International Journal on Emerging Technologies **10**(4): 335-344(2019)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Microbial Mineral Precipitation to Develop the Properties of the Concrete – A Review

K.B. Vaghela[1] and J.R. Pitroda[2]
[1]Assistant Professor, Department of Applied Mechanics, Govt. Engineering College, Rajkot (Gujarat), India.
[2]Associate Professor, Department of Civil Engineering, BVM Engineering College, VV Nagar (Gujarat), India.

(Corresponding author: K.B. Vaghela)
(Received 05 September 2019, Revised 01 November 2019, Accepted 15 November 2019)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Concrete is a vastly used building-material in the globe. It has low tensile strength, so it is prone to cracking. The strength and durability of the concrete structures turn down because of cracking in concrete and expose of steel bars to the outside environment. Thus it is necessary to control crack width to improve the service life of the concrete structures. The microbial mineral precipitation is a novel technique used to enhance the quality of concrete by precipitation of calcium carbonate. The method of Calcite Precipitation by bacteria in concrete is more desirable because it is pollution-free and natural. This paper briefly describes the different types of microorganisms, its genetic constituents, different factors affecting the calcite precipitation in concrete. It gives a short explanation about the different ways of incorporation of bacteria into the concrete and consequence of calcite precipitation by microbes on the properties of the concrete. It also presents an inclusive report on the different kinds of bacteria used by researchers with its optimum concentration to develop the overall quality of the concrete. It is summarized that which type of bacteria was highly utilized in the past by the researchers to improve the compressive strength, water absorption and permeability of the concrete. At last, the literature shows that the direct application of bacteria in concrete can be used to improve the strength and durability properties of concrete.

Keywords: Bacteria, Bacterial Concrete, Biomineralization, $CaCo_3$ precipitation, Calcite precipitation, Compressive strength, Concrete, Durable Concrete, Mineral precipitation.

Abbreviations: MICP, microbial induced calcite precipitation; YE, Yeast extract; NB, Nutrient broth; LB, Lysogeny broth; cfu, colony-forming unit; OD, optical density; C-Ca, calcium chloride; A-Ca, Calcium Acetate; N-Ca, Calcium Nitrate; L-Ca, Calcium Lactate; G-Ca, Calcium Di-glutamate; CERUP, Cyclic Enriched Ureolytic Powder; GNP Graphite nano-platelets; SEM, scanning electron microscope; EDS, Energy dispersive spectroscopy; XRD, X-Ray Diffraction analysis; PU, polyurethane

I. INTRODUCTION

Concrete is a highly used construction material in the world. Worldwide the use of Concrete is increased by about 2.5% yearly [1]. Crack in the concrete is unavoidable for the reason that it has low tensile strength. Concrete can be cracked due to so many reasons like shrinkage, stresses due to temperature variation, loading, corrosion of reinforcement bar, etc. For instance, small cracks might be generated because of drying or plastic shrinkage and with the effect of external loading it creates a network of cracks. Now hazardous gases and moisture can easily penetrate into the cracks and deterioration of concrete will start. We can repair Crack generated into the concrete manually however there is some bad impact on the environment of repairing techniques and material used during repairing. Various types of chemicals and materials based on cement are used nowadays to repair concrete. The use of different types of chemicals to repair concrete creates problems related to human health and environment and also it is not compatible with concrete [2]. In addition to this it is uneconomical and time-consuming process.

There are some microorganisms that have the capacity to produce Calcium Carbonate through its metabolic activity to improve the properties of the concrete which is called Microbiological Induced Calcite Precipitation (MICP). These specific microorganisms can survive up to 100 years, it's safe for human life and such specific bacteria can be developed easily. These microscopic organisms can work under a wide scope of pH, temperature, and dampness levels. Bacterial spores and its food calcium nutrient sources are to be added into the concrete at a time of mixing all other ingredients of the concrete. Bacterial spores are in dormant mode at a time of mixing so it can resist pressure generated during mixing. These microorganisms are capable to manipulate the production of calcite after the production of the urea's enzyme. One super saturation level is achieved by various nucleations on the microorganism cell wall the precipitation of calcite crystals starts. As crystal produces inside the concrete, it densifies the concrete by filling micro cracks and porous available in the concrete. Thus MICP technique has the potential to improve the strength and durability of concrete compared to normal concrete.

II. FACTORS AFFECTING ON THE CALCITE PRECIPITATION

A. The Genetic Constitution of Bacteria

There are extensive groups of bacteria that have the capacity to produce calcite but not all can be used to incorporate into the concrete for the improvement of concrete properties. Concrete is differentiated by high pH value about 11, relatively low dampness subsequent to curing and absence of air circulation inside the voids. Just microscopic organisms whose vegetative cells and spores can bear up these difficult conditions would fit the bill for application in Cement Mortar and Concrete innovation [3].

B. Culture medium

Like every single organic element, microorganisms likewise require a wide scope of dietary parts. Thus we have to prepare a culture media for the initial growth of bacteria before adding it to the concrete. It is necessary to add the same culture media at the time of mixing for the initiate and continue to support the process of metabolism for the precipitation of calcite inside the concrete or mortar.

Yeast Extract (YE), Nutrient Broth (NB) and Lysogeny Broth (LB) are the three culture media that are commonly used for calcite precipitation. The effect of different types of culture media on the calcite precipitation in the concrete has been quantified by Achal *et al.*, and Al-Qabany *et al.*, [4, 5]. Bang *&* Ramakrishnan [6] and Bachmeier *et al.*, [7] used yeast extract medium to develop bacterial cells and moreover physically confirmed the evidence of calcite precipitation in both studies. There are a few different examinations in which researchers have used either YE [8, 9] or NB medium [10-12], which seems, by all accounts, to be the most reasonable media for this application.

C. Cell concentration

Bacterial cell-walls being the specific nucleation site for calcite precipitation, their concentration inside is an essential issue for possible utilization of microbial induced mineral precipitation strategies [11-16]. Normally the cell count of bacteria measure and added into the concrete in cells/ml or cfu/ml or cells/mm^3. Some of the researchers have also used Optical Density (OD) as a unit of bacterial cell concentration.

Determine the optimum concentration of microscopic organisms for the strength reason by the direct application of microbes into the concrete and it was 30 × 10^5 cfu/ml Andalib *et al.,* [17]. While most examinations have detailed a cell count of 10^7 cells/ml to be ideal for various bacterial strains. Okwadha and Li [18] have used *Sporosarcina pasteurii* with a concentration of 10^8 cells/ml and found better calcite precipitation in concrete. It was found by some of the researchers that concentration of bacterial cell affects strength and durability of mortar or concrete structure [44, 48-54]. Table 1 shows the effect of different types of bacteria used by researchers with different concentration to develop the compressive strength and reduce water absorption of mortar or concrete.

