International Journal of Innovation Scientific Research and Review
Vol. 04, Issue, 01, pp.2207-2212, January 2022
Available online at http://www.journalijisr.com
SJIF Impact Factor 4.95

Review Article

ISSN: 2582-6131

A REVIEW ON BACTERIA BASED SELF-HEALING CONCRETE

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Received 11th November 2021; Accepted 12th December 2021; Published online 21th January 2022

ABSTRACT

Concrete is the utmost sorted and vital component in construction because of its low price, easy availability of constituent materials and has strong compression strength. The downside of concrete is it's weakness in withstanding tension, which leads to cracks inside the systems. Cracks permit water in the concrete and cause decay of the iron steel bar. Cracks are primary weaknesses of concrete which finally leads to structural failure. To prevent such, frequent maintenance and the use of artificial synthetics may be used for improvement however, they are costly and additionally not environment friendly. In current years MICCP (microbiologically induced calcium carbonate precipitation) by microorganismis considered as an environment conservation and preservation approach that increases the properties and repairs the matrix. The use of self-recuperation concrete has developed lately, in improving the overall behaviour of concrete, a calcium carbonate precipitating and sporulating bacteria is incorporated into concrete. As water ooze through the cracks, it helps the bacteria precipitate calcium carbonate as a by product, which fills the cracks (self-healing). Therefore, research is embarked on to discuss bacterial in concrete, it's kinds, benefits and downside of bacterial use in concrete and application with the help of previous journals and assessment of bacterial concrete durability. The bacterial calcite precipitation was examined with the aid of X-ray diffraction (XRD)and envisage with Scanning Electron Microscope (SEM).

Keywords: Self-healing, sporulating, MICCP, synthetic, performance, SEM, XRD.

INTRODUCTION

One of the utmost used components for construction in the field of engineering is concrete cement, due to its low cost of constituents and construction. Cement concrete possess high compression strength, however it's vulnerable in tension. This is why reinforcement is needed to cater for it when the concrete cracks as a result of the loading. However, the cracks in the concrete pose lag [1]. Because of conditions like freeze-thaw reactions, shrinkage, reduced life span of concrete and so forth, cracks arises as concrete hardens and this consequently leads to weakening of the buildings. If water droplets enter into the concrete structure, as end result to lack of permeability then it can harm the steel reinforcements present within the concrete member. In such scenario, the strength of the concrete decreases and which ends up in decay of the composite members [2]. Synthetic materials like epoxies can also be used for preventing cracks in concrete but they are expensive and require frequent maintenance. Using chemicals are moreover harmful to man and causes damage to the surroundings. This calls for a human and environment friendly approach and effective crack remediation method which gave rise to the use of bacteria to improve concrete properties [3]. The necessary principle in this reaction is the microbial urease catalyzes the hydrolysis of urea into ammonia and CO2 and consequently the ammonia being released into the environment eventually increases the pH and forms calcium carbonate [3]. Past research has shown that Europe spent approximately half of its production budget in construction renovations [4]. This cannot be disputed, as massive quantities of bridges were constructed in the mid-nineties [5]. Recent findings has proved that Belgium e invested just 0.3% of its gross domestic commodities from 2016 in street infrastructure, out of which half was used to preserve the existing structures [6]. These projects are degrading as the useful life goes by and these calls for structures that will last longer and with little or no maintenance and repair interventions. A long lasting structure which will also reduce global warming is sorted for. Using information from 2009, it was reported that the construction industry globally has generated 23% of CO2 emissions [7]. Durable and long lasting structures with improved properties and environmental friendly Self- recovery concrete is achieved [8].

