AN EXPERIMENTAL STUDY ON SELF HEALING OF CONCRETE USING BACILLUS SUBTILIS IN CULTURED FORM

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Abstract: This paper presents an experimental study on the compressive strength and self-healing property of bio-concrete using Bacillus subtilis as bacteria. Concrete is the most widely used construction material and strength and durability of concrete is mainly affected due to the formation of cracks. Micro cracks are the main cause for structural failure since they lead to durability problems, while larger cracks affect structural integrity. Water ingress and chemicals in micro-cracks cause the degradation of embedded steel. In order to overcome this, an attempt is made in the form of Bacterial concrete with non-pathogenic, spore forming, calcite mineral precipitating bacteria "Bacillius subtilis". In this paper M20, M25 and M30 grade of concrete is prepared with different bacterial cell percentage of 2.5%, 5% and 10%. The overall development of strength and durability of self-healing concrete using Bacillius subtilis has been investigated and compared with control concrete. It was observed that the optimum strength is obtained at 5% of bacterial cells concentration, which increases the compressive strength in between 11% to 23%. It was also noticed that after hairline fracture was introduced through Compression Testing Machine, the concrete cubes were able to regain 65% to 70% of their original strength within 30 to 40 days of self-healing. The percentage of increment in strength clearly shows that the self-healing concrete is advantageous.

***Index Terms* – Self-healing, bio-concrete, micro cracks, bacteria, Bacillus subtilis.**

I. Introduction

Concrete is the most common material used for all types of construction. Due to its strength and durability, concrete became inevitable. The only defect in the use of concrete is that it is weak in tension. Since the concrete is weak in tension the possibility of formation of cracks is more. Apart from this, freeze–thaw action and shrinkage also leads to cracking in concrete. Durability of concrete is highly affected due to these cracks and it leads to corrosion of reinforcing bars. So it is very essential to find the suitable repair mechanism for regaining the strength of concrete .In concrete structure, repair of cracks usually involves applying a cement slurry or mortar which is bonded to the damaged surface. Repairs can particularly be time consuming and expensive. For crack repair, a variety of techniques are available like impregnation of cracks with epoxy based fillers.

Self-healing materials are artificial or synthetically-created substances that have the built-in ability to automatically repair damage to themselves without any external diagnosis of the problem or human intervention. Generally, materials will degrade over time due to fatigue, environmental conditions, or damage incurred during operation. Cracks and other types of damage on a microscopic level have been shown to change thermal, electrical, and acoustical properties of materials, and the propagation of cracks can lead to eventual failure of the material. In general, cracks are hard to detect at an early stage, and manual intervention is required for periodic inspections and repairs. Tiny cracks in concrete do not necessarily affect structural integrity in short term, but they do allow water and other chemicals to seep into the structure, which may cause problems over time. Self-healing concrete has embedded clay particles that contain dormant bacteria and a food source. When a crack appears in the concrete, water seeps in and activates the bacteria. When they wake, the bacteria eat their packed lunch and then conveniently excrete chalk, which fills the crack.

In many civil engineering structures tensile forces can lead to cracks and these can occur relatively soon after the structure is built. Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height.

II. Literature Review

In the past few decades' considerable emphasis has been given to the problem of cracks occurring on concrete structures. The several research works related to self-healing on structures are reviewed and presented in this paper.

Breugel (2012) studied on self-healing material concepts as solution for aging infrastructures. The comparison between bacterial and control specimens was performed and it revealed a significant difference in permeability of concrete.

Pelletier et al (2013) developed a self-healing concrete that was inexpensive to produce by creating a concrete matrix that was embedded with a micro-encapsulated sodium silicate healing agent. When cracks were formed in the concrete, the capsules ruptured and released the agent into the adjacent area. It was found that the sodium silicate reacted with the calcium hydroxide already present in the concrete, and formed a calcium-silica-hydrate gel that healed the cracks and blocked the concrete's pores. When Pelletier's concrete was stress-tested to the point of almost breaking; it proceeded to recover 26% of its original strength. By contrast, conventional concrete only recovers 10%. Pelletier believes that she could boost the strength of her mix even higher, by increasing the quantity of the healing agent.

Meera & Subha (2016) studied on the strength and durability assessment of bacteria based self-healing concrete using Bacillus subtilis bacteria. It was found that the bacteria based self-healing process healed cracks completely up to 0.5 mm width. On the surface of control concrete, calcium carbonate forms due to the reaction of CO_2 present with Calcium Hydroxide in the concrete matrix according to the following reaction: $CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$. As $Ca(OH)_2$ is a soluble mineral, it gets dissolved in water and diffuses out of the crack in the form of leaching.