Table 1: Different types of microbes with changing in concentration used by researchers to develop the compressive strength and reduce water absorption of mortar or concrete.

Column No.	Author & Journal Detail	Country	Bacteria used	Bacterial concentration	Increased in Compressive strength	Reduction in Water Absorption
1.1	Achal *et al.*, [27]	China & India	*Bacillus* sp. CT-5	Optical Density (600 nm) of 1.0.	36%	60%
1.2	Achal *et al.*, [28]	India	*Bacillus* sp. CT-5	5 × 10^7 cells /mm^3	40%	50%
1.3	Kunal *et al.*, [23]	India	*Bacillus* sp. Strain KG1	(OD) of 0.8 at 600 nm.	26%	30%
2.1	Andalib *et al.*, [17]	Malaysia	*Bacillus megaterium*	30 × 10^5 cfu /ml	24%	20%
2.2	Achala *et al.*, [20]	China	*Bacillus megaterium* ATCC 14581	5 × 10^7 cfu /ml	19%	32%
2.3	Krishnapriya & Babu [29]	India	*B. megaterium* MTCC 1684.	10^5 cells/ml	16%	—
2.4	Andalib *et al.*, [17]	Malaysia	*Bacillus megaterium*	30 × 10^5 cfu /ml	24%	—
2.5	Chaurasia *et al.*, [30]	India	*B. megaterium* MTCC 10086	3 × 10^7 cells /ml	40%	—
2.6	Kaur *et al.*, [31]	India	*Bacillus megaterium* (SS3)	OD_{600} = 1.5	56%	—
3.1	Khaliq & Ehsan [10]	Pakistan	*Bacillus subtilis*	2.8 × 10^8 cells /ml	12%	—
3.2	Sunil Pratap Reddy *et al.*, [32]	India	*Bacillus subtilis*	10^5 cells/ml	14%	—
3.3	Park *et al.*, [33]	Korea	*B. subtilis* 168	(OD) of 0.8 at 600 nm.	19%	—
4.1	Siddique *et al.*, [19]	India	*Bacillus aerius*	10^5 cells/ml	12%	46%
4.2	Siddique *et al.*, [21]	India	*Bacillus aerius* Strain - AKKR5	10^5 cells/ml	11%	30%
5.1	Ramchandran *et al.*, [34]	South Dakota	*S. pasteurii* or *Bacillus pasteurii*	10^5 cells/ml	35%	—

5.2	Chahal *et al.*, [35]	India	*S. pasteurii* or *Bacillus pasteurii*	10^5 cells/ml	20%	—
5.3	Chahal *et al.*, [36]	India	*S. pasteurii* or *Bacillus pasteurii*	10^5 cells/ml	38%	—
5.4	Achal *et al.*, [37]	India	*S. pasteurii* NCIM 2477	OD_{600}	17%	15%
5.5	Abo-El-Enein *et al.*, [38]	Egypt	*S. pasteurii* NCIMB 8841 or *B. pasteurii*	OD at 600 nm of 0.5, 1.0 and 1.5	33%	18%
5.6	Ramakrishnan *et al.*, [8]	USA	*Sporosarcina pasteurii* or *Bacillus pasteurii*	10^7 cells/ml	10%	—
5.7	Balam *et al.*, [39]	Iran	*Sporosarcina pasteurii* or *Bacillus pasteurii*	10^6 cells/ml	20%	10%
5.8	Chaurasia *et al.*, [30]	India	*B. pasteurii* MTCC 1761	3×10^7 cells /ml	37%	24%
5.9	Maheswaran *et al.*, [40]	India	*B. pasteurii*	10^5 cells/ml	29%	30%
5.10	Li & Jin [41]	China	*Sporosarcina pasteurii*	2.8×10^7 cfu/ml	15%	—
5.11	Al-Salloum *et al.*, [42]	Saudi Arabia.	*Sporosarcina pasteurii* (ATCC 6453)	10^8 cells/ml	24%	—
6	Ghosh *et al.*, [24]	India	*Shewanella* Species	10^5 cells/ml	25%	—
7	Nosouhian *et al.*, [43]	Iran	*S. pasteurii* with *B. subtilis*	2×10^9 cells /ml	20%	11%
8	Ganesh *et al.*, [44]	India	Bacteria isolate from Cement godown	Bacteria in NB 38.32 Lit./m^3	23%	35%
9.1	Kunal *et al.*, [45]	India	*Bacillus halodurans* strain KG1	OD1.0 = 10^8 cells/ml	26%	20%
9.2	Zhang *et al.*, [46]	Singapore	*Bacillus halodurans* DSM 497	OD_{600} of 0.01–0.2 equivalent to around 10^7 to 10^8 cells/ml	19%	—
9.3	Zhang *et al.*, [46]	Singapore	Mutant one based on *Bacillus halodurans* DSM 497	OD_{600} of 0.01–0.2 equivalent to around 10^7 to 10^8 cells/ml	26%	—
10	Chaurasia *et al.*, [30]	India	*B. cohnii* MTCC 10,221	3×10^7 cells /ml	25%	22%
11.1	Li *et al.*, [47]	China	*Acinetobacter johnsonii*	4×10^7 cfu /ml	21%	66%
11.2	Li *et al.*, [48]	China	*Acinetobacter johnsonii*	4×10^7 cfu /ml	20%	—
12.1	Maheswaran *et al.*, [40]	India	*Bacillus cereus*	10^6 cells/ml	38%	—
12.2	Sung-Jin *et al.*, [33]	Korea	*B. cereus* KCTC3624	(OD) of 0.8 at 600 nm.	14%	—
13	Jongvivatsakul *et. al.* [49]	Thailand	*Bacillus sphaericus* (LMG 22257)	1.8×10^{12} cells/ml	43%	—
14	Kaur *et al.*, [50]	India	*Eupenicillium crustaceum* (Fungal)	1.7×10^7 cells/ml	24%	44%
15	Biswas *et al.*, [51]	India	Thermo an aerobactor	10^5 cells/ml	25%	65%
16.1	Al-Salloum *et al.*, [42]	Saudi Arabia	*E. coli* DH5a (ATCC 53868)	10^8 cells/ml	02%	—
16.2	Park *et al.*, [33]	Korea	*E. coli* K12	(OD) of 0.8 at 600 nm.	00%	—

III. EFFECT OF MICROBIAL CALCITE PRECIPITATION ON PROPERTIES OF CONCRETE

A. Compressive strength

The strength and the durability of the concrete can be improved by incorporating microbes into the concrete. The process and the biochemical reaction involved during Microbial Induced Calcite Precipitation were explained by Ramchandran *et al.*, [34]. Luo and Qian used the reactive spore powder in cement mortar to improve the compressive strength of cement mortar [68]. Andalib *et al.*, [17] used *Bacillus megaterium* microscopic organisms of concentration 30 × 10^5 cfu/ml in higher and lower grades of concrete and concluded that the production of calcite was higher in a higher grade of concrete as compared to a lower grade. Da Silva *et al.*, [72] used Cyclic Enriched Ureolytic Powder in cement mortar at 0.5%, 1%, 3% and 5% by weight of cement. They observed that for 0.5% and 1% CERUP did not unfavorably influence the compressive strength but rather the higher dose of 3% and 5% reduced the compressive strength of concrete. Pei *et al.*, [73] used bacteria cells wall inside the concrete and observed that the bacteria cell-wall has improved the strength of concrete.

