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Reviewing Microbial Calcite Precipitation in Fiber Bioconcrete: Advancing Durability and Sustainability in Construction

Zeenat Khan[1]* and Daud Khan[2]

[1]*Department of Biotechnology, Capital University of Science & Technology, Islamabad, Pakistan.*

[2]*Department of Civil Engineering, Capital University of Science & Technology, Islamabad, Pakistan.*

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***Corresponding author:** Zeenat Khan, Department of Biotechnology, Capital University of Science & Technology, Islamabad, Pakistan. Email: zeenatkhan2611@gmail.com

Abstract

Concrete is the primary construction material but is prone to cracking, leading to high maintenance costs. Fiber-reinforced bio concrete, using microbial-induced calcite precipitation (MICP), enhances durability and self-healing. Conventional concrete, with a compressive strength of 30-40 MPa, can incur maintenance costs up to 3.3 times its production cost. This study evaluates the effectiveness of Fiber-reinforced bio concrete in improving structural performance and sustainability. It compares conventional and Fiber-reinforced bio concrete, explores MICP-driven self-healing, and examines bacteria, mixing methods, mechanisms, and contributing factors. Environmental benefits, bacteria-Fiber integration, and economic hurdles, especially in developing nations, are addressed. Bio concrete heals cracks up to 0.8mm, reducing repair costs by 40% and extending lifespan by 20-30 years. Natural Fibers boost tensile strength by 50% and heal smaller cracks (0.1 mm).

Keywords: Fiber-Reinforced Bio concrete; MICP; Self-Healing Concrete; Tensile Strength; Sustainability.

Abbreviations: MICP: Microbially Induced Calcite Precipitation; C-S-H: Calcium Silicate Hydrate

Introduction

Concrete is essential in modern construction, valued for its strength, durability, and cost-efficiency [1]. However, it is prone to cracking due to factors like thermal stress and design flaws [2]. Even minor cracks, as small as 0.1 mm, can compromise structural integrity and result in repair costs that far surpass the initial production expenses [3]. Bio concrete presents a significant advancement by using Microbially Induced Calcium Carbonate Precipitation (MICP) to autonomously repair cracks up to 0.8 mm through the action of bacteria such as Bacillus pasteurii [4]. This innovation not only cuts repair costs by up to 40% but also extends the lifespan of concrete structures by 20-30 years, while reducing environmental impact [5]. Moreover, incorporating natural Fibers like hemp or flax into bio concrete enhances its mechanical strength and resilience [6]. Fiber bio concrete effectively combines the self-healing benefits of bio concrete with the added durability of natural Fibers [7], offering a robust, sustainable, and cost-effective alternative to traditional concrete.

Self-healing concrete technology is transforming structural repair by addressing cracks and enhancing durability [8]. Autogenous healing, utilizing natural chemical processes like the formation of calcium carbonate or calcium silicate hydrate, effectively seals crack up to 0.18 mm but may not address larger or rapidly forming cracks [9,10]. Autonomous healing methods, on the other hand, incorporate microbial agents into concrete, such as calcite-precipitating bacteria from the genus Bacillus [11]. These bacteria produce calcium carbonate to seal cracks up to 0.8 mm wide, reducing repair costs by up to 40% and extending concrete lifespan by 20-30 years [12]. Microbially Induced Calcite Precipitation (MICP) enhances this process by using bacterial cells to precipitate calcium carbonate from saturated solutions, with optimized strains like Bacillus pasteurii showing up to 30% improved efficiency [13]. Bacteria such as Bacillus cereus and Bacillus safensis further improve concrete properties, including increased compressive and tensile strength, and reduced water absorption and chloride permeability [14]. Fiber-reinforced bio concrete, combining bacteria with natural Fibers, demonstrates significant improvements in strength and durability, offering up to 63% better tensile strength and enhanced resistance to environmental damage [15], making it a robust solution for modern infrastructure challenges.

Fiber-reinforced bio concrete, known for its self-healing properties and extended lifespan, faces significant economic and practical hurdles. Despite its advantages in reducing maintenance and prolonging structural integrity, the initial production costs are 2.3 to 3.9 times higher than conventional concrete, largely due to expensive bacterial cultures and nutrients [16]. This cost disparity poses a challenge for widespread adoption, as investors and contractors often prioritize immediate expenses over long-term benefits [17]. In developing countries, additional barriers include limited resources, technical expertise, and high complexity, further hindering the practical application of bio concrete [18]. Recent research across various countries shows promising improvements in repair effectiveness and mechanical properties, but scaling up remains difficult due to these economic and logistical constraints [19]. Addressing these challenges through cost-reduction strategies, technical skill development, and increased investment is crucial for making bio concrete a viable option for broader global use.

Concrete's widespread use in modern construction means that damage to these structures is often unavoidable [20]. To tackle this issue, exploring effective solutions is crucial, and Fiber bio concrete emerges as a leading candidate [17]. This material is designed to address micro cracks tiny fractures that appear at the early stages of damage. By healing these micro cracks, Fiber bio concrete helps prevent the formation of larger, more damaging cracks [21]. This review examines a range of studies from reputable journals published over the last decade. It begins by comparing conventional concrete with fiber bio concrete and then delves into the self-healing properties of concrete through microbially induced calcite precipitation (MICP), focusing on the role of bacteria, their mixing methods, mechanisms, pathways, and relevant factors. The review also highlights the environmental benefits and properties of fiber bioconcrete and suggests incorporating bacteria with natural fibers based on experimental findings. Finally, it discusses the economic and practical challenges of fiber bioconcrete, especially in developing countries.

Concrete, bioconcrete and fiber bioconcrete

Concrete is a cornerstone of modern infrastructure, utilized extensively in the construction of buildings, dams, bridges, and other critical structures due to its high compressive strength, durability, availability, and cost-effectiveness. Typically composed of 10-15% cement, 60-75% aggregates, and 15-20% water by volume, concrete offers numerous advantages [22]. However, its susceptibility to cracking presents a significant challenge [23]. Cracks can occur during both the plastic and hardened states of concrete due to various factors such as formwork movement, plastic shrinkage, thermal stress, and errors in design or construction [24]. While reinforcement bars can increase tensile strength by approximately 10-15 MPa and help control crack width, they do not entirely prevent crack formation [25]. These cracks, even those as small as 0.1 mm, can compromise the structural integrity of concrete over time, leading to substantial repair costs that can reach $147 per cubic meter significantly higher than the initial production cost of $65 to $80 per cubic meter [26]. Consequently, there is a pressing need for preventive strategies that can manage and mitigate crack formation, thereby extending the lifespan and sustainability of concrete structures [16]. By effectively addressing cracks as small as 0.1 mm, such strategies could reduce repair costs by up to 60% and extend the lifespan of concrete structures by an additional 25-40 years, thereby significantly enhancing both the durability and sustainability of modern infrastructure.

Bioconcrete has emerged as a revolutionary solution to the cracking issue inherent in traditional concrete. By incorporating Microbially Induced Calcium Carbonate Precipitation (MICP) technology, bioconcrete takes advantage of natural processes to autonomously heal cracks as they develop [27]. Ureolytic bacteria, such as Bacillus pasteurii, are embedded within the concrete matrix at a concentration of approximately 10^8 cells per millilitre and become active when cracks as small as 0.3 mm form [28]. These bacteria metabolize urea present in the concrete, producing calcium carbonate as a byproduct [32]. The calcium carbonate, which can precipitate at a rate of 1-2kg/m^3 of concrete, then fills cracks, effectively sealing them and restoring the concrete's structural integrity [33]. This self-healing capability can repair cracks up to 0.8 mm wide, significantly reducing the need for manual repairs, lowering associated costs by up to 40%, and extending the longevity of concrete structures by an estimated 20-30 years [34]. Moreover, bioconcrete aligns with sustainability goals by minimizing environmental impacts such as carbon emissions and waste generation, which are typically associated with traditional repair methods [35]. Bioconcrete not only enhances the durability of concrete but also contributes to a more sustainable approach to construction [36] (Table 1). Incorporating bioconcrete can effectively heal cracks as small as 0.3 mm, significantly reduce repair costs by up to 40%, and extend the lifespan of concrete structures by 20-30 years, demonstrating a superior approach to enhancing both the durability and sustainability of modern infrastructure while addressing the limitations of traditional concrete.