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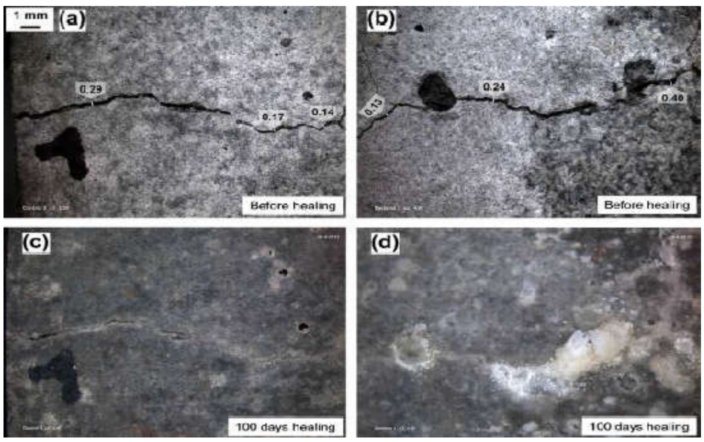

Fig 1: showing the self-healing process of concrete from a – d. [9]

Bacteria

Bacteria are microscopic, single cell microbes that come in different shapes. They are classified into three categories as shown below:

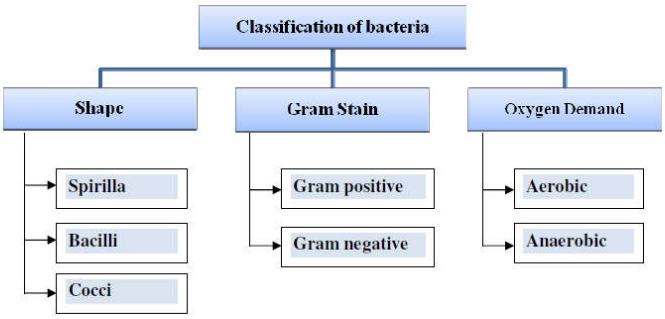

Fig 2: Classification of Bacterial [10]

Kinds of Bacterial

There are various Kinds of bacteria that can be utilized in bioconcrete construction, namely:

- Bacillus balodurans
- Bacillus pseudofirmus
- Bacillus cohnii
- Bacillus pasteurizing
- Bacillus sphaericus
- Bacillus subtilis

Techniques of Self-Healing

There two techniques of self-healing of concrete are Autogenous and Autonomous [11]. Autogenous self-recovery relies upon the composition of concrete and is unblemished via hydration response of cementitious products within the concrete matrix. 15-25% of the cement used in conventional concrete is most times un-hydrated. When cracking develops in concrete, it allows the passage of moisture into the concrete matrix. Hydration reaction takes place as the moisture and the un-hydrated cement comes in contact and fills the crack. This inherent self-recovery mechanism is known seeing that lengthy and mentioned as autogenous restoration. It's frequently powerful for very narrow cracks [12, 13, 134, but not able to heal wide cracks [15]. It's less complicated in fresh concrete as regular delivery of water is needed [11].

$H_2O + Cao \rightarrow Ca\ (OH)_2$ (1)

$CO_2 + Ca\ (OH) \rightarrow CaCO_3 + H_2O$ (2) [10]

Autonomous self-recovery depicts the induction of engineered unorthodox supplements into the concrete matrix to spark off the self-restoration capacity [16, 17]. Bacteria spores are integrated to intermediate the self-healing by way of precipitation of carbonate but they failed to survive for an extended time due to the alkaline medium and shrinkage of pores [18, 19, 20]. Furthermore bacterial spores are capsulated and incorporated in concrete which increases the lifespan of bacterial in the concrete [21]. This can heal as much as crack width of 0.5 mm [22]. When water or moisture seeps into the cracks, the inactive microorganism gets energy [23]. They reproduce and germinate within the salt and blend with carbonate ions to make insoluble carbonate which fills the cracks [17]. The reaction of water and ureaCO (NH2)2 to produces an ammonium (NH4^{+}) and carbonate(CO3^{2-}) as shown bellow

$CO\ (NH2)2 + H2O \rightarrow CO_3^{2-} + 2\ NH^{4-} + 2\ H2O$ (3)

The use of microbes to optimize the properties of concrete cement is termed as Bio-mineralization [26]. After activation, microorganism undergo some metabolism like sulphate discount, photosynthesis and urea hydrolysis and finally forms carbonate as a byproduct. Factors such as: Availability of nucleation sites, pH value, concentration of dissolved inorganic carbon concentrates, calcium concentration, determines the amount of calcium carbonate formed [27]. For accomplishment of self-healing phenomenon, it's most vital that the bacteria must be geared up to convert the organic contents into insoluble calcium carbonate crystal that fills the openings in the concrete. Self-healing agent consists of bacteria which act as catalyst and calcium calcite which will be transformed into carbonate [28].