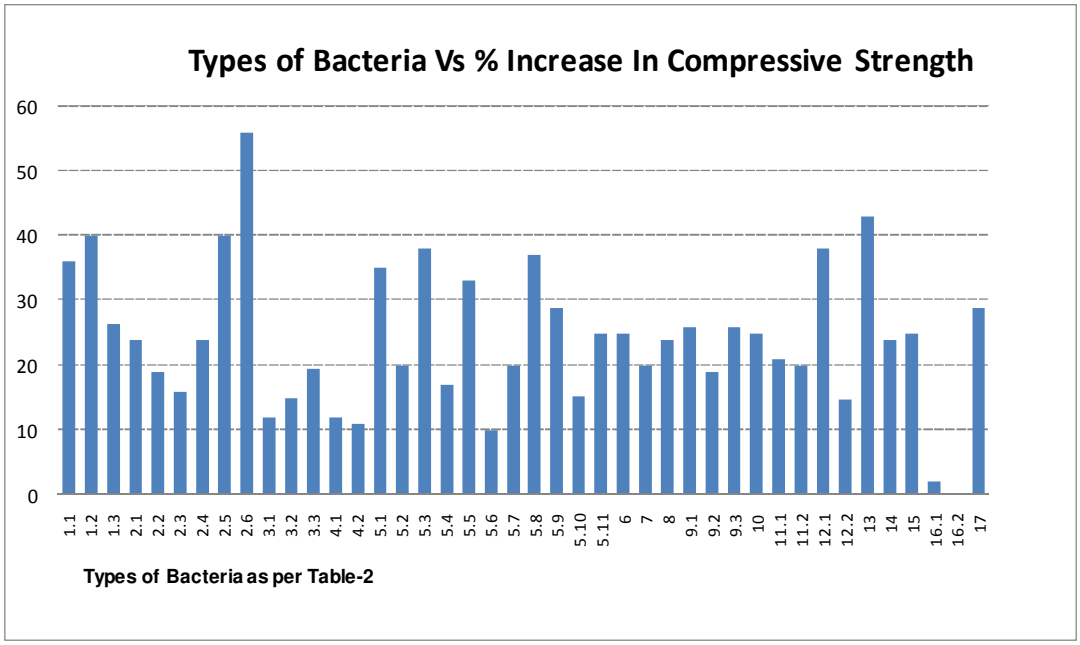

Fig. 1. Different types of bacteria Vs % Increase in Compressive Strength.

Table 2.

	Types of Bacteria used	Column. No.	Types of Bacteria used
1.1	*Bacillus* sp. CT-5 [27]	5.8	*B. pasteurii* MTCC 1761 [30]
1.2	*Bacillus* sp. CT-5 [28]	5.9	*B. pasteurii* [67]
1.3	*Bacillus* sp. Strain KG1 [23]	5.10	*Sporosarcina pasteurii* [41]
2.1	*Bacillus megaterium* [17]	5.11	*Sporosarcina pasteurii* (ATCC 6453) [42]
2.2	*Bacillus megaterium* ATCC 14581 [20]	6	*Shewanella* Species [24]
2.3	*B. megaterium* MTCC 1684. [29]	7	*S. pasteurii* with *B. subtilis* [43]
2.4	*Bacillus megaterium* [17]	8	Bacteria isolate from Cement godown [44]
2.5	*B. megaterium* MTCC 10086 [30]	9.1	*Bacillus halodurans* strain KG1 [45]
2.6	*Bacillus megaterium* (SS3) [31]	9.2	*Bacillus halodurans* DSM 497 [46]
3.1	*Bacillus subtilis* [10]	9.3	Mutant one based on *Bacillus halodurans* DSM 497[46]
3.2	*Bacillus subtilis* [32]	10	*B. cohnii* MTCC 10,221 [30]
3.3	*B. subtilis* 168 [33]	11.1	*Acinetobacter johnsonii* [47]
4.1	*Bacillus aerius* [19]	11.2	*Acinetobacter johnsonii* [48]
4.2	*Bacillus aerius* Strain - AKKR5 [21]	12.1	*Bacillus cereus* [40]
5.1	*S. pasteurii* or *Bacillus pasteurii* [34]	12.2	*B. cereus* KCTC3624 [33]
5.2	*S. pasteurii* or *Bacillus pasteurii* [35]	13	*Bacillus sphaericus* (LMG 22257) [49]
5.3	*S. pasteurii* or *Bacillus pasteurii* [36]	14	*Eupenicillium crustaceum* (Fungal) [50]
5.4	*S. pasteurii* NCIM 2477 [37]	15	Thermo an aerobactor [51]
5.5	*S. pasteurii* NCIMB 8841 or *B. pasteurii* [38]	16.1	*E. coli* DH5a (ATCC 53868) [42]
5.6	*Sporosarcina pasteurii* or *Bacillus pasteurii* [8]	16.2	E. coli K12 [33]
5.7	*Sporosarcina pasteurii* or *Bacillus pasteurii* [39]	17	*Enterobacter* sp. FJ 973550 (EB) [16]

Chahal *et al.*, [35, 36] used *Sporosarcina pasteurii* microorganisms to improve the strength of concrete by replacing cement with fly ash and silica fume the concentration of bacteria was 10^5 cells/ml. Achal *et al.*, [20] used bacteria cell to improve the compressive strength of mortar by replacing cement of 10%, 20%, and 40% with fly ash and consequently the finding was an improvement in compressive strength by 19%, 14%, and 10%, compared to normal concrete. For the consistent distribution of bacteria inside the concrete. Khaliq and Ehsan [10] utilized *Bacillus subtilis* in addition to Graphite nanoplatelets (GNP) as a carrier compound to improve the strength of concrete. Tziviloglou *et. al.*, [74] used *Bacillus subtilis* bacteria to improve the quality of the concrete by incorporating lightweight aggregate and graphite nanoplatelets. There were few researchers who have used bacteria to improve the properties of the concrete in addition to mineral admixtures such as fly ash and slag [21, 63, 75]. Fig. 1 gives the details of bacteria used and its effect on the compressive strength; these may vary depending on the bacterial concentration and the calcium source supplied to the bacteria.

