extending structural lifespan, and lowering material consumption and carbon emissions. This review highlights recent developments, advantages, challenges, and future prospects of self-healing concrete for modern infrastructure applications.

Keywords: Self-healing concrete; Experimental investigation; Bacterial concrete; Crack healing; Calcium carbonate precipitation; Durability; Sustainable construction; Microcapsules; Mechanical properties; Concrete technology

1. Introduction

An Experimental Investigation of Self-Healing Concrete focuses on studying the ability of concrete to repair its own cracks and restore performance without extensive external maintenance. Conventional concrete possesses excellent compressive strength but relatively poor tensile strength, making it susceptible to the formation of micro-cracks caused by shrinkage, temperature variation, loading, environmental exposure, and aging. Although these cracks may initially appear insignificant, they create interconnected pathways that allow the ingress of water, oxygen, chlorides, sulfates, and other aggressive substances into the concrete matrix. Once these harmful agents reach the embedded steel reinforcement, corrosion begins, causing expansion of steel, internal stresses, spalling of concrete cover, reduction in load-carrying capacity, and ultimately premature deterioration of structures.

Self-healing concrete is developed to address this limitation by incorporating healing mechanisms that activate automatically when cracks occur. These mechanisms can be broadly classified into autogenous self-healing and autonomous self-healing. Autogenous healing is the natural ability of concrete to seal very small cracks through continued cement hydration and calcium carbonate precipitation. However, this process is limited and effective only for narrow crack widths. Autonomous self-healing involves embedding healing agents such as bacteria, capsules containing chemical agents, mineral additives, polymers, or vascular networks that actively trigger repair when cracking occurs. Among these, bio-based self-healing concrete has gained considerable attention because of its sustainable and environmentally friendly approach.

In bacterial self-healing concrete, selected microorganisms commonly species of Bacillu*s* are incorporated into the concrete together with nutrients and protective carriers. These bacteria remain dormant inside the hardened concrete and become activated when water enters through cracks. During activation, bacterial metabolic processes produce calcium carbonate ($CaCO_3$), commonly known as limestone, which precipitates and fills the cracks. The deposited mineral restores continuity in the concrete structure, reduces permeability, and limits further penetration of harmful substances.

Experimental investigation of self-healing concrete generally involves preparing multiple concrete specimens with different healing agents and comparing their performance with conventional concrete. Laboratory testing includes compressive strength tests to evaluate load-bearing recovery, split tensile strength tests to assess resistance to cracking, flexural strength tests to determine bending performance, and water absorption or permeability tests to examine durability improvements. Crack-healing efficiency is commonly measured by intentionally creating controlled cracks and monitoring crack closure over time using optical microscopy, ultrasonic pulse velocity, scanning electron microscopy, or permeability reduction analysis. Durability studies may also include chloride penetration tests, acid resistance tests, and freeze–thaw cycling to assess long-term behavior.

The results of experimental investigations generally show that self-healing concrete significantly improves durability and extends service life by reducing crack width, decreasing water permeability, limiting reinforcement corrosion, and recovering part of the lost mechanical strength. Although self-healing concrete may involve higher initial material costs, the reduction in maintenance, repair expenses, and environmental impact over the structure’s lifecycle makes it a promising advancement for sustainable construction. This technology has strong potential for applications in bridges, tunnels, marine structures, water-retaining systems, pavements, and other infrastructures where long-term durability is critical.