Jadhav et al (2016) studied on bio concrete and found that bio concrete is the science of precipitation of minerals by living organisms. Bacteria have a remarkable ability to precipitate calcite, carbonate, phosphate, oxides and sulphite. In bio concrete Bacterial species like, B. Sphaericus, Proteus, Vulgarious, etc,.deposit calcium carbonate by their bacterial activity in this system. Presence of layer of Calcium precipitation improves the strength and durability of concrete. It was observed that inducing bacteria along with precursor compound heals crack by calcite precipitation, which increases the compressive strength and durability of structure.

Monishaa & Nishanthi (2017) studied on the strength of self-healing concrete and concluded that the strength and durability of concrete is mainly affected due to the formation of cracks. M20 grade concrete was prepared with different bacterial cell concentration of 104, 105 and 106 cells/ mL of water and polyethylene fiber kept at constant as 0.4%. The overall development of strength and durability of self-healing concrete using Bacillus subtillis and polyethylene fiber were investigated and compared with control concrete.

III. MATERIALS USED

The physical properties of cement, fine aggregates, coarse aggregates, bacillus subtilis and water used for mix design of M20, M25 and M30 grade of concrete were tested in laboratory and are mentioned below.

3.1Cement

Portland Pozzolana Cement confirming to IS 1489 (Part 1): 1991 was used in the present study. The properties of PPC were investigated through various experiments performed in the laboratory and are listed below in Table 1.

Table 1: Physical properties of Portland pozzolona cement

S. No.	Properties	Results
1.	Unit weight (gm/cc)	1.18
2.	Specific Gravity	2.78
3.	Normal Consistency	37%
4.	Initial setting time	59 min.
5.	Final setting time	297 min.
6.	Soundness	1 mm
7.	Fineness	4%

3.2 Aggregates

In this study, limestone aggregates of maximum nominal size 10 mm were used with fineness modulus of 5.99. The properties of aggregates evaluated through various lab experiments are listed below in Table 2.

Table 2: Physical Properties of Aggregates

Aggregates	Properties			
	Fineness Modulus	Unit weight (gm/cc)	Specific Gravity	Water Absorption
C.A. (10)	5.99	1.54	2.83	0.55%
Sand	2.63	1.68	2.66	1.32%

3.3 Bacillus Subtilis

Bacillus subtilis, also known as the hay bacillus or grass bacillus, is a Gram-positive bacterium, found in soil and the gastrointestinal tract of ruminants and humans. Bacillus subtilis is rod-shaped, and can form a tough, protective endospore, allowing it to tolerate extreme environmental conditions. It is historically classified as an obligate aerobe, though evidence exists that it is a facultative anaerobe. B. subtilis is also considered the best studied Gram-positive bacterium and a model organism to study bacterial chromosome replication and cell differentiation. It is one of the bacterial champions in secreted enzyme production and used on an industrial scale by biotechnology companies.

3.3.1 Calcium Carbonate

Calcium carbonate ($CaCO_3$) is one of the most naturally precipitated minerals on earth in the form of natural rocks and exists in environments such as marine water, fresh water, and soils. The variability of the concentration in the solubility of the calcium or carbonate in solution causes the natural precipitation of $CaCO_3$. Even a biotic change or biotic action (microbial action) results in the natural precipitation of $CaCO_3$. Stocks Fischer et al (1999) have found that this microbial rate of precipitation of $CaCO_3$ is significantly faster than that of chemical precipitation. Hammes and Verstraete (2002) suggested that the chemical $CaCO_3$ precipitation is controlled by the calcium ions concentration, carbonate concentration, pH and presence of nucleation sites.

3.4 Water

Fresh tap potable water was used for the preparation of test samples as well as for the curing of the test specimens.

IV. METHODOLOGY

The aim of the present study was to study the effect of Bacillus subtilis on compressive strength of concrete by partial replacement of water with 0%, 2.5%, 5% and 10% of B. subtilis in cultured form.The concrete mix of M20, M25 and M30 grade was prepared as per IS10262:2009 having mix ratio as 1:1.5:3, 1:1:2 and 1:1:3 respectively with w/c ratio of 0.55, 0.45 and 0.40. To carry out the experimental investigation total 36 cubes of size 150mm x 150mm x 150mm were casted. 9 cubes were casted to determine the compressive strength of normal concrete with no bacteria. Similarly, each set of 9 cubes were casted to determine the compressive strength for 2.5%, 5% and 10% replacement of water with bacillus subtilis respectively. From these 9 cubes, each set of 3 cubes were utilized to determine the compressive strength of concrete after 7 days,14 days and 28 days of curing as shown in Fig. 1. Compression Testing Machine of 2000kN capacity as shown in Fig. 2 was used to determine the total compressive load taken by concrete at different ages. This ultimate load divided by the cross-sectional area of the cube (150mm x 150mm x 150mm) yields the compressive strength of concrete.

Figure 1: