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Role of Microbial Induced Calcite Precipitation in Sustainable Development

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ABSTRACT

In past few decades urbanization is unprecedented in its magnitude and rate, which has led to construction of buildings and other material at large scale. Though cement is most preferred construction material used till date, technologies used to improve construction material and make it more environment friendly till date are not impressive e.g. grouting applications also has adverse effect on environment. It is only interdisciplinary research of Microbiology, Civil engineering and Geochemistry which can come up with a method like Microbial Induced Calcite Precipitation (MICP) and has become the focus of many studies as a first foray into developing a biomediated soil improvement technology due to the relative ease of investigation in the laboratory, no requirement of injections and low input as cultures can be reused. This paper is focused primarily on basic mechanism of calcite precipitation, factors affecting, its advantages and disadvantages. Potential applications and challenges in implementation of this technology at large scale are also discussed.

Keywords: MICP, Calcite precipitation, Biomediated soil improvement, Urease, Bacteria

INTRODUCTION

As civilization progressed cement has been the most powerful material for construction purpose, but with duration of time little cracks appear which can though not necessarily but, can result in strength loss and due to ingress of water and other reactive material corrosion rate of steel may also be enhanced. There are certain other reasons such as autogenous shrinkage, freeze thaw reactions; mechanical compressive and tensile forces play a major role in cracks appearance. Thus cracks minimization should be a matter of concern to avoid durability loss in major construction works like bridges, commercial and residential buildings etc. Different kinds of repair systems are available in present scenario. One such mechanism involves secondary hydration reactions of reacted cement particles. However, in secondary hydration reaction material characteristics of the initial concrete structure may not be satisfactorily as it may be more brittle and initially weaker as wanted. In recent years sustainable technology and innovation in engineering has given new dimensions to quality of construction materials, one such technology is the use of Microbial Induced Calcite Precipitates (MICP). MICP involves bacteria which occur virtually everywhere on earth, not only on surface but deep within e.g. in sediment and rock at a depth of more than 1 km [1]. These bacteria, found in extreme conditions like desiccated desert [2,3] but also inside the rocks and even in ultra-basic environments [4] which can be considered homologous to the internal concrete environment.

Many extremophiles (e.g. Desiccation- and/or alalki-resistent bacterial species) form endospores, which are characterized by extremely low metabolic activity and know to be able to resist high mechanical and chemical stress [5]. Due to this ability these kind of microorganism are able to survive up to 200 years [6]. Scientists have reported potential use of MICP in various engineering applications like in bio mineralized concrete, i.e., remediation of cracks in concrete, biological mortar and self-healing of cracks [7-12] reductions in foundation settlement and slope stabilization [13], piping prevention for dams, liquefaction mitigation [14], soil stabilization [15], improvement in the stiffness strength of sandy soil [16,17], reduction in soil permeability [18], dust control [19].

Studies have also reported that application of extremophiles (mineral precipitating) for strength improvement of cement-sand mortar and cleaning of concrete surfaces [20]. Crack healing potential of bacteria on ornamental stone surfaces [21], degraded lime stone [22] and as well as on concrete surfaces have also been researched and stated. However in latter researches bacteria and/or compounds needed for mineral precipitation could only is externally applied after the crack appears on surface. This was mainly due to limited lifespan (hours to few days) of urease based enzymatic activity and viability of applied bacterial species.

MECHANISMS OF ACTION

Mechanism of action depends upon the type of bacteria used in MICP process [22]. In MICP by urea hydrolysis, the enzyme urease catalyses substrate urea and precipitates carbonate ions in presence of ammonium. These carbonate ions in presence of a calcium source readily precipitate calcium carbonate as shown in Figure 1. This urea hydrolysis is the result of metabolic processes, which depends on the type of bacteria being, used [23].

