**Bioconcrete : Innovative approach to Carbon di oxide sequestration**

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**Introduction**

Concrete has been used in construction for a long time. It is still the primary building material that is employed in every project to the greatest extent even in the twenty-first century. Due to the 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. In order to create green concrete, cement consumption has been reduced through partial substitution of cement with additional cementitious materials or complete replacement of cement with geopolymers. Attempts have lately been made to reduce the carbon footprint connected with the manufacture of concrete in addition to these. Recently, efforts have been made to use an accelerated carbonation regime to sequester carbon dioxide to either recycled aggregates or the mixtures of mortars and concrete. Due to the reaction between carbon dioxide and cement compounds (tricalcium and dicalcium silicates) and the calcium hydroxide created by the initial hydration of cement, a variety of mixtures, including cement paste (slurry), mortar, and concrete produced using cement as a binder, have the potential to sequester carbon dioxide. The recycled aggregates made from demolished mortar and concrete also have the capacity to sequester carbon dioxide as a result of a reaction between the gas and the cement paste that is adhered to their surface. Concrete, mortar, or recycled aggregate have all experienced increased carbon dioxide sequestration. The quality of these carbonated building materials has greatly enhanced while at the same time a sizeable amount of carbon dioxide gets fixed inside of them, lowering 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.

**Bioconcrete – Simply by biomineralization**

Biological healing process is based on the production of calcium carbonate through biomineralization. Successful implementation of this innovative treatment method will result in a longer lifespan of concrete structures as well as significant reduction in cement production and structural replacement. 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. Mineral precipitation happens when positively charged ions successfully bond with negatively charged microbial cell walls. Biologically induced mineralization usually occurs in an anaerobic environment or at oxic–anoxic boundary. Its effectiveness highly depends on the concentration of dissolved inorganic carbon, nucleation site, pH, temperature and Hartree energy (Eh) (Fortin *et al*., 1997). Among widespread production of minerals through biomineralization, precipitation of calcium carbonate has drawn interest due to the efficient bonding capacity and compatibility with concrete compositions.

**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 neutral pH, the carboxyl, phosphoryl, and amino groups on the surface of bacteria 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 Ca2+ and Mg 2+. Calcium carbonate precipitates when calcium ions are present around the bacterial cell wall (Douglas and Beveridge, 1998). Four groups of microorganisms, such as photosynthetic organisms like cyanobacteria and algae, sulfate reducing bacteria, organisms utilizing organic acids, and organisms involved in the nitrogen cycle, are reported to be involved in the process of biocementation.

**Routes of Biomineralization:**

The process of biomineralization connected with the microorganisms often involves two distinct metabolic pathways: (1) the autotrophic pathway and (2) the heterotrophic pathway. The conversion of CO2 into calcium carbonate crystals by bacteria in the presence of CO2 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. CO2 is used as the carbon source in each of the three autotrophic pathways. Methanogenic archae bacteria utilize CO2 and H2 to produce methane in the absence of oxygen as part of the nonmethylotrophic methanogenesis pathway (Castanier *et al*., 1999).

The potential of MICP technology in cementitious materials to increase the mechanical properties as well as to reduce the permeability properties has been reported by various researchers. Reduced permeability and enhanced strength of the concrete structure are the results of CaCO3 precipitation by bacteria within the cement matrix. *Sporoscarcina 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 Dhami *et al*., (2013), calcifying bacteria may increase the durability of energy-efficient green building materials. 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. CT-5 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 to microorganisms 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.

According to Ramachandran *et al*., 2001, the compressive strength of fractured mortar cubes was improved by calcite that precipitated during microbial development. Because bacteria grow more aggressively in the presence of oxygen, the mineralization process in shallow fractures was more effective than in deeper ones. 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. In this study, encouraging findings regarding crack filling and the effectiveness of calcifying bacteria immobilized on silica as a self-healing agent were revealed.

It was also suggested that the cracks may be repaired using a biochemical healing agent made of a combination of alive but dormant bacteria and organic substances packed in porous expanded clay particles (Jonkers, 2011). The direct inclusion of bacterial spores and calcium lactate imbedded in expanded clay as a self-healing agent in concrete was studied by Wiktor *et al*., (2011). The specimen developed several cracks with widths ranging from 0.05 to 1.0 mm, however the bacterial-based specimen displayed complete healing of a crack with a diameter of 0.42 mm after 100 days of submersion in water. Achal *et al*., 2013 looked at the microbiological filling of fissures that were intentionally made to be 3 mm wide and 13.4, 18.8, and 27.2 mm deep.

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 nonureolytic 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.

**Enzyme involved in CO2 sequestration**

Carbonic anhydrase (CA) is the first-discovered zinc-containing metalloenzyme that is widespread in animals, plants, and microorganisms that catalyses the conversion of CO2 and water into bicarbonate (Smith and Ferry, 1999). The CA is widespread in metabolically diverse species of bacteria indicating that this enzyme plays a significant role in concentrating CO2 (Dhami *et al*., 2014). In natural process of photosynthetic assimilation of CO2, CA enzyme acts as biocatalyst (Jansson and Northen, 2010). Potential role of CA enzyme in addressing environmental issues such as reducing carbon emissions through CO2 sequestration has gained considerable attention. CA enzyme is reported to be a potential tool to sequester CO2 from emission sources (Bose and Satyanarayana, 2017). It was reported that partially purified CA from *B. pumilus* immobilized on chitosan beads has improved calcium carbonate precipitation than free CA enzyme in carbonation reaction (Wanjari *et al*., 2011). Immobilization of CA enzyme into alginate beads showed better operational stability by retaining nearly 67% of its initial activity and entrapped CA hydrates CO2 to bicarbonate and/or carbonate, which on reaction with Ca 2+ ions, transform into calcite (Yadav *et al*., 2012). It was reported as a commercialized development for the onsite scrubber for CO2 sequestration. Zhang *et al*. (2011) reported the effective absorption of CO2 into the potassium carbonate solution with biocatalyst CA immobilized into controlled pore glass material. The immobilized enzyme retained at least 60% of their initial activities and significantly improved resistance to concentrations of sulfate (0.4 M), nitrate (0.05 M), and chloride (0.3 M) conditions in flue gas expected in the Integrated Vacuum Carbonate Absorption Process.

**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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