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Coupled Effect of Bacillus Bacteria with Supplementary Cementitious Materials on Mechanical and Durability Properties of Concrete: A Review

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Abstract-**Concrete is widely used in the construction of buildings, bridges, skyscrapers, sidewalks, highways, dams, etc. Nowadays, the application of concrete has been expanded in construction development due to the easy availability of material and concrete structures are more durable and rigid structure than other construction material structures. Cracks development in concrete due to heat of hydration influences mechanical properties such as compressive, tensile and flexural strength and durability properties such as water absorption and rapid chloride permeability. This review paper is the overview of application of various bacillus family bacteria with optimum concentration in addition with supplementary Cementitious materials (SCMs) as replacement of cement to intensify mechanical and durability properties of concrete. Bacillus family bacteria remediate cracks by Microbial induced calcite precipitation (MICP) process and implementation of SCMs approach to reduce the CO2 emission on environment.**

Keywords: **Bacillus family bacteria, Compressive strength, Water Absorption, Rapid Chloride permeability, Supplementary Cementitious materials**

I. INTRODUCTION

Most buildings need concrete, and most of the parts of concrete are used in different kinds of buildings [1]. Using cement concrete all the time has a big effect on the climate and puts the ozone layer in danger by releasing greenhouse gases [2], [3]. It is also the most common building material in the world because it is easy to find, reliable, and easy to work with. When cement concrete is used a lot, it gets worse over time as a building material [4]. Common signs of this kind of damage are micro cracks, less resistance, less mechanical strength, and a big drop in the concrete's durability [5]. The more of these precursors there are, the less resistant the structures are to climate change. This means that the structures lose strength and become more porous [5], [6]. Many researchers turn to supplementary Cementitious materials (SCMs) or pozzolans to find solutions to these issues. As pozzolans, previous research [7], [8] has made use of rice husk ash, silica fumes, ground granulated blast furnace slag, and fly ash. Cement concrete made with calcined clay and a bacterial culture is a novel concept that has the potential to contribute to a reduction in CO_2 emissions and improve the concrete's physical properties [9]. When calcined clay and bacteria are combined to make concrete, the resulting structure is improved in terms of cleanliness, greenery, and long-term durability. The production of concrete makes use of a wide variety of bacterial cultures, some of which include Bacillus subtilus[10], Bacillus megaterium[11], and Bacillus cereus [5]. Alkaliphilic bacteria with a concentration of 10^5cfu/ml of water

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and silica fume were used to make cement concrete by Siddique et al. [8]. The bacteria served as a partial replacement for 5, 10, and 15 percent of the cement in the mixture, respectively. It was suggested that adding silica fume to the concrete cell was the most effective way to prevent unwanted agents from entering the cell. Tziviloglou and colleagues [12] investigated what takes place when mortar and concrete can repair themselves. New colonies of calcite-forming bacteria that were not related to the Bacillus family but were capable of surviving in the alkaline environment of cement concrete were investigated by Shashank et al. [13]. According to the findings of this study, the discovery of this new calcite bacteria contributes to an increase in the mechanical strength and durability of concrete. Priya et al. [11] demonstrate that the experimental performance of micronized biomass silicon cement concrete with bacterial culture to evaluate the mechanical and durable properties of high-strength concrete has been successful. Using fly ash as supplementary cementitious material, Kadapure et al. [14] and [15] investigated the effects of varying doses of alkaline bacterial culture on the production of cement concrete. They discovered that using a greater quantity of bacterial culture over a longer time produced concrete that was both more durable and more resistant to breaking. Using bar chit, steel, and polypropylene fiber in proportions of 0.75 percent, 1 percent, and 0.3 percent, along with a strain of B. Subtilus at a concentration of 10^7 cells/ml of water, Karimi, and Mostofinejad[16] were able to create a solution for the problems that plague traditional concrete. After curing for 28, 56, and 90 days in either water or calcite lactate urea solution, the samples were put through a series of tests to determine their quality. According to the findings, these treatments are very helpful in lowering the number of chloride ions that enter the system, which in turn lowers the amount of carbon dioxide that enters the system. The microbial calcite precipitation uptake using B. megaterium and fly ash was demonstrated by Achal et al. [17] in conjunction with mortar concrete for compressive strength, water absorption, and water impermeability testing. The author discovered that people had a favorable opinion regarding how B. megaterium and fly ash pozzolana enhanced the durability and mechanical properties of the material.