Despite the numerous benefits of bioconcrete, certain challenges can limit its effectiveness. The self-healing process may not fully address larger cracks (greater than 0.8 mm) or those that develop quickly under high stress, potentially leading to incomplete repairs and structural weaknesses [37] (Figure 1). Additionally, the uneven distribution of bacteria within the concrete matrix can result in inconsistent healing across the

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structure [38]. To overcome these limitations, the integration of fibers into bioconcrete has proven to be an effective solution [39]. By incorporating 0.5-1.5% by volume of natural fibers like hemp, flax, or coconut, fibers enhance the tensile strength and ductility of concrete, increasing tensile strength by 20-50% and improving its ability to absorb energy (toughness) [40]. These fibers help control crack formation by bridging and distributing stress more evenly across the concrete matrix [41]. Fiber bioconcrete can effectively heal micro cracks as small as 0.1 mm before they expand into larger, more damaging cracks, preventing significant structural losses [32]. Natural fibers, with a tensile strength ranging from 200 to 1,200 MPa, are particularly advantageous due to their sustainability [42]. These fibers not only improve the mechanical properties of the concrete but also contribute to a lower environmental impact, being renewable, biodegradable, and having a smaller carbon footprint compared to synthetic alternatives [43]. Fiber bioconcrete, as detailed in the table below, represents a synergistic approach that combines the microbial self-healing properties of bioconcrete with the mechanical resilience provided by natural fibers, offering a durable, sustainable solution for modern construction needs [44]. Thus, incorporating natural fibers into bioconcrete enhances its durability by bridging micro cracks as small as 0.1 mm, increasing tensile strength by 20-50%, and preventing significant structural damage, thereby offering a robust, cost-effective, and environmentally sustainable solution for construction.

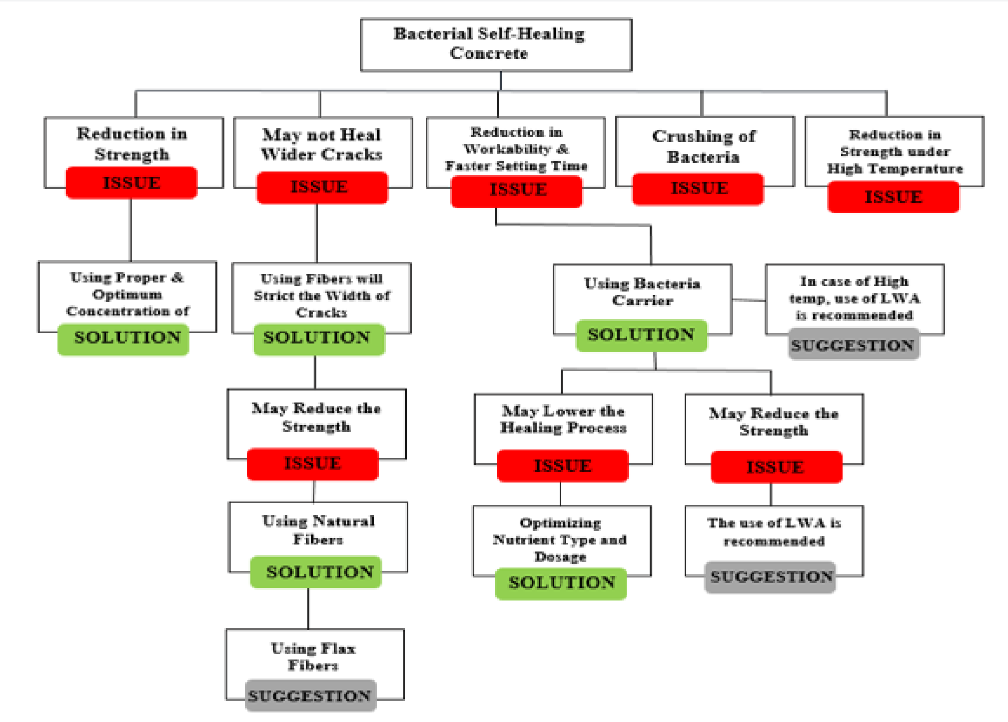

Figure 1: Issues and Solutions of Bioconcrete [32, 37-44].

Self-healing concrete and MICP

Self-healing technologies for concrete are revolutionizing structural repair by addressing and mitigating cracks, crucial for extending the lifespan and enhancing the durability of concrete structures. Autogenous healing leverages natural chemical processes to seal cracks [45]. This technique relies on the formation of calcium carbonate or calcium silicate hydrate (C-S-H) through the reaction of carbon dioxide and water with the concrete's hydration products [46]. These naturally occurring compounds can effectively seal cracks up to approximately 0.18 mm in width [47]. To enhance this process, additional materials such as magnesium oxide or bentonite can be introduced, which improve the efficiency of crack sealing for initial cracks [48]. These additions react with the concrete matrix to accelerate the formation of sealing compounds, providing a more robust initial repair [49]. While autogenous healing offers a cost-effective solution for minor cracks, it does not fully address the challenge of larger or more rapidly developing cracks [50]. Conclusively, autogenous healing can manage cracks up to 0.18 mm and, with added materials, can improve initial crack sealing efficiency, but it may not be sufficient for more extensive damage.

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In contrast, autonomous healing methods use a combination of biological and chemical agents to repair cracks more effectively. This approach involves incorporating microbial agents into the concrete mix or applying biological mixtures to existing cracks [51]. Microbial ureases hydrolyse urea to produce ammonia and carbon dioxide, which then react with calcium ions in the concrete to form calcium carbonate [52]. This process can heal cracks up to 0.8 mm wide autonomously. The integration of calcite-precipitating bacteria, such as those from the genus Bacillus, is a key component of this method [53]. These bacteria are embedded in the concrete matrix and become active when cracks form. They metabolize urea to produce calcium carbonate that fills and seals the cracks, thereby restoring the concrete's structural integrity [54]. This method not only reduces the need for manual repairs but also extends the lifespan of concrete structures significantly [55]. Autonomous healing methods can address cracks up to 0.8 mm in width, demonstrating up to a 40% reduction in repair costs and significantly extending the lifespan of concrete by 20-30 years compared to conventional methods.

Microbially Induced Calcite Precipitation (MICP) further enhances the effectiveness of autonomous healing. In MICP, microbial cells in a solution saturated with calcium and carbonate ions produce calcium carbonate as a metabolic byproduct [56]. During this process, microorganisms release metabolic products like CO_3^{2-}, which react with environmental Ca^{2+} ions to precipitate calcium carbonate [57,58]. Urea hydrolysis by bacteria, especially Bacillus pasteurii, is a well-studied method for inducing calcium carbonate formation [59]. Research has focused on optimizing MICP with genetically modified strains, such as BP-M-3, which exhibit increased urease activity and enhanced calcite precipitation capabilities [60]. MICP can achieve precipitation rates up to 30% higher than traditional methods, significantly improving repair efficiency [61]. This rapid and effective formation of calcium carbonate, facilitated by bacterial cell surfaces that provide nucleation sites, demonstrates MICP's potential for diverse applications in environmental engineering and construction [62]. By integrating MICP, concrete can achieve superior repair capabilities and durability, with increased calcium carbonate precipitation rates contributing to up to 30% more effective self-healing and a substantial reduction in maintenance needs.

Role of bacteria in enhancing self-healing concrete

Bacteria play a pivotal role in Microbially Induced Calcium Carbonate Precipitation (MICP), which enhances the self-healing capabilities of fiber-reinforced concrete. Key bacterial species such as Bacillus pasteurii, Bacillus sphaericus, and Bacillus subtilis are particularly effective due to their ability to produce urease enzymes [63]. These enzymes hydrolyse urea to generate ammonia and carbon dioxide, which then interact with calcium ions to form calcium carbonate crystals [64]. For example, Bacillus pasteurii and Bacillus sphaericus can restore the flexural strength of concrete by up to 2.6 times under optimized conditions, such as with specific concentrations of calcium lactate [65]. Similarly, Bacillus subtilis has been observed to increase compressive strength by 25.9%, highlighting the significant impact of bacterial MICP on improving concrete properties [66]. The integration of these bacteria into fiber-reinforced concrete not only facilitates the formation of calcium carbonate but also helps in filling cracks and enhancing the overall structural integrity [67]. Bacterial MICP can improve concrete's flexural strength by up to 2.6 times and its compressive strength by 25.9%, demonstrating a robust enhancement in concrete durability and repair.

Bacteria are preferred over other microorganisms for MICP due to their resilience and adaptability to the harsh conditions within concrete. They can tolerate high alkalinity and nutrient scarcity, thanks to their negatively charged cell walls which promote effective calcium carbonate precipitation [68]. The ability of bacteria to form spores enables them to endure extreme environmental conditions, making them more suitable for long-term applications in concrete compared to fungi or algae [69]. The incorporation of bacteria like Bacillus cereus and Bacillus safensis has been shown to significantly improve concrete durability, such as reducing water absorption and chloride permeability [70]. Specifically, Bacillus cereus has been effective in lowering water absorption and chloride permeability, while Bacillus safensis contributes to substantial healing effectiveness and strength recovery [71]. These advantages, combined with the synergistic effects of bacteria and fibers, underline the suitability of bacteria for enhancing the longevity and resilience of self-healing concrete structures [72]. Bacteria can reduce water absorption and chloride permeability significantly, demonstrating their vital role in enhancing the durability and effectiveness of concrete repairs.