2. Literature Review

M.Chandrakanth et al (2025) Self-healing concrete has emerged as an advanced construction material capable of autonomously repairing cracks while maintaining or improving the structural performance and durability of concrete structures. The fundamental challenge with conventional concrete is that, although it exhibits excellent compressive strength, it possesses relatively low tensile capacity, making it vulnerable to the formation of micro-cracks and visible cracks during loading, shrinkage, thermal changes, and environmental exposure. These cracks become pathways for the ingress of water, oxygen, chlorides, and other harmful substances that accelerate reinforcement corrosion and reduce the service life of structures. To address this issue, bacterial self-healing technology introduces microorganisms into the concrete matrix to activate healing processes when cracks develop. In this project, Bactaheal–PR bacteria were incorporated into concrete to promote crack repair through microbiologically induced calcium carbonate ($CaCO_3$) precipitation. When moisture enters the cracked region, the dormant bacteria become active and initiate biochemical reactions that convert available nutrients and calcium sources into calcium carbonate crystals. These crystals gradually deposit inside cracks and pores, effectively sealing the damaged regions and restoring structural continuity. Since calcium carbonate is a naturally occurring mineral and the process occurs through biological activity, the mechanism is environmentally friendly and pollution-free. Besides crack healing, the study also examined whether introducing bacteria influences the mechanical properties of intact (uncracked) concrete, especially compressive strength, which is a critical parameter for structural design. Along with bacterial incorporation, cement was partially replaced with fly ash—an industrial by-product possessing pozzolanic properties that reacts with calcium hydroxide produced during cement hydration to form additional calcium silicate hydrate (C–S–H) gel, thereby improving strength, workability, long-term durability, and sustainability while reducing cement consumption and carbon emissions. Initially, concrete mixes without bacteria were prepared using different fly ash replacement levels of 6%, 8%, 10%, 12%, 30%, and 40%, and after curing for 7 and 28 days, compressive strength tests were conducted. The results showed that strength increased progressively up to a certain replacement level because moderate fly ash addition improved particle packing and secondary hydration; however, excessive replacement reduced available cement content and consequently lowered strength development. Among these mixes, the highest compressive strength was obtained at 12% fly ash replacement without bacterial addition, indicating an optimum balance between cement hydration and pozzolanic reaction. Subsequently, bacterial concrete mixes containing Bactaheal–PR at concentrations of 0.25% and 0.5% were produced with selected fly ash replacement levels of 12%, 30%, and 40%, followed by similar curing and compressive strength evaluation. The findings demonstrated that bacterial incorporation further enhanced compressive strength compared with corresponding mixes without bacteria due to additional $CaCO_3$ precipitation filling pores, reducing internal voids, densifying the microstructure, and improving the bond between cement paste and aggregates. The optimum overall performance was achieved with 12% fly ash replacement combined with 0.5% Bactaheal–PR, producing the highest compressive strength among all tested combinations. Furthermore, when the strength of healed specimens was compared with that of intact uncracked cubes, the crack-healed specimens exhibited superior strength recovery, showing that bacterial action not only restored damaged sections but in some cases produced a denser internal structure than the original concrete. Therefore, the study confirms that the combined use of Bactaheal–PR bacteria and fly ash can successfully improve both self-healing capability and compressive strength, resulting in stronger, more durable, sustainable, and longer-lasting concrete structures.

Andrea Calabrese et al (2024) this research focuses on the development of **self-healing concrete** as a sustainable solution to overcome the common problem of cracking in concrete structures. Although concrete is widely used due to its high compressive strength, durability, and versatility, cracks can reduce structural performance, increase permeability, and accelerate corrosion of reinforcing steel. To address this issue, the study applies **Microbially Induced Carbonate Precipitation (MICP),** a biological healing process in which bacteria produce **calcium carbonate ($CaCO_3$)** to seal cracks naturally. Three bacterial species were investigated: Bacillus subtilis, Bacillus megaterium, and Sporosarcina pasteurii, selected for their ability to survive in the alkaline environment of concrete and promote mineral formation. The experiment included five specimen groups consisting of uncracked control samples, cracked untreated samples, and cracked samples treated with each bacterial species, with each group containing 11 specimens made from 40 MPa grade concrete. All specimens were prepared using a standardized mixing process and cured according to ASTM standards to ensure consistent hydration and strength development. After curing, bacterial solutions were introduced into the cracks three times to stimulate healing through calcium carbonate deposition. Finally, after 84 days, the specimens were tested using a Humboldt Compression Machine to evaluate compressive strength and healing efficiency. The study concluded that bacterial self-healing concrete can effectively reduce crack effects, improve durability, extend service life, lower maintenance requirements, and support environmentally sustainable construction practices.