II. OBJECTIVE

This review paper is the overview to evaluate the effect of various bacillus family bacteria inoculated in concrete with substitution of cement by weight with various supplementary cementitious materials, on mechanical and durability properties of bacterial concrete.

III. BACTERIA PREPARATION

In this review, the bacteria Bacillus family bacteria were used to reduce the porosity of concrete by allowing calcite precipitation to enter the voids that are present in the material. To put bacillus bacteria to use in concrete, the frozen bacteria must first be converted into a liquid form concentration of bacteria. In this procedure, 100 ml of nutrient broth media will be autoclaved for 45 minutes and contained the following chemical compositions: 0.5 grams of peptone, 0.5 grams of sodium chloride, and 0.3 grams of beef extract for every 100 ml of nutrient broth media. The bacillus bacteria then inoculated in conical flasks with nutrient broth in front of fire flames to prevent contamination from the environment. The flasks would be maintained at a temperature of 4 degrees Celsius. After twenty-four hours, a bacterial sticking were performed on the agar plate and the petri dish to promote additional bacterial growth, and the results had utilized for the cultivation of additional bacteria cultures. Now, this bacterial culture in a conical flask should be kept at 37 °C in a shaker incubator for the next 24 hours. Once the bacterial growth will complete, a sample of 5 ml bacterial media in culture tubes would take for a count of bacterial cells/ml using the McFarland method, and Optimum Density (OD) was calculated by using spectrophotometer equipment at a wavelength of 600 nm that will passed between the bacterial media and Next, inoculate broth media into a culture tube once more; at this point, the bacterial concentration would be prepared to be diluted in the water that was used in the process of casting concrete.Classification of bacteria shown in Figure 1.

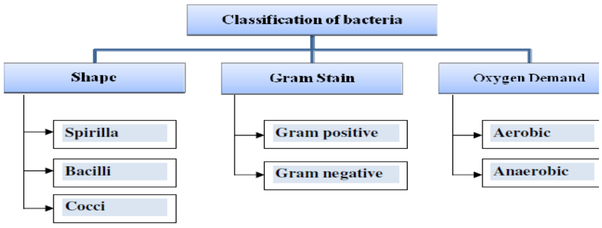

Fig. 1. Classification of Bacillus family bacteria[18]

IV. RESULT AND DISCUSSIONS

4.1.Coupled effect of various bacillus bacteria supplementary cementitious materials on mechanical and durability properties of bacterial concrete

During concrete preparation cement acts as a binder of coarse aggregates to fine aggregates mixed with water and produces heat of hydration. Cracks are developed in concrete due to the production of the heat of hydration in the concrete mixture by cement. Due to cracks development in concrete, there are many problems created for the concrete structures such as the strength of concrete is decreased, water absorption of structure is also increased so that these problems directly decrease the durability of the structure, and the concrete structure will become weak. Here, one concept has evolved that decrement of cement from the concrete mix is the main cause of decrement of the heat of hydration from concrete. Many researchers turn to supplementary cementious materials, also known as SCMs or pozzolans, to address these challenges. Previous research papers have made use of pozzolans such as rice husk ash, silica fumes, ground granulated blast furnace slag, and fly ash. NavneetChahalet. al aimed to analyze the results of compressive strength and rapid chloride penetration in concrete by the application of Sporoscarcinapasteurii bacteria in concrete with different bacterial cell counts (0, 10^3, 10^5, 10^7 cells/ml) with the replacement of cement by a percentage of (10, 20, 30) with fly ash by weight of cement [19]. Test results indicated that the application of S. pasteurii bacteria in fly ash concrete enhanced compressive strength by 22% more than the controlled concrete specimen and four-times reduction of porosity was observed with 10^5 cells/ml of bacteria. It also concluded that eight times reduction of chloride permeability due to the deposition of calcite on the surface of the concrete structure. Santosh Ashok Kadapureet. al; Fly ash was used as a replacement for cement by weight up to 30% with the application of bacteria embedded concrete to the analysis of compressive strength and tensile strength of cement concrete with different w/c ratios about 0.3 and 0.6 [15]. The author's result reveals that the compressive strength was enhanced in comparison to conventional concrete at both w/c ratios while the tensile strength was reduced as compared to OPC cement concrete [15]. The strength was increased up to 25% with the precipitation of calcite by Bacillus bacteria in concrete at 0.6 w/c ratios while less effective at 0.3 w/c ratios.

