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Evaluation of the Performance of Cement Concrete Including Bacteria

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ABSTRACT

It is nearly impossible to stop cracks from forming on the surface of concrete, even with the finest materials and skill. Even when the concrete is in excellent condition, this is still the case. The strength and longevity of the concrete may gradually start to decline as a result of these defects. Therefore, it is crucial to seal these gaps in order to lessen or completely prevent the damaging effects of any degrading substances that might seep into the concrete through these fractures. Various fractures may allow for the entry of these degrading agencies. A overview of the effects of several bacillus family bacteria on the properties of concrete, specifically its strength and durability, is provided in this article. We considered bacteria in this investigation that ranged in concentration from 100 CFU to 108 CFU. This work also discusses the possibility that some bacteria from the bacillus family can heal themselves. The method by which concrete cracks may mend themselves by introducing bacteria from the bacillus family into the concrete mix is known as "self-healing." Additionally, this procedure lessens the detrimental impact that these germs may have on the longevity and strength of the concrete.

Keywords: *Bacterial concrete; Cracks in concrete; Autogenous healing; Compressive strength.*

1.0 Introduction

One of the materials that is most frequently used in the construction industry is concrete [1]. Because concrete is weak in tension and strong in compression, surface fractures can occur in it[2]. Microcracking on concrete's surface is unavoidable and can weaken the material, increase permeability, and limit its lifespan[3][4]. Additionally, cement mortars are especially prone to this problem of cracking[5]–[7]. Early age cracking of concrete structures is caused by variations in temperature and humidity, which generates gaps for hazardous degrading agents to enter and gradually diminish the strength and durability of concrete [8]. In an attempt to mitigate or eliminate the effects that surface cracks have on concrete, a number of research have looked into how to keep them from occurring[5, [9]–[12]. One technique, called autogenous healing, produces calcium carbonate, which aids in the closure of fractures[13]. The success of calcite precipitation-based approaches has led to a plethora of studies on the use of bacteria in concrete. To strengthen and prolong the life of concrete, a variety of microorganisms have been added to the cement[14]. By creating calcite precipitation to fill the voids and pores present in the concrete, Bacillus family bacteria are the most effective microbial mineral method to improve the mechanical and durability qualities of concrete[14]–[17].

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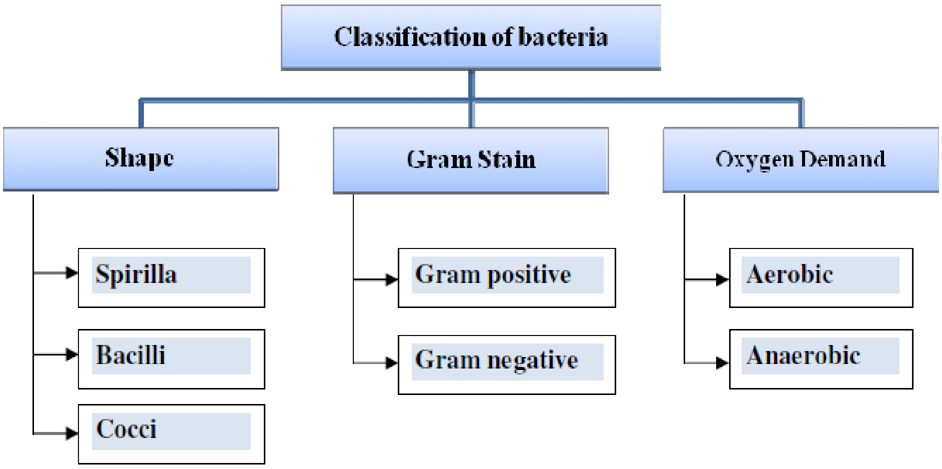
According to E. Madhavi et al. (2016), the mechanical properties of fly ash and GGBS-based concrete are enhanced by the addition of bacteria at a concentration of 106 cells/ml [18]. Sanjay et al. have investigated the adaptation of the bacteria in nutritious broth medium and urea media, as well as the rise in strength in both mediums (2016). It was shown that the bacterium performed better in nutritious broth medium than in urea medium and was more adaptable there [19].

The endurance and mechanical qualities of concrete have been studied in this study in relation to the impact of bacillus family bacteria such subtilis, megaterium, sporosarcina pasteurii, and sphaericus. In the current investigation, bacterium concentrations of up to 10^8 cells/ml have been taken into account.