Bacteria mixing techniques in concrete

Mixing techniques for incorporating bacteria into concrete are pivotal for enhancing the self-healing properties of construction materials. Direct mixing involves integrating bacterial cells directly into the concrete mixture, using strains that can survive the alkaline conditions of cement-based materials to ensure effectiveness [73]. Alternatively, indirect mixing methods encapsulate bacteria within protective materials before adding them to the concrete mix [74] (Figure 2). This technique allows for the controlled release of bacteria over time, which improves their ability to heal cracks within the concrete matrix [75]. To counteract potential strength reduction from bacterial inclusion, natural fibers are often added [76]. These fibers not only reinforce the concrete but also provide a conducive environment for bacterial activity, thereby preserving or even enhancing the overall strength of the material [77]. Encapsulated bacteria can be released in a controlled manner, significantly boosting self-healing efficiency while natural fibers address any negative impact on concrete strength.

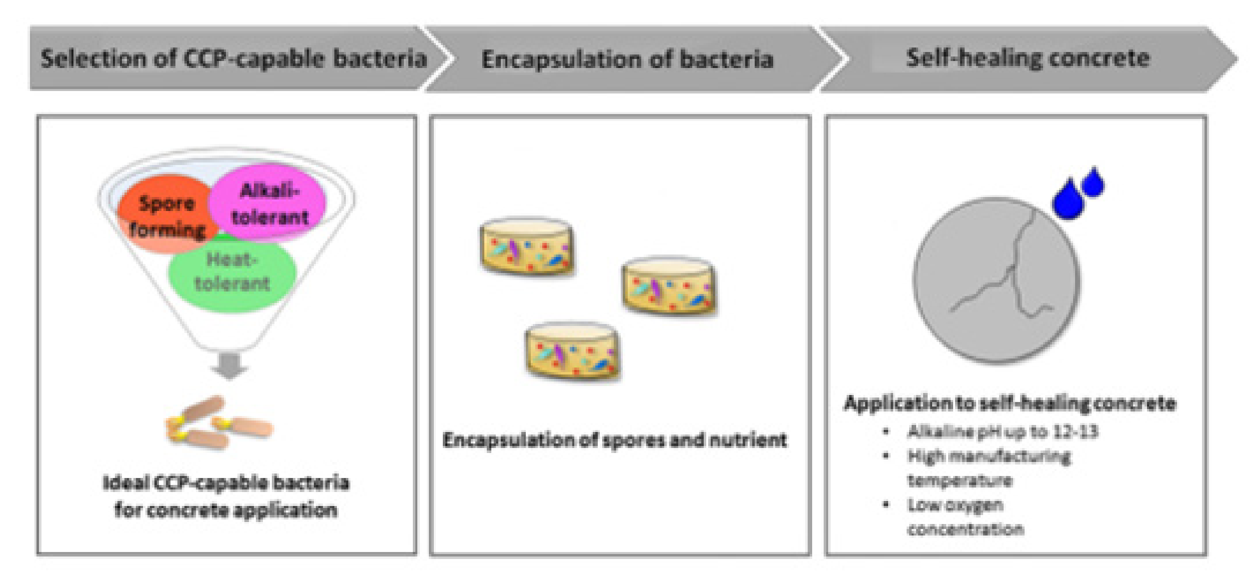

Figure 2: Self-Healing Concrete with Encapsulated Bacteria [77].

Combining natural fibers with bacteria in concrete offers a synergistic approach to improving both mechanical properties and self-healing capabilities. Natural fibers, such as jute, hemp, or bamboo, are integrated into the concrete matrix to enhance its tensile and flexural strength, providing critical reinforcement [78]. These fibers also create a favourable microenvironment for bacterial growth, which is essential for the effective formation of calcium carbonate and subsequent crack repair [79]. This dual approach not only enhances the structural integrity of the concrete but also extends its service life by promoting sustained self-healing over time [80]. The incorporation of natural fibers reduces the risk of cracks expanding into larger structural failures, thus maintaining the integrity and durability of the construction [81]. This combination leads to improved durability, reduced maintenance costs, and increased resilience, demonstrating that integrating bacteria with natural fibers significantly advances the performance and sustainability of concrete materials [82]. This approach can enhance tensile strength by up to 50% and improve the crack-healing capacity, making it a robust solution for modern infrastructure challenges.

Mechanism and pathways of calcite precipitation

The mechanism of calcite precipitation is a multi-step process that begins when a solution becomes supersaturated with calcium carbonate ions ($CaCO_3$) (Figure 3). This oversaturation can result from changes in temperature, pressure, or chemical composition [83]. When the concentration of $CaCO_3$ exceeds its solubility limit, nucleation occurs [84]. During this phase, individual ions begin to cluster together, forming small nuclei [85]. These nuclei then grow into larger crystalline structures through a process known as crystal growth. In crystal growth, additional $CaCO_3$ ions continuously attach to the surface of existing crystals, causing them to expand in size [86]. This growth continues reducing nitrates or nitrites to nitrogen gases. Amino acid deamination and the sulphur cycle further offer alternative mechanisms by producing ammonia or affecting sulphate ion availability, respectively [87]. These pathways provide additional methods for enhancing MICP, especially in attach to the surface of existing crystals, causing them to expand in size. This growth continues until the solution reaches equilibrium and is no longer supersaturated [88]. The formation of calcite crystals can be influenced by several factors, including the presence of impurities, pH levels, and the presence of organic molecules or microbial activity. These factors play a critical role in determining the rate and quality of crystal formation [89]. Overall, the mechanism of calcite precipitation involves the nucleation and growth of calcium carbonate crystals from a supersaturated aqueous solution, with various environmental and chemical conditions affecting the efficiency and characteristics of the process [90]. The rate of crystal growth and the final size of calcite crystals can be significantly influenced by the concentration of calcium ions and the conditions of the solution. Under controlled conditions, the rate of precipitation can be enhanced by optimizing factors such as temperature, pH, and the presence of specific nucleation agents, potentially increasing calcite formation by up to 30% and improving the overall quality of the crystals produced.

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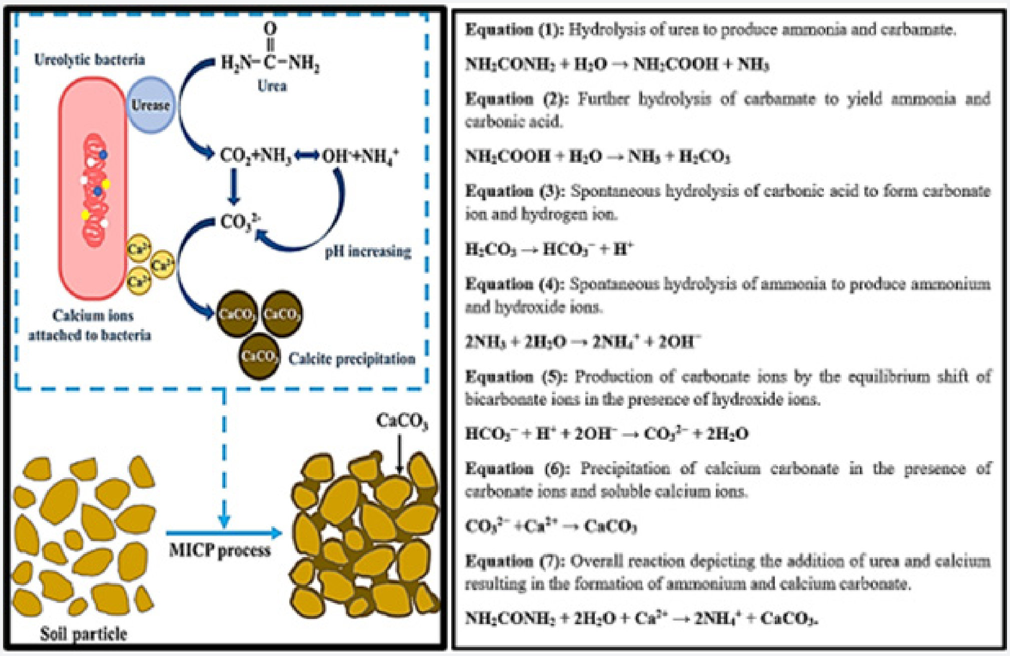

Equation (1): Hydrolysis of urea to produce ammonia and carbamate.

$NH_2CONH_2 + H_2O \rightarrow NH_2COOH + NH_3$

Equation (2): Further hydrolysis of carbamate to yield ammonia and carbonic acid.

