

BIOCONCRETE: INNOVATIVE APPROACH TO CARBON DI OXIDE SEQUESTRATION

Abstract

Concrete is widely utilized in the construction industry, yet its inherent limitations necessitate ongoing research for enhanced properties. Bioconcrete has emerged as a promising solution, offering self-healing capabilities and additional benefits such as improved durability, strength, and reduced water absorption. Despite significant research efforts in bioconcrete development, there remains a gap in the comprehensive evaluation of its pros and cons. This review aims to address this gap by systematically assessing the positive and negative impacts of bioconcrete application on various aspects including strength, durability, permeability, recycling, and human health. By synthesizing recent literature, this paper provides a comprehensive examination of the diverse advantages of bioconcrete, such as its ability to enhance durability, strength, permeability, and potential for recycling. Additionally, it discusses concerns regarding the potential health hazards associated with bioconcrete use. The findings of this study are relevant for stakeholders in the construction sector and engineers, offering valuable insights into the potential use of bioconcrete while considering both its benefits and drawbacks. Ultimately, this review emphasizes the importance of understanding the advantages and disadvantages of bioconcrete for making informed decisions regarding its commercial application in the construction industry.

Keywords: Biological concrete, Durability, Health hazard, Sustainability.

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I. INTRODUCTION

Concrete has been used in construction for a long time. It is still the most promising building material that is employed in every project to the greatest extent even in the twenty-first century. Because of greenhouse effect, the large-scale production of concrete around the world has caused severe environmental concerns because the production of cement is directly linked to the production of carbon dioxide. Through partial substitution of cement with extra cementitious materials or full replacement of cement with geopolymers, cement usage has been decreased in order to produce green concrete. In addition to these, recent efforts have been made to lessen the carbon footprint associated with the production of concrete. Recently, efforts have been undertaken to sequester carbon dioxide into mortar and concrete mixtures or recovered aggregates using an accelerated carbonation regime. Cement paste (slurry), mortar, and concrete made with cement as a binder all have the potential to sequester carbon dioxide due to the reaction between carbon dioxide and cement compounds (tricalcium and dicalcium silicates) and the calcium hydroxide produced by the initial hydration of cement. The carbon dioxide gas reacts with the cement paste that is applied to the surface of the recycled aggregates made from dismantled mortar and concrete to sequester the gas. Carbon dioxide has been more effectively absorbed by concrete, mortar, or recycled aggregate. These carbonated building materials have significantly improved quality while also absorbing a sizable amount of carbon dioxide, reducing the greenhouse effect. Before creating onsite or ready-mix concrete mixtures, the accelerated carbon dioxide sequestration technique can be used to improve the physical and mechanical properties of recycled aggregates. It can also be used to cure concrete an alternative to water curing.

- 1. Bioconcrete – Simply by Biomineralization:** Calcium carbonate is produced by biomineralization as part of the biological healing process. In addition to significantly reducing cement output and the need for structural replacement, successful application of this novel treatment technology will extend the lifespan of concrete structures. If this novel treatment procedure is put into practice effectively, concrete structures will last longer and there will be a large decrease in the need for new construction and cement (Tebo *et al.*, 2005). The uncontrolled result of microbial metabolic activity is biologically induced mineralization, which typically takes place in an open environment. Biomineralization, a common occurrence in nature, is the process of mineral production by living organisms. A physiologically induced mineralization process can be used to achieve biomineralization. In an open setting, biologically induced mineralization typically happens as an unregulated byproduct of microbial metabolic activity (Barton *et al.*, 2011). In this process, biominerals are created as a result of an interaction between the environment and the metabolic byproducts produced by bacteria. Cations that successfully bind with negatively charged microbial cell walls cause mineral precipitation. Normally biomineralization typically takes place at the oxic-anoxic boundary or in an anaerobic environment. The amount of dissolved inorganic carbon, nucleation location, pH, temperature, and Hartree energy (Eh) all have a significant role in its success (Fortin *et al.*, 1997). Due to its effective bonding ability and compatibility with concrete compositions, precipitation of calcium carbonate has attracted interest among the widely used biomineralization processes for mineral synthesis.
- 2. Bioconcrete - Microbes Involved:** Calcium carbonate is deposited as a result of the ecological process known as biocementation, which is based on the Microbial Induced