Bacterial selection

The selection of bacteria for bio-concrete includes searching for bacterial that can continue to exist and function in an intense alkaline environment. The combination of water and cement gives rise to a PH value of about 13 that is not favorable for microorganism. Almost all organisms die at a PH of 10 or above[29]. The quest was based on microorganisms that can survive in alkaline natural environment; samples of bacteria that inhabit stones are collected alongside bacteria observed in sediment. Groups of genus Bacillus are discovered to survive in this high PH condition. The kinds of bacteria which may also live in this sort of high PH surrounding are listed above and in table 1, it was discovered that the main class of bacteria that can exist and live are those that produce spores like. Such spores have extraordinary dense cell wall which helps them to stay in dormant state for many years up to 2 centuries and waits for the favorable condition to evolve. They tend to activate when the concrete develops crack, with access to nutrient (calcium lactate), water enters into the concrete and reduces the alkalinity to about10 – 11.5 so that the bacteria spore can function as catalyst [30].

Bacteria Isolation/Cultivation

The standard steps for isolation of micro-organisms from soils are:

Step1: collection of soil specimen, mix with water in test tube and then shake properly.
Step2: Take 1ml of the proper shake mixture into another test tube and add 9ml of water into it.
Step3: This new solution should be kept in a tube (has a concentration of 10^{-1})
Step4: Mix 1ml solution from step 1 and 9ml solution from step 2
Step5: The above steps should be done many times repeatedly to distribute the individual cells across the medium so that when they produce, each will form a discrete colony and obtain a conc. of about 10^{-4} to 10^{-6}
Step6: Pour the solution obtained from the tube in 5 above into a plate and observe after 2days
Step7: using a sterile tool, identify and separate the different colonies into different plate.
Step8: Using gram staining technique to ascertain the form and structure of the different microbe. [31]

Benefits and Downsides of Bacteria Concrete [32]

Benefits of Bacteria concrete:

- Self-recuperating of cracks by the bacteria in the concrete with none external aid.
- It shows maximum rise in compression and flexural strength when compared to convention concrete matrix.
- It helps to oppose and withstand the highly destructive forces of cyclic freezing and thawing occurrence in concrete.
- Brings about a decrease in porosity of concrete.
- It's a corrosion protective method for reinforced concrete.
- Bacillus microorganisms are innocuous to the environment.

Downsides of Bacterial Concrete:

- Bio concrete is expensive, almost twice when compared to normal concrete.
- Cultivation/isolation of bacteria can't be accurate for all media.
- No provision for concrete mix design with bacteria in any code.
- Examination of the calcium carbonate precipitate requires huge funding.

LITERATURE REVIEW

This review was done with respect to some books and journals.

Durability test

The durability, water permeability and chloride penetration reduces by incorporating bacteria in concrete when compared to control mix [33]. By using Bacillus Halodurans there are reduction in porosity and water absorption in the concrete at 12.4% in 91 days [34] and also an improvement in resistance against penetration of water and hazard material and 40% decrease in water absorption after 28 days bio remediation [35]. By incorporation of Baccilus Sphaericus, concrete matrix performed better against permeability due to bio deposition [36]. More resistance against chloride penetration compared to control specimen reports that bio remediating concrete is effective in corrosion protection of reinforcement [37, 38]. Due to the compressed nature of the interfacial transition zone in sporosarcina pasteurii treated concrete matrix show better resistance against water permeability compared to controlled specimen [39]. Another journal reports a reduction in permeability and porosity in concrete by Bacillus pasteurii [40]. Also the use of bacteria in mix reduces the rate of absorption capacity of concrete by about 20% compared to normal mix and crack width is decreased by 48% and 63% at 14 and 28 days respectively [41].