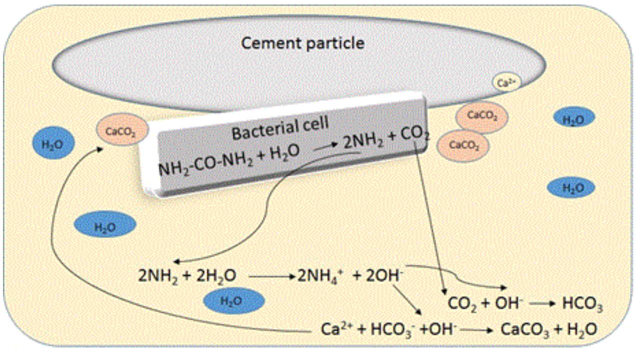

Figure 1: Interaction of microbes at the site of crack healing

In general, five modes of regulation exist for the synthesis of urease in microbial systems [24]; (i) Constitutive, which means regardless of environmental conditions there is constant expression of enzymes (ii) Inducible, where a background level of enzyme activity is expressed per cell which can be induced by the presence of an inducer molecule (e.g. urea) or some other environmental factor (iii) Repressible, by the presence of ammonia or ammonia precursors including urea. This synthesis is de-repressed (i.e., enzyme activity increases) under nitrogen limiting conditions. (iv) Developmental, where an organism in different developmental stages (e.g. swarming versus non-swarming) has variable expression of urease. (v) Regulation by pH, where the urease level is controlled by pH through controlling the rate of urease synthesis [25].

Formation of calcite within cracks of cement is quite similar to the process happens anywhere else with the same type of bacteria used. Once into contact with copious amounts of water and growth substrates (yeast extract and peptone), due to high activity of bacterial cells rapid conversion of organic compound happens and CO_2 is produced which will chemically react with calcium hydroxide produced from C_2S and C_3S hydration reactions. This CO_2 reacts with calcium hydroxide released from cement pore system and precipitates as calcite or any other calcium carbonate. This hypothesis was proved by observing calcite like crystals found on the surface of bacterial surface but not on control cement stone samples [26].

Freshly formed cracks allow water to flow in which in turn activates bacterial endospores. In addition to that for precipitation process organic substrate is needed which can be metabolically converted into inorganic carbon which can result into precipitate with free calcium to calcium carbonate. Free calcium is usually present in the concrete matrix, but organic carbon is not, thus yeast extract works as a carbon source for bacteria.

Molecular basis of calcite production

The mechanism of calcium carbonate formation is poorly understood at both the molecular and genetic level. First study suggested that the calcium carbonate biomineralization process was genetically controlled which also concluded that these mutant strains were formed by insertional mutagenesis and genes responsible for calcium carbonate formation in *B. subtilis* were also identified [27]. The operon icfA consists of five genes icfA, ysiA, ysiB, etfB and etfA as shown in Figure 2. Transcriptional unit (icfA, ysiA, ysiB, etfB and etfA) as a cluster of genes encoding proteins used in fatty acid metabolism was also studied [28]. Mutant strains after insertion were unable to produce calcium carbonate. Thus, they suggested that all the genes in the icfA operon could be participating in calcium carbonate precipitation. Moreover, other studies also confirmed that there is a link between the calcium carbonate and fatty acid formation [29,30].

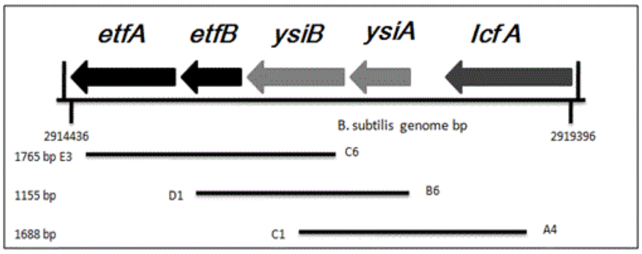

Figure 2: Gene map of the *B. subtilis* chromosome region containing urease gene cluster (from icfA to etfA) and results of RT-PCR as described by Barabesi et al. [27]. Arrows show the direction of the transcription. At both ends of the region, there are two transcription terminators. Major RT-PCR cotranscripts (A4-C1, B6-D1 and C6-E3) are shown as bars with their sizes in base pairs

Co-inoculation with other microbes

Increased microbial induced calcite production was observed by using co-culture of ureolytic and non ureolytic bacteria by Daniella et al. [31]. For co-culture they used *Sporosarcina pasteurii* as ureolytic species and *Bacillus subtilis* as non ureolytic species. *S. pasteurii* was used as control in experiments. In their experiments pH, dissolved calcium, optical density, dissolved inorganic carbon and evolution of ammonium were studied. Their study revealed that co-culture resulted in faster precipitation of calcium carbonate despite of less favourable conditions like lower pH and lower carbonates concentration. Within mixed culture of bacterial cultures *B. subtilis* showed more calcite formation than *S. pasteurii*. This research emphasized that scaling up of ureolytic MICP must take into consideration the non ureolytic and ureolytic bacteria, their interaction and effect on precipitation process. Figure 3 shows role of ureolytic bacteria in calcium carbonate precipitation.