VarenyamAchalet. al; In this study, an innovative approach to the application of Bacillus Magaterium bacteria has been incorporated in concrete in which cement was also replaced with fly ash to analyse the effect of compressive strength and water absorption in mortar and water impermeably test in concrete. This study result reveals that compressive strength was enhanced by 19%, 14%, and 10% when 10%, 20%, and 40% cement was replaced with fly ash in mortar cubes as compared to nominal cement mortar samples. While water absorption of bacteria embedded samples was reduced by three times than OPC mortar cubes. In concrete cubes, water permeability had been reduced due to calcium carbonate precipitate in concrete pores [17]. The calcite precipitation has been easily observed by SEM images. Due to calcite precipitation durability of cement mortar cubes also increased. C. Venkata Siva Rama Prasad et. al; In this paper, an experimental study carried out using Bacillus subtilis bacteria and calcium lactate to heal the cracks in the concrete at different percentages such as 5%, 10%, and 15% of cement weight for concrete grade M40 [20]. This study results show that the maximum strength of bacterial concrete at 10% replacement of cement by crushed stone dust sand. Increment of compressive strength at all stages of bacterial concrete as compared to conventional concrete. SEM pictures reveal that calcite precipitation has occurred in voids of concrete helpful to heal the cracks of concrete. High-velocity wavelength passing through concrete at different ages confirms the improvement in the quality of bacterial concrete at different ages. Prince Akash Nagar et. al; In this study, calcined clay is utilized as a supplementary cementitious material (SCM) to partially replace cement in the following percentages: 10%, 15%, and 20%. In addition, the production of Bacillus Sphaericus bacteria at a bacterial count of 10^8 cells/ml is utilized in conjunction with calcined clay to perform an analysis of the self-healing properties of concrete [21]. The findings show that after 28 days, bacteria-embedded concrete with partial replacement of calcined clay increases compressive strength by 21%, 24%, and 25%, respectively. As a result, bacteria-embedded concrete with calcined clay has less water absorption and increased compressive strength, making it a green and cost-effective concrete construction method [21]. Because bacterial incorporation causes calcite precipitation between aggregate pores, it significantly improves the aggregate's compressive strength [21]. Because the pores in calcined clay concrete are filled with fine calcined clay, calcined clay concrete absorbs significantly less water than traditional concrete [21]. The performance of bacterial concrete was satisfactory when compared to the performance of conventional concrete in terms of achieving higher structural strength and lower permeability [21]. Arun Kumar Parasharet. al; The goal of this study was to develop a new bacterial tool for improving the strength and management of micro-cracks in calcined clay concrete [22]. The compressive strength of bacterial calcined clay concrete replacements of 10 percent, 15 percent, and 20 percent increased to 25 percent, 27 percent, and 28 percent respectively compared to nominal concrete at 28 days of curing condition. At the same time, water absorption of the specimens was reduced in bacterial calcined clay concrete in comparison to calcined clay concrete [22]. The capacity of bacteria-embedded calcined clay concrete to absorb water is lower in comparison to that of nominal concrete and calcined clay concrete. The percentage of water absorbed by B. fell by 18.30 percent, 17.38 percent, and 13.59 percent, respectively,