Suraj Bhan Singh et al (2022) cracking in concrete is an unavoidable and widespread phenomenon due to factors such as drying shrinkage, thermal stresses, chemical reactions, excessive loading, environmental exposure, and structural aging. If these cracks are not identified and repaired at an early stage, they tend to propagate over time, allowing water, oxygen, carbon dioxide, chlorides, sulphates, and other harmful substances to penetrate into the concrete matrix. This penetration accelerates the corrosion of embedded steel reinforcement, reduces structural durability, causes leakage in water-retaining structures, and eventually leads to costly maintenance and repair operations. Although modern construction techniques and improved materials can reduce crack formation, complete elimination of cracks remains difficult. To address this challenge, researchers have developed an innovative and sustainable solution known as self-healing concrete, which possesses the ability to repair its own cracks autonomously without external intervention. One of the most promising approaches is biological self-healing concrete, where environmentally friendly microorganisms are incorporated into the concrete matrix. In this study, *Bacillus subtilis*, a naturally occurring soil bacterium, is utilized because of its ability to survive harsh conditions and induce calcium carbonate ($CaCO_3$) precipitation. The bacteria are embedded into concrete along with nutrients or mineral precursor compounds that remain dormant until cracks form and moisture enters the structure. When water reaches the cracked region, the bacterial spores become active and metabolize the supplied compounds, producing carbonate ions that react with calcium ions available in the concrete to form calcium carbonate crystals. These crystals gradually accumulate within the crack space, sealing the openings and restoring impermeability and durability. This process, known as Microbially Induced Calcium Carbonate Precipitation (MICP), creates a continuous and natural crack remediation mechanism. The concept represents a form of smart concrete because it can detect crack formation indirectly through moisture ingress and initiate a healing response automatically. The use of bacterial self-healing technology also contributes to environmental sustainability by reducing the frequency of repairs, extending service life, lowering material consumption, and decreasing carbon emissions associated with cement production. Since the cement industry contributes significantly to global CO_2 emissions, developing durable and self-repairing concrete offers an effective strategy to reduce environmental impact while improving structural performance. Consequently, bacteria-based self-healing concrete has emerged as an advanced construction material capable of increasing longevity, minimizing maintenance costs, enhancing durability, and supporting sustainable infrastructure development.

Vandana Bhargava et al (2022) Concrete is a widely used construction material because of its high compressive strength, durability, and ability to withstand heavy loads; however, it possesses relatively low tensile strength, making it highly susceptible to cracking under tensile stresses, shrinkage, thermal variations, loading, and environmental effects. The formation of cracks in concrete structures is a major concern because these cracks act as pathways that allow water, oxygen, chlorides, sulfates, and other harmful chemicals to penetrate into the concrete matrix. This ingress accelerates corrosion of steel reinforcement, weakens the bond between concrete and steel, reduces structural integrity, decreases durability, and ultimately shortens the service life of structures. Frequent maintenance and repair activities not only increase construction costs but also contribute to environmental degradation through additional consumption of raw materials, energy, and emissions associated with repair processes. Therefore, extending the service life of concrete structures is an effective approach toward achieving sustainable construction and environmental conservation. In this context, the application of bacterial technology in concrete, commonly known as bacterial concrete or self-healing concrete, has emerged as an innovative and eco-friendly solution. This technology utilizes specific bacteria capable of precipitating calcium carbonate ($CaCO_3$) through microbial activity. When cracks develop and moisture enters the concrete, dormant bacterial spores become active and initiate biochemical reactions that produce limestone deposits, which fill and seal the cracks automatically. This self-healing process restores impermeability, reduces chemical penetration, improves durability, enhances long-term mechanical performance, and minimizes maintenance requirements. Therefore, this paper presents a review of existing literature related to the utilization of bacterial effects in concrete, focusing on crack-healing mechanisms, strength improvement, durability enhancement, sustainability benefits, and the overall potential of bacterial concrete as an advanced construction material for future infrastructure development.

Wei Zhang et al. (2020) cement concrete, although widely used in construction due to its high compressive strength and durability, possesses inherently low tensile strength, making it highly susceptible to cracking under different conditions such as drying shrinkage, creep deformation, repeated loading, temperature variation, and exposure to aggressive environmental conditions. Similarly, asphalt concrete pavements are vulnerable to cracking and surface wear because of temperature fluctuations, aging of bituminous binders, and reduced flexibility over time. The formation of cracks in both cement and asphalt concrete creates pathways that allow water, oxygen, chlorides, sulfates, and other corrosive substances to penetrate deep into the material, accelerating deterioration processes such as reinforcement corrosion, internal expansion, loss of structural integrity, reduction in load-carrying capacity, and shortened service life of infrastructure. Conventional repair methods generally depend on manual inspection and external maintenance techniques such as patching, sealing, or replacement, which are costly, labor-intensive, and often ineffective for repairing micro cracks that are not visible at early stages. To overcome these limitations, self-healing technology has emerged as an advanced solution capable of autonomously repairing small cracks through physical, chemical, or biological mechanisms before they develop into severe structural damage. Self-healing may occur through mechanisms such as continued cement hydration, precipitation of healing products like calcium carbonate, encapsulated healing agents, or microbial activity that seals cracks and restores impermeability. This technology significantly reduces maintenance requirements, enhances durability, improves structural safety, and extends the operational lifespan of infrastructure. Its application is particularly valuable in marine structures exposed to chloride-rich environments, underground concrete facilities used for hazardous material storage where leakage prevention is critical, and large-scale concrete infrastructures where conventional repair is difficult and expensive, thereby contributing to more sustainable and cost-effective construction practices.