Tensile strength

For tensile strength, by incorporating Bacillus Subtilis in concrete there is a rise in 38.14% for 7days and 14.41% for 28 days But for Bacciluc Sphaericus it increases by 31.14% for 7 days and 2.76% 28 [42]. An improvement of 30.94% of the split tensile strength by using Bacillus Subtilis compared to ordinary concrete[43]. Another journal reported a rise of about 56% in tensile strength of microbial mortar when remediated with Enter obacter Sp. [35].Similarly by replacing with Bacillus Sphaericus the tensile strength rises by 13.8% for 3 days, 14.3% for 7 days and 18.44% at 28days [35]. Incorporating Baccilus Pasteurii recorded a flexural strength increment of 17.34% for 7 days and 11.18% for 28 days [42] and reduction by 17% flexural strength in 28days by using calcium nitrate encapsulation[44].

Water absorption and 28 days compressive strength

Table - 1 Compressive strength and Water absorption after 28days [45 - 61]

s/no	Bacterial	Compressive strength after 28days	Water absorption result after 28days	Reference
1	Bacterial Sphaericus	Increased by 30-35% more than the normal concrete specimen	The normal concrete specimen is 45-50% more than the bacterial infused concrete	45, 46, 47, 48, 49
2	Bacillus Subtilis	Increased by 12-17% more than the normal concrete specimen	The normal concrete specimen is 50% more than the bacterial infused concrete	50, 51, 52, 53
3	Bacillus magaterium	Increased by 24% more than the normal concrete specimen	The normal concrete specimen is 46% more than the bacterial infused concrete	54
4	Bacillus pasteurii	Increased by 2 - 4% more than the normal concrete specimen	The normal concrete specimen is 50-70% more than the bacterial infused concrete	55, 56, 57, 45, 58, 51
5	Bacillus cohnii	Increased by 15% more than the normal concrete specimen	The normal concrete specimen is 35% more than the bacterial infused concrete	59
6	Baciillus flexus	Increased by 10-18% more than the normal concrete specimen	The normal concrete specimen is 40% more than the bacterial infused concrete	60
7	Bacillus cereus	Increased by 30-40% more than the normal concrete specimen	The normal concrete specimen is 50% more than the bacterial infused concrete	46, 61

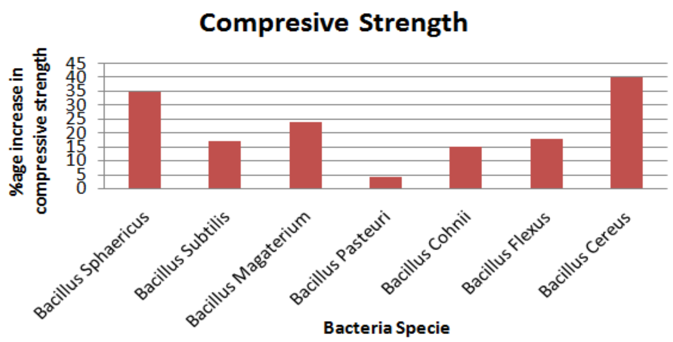

Fig 3: Compressive strength of Bacterial concrete [45-61]

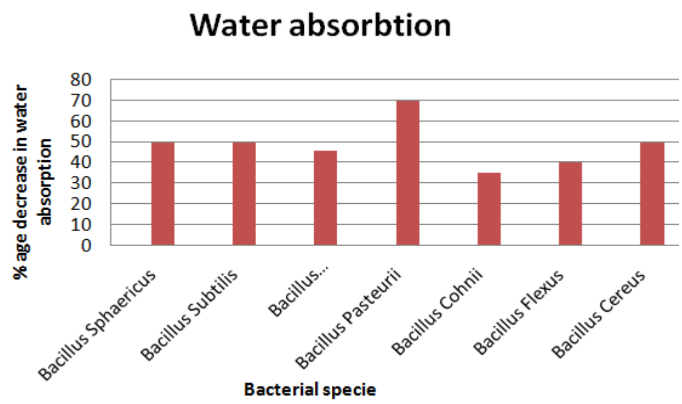

Fig4: Water absorption in Bacterial Concrete [45-61]

Analysis Using Scanning Electron Microscope and X-ray Diffraction.

