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A Review of Self-Healing Concrete Using Bacillus Bacteria as Healing Agent on Compressive Strength of Concrete

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Abstract: Bio concrete or bio influenced self-healing concrete is a product which has the ability to heal concrete by producing chemical reaction from intentionally mixing the micro-organism into the concrete. When cracks are produced, water seeps into the cracks and activates the present dormant micro-organism. These micro-organisms later produce mineral that will fill the cracks. The main objective of this study is to investigate the effect of bacteria as a self-healing agent on concrete and to identify the most factors effect self-healing in bio-concrete using bacteria through case study. In this study, the systematic review used to evaluate the effect of bacteria in concrete structure as self-healing agent. It undergoes a few processes to get the suitable article to use for this study. The article has been chosen based on the year and published type which are in timeline of 2017-2021 and review and research article published. From previous study, the method used is Compressive Strength Test to confirmed that bacteria have ability to precipitate calcium carbonate. From this study, it helps to identify the effect of bacteria on concrete as self-healing agent.

Keywords: Concrete, Self-healing, Bacteria

1. Introduction

Self-healing concrete is a type of concrete that can fix cracks on its own, without the need for external help [1]. Because of its high performance and inexpensive cost, concrete is a commonly utilized material [2]. Despite the fact that the amounts of cement, water, aggregates, chemical additives, and mineral additives can vary within a wide range, concrete is known for its brittleness, low tensile strength, poor deformation performance, and a variety of breaking behaviours [2]. The small cracks that are formed on the concrete leads to decrease in strength and durability [3].

Carbon dioxide emissions from the vast amount of cement used, as well as cracks, particularly micro cracks, are two main issues with concrete structures [4]. In general, micro cracks in concrete operate as an open portal for water, air, and other harmful substances. This reduces the concrete's

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strength, weight carrying capacity, and durability, making it more susceptible to corrosion. If these cracks are not repaired within the specified time, the structure's operation may come to a halt, leading to collapse.

Concrete's self-healing ability can be triggered by putting bio agents (bacteria) into the mix. Generally, bacteria are incorporated in dormant form which stays inactive until cracks are produced allowing water penetration in the concrete. Bacteria become active when come in contact with water and calcium carbonate is produced as the result of metabolic action of bacteria on calcium lactate and seals the crack [5], restricting the water penetration in concrete hence increasing durability of concrete.

This project aim is to identify the behavior of a mix concrete with the presence of bacteria by making a review with other research and focusing on their compressive strength. Most bacteria-based self-healing concrete systems require spores to be immobilised and separated from any germination triggers before being put to concrete, which is commonly done through encapsulation [6].

2. Bio

There have been trends in the invention of innovative materials capable of actively interacting with external elements in recent years, due to the constant improvement of present materials that is a result of a unique mix of features. The material was enhanced to increase the system's service life as a result of technological advancements. Concrete has a built-in recovery mechanism that is triggered by ongoing physical, chemical, and mechanical activities. According to Seifan et al. [7], bio-concrete is one of the upgraded materials to improve strength and life span, and it has attracted a lot of interest as a material that has the potential to alter building construction. The calcite promoting spore forming microscopic organisms is forced into concrete in this way. When moisture enters the crack with the additional microbe, the structure encourages calcium carbonate formation, allowing the surface to split away [8].

The most important goal for most civil engineering researchers has been the development of self-healing concrete technology. The natural phenomena of species such as trees and animals inspired the concept of bio-concrete [9]. Natural self-healing concrete, biological self-healing concrete, and chemical self-healing concrete are three forms of self-healing concrete that should be learned. While employing microorganisms can have certain benefits, such as greater durability and high tension, it can also be destructive to humanity's psychological and physical well-being [10].

According to Wiktor & Jonkers [11], self-healing aggregates can be utilised to replace a tiny amount of traditional concrete aggregate enclosed in a porous clay particle that acts as a reservoir. Keyvanfar et al. [10], discovered that a self-healing substance containing bacterial spores and calcium lactate causes bacterial-induced calcium carbonate synthesis, which seals microcracks up to 0.46 mm in diameter. This finding demonstrates that a bio-chemical self-healing ingredient can improve concrete's wet weather durability. The bacterial cement helps cementitious materials last longer by repairing solid fractures and forming extremely strong breaks.

3. Methods

A systematic review requires a comprehensive and logical overview of the results and available publications on a specific subject or clinical issue. The Preferred Reporting Items for Systematic Reviews (PRISMA) standards were used to conduct this systematic review. It is systematically explored articles and grey literature from international databases. Several databases, including Research gate, Google Scholar and ScienceDirect, were systematically investigated. The keywords were selected based on the topic which is the effect of bacillus bacteria on concrete as self-healing agent

The first step included identification based on the database using a Boolean operator to combine the terms which are "concrete" AND "self-healing" AND "bacteria". The result shows that the total articles obtained based on these keywords were 645. In the next step, the article has been chosen based on the year and published type (2017-2021). Next, the extracted articles were screened again based on the related title, which is 67 in total. The full article chosen is 34 and finally, number of case studies used in this review article were 15.