Carbonate Precipitation (MICP) mechanism. In alkaline conditions with a high concentration of calcium ions, diverse bacterial species precipitate carbonates through a variety of methods (Ehrlich, 1998). According to Boquet *et al.*, 1973 practically all microorganisms commonly produce calcium carbonate under the right circumstances. At pH 7, the amino, carboxyl and phosphoryl groups on the bacterial surface provide heterogeneous electronegativity charge, which later serves as the basis for the formation of a site that favors the adsorption of positively charged cations such as Ca^{2+} and Mg^{2+} . Calcium carbonate precipitates when calcium ions are present around the bacterial cell wall (Douglas and Beveridge, 1998). Different types of microorganisms, like photosynthetic organisms like blue green algae, sulfate reducing bacteria, organisms utilizing organic acids, and microbes involved in the nitrogen cycle, are found to be involved in the process of biomineralization.

II. ROUTES OF BIOMINERALIZATION

Biomineralization process connected with the microorganisms often involves two distinct metabolic pathways: (1) the autotrophic pathway and (2) the heterotrophic pathway. The conversion of carbon di oxide into calcium carbonate crystals by bacteria in the presence of CO_2 and a calcium supply is known as the autotrophic route. According to Castanier *et al.*, 1999, non methylotropic methanogenesis and oxygenic and anoxygenic photosynthesis are two examples of autotrophic precipitation of carbonates. CO_2 is used as the carbon source in each of the three autotrophic pathways. Methanogenic archae bacteria utilize CO_2 and H_2 to produce methane in anaerobic condition as part of the nonmethylotropic methanogenesis pathway (Castanier *et al.*, 1999).

Numerous researches have noted the importance of MICP technology in construction materials to improve the mechanical qualities at the same time lowering the permeability features. Reduced permeability and enhanced strength of the concrete structure are the results of CaCO_3 precipitation by microorganism within the cement matrix. *Sporosarcina pasteurii* cells were directly incorporated into the cement matrix, according to Ramachandran *et al.*, (2001), increasing the compressive strength of cement mortar cubes. According to De Muynck *et al.*, (2008), using pure cultures of *Bacillus sphaericus* rather than mixed ureolytic cultures resulted in a noticeably lower uptake of water and gas permeability in concrete structures. According to Achal *et al.*, (2011), the compressive strength of cement mortar specimens treated with bacteria increased by up to 36% when compared to control specimens. Comparing the bacteria-treated specimen to the control specimen, water absorption was reduced by six times. After applying two bacterial strains, *B. sphaericus* and *S. pasteurii*, to the surface of concrete specimens, Kim *et al.*, 2013 looked at the distribution of calcium carbonate precipitation and capillary water absorption. In comparison to specimens treated with *S. pasteurii* strain, those treated with *B. sphaericus* strain showed denser calcium carbonate crystals and the lowest weight increase. According to Dharmi *et al.*, (2013), calcifying bacteria may increase the durability of energy-efficient buildings. In compared to control specimens, biogenic surface-treated specimens showed a reduction of 40% in water absorption and 31% in porosity. Bundur *et al.*, 2015 reported that mortar specimens prepared with the integration of vegetative bacterial cells had greater compressive strength than the control specimen. *Exiguobacterium mexicanum*, a halophilic bacteria isolated from sea water, increased the compressive strength of concrete specimens by 23.5% while decreasing water absorption by five times (Bansal *et al.*, 2016). *Bacillus cohnii*, a nonureolytic microbe,

increased compressive strength by 49%, according to Kumari *et al.*, 2017. Reinforced concrete specimens treated with *Bacillus* sp. had lower rates of corrosion, less mass loss, and higher pullout strengths than control specimens (Achal *et al.*, 2012). According to Kalhori and Bagherpour (2017), Concrete specimens treated with bacteria had a 30% higher compressive strength than control specimens. Other than soil bioclogging and concrete restoration, many techniques have been used to use bacteria to repair concrete fractures.

Ramachandran *et al.*, (2001) found that calcite that precipitated during microbial development increased the compressive strength of fractured mortar cubes. The mineralization process was more successful in shallow fractures than in deeper ones because bacteria proliferate more aggressively in the presence of oxygen. Additionally, realistic cracks with widths ranging from 0.05 to 0.87 mm and standard cracks of 0.3 mm in diameter with two depths of 10 and 20 mm were produced in concrete samples. Additionally, it was proposed that the fractures might be filled using a biochemical healing agent composed of a mixture of organic compounds and living but dormant bacteria packed inside porous expanded clay particles (Jonkers, 2011). Wiktor *et al.* (2011) investigated the direct incorporation of calcium lactate and bacterial spores embedded in expanded clay as a self-healing agent in concrete. However, the bacterial-based specimen showed complete healing of crack with a diameter of 0.42 mm after 100 days of submersion in water. The specimen produced multiple cracks with widths ranging from 0.05 to 1.0 mm. The microbiological filling of fissures that were purposefully produced to be 3 mm broad and 13.4, 18.8, and 27.2 mm deep was examined by Achal *et al.*, in 2013.