Sarda *et al.,* and Belie [78, 79] utilized different types of bacteria to improve the quality of concrete and finally concluded that *Sporosarcina pasteurii* and *Bacillus megaterium* was the widely used bacteria by the researchers, that was only because of its efficiency to survive in highly alkaline (pH up to 10) and airtight atmosphere, ability to sustain high temperature generated due to heat of hydration, ability to adapt dormant mode in case of lack of nutrition and moisture and its ability to develop in culture media and mortar or concrete matrix. Fig. 2 gives the details of highly used bacteria by researcher to improve the compressive strength of the concrete.

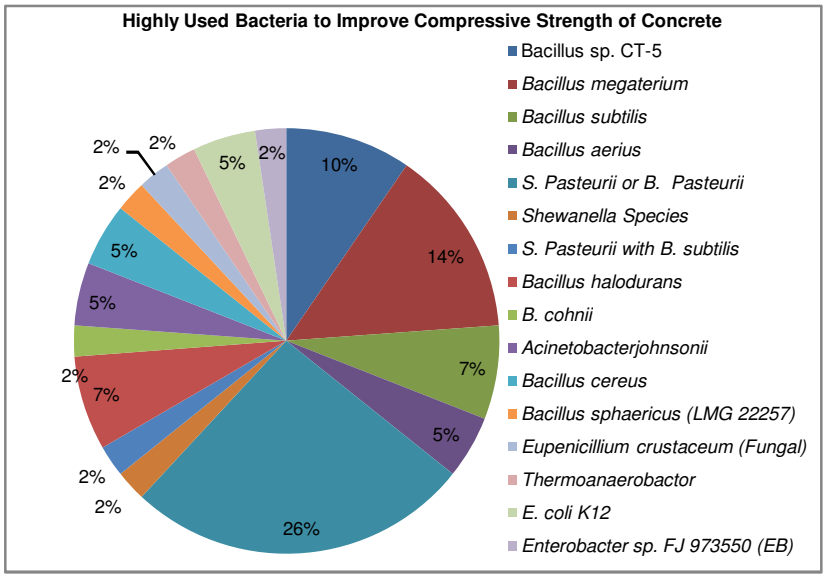

Fig. 2. Highly used bacteria to improve the compressive strength of the concrete.

B. Permeability and Water Absorption

The permeability and water absorption of the concrete are an important property of the concrete because the diffusion of the substances which are responsible for the degradation of the concrete is controlled by size, degree, and connectivity of the pore network [80]. Calcium carbonate precipitated through microorganisms inside the concrete-filled the porous and reduce the permeability and water absorption [36, 81].

Jonkers *et al.*, (2011) [56] utilized pressed viable and dormant microscopic organisms in a mixture of porous expanded clay particles to improve the permeability of the mortar. De Muynck *et. al.* used *Bacillus sphaericus* bacteria to reduce the porosity in mortar and concrete [11]. Ramakrishnan *et al.*, and De Muynck *et al.*, utilized microorganisms to block the pores and microcrack [11, 55]. Ling [82] used *Paenibacillus mucilaginosus* bacteria to improve the permeability of the concrete. Wang *et al.*, [61] used *Bacillus sphaericus* bacteria to improve the durability of the concrete. Sarkar *et al.*, [83] incorporated *Bacillus subtilis* the spore-forming bacteria into the mortar and found an increased in the strength and durability of mortar. Zhong and Islam [84] reported that *Bacillus pasteurii* bacteria can be used in microbial mineral plugging technique and it was effective in plugging fractures. Chunxiang *et al.*, [85] used *Bacillus pasteurii* to reduce the water absorption of the concrete and they concluded that the calcite precipitation through bacteria reduces the water absorption of the concrete. Zhu *et al.*, [1] used *Cyanobacteria synechococcus* PCC8806 to improve the properties of the cement mortar and the results revealed the reduction in the water absorption caused by the precipitation of calcite. Balam *et al.*, [86] discovered a 20-30% decrease in water by adding *Sporosarcina pasteurii* microorganisms into the concrete not withstanding this they got same outcomes after around 20 days, demonstrating that the deposits stayed over this time frame.

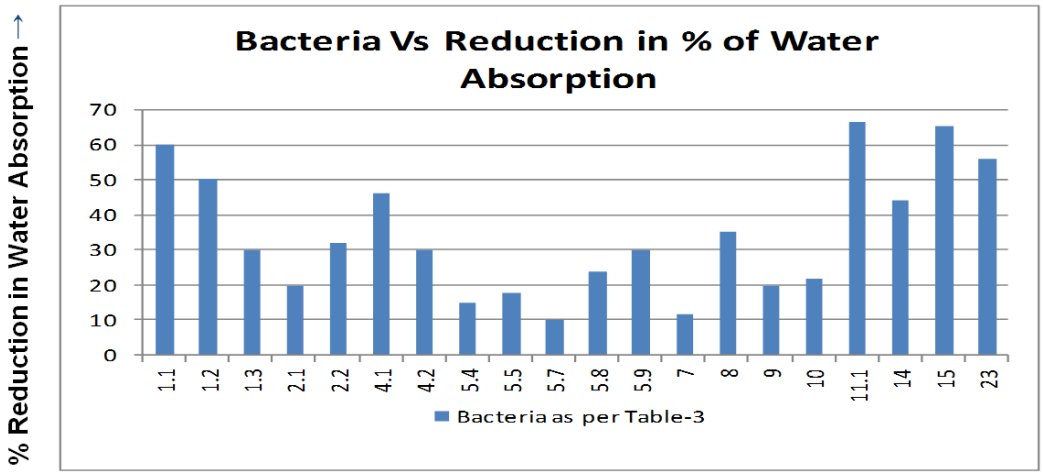

Fig. 3.

Table 3: Different types of bacteria Vs % Reduction in Water Absorption.