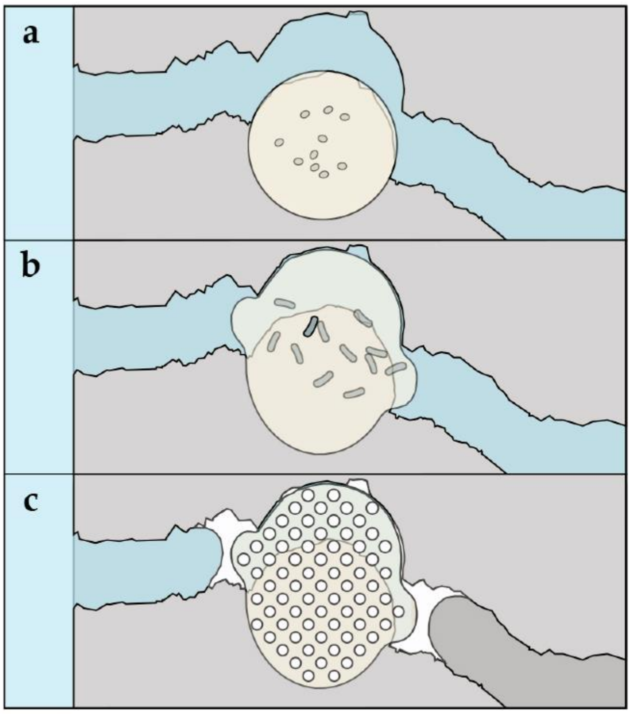
Figure 1: Classification of Bacteria [20]



2.0 Methods

It is possible to produce concrete with outstanding self-healing properties by utilising biological agents. Bacillus subtilis, Bacillus sphaericus, Bacillus pasteurii, and Bacillus megaterium were the bacteria that the researchers used to investigate how various bacteria affect the mechanical and durability qualities of concrete. The self-healing technology that initiates as soon as concrete fissures are detected is the best one. Using the self-healing technology, it is very simple to retrofit or fix the cracks that have formed in the existing buildings. Autogenous healing methods are a quick and effective way to fix superficial microcracks. The precipitation of calcite is confirmed by a layer of calcium carbonate that develops in the cracks in concrete following the addition of bacteria[21], [22]. The addition of microorganisms keeps the concrete's high alkalinity[23], [24]. Calcite precipitation caused by bacteria strengthens the binding between cement gel, sand, and aggregates in concrete[25]. The concrete's resistance is increased by the filling of the microcracks and gaps. Cracks that are smaller than 0.2 mm in width can be successfully filled by this bacterial precipitation; however, the self-healing mechanism is unable to do so. The bacteria in the bacterium-induced concrete come out of dormancy and begin to act when cracks of any size appear. Concrete begins to self-heal as soon as the calcite precipitation begins because the calcium carbonate fills up any spaces. Once the cracks are filled, the germs go back to sleep. Every time a fracture appears in the concrete, this cycle is repeated. The long-lasting healing process called "microbiologically induced calcium carbonate precipitation" is caused by bacteria (MICP).

Figure 2: Bacteria based Self-healing Concrete[26]



3.0 Effect of Bacteria on Concrete Properties

The bacillus family of bacteria can be used in a variety of ways to improve the unique qualities of concrete. The bacteria has been used up to a maximum of 108 colony forming units at different concentrations (CFU). The majority of the time, adding bacteria to concrete improved the material’s durability and mechanical qualities. However, because of the varying concentration of bacteria, there were differences in the attributes.