In a specimen that had undergone microbial treatment, the deepest crack, measuring 27.2 mm in depth, was successfully repaired using the bacterial strain *Bacillus* sp. CT-5 and unprocessed natural sand. Xu and Yao (2014) used *B. cohnii* spores to study non ureolytic bacterially generated CaCO₃ precipitation as a self-healing method for concrete cracking. They proposed that adding bacteria and calcium-source foods to concrete as a two-component healing agent causes CaCO₃ to precipitate when cracks form. Early age cracks in cement-based materials were reported to be repaired by *Bacillus mucilaginous* L3 in study by Qian *et al.*, 2015. According to their research, the early-stage cracks were totally repaired (up to 0.4 mm) by bacterial treatment, and the healing efficacy diminished as the age of the crack increased.

III. ENZYME INVOLVED IN CO₂ SEQUESTRATION

In animals, plants, and microbes, carbonic anhydrase (CA) is a widely present as metalloenzyme that contains zinc and catalyzes the formation of bicarbonate from CO₂ and water (Smith and Ferry, 1999). The fact that the CA is present in a wide range of metabolically varied bacterial species suggests that this enzyme is crucial for CO₂ concentration (Dhami *et al.*, 2014). The CA enzyme functions as a biocatalyst in the photosynthetic absorption of CO₂ in nature (Jansson and Northen, 2010). Significant attention has been paid to the CA enzyme's potential contribution to solving environmental problems like lowering carbon emissions through CO₂ sequestration. According to Bose and Satyanarayana (2017), carbonic anhydrase enzyme has the potential to be used as a technique to sequester CO₂ from emission sources. Significant attention has been paid to the CA enzyme's potential contribution to solving environmental problems like lowering carbon emissions through CO₂ sequestration. According to Bose and Satyanarayana (2017), CA

enzyme has the potential to be used as a technique to sequester CO₂ from emission sources. According to research by Wanjari. (2011), calcium carbonate precipitation from *B. pumilus* partly purified CA mounted on chitosan beads is superior than free enzyme in the carbonation reaction. The CA enzyme was immobilized inside alginate beads, where it maintained almost 67% of its initial activity and converted CO₂ to bicarbonate and/or carbonate, which, when combined with Ca²⁺ ions, produced calcite (Yadav *et al.*, 2012). According to Zhang *et al.* (2011), the biocatalyst CA encapsulated in controlled porosity glass material effectively absorbed CO₂ into the potassium carbonate solution. The immobilized enzyme greatly increased resistance to flue gas conditions containing sulfate (0.4 M), nitrate (0.05 M), and chloride (0.3 M), which are anticipated in the integrated vacuum carbonate absorption process, while also retaining at least 60% of their initial activity.

IV. CHALLENGES AND FUTURE TRENDS

Cyanobacteria-based biomineralization of CO₂ offers a creative and self-sustaining method for carbon sequestration. A practical and eco-friendly method to reduce the rising CO₂ levels in the atmosphere is biocementation. Construction materials that can be used as building materials can be made from the calcium carbonates that are produced after sequestration utilizing bacteria and microalgae. Microalgae are simple to grow and have a significant potential for use in the production of biocement. According to Dapurkar and Telang (2017), the number of patents relating to the use of microbes with ureolytic pathways in building biotechnology is rapidly rising, necessitating the completion of crucial research to make the use of algae as a viable biocementation producer.

The potential of biomineralization to increase the tensile strength of construction materials has been studied by scientists from all over the world. The microbiological use of this technology in concrete, however, is still being evaluated qualitatively and quantitatively on a laboratory scale. A few researchers have also reported positive outcomes from the use of bacterial-based treatment in the field. There are some restrictions that must be taken into account before this technology may be used on a large basis commercially. Implementation of laboratory-grade nutrient supplies, which restricts the implementation of this technique in numerous situations, is one of the restrictions on applying this technology at a field scale. Economical substitutes for the medium elements are necessary for the technology to be commercialized successfully. The technique needs affordable substitutes for the medium elements, which can account for up to 60% of the overall operating expenses.

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