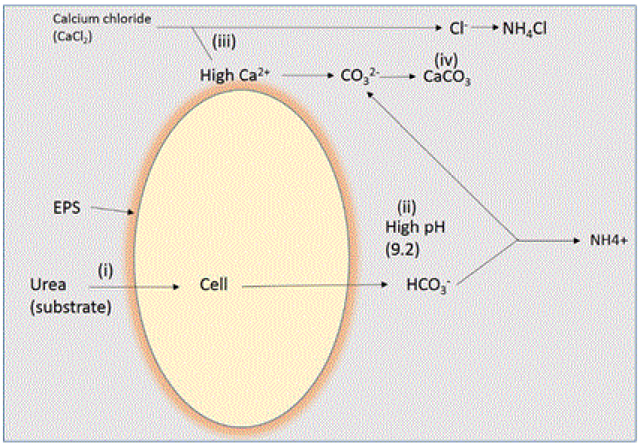

Figure 3: Schematic model summarizing the role of ureolytic bacteria in calcium carbonate precipitation in the presence of a high concentration of Ca^{2+} ions. The processes involved in Calcium carbonate precipitation are: (i) hydrolysis of urea, (ii) increasing the alkalinity, (iii) surface adsorption of Ca^{2+} ions and (iv) nucleation and crystal growth. EPS stands for extra-polysaccharide in the case of the presence of EPS surrounding the ureolytic cells

Some of the filamentous structures from genera Haliscomenobacter, Nocardia, Thiothrix, Microthrix and Beggiatoa are common examples which are generally used in aerobic tanks of wastewater treatment plants and are potential candidates for bio-binding purpose. Other microaerophilic bacteria could also be used for the biobinding of soil particles for enhancement of cement strength because many strains of microaerophilic bacteria are combined in filaments or joined by sheathes [32] and these filamentous structures could be advantageous for biobinding purpose [33].

FACTORS INFLUENCING MICROBIAL INDUCED CALCITE PRECIPITATION

In MICP process bacteria plays most crucial role and thus it is most influential factors in precipitation process. Bacteria are only living organism found in MICP process and considered as major player of soil carbonate deposits.

So, bacterial population used could affect several parameters during crack healing and in turn get affected by different parameters also.

Groups of bacteria with reference to cracks healing

Table 1 shows different microbial processes that can bring about biocementation. Sulphate reducing bacteria produces sulphides of metals and soil particles bind to it so, table includes attachment of the soil particles with sulphides of metals; binding of the particles with carbonates of metals due to hydrolysis of urea; and reaction of soil particles with ferrous and ferric salts and hydroxides, produced due to iron reducing bacteria [33].

Table 1: Possible microbial processes that can lead potentially to biocementation

Physiological group of microorganisms	Mechanism of biocementation	Essential conditions for biocementation	Potential geotechnical applications
Sulphate reducing bacteria	Production of undissolved sulphides of metals	Anaerobic conditions; presence of sulphate and carbon source in soil	Enhance stability for slopes and dams
Ammonifying bacteria	Formation of undissolved carbonates of metals in soil due to increase of pH and release of CO_2	Presence of urea and dissolved metal salt	Mitigate liquefaction potential of sand. Enhance stability for retaining walls, embankments, and dams; Increase bearing capacity of foundations
Iron-reducing bacteria	Production of ferrous solution and precipitation of undissolved ferrous and ferric salts and hydroxides in soil	Anaerobic conditions changed for aerobic conditions; presence of ferric minerals	Density soil on reclaimed sites and prevent soil avalanching-Reduce liquefaction potential of soil

Type of bacteria

The type of bacteria used in MICP process could affect urease activity and thus consequently control the efficiency of the precipitation process [34]. Most of the MICP processes take into account the type of microorganism used and metabolic pathway to improve the efficiency of the biodeposition process [35]. The bacteria types that are suitable for MICP application should be able to catalyst urea hydrolysis, and they are usually urease positive bacteria. Example of urease bacteria includes genera Spoloactobacilus, Sporosarcina, Bacillus, Clostridium and Desulfotomaculum [36]. The aerobic bacteria are more advantageous as they release CO_2 by cellular respiration which is paralleled by pH rise because of ammonia production. *Bacillus sporosarcina* is a more common type of bacteria used to precipitate calcium carbonate in the soil as it transforms urea to ammonia and carbon dioxide [37].

Performance of biomediated soil improvement by using *B. megaterium* to trigger calcite precipitation on different types of soils was studied by some workers [38]. External application of bacteria was studied by some of the scientist for concrete and monument crack repair [39] but results were not inspiring as it limits the reach of bacteria deep inside the crack and more viable bacterial strains used were also a concern. While in spore mixed cement technique the estimated number of viable spores retrieved from young cement stone, i.e. after ten days curing, was between 1.9 and 7.0% of the number of viable spores present in the original spore suspension used for the preparation of cement stone samples [40].

Concentration of bacteria

A high bacterial cell concentration supplied to the soil sample would certainly increase the amount of calcite precipitated from MICP process [40] as more number would increase number of viable bacteria in MICP process. Better calcite production was reported when high concentration of bacteria is used close to injection well [41].

Size and shape of bacteria

The size of bacteria influences bacterial calcification. Bacteria size typically ranges between 0.5 and 3.0 µm [42], but the length of microbial cellular filaments can be an obstacle in penetration of filamentous microorganisms into soil as it can be up to 100 µm. Transportation of microbial cells into soil depends on cell size, cell surface properties and cell physiological state [43].

Soil particle size

Soil particle size also affect MICP process as the size of soil pores should be sufficient to transport bacteria with size of 0.5-3.0 μm in length [42]. Soil particle size and bacterial cell size both are important factor for MICP treatment because soil particle size/grain size will form soil pores which allow bacterial movement during the MICP process [44]. The efficiency of MICP process will depend on ability of bacteria to move within the pores. Other studies also confirmed that MICP treatment is effective for soils with particle sizes of about 25 μm diameter (silty soils) and larger [45,46].

Nutrients

In MICP system, the bacteria are the only organism needs energy source to continue the metabolic processes which in turn helps in continuation of the precipitation. Nutrients are the energy sources for bacteria, and which are provided to bacteria through both culture stage and soil treatment stage. For better precipitation of carbonates a positive correlation between attached microbial biomass and the soil hydraulic conductivity was proved using dextrose-nutrient solution [47] by doing experiments on reduction of soil hydraulic conductivity of increased biomass. Common nutrients for bacteria include CO_2, N, P, K, Mg, Ca, Fe, etc. [48], but these nutrients have high cost. The nutritional profile of bacterial cultures indicates a high preference for protein based media as for *S. pasteur* [49]. Other alternative nutrients to reduce the cost and protect the environment have been proposed [50]. Various studies have been conducted on growth and feasibility of urease producing bacteria. Most of these studies included 3 g/L of nutrient broth into the treatment solution for better growth of microbial biomass [51,52].

Chemical solutions

Various chemical solutions have been applied to enhance calcite production by injecting them into the cracks which induces calcite production by hydrolysing urea [53-56]. Various chemical solutions have been studied till now in this process like calcium sulfate, calcium chloride, sodium carbonate, sodium chloride, sodium acetate, ammonia and alcohol. Most of the studies adopted Urea-calcium (urea-$CaCl_2$) based cementation media were used to influence on analytic-driven calcium carbonate precipitation. The quantity of the added chemical solutions determines the difference between bioclogging and biocementation. So, at low quantity of the added chemical solutions the precipitation of calcium carbonate is going mainly in the sites of particle contacts, which is sealing the micro channels while at higher quantity of added chemical solutions precipitation will be in the pores creating high strength. Study on influence of the concentration of calcium salts and urea, on the efficiency of the bio deposition treatment showed 50% water absorption reduction with increase of calcium dosage [57]. Repeated injection of chemical solutions of urea or a mixture of urea and calcium chloride was reported for increase in water proofing effect on porous media [58]. However increases in reactant concentrations up to a certain level (urea and $CaCl_2 \bullet 2H_2O$ concentrations: 36 and 90 g/L, respectively) resulted in increased calcium carbonate production. Some more studies shown that using $Ca(CH_3COO)_2$ as the calcium source have a higher strength and a more distribution in the pore of soil than those using $CaCl_2$ or $Ca(NO_3)_2$. The crystal type of the MICP of the samples treated with $Ca(CH_3COO)_2$ is chiefly aragonite, while that of the others is chiefly calcite and also proved that $Ca(CH_3COO)_2$ is an appropriate alternative calcium source to replace $CaCl_2$ for the MICP technology applied in the reinforced concrete structures [59] as shown in Figure 4.

Another study showed that the cementing mechanism of the biophosphate cement is that barium hydrogen phosphate particles by microbial precipitation can form large agglomerates with each other and interact with quartz sand to produce van der Waals bonds in sandstones [60]. Change in the crystal structure type and morphology was observed with increase in magnesium concentration [61].

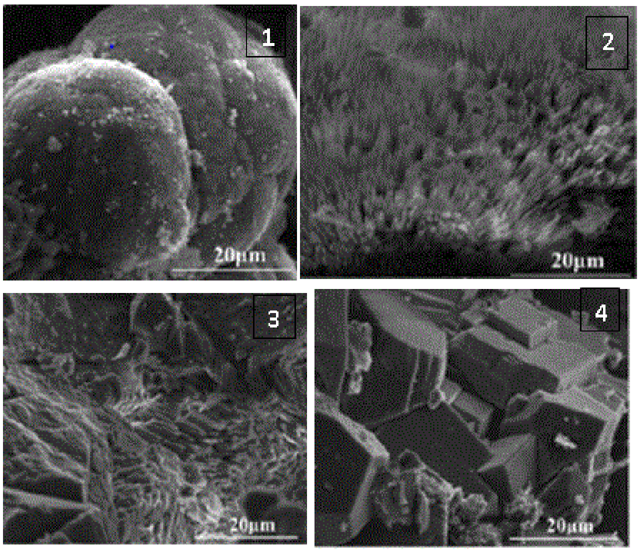

Figure 4: Scanning electron micrographs of biogrouted samples of different calcium sources (i) vaterite (ii) aragonite (acetate sample) (iii) calcite (nitrate sample) (iv) calcite (chloride sample)

Also, the presence of magnesium chloride leads to the retardation of microbial precipitation rate, producing little content of carbonate containing phases. Magnesium was also studied as one of the substitute material for Microbial Induced calcite precipitation treatment in which magnesium chloride was added to chemical solution to delay the reaction rate and to increase carbonate production [62].

pH

pH plays a very big role in microbial system and the carbonate ions concentration at MICP process. MICP treatment utilizes organic acids [63] due to which there is an increase of both pH and concentration of dissolved inorganic carbon. Urease activity or urease hydrolysis by some bacteria has been extensively studied as compare to other biological systems for calcite production. This under surface activity of urease hydrolysing bacteria could produce NH^{4+} and bicarbonate ions causing an increased pH due to calcium carbonate production. Urease catalyzes the hydrolysis of urea into CO_2 and ammonia leading into increased pH in bacterial environment. MICP treatment occurs at pH range of 8.3-9.0, as urease activity remains high at this pH [64]. Various workers studied series of events happening during ureolytic calcification using *S. pasteurii* [65].

Temperature

Urease catalyzed ureolysis is a temperature dependent process and suitable temperature range is from 20°C to 37°C because, ideal temperatures have a good effect on precipitation of calcite by bacteria and increasing the ability of the strain to form crystals. Other report states that increase in temperature will results in an increase in urease activity up to 60°C [66]. This feature is particularly interesting for those countries where temperature remains high. They concluded that if there is an increase of 10° over the range 5-35°C there will be an increase in urease activity also by the factor of 24. They also revealed that no urease activity was seen in soil temperature below 5°C, which could also be explained as at this temperature bacterial cells have limited activity. Most of the studies on temperature have been conducted at an ambient laboratory temperature of 20 ± 2°C. Calcium carbonate of calcite type can stay stable at room temperature [67].

Nickle ion concentration

Effect of nickel ion concentration was studied using *Bacillus cohnii* [68]. They titrated 6 samples of culture medium (*Bacillus cohnii*) with or without nickel ion with EDTA solution so as to certain the amount of calcium carbonate precipitated and estimated calcium ion. They found that incorporation of nickel ion served the purpose of increasing the urease activity as well as increased calcium carbonate precipitation as urease is nickel ion dependent enzyme.

Injection strategies

A suitable injection method is needed for successful MICP treatment. Microbial grouting can be achieved in several ways. The most important factor in order to achieve even calcite precipitation throughout the soil mass is uniform distribution of microbial cells followed by fixation inside the porous structure. Several ways of introducing/injecting bacterial cells in MICP treatment process have been studied. Prior mixing of bacterial cells and cement material leads to immediate flocculation of bacteria and crystal growth which may play an important role in treatment of surfaces [69]. This could lead to rapid clogging of injection point and surrounding areas pore space for many of the fine or medium sand. The two-phase injection is another strategy has been conducted, where the bacterial cell solution is injected first, followed by the cementation solution [70]. This strategy applied to prevent crystal accumulation around the injection point and led to a more homogeneous distribution of calcium carbonate. A more uniform distribution of calcite precipitation was achieved over a greater distance in the sand [71-73].

HUMAN HEALTH AND MICP

Concrete is the basic material used worldwide for construction purpose but cracks appear as an unavoidable hurdle in maintaining structure in their original forms. However this cement causes various health hazards as follows-

(i) Research has proved that people who are constantly exposed to cement dust have decreased ventilator function and increased frequency of respiratory symptoms which is not dependent on age, BMI and smoking [74].

(ii) Manufacturing and processing of cement involves heavy metals like nickel, lead, cobalt which are hazardous to environment affecting vegetation, human and animal health and whole ecosystem. Lead can replace calcium in bones and can cause major health problems to humans, especially to children under the age of six where even low levels can cause mental retardation, anaemia and can slow growth. [75].

(iii) Cement dust is known to irritate not only exposed mucous membranes but skin too and causes reactions leading to three increased pH values around mucous membrane which can lead to chronic impairment of lung function in human population [76].

(iv) Intermittent exposure to cement dust is also reported to cause harm to human health as it is associated with enhanced risk of liver abnormalities and some cancers as exposure to cement dust causes increased plasma lipid peroxidation and decreased antioxidant activity [77].

(v) Cement dust also destroy natural water quality by producing hydroxides after coming in contact with water. A fine layer of cement covers the surface of wells and ponds. The addition of salts of Ca, Na, K, Mg and Al as hydroxides, sulfates and silicates affect the hardness of the water that subsequently are responsible for the respiratory and gastro-intestinal diseases in the area [78].

Advantages of biocementation

The biocementation process (microbial consolidation) has several advantages over the ordinary cementation processes because:

(i) It improves the load bearing capacity without making soil impermeable to other fluids [79]. Retention of the permeability was evident by the absorbance of water recorded in the biocemented surfaces. For consolidation of loose material, it is vital to conserve the permeability so that the water moves through the voids in the stone hindering the deterioration due to water logging [80].

(ii) Microbial induced precipitation Bacterial process is cost effective too as bacterial cells used can be reused several times from 2-3 times to 20 times. Studies showed that bacterial enzyme could be reused in subsequent applications of calcium and urease only. Therefore it can be considered as cost effective method as cost of culturing bacterial cells is not required every time [81].

(iii) MICP process is more cost effective than its parallel other processes like Calcite In-situ Precipitation System (CIPS) technology. One of the components of CIPS cementation solution is originated from a plant source. Thus CIPS is a challenging process since it is subjected to seasonal variation, extraction cost and transport [82].

(iv) Bacteria are more tolerant than plant source towards extreme conditions of cement which makes them better source material for biocementation process [83].

Potential risk factors

In spite of a number of advantages there are certain reservations and/or limitations regarding the use MICP in cement crack healing on commercial basis.

(a) Urease enzyme has been extensively studied by various scientist, commercial use of such ureolytic bacterial strains may cause problem as this enzyme is associated with increased virulence among pathogenic bacterial strains [84,85]. Urease enzyme was also found as a general nitrogen volatilization phenomenon in agricultural soils [86-88].

(b) To combat the challenge of accumulation and release of pathogenic bacteria during bioclogging and bio cementation, the following selective conditions can be used.

(c) Simple carbon source which is used by saprophytic bacteria in natural conditions like cellulose, vegetable processing waste, cellulose-containing agricultural waste are used.

(d) Growth of autolithotrophs is promoted using specific conditions like carbon di oxide is used as carbon source and some inorganic chemicals for e.g. NH^{4+}, Fe^{2+}, S are used as electron donors.

(e) Conditions suitable for aerobic bacteria are provided with SO_4^{2-} or Fe^{3+} as electron acceptors.

(f) Low carbon source concentration is kept to promote oligolithotroph enrichment in biocementation process.