3.1 Effect of Bacillus subtilis bacteria

Concrete’s durability and other qualities have been enhanced by the Bacillus subtilis bacteria. Up to 108 microorganisms per millilitre have been used. Shradha Jena et al. [27] employed Bacillus subtilis bacteria in concentrations of 100, 102, 103, 104, 105, and 106 cells/ml in their concrete. Up to 105 cells/ml, the data justified rising intensities. The gains in compressive strength above ordinary concrete at 7, 14, and 28 days were 27.27, 29.59, and 32%, respectively. After the concentration of 105 cells/ml, strength decreased. The use of Bacillus subtilis bacteria in concrete illustrates the strength gain resulting from calcite precipitation. Concrete cracks are filled and repaired with precipitating calcium carbonate. Chereddy Sonali Sri Durga et al. (2019) [28] used ultrasonic pulse velocity, flexural strength test, compressive strength test, splitting tensile strength test, and water absorption test to investigate the impact of microorganisms on the strength and durability of concrete. The test results show that throughout the course of the 28-day testing period, the flexural, compressive, and split tensile strengths improved by 11%, 22%, and 16%, respectively, in comparison to ordinary concrete. In comparison to samples of regular concrete, the water absorption for bacterial mix concrete decreased from 1.28 percent to 0.22 percent. Seven, fourteen, and 28 days after casting, the concrete specimens were subjected to a direct transmission ultrasonic pulse velocity test. As the ultrasonic wave speed increases, the CaCO3-induced fractures in the concrete shrink and the concrete becomes more impermeabile. In their 2019 study, Nidhi Nain et al. [29] used bacillus subtilis bacteria at a concentration of 108 cells/ml to investigate the impact of bacteria on the mechanical and durability properties of concrete. The test results showed that, in comparison to control concrete, the use of bacillus subtilis bacteria in concrete increased compressive and split tensile strength at rates of 14.36 percent and 25.3 percent, respectively. In addition to increasing concrete's strength, microorganisms also extend the time between surface replacements.

Concrete cracks appear to be mending. Using Bacillus subtilis bacteria at a concentration of 107 cells/ml, Farnaz Salmasi et al. [30] assessed the durability properties using the chloride penetration test, water absorption, carbonation depth, and water penetration depth test. The test results demonstrated that introducing bacteria to concrete reduced the penetration of water, carbonation, chloride, and water by 20.5 percent, 13.1 percent, 27.2 percent, and 44.3 percent, respectively, in contrast to controlled concrete. Bacillus subtilis bacteria were employed at a concentration of 3 x 108 cells/ml by Wasim Khaliq [2] to investigate the impact of bacteria on the durability and strength of concrete. Comparing bacterial concrete to control concrete, it was discovered that there was a 12 percent improvement in compressive strength. The process of bacterial self-healing boosted the strength of the concrete.

3.2 Bacillus megaterium

Using energy dispersive spectroscopy, split tensile strength testing, and compressive strength testing, Nidhi Nain et al. (2019) [29] examined the effect of these microorganisms on the durability and strength properties of the concrete. The microorganisms used were Bacillus megaterium, with a concentration of 108 cells/ml (EDAX). The test results indicated that introducing bacillus megaterium bacteria to concrete increased its split tensile strength by 18.29 percent and its compressive strength by 22.58 percent, respectively, when compared to control concrete. The genus Bacillus megaterium of microorganisms improves the durability and strength of concrete. Bacillus megaterium bacteria at a concentration of 105 cells/ml and metakaolin pozzolan were employed by Vighnesh Rameshkumar et al. (2020) [31] to assess how bacteria affected the mechanical and durability qualities of the concrete. The concrete's strength and durability had increased, according to the test findings. The concrete was given calcium carbonates by the bacteria Bacillus megaterium and metakaolin, which also filled the voids in the concrete. Bacillus megaterium bacteria were used at concentrations of (103, 105, and 107 cells/ml) by Ramin Andalib et al. [32] to test the strength qualities of the concrete. It was discovered that at 105 cells per millilitre, there was the biggest strength increase. The strength changed as the concentration was adjusted from 10 to 50 x 105 cells per millilitre. 30 x 105 cells/ml was the cell density that produced the greatest results. Using bacillus megaterium bacteria at concentrations of (103, 105, and 107 cells/ml), V. Nagarajan et al. [33] tested the strength of bacterial concrete using compressive strength, flexural strength, and split tensile strength tests. Flexural, compressive, and split tensile strength all rose up to a concentration of 105 cells/ml, according to the data. The strengths then began to diminish.