Lagazo, Magil et. al. (2019) the research paper introduced the use of microorganisms-Bacillus Subtlis as its very profitable for building up an intense system and set forth a concentrated exertion retouching concrete as a technique for brake control to overhaul organization life in a strong structure. The framework Microbiologically Induced Calcite Precipitation (MICP) was grasped. It was the usage of Bacillus Subtilis close by its supplements which are the Sodium Bicarbonate (NaHCo3), Ammonium Carbonate (NH4Cl), Calcium Chloride Dehydrate (CaCl2), and supplement stock. The blending extent utilized was 1:2 ½: 5:0.45 alongside 30 ml fluid type of Bacillus Subtilis with the cell convergence of 105 cells/ml. The strength of solid blend was assessed by directing a test on 150mm x 150mm x 150mm 3D shape for compressive strength test, 6in x 12in the round and hollow form for split elasticity test, 21in x 6in x 6in rectangular pillars for flexural strength text and 3in x 6in for water assimilation test, 3 examples each test. All example used for recovering is 4in x 2in x 2in which was purposely broken. The examination exhibits that there was a critical augmentation in the nature of concrete added with microbes or bacterial cement diverged from ordinary concrete and thusly calcium carbonate precipitation is clear after 3 a month in limited scope parts. The outcomes reasoned that the development of minute life forms that the expansion of bacterial arrangement Bacillus Subtilis in cement introduced upgrades in various properties of concrete the extent that a compressive quality test, split rigidity test, water ingestion test, and flexural quality test.

Abubakar Magaji et. al. (2019) the exploration paper researched on self-mending of breaks in concrete based substances and black-top cement. The break arrangement was a fundamental well known to marvel in a solid structure that empowers the water and different kind of synthetic substances into the solid into the breaks and diminishes their solidness, strength and which assaults the fortification in the event that it interacts with water, CO2 in addition to different synthetic substances. Self-mending cement could resolve the snag of solid structures deteriorating impressively before the finish of their life expectancy. Presenting the microbes inside the solid performs it incredibly valuable it improves the characteristic of the solid, which is higher than the customary cement. Microorganisms fix the breaks in cement by giving the calcium carbonate gem that hinders the breaks and fixes them. Numerous scientists have taken care of their work on oneself mending kind of cement and they had gotten the ensuing outcome that microbes build up the property of customary cement, for example, increase in 13.75 percent strength brought up in 3 days, 14.28 percent in multi-week just as 18.35% in week one. In any case, on the off chance that solid could distinguish breaking and mend itself, at that point there would not exclusively be significant cost reserve funds yet additionally save an ecological increase furthermore in light of the fact that solid creation represents a significant amount of the world's CO2 discharges.

Kusuma K et. al. (2018) the examination paper introduced the impact on compressive strength, water assimilation and water porousness of concrete solid 3D squares because of the blending of microbes, the stopping of a fake break-in concrete solid utilizing Bacillus megaterium. It was discovered that the utilization of Bacillus Megaterium improves the compressive strength and firmness of cement. It likewise introduced that there was a decrease in water retention and water porousness when contrasted with customary cement. The microbes which would have been presented in cement ought to have the property of antacid opposition and it likewise should frame endospore, so it withstands the anxieties delivered in cement while blending, shipping and setting. The outcomes introduced urease positive microbes (the microscopic organisms which can accelerate calcium carbonate, for example, Bacillus subtilis, bacillus pasterui, Bacillus megaterium and to introduce the mending method of breaks in cement by them. The examination surveyed the various kinds of microscopic organisms that can be utilized for curing breaks in cement. There was the upgrade of compressive strength of cement. The utilization of such microbes positively affects water assimilation, playfully and water porousness in cement. The conclusion expressed that utilizing self-mending cement can be a capable other option and excellent solid sealant which was eco- accommodating, practical and furthermore brings about an improvement in the sturdiness of building materials.

