APPLICATIONS OF BACTERIA IN CONSTRUCTION INDUSTRY- A REVIEW

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Abstract
Microbially-mediated construction methods and microbial manufacturing of construction materials are new areas of Science and Engineering, which is the branch of construction microbial biotechnology. Production-related biotechnologies are primarily based on pastime of various microorganisms. These include cyanobacteria, algae, microscopic fungi as well as urease, acid, sodium, alkaline producers, as well as denitrifying, iron- and sulfate-decreasing microorganisms. The bio-associated substances and strategies may be used for bioaggregation, soil biogrouting and bioclogging, in crack remediation, self-healing, and biomediated ground improvement. Microbial biotechnology in costruction is progressing in the direction of business products and huge scale packages. The produced materials biotechnologically and construction-associated have lots of blessings over traditional created materials and methods such as cost effective and green alternative to traditional methods of stabilizing soils, it needs a reduced production time and the in-situ process raw materials of biocements are produced at low temperature. More efficient compared to ordinary cement which use temperature up to 1500˚C in production process. The successful commercialization of the technique requires economical alternatives of the medium ingredients that cost 61% of the operating costs. Factors affecting the use of bacteria in construction industry include type of the bacteria and their cell concentration, pH, temperature, calcium and urea concentration. Microbial concrete biotechnology has shown better qualities above several traditional technologies.

Key words: Microbial concrete biotechnology, construction, bioaggregation, biogrouting and bioclogging.

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1. INTRODUCTION

The microbial production of concrete-construction materials and the packages of microorganisms in manufacturing method are main directions in microbial biotechnology of construction items. Many specific products of biotechnologies for civil engineering are developing inside those instructions (Ivanov, 2010). Manufacturing of cement, the most important material needed in civil engineering work, is power-consuming and not friendly to the environment. Power consumption represents 20–40 % of the total outlay of cement production due to the fact higher temperature (greater than 950℃) is wanted for the conversion of limestone to cement clinker. Novel building materials, microbial biocements, can be manufactured using dolomite, limestone or iron ore at temperature 20–60˚C with much less than 10 % of power used for the production of traditional cement. For that reason, price of biocements can be lesser when compared to that of conventional cement.

There are loads of alternative blessings of microbially-based biocementing or bioclogging materials over typical cements and grouts, for instance it lasts longer because it can be produced from organic substances, reduced viscosity, and negligible danger of bad environmental cost. It's far important that biocement should be created from the same raw substances that are using for cement manufacturing. (Dhami *et al.*, 2012).

Another form of biologically derived materials used in building constructions are manufactured in industries or manufactured by microbial polysaccharides such as xanthan, welan, succinoglucan, curdlan, chitosan are used in mortars mixing, plastering of walls, leveling of floors, viscosity improvement through grouts injection, retention of water, retarding of set, (Plank, 2004).

Modification of soil properties can be achieved by manufacturing of bacterial polysaccharides in soil when bacterial cells and necessary nutrients were added in situ. The method could be used for mitigating natural problems such as control of dam, soil, wind, and erosion, mitigation of earthquake liquefaction, reactive barrier construction, and containment of contaminated soils (Achal *et al.*, 2010).

Numerous microbes are involved in construction industries that are microbial-mediated. Though, the preferred organism are bacteria because of their cell size that is small (0.5–10 lm), wide diversity in physiology (pH of 2–10; temperature of -10 to +110^{o}C), wide variety of biochemical reactions (oxidation-reduction potentials, O_2, nitrate, ferric, sulfate), doubling time and rates of metabolic activities (Li *et al.*, 2011).

2. APPLICATIONS OF BACTERIA IN CONSTRUCTION AREA

The uses of bio-concrete Construction Engineering have grown to be gradually trendier (Rebata-Landa, *et al.,* 2012). Production of construction materials through biological processes is a reliable procedure since biological biomass remains that are renewable are utilized as raw materials and as the constituents of merged biologically-derived cement (Mitchell and Santamarina, 2005). Construction material and bioplastic microbial origin could be produced from organic fraction and solid agricultural wastes from cities. In a number of soil mechanics and foundation engineering processes, microbes perform useful function on their own (Stabnikov *et al.*, 2013).

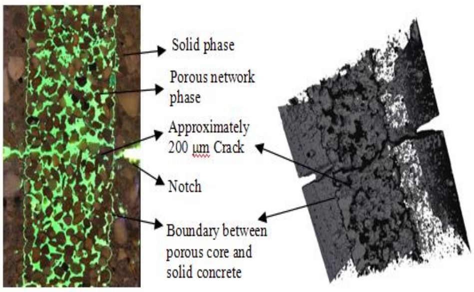
About eight types of processes in concrete-related biotechnology are classified as a result of the microbial approach: (i) Particles/soil bioaggregation. This is used to increase the amount of the very small particles to facilitate aqua, top soil and wind erosions, movement of sand, as well as dust production will be abridged (Bang *et al.,* 2011); (ii) Soil surface biocrusting; a method to develop soil minerals or crude crust on top of soil subsequently reducing erosion, emission of dust, and infiltration of water (Stabnikov and Ivanov, 2011); (iii) Solid surface biocoating which entails the development of a coat on the surface of the soil with the intention of enhancing the aesthetics or colonization of soil surface (Chu *et al.,* 2012); (iv) Filling of the openings and canals in soil so that porous matrix and hydraulic conductivity of soil will be significantly reduced through bioclogging (Ivanov *et al.*, 2012); (v) Soil or particles biocementation; a method employed to enhance extensively compact of soil or dusts (De Muynck *et al.*, 2012; Harkes *et al.*, 2010; Li, and Qu, 2012; Dosier, 2013; Raut *et al.*, 2014); (vi) Biodesaturation of soil is a practice used to reduce diffusion and melting potentials of dusts by production of biogas in the soil (He *et al.*, 2013) (vii) Clay/soil/particles bioencapsulation is a method employed to raise potency of soft clayey and normal soil by the formation of tough shield covering the pliable substance (Ivanov *et al.*, 2014) and (viii) Soil bioremediation; a method used in the removal of contaminant from soil or halt pollutant dispersion in soil prior erection of any concrete work (Mitchell and Ferris, 2005).

The biotechnological approach involved the manufacture of materials used in construction work encompass major three phases: (i) First stage involves medium preparation, equipment, and microbes inocula (minute or dried); (ii) Second stage which is a major procedure such as culturing of microbes;(iii) Final stage which includes aggregation of microbial biomass or its product; packaging, drying, equipments washing, wastes disposal or treatment (Stocks-Fischer *et al.*, 1999).

Various bacteria helped in the enhancement and durability of cementation materials, improvement in sand properties, restore of sandstone properties, covering of cracks in concrete, highly durable bricks production. Various applications of bacteria in building construction by diverse writer presented in Table 1.

Microorganisms are involved in several construction processes. Examples include the production of biocement.

Table 1: Application of various bacteria in construction area (Stabnikov 2011)

APPLICATION	ORGANISM
Concrete and mortar cement 	*B. cereus* (Levrel *et al.*, 1999), *Bacillus* sp. CT-5 37 (Achal *et al.*, (2011), *Bacillus pasteurii* (Ramanchandran, 2001), *Shewanella* (Ghosh, *et al.*, (2005), *Sporosarcina pasteurii* (Achal *et al.*, 2011).
Cracks in concrete remediation 	*Sporosarcina pasteurii* (Bang *et al.*, 2011) *Bacillus pasteurii* (Ramakrishan, 2007). *Bacillus shaericus* (Ramanchandran *et al.*, 2001, De Belie *et al.*, 2008). *Bacillus shaericus* (De Muynck *et al.*, 2007).
Self-healing 	*Bacillus pseudifirmus and B. cohnii* (Jonkers, 2007).

Different types of biocementation based on diverse biological, geological and chemical interactions are carried out by microbes (Ivanov and Chu, 2008).

In many of the study carried out on biocementation processes, *Sporosarcina pasteurii* (former *Bacillus pasteurii*), especially *S. pasteurii* ATCC 11859 (DSM 33) strain which is Gram negative bacteria is utilized due to its increase in activities of urease and capacity to develop at alkaline pH of above 8.5 and at higher accumulation of calcium; 0.75 M Ca^{2+} which is mostly important for microbial induced calcite precipitation (MICP). Other species that are related physiologically that used for biocementing work represents the *Bacillus* genus: *B. megaterium* (De Muynck *et al.*, 2010), *B. cereus* (Castainer, 2000), *B. pseudofirmus* (Jonkers *et al.*, 2010), *B. sphaericus* (Wang *et al.*, (2012), *B. subtilis* (Reddy *et al.*, (2010), *B. alkalinitrilicu* (Wiktor and Jonkers, 2011), *B. lentus* (Zell *et al.*, 2008), *B. licheniformis* (Vahabi, *et al.*, 2014), and not identified species (Stabnikov *et al.*, 2013: Hammes *et al.*, 2003; Lisyandati and Kaltwasser, 2011).

Biocementation will be executed as bulk biocementation through the provision of microorganism suspension altogether or on individual basis with solutions of calcium and carbide by insertion, and using surface percolation (Oka *et al.*, 1993) or exterior spraying (Stabnikov *et al.*, 2013; Stocks-Fischer *et al.*, 1999; Chu *et al.*, 2012).

Few numbers of disadvantages are present in conventional process of MICP:

(1) Ammonium and ammonia are the by-products of hydrolysis of urea are toxic

substances for workers, dangerous for aquatic inhabitants and air, and enhance the danger of metal corrosion because of acidic nature; (2) The calcite crystals bonding the soil particles weakness; and (3) The expenditure of purchasing calcium reagent and urea were higher when compared to the costs limestone based cement (Sarda, (2009). For that reason, there is need to improve MICP likewise novel biocementation processes should be adopted to rise above the above drawbacks of conventional MICP.
An example of biocement made by microorganism is calcium and urea-dependent cements as described below:

Biocementation of Calcium- and Urea-Dependent
Calcium carbonate precipitation induced by microorganism (MICCP) are the most popular type of biocementation, which is the formation of calcium carbonate minerals such as aragonite, vaterite, or calcite on the exterior of soil particles due to: (i) Adhesion of bacteria producing urease to the surface of particle; (ii) Production of few concentration of pH and carbonate in the position of attached by cell due to broken down of urea by urease of urease producing bacteria. The reactions of biogeochemical reactions in biocement production process are as follows:

$$(NH_2)_2CO + 2\ H_2O \xrightarrow{\text{Urease}} CO_2 \uparrow + 2NH_4OH, \quad (1)$$

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \xrightarrow{\text{Carbonicanhydrase}} H^+ + HCO_3^- \longleftrightarrow 2H^+ + CO_2, \quad (2)$$

$$CaCl_2 + H_2CO_3 \longrightarrow CaCO_3 \downarrow + 2HCl, \quad (3)$$

$$2HCl + 2\ NH_4OH \longrightarrow 2NH_4Cl + 2H_2O, \quad (4)$$

Total

$$(NH_2)_2CO + 2H_2O + CaCl_2 \xrightarrow{\text{Urease and carbonicanhydrase}} CaCO_3 \downarrow + 2NH_4Cl \quad (5)$$

Urease enzyme (EC 3.5.1.5) is generated by a broad array of microbes as urea is the end product of human and animal's metabolism of nitrogen and are the source of nitrogen for many microorganisms in nature. Another enzyme that also play important role in MICP is Carbonic anhydrase (EC4. 2.1.1) is present in *Bacillus* species speeding the rate of the reversible hydration of carbondioxide (Dhami, *et al.*, 2014). MICCP is under research and trials in the ex situ mostly for numerous geological and other technical purposes (Seagren *et al.*, 2010; DeJong *et al.*, 2010; DeJong *et al.*, 2013; Sarayu *et al.*, 2014) in order to improve immovability of the dams and slopes (van Paassen *et al.*, 2010; Stabnikov and Ivanov, 2011) for construction of highway and mitigation of wearing down of soil (Mitchell and Santamarina, 2005; Whiffin *et al.*, 2007; Ivanov, and Chu, 2008); for the fish ponds construction and basins in sandy soil or channels, (Chu and Ivanov, 2013; Stabnikov and Ivanov, 2011) for soil control and dust suppression (Bang *et al.*, 2011; Stabnikov *et al.*, 2013) to strengthen soil in areas near to shore (van der Ruyt, and van der Zon, 2009).

Crack Remediation using Microbial Concrete
Enhanced crack remediation using microorganisms has been stated where *B. pasteurii* was make use of in inducing precipitation of calcium carbonate (Pacheco-Torgal and Labrincha, 2013; Pacheco-Torgal and Jalali, 2014).
May (2005), proposed microbiologically enhanced crack remediation (MECR) in concrete. Samples were crammed with bacteria, substrate and soil and there was significance

improvements in compressing power with rigidity rates when evaluated with the others devoid of microbes were verified.

Jimenez-lopez, *et al.,* (2008), examined the encapsulation of cells of bacterial in polyurethanes and stated that enhanced crack remediation with microbes by polyurethane immobilized cells of bacterial was successful. The effects of immobilized bacterial cells on strength of cement cubes by varying the concentration of immobilized cells per crack were also studied. Remediated cubes with $5x10^9$ cfu/ml immobilized cells crack for 7 days had the highest compressive power while following that, increased strength was observed to be insignificant.

Application of Bacteria in Self Remediation or Self-Healing Process

Self-healing concrete remediation is a result that will microbiologically make granite to repair fault which show on the exterior of concrete structures. *Bacillus* Genus *(Bacillus pseudifirmus* and *Bacillus cohnii),* are specially selected types of the bacteria genus along with a substrate that is calcium-based known as calcium lactate, supplemented with phosphorus and nitrogen (N) to the constituents of the concrete when it is being mixed. Dormancy can exist in self healing agents inside the concrete for approximately 20 decades (Jonkers, 2007).

On the other hand, germination bacterial spores start on contact with aqua and substrates when a concrete structure is damaged and water starts to seep through the fracture that appears in the concrete. After activation, the bacterial cells commenced to utilize calcium lactate as food. During feeding, oxygen is also consumed and calcium lactate is being converted to insoluble limestone, resulting to the solidification of limestone on the cracked surface, and finally sealing it up. It imitates the process by which fractures in human bone are naturally restored by cells of osteoblast that mineralise for bone reform (De Muynck, *et al.,* 2008).

Additional advantage is available when of oxygen is being consumed during the bacterial conversion of calcium lactate to limestone. Corrosion cannot take place in the absence of oxygen as it is an essential element in the process of corrosion of steel and when it has been consumed by bacterial activity, increase in strength of steel that reinforced concrete constructions occurs (Jonkers *et al.*, 2010).

Application in Biologically induced Soil Enhancement

The two major problems in geo-engineering are soften of loose sands in hydraulic fills and natural (underwater) or manmade slope. Life and massive financial loss are the consequences of piping and liquefaction associated with sudden and catastrophic failures. Sustainable level of conventional methods in mitigating the effects such as ground improvement or compaction methods as employed in jet-grouting or soil mixing are not guaranteed because consumes high amounts of energy, materials and costs coupled with significant impact on the environment (van Paassen *et al.*, 2010).

Biologically-induced precipitation of carbonate by broken down of urea has revealed great potential for soil enhancement. Recently, studies carried out by Mitchell and Santamarina, 2005; Whiffin *et al.*, 2007; Neville, 1995, revealed that the calcite crystals form solid "bridges" between existing sand particles, increasing power and inflexibility of sand with limited reduction in permeability.

Suggested fixation process is the outcome of effect of ionic strength on microorganism movement. Biogrout; a microbiologically induced calcium carbonate was used to achieve the uniform strength which resulted to improved ground strength. A method designed to increase fixation and dissemination of microbial cells with protein synthesized increased their activity in soil so as to enhance the prospective of microbiologically induced carbonate precipitation as soil reinforcement technique in fine-grained sand. The method involves an injection in various stages; inoculums suspension is injected, seconded by a fascination liquid (i.e. saline solvent) and finally cementation solution is added (Harkes *et al.,* 2010).

Application in Reduction of Reinforced Concrete Corrosion

Steel corrosion and rebar structures in concrete are some of the major reasons for collapse of constructions. Corrosion commence as a result of entrance of humidity, chloride ions and CO_2 from the concrete to the surface of the steel. Permeation and corrosion are used interchangeably; water and pollutant's permeability are amongst the major pressure to reinforced concrete. This resulted to inflow of moisture and chloride ion which is responsible for premature steel corrosion and leakages. Corrosive produce i.e iron oxides and hydroxides resulted in expansion that fracture and spall the cover of concrete which later depict reinforcement to direct environmental attack that results in accelerated worsening of the buildings (Mukherjee *et al.*, 2010).

When microbial induced calcite is used in concrete work, it helps in sealing the paths of cracks and improved the life of reinforced concrete structures (Jonkers, 2007). In research conducted by Qian *et al.*, (2010), it was reported that four (4) folds decrease in corrosion of reinforced concrete samples when *Bacillus* sp. CT-5 is applied. They also reported decrease in aqua and chloride ion inflow when calcite formed by *Sporosarcina pasteurii*. Achal *et al.*, (2009), utilized *B. pasteurii* to verify its effect on resistance to moisture inflow and acid hit and reported that microbial calcite enhances resistance to surface permeability and acid attack (at pH above 1.5).

ADVANTAGES AND LIMITATIONS OF THE USE OF BACTERIA IN CONSTRUCTION INDUSTRY

As previously mentioned, microorganisms especially bacteria are involved in various aspects of construction industry. Some advantages and limitations of the use of microorganisms in construction industry are discussed below:

Advantages of the use of bacteria in construction industry

The use of microorganisms in construction technology can offer ways for reduced cost and strong high-way, durable buildings that can last for decades, durable river banks, prevention of erosion of weak soil and cheap durable house. Production of conventional construction materials affects environment negatively by high production of greenhouse gases and increased costs of production (Achal *et al.*, 2010). Greenhouse gases emission during production processes of construction materials contributes largely to global warming. In addition to this, high cost of construction and building materials are other issues that require great consideration (Dosier, 2013). Microbial induced calcium precipitation is a promising technique that can be used for containment of various contaminants and heavy metals (Achal *et al.*, 2010). Biocement needs a much shorter time for production and the in-situ process raw materials of biocements are produced at low temperature (Raut *et al.*, 2014). More efficient compared to ordinary cement which use temperature up to 1500˚C in production process (Dosier, 2013), bio cement can be used as eco construction material since it consume less energy and less CO_2 emission in the production process as compared to other ordinary cement (Vahabi, *et al.*, 2014), it increases compressive strength of mortar by up to 38 % (Stabnikov *et al.*, 2013). To make the process economical, microbial additives can be prepared by growing cells using industrial by products such as lactose mother liquor and steep liquor from corn as nutrient sources Li and Qu, (2012). It enhances the durability of bricks by reducing their permeability and increasing compressive strength (Sarda *et al.*, 2009). The reduced permeability rates resulting from the microbial additive will increase the concrete structures useful life (Castainer, 2000). Bio cement can remediate cracks in building materials and monumental stones and regain strength within 28 days (He *et al.*, 2013).

Limitations of the use of bacteria in construction industry

Cost of production

Among the main factors obstructing the application of MICCP methodology is the increased costs needed for their manufacturing. The required cost is ascribed to price of microorganism metabolite and the required number of applications used. For improved carbonates concentration, the required is increased through which the material used in building has to be wet. Multiple introduction of substrates above several days is required in order to guarantee the existence of adequate volume of aqua, (Le Metayer-Levrel*et al.*, 1999), or the introduction of a pilot materials have been projected (May, 2005).

Reducing the cost this approach, scientists have searched for available cheap substrate sources. There are numerous effluents from various industries that are rich in proteins. If freed inside the altered shape, they are dangerous for the atmosphere. So, the twofold advantages of price reduction and protection of environment are possible. Two of such wastes are lactose mother liquor (LML) and corn steep liquor (CSL). Lactose mother liquor is an industrial effluent of the dairy enterprise (Sutton *et al.*, 2008).

Concentration of ammonia and salts

The production of ammonia for the duration of hydrolysis of urea would possibly enhance a few troubles of environmental challenge due to the fact that atmospheric ammonia is being diagnosed as a pollutant. Atmospheric ammonia is thought to make a contribution to numerous environmental problems, including direct poisonous effects on plant life, atmospheric nitrogen deposition, leading to the eutrophication and acidification of touchy ecosystems, and to the formation of secondary particulate count number in the environment, with results on human health, atmospheric visibility and global radioactive stability (Ng et al., 2012).

Survival of bacteria

Inoculum size and survival of bacteria doubtlessly affects formation of calcite by bacteria (Achal et al., 2010). Okwadha and Li, (2010), studied the survival of micro organism internal carbonate crystals for up to 330 days. Tremendous reduction inside the possible cells turned into noticed after thirteen days and after three hundred and thirty days, no cells are viable. This means that, it may be challenging for bacteria to survive in cements and the survival of bacteria within the building material also influences the extent of calcification. In addition, MICP is more complex than the chemical one as the microbial activity depends on many environmental factors including temperature, pH, concentrations and diffusion rates of nutrients and metabolites (May, 2005). The cost of field applications of bacteria consortium also restricts the use of this technology in several cases (Ng *et al.*, 2012). Successful commercialization of the technique requires economical alternatives of the medium ingredients that cost as high as 60 % of the total operating costs (Stabnikov *et al.*, 2013).

3. FACTORS AFFECTING THE USE OF BACTERIA IN CONSTRUCTION INDUSTRY

Factors affecting the use of bacteria in construction industry include type of the bacteria and their cell concentration, pH, temperature, calcium and urea concentration (Zamareno *et al.*, 2009).

Type of bacteria

Many bacteria have been investigated for this purpose, but *Bacillus* species are familiar species of microbes exploit in biocement production. For example, *Sporosarcina pastuerii* is the foremost microorganism exploited for diverse approaches like crack remediation, biocementation, and soil improvement.

Bacterial cell concentration

High concentration of bacteria inocula (between 10^6 and 10^8 cells) increases the amount the rate at which calcite precipitation by MICP takes place[65]. It was also reported by Stocks-Fischer *et al.* (1999) that bacterial cells served as nucleation sites for $CaCO_3$ precipitation, due to the fact that the supply of the nucleation site is important for calcite precipitations (Gorospe *et al.*, 2013).

pH

The acidity and alkalinity influence the rate of calcite formation because the urease will only be active at pH values specific for urea hydrolysis. There has been numerous reports by investigators that the optimum pH for urease is 8.0, above which the enzyme activity decreases. A high pH is very important for ammonia production by urea hydrolysis.

Aerobic bacteria release CO_2 via cell respiration, which is paralleled by an increase in pH due to ammonia production. If the pH levels become low, the carbonate will tend to dissolve rather than precipitate (Pacheco-Torgal and Jalali, 2014).

Temperature

The catalysis of urea via urease is temperature based, similar to other enzymatic reactions. The optimum temperature for maximum ureases ranges between 20 to 37 °C and the most appropriate range of the enzymatic reaction relies upon on environmental conditions and attention of reactants in the structure. It turned into reported that the urease hobby multiplied by using approximately five instances and 10 times when the temperature improved from fifteen to twenty Celcius and 10 to 20 °C, respectively (shares-Fischer, 1999). De Muynck, et al., (2010), reported that urease turned into completely stability at 35 °C, but while the temperature elevated to fifty five Celcius the enzyme viability decreased by means of nearly forty seven percent.

Concentrations of Calcium ion and Urea

The hydrolysis of urea by means of urease no longer best increases the pH, but additionally uses it as a nitrogen and electricity supply (Sutton et al., 2008). Excessive concentrations of urea and CaCl2 (beyond 0.5M) decrease the performance of calcite precipitation and accelerated effectiveness was noted at low concentrations (0.05–0.25 M). Gorospe *et al*., (2013), pronounced that the first-rate urea and $CaCl_2$ concentrations for precipitation of calcite are 0.5 and 0.25 M, respectively. In reality, the calcium ion isn't always likely used by metabolic procedures, but concentrates outside the cells, in which it's far with ease available for $CaCO_3$ precipitation. It was also pronounced that the quantity of $CaCO_3$ precipitation relies upon more on Ca^{2+} concentrations than urea concentrations (Gorospe *et al*., 2013).

4. CONCLUSIONS

Applications of microorganisms in construction industry has demonstrated to be alternative to many existing methods due to its ecologically friendly in nature, abilities of self-healing and increase in strength of a variety of construction materials. Biocementation is extremely simple and easy to use. This will quickly provide the base form excellence, cost effective and environmentally safe buildings. Though, further research is essential to develop the possibility of this technique from both financial and research viewpoints.

The use of biocement, biogrout in constructions involve cementation, research should be intensified on the alternative sources of substrates for microorganisms such as molasses in the production, public awareness on the use these products due to their advantages such as less CO_2 emission, crack-healing, durability.

6. REFERENCES

[1]. Ivanov, V., (2010). Environmental microbiology for engineers. CRC Press, Taylor & Francis Group, Boca Raton, 402.

[2]. Dhami, N. K., Reddy, M. S., and Mukherjee, A., (2012). Improvement in strength properties of ash bricks by bacterial calcite. *Ecology Engineering*, 39:31–35.

[3]. Plank, J., (2004). Application of biopolymers and other biotechnological products in building material. *Applied Journal of Microbiology and Biotechnology*, 66:1–9.

[4]. 4 Achal, V., Mukherjee, A., and Reddy, M. S., (2010). Microbial concrete: way to enhance the durability of building structures. *Journal of Material Civil Engineering*, 23:730–734.

[5]. Li, M., Guo, H., and Cheng, X., (2011). Application of response surface methodology for carbonate precipitation production induced by a mutant strain of *Sporosarcina pasteurii*. In: Geo-Frontiers, ASCE, 4079 – 4088.

[6]. Rebata-Landa, V., and Santamarina, J. C., (2012). Mechanical effects of biogenic nitrogen gas bubbles in soils. *Journal of Geotechnical and Geoenvironmental Engineering*, 138:128–137.

[7]. Mitchell, J. K., and Santamarina, J. C., (2005). Biological considerations in geotechnical engineering. *Journal of Geotechnology and Geoenvironmental Engineering*, 131:1222–1233.

[8]. Stabnikov, V., Chu, J., Myo, A. N., and Ivanov, V., (2013). Immobilization of sand dust and associated pollutants using bioaggregation. *Water, Air, and Soil Pollution*, 224:1631.

[9]. 9 Bang, S. S., Galinat, J. K., and Ramakrishnan, V., (2011). Calcite precipitation induced by

polyurethaneimmobilized *Bacillus pasteurii*. *Enzyme Microbial Technology*, 28:404–409.
[10]. Stabnikov, V. P., and Ivanov, V. N., (2011). The effect of various iron hydroxide concentrations on theanaerobic fermentation of sulfate-containing model wastewater. *Applied Biochemistry and Microbiology*,42:284–288.
[11]. Chu, J., Stabnikov, V., and Ivanov, V. (2012). Microbially induced calcium carbonate precipitation on surface or in the bulk of soil. *Geomicrobiology Journal*, 29:1–6.
[12]. Ivanov, V., Stabnikov, V., and Hung, Y. T., (2012). Screening and selection of microorganisms for the environmental biotechnology process. In: Yung-Tse, H., Lawrence, K. W., Nazih, K. S., (eds) *Handbook of environment and waste management: air and water pollution control.* World Scientific Publishing Co., Inc., Singapore, 1137–1149.
[13]. De Muynck, W., Verbeken, K., De Belie, N., and Verstraete, W., (2012). Influence of temperature on the effectiveness of a biogenic carbonate surface treatment for limestone conservation. *Applied Microbiology Biotechnology*, 97 (3):1335–1347.
[14]. Harkes, M. P., van Paassen, L. A., Booster, J. L., Whiffin, V. S., and van Loosdrecht, M., (2010). Fixation and distribution of bacterial activity in sand to induce carbonate precipitation for ground reinforcement. *Ecology Engineering*, 36:112–117.
[15]. Li, P., and Qu, W., (2012). Microbial carbonate mineralization as an improvement method for durabilityof concrete structures. *Advanced Material Resources*, 365:280–286.
[16]. Dosier, G. K., (2013). Methods for making construction material using enzyme producing bacteria. *United States Patent Applications*, 13:93-335.
[17]. Raut, S. H., Sarode, D. D., and Lele, S. S., (2014). Biocalcification using B. pasteurii for strengthening brick masonry civil engineering structures. *World Journal of Microbiology and Biotechnology*, 30:191–200.
[18]. He, J., Chu, J., and Ivanov, V., (2013). Mitigation of liquefaction of saturated sand using biogas. *Geotechnique*, 63:267–275.
[19]. Ivanov, V., Chu, J., Stabnikov, V., and Li, B., (2014). Strengthening of soft marine clay using biocementation. *Marine Georesource Geotechnology*, 63:267–275.
[20]. Mitchell, A. C., and Ferris, F. G., (2005). The coprecipitation of Sr into calcite precipitates induced by bacterial ureolysis in artificial groundwater: temperature and kinetic dependence. *GeochimCosmochimActa.* 69:4199–4210.
[21]. Stocks-Fischer, S., Galinat, J. K., and Bang, S. S. (1999). Microbiological precipitation of $CaCO_3$. *Soil Biology and Biochemistry*, 31:1563–1571.
[22]. Ivanov, V., and Chu, J., (2008). Applications of microorganisms to geotechnical engineering for bioclogging and biocementation of soil in situ. *Review of Environmental Science and Biotechnology*, 7:139–153.
[23]. Castainer, S., (2000). Purification and subunit determination of the nickel-dependent *Staphylococcus xylosus* urease. *FEMS Microbiology Letter*, 80:271–275.
[24]. De Muynck, W., De Belie, N., & Verstraete W. (2010). Microbial carbonate precipitation in construction materials: a review. *Ecology Engineering*, 36:118–136.
[25]. Wang, J. Y., De Belie, N., and Verstraete, W., (2012). Diatomaceous earth as a protective vehicle for bacteria applied for self-healing concrete. *Journal of Industrial Microbiology and Biotechnology*, 39:567–577.
[26]. Jonkers, H. M., Thijssen, A., Muyzer, G., Copuroglu, O., and Schlangen, E., (2010). Application of bacteria as self-healing agent for the development of sustainable concrete. *Ecology Engineering*, 36:230–235.
[27]. Reddy, S., Rao, M., Aparna, P., and Sasikala, C., (2010). Performance of standard grade bacterial (*Bacillus subtilis*) concrete. *Asian Journal of Civil Engineering*, 11:43–55.
[28]. Wiktor, V., and Jonkers, H., (2011). Quantification of crack-healing in novel bacteria-based self-healing concrete. *Cement Concrete Composition*, 33:763–770.
[29]. Vahabi, A., Ramezanianpour, A. A., Sharafi, H., Shahbani, H. Z., Vali, H., and Noghabil, K. A., (2014). Calcium carbonate precipitation by strain *Bacillus licheniformis* AK01, newly isolated from loamy soil: a promising alternative for sealing cement-based materials. *Journal of Basic Microbiology*, 53:1–7.
[30]. Zell, C., Resch, M., Rosenstein, R., Albrecht, T., Hertel, C., and Götz, F., (2008). Characterization of toxin production of coagulase-negative staphylococci isolated from food and starter cultures. *International Journal of Food Microbiology*, 127:246–251.
[31]. Hammes, F., Boon, N., de Villiers, J., Verstraete, W., and Siciliano, S. D., (2003). Strain-specific ureolytic microbial calcium carbonate precipitation. *Applied Environmental Microbiology*, 69:4901–4909.
[32]. Lisyandati, G. and Kaltwasser, H., (2011). Ammonium assimilation in Proteus vulgaris, *Bacillus pasteurii*, and *Sporosarcina ureae*, *Architecture Microbiology*. 152:125–131.
[33]. Oka, T., Suzuki, M. and Konnya, T., (1993). The estimation of energy consumption and amount of pollutants due to the construction of buildings, *Energy and Buildings*, 19:303–311.
[34]. Pacheco-Torgal, F., and Labrincha, J. A., (2013). Biotech cementitious materials: Some aspects of an innovative approach for concrete with enhanced

durability. *Construction Building Materials*, 40:1136–1141.
[35]. Sarda, D., Choonia, H. S., Sarode, D. D., and Lele, S. S., (2009). Biocalcification by *Bacillus pasteurii* urease: a novel application. *Journal of Industrial Microbiology and Biotechnology*. 36:1111–1115.
[36]. Le Metayer-Levrel, G., Castanier, S., Orial, G., Loubiere, J. F. and Perthuisot, J. P., (1999). Applications of bacterial carbonatogenesis to the protection and regeneration of limestones in buildings and historic patrimony. *Sedimentary Geology*, 126: 25–34.
[37]. Achal, V., Mukherjee, A., and Reddy, M. S., (2011). Effect of calcifying bacteria on permeation properties of concrete structures. *Journal of Industrial Microbiology and Biotechnology*, 38:1229–1234.
[38]. Ramanchandran, R. R., Medina, V. F., and Conca, J. L., (2001). The use of fixatives for response to a radiation dispersal devise attack – a review of the current (2009).
[39]. Ghosh, P., Mandal, S., Chattopadhyay, B. D., and Pal, S., (2005). Use of microorganism to improve the strength of cement mortar. *Cement Concrete Resource*, 35:1980–1983.
[40]. Ramakrishan, S., (2007). Coagulase-negative staphylococci isolated from bovine extramammary sites and intramammary infections in a single dairy herd. *Journal of Dairy Resources*, 75:422–429.
[41]. De Belie, A., Singh, S. V., and Singh, Y. P. (2008). Comparative assessment of energy requirements for different types of residential buildings in India, *Energy and Buildings*, 23:141–146.
[42]. De Muynck, W., Cox, K., Verstraete, W., and De Belie, N., (2007). Bacterial carbonate precipitation as an alternative surface treatment for concrete. *Construction Building Materials*, 22:875–885.
[43]. Jonkers, H. M., (2007). Self healing concrete: a biological approach. *In: van der Zwaag, S. (ed) Self healing materials: an alternative approach to 20 centuries of materials science*. Springer, Berlin, 195–204.
[44]. Whiffin, V. S., van Paassen, L. A., and Harkes, M. P., (2007). Microbial carbonate precipitation as a soil improvement technique. *Geomicrobiology Journal*, 24:417–423.
[45]. Dhami, N. K., Reddy, M. S., and Mukherjee, A., (2014). Synergistic role of bacterial urease and carbonic anhydrase in carbonate mineralization. *Applied Biochemistry Biotechnology*, 172:2552–2561.
[46]. Seagren, E. A., and Aydilek, A. H., (2010). Bioremediated geomechanical processes. In: Mitchell, R., Gu J-D (eds) *Environmental Microbiology*, 2nd edition. Wiley, Hoboken, 319–348
[47]. DeJong, J. T., Mortensen, B. M., Martinez B. C., and Nelson, D. C., (2010). Bio-mediated soil improvement. *Ecology Engineering*, 36:197–210.
[48]. DeJong, J. T., Soga, K., and Kavazanjian, E., (2013). Biogeochemical processes and geotechnical applications: progress, opportunities and challenges. *Geotechnique*, 63:287-301.
[49]. Sarayu, K., Iyer, N. R., and Murthy, A. R., (2014). Exploration on the biotechnological aspect of the ureolytic bacteria for the production of the cementitious materials—a review. Applied *Biochemistry and Biotechnology*, 63:267–275.
[50]. Van Paassen, L., Ghose, R., van der Linden, T., van der Star, W., and van Loosdrecht, M., (2010). Quantifying biomediated ground improvement by ureolysis: large-scale biogrout experiment. *Journal Geotechnology and Geoenvironment Engineering*, 136:1721–1728.
[51]. Chu, J., He, J., and Ivanov, V., (2013). Mitigation of liquefaction of saturated sand using biogas. *Geotechnique*, 63:267–275.
[52]. Van der Ruyt, M., and van der Zon, W., (2009). Biological in situ reinforcement of sand in near-shore areas.*Geotechology Engineering*, 162:81–83.
[53]. Pacheco-Torgal, F., and Jalali, S., (2014). *Eco-efficient construction and building materials. Springer*, London, 247.
[54]. May, E. (2005). Biobrush research monograph: novel approaches to conserve our European heritage. EVK4-CT-2001-00055.
[55]. Jimenez-lopez, M., Rosario, W., Walter, E., and Calhoun, D. H., (2008). Development of a large-scale HPLC-based purification for the urease from *Staphylococcus leei* and determination of subunit structure. *Protein Expro Purification*, 34:111–117.
[56]. De Muynck, W., De Belie, N., and Verstraete, W., (2008). Microbial carbonate precipitation in construction materials: a review. *Ecology Engineering*, 36:118–136.
[57]. Neville, A. M., (1995). Properties of concrete, 4th edn. *Pearson Higher Education*, Prentice Hall, New Jersey.
[58]. Mukherjee, A., Achal, V., and Reddy, M. S., (2010). Microbial concrete: way to enhance the durability of building structures. *Journal of Material Civil Engineering*, 23:730–734.
[59]. Qian, L. A., Maurice, P. A., Parmar, N., and Ferris, F. G., (2010). Microbially mediated calcium carbonate precipitation: implications for interpreting calcite precipitation and for solid-phase capture of inorganic contaminants. *Geomicrobiology Journal*, 18:93–115.
[60]. Achal, V., Mukherjee, A., Basu, P. C. and Reddy, M. S., (2009). Lactose mother liquor as an alternative nutrient source for microbial concrete production by *Sporosarcina pasteurii*, *Journal of Industrial Microbiology and Biotechnology*, 36:433-438.
[61]. Sutton, M., Reis, S., and Baker, S. (2008). Atmospheric ammonia: detecting emission changes and environmental impact. *In: Results of an Expert*

Workshop Under the Convention on Long-Range Transboundary Air Pollution, Springer, 490.
[62]. Zamareno, L. S., Lemos, P. and Reis, M. A. (2009). Strategies for PHA production by mixed cultures and renewable waste materials. *Applied Microbiology and Biotechnology*, 81:615–628.
[63]. Ng, S. W., Lee, M. L., and Hii, S., L. (2012). An overview of the factors affecting microbial-induced calcite precipitation and its potential application in soil improvement. *World Academy of Science and Engineering Technology*, 62:723–729.
[64]. Okwadha, G., D., O., & Li, J. (2010). Optimum conditions for microbial carbonate precipitation. *Chemosphere,* 81:1143–1148.
[65]. Gorospe, C. M., Han, S. H., Kim, S. G., Park, J. Y., Kang, C. H., Jeong, J. H., and So, J. S. (2013). Effects of different calcium salts on calcium carbonate crystal formation by *Sporosarcina pasteurii* KCTC 3558. *Biotechnology and Bioprocessing Engineering,* 18:903–908.