3.3 Bacillus sp.

The concrete self-healing approach was presented in 2013 by N. Chahal and R. Siddique [34]. Sporosarcina pasteurii bacterial stain was employed in this experiment. Silica fume now makes up 5 percent and 10 percent of the cement, replacing the percentages of fly ash, which formerly made up 10 percent, 20 percent, and 30 percent of the cement. This mixture was changed in a medium containing bacterial solutions comprising 103, 105, and 107 cells/ml. In addition, 91 days were spent testing the material's compressive strength, porosity, chloride permeability, and water absorption. Eventually, they concluded that S. Pasteurii had several positive effects on concrete, such as increasing compressive strength and decreasing permeability and porosity, when combined with fly ash and silica fume. It was also discovered that the bacteria fills in any recently developed fissures. P. Ingle et al. (2017) [35] investigated a wide range of topics with bio concrete. In addition, they conducted testing for compressive strength and permeability, among other qualitative evaluations. B. Pasteurii is the type of bacteria that was employed in this experiment. For the purpose of making concrete, bacterial solutions containing103,105, and 107 cells/ml were utilised. In addition, it was discovered that rice husk concrete had reduced porosity and improved permeability, both of which are indicators of increased strength and longevity. The tests for compressive strength, water absorption, fast chloride, and water permeability have all been detailed by N. Balam [36]. They employed 106 cells/ml of S. pasteurii stain-based bacterial cultures in light weight aggregate concrete (LWAC). They discovered that there have been declines of 21.1 and 10.2 percent in water absorption and chloride permeability, respectively. Along with a 20.1 percent increase in compressive strength in the experimental sample, they also noticed comparable features in the control samples. Furthermore, they noted that, in comparison to concrete mixed with just bacteria, the porosity of the LWAC sample containing bacteria is lower and more condensed.

Using fly ash as a partial replacement (10%, 20%, and 30%) for cement, Navneet Chahal et al. [37] tested the durability and strength of the mixture using compressive strength, water absorption, and rapid chloride penetration tests. The bacteria used were Bacillus sp. at concentrations of 0, 103, 105, and 107 cells/ml. The results of the test indicated that the ideal bacterial concentration was 105 cells/ml since the compressive strength increased to that level before falling. At 105 cells/ml of cell density, the least amount of water absorption was attained.

3.4 Bacillus sphaericus

B. Madhu Sudana Reddy et al. [38] used Bacillus sphaericus bacteria to show that the maximum effects were produced at a cell concentration of 105 cells/ml. The reasons for this are improved concrete pore packing and precipitation of calcium carbonate. The strength test findings for M20 grade concrete were 27 MPa, 32.4 MPa, 35.5 MPa, and 31.6 MPa, respectively, at 103,105,107 bacterium cells/ml. The findings for tension were 3.78 MPa, 4.23 MPa, 4.52 MPa, and 4.28 MPa, and for flexure they were 3.71 MPa, 3.92 MPa, 5.21 MPa, and 4.52 MPa. Prince Akash Nagar et al.[39] investigated the durability and strength of concrete using compressive strength tests, water absorption tests with Bacillus sphaericus bacteria at a concentration of 108 cells/ml, and calcined clay (10 percent, 15 percent, and 20 percent) in place of cement. The results of the tests indicated that strength decreased with increasing calcined clay concentration. When calcined clay was substituted for ordinary concrete in percentages of 10%, 15%, and 20%, respectively, the compressive strength dropped by approximately 3.8 percent, 7.38 percent, and 17.17 percent. The percentage of water absorbed dropped by 16.84, 8.42, and 5.41 percent. The addition of Bacillus sphaericus bacteria resulted in a 21 percent, 24 percent, and 24 percent increase in the concrete's compressive strength, respectively. When calcined clay was substituted for cement to the extent of 10%, 15%, and 20%, respectively, water absorption dropped by 30.97%, 14.52%), and 11.14 percent. According to Jagannathan et al. (2018)[40], adding fly ash and Bacillus sphaericus and pasteurii bacteria in place of 10%, 20%, and 30% of the cement, respectively, improved the mechanical qualities of the concrete. Comparing the concrete to normal concrete, the increases in compressive, flexural, and split tensile strengths were 10.82 percent, 5.25 percent, and 29 percent, respectively. Microorganisms belonging to

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the Bacillus sphaericus genus were incorporated into the concrete mixture by Gavimath et al. [41] as a self-healing element. After 3, 7, and 28 days, it was found that the compression strength had improved by 31.05 percent, 45.98 percent, and 31.80 percent, respectively. Furthermore, at 3, 7, and 28 days of testing, the split tensile strength increased by 14.10 percent, 13.90 percent, and 19.01 percent, respectively.

