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Comparative analysis of compressive strength and water absorption in bacterial concrete

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***Abstract*— Bacterial-based self-healing concrete is comparatively a new technology, so it is essential to collect more results in real-world conditions before implemented on larger-scale applications. This article reviews the types of bacteria used in concrete and how they are used as healing agents. This article also briefly describes the various properties of concrete, which vary with the addition of bacteria. Micro-cracks are inherently present in concrete, which causes the concrete to degrade, causing harmful substances to enter the concrete, resulting in structural deterioration. To overcome these situations, self-healing techniques are employed. Calcite and calcium sources are produced by the addition of bacteria that forms precipitation of calcite in concrete. Bio-mineralization technology provides promising results for sealing micro cracks in concrete. The freshly formed micro cracks can be sealed by a permanent hydration process in the concrete. In order to improve the pore structure in concrete, the bacterial concentration was optimized to obtain better results. At last, comparison of compressive strength and water absorption is presented.**

***IndexTerms*— bacterial concrete, micro cracks, compressive strength, water absorption**

I. INTRODUCTION

Cement concrete is the most commonly used concrete material in the construction field. This is used widely as the cost of construction using cement for manufacturing concrete structure is low. Concrete has an advantage of bearing high load, but the material is weak in tension [1]. Due to this, steel reinforcement is offered and the steel bars take over the load at the moment when the concrete cracks are in tension. The cracks in the concrete create a problem. Because of the reasons such as contraction, the low tensile strength of concrete, cracks take place during the process of concrete hardening, which decreases the building strength. Therefore, the case, when the water droplets enter into these cracks cause to reduce the strength of the steel bars. This will reduce the life of the concrete structure. To overcome this problem the material such as epoxies can be used, but, they are very expensive and require regular maintenance [2]. The use of the chemical is also harmful to the environment. Thus we need a material, which is environment as well as economic friendly, which is known as bacterial concrete material.

1.1 Bacterial Concrete

Bacteria are moderately simple, solitary celled organisms, which are divided into three groups, (i) on the basis of shape, (ii) gram stain and (iii) oxygen demand [3].

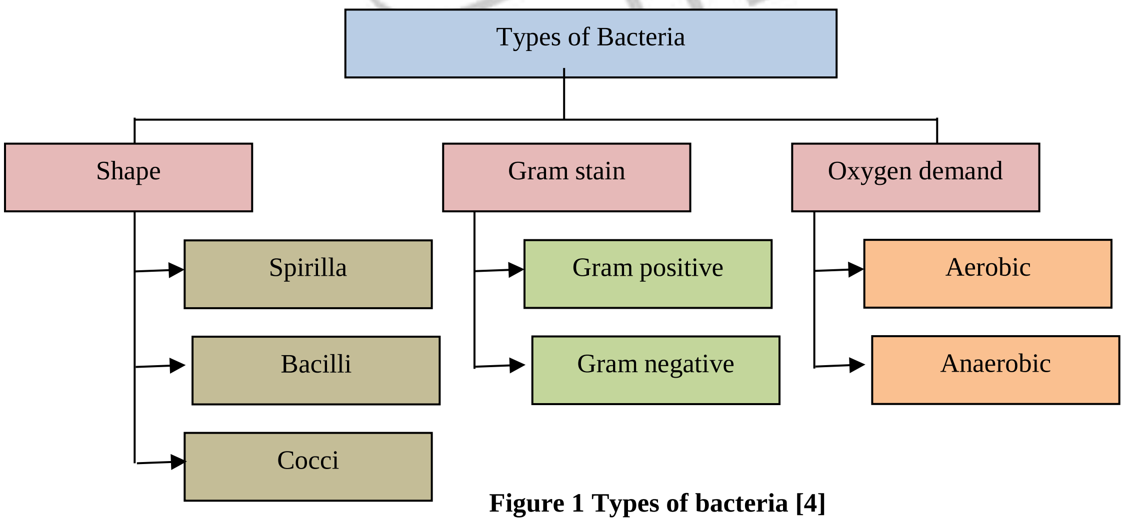

Figure 1 Types of bacteria [4]

Table 1: Types of bacteria

Bacteria type	Description
Based on shape	On the basis of shape and size, the bacteria can be further subdivided into three types named as Bacilli, Cocci and the spirilla. The Bacilli is in road shape, Cocci bacteria's shape is like a sphere and the spirillia shape is like a spiral.
Gram strain	It is also known as "Gram's method", which is used to classify bacterial species mainly into two classes such as positive and negative. This technique is developed by "Danish bacteriologist Hans Cristian Gram" and hence known as Gram stain bacterial technique. The bacteria are distinguished on the basis of physical and chemical properties of the cell walls.
Oxygen demand Bacteria	Microorganisms like bacteria are responsible for decaying organic waste such as dead plants, leaves, grass sewage or the food waste. When this waste organic material is present in the water, bacteria starts growing by breaking down the waste. The bacteria are growing by consuming the dissolved oxygen and robbing another water organism of the oxygen. The oxygen demand bacteria are further subclassified into two classes named Aerobic and Anaerobic.

1.2 Self-healing approach

Self-healing concrete is a bio-product that produces limestone to repairs cracks on the surface of concrete structures. Concrete is mixed to a specially selected bacterial genus, Bacillus, and calcium-based nutrients called calcium lactate and nitrogen and phosphorus to form the composition of the concrete [5]. These self-healing agents can remain in concrete at least for 200 years. However, when the concrete structure is damaged and the water enters into the cracks that appear in the concrete, the spores of the bacteria grow when they come into contact with water and nutrients. As the bacteria feed, oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. Limestone solidifies on the surface of the crack and sealing it [6]. Since oxygen is consumed by bacteria in the process, it can prevent the corrosion of embedded steel bars, thereby improving the durability of steel.

On the surface of cracked concrete, carbon dioxide (CO_2) come in contact with Calcium Hydroxide of the concrete and form Calcium Carbonate. The reaction form is written below:

$$CO_2 + Ca(OH)_2 \rightarrow CaCo_3 + H_2O \quad (1)$$

$CaCo_3$ is the soluble mineral, which dissolved in the presence of water and diffuse out of the crack in the form of leaching. The self-healing process of bacterial mixed concrete is more efficient, due to the active metabolism conversion of calcium nutrients by bacteria present in concrete [7].

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCo_3 + 5CO_2 + 5H_2O \quad (2)$$

Here, calcium carbonate is directly produced by the microbial metabolic process and is also produced indirectly due to the self healing process. This process produces an effective bacterial-based crack sealing mechanism [8].

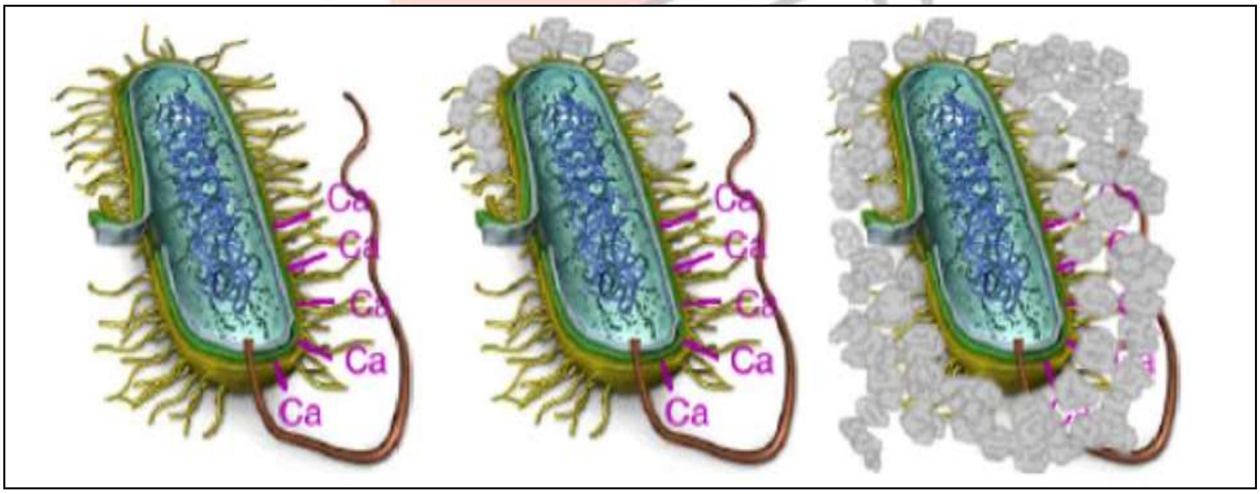

Figure 2 Calcium carbonate formation on bacterial cell wall [8]

A perfect self-healing system should sense damage or cracks, which can discharge the healing agent. Self-healing technology is a good way to repair microcracks in concrete. Self-healing technology shows good results for the healing of micro-cracks on the concrete surface. In addition, Bacteria create a permeable layer on concrete cracks. This is consistent with the precipitation of calcium carbonate[9].

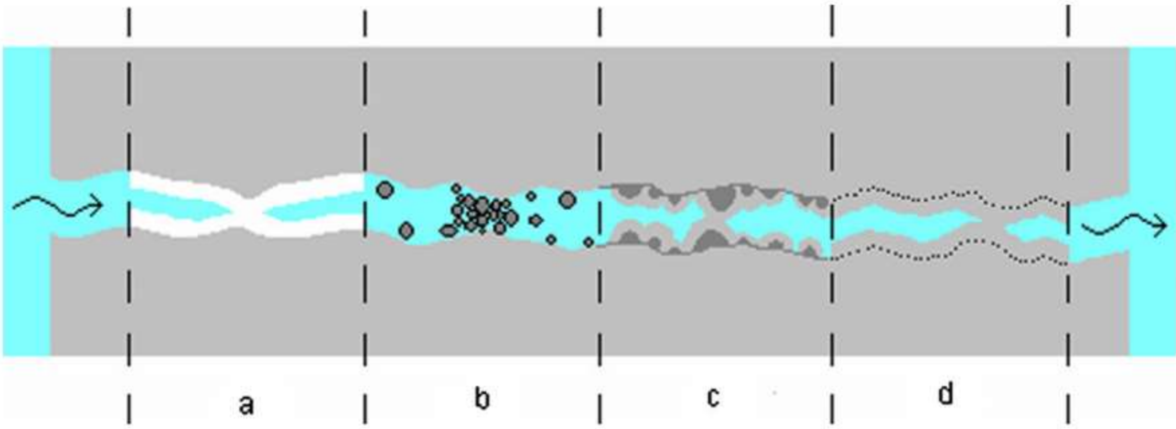

Figure 3 Possible self-healing mechanisms for cementitious materials [8]

The above figure represents the self- healing system, which utilized the cementitious materials in concrete. As shown in the figure above, 'a' slot represents the crack occur in concert. In slot 'b', bacteria are added to heal the crack. In slot 'c', the bacteria starts mixining into the concrete and in slot'd', the cracks are healed[10].

1.3 Method to apply the healing agent in concrete

The bacteria can be inserted into the concrete material either by direct application or by encapsulation scheme. The bacteria are added directly in the LWA (light weight aggregates) and GNP (Graphic nano platelets). GNP is a better carrier compound for bacteria and results in better crack healing [11]. The direct application healing agents are mostly used to determine the optimal concentration (30×10^5cfu/ml) of bacteria for strength purpose. In the encapsulating method, various encapsulating materials, such as glass tubes, ceramics tubes, lightweight aggregates and polymers have been used to form Self-healing effect in concrete. Polymer microcapsule is mostly used, as they are prepared by an oil-in-water dispersion mechanism of polymer materials, which is mainly based on Miniemulsion polymerization scheme [12].

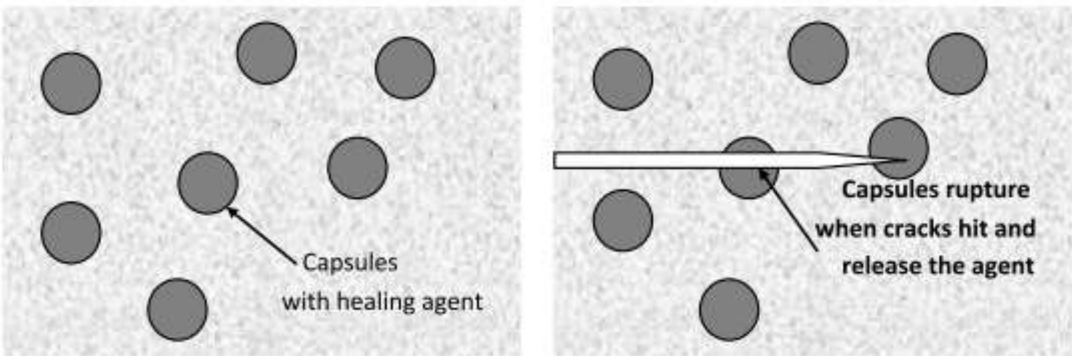

Figure 4 Schematic of capsule-based self-healing approach [13]

II. RELATED WORK

In this section, the comparative analysis performed by different authors in the field of bacterial concrete has been presented. The parameters such as compressive strength and water absorption are measured for 28 days.

Table 2 Comparative analysis of existing work

Reference	Bacteria type	Number of days	Compressive strength results	Water absorption results
[14]	Bacillus sphaericus	28	The concrete strength varies from 37% to 43%	Reduced up to 45 to 50 % when micro molecules are added
[15]	Bacillus pasteurii	28	Increased by 2 to 4 %	Less than 50 to 70 % of the controlled concrete sample
[16]	Bacillus subtilis	28	Increased by 12 to 17 % as compared to the controlled concrete sample	Approximately 50 % less than that of the controlled concrete sample
[17]	Bacillus magaterium	28	Increased by 24.2 % as compared to the controlled sample	46 % less than the controlled sample
[18]	Bacillus cohnii	28	Increase approximately 15 % as compared to the controlled concrete sample	Reduced by 35 % than that of controlled concrete sample

[19]	Bacillus flexus	28	Increased nearby 10 to 18 % than that of the controlled sample	Reduced nearly by 40 %
[20]	Bacillus cereus	28	Increased by 30 to 40 % as compared to the controlled concrete sample	Reduced approximately 50 % as compared to the controlled concrete sample

III. COMPARISON OF PREVIOUS APPROACHES

In this section, the comparison of compressive strength along with water absorption values measured by various authors in self-healing concrete is provided. The experiments are performed with and without a healing agent for 28 days.

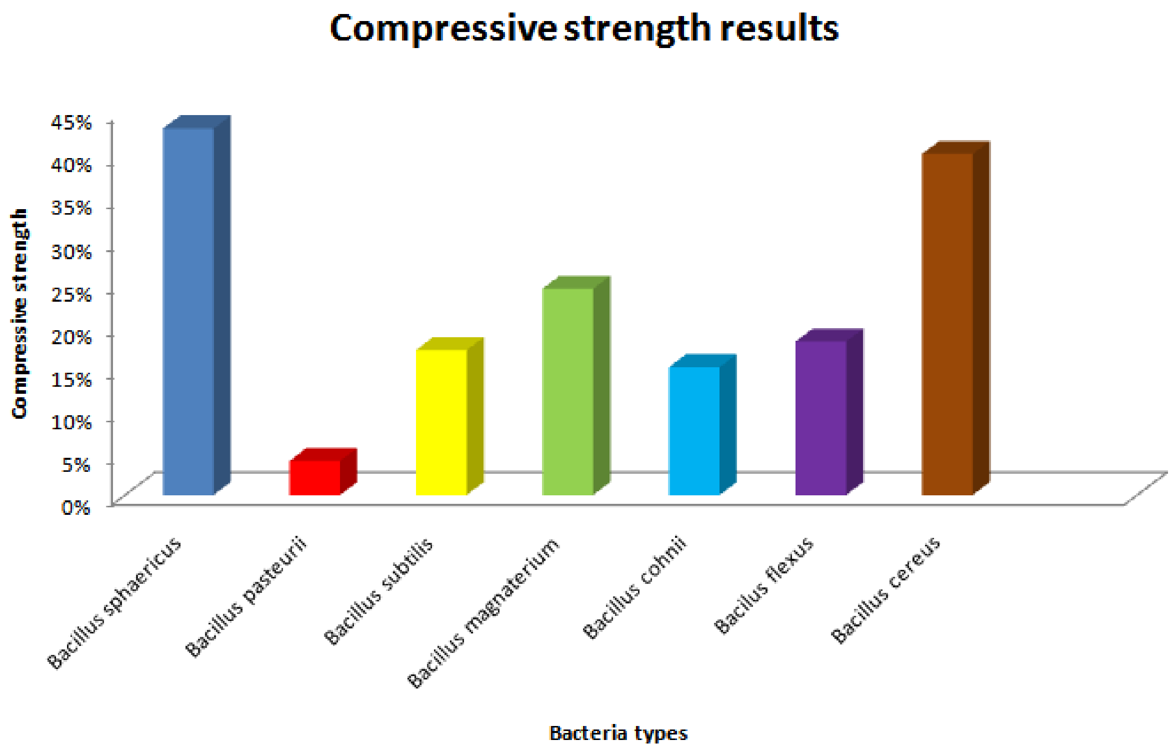

Figure 5 Comparison of compressive strength

The above figure represents the Compressive strength measured by different authors listed in table 2. Different authors perform the experiment on various self-healing agent named as Bacillus sphaericus, Bacillus pasteurii, Bacillus subtilis, Bacillus magaterium, Bacillus cohnii, Baciillus flexus, and Bacillus cereus. From the above figure, we analyzed that when Bacillus sphaericus material is added into the concrete the compressive strength is increased upto 45 % of the controlled concrete sample. Bacillus pasteurii material provides less compressive strength as compared to other materials listed in the figure above.

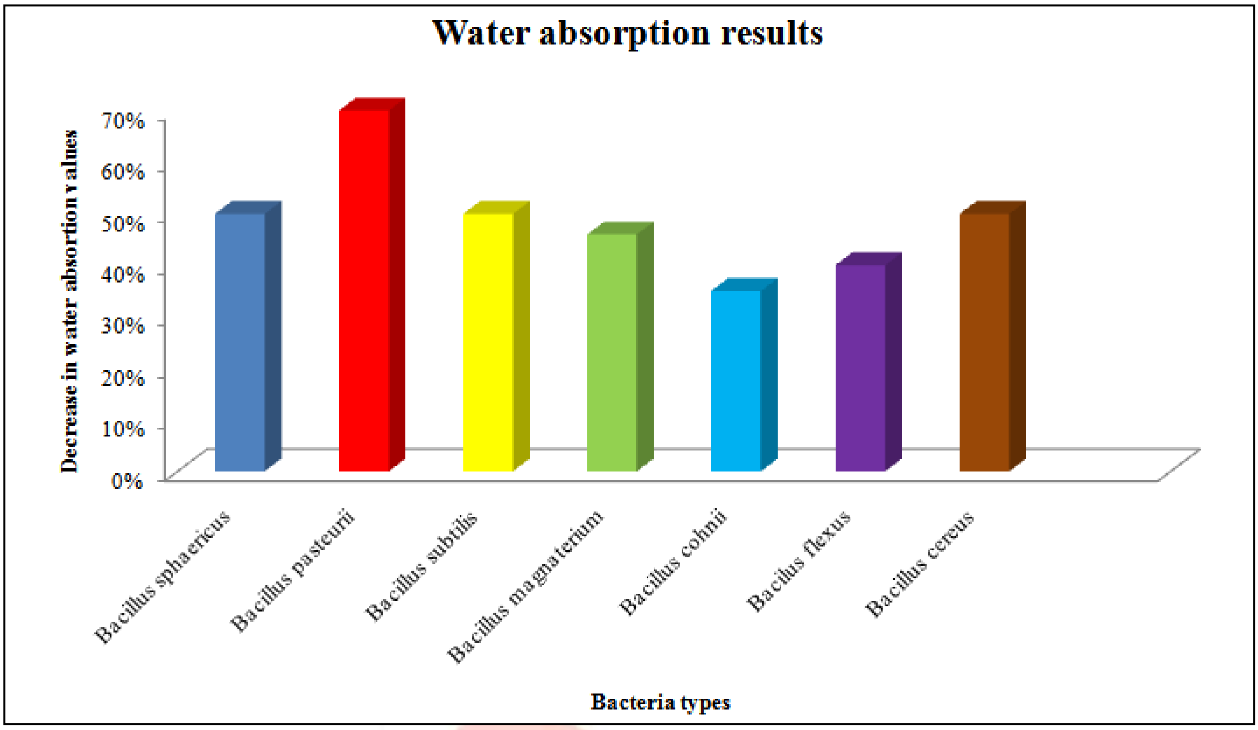

Figure 6 Comparison of water absorption values

The above fig. 6 represents the values of percentage decrease in water absorption values with respect to the different types of bacteria. The x-axis represents the bacteria types whereas the y-axis represents the decrease in water absorption values. From the above figure, it is concluded that Bacillus pasteurii material absorbs less water than that of other materials when added to concrete.

IV. CONCLUSION

At present, the design of bacterial concrete is the most popular research topic for researchers. Till now, it has been found that the use of bacterial concrete can enhance durability, mechanical properties and Infiltration of concrete. According to previous research, it has been discovered that the maximum compressive strength is obtained by adding Bacillus cereus into the concrete. The maximum reduction in water absorption has been obtained for Bacillus pasteurii material which is reduced up to 75 %. According to previous work in the field of bacterial concrete, some bacteria are not good for human health, but some bacteria are good for human health. The bacteria such as bacillus Sphaericus, bacillus pasteurii, bacillus subtilis, and bacillus flexus do not have any adverse effects on human health, and also shows higher calcite precipitation ability that makes these bacteria as ideal bacteria for bacterial concrete design. Also, it is concluded that the life of bacterial concrete is more than that of conventional concrete.

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