Column. No.	Bacteria used	Column. No.	Bacteria used
1.1	Bacillus sp. CT-5 [27]	5.8	*B. pasteurii* MTCC 1761 [30]
1.2	Bacillus sp. CT-5 [28]	5.9	*S. pasteurii* (PTCC 1645; DSM 33) [40]
1.3	*Bacillus subtilis* (PTCC 1715; BGSC 1A747) [23]	7	*S. pasteurii* with *Bacillus subtilis* [43]
2.1	*Bacillus megaterium* ATCC 14581 [17]	8	Bacteria isolate from Cement godown [44]
2.2	*B. megaterium* MTCC 10086 [20]	9	*Bacillus halodurans* strain KG1 [45]
4.1	*Bacillus aerius* [19]	10	*B. cohnii* MTCC 10,221 [30]
4.2	*Bacillus aerius*- AKKR5 [21]	11.1	*Acinetobacter johnsonii* [47]
5.4	*S. pasteurii* or *B. pasteurii* [37]	14	*Eupenicillium crustaceum* (Fungal) [50]
5.5	*S. pasteurii* or *B. pasteurii* [38]	15	*B. sphaericus* LMG 225 57 [51]
5.7	*S. pasteurii* NCIMB 8841 or *B. pasteurii* [39]	23	*Enterobacter* sp. FJ 973550 (EB) [16]

C. Chloride ion permeability

Siddique *et al.*, [19] utilized *Bacillus aerius* bacteria in Rice Husk Ash concrete and the result they have observed reduction in chloride ion permeability compared to ordinary concrete. Chahal *et al.*, [35, 36] observed good resistance against chloride ion permeability by using *Sporosarcina pasteurii* microscopy organism in fly ash concrete and silica fume concrete. De Muynck *et al.*, [11, 55] used *Sporosarcina sphaericus* bacteria to improve the properties of the cement mortar cubes having different w/c ratios and consequently concrete with varying in porosity. They observed cement mortar cubes treated with bacteria have developed good resistance to penetrate water, moisture, and chloride across the sample layers.

D. Analysis of Microstructure

The precipitation of calcite by utilization of microorganisms into the concrete can be confirmed by scanning electron microscope (SEM), Energy dispersive spectroscopy (EDS) and X-Ray Diffraction (XRD) analysis. Siddique *et al.*; Kim *et al.*; Luo and Qian [19, 58, 87] had performed microstructure analysis through SEM, EDS, and XRD; the SEM examination demonstrated the calcite crystals implanted with microorganisms, EDS and XRD investigation confirmed the large quantity of calcium in the sample. Bachmeier *et al.*; Chahal *et al.*, and Gorospe *et al.*, [7, 36, 88] observed the precipitation of calcite through SEM and XRD analysis.

Bang and Ramakrishnan; Bang *et al.*, utilized Sporosarcina pasteurii bacteria's dormant cells in polyurethane (PU) to develop the properties of the concrete and they confirmed the precipitation of calcite by using SEM. Vahabi *et al.*, [90] used bacteria isolated from the soil sample to know its efficiency of calcite precipitation. The result they have observed that *Bacillus licheniformis* an isolated bacteria from soil have the ability to precipitate the calcite and it was confirmed through SEM image. Al-Salloum [42] used *Sporosarcina pasteurii* bacteria in cement mortar to get better the quality of the mortar and the results were verified through SEM.

IV. CONCLUSION AND SCOPE OF FUTURE WORK

The motivation behind the completed literature survey was to go through the accessible literature on uses of organisms to encourage calcite in concrete and cement mortar. Microorganisms can be applied to concrete and mortar in two different ways; (1) Direct application and (2) By encapsulation techniques. We have uniquely centered around the literature identified with the direct applications of organisms to improve the mechanical properties and durability of the concrete. The majority of the investigations in the writing demonstrate that *Sporosarcina pasteurii* and *Bacillus megaterium* are the fittest species for calcite precipitation in mortar or concrete.

Endeavors might be made to find or grow new strains of this or different species with better calcification efficiencies and flexibility to process conditions for various applications.

The literature survey has checked on various kinds of microscopic organisms, its morphology, different polymorphs of calcite and the various clusters of microorganisms associated with calcite precipitation. The effect of Culture media, the concentration of

microorganism's cell, substrate, calcium sources, and the surrounding environment during the process of microbial mineral precipitation has been fundamentally investigated. As may be recognized from the investigation of the literature, less importance has been given to the effect of culture medium on microbial mineral precipitation, biochemical reaction between cement and chemical sources. Before the field application of microbial mineral precipitation, it is equally important to know the optimize quantity of substrates and calcium sources used for the process microbial induced calcite precipitation in concrete or mortars.

At present the underlying expense of production, revival, and addition of microorganisms into the mortar or concrete is high. There might be two potential approaches to make it suitable for the construction industry; by decreasing the expense of isolation, storage, and revival of bacteria and by increasing the life of the structure as a result of improving its durability through the process of microbial induced mineral precipitation. We can minimize the expenses that occurred on the maintenance of a reinforced concrete structure by adapting this technique. White *et al.*, [91] clarified it by performing some experiments on life cycle expenses of concrete structure and concluded that in some cases the expenses involved in repair and rehabilitation of concrete structure might exceed the initial construction cost.

Quality parameters of concrete other than strength like Shrinkage, erosion, carbonation properties and changes in the biochemical reactions of calcite precipitation throughout various phases of cement hydration and its belongings on the characteristics of concrete or mortar are yet to be studied in detail. Its proficiency in securing bigger size structural members should be tried further under non-perfect temperature ranges, high salty atmosphere, etc. for a longer period of time. Likewise, the issue of enhancement of supplement media should be tended to. At long last, details and test guidelines ought to be created to evaluate microbial concrete execution in structures and its usage in concrete structure might be expected in the future.

The mechanism and the biochemical reaction by an enzyme urease to create calcite precipitation were audited profoundly through various sources of literature. This study recognized that microorganisms positively affect the compressive strength of the cement mortar and concrete. The investigation has likewise concluded that it diminishes the permeability by deposition of calcite. The present literature survey prescribes that the concrete using microbes has the potential to be a substitute and high-class concrete which is economical, natural, and in the end-use for the improvement in the durability of concrete structure materials.

REFERENCES

[1]. Zhu, T., Paulo, C., Merroun, M. L., & Dittrich, M. (2015). Potential application of biomineralization by *Synechococcus* PCC8806 for concrete restoration. *Ecological engineering*, *82*, 459-468.

[2]. De Muynck, W., De Belie, N., & Verstraete, W. (2010). Microbial carbonate precipitation in construction materials: a review. *Ecological Engineering*, *36*(2), 118-136.

[3]. Seifan, M., Samani, A. K., & Berenjian, A. (2016). Bioconcrete: next generation of self-healing concrete. *Applied microbiology and biotechnology*, *100*(6), 2591-2602.

[4]. Achal, V., Mukherjee, A., Basu, P. C., & Reddy, M. S. (2009). Strain improvement of Sporosarcina pasteurii for enhanced urease and calcite production. *Journal of industrial microbiology & biotechnology*, *36*(7), 981-988.

[5]. Al Qabany, A., Soga, K., Asce, M., Santamarina, C., & Asce, A. M. (2012). Factors affecting efficiency of microbially induced calcite precipitation. *Journal of Geotechnical and Geoenvironmental Engineering*, *138*(8), 992-1001.