G. Balaji wt al (2017) the aim of this research project is the development of a new type of concrete in which integrated bacteria promote self-healing of cracks. Traditional concrete does usually show some self-healing capacity what is due to excess non-hydrated cement particles present in the material matrix. These particles can undergo secondary hydration by crack ingress water resulting in formation of fresh hydration products which can seal or heal smaller cracks. However, the integration of excess cement in concrete is unwanted from both an economical and environmental viewpoint. Cement is expensive and, moreover, its production contributes significantly to global atmospheric CO2 emissions. In this study we developed a two-component self-healing system which is composed of bacteria which catalyze the metabolic conversion of organic compounds to calcite. Both components are mixed with the fresh cement paste, thus becoming an integral part of the concrete. Experimental results show that ingress water channeled through freshly formed cracks activate present bacteria which through metabolic conversion of organic mineral-precursor compounds produce copious amounts of calcite. This new bio-based two-component system may represent a new class of self-healing mechanisms which can be applied to cement-based systems. The self-healing capacity of this system is currently being quantified what should result in an estimate of the materials durability increase. A self-healing concrete may be beneficial for both economic and environmental reasons. The bacteria based concrete proposed here could substantially reduce maintenance, repair and premature structure degradation what not only saves money but also reduces atmospheric CO2 emissions considerably as less cement is needed for this type of self-healing concrete. The recent research shows that specific species of bacteria can actually be useful as a tool to repair cracks in early stage of already existing concrete structures. A highly impermeable calcite layer formed over the surface of an already existing concrete layer, due to microbial activities of the bacteria (Bacillus subtilus) seals the cracks in the concrete structure and also has excellent resistance to corrosion.

E. Tziviloglou et al. (2016) studied the concept of self-healing concrete as an innovative and advanced construction material capable of repairing its own micro-cracks without requiring conventional external maintenance or repair methods. Their research focused on improving the long-term durability and service life of concrete structures by enabling autonomous crack healing. Concrete structures naturally develop micro-cracks due to shrinkage, thermal variations, mechanical loading, environmental exposure, and aging. Although these cracks may initially appear insignificant, they create pathways that allow aggressive substances such as water, carbon dioxide, oxygen, chlorides, sulfates, and other harmful liquids and gases to penetrate into the concrete matrix. This ingress accelerates deterioration processes, particularly corrosion of steel reinforcement, reduction in mechanical strength, increased permeability, and eventual structural degradation. The study highlighted that self-healing concrete introduces engineered healing mechanisms that activate once cracking occurs and restore the material’s functionality. Various self-healing approaches were examined, including autogenous healing (natural crack closure through continued cement hydration and calcium carbonate precipitation) and autonomous healing systems that incorporate encapsulated healing agents, bacteria, polymers, or mineral-producing compounds within the concrete. When cracks form and moisture enters, these embedded agents become activated and generate healing products that seal the cracks. A major objective of their work was the restoration of water tightness, meaning the healed concrete regains its resistance to water penetration and prevents further transport of aggressive chemicals into the structure. Restoring water tightness is particularly important in infrastructures such as bridges, tunnels, reservoirs, marine structures, and underground constructions where water ingress significantly affects durability. The study demonstrated that self-healing concrete has the potential to reduce maintenance costs, extend structural lifespan, improve sustainability by lowering repair material consumption, and enhance the reliability and safety of concrete infrastructure over time.

V. Ramakrishnan, et al (2015) the authors explained an innovative approach to improving the performance and durability of concrete through the use of bacteria-induced mineral formation. Their research focused on introducing a common soil bacterium into concrete that possesses the ability to precipitate calcium carbonate ($CaCO_3$), commonly known as calcite. When cracks develop in concrete due to shrinkage, loading, temperature variation, or environmental exposure, water entering these cracks activates the bacteria. Through microbial metabolic activity, the bacteria convert available nutrients into calcite crystals, which gradually deposit inside the cracks and fill the voids. This biologically induced calcite precipitation acts as a natural self-healing mechanism and restores the continuity of the concrete matrix. Since the process occurs naturally without harmful chemical emissions, it is considered an environmentally friendly and pollution-free repair technique. To evaluate its effectiveness, the researchers compared cracked concrete specimens treated with bacteria to untreated control specimens. Experimental results showed that bacterial treatment significantly increased compressive strength by strengthening internal bonding and reducing pore spaces. The stiffness of concrete was also enhanced, indicating improved resistance to deformation under applied loads. Additionally, the study examined the strength-regaining capacity of cracked concrete beams through modulus of rupture tests, where beams treated with varying bacterial concentrations demonstrated better recovery of flexural strength than conventional concrete. The durability performance was further assessed under aggressive environmental conditions including alkaline exposure, sulfate attack, and freeze–thaw cycles. Concrete containing bacteria exhibited superior resistance because the calcite deposits reduced permeability and blocked pathways for water and harmful chemicals. To understand the mechanism at the microscopic level, Scanning Electron Microscopy (SEM) analysis was conducted, which confirmed the formation of calcium carbonate crystals inside cracks and pores. These mineral deposits created a denser internal structure, minimizing crack propagation and improving long-term performance. Overall, the study concluded that bacterial concrete has significant potential as a future construction material because it enhances self-repair capability, improves compressive and flexural strength, increases stiffness, and provides greater durability while supporting sustainable and eco-friendly construction practices.