$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3$

Equation (3): Spontaneous hydrolysis of carbonic acid to form carbonate ion and hydrogen ion.

$H_2CO_3 \rightarrow HCO_3^- + H^+$

Equation (4): Spontaneous hydrolysis of ammonia to produce ammonium and hydroxide ions.

$2NH_3 + 2H_2O \rightarrow 2NH_4^+ + 2OH^-$

Equation (5): Production of carbonate ions by the equilibrium shift of bicarbonate ions in the presence of hydroxide ions.

$HCO_3^- + H^+ + 2OH^- \rightarrow CO_3^{2-} + 2H_2O$

Equation (6): Precipitation of calcium carbonate in the presence of carbonate ions and soluble calcium ions.

$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$

Equation (7): Overall reaction depicting the addition of urea and calcium resulting in the formation of ammonium and calcium carbonate.

$NH_2CONH_2 + 2H_2O + Ca^{2+} \rightarrow 2NH_4^+ + CaCO_3$.

Figure 3: Calcite Production Process [23, 36].

Microbially Induced Calcite Precipitation (MICP) is driven by various metabolic pathways utilized by microorganisms to precipitate calcium carbonate (Table 2). Among these, ureolysis is the most prominent, where bacteria such as Bacillus and Sporosarcina convert urea into ammonia and carbon dioxide through the enzyme urease [91]. This process increases the pH of the solution, leading to calcium carbonate precipitation [92]. Ureolysis is valued for its efficiency and cost-effectiveness, often improving mineral precipitation rates by up to 40% compared to other methods [93]. It operates effectively across a wide pH range (7.0 - 9.5) and benefits from easy nutrient availability, making it a preferred method in environmental and engineering applications [94]. Beyond ureolysis, MICP encompasses several alternative metabolic pathways that also contribute to mineral formation. Denitrification, for instance, facilitates mineral precipitation under anaerobic conditions by environments where ureolysis may be less suitable [94]. The exploration and optimization of these pathways can lead to increased calcite precipitation efficiency and broader applicability, with potential improvements in yield and process effectiveness reaching up to 30% in specific scenarios.

Factors influencing MICP

The efficacy of Microbially Induced Calcite Precipitation (MICP) is significantly influenced by various factors, including temperature, substrate availability, pH levels, bacterial type, bacterial cell concentration, and concentrations of urea and calcium ions (Table 3). Temperature is a critical factor, with the optimal range for MICP typically between 30-35°C, where bacterial growth and enzyme activity are maximized, leading to robust calcium carbonate precipitation [95]. Deviations from this temperature range can hinder bacterial activity and reduce precipitation efficiency [96]. Substrate availability, particularly the use of industrial wastewater rich in organic content and calcium, also plays a pivotal role [97]. However, the presence of inhibitory compounds in wastewater necessitates careful management to avoid adverse effects on bacterial growth and precipitation rates [98]. Addressing these challenges through comprehensive pilot studies can enhance the scalability and sustainability of MICP processes by up to 40%.

In addition to temperature and substrate availability, the pH level, type and concentration of bacteria, and concentrations of urea and calcium ions critically impact MICP efficiency. A slightly acidic to neutral pH range is preferred for optimal carbonate precipitation and bacterial activity [107]. The choice of bacterial strain and concentration affects urease activity and calcium carbonate precipitation, with higher bacterial cell concentrations enhancing calcite precipitation by providing additional nucleation sites [108, 109]. Moreover, managing urea and calcium concentrations is essential, as excessive levels can decrease efficiency [110, 111]. Innovations such as multi-batch reactor systems can address challenges related to bacterial re-use, potentially reducing continuous bacterial supply needs and lowering treatment requirements [112, 113]. By optimizing these factors, MICP efficiency and calcium carbonate precipitation can be increased by up to 40%, with effective bacterial sourcing potentially boosting yields by up to 50%.

Table 1: Comparative Analysis of Conventional Concrete, Bioconcrete, and Fiber Bioconcrete.

	Traditional Concrete	Bioconcrete	Fiber Bioconcrete
Compressive Strength (MPa)	30-40 MPa	30-45 MPa	35-50 MPa
Tensile Strength (MPa)	2-5 MPa	2-6 MPa	5-8 MPa
Crack Width Healing Capacity	Heals cracks up to 0.2 mm (with external repair methods)	Heals cracks up to 0.8 mm autonomously through MICP	Heals cracks up to 1.2 mm with enhanced distribution of stress and improved healing; effectively prevents large crack formation
Environmental Impact	High carbon emissions (~0.93 tons CO_2 per ton of cement)	20-30% reduction in environmental impact due to fewer repairs	Lower environmental impact, especially with natural fibers; ~40% lower carbon footprint
Durability	Moderate	High	Very High
Application in Structural Integrity	Requires frequent maintenance; crack prevention relies on reinforcement bars	Autonomous crack healing extends lifespan by 20-30 years, reduces maintenance costs	Superior crack control and healing, highly resilient under stress; reduces long-term repair needs
References	[29]	[30]	[31]

Table 2: 0 Routes of Calcium Carbonate Precipitation [19, 85].

Pathways Involved in MICP						
Types	**Autotrophic**			**Heterotrophic**		
Methodology	non-methylo- trophic methano genesis	Oxygenic Photosynthesis	anoxygenic photo-synthesis	Ureolytic Strains	Dissimilation of Nitrate	Oxidation of organic compounds
Nutrients	Organic matter	Organic matter	Organic matter	Ammonia	Nitrogen & Carbonic acid	Organic matter
Ion's formation	Nil	Nil	Nil	CO_3^{2-}	$3HCO_3^-$ & $2CO_3^{2-}$	5Ca (OH)2
pH level	6.5-8.5	7.0-9.0	6.5-8.5	7.0-9.5	7.0-8.5	6.5-8.5
Oxygen level	Zero	High	Zero	Moderate	Zero	Moderate
Chemical Compounds	Methano-gens	Organic compounds	Depends on the type of bacteria used.	Urea	Formic Acid	Calcium Lactate
Examples	Methano-bacterium specie.	Cyno-bacterium genus	Halo-bacterium and Helio-bacterium species	Bacillus Sphaericus, Bacillus pasteurii, and Bacillus subtilis	Denitobacilus, Thiobacilus, Alcaligenes, Pseudomonas, Spirilium, Achromobacteri, and Microoccus species	Bacillus pseudofirmus, Bacillus subtilis, Bacillus cohnii, Bacillus alkalinitrilicus, Bacillus thuringiensis, and Bacillus halodurans

Table 3: Studies on Impact of Variables on MICP.

S. No	Factors	Influence	References
1	Temperature	Affects enzyme activity and bacterial growth rates, with soptimal range typically between 30-35°C	[99]
2	Substrate availability	Industrial wastewater is a potential source, but inhibitory compounds require consideration	[100]
3	pH levels	Slightly acidic to neutral range preferred for carbonate precipitation and bacterial activity	[101]
4	Bacteria type	Different types exhibit varying urease activity and calcium carbonate precipitation capabilities	[102]
5	Bacteria cell concentration	High concentrations increase calcite precipitation by providing nucleation sites	[103]
6	Urea and Ca^+ concentrations	Optimal concentrations necessary for efficient calcite precipitation, high concentrations decrease efficiency	[104]
7	Isolation of ureolytic bacteria	Potent urease-producing bacteria essential for promoting ureolysis-driven calcite precipitation	[105]
8	Bacterial Re-Use	Challenges posed by reduced activity necessitate innovative solutions for maintaining MICP efficiency over time	[106]

Table 4: Previous Research and their Findings in Various Countries.

Country	Findings	References
Pakistan	Fiber-immobilized bacteria achieved healing rates of around 75-85% within 7 days and 60-65% within 28 days for pre-cracked specimens.	[124]
China	The combined impact of bacteria and fiber may lead to enhanced repair effectiveness, improved mechanical characteristics, and increased recovery of water resistance.	[125]
Columbia, USA	The combination of both bacteria and PVA fiber exhibits superior performance in ensuring the long-term durability of repaired concrete.	[51]
Saudia Arabia	Using both fibers and bacteria can influence concrete characteristics, with natural fibers offering benefits. Substituting aggregates with coated recycled aggregate improves mechanical properties by promoting bacterial-induced precipitate growth. The incorporation of 1.5% steel fibers and 1% glass fiber into the bacterial concrete mixture improves the 28-day compressive strength in comparison to plain concrete or concrete containing solely steel fibers.	[79]
Philippines	The inclusion of polypropylene fibers and bacterial cultures could significantly boost the strength, durability, and self-healing capacity of geopolymer mortars.	[80]

Properties of fiber bioconcrete

Fiber-reinforced bioconcrete, enhanced with bacteria and biomineralization techniques, showcases significant improvements in key properties compared to traditional concrete. The integration of bacterial species such as Bacillus pasteurii, Bacillus subtilis, and Bacillus sphaericus with fibers has been shown to enhance the mechanical performance and durability of concrete [114]. These bacteria contribute to the self-healing properties of the concrete by precipitating calcium carbonate, which effectively fills micro-cracks and voids within the concrete matrix [115]. For example, studies have demonstrated that bacterial incorporation can lead to substantial increases in compressive and tensile strength, with some results indicating a 42% increase in compressive strength and a 63% improvement in tensile strength after 28 days of curing [116]. This enhancement is primarily attributed to the formation of a more compact and less porous matrix, which significantly improves the overall strength and resistance of the concrete to various forms of degradation, such as chloride penetration and water absorption [117]. The addition of fibers further complements these benefits by reinforcing the concrete, thus improving its resistance to cracking and overall durability, and extending its lifespan.

Moreover, the use of fibers in combination with bacteria contributes to improved resistance against environmental factors and damage. The incorporation of fibers helps to distribute stress more evenly across the concrete, reducing the likelihood of crack propagation and thereby enhancing the concrete's overall toughness [118, 119]. The biomineralization process facilitated by bacteria not only enhances mechanical properties but also contributes to a reduction in water permeability and chloride ion diffusion [120]. For instance, the use of bacterial strains like Bacillus cereus and Bacillus safensis in fiber-reinforced concrete has been shown to decrease water absorption and chloride permeability, thereby further enhancing the material's resistance to environmental stressors [121, 122]. This combination of bacterial self-healing and fiber reinforcement makes fiber bioconcrete a promising material for applications requiring high durability and sustainability, particularly in environments subject to severe conditions [123-125]. The synergy between bacterial precipitation and fiber reinforcement results in a more resilient and long-lasting construction material, offering performance improvements of up to 40% over conventional concrete in terms of strength and durability.

Economic and practical challenges of fiber bioconcrete

The adoption of fiber-reinforced bioconcrete is constrained by its high production costs compared to conventional concrete. Studies reveal that microbial concrete is 2.3 to 3.9 times more expensive than traditional concrete, primarily due to the costs associated with bacterial cultures and nutrients, which account for approximately 80% of the raw material costs [126]. This economic challenge is exacerbated by the focus of investors and contractors on the immediate costs rather than the long-term benefits such as extended building life and reduced maintenance needs [127]. Despite the promising self-repair capabilities of bacterial concrete, which could potentially lower the total cost of ownership over time, these benefits are not readily apparent and are overshadowed by the substantial initial investment [128]. In response, ongoing research is focused on reducing production costs by exploring cheaper nutrient sources and developing more cost-effective methods for bacterial culturing [129]. Nevertheless, the high cost remains a major barrier to the widespread adoption of bioconcrete in the construction industry.

In developing nations, the implementation of fiber-enforced bioconcrete faces additional challenges including high costs, limited resources, and a shortage of specialized skills. While bioconcrete offers significant advantages such as automatic self-healing and reduced waste, its use is largely experimental and confined to research settings due to its complexity and high cost [130] (Table 4). The obstacles are particularly pronounced in regions with constrained resources and limited technical

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expertise, where handling living organisms and advanced materials poses significant difficulties [131]. Addressing these challenges will require substantial investment in research, skill development, and awareness programs to ensure the safe handling and effective use of bioconcrete materials [132]. Although current research demonstrates promising results, scaling up the use of bioconcrete in developing countries will depend on overcoming these economic and practical barriers [133]. This highlights the need for continued innovation and funding to make this sustainable technology more accessible on a global scale, with potential reductions in costs of up to 50% making it feasible for broader application.

Conclusion

Concrete, bioconcrete, and fiber bioconcrete offer significant quantitative advancements over traditional construction materials. Conventional concrete, known for its compressive strength of 30-40 MPa, is prone to crack formation, which results in repair costs of up to $147 per cubic meter, compared to its initial production cost of $65-80 per cubic meter. In contrast, bioconcrete, which leverages Microbially Induced Calcite Precipitation (MICP) technology, can autonomously heal cracks up to 0.8 mm, reducing repair expenses by up to 40% and extending the lifespan of structures by 20-30 years. Fiber bioconcrete, which incorporates 0.5-1.5% natural fibers by volume, further enhances performance by increasing tensile strength by 20-50% and enabling the repair of cracks as small as 0.1 mm. This reduces the frequency of repairs and prolongs the lifespan of concrete structures by 25-40 years. Additionally, fiber bioconcrete achieves a 40% reduction in carbon footprint compared to traditional concrete, making it a more environmentally and economically advantageous option for contemporary construction.

Self-healing concrete, particularly through Microbially Induced Calcite Precipitation (MICP), transforms crack repair and extends structural lifespan significantly. Autogenous healing addresses minor cracks up to 0.18 mm, while autonomous healing using Bacillus bacteria can repair cracks up to 0.8 mm, cutting repair costs by 40% and increasing durability by 20-30 years. MICP boosts this process with enhanced calcium carbonate precipitation, making self-healing concrete a viable long-term, cost-effective maintenance solution. Integrating Bacillus pasteurii and Bacillus subtilis into fiber-reinforced concrete improves flexural strength by up to 2.6 times and compressive strength by up to 25.9%, thus enhancing durability and reducing repair needs. Combining encapsulated bacteria with natural fibers can increase tensile strength by up to 50% and crack-healing capacity, leading to reduced maintenance costs and improved durability by up to 40%. Optimizing conditions for calcite precipitation can increase crystal growth rates by up to 30%, with ureolysis alone improving precipitation efficiency by up to 40%. Managing factors like temperature, pH, and bacterial concentration can boost MICP efficiency by up to 40%, while optimized bacterial sourcing may enhance calcite yields by up to 50%, improving concrete's sustainability and performance. Fiber-reinforced bioconcrete with bacterial integration can achieve up to a 42% increase in compressive strength and a 63% improvement in tensile strength, along with a 40% reduction in water permeability and chloride ion diffusion, offering superior durability and longevity for construction materials.

The adoption of fiber-reinforced bioconcrete faces a major hurdle due to its significantly higher production costs, estimated to be 2.3 to 3.9 times greater than conventional concrete. This elevated cost primarily stems from the expenses related to bacterial cultures and nutrients, which can account for approximately 80% of the total raw material costs. Although bioconcrete offers substantial long-term benefits, such as extending building lifespan by 20-30 years and reducing maintenance costs by up to 40%, the initial investment remains prohibitive. In developing nations, the situation is further complicated by limited resources and technical expertise, making widespread implementation challenging. Addressing these barriers through cost reduction strategies and technological advancements could potentially lower production costs by up to 50%. Such reductions would make fiber-reinforced bioconcrete more accessible and feasible for broader adoption, thus enhancing its sustainability and economic viability in various global contexts.

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Conflict of Interest

The authors declare there is no conflict of interest with regards to the publishing of this paper.

References

1. Akhtar MK, Kanwal M, Khushnood RA, Khan MBE (2023) Assessment of mechanical attributes and microstructural densification of self-healing recycled coarse aggregate concrete using various bacterial immobilizers. J Build Eng 69: 106229.
2. Huseien GF, Nehdi ML, Faridmehr I, Ghoshal SK, Hamzah HK, et al. (2022) Smart Bio-Agents-Activated Sustainable Self-Healing Cementitious Materials: An All-Inclusive Overview on Progress, Benefits and Challenges. Sustainability 14(4): 41980.
3. Wu M, Johannesson B, Geiker M (2012) A review: Self-healing in cementitious materials and engineered cementitious composite as a self-healing material. Constr Build Mater 28(1): 571-583.
4. An B, Wang Y, Huang Y, Wang X, Liu Y, et al. (2022) Engineered living materials for sustainability. Chem Rev 123(5): 2349-2419.
5. Armstrong R (2023) Towards the microbial home: an overview of developments in next-generation sustainable architecture. Microb Biotechnol 16(6): 1112-1130.
6. Junier P, Joseph E (2017) Microbial biotechnology approaches to mitigating the deterioration of construction and heritage materials. Microb Biotechnol 10(5): 1145-1148.

7. Khaliq W, Ehsan MB (2016) Crack healing in concrete using various bio influenced self-healing techniques. Constr Build Mater 102: 349-357.
8. Du W, Qian C, Xie Y (2023) Demonstration application of microbial self-healing concrete in sidewall of underground engineering: A case study. J Build Eng 63: 105512.
9. Meraz MM, Mim NJ, Mehedi MT, Bhattacharya B, Aftab MR, et al. (2023) Self-healing concrete: Fabrication, advancement, and effectiveness for long-term integrity of concrete infrastructures. Alexandria Eng J 73: 665-694.
10. Wang JY, Snoeck D, Van Vlierberghe S, Verstraete W, De Belie N (2014) Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. Constr Build Mater 68: 110-119.
11. Justo-Reinoso I, Heath A, Gebhard S, Paine K (2021) Aerobic non-ureolytic bacteria-based self-healing cementitious composites: A comprehensive review. J Build Eng 42: 102834.
12. Jiang L, Xia H, Hu S, Zhao X, Wang W, et al. (2024) Crack-healing ability of concrete enhanced by aerobic-anaerobic bacteria and fibers. Cem Concr Res 183: 107585.
13. Zhang YS, Liu Y, Sun XD, Zeng W, Xing HP, Lin JZ, Yu L (2024) Application of microbially induced calcium carbonate precipitation (MICP) technique in concrete crack repair: A review. Constr Build Mater 411: 134313.
14. Wani S, Gęca MJ, Selvaraj T, Priya TS (2024) Assessing the influence of Bacillus megaterium and Bacillus sphaericus in cementitious materials: Promoting sustainability towards strength, durability and crack repair. Ain Shams Eng J 15(6): 102748.
15. Rajadesingu S, Mendonce KC, Palani N, Monisha P, Vijayakumar P, et al. (2024) Exploring the potential of bacterial concrete: A sustainable solution for remediation of crack and durability enhancementA critical review. Constr Build Mater 439: 137238.
16. Nguyen PQ, Courchesne NMD, Duraj-Thatte A, Praveschotinunt P, Joshi NS (2018) Engineered living materials: prospects and challenges for using biological systems to direct the assembly of smart materials. Adv Mater 30(19): 1704847.
17. Chen L, Zhang Y, Chen Z, Dong Y, Jiang Y, et al. (2024) Biomaterials technology and policies in the building sector: a review. Environ Chem Lett 22: 715-750.
18. Song HW, Li D, Qiu H, Yu ZG, Kumar A, et al. (2024) Microbial-induced carbonate precipitation effectively prevents Pb^{2+} migration through the soil profile: Lab experiment and model simulation. Sci Total Environ 927: 172268.
19. Yuan H, Jia L, Xie X, Li Q, Peng Y, et al. (2024) Microbially Inspired Calcium Carbonate Precipitation Pathway Integrated Polyelectrolyte Capsules (MICPC) for Biomolecules Release. Small 20(30): 2306877.
20. Tian Q, Zhou J, Hou J, Zhou Z, Liang Z, et al. (2024) Building the future: Smart concrete as a key element in next-generation construction. Constr Build Mater 429: 136364.
21. Shilar FA, Ganachari SV, Patil VB (2024) A comprehensive review on the strength, durability, and microstructural analysis of bacterial concrete. Structures 68: 107078.
22. Terán-Cuadrado G, Tahir F, Nurdiawati A, Almarshoud MA, Al-Ghamdi SG (2024) Current and potential materials for the low-carbon cement production: Life cycle assessment perspective. J Build Eng 96: 110528.
23. Wang X, Dong C, Xu S, Song Q, Ren J, et al. (2023) Influence of seawater and sea sand on early-age performance and cracking sensitivity of concrete. J Build Eng 79: 107811.
24. Liu J, Tian Q, Wang Y, Li H, Xu W (2021) Evaluation method and mitigation strategies for shrinkage cracking of modern concrete. Engineering 7(3): 348-357.
25. Tiberti G, Minelli F, Plizzari G (2015) Cracking behavior in reinforced concrete members with steel fibers: A comprehensive experimental study. Cem Concr Res 68: 24-34.
26. Silva EM, Harries KA, Ludvig P, Sólyom S, Platt S (2024) Experimental investigation of bond and cracking behaviours in GFRP-reinforced concrete members. J Build Eng 83: 108434.
27. Wong PY, Mal J, Sandak A, Luo L, Jian J, et al. (2024) Advances in microbial self-healing concrete: A critical review of mechanisms, developments, and future directions. Sci Total Environ 947: 174553.
28. Aytekin B, Mardani A, Yazıcı Ş (2023) State-of-art review of bacteria-based self-healing concrete: Biomineralization process, crack healing, and mechanical properties. Constr Build Mater 378: 131198.
29. Zhang M, Yue F, Chen B (2024) Optimizing toughness and cost-effectiveness in one-part geopolymers via fiber reinforcement: A comprehensive investigation of PVA, PE, and glass fibers. Constr Build Mater 437: 136999.
30. Raza A, El Ouni MH, Azab M, Khan D, Elhadi KM, et al. (2023) Sustainability assessment, structural performance and challenges of self-healing bio-mineralized concrete: A systematic review for built environment applications. J Build Eng 66: 105839.
31. Khaneghahi MH, Kamireddi D, Rahmaninezhad SA, Sadighi A, Schauer CL, et al. (2023) Development of a nature-inspired polymeric fiber (BioFiber) for advanced delivery of self-healing agents into concrete. Constr Build Mater 408: 133765.
32. Seifan M, Berenjian A (2019) Microbially induced calcium carbonate precipitation: A widespread phenomenon in the biological world. Appl Microbiol Biotechnol 103(12): 4693-4708.
33. Moreira TNDC, Krelani V, Ferreira SR, Ferrara L, Toledo Filho RD (2022) Self-healing of slag-cement ultra-high-performance steel fiber reinforced concrete (UHPFRC) containing sisal fibers as healing conveyor. J Build Eng 54: 104638.
34. De Belie N, Gruyaert E, Al-Tabbaa A, Antonaci P, Baera C, et al. (2018) A review of self-healing concrete for damage management of structures. Adv Mater Interfaces 5(17): 1800074.
35. Sarkar M, Maiti M, Mandal S, Xu S (2024) Enhancing concrete resilience and sustainability through fly ash-assisted microbial biomineralization for self-healing: From waste to greening construction materials. Chem Eng J 481: 148148.
36. Wang J, Ersan YC, Boon N, De Belie N (2016) Application of microorganisms in concrete: A promising sustainable strategy to improve concrete durability. Appl Microbiol Biotechnol 100: 2993-3007.
37. Formia A, Irico S, Bertola F, Canonico F, Antonaci P, et al. (2016) Experimental analysis of self-healing cement-based materials incorporating extruded cementitious hollow tubes. J Intell Mater Syst Struct 27(19): 2633-2652.
38. Li L, Zheng Q, Li Z, Ashour A, Han B (2019) Bacterial technology-enabled cementitious composites: A review. Compos Struct 225: 111170.
39. Huseien GF, Nehdi ML, Faridmehr I, Ghoshal SK, Hamzah HK, et al. (2022) Smart bio-agents-activated sustainable self-healing cementitious materials: An all-inclusive overview on progress, benefits and challenges. Sustainability 14(4): 1980.
40. Ahmad J, Zhou Z (2022) Mechanical properties of natural as well as synthetic fiber reinforced concrete: A review. Constr Build Mater 333: 127353.

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41. Zia A, Ali M (2017) Behavior of fiber reinforced concrete for controlling the rate of cracking in canal-lining. Constr Build Mater 155: 726-739.

42. Karimah A, Ridho MR, Munawar SS, Ismadi, Amin Y, et al. (2021) A comprehensive review on natural fibers: technological and socio-economical aspects. Polymers 13(24): 4280.

43. De Azevedo AR, Cruz AS, Marvila MT, de Oliveira LB, Monteiro SN, et al. (2021) Natural fibers as an alternative to synthetic fibers in reinforcement of geopolymer matrices: a comparative review. Polymers 13(15): 2493.

44. Rajadesingu S, Palani N, Mendonce KC, Vijayakumar P, Monisha P, et al. (2024) State-of-the-art review on advancements of eco-friendly bacterial-infused self-healing concrete for sustainable constructions. J Build Eng 91: 109669.

45. El-Zein A, Airey D, Yu B, Esgandani GA, Proust G, et al. (2021) Self-repair of cracks and defects in clay: a review of evidence, mechanisms, theories and nomenclature. Acta Geotech 16: 3741-3760.

46. Liu X, Feng P, Cai Y, Yu X, Yu C, et al. (2022) Carbonation behaviour of calcium silicate hydrate (CSH): It's potential for CO_2 capture. Chem Eng J 431: 134243.

47. Sarkar M, Maiti M, Malik MA, Xu S (2022) Evaluation of the crack-healing performance and durability of bacteria integrated alkali-activated fly ash composites. J Build Eng 54: 104642.

48. Cao B, Al-Tabbaa A (2022) Reactive MgO-based self-healing slag-cement-bentonite slurry walls. Cem Concr Compos 131: 104565.

49. Aspiotis K, Sotiriadis K, Ntaska A, Mácová P, Badogiannis E, et al. (2021) Durability assessment of self-healing in ordinary Portland cement concrete containing chemical additives. Constr Build Mater 305: 124754.

50. Davolio M, Al-Obaidi S, Altomare MY, Monte FL, Ferrara L (2023) A methodology to assess the evolution of mechanical performance of UHPC as affected by autogenous healing under sustained loadings and aggressive exposure conditions. Cem Concr Compos 139: 105058.

51. Hassanin A, El-Nemr A, Shaaban HF, Saidani M, Shaaban IG (2024) Coupling behavior of autogenous and autonomous self-healing techniques for durable concrete. Int J Civil Eng 925-948.

52. Carter MS, Tuttle MJ, Mancini JA, Martineau R, Hung CS, et al. (2023) Microbially induced calcium carbonate precipitation by sporosarcina pasteurii: a case study in optimizing biological CaCO3 precipitation. Appl Environ Microbiol 89(8): e01794-22.

53. Stanaszek-Tomal E (2020) Bacterial concrete as a sustainable building material? Sustainability 12(2): 696.

54. Hossain MR, Sultana R, Patwary MM, Khunga N, Sharma P, et al. (2022) Self-healing concrete for sustainable buildings: A review. Environ Chem Lett 20: 1265-1273.

55. Zhang X, Al-Dossary A, Hussain M, Setlow P, Li J (2020) Applications of Bacillus subtilis spores in biotechnology and advanced materials. Appl Environ Microbiol 86(17): e01096-20.

56. Kolodkin-Gal I, Parsek MR, Patrauchan MA (2023) The roles of calcium signaling and calcium deposition in microbial multicellularity. Trends Microbiol 31(12): 1225-1237.

57. He Z, Xu Y, Wang W, Yang X, Jin Z, et al. (2023) Synergistic mechanism and application of microbially induced carbonate precipitation (MICP) and inorganic additives for passivation of heavy metals in copper-nickel tailings. Chemosphere 311: 136981.

58. Xue ZF, Cheng WC, Wang L, Qin P, Xie YX, et al. (2023) Applying the first microcapsule-based self-healing microbial-induced calcium carbonate materials to prevent the migration of Pb ions. Environ Res 239: 117423.

59. Lange-Enyedi NT, Németh P, Borsodi AK, Spötl C, Makk J (2024) Calcium carbonate precipitating extremophilic bacteria in an Alpine ice cave. Sci Rep 14(1): 2710.

60. Tang S, Wang Y (2024) The optimized microbial-induced calcium carbonate precipitation process to fabricate underwater superoleophobic mesh for efficient oil-water separation. J Environ Chem Eng 12(1): 111805.

61. Jones EM, Marken JP, Silver PA (2024) Synthetic microbiology in sustainability applications. Nat Rev Microbiol 22(6): 345-359.

62. Sun X, Miao L, Tong T, Wang C (2019) Study of the effect of temperature on microbially induced carbonate precipitation. Acta Geotech 14: 627-638.

63. Raveh-Amit H, Gruber A, Abramov K, Tsesarsky M (2024) Mitigation of aeolian erosion of loess soil by Bio-Stimulated microbial induced calcite precipitation. Catena 237: 107808.

64. Song HW, Li D, Qiu H, Yu ZG, Kumar A, et al. (2024) Microbial-induced carbonate precipitation effectively prevents Pb^{2+} migration through the soil profile: Lab experiment and model simulation. Sci Total Environ 927: 172268.

65. Rajasekar A, Wilkinson S, Moy CK (2021) MICP as a potential sustainable technique to treat or entrap contaminants in the natural environment: A review. Environ Sci Ecotechnol 6: 100096.

66. Rajasekar A, Moy CK, Wilkinson S, Sekar R (2021) Microbially induced calcite precipitation performance of multiple landfill indigenous bacteria compared to a commercially available bacteria in porous media. PLoS ONE 16: e0254676.

67. Kumar A, Song HW, Mishra S, Zhang W, Zhang YL, et al. (2023) Application of microbial-induced carbonate precipitation (MICP) techniques to remove heavy metal in the natural environment: A critical review. Chemosphere 318: 137894.

68. Dubicka Z, Gorzelak P (2017) Unlocking the biomineralization style and affinity of Paleozoic fusulinid foraminifera. Sci Rep 7: 15218.

69. Murugan R, Suraishkumar GK, Mukherjee A, Dhami NK (2021) Influence of native ureolytic microbial community on biocementation potential of Sporosarcina pasteurii. Sci Rep 11(1): 20856.

70. Van Dijl J, Hecker M (2013) Bacillus subtilis: from soil bacterium to super-secreting cell factory. Microb Cell Fact 12: 3.

71. Javeed Y, Goh Y, Mo KH, Yap SP, Leo BF (2024) Microbial self-healing in concrete: A comprehensive exploration of bacterial viability, implementation techniques, and mechanical properties. J Mater Res Technol 29: 2376-2395.

72. Sarkar M, Maiti M, Mandal S, Xu S (2024) Enhancing concrete resilience and sustainability through fly ash-assisted microbial biomineralization for self-healing: From waste to greening construction materials. Chem Eng J 481: 148148.

73. Park M, Park S, Yoo JY, Kim Y, Lee KM, et al. (2022) Enzyme-mediated biocalcification by a novel alkaliphilic Bacillus psychrodurans LC40 and its eco-friendly application as a biosealant for crack healing. Sci Total Environ 802: 149841.

74. Ren M, Jones B, Nie X, Lin X, Meng C (2024) Carbonate microbialites and chemotrophic microbes: Insights from caves from southeast China. Sedimentology 71(5): 1558-1590.

75. Gebru KA, Kidanemariam TG, Gebretinsae HK (2021) Bio-cement production using microbially induced calcite precipitation (MICP) method: A review. Chem Eng Sci 238: 116610.

76. Zhu X, Wang J, Wang H, Li Y (2024) A numerical model of the MICP multi-process considering the scale size. PLoS ONE 19(1): e0297195.

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77. Kadapure SA, Deshannavar UB, Katageri BG, Kadapure PS (2023) A systematic review on MICP technique for developing sustainability in concrete. Eur J Environ Civil Eng 27: 4581-4597.

78. Nodehi M, Ozbakkaloglu T, Gholampour A (2022) A systematic review of bacteria-based self-healing concrete: Biomineralization, mechanical, and durability properties. J Build Eng 49: 104038.

79. Osta MO, Mukhtar F (2023) Effect of bacteria on uncracked concrete mechanical properties correlated with damage self-healing efficiency-A critical review. Dev Built Environ 17: 100301.

80. Griño Jr AA, Soriano HSP, Promentilla MAB, Ongpeng JMC (2023) Exploring the potential of polypropylene fibers and bacterial co-culture in repairing and strengthening geopolymer-based construction materials. Buildings 13(10): 2668.

81. Brito DJ, Kurda R (2021) The past and future of sustainable concrete: A critical review and new strategies on cement-based materials. J Clean Prod 281: 123558.

82. Chen L, Chen Z, Xie Z, Wei L, Hua J, et al. (2023) Recent developments on natural fiber concrete: A review of properties, sustainability, applications, barriers, and opportunities. Dev Built Environ 16: 100255.

83. Naveed M, Duan J, Uddin S, Suleman M, Hui Y, et al. (2020) Application of microbially induced calcium carbonate precipitation with urea hydrolysis to improve the mechanical properties of soil. Ecol Eng 153: 105885.

84. Zhu T, Dittrich M (2016) Carbonate precipitation through microbial activities in natural environment, and their potential in biotechnology: A review. Front Bioeng Biotechnol 4: 4.

85. Su F, Yang G, Raveh Y (2024) Bio Processes Generating MICP and Identification of the Functional Bio Processes During Soil Modification. Heliyon.

86. Medina Ferrer F, Hobart K, Bailey JV (2020) Field detection of urease and carbonic anhydrase activity using rapid and economical tests to assess microbially induced carbonate precipitation. Microbiol Biotechnol 13(6): 1877-1888.

87. Medina Ferrer F, Rosen MR, Feyhl-Buska JR, Russell VV, Sønderholm F, et al. (2022) Potential role for microbial ureolysis in the rapid formation of carbonate tufa mounds. Geobiology 20(1): 79-97.

88. Feng X, Guo H, Feng X, Yin Y, Li Z, et al. (2024) Denitrification induced calcium carbonate precipitation by indigenous microorganisms in coal seam and its application potential in CO_2 geological storage. Fuel 365: 131276.

89. Huang G, Abou-Chakra A, Geoffroy S, Absi J (2024) Improving the mechanical and thermal performance of bio-based concrete through multi-objective optimization. Constr Build Mater 421: 135673.

90. Huang W, Chen Z, Liu H, Wang H, Wei Z (2024) Microbial induced carbonate precipitation for cadmium removal in flue gas from sludge incineration. J Environ Chem Eng 12(3): 112573.

91. Hemayati M, Nikooee E, Habibagahi G, Niazi A, Afzali SF (2023) New non-ureolytic heterotrophic microbial induced carbonate precipitation for suppression of sand dune wind erosion. Sci Rep 13(1): 5845.

92. Zhou Y, Hu J, Wu Y, Zeng H, Zeng D, et al. (2022) Experimental Study on the Preparation of a Highly Active Bacterial Suspension for MICP in the South China Sea. Sustainability 14(15): 9748.

93. Zhou G, Xu Y, Wang Y, Zheng L, Zhang Y, et al. (2023) Study on MICP dust suppression technology in open pit coal mine: Preparation and mechanism of microbial dust suppression material. J Environ Manag 343: 118181.

94. Debnath A, Hazra C, Sen R (2023) Insight into biomolecular interaction-based non-classical crystallization of bacterial biocement. Appl Microbiol Biotechnol 107(21): 6683-6701.

95. Zhao Q, Li L, Li C, Li M, Amini F, et al. (2014) Factors affecting improvement of engineering properties of MICP-treated soil catalyzed by bacteria and urease. J Mater Civil Eng 26(12): 04014094.

96. Zhang YS, Liu Y, Sun XD, Zeng W, Xing HP, et al. (2024) Application of microbially induced calcium carbonate precipitation (MICP) technique in concrete crack repair: A review. Constr Build Mater 411: 134313.

97. Zhang L, Wang W, Yue C, Si Y (2024) Biogenic calcium improved Cd^{2+} and Pb^{2+} immobilization in soil using the ureolytic bacteria Bacillus pasteurii. Sci Total Environ 921: 171060.

98. Zhang K, Tang CS, Jiang NJ, Pan XH, Liu B, et al. (2023) Microbial induced carbonate precipitation (MICP) technology: A review on the fundamentals and engineering applications. Environ Earth Sci 82: 229.

99. Zhang J, Su P, Li Y, Li L (2021) Environmental investigation of bio-modification of steel slag through microbially induced carbonate precipitation. J Environ Sci 101: 282-292.

100. Santomartino R, Averesch NJ, Bhuiyan M, Cockell CS, Colangelo J, et al. (2023) Toward sustainable space exploration: a roadmap for harnessing the power of microorganisms. Nat Commun 14(1): 1391.

101. Li Q, Wang Y, Zhang G, Su R, Qi W (2023) Biomimetic mineralization based on self-assembling peptides. Chem Soc Rev 52: 1549-1590.

102. Li W, Cai Y, Li Y, Achal V (2024) Mobility, speciation of cadmium, and bacterial community composition along soil depths during microbial carbonate precipitation under simulated acid rain. J Environ Manage 353: 120018.

103. Li X, He X, Ren K, Dong H, Lian B (2023) Mechanisms of carbonate precipitation induced by two model bacteria. Chem Geol 628: 121461.

104. Chuo SC, Mohamed SF, Mohd Setapar SH, Ahmad A, Jawaid M, et al. (2020) Insights into the current trends in the utilization of bacteria for microbially induced calcium carbonate precipitation. Biomaterials 13(21): 4993.

105. Clark MS (2020) Molecular mechanisms of biomineralization in marine invertebrates. J Exp Biol 223: 206961.

106. Dhami NK, Reddy MS, Mukherjee A (2013) Biomineralization of calcium carbonates and their engineered applications: a review. Front Microbiol 4: 314.

107. Dong H, Huang L, Zhao L, Zeng Q, Liu X, et al. (2022) A critical review of mineral-microbe interaction and co-evolution: mechanisms and applications. Nat Sci Rev 9(10): 128.

108. Hoffmann TD, Paine K, Gebhard S (2021) Genetic optimisation of bacteria-induced calcite precipitation in Bacillus subtilis. Microb Cell Fact 20(1): 214.

109. Liu Y, Ali A, Su JF, Li K, Hu RZ, et al. (2023) Microbial-induced calcium carbonate precipitation: Influencing factors, nucleation pathways, and application in waste water remediation. Sci Total Environ 860: 160439.

110. Rahman MM, Hora RN, Ahenkorah I, Beecham S, Karim MR, et al. (2020) State-of-the-art review of microbial-induced calcite precipitation and its sustainability in engineering applications. Sustainability 12(15): 6281.

111. Seifan M, Berenjian A (2019) Microbially induced calcium carbonate precipitation: a widespread phenomenon in the biological world. Appl Microbiol Biotechnol 103(12): 4693-4708.

112. Seifan M, Samani AK, Berenjian A (2016) Induced calcium carbonate precipitation using Bacillus species. Appl Microbiol Biotechnol 100(23): 9895-9906.

113. Xu X, Kovács ÁT (2024) How to identify and quantify the members of the Bacillus genus? Environ Microbiol 26(2): e16593.

114. Bagga M, Hamley-Bennett C, Alex A, Freeman BL, Justo-Reinoso I, et al. (2022) Advancements in bacteria based self-healing concrete and the promise of modelling. Constr Build Mater 358: 129412.

115. Beatty DN, Williams SL, Srubar III WV (2022) Biomineralized materials for sustainable and durable construction. Annu Rev Mater Res 52: 411-439.

116. Benjamin S, Zachariah J, Sudhakumar J, Suchithra TV (2024) Harnessing construction biotechnology for sustainable upcycled cement composites: A meta-analytical review. J Build Eng 86: 108973.

117. Heveran CM, Williams SL, Qiu J, Artier J, Hubler MH, et al. (2020) Biomineralization and successive regeneration of engineered living building materials. Matter 2(2): 481-494.

118. Hong M, Niu D, Fu Q, Hui Z, Wan Z (2024) Insights into bio-deterioration of concrete exposed to sewer environment: A case study. Constr Build Mater 412: 134835.

119. Junier P, Joseph E (2017) Microbial biotechnology approaches to mitigating the deterioration of construction and heritage materials. Microb Biotechnol 10(5): 1145-1148.

120. Khaneghahi MH, Rahmaninezhad SA, Kamireddi D, Sadighi A, Sales CM, et al. (2024) Carbonate biomineralization potential of endospore-laden polymeric fibers (BioFibers) for bio-self-healing applications. Dev Built Environ 17: 100351.

121. Luo M, Ji A, Li X, Yang D (2024) Performance evaluation of self-healing recycled concrete using biomineralization modified recycled aggregate as bacterial carrier. J Build Eng 86: 109000.

122. Mohamed O, Zuaiter H (2024) Fresh properties, strength, and durability of fiber-reinforced geopolymer and conventional concrete: A review. Polymers 16(1): 141.

123. Nasser AA, Sorour NM, Saafan MA, Abbas RN (2022) Microbially-Induced-Calcite-Precipitation (MICP): A biotechnological approach to enhance the durability of concrete using Bacillus pasteurii and Bacillus sphaericus. Heliyon 8(7): e09879.

124. Rauf M, Khaliq W, Khushnood RA, Ahmed I (2020) Comparative performance of different bacteria immobilized in natural fibers for self-healing in concrete. Constr Build Mater 258: 119578.

125. Su Y, Qian C, Rui Y, Feng J (2021) Exploring the coupled mechanism of fibers and bacteria on self-healing concrete from bacterial extracellular polymeric substances (EPS). Cem Concr Compos 116: 103896.

126. Mirshahmohammad M, Rahmani H, Maleki-Kakelar M, Bahari A (2022) Effect of sustained service loads on the self-healing and corrosion of bacterial concretes. Constr Build Mater 322: 126423.

127. Peplow M (2020) Bioconcrete presages new wave in environmentally friendly construction. Nat Biotechnol 38(7): 776-778.

128. Ratner M (2015) Microbial cocktails join fecal transplants in IBD treatment trials. Nat Biotechnol 33(8): 787-788.

129. McBee RM, Lucht M, Mukhitov N, Richardson M, Srinivasan T, et al. (2022) Engineering living and regenerative fungal-bacterial biocomposite structures. Nat Mater 21: 471-478.

130. Liu AP, Appel EA, Ashby PD, M Baker B, Franco E, et al. (2022) The living interface between synthetic biology and biomaterial design. Nat Mater 21(4): 390-397.

131. Sandak A (2023) Engineered living materials for sustainable and resilient architecture. Nat Rev Mater 8: 357-359.

132. Tang TC, An B, Huang Y, Vasikaran S, Wang Y, et al. (2021) Materials design by synthetic biology. Nat Rev Mater 6: 332-350.

133. Knoben W (2011) Bacteria care for concrete. Mater Today 14: 444.

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