[6]. Bang, S. S., & Ramakrishnan, V. (2001). Microbiologically-enhanced crack remediation (MECR). In *proceedings of the international symposium on industrial application of microbial genomes*, 1-13.

[7]. Bachmeier, K. L., Williams, A. E., Warmington, J. R., & Bang, S. S. (2002). Urease activity in microbiologically-induced calcite precipitation. *Journal of Biotechnology*, *93*(2), 171-181.

[8]. Ramakrishnan, V., Panchalan, R. K., Bang, S. S., & City, R. (2005). Improvement of concrete durability by bacterial mineral precipitation," in 11th International Conference on Fracture 2005, ICF11. *3*, 2095–2100.

[9]. Muthukkumaran, K., & Shashank, B. S. (2016). Durability of microbially induced calcite precipitation (micp) treated cohesionless soils. *Japanese Geotechnical Society Special Publication*, *2*(56), 1946-1949.

[10]. Khaliq, W., & Ehsan, M. B. (2016). Crack healing in concrete using various bio influenced self-healing techniques. *Construction and Building Materials*, *102*, 349-357.

[11]. De Muynck, W., Cox, K., De Belie, N., & Verstraete, W. (2008). Bacterial carbonate precipitation as an alternative surface treatment for concrete. *Construction and Building Materials*, *22*(5), 875-885.

[12]. Ng, W. S., Lee, M. L., & 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, Engineering and Technology. *International Journal of Civil and Environmental Engineering*, *6*(2), 188-194.

[13]. Anbu, P., Kang, C. H., Shin, Y. J., & So, J. S. (2016). Formations of calcium carbonate minerals by bacteria and its multiple applications. *Springerplus*, *5*(1), 1-26.

[14]. Richardson, K. A., Coventry, A. M., Forster, A. M., & Jamison, C. (2014). Surface consolidation of natural stone materials using microbial induced calcite precipitation. *Structural Survey*, *32*(3), 265-278.

[15]. Kumar, V. R., Bhuvaneshwari, B., Maheswaran, S., Palani, G. S., Ravisankar, K., & Iyer, N. R. (2011). An overview of techniques based on biomimetics for sustainable development of concrete. *Current Science (Bangalore)*, *101*(6), 741-747.

[16]. Senthilkumar, V., Palanisamy, T., & Vijayakumar, V. N. (2015). Strength characteristics of microbial cement mortars treated in different calcium sources. *Advances in Cement Research*, *27*(5), 289-296.

[17]. Andalib, R., Majid, M. Z. A., Hussin, M. W., Ponraj, M., Keyvanfar, A., Mirza, J., & Lee, H. S. (2016). Optimum concentration of *Bacillus megaterium* for strengthening structural concrete. *Construction and Building Materials*, *118*, 180-193.
[18]. Okwadha, G. D., & Li, J. (2010). Optimum conditions for microbial carbonate precipitation. *Chemosphere*, *81*(9), 1143-1148.
[19]. Siddique, R., Singh, K., Singh, M., Corinaldesi, V., & Rajor, A. (2016). Properties of bacterial rice husk ash concrete. *Construction and Building Materials*, *121*, 112-119.
[20]. Achal, V., Pan, X., & Özyurt, N. (2011). Improved strength and durability of fly ash-amended concrete by microbial calcite precipitation. *Ecological Engineering*, *37*(4), 554-559.
[21]. Siddique, R., Nanda, V., Kadri, E. H., Khan, M. I., Singh, M., & Rajor, A. (2016). Influence of bacteria on compressive strength and permeation properties of concrete made with cement baghouse filter dust. *Construction and Building Materials*, *106*, 461-469.
[22]. Ghosh, S., Biswas, M., Chattopadhyay, B. D., & Mandal, S. (2009). Microbial activity on the microstructure of bacteria modified mortar. *Cement and Concrete Composites*, *31*(2), 93-98.
[23]. Kunal, Siddique, R., & Rajor, A. (2014). Strength and microstructure analysis of bacterial treated cement kiln dust mortar. *Construction and Building Materials*, *63*, 49-55.
[24]. Ghosh, P., Mandal, S., Chattopadhyay, B. D., & Pal, S. (2005). Use of microorganism to improve the strength of cement mortar. *Cement and Concrete Research*, *35*(10), 1980-1983.
[25]. Senthilkumar, V., Palanisamy, T., & Vijayakumar, V. N. (2014). Enrichment of compressive strength in microbial cement mortar. *Advances in Cement Research*, *26*(6), 353-360.
[26]. Park, S. J., Park, Y. M., Chun, W. Y., Kim, W. J., & Ghim, S. Y. (2010). Calcite-forming bacteria for compressive strength improvement in mortar. *Journal of microbiology and biotechnology*, *20*(4), 782-788.
[27]. Achal, V., Mukherjee, A., & Reddy, M. S. (2010). Microbial concrete: way to enhance the durability of building structures. *Journal of Materials in Civil engineering*, *23*(6), 730-734.
[28]. Achal, V., Mukerjee, A., & Reddy, M. S. (2013). Biogenic treatment improves the durability and remediates the cracks of concrete structures. *Construction and Building Materials*, *48*, 1-5.
[29]. Krishnapriya, S., & Babu, D. V. (2015). Isolation and identification of bacteria to improve the strength of concrete. *Microbiological research*, *174*, 48-55.
[30]. Chaurasia, L., Bisht, V., Singh, L. P., & Gupta, S. (2019). A novel approach of biomineralization for improving micro and macro-properties of concrete. *Construction and Building Materials*, *195*, 340-351.
[31]. Kaur, G., Dhami, N. K., Goyal, S., Mukherjee, A., & Reddy, M. S. (2016). Utilization of carbon dioxide as an alternative to urea in biocementation. *Construction and Building Materials*, *123*, 527-533.
[32]. Sunil, P. R., Seshagiri Rao, M. V., Aparnac, P. & Sasikala, Ch. (2010). Performance of standard grade bacterial (*Bacillus subtilis*) concrete. *Asian journal of civil* engineering (building and housing). *11*(1), 43-55.
[33]. Park, S. J., Park, J. M., Kim, W. J., & Ghim, S. Y. (2012). Application of *Bacillus subtilis* 168 as a multifunctional agent for improvement of the durability of cement mortar. *J. Microbiol. Biotechnol*, *22*(11), 1568-1574.
[34]. Ramachandran, S. K., Ramakrishnan, V., & Bang, S. S. (2001). Remediation of concrete using micro-organisms. *ACI Materials Journal-American Concrete Institute*, *98*(1), 3-9.
[35]. Chahal, N., Siddique, R., & Rajor, A. (2012). Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete. *Construction and Building Materials*, *28*(1), 351-356.
[36]. Chahal, N., Siddique, R., & Rajor, A. (2012). Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of concrete incorporating silica fume. *Construction and Building Materials*, *37*, 645-651.
[37]. Achal, V., Mukherjee, A., Basu, P. C., & Reddy, M. S. (2009). Lactose mother liquor as an alternative nutrient source for microbial concrete production by Sporosarcina pasteurii. *Journal of industrial microbiology & biotechnology*, *36*(3), 433-438.
[38]. Abo-El-Enein, S. A., Ali, A. H., Talkhan, F. N., & Abdel-Gawwad, H. A. (2013). Application of microbial biocementation to improve the physico-mechanical properties of cement mortar. *HBRC Journal*, *9*(1), 36-40.
[39]. Balam, N. H., Mostofinejad, D., & Eftekhar, M. (2017). Effects of bacterial remediation on compressive strength, water absorption, and chloride permeability of lightweight aggregate concrete. *Construction and Building Materials*, *145*, 107-116.
[40]. Maheswaran, S., Dasuru, S. S., Murthy, C., Rama, A., Bhuvaneshwari, B., Kumar, V. R., Palani, G. S., Iyer, N. R., Krishnamoorthy, S., & Sandhya, S. (2014). Strength improvement studies using new type wild strain Bacillus cereus on cement mortar. *Current Science*, *106*(1), 50-57.
[41]. Li, P. H., & Jin, B. (2012). Healing of cracked concrete by Sporosarcina pasteurii mediated carbonate deposition. In *Applied Mechanics and Materials*, *164*, 103-106. Trans Tech Publications.
[42]. Al-Salloum, Y., Abbas, H., Sheikh, Q. I., Hadi, S., Alsayed, S., & Almusallam, T. (2017). Effect of some biotic factors on microbially-induced calcite precipitation in cement mortar. *Saudi journal of biological sciences*, *24*(2), 286-294.
[43]. Nosouhian, F., Mostofinejad, D., & Hasheminejad, H. (2015). Concrete durability improvement in a sulfate environment using bacteria. *Journal of Materials in Civil Engineering*, *28*(1), 1-12.
[44]. Ganesh, G. M., Shanthi, A. S., Elumalai, Anand, Gurumurthy, K. (2015). To Experimental investigation of bacterial concrete to improve compressive strength: A microbiology and civil engineering approach. *Indian Concr. J., 89*(6), 24-30.
[45]. Kunal, Siddique, R., & Rajor, A. (2014). Influence of bacterial treated cement kiln dust on the properties of concrete. *Construction and Building Materials*, *52*, 42-51.