The SEM analysis of cement specimens reveals the precipitate product in the cracks, scrutinized by X-ray diffraction brings to conclusion that this technique can be used to achieve the aim of self-healing and study [62].

X-ray Diffraction (XRD):

This is a technique used for qualitative evaluation of substances. An X-ray supply is employed to irradiate the specimen and to cause the weather inside the specimen to emit (or fluoresce) their feature X-rays. A detection device (wavelength dispersive) is employed to live the peaks of the emitted X-rays frequency measurements of the weather and their amounts. In the present study the precipitation changed into analyzed for its chemical characteristics by using X-ray diffraction and end result indicated positively as carbonate. Fig.5 (a) & (b) indicates the assessment between control concrete and Bacterial concrete composite. [63]

- It is evident from experimental studies Fig. 5(a) & (b) the principal calcite peak scan were observed at 23.3^{0}, 29.60, 36.2^{0}, 39.2^{0}, 43.4^{0}, $47.7^{0}$and 57.4^{0}which validate presence of calcite in the microbes induced concrete and also in conventional concrete.
- There is a higher amount of calcite produced by the bacteria which increases the compressive strength of the mortar [63]

Scanning Electron Microscopy (SEM):

This is employed for examining the structural morphology at very excessive magnifications degree. SEM inspection is commonly utilized within the evaluation of cracks and fracture surfaces, bond disasters, and physical defects. Fig. 6(a) & 6(b) suggests the comparison among fracture floor of manipulate concrete and bacterial concrete composite.

- It is evident from Fig. 6 (a) & (b) that calcite are crystalline materials that grows in concrete on the addition of bacterial, thereby reducing the pores.
- In Fig 6 (a). The calcite is seen as spherical particles. The increase in strength and durability of the composite concrete is due to the microbiologically produced calcite which filled up the pores [63].

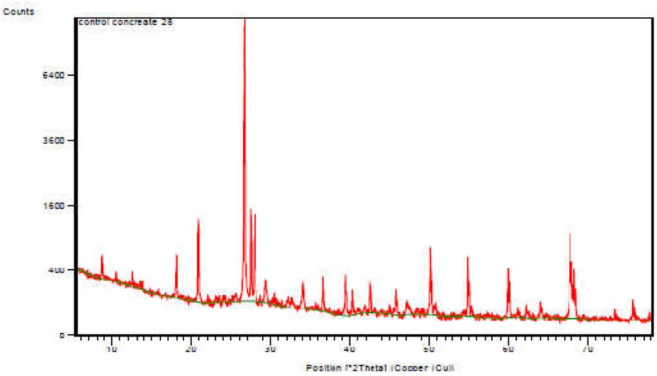

Fig. 5: **(a)** X-ray diffraction spectrum of control concrete [63]

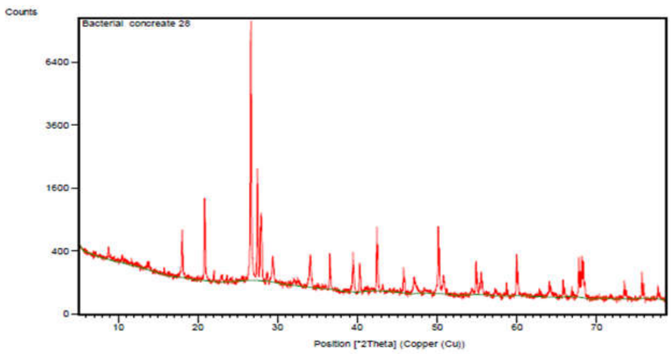

Figure 5: (b) Bacterial Concrete spectrum with X-Ray Diffraction [63]