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throughout the experiment. In 28 days, subtiliscalcined clay concrete could be produced when calcined clay was replaced at a percentage of 10 percent, 15 percent, or 20 percent[22]. The results of this study indicate that the optimal dosage of calcined clay replacement with cement is 10 percent when compared to other proportions of calcined clay pozzolana[22]. This dosage was found to achieve higher compressive strength than the other proportions of calcined clay pozzolana. RafatSiddiqueet. al; In this study, the effect of bacteria on the properties of concrete by replacing cement (0%, 5%, 10%, 15%, and 20% by weight) with Rice Husk Ash and author mixed Bacillus aerius (10^5 cells/mL) bacterium concentration during making concrete mix [23]. The author performs various tests on bacterial concrete with replacement of cement by RHA such as compressive strength, water absorption, porosity, chloride penetration test and abrasion test at age of 56 days of concrete enhance results better than conventional concrete as well as RHA concrete on same days [23]. Results reveal that the maximum compressive strength of (bacterial concrete with RHA) is 36.1 MPa, and 40 MPa at 28 days and 56 days respectively at 10% cement replaced with RHA by weight. Water absorption, permeability, and porosity properties decreased on all testing days due to calcite precipitation which improves the density of concrete and enhances durability by the formation of ettringite of calcium silicate hydrate (CSH) gel into the pores of concrete [23]. Compressive strength was enhanced by 9% and 11.8% by the replacement of cement with an optimum dose of 10% of RHA bacterial concrete at the curing period of 28 and 56 days respectively. The water absorption and porosity effect are reduced in RHA bacterial concrete due to the precipitation of calcite into the pores of the concrete. The abrasion loss was less in bacterial concrete mixes compared to control concrete mixes at all ages [23]. Bhavanaet. al; In this current study, replacement of fly ash (0%, 10%, 20%) with cement used along with Subtilis bacteria of 10^5 cells/ml in the concrete[24].Effect of various bacteria with SCMS on mechanical and durability properties of bacterial concrete tabulated in Table 1.

V. CONCLUSIONS

The purpose of this review paper is to provide the application of various bacillus bacteria with optimum concentration mix with concrete to remediate of cracks by microbial precipitation process. Combined effect of supplementary material and calcite precipitation in concrete also reduces CO_2 emission in the production of cement and enhances significantly mechanical and durability properties in contrast of controlled concrete. Following are some significant conclusions derived from this review paper are as follows:

a. Bacillus family bacteria with optimum concentration of 10^5cells/ml enhance mechanical properties such as compressive strength along with application of various pozollans.
b. Bacillus bacterial concrete also improves the durability properties by decrement of water absorption of by formation of calcium carbonate in to the pores of concrete specimen.
c. The application of bacillus bacteria leads to prevent chloride and sulphate attacks on concrete.
d. Due to production of calcium carbonate in to tiny pors of concrete reduces cracks so, enhances lifespan and durability of bacterial concrete structure.
e. Application of supplementary

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Cementitious material in place of cement make concrete structure eco-friendly.

Table 1. Detailed effect of bacillus bacteria on mechanical and durability properties on bacterial concrete

Sr. No.	Types of Bacteria	Bacterial Concentration cells/ml	Supplymentory Cementious Materials	Mechanical Properties	Durability Properties	References
1	Sporoscarcin apasteurii	10^5	Flyash	Compressive strength increased by 22%	4 times porosity and 8 times chloride permeability decreased	[19]
2	Bacillus Megaterium	10^5	Flyash	Compressive strength increased by 25%	Water absorption decreased	[17]
3	Bacillus Subtilis	10^5	Crushed Stone Dust	Compressive strength increased	Ultrasonic Pulse Wavelength time decresed	[20]
4	Bacillus Sphaerricus	10^8	Calcined Clay	Compressive strength increased by 25%	Water absorption decreased	[21]
5	Bacillus Subtilis	10^5	Calcined Clay	Compressive strength increased by 28%	Water absorption decreased	[22]
6	Bacillus Aerius	10^5	Rice Husk Ash	Compressive strength increased by 10%	Water absorption,permeability and porosity decreased	[23]
7	Bacillus Subtilis	10^5	Flyash	Compressive strength increased by 30%	Water absorption decreased	[24]

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