[46]. Zhang, Z., Ding, Y., & Qian, S. (2019). Influence of bacterial incorporation on mechanical properties of engineered cementitious composites (ECC). *Construction and Building Materials*, *196*, 195-203.
[47]. Li, P., Liu, C., & Zhou, W. (2015). Improved strength and durability of concrete by bacterial carbonate precipitation. In *3rd International Conference on Mechatronics, Robotics and Automation*. 4, 119-122. Atlantis Press.
[48]. Li, P., Liu, C., & Zhou, W. (2015). Influence of bacterial carbonate precipitation on the compressive strength and water absorption of fly ash concrete. In *3rd International Conference on Mechatronics, Robotics and Automation*. 123-126. Atlantis Press.
[49]. Jongvivatsakul, P., Janprasit, K., Nuaklong, P., Pungrasmi, W., & Likitlersuang, S. (2019). Investigation of the crack healing performance in mortar using microbially induced calcium carbonate precipitation (MICP) method. *Construction and Building Materials*, *212*, 737-744.
[50]. Kaur, G., Siddique, R., & Rajor, A. (2012). Influence of fungus on properties of concrete made with waste foundry sand. *Journal of Materials in Civil Engineering*, *25*(4), 484-490.
[51]. Biswas, M., Majumdar, S., Chowdhury, T., Chattopadhyay, B., Mandal, S., Halder, U., & Yamasaki, S. (2010). Bioremediase a unique protein from a novel bacterium BKH1, ushering a new hope in concrete technology. *Enzyme and Microbial Technology*, *46*(7), 581-587.
[52]. Stocks-Fischer, S., Galinat, J. K., & Bang, S. S. (1999). Microbiological precipitation of $CaCO_3$. *Soil Biology and Biochemistry*, *31*(11), 1563-1571.
[53]. Siddique, R., & Chahal, N. K. (2011). Effect of ureolytic bacteria on concrete properties. *Construction and building materials*, *25*(10), 3791-3801.
[54]. Van Tittelboom, K., De Belie, N., De Muynck, W., & Verstraete, W. (2010). Use of bacteria to repair cracks in concrete. *Cement and Concrete Research*, *40*(1), 157-166.
[55]. De Muynck, W., Debrouwer, D., De Belie, N., & Verstraete, W. (2008). Bacterial carbonate precipitation improves the durability of cementitious materials. *Cement and concrete Research*, *38*(7), 1005-1014.
[56]. Jonkers, H. M. (2011). Bacteria-based self-healing concrete. *Heron, 56 (1/2)*.
[57]. Alazhari, M., Sharma, T., Heath, A., Cooper, R., & Paine, K. (2018). Application of expanded perlite encapsulated bacteria and growth media for self-healing concrete. *Construction and Building Materials*, *160*, 610-619.
[58]. Kim, H. K., Park, S. J., Han, J. I., & Lee, H. K. (2013). Microbially mediated calcium carbonate precipitation on normal and lightweight concrete. *Construction and Building Materials*, *38*, 1073-1082.
[59]. Wang, J. Y., Snoeck, D., Van Vlierberghe, S., Verstraete, W., & De Belie, N. (2014). Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. *Construction and building materials*, *68*, 110-119.
[60]. Wang, J. Y., Soens, H., Verstraete, W., & De Belie, N. (2014). Self-healing concrete by use of microencapsulated bacterial spores. *Cement and Concrete Research*, *56*, 139-152.
[61]. Wang, J., Dewanckele, J., Cnudde, V., Van Vlierberghe, S., Verstraete, W., & De Belie, N. (2014). X-ray computed tomography proof of bacterial-based self-healing in concrete. *Cement and Concrete Composites*, *53*, 289-304.
[62]. Wang, J., Van Tittelboom, K., De Belie, N., & Verstraete, W. (2012). Use of silica gel or polyurethane immobilized bacteria for self-healing concrete. *Construction and building materials*, *26*(1), 532-540.
[63]. Wiktor, V., & Jonkers, H. M. (2011). Quantification of crack-healing in novel bacteria-based self-healing concrete. *Cement and Concrete Composites*, *33*(7), 763-770.
[64]. Xu, J., Chen, B., & Xie, T. (2014). Experimental and theoretical analysis of bubble departure behavior in narrow rectangular channel. *Progress in Nuclear Energy*, *77*, 1-10.
[65]. Xu, J., Yao, W., & Jiang, Z. (2013). Non-ureolytic bacterial carbonate precipitation as a surface treatment strategy on cementitious materials. *Journal of Materials in Civil Engineering*, *26*(5), 983-991.
[66]. Wiktor, V. A. C., & Jonkers, H. M. (2012). The potential of bio-based repair system to increase the durability of repaired concrete structures. In *Second International Conference on Microstructural-related Durability of Cementitious Composites, RILEM Proceedings* pro083, 01-08, *Amsterdam, The Netherlands*. RILEM Publications SARL.
[67]. Zhang, Y., Guo, H. X., & Cheng, X. H. (2015). Role of calcium sources in the strength and microstructure of microbial mortar. *Construction and Building Materials*, *77*, 160-167.
[68]. Luo, M., & Qian, C. (2016). Influences of bacteria-based self-healing agents on cementitious materials hydration kinetics and compressive strength. *Construction and Building Materials*, *121*, 659-663.
[69]. Jonkers, H. M., Thijssen, A., Muyzer, G., Copuroglu, O., & Schlangen, E. (2010). Application of bacteria as self-healing agent for the development of sustainable concrete. *Ecological engineering*, *36*(2), 230-235.
[70]. Xu, J., & Yao, W. (2014). Multiscale mechanical quantification of self-healing concrete incorporating non-ureolytic bacteria-based healing agent. *Cement and concrete research*, *64*, 1-10.
[71]. Mortensen, B. M., Haber, M. J., DeJong, J. T., Caslake, L. F., & Nelson, D. C. (2011). Effects of environmental factors on microbial induced calcium carbonate precipitation. *Journal of applied microbiology*, *111*(2), 338-349.
[72]. Da Silva, F. B., De Belie, N., Boon, N., & Verstraete, W. (2015). Production of non-axenic ureolytic spores for self-healing concrete applications. *Construction and Building Materials*, *93*, 1034-1041.
[73]. Pei, R., Liu, J., Wang, S., & Yang, M. (2013). Use of bacterial cell walls to improve the mechanical performance of concrete. *Cement and Concrete Composites*, *39*, 122-130.
[74]. Tziviloglou, E., Wiktor, V., Jonkers, H. M., & Schlangen, E. (2016). Bacteria-based self-healing