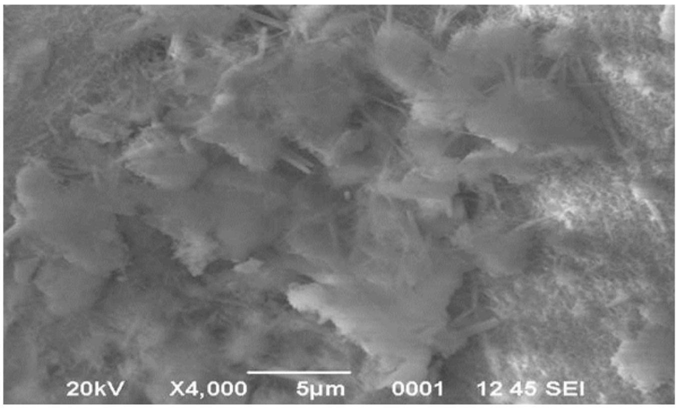

Figure 6: (a) Image of bacteria infused in concrete with fracture and viewed with SEM. [63]

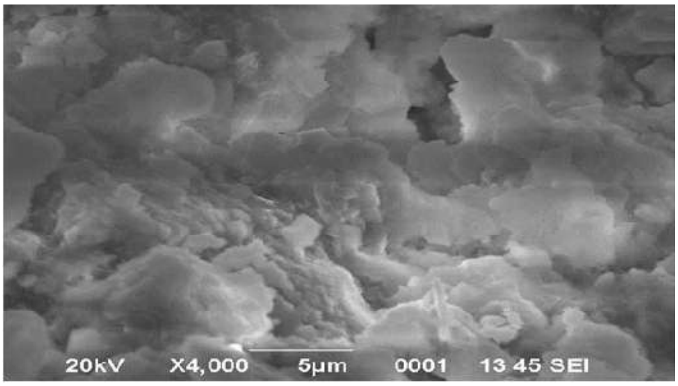

Figure 6: (b) Image of surface Control concrete under SEM [63]

Application

Bacterial induced concrete is environmental friendly carbonate precipitation self-healing technique and has become increasingly popular in the following:

- Its application is expedient in underground and offshore structure etc. where even very little crack is avoided.
- Bacteria concrete can also be employed in constructing irrigation structure.
- Improvement in properties of sand to enhance durable cementitious materials.
- It can be applied to fix limestone monuments and restore them to a sound state.
- Used for Sealing off cracks in concrete.
- For construction of low cost durable house.

CONCLUSION

According to my findings, a few microbes are dreadful for human wellbeing but some microbes from the bacillus family such as bacillus sphaericus, bacillus pasteurii, bacillus subtilis , and bacillus flexus doesn't pose any awful impact on human wellbeing additionally produces higher capacity of calcium carbonate precipitation, these properties makes the class bacilus as perfect microscopic organisms to be integrated into bacterial concrete. From my research i can deduce that bacterial concrete serviceability life is more than the ordinary concrete. With respects to the information gathered from the other journals consulted, it can be concluded that the cost for bio concrete can be as high as 30% than the ordinary concrete, depending upon the kind and concentration of microscopic organisms utilized but the maintenance cost for the conventional concrete are mostly decreased by the utilization of bacterial concrete. It's exceptionally effective in increasing the strength and toughness of concrete. It exhibits also a high level of drying shrinkage resistance, resistance to attack by corrosion, more resilience to sulfate. There was an in-depth comprehension of bacterial concrete through this study. By infusing the right microorganism in concrete there was optimization in properties such as permeability reduction, water absorption and corrosion, drastic rise in comprehensive and flexural strength when juxtaposed with conventional concrete. To enhance bacterial infusion in concrete more investigation and study are require in the following: The means by which bacteria obtains its energy and nutrient required to live and reproduce, retention of these nutrients and metabolism while being used in concrete, also durability and behavior of bio concrete.

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