3.5 Miscellaneous bacteria

Different forms of fibre were utilised by Nasrin Karimi et al. (2019)[42] at a concentration of 107 Bacillus subtilis cells/ml. Water was replaced with bacterial culture in the concrete mixture, and a gel was utilised to treat the surface. In samples containing bacteria, there were reductions in water absorption, carbonation depths, and chloride ions of 63.88 percent, 27.51 percent, and 39.84 percent, respectively. In order to minimise porosity in samples with fibre reinforcement, concrete has the ability to fill voids, as demonstrated by the addition of microorganisms to the concrete mixture and the concrete's curing in a calcium lactate-urea solution. Using a chloride test, H. Ling et al.[43] documented how bacteria affected the ability of concrete cracks to mend themselves. Chloride transport was also accelerated by the electromigration method. They saw how bacteria can bridge gaps and reassemble themselves. Bacteria can protect reinforced concrete elements by keeping chloride from penetrating cracks. Additionally, the experiment demonstrates how microbial self-healing can be applied more widely in real buildings. The effects of bio concrete at different concentrations have been presented by R. Siddque et al. For the experiment, 105 cells/ml of bacterial concentration and cement substitutes of 5, 10, and 15% silica fume were utilised. Over the course of 28 days, there was a 10- to 12-percent increase in compressive strength.

Table 1: Effect of Bacteria Concentration on Strength and Water Absorption Properties of Concrete

Type of Bacteria	Bacteria Conc. (cells/ml)	Strength	Water Absorption	References
Bacteria Subtilis	10^0, 10^1, 10^2, 10^3, 10^5,10^7,10^8.	Strength increased upto 10^5 cells/ml bacterial concentration then it started decreasing.	Water absorption decreased with the use of bacillus subtilis at 10^7 and 10^8cells/ml.	[27][28] [29][30]
Bacillus megaterium bacteria	10^0, 10^1, 10^2, 10^3, 10^5,10^7,10^8.	Flexural, Compressive and split tensile strength increased up to 10^5cells/ml concentration and beyond that strength started decreasing.	Water absorption of bacterial concrete was deceased as compared to standard concrete.	[29][31] [33][32]
Bacillus sp. bacteria	10^0, 10^1, 10^2, 10^3, 10^5,10^7,10^8.	Compressive strength increased up to 10^5cells/ml and after that it started decreasing	Reduced permeability and water absorption when used in a combination with silica fume and fly ash concrete. Maximum reduction at 10^5cells/ml.	[34][37] [35][36]
Bacillus sphaericus bacteria	10^0, 10^1, 10^2, 10^3,10^5,10^7,10^8.	10^5cells/ml concentration gave the best strengths. Calcined clay concrete at 10^8 cells/ml concentration showed improved strength.	Water absorption of concrete was reduced using the bacteria in concrete.	[38][39] [40][41]

The scientists discovered that bacterial concrete is significantly superior to non-bacterial concrete. The presence of bacteria in concrete reduces the material's porosity, permeability to chloride, and water absorption capacity. The results of treating bacterial concrete with 10, 20, and 30% of CBFD instead of cement have been noted by Siddique et al. [45]. It was discovered that the bacterial solution had 105 cells per millilitre. The characteristics of the bacterial concrete were tested at 28 and 56 days of curing. It was found that the strength and durability of the concrete were increased when CBFD and bacterial solution were used in place of cement. The impact of the various bacterial concentrations on the concrete's strength and water-absorption capabilities is shown in the Table 1.

4.0 Conclusions

This review article has following conclusions.

- When compared to other concentrations, the bacillus family of bacteria produces the greatest increase in mechanical characteristics at a bacterial concentration level of 10-5 cells/ml.
- The primary cause of the sealing of fractures and increased strength is the presence of bacteria from the Bacillus family, which increases the autogenous healing potential.
- By decreasing the concrete's permeability and porosity, microorganisms increase its durability by limiting the concrete's capacity to absorb water, absorb chloride, and undergo deep carbonation.
- When pozzolanic elements like fly ash and silica fume are added to concrete, the attributes of strength and durability can be enhanced by the addition of bacteria.
- There is always room for development. The effects of adding bacteria to concrete that has a binder other than cement, like geopolymer concrete, can be studied further.

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