Baban Kumar et al (2015) the objective of the research paper was to report the effects of bacteria-based additives on the properties of concrete such as compressive strength, split tensile strength and flexural strength and a clear comparison can be made for strengths of different specimens of bio concrete using different bacteria and conventional concrete. Moreover, the water permeability and chloride penetration resistance properties of concrete specimens were investigated. Self-healing was also confirmed by SEM photographs and XRD analysis.

J.Y. Wang et al. (2014) investigated an innovative biological approach for self-healing concrete by incorporating bacterial spores inside protective microcapsules and embedding them into mortar specimens to enable autonomous crack repair. The main purpose of encapsulation was to protect bacterial spores from the highly alkaline environment of concrete and preserve their activity until cracks formed. When cracking occurred, the microcapsules ruptured due to mechanical stress, releasing the dormant bacteria into the damaged region. The breakage and activation mechanism of these microcapsules was confirmed using Scanning Electron Microscopy (SEM), which showed that the capsules successfully opened along the crack paths. Once exposed to moisture and environmental conditions favorable for bacterial growth, the bacteria became active and produced mineral precipitation, mainly calcium carbonate ($CaCO_3$), which gradually filled and sealed the cracks. To evaluate performance, researchers measured both crack healing ratio and water permeability of the mortar. The results demonstrated a significantly improved healing efficiency in specimens containing bacterial microcapsules, achieving crack healing ratios between 48% and 80%, compared with only 18% to 50% in specimens without bacteria. In terms of crack repair capacity, bacterial specimens were able to heal cracks up to 970 µm wide, which was nearly four times greater than the non-bacterial specimens that healed only up to 250 µm. Furthermore, permeability testing showed that bacterial mortar had approximately ten times lower water permeability, indicating that crack sealing effectively reduced water penetration and improved durability. The study also revealed that environmental conditions strongly influenced healing performance: wet–dry cycles enhanced bacterial activation and promoted mineral deposition, whereas specimens stored continuously at 95% relative humidity exhibited little or no self-healing because liquid water was absent. This finding highlighted that water acts as an essential trigger for bacterial metabolism and mineral formation. Overall, the research demonstrated that microencapsulated bacteria provide an effective and durable self-healing mechanism capable of improving crack closure, reducing permeability, and extending the service life of concrete structures.

H. M. Jonkers et al (2011) the research paper investigated the crack healing capacity of a specific bio-chemical additive, consisting of a mixture of viable but dormant bacteria and organic compounds packed in porous expanded clay particles. Microscopic techniques in combination with permeability tests revealed that complete healing of cracks occurred in bacterial concrete and only partly in control concrete. The mechanism of crack healing in bacterial concrete presumably occurs through metabolic conversion of calcium lactate to calcium carbonate what results in crack-sealing. This biochemically mediated process resulted in efficient sealing of sub-millimeter sized (0.15 mm width) cracks. It was expected that further development of this new type of self-healing concrete will result in a more durable and moreover sustainable concrete which will be particularly suited for applications in wet environments where reinforcement corrosion tends to impede durability of traditional concrete constructions.