concrete to increase liquid tightness of cracks. *Construction and Building Materials*, *122*, 118-125.
[75]. Chahal, N., & Siddique, R. (2013). Permeation properties of concrete made with fly ash and silica fume: Influence of ureolytic bacteria. *Construction and Building Materials*, *49*, 161-174.
[76]. Özbay, E., Šahmaran, M., Lachemi, M., & Yücel, H. E. (2013). Self-Healing of Microcracks in High-Volume Fly-Ash-Incorporated Engineered Cementitious Composites. *ACI Materials Journal*, *110*(1).
[77]. Palin, D., Wiktor, V., & Jonkers, H. M. (2015). Autogenous healing of marine exposed concrete: characterization and quantification through visual crack closure. *Cement and Concrete Research*, *73*, 17-24.
[78]. Sarda, D., Choonia, H. S., Sarode, D. D., & Lele, S. S. (2009). Biocalcification by Bacillus pasteurii urease: a novel application. *Journal of industrial microbiology & biotechnology*, *36*(8), 1111-1115.
[79]. Belie, N. De (2015). Application of modified-alginate encapsulated carbonate producing bacteria in concrete : *a promising strategy for crack self-healing*, *6*, 1–14.
[80]. Phung, Q. T., Maes, N., De Schutter, G., Jacques, D., & Ye, G. (2013). Determination of water permeability of cementitious materials using a controlled constant flow method. *Construction and Building Materials*, *47*, 1488-1496.
[81]. Pacheco-Torgal, F., & Labrincha, J. A. (2013). Biotech cementitious materials: some aspects of an innovative approach for concrete with enhanced durability. *Construction and Building Materials*, *40*, 1136-1141.
[82]. Ling, H., & Qian, C. (2017). Effects of self-healing cracks in bacterial concrete on the transmission of chloride during electromigration. *Construction and Building Materials*, *144*, 406-411.
[83]. Sarkar, M., Adak, D., Tamang, A., Chattopadhyay, B., & Mandal, S. (2015). Genetically-enriched microbe-facilitated self-healing concrete–a sustainable material for a new generation of construction technology. *RSC Advances*, *5*(127), 105363-105371.
[84]. Zhong, L., & Islam, M. R. (1995). A new microbial plugging process and its impact on fracture remediation. In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers, 703-715.
[85]. Chunxiang, Q., Jianyun, W., Ruixing, W., & Liang, C. (2009). Corrosion protection of cement-based building materials by surface deposition of CaCO3 by Bacillus pasteurii. *Materials Science and Engineering: C*, *29*(4), 1273-1280.
[86]. Balam, N. H., Mostofinejad, D., & Eftekhar, M. (2017). Use of carbonate precipitating bacteria to reduce water absorption of aggregates. *Construction and Building Materials*, *141*, 565-577.
[87]. Luo, M., & Qian, C. X. (2016). Performance of two bacteria-based additives used for self-healing concrete. *Journal of Materials in Civil Engineering*, *28*(12), 1-6.
[88]. Gorospe, C. M., Han, S. H., Kim, S. G., Park, J. Y., Kang, C. H., Jeong, J. H., & So, J. S. (2013). Effects of different calcium salts on calcium carbonate crystal formation by Sporosarcina pasteurii KCTC 3558. *Biotechnology and bioprocess engineering*, *18*(5), 903-908.
[89]. Bang, S. S., Galinat, J. K., & Ramakrishnan, V. (2001). Calcite precipitation induced by polyurethane-immobilized Bacillus pasteurii. *Enzyme and microbial technology*, *28*(4-5), 404-409.
[90]. Vahabi, A., Ramezanianpour, A. A., & Akbari Noghabi, K. (2015). A preliminary insight into the revolutionary new line in improving concrete properties using an indigenous bacterial strain Bacillus licheniformis AK01, as a healing agent. *European Journal of Environmental and Civil Engineering*, *19*(5), 614-627.
[91]. White, S. R., Sottos, N. R., Geubelle, P. H., Moore, J. S., Kessler, M., Sriram, S. R., ... & Viswanathan, S. (2001). Autonomic healing of polymer composites. *Nature*, *409*(6822), 794-797.

How to cite this article: Vaghela, K.B. and Pitroda, J.R. (2019). Microbial Mineral Precipitation to Develop the Properties of the Concrete – A Review. *International Journal on Emerging Technologies*, *10*(4): 335–344.