There are known similar applications of starter cultures to start up the large-scale non aseptic environmental processes for faster start-up and increased biosafety [89]. Some of them are enlisted below-

(i) Bacterial encapsulation using polyurethane, silica gel or microcapsules [90].

(ii) In MICP process prediction of unknown bacterial species under the subsurface is a difficult task which is enhanced due to complexity of indigenous microbial consortia and their ecological function [91].

(iii) Reduction of precipitation occurs in presence of ammonia and high concentration of ammonia again may possess threat to human and animal health.

(iv) Urease producing bacteria involved in MICP process can be grouped into two part- (a) whose activity is repressed in presence of ammonia, e.g. *Alcaligenes eutrophus*, *Bacillus megaterium*, *Pseudomonas aeruginosa* and *Klebsiella aerogenes* [92] and (b) whose activity is independent of presence of ammonia as shown in Table 2. Therefore, microorganisms whose urease activity is not repressed by the high content of ammonium are preferred in bio-mediated soil improvement since high concentrations of urea are hydrolysed in the process.

(v) Gene transfer in other related species and mutation may cause problem.

Table 2: Microorganisms with urease activity that is not repressed in the presence of ammonium

Microorganism	High activity	Not repressed by NH^{4+}	Not Pathogenic or GM
Sporosarcina pasteurii	+	+	+
Proteus vulgaris	Unknown	+	Moderate
Proteus mirabilis	Unknown	+	-
Helicobacter pylori	+	+	-
Ureaplasmas (Mocllicutes)	+	+	-

From the technological and biological points of view, the most suitable physiological groups for the soil bioclogging and in situ biocementation process include both aerobic and anaerobic conditions. MICP treatment can be designed and customized according to the site conditions of soil and accordingly can be implemented to ensure the sequence of anaerobic and aerobic biogeochemical processes and facilitate soil bioclogging or biocementation.

Recommendations

Complete elimination of cement material is not possible as of now but certainly risk factor due to reconstruction work to seal the gaps/cracks developed during the course of time can be minimized using MICP process. In the MICP process all is needed is water to activate bacterial cells to start calcite formation. Apart from using techniques like MICP other measures like continuous online monitoring and adherence to the emission norms prescribed under pollution control legislation are needed. In addition to these urease-producing bacteria for bio-mediated applications should not be pathogenic, genetically being modified or enclosing any exchangeable elements that may enhance the pathogenicity of environmental microbes.

Future prospects

Various efforts can be made in order to include MICP process as sustainable construction purpose and to reduce possible hazardous consequences. One such application is to isolate indigenous soil bacteria to reduce the mobility of lead in soils and to isolate metal adapted ureolytic bacteria for bioremediation [92], similar work can be done in near future using indigenous microbes of different geographical conditions. Free calcium is usually present in the concrete matrix, but organic carbon is not. Therefore, currently organic carbon source is applied externally in MICP treatment whereas ideally it should be mixed with concrete for better precipitation. What type of specific organic compounds is suitable to include in the concrete matrix can be optimized. Type of organic compound should be taken care of as these are suitable food source for bacteria as well as it should be compatible with concrete. Certain classes of organic compounds are less- or not suitable at all, e.g. compounds such as carbohydrate derivatives that are known to inhibit the setting of concrete even at low concentrations.

Other ongoing investigations address the possible decrease in concrete permeability and the change of mechanical characteristics of healed cracked concrete due to bacterial calcite precipitation. There are certain methods which not only results into calcite formation but also improves soil particles involved in construction.

CONCLUSION

With the global rise in temperature there is more thrust given on sustainable and environment friendly approach in every field including construction of building materials. Microbial Induced Calcite Precipitates (MICP) has shown its promising role as a new and sustainable technology to improve the mechanical and physical properties of construction materials. Since MICP is a process that depend on chemical and biological reactions there will be many factors influencing it and any kind of effect on human health will depend on type of bacteria used in the process. Nevertheless, this process could be used in other applications like soil improvement against landslide, soil erosion and reduce the liquefaction resulting for earthquakes which will ultimately benefit the society and environment both.

Therefore, it can be concluded that MICP relies in the fact that calcite produced does not have any specific biological functions which may be genetically related to bacteria involved in the process. This confirms that microbial induced mineralization to produced carbonate is the most prevailing process. Nevertheless, different mechanism with respect to role of microorganism in the calcite precipitation explains the complexity of bio-mineralization process and need for further research for better tomorrow.

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