3. Methodology

This study adopted an experimental research methodology to investigate the performance of bacterial self-healing concrete and evaluate its ability to improve crack-healing efficiency, compressive strength, and overall durability. Initially, a conventional concrete mix was designed according to standard mix proportion procedures and used as the control specimen. To develop self-healing concrete, selected bacterial strains capable of inducing calcium carbonate ($CaCO_3$) precipitation, such as Bacillus subtilis, Bacillus megaterium, or Bactaheal–PR, were incorporated into the concrete matrix along with suitable nutrients and calcium sources to support bacterial activity. In some mixes, cement was partially replaced with fly ash at varying percentages to improve sustainability and enhance hydration reactions. Concrete specimens were cast in standard cube, cylinder, and prism moulds and cured under controlled conditions for predetermined periods such as 7, 28, days. After curing, controlled cracks were intentionally induced in selected specimens to simulate real structural damage. Moisture exposure activated the dormant bacteria present inside the concrete, initiating Microbially Induced Calcium Carbonate Precipitation (MICP), through which bacteria converted nutrients into calcium carbonate crystals that gradually filled cracks and pores. The healing process was monitored over time through visual observation and crack closure measurements. Mechanical and durability evaluations were then performed using compressive strength tests, split tensile strength tests, flexural strength tests, water permeability tests, and water absorption tests to compare bacterial concrete with conventional concrete. In addition, microstructural analysis techniques such as Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) were employed to confirm the formation and deposition of calcite crystals inside healed cracks. The experimental results were analyzed to determine the optimum bacterial concentration and mix composition capable of maximizing strength recovery, reducing permeability, improving durability, and enhancing the long-term sustainability of concrete structures.

4. Result and discussion

The experimental investigation, as discussed in A Review - Experimental Investigation of a Self-Healing Concrete, demonstrated that bacterial self-healing concrete significantly improved the mechanical performance, crack-healing capability, and durability characteristics compared with conventional concrete. The incorporation of bacteria into the concrete matrix resulted in the formation of calcium carbonate ($CaCO_3$) crystals through Microbially Induced Calcium Carbonate Precipitation (MICP), which effectively filled internal pores and sealed developed cracks. Compressive strength test results showed that bacterial concrete achieved higher strength values than control specimens due to the densification of the concrete microstructure and improved bonding between cement paste and aggregates. The inclusion of fly ash at moderate replacement levels further enhanced performance by promoting additional pozzolanic reactions and improving particle packing, whereas excessive replacement reduced strength because of lower cement availability. Crack-healing observations revealed that bacterial specimens exhibited greater crack closure efficiency and recovered structural continuity more effectively than untreated concrete. Water permeability and absorption tests indicated a substantial reduction in water penetration because the precipitated calcite blocked capillary channels and minimized porosity, thereby improving resistance against moisture ingress and chemical attack. Microstructural analyses using SEM and XRD confirmed the presence of calcium carbonate deposits within healed regions, validating the bacterial healing mechanism. The results also showed that bacterial activity was influenced by environmental conditions, particularly moisture availability, which acted as a trigger for bacterial activation and mineral formation. Overall, the findings confirm that bacterial self-healing concrete, as synthesized in A Review - Experimental Investigation of a Self-Healing Concrete, offers an effective and sustainable solution for extending service life, reducing maintenance requirements, increasing structural durability, and supporting environmentally friendly construction practices.

5. Conclusion

This review titled “A Review – Experimental Investigation of Self-Healing Concrete” critically examined the performance of bacterial self-healing concrete through experimental findings reported in previous studies. The overall findings confirm that self-healing concrete represents a promising advancement over conventional cementitious materials for enhancing durability and service life. The incorporation of bacteria such as Bacillus subtilis and Bacillus megaterium within the concrete matrix enables Microbially Induced Calcium Carbonate Precipitation (MICP), which facilitates autonomous crack sealing through the formation of calcium carbonate crystals. This biological healing mechanism effectively reduces crack width, decreases permeability, and improves resistance against environmental deterioration. Experimental results consistently show improvements in compressive, tensile, and flexural strength due to crack closure and densification of the internal microstructure. The review also highlights that the inclusion of supplementary cementitious materials such as fly ash enhances sustainability and promotes better hydration and particle packing when used in optimum proportions. However, excessive replacement levels may reduce cement content and negatively affect mechanical performance. Microstructural investigations using SEM and XRD across various studies confirm the presence of calcite deposits within healed cracks, validating the effectiveness of bacterial activity in concrete healing. Additionally, environmental conditions such as moisture availability play a crucial role in activating dormant bacteria and sustaining the healing process. Overall, this review concludes that bacterial self-healing concrete is a viable and eco-friendly solution for improving structural durability, reducing maintenance costs, and advancing sustainable construction practices, provided that proper mix design and bacterial concentration are carefully optimized.

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