4. Results and Discussion

The results after the finished study were conducted based on previous research related to the effect of *Bacillus Bacteria* on the concrete as a self-healing agent, representing all the data obtained from the selected article. The result includes the factor that affects bacteria reaction toward the concrete.

3.1 Analyzation of self-healing on bio concrete

Durga et al.[12] investigated the healing rate's performance in bacterial concrete. At a water-cement ratio of 0.41 percent, *Bacillus subtilis* is introduced to the concrete mix in liquid form with a cell concentration of 10^8 cells/ml. When compared to control samples, bacterial mix samples have a compressive strength enhancement of 64.25 MPa. Following 28 days of curing after cracking, bio concrete specimens restored up to 22% of their compressive strength.

Bacillus Sphaericus and *Bacillus Pasteurii* were used by Jagannathan et al. [13] to induce self-healing in the concrete matrix, and the selected bacteria were cultured. They were kept at 4°C for 15 days on nutrient agar slants before being subcultured in a filter-sterilized medium. The M20 concrete mix was used, with a water-cement ratio of 0.46, and fly ash was added at 10%, 20%, and 30% of the cement weight, respectively. After 28 days, mechanical measures such as compressive strength have improved by 10.8% when compared to control and Bacillus Pasteurii.

Nain et al. [14] investigated the strength of concrete, *Bacillus subtilis* and Bacillus *megaterium* are added to the concrete, by replacing 100 ml bacterial solution with 1000 ml of water. M30 concrete was used to create the samples. After 7 days, the compressive strength of bacillus subtilis samples was 31.93 MPa, and after 28 days, it was 43.55 MPa. Compressive strengths increased by 22.5 percent, 14.3%, and 15.8%, respectively.

B. M. S. Reddy, Madhu Sudana Reddy, and Revathi [15] employed M20 grade concrete with a water to cement ratio of 0.52 percent in all of their mixes, with varying cell concentrations (10^0,10^3,10^5,10^7, respectively) and compressive strengths of 28Mpa, 33Mpa, 36Mpa, and 32Mpa. At a cell concentration of 10^5 cells/ml, the best results were obtained.

To investigate the self-healing time and mechanical qualities of concrete, Safiuddin et al. [16] utilised Bacillus Subtilis and Escherichia Coli in their experiment. Different amounts of bacteria were cast in various mixes. The bacteria were mixed individually in percentages of 2%, 3%, 4%, and 6% by weight of cement, and then combined at 50% to produce a total of 2% and 3% mixed bacteria by weight of cement. Bacillus Subtilis-2 percent, Bacillus Subtilis-3 percent, and Bacillus Subtilis-4 percent repaired the cracks in 48 hours, 32 hours, and 72 hours, respectively. After 72 hours, other bacteria mix variants (6% Bacillus Subtilis, all percentages of Escherichia Coli, and mix bacteria) did not recover appreciably.

Joshi [17] study on the compressive strength and self-healing property of bio-concrete using *Bacillus subtilis* as bacteria. In this study, different bacterial cell percentages of 2.5 percent, 5 percent, and 10% are used to make M20, M25, and M30 grade concrete. It was discovered that replacing 5% of the water in concrete with *Bacillus subtilis* bacteria resulted in the greatest improvement in compressive strength, which ranged from 11% to 22% for different concrete classes. As a result, when 10% of the water in concrete is replaced with *Bacillus subtilis* bacteria, the compressive strength of the concrete drops by up to 18%, since the cement does not receive enough water for hydration, resulting in a loss of compressive strength.

According to another researchers, Pourfallahi et al. [18] two types of cement were used for Darab city: Portland pozzolanic cement (PPC) and Portland cement type 2 (PC2) for Hormozgan-Bandar Khamir. *Bacillus paralicheneniformis* was found in bacterial samples collected from PPC concrete with certainty, however *Bacillus sphaericus* was found only in bacterial samples acquired from PC2. The compressive strength of bacterial concrete with PPC was 1.94 percent greater than the control sample, while the compressive strength of bacterial concrete with cement PC2 was 5.65 percent lower.

3.2 Discussions

Based on the analysis data on the effect of bacteria on concrete creates by the previous researcher, it could be concluded that the role of bacteria has a positive impact on the construction industry. The self-healing of concrete happened when the bacteria with nutrients were added together with the concrete mix. The water and oxygen will find their way in when a crack occurs. The dormant bacteria will germinate with enough water and oxygen, and the precipitated calcium carbonate will heal the crack on concrete. *Bacillus* bacteria have been employed extensively by earlier researchers, demonstrating their ability to resist high alkalinity in concrete media. These investigations further demonstrate that after being stimulated by water, *Bacillus* bacteria can precipitate $CaCO_3$ to cover the cracks.

Based on experimental done by Nain et al. [14], they two different type of bacillus bacteria with the same concentration and same curing condition yet produced different value of compressive strength. This prove that the bacteria have their own characterization, where they produce calcium carbonated on different paced with other bacteria even if in same condition. The effectiveness of sealing is determined not only by the type of bacteria used, but also by the volume of bacteria and nutrients injected to the concrete. Although the amount of bacteria spore mixed into the concrete may speed up the crack-sealing process, nutrients are required to form $CaCO_3$ after the spore is activated by water. The compressive strength value is also affected by the water cement ration in a specimen Joshi [17] replace water in the concrete with bacteria subtilis and the result noted that with the decreasing amount of water present in concrete the ability of bacteria to produce calcium carbonated are limited. Table 1 summaries prior research on self-healing concrete done by a few researchers.

5. Conclusion

Many previous studies on self-healing concrete have found that the initial cost is high. The self-healing properties of concrete induced by the addition of bacteria can lower the structure's maintenance costs. The ability of concrete to self-heal can extend the life of constructions. The technology of concrete self-healing is still in its early stages. Future studies should aim at the healing efficiency through variety sizes of crack and different type of curing media other than tap water. According to the literature review, the factors that affect self-healing in bio-concrete using bacteria are the type of bacillus bacteria, the concentration of bacteria and amount of water presence in concrete.

Table 1 Comparison of element used on each article

Author reference	Bacteria	Cell concentration	Curing method	Compressive Strength	
				7 days	28 days
[15]	*Bacillus Sphaericus*	10^0 cells/ml	Normal tap water	24 MPa	28 MPa
		10^3 cells/ml		26 Mpa	32 MPa
		10^5 cells/ml		28 MPa	35 MPa
		10^7 cells/ml		27 MPa	33 MPa
[13]	*Bacillus Sphaericus*	0% fly ash + *bacillus sphaericus*	Not stated		
		10% fly ash + *bacillus sphaericus*			32.5 MPa
		20% fly ash + *bacillus sphaericus*			23.55 MPa
		30% fly ash + *bacillus sphaericus*			22.45 MPa
[1]	*Bacilus Megaterium*	10^5 cells/ml	Normal tap water	18.81 N/mm2	47.88 N/mm2
[14]	*Bacilus Megaterium*	10^8 cells/ml	Bacterial solution	27.6 MPa	46.68 MPa
	Bacilus Subtilis	10^8 cells/ml	Bacterial Solution	31.93 MPa	43.55 MPa
[12]	*Bacilus Subtilis*	10^8 cells/ml with w/c ratio 0.41%	Not stated	40 MPa	64.25 MPa
[16]	*Bacilus Subtilis*	2%, by weight of cement	Normal tap water	23.21 MPa	33.23 MPa
		3%, by weight of cement		26.19 MPa	35.15 MPa
	Escherichia Coli	2% by weight of cement		33.86 MPa	43.48 MPa
		3% by weight of cement		34.2 MPa	45.12 MPa
	Mix Bacteria (*B.Subtilis* + *E.Coli*)	2% by weight of cement		13.36 MPa	18.86 MPa
		3% by weight of cement		12.88 MPa	19.32 MPa

Table 1 (continued)

Author reference	Bacteria	Cell concentration	Curing method	Compressive Strength	
				7 days	28 days
[13]	*Bacillus Pasteurii*	0% fly ash + *bacillus sphaericus*	Not stated		
		10% fly ash + *bacillus pasteurii*			26.45 MPa
		20% fly ash + *bacillus pasteurii*			21.25 MPa
		30% fly ash + *bacillus pasteurii*			20.39 MPa
[17]	*Bacillus Subtilis*	0% replace water	Normal Tap Water		21.2 MPa (M20)
					28.6 MPa (M25)
					31.2 MPa (M30)
		2.5% replace water			22.26 MPa (M20)
					31.46 MPa (M25)
					33.36 MPa (M30)
		5% replace water			23.54 MPa (M20)
					34.9 MPa (M25)
					36.53 MPa (M30)
		10% replace water			18.02 MPa (M20)
					24.6 MPa (M25)
					26.52 MPa (M30)
[18]	*Bacillus Sphaericus*	5% by the weight of cement	Normal tap water	18.3 N/mm^2	30.94 N/mm2
[19]	*Bacillus Subtilis*	10^5 cells/ml	Normal tap water		27.5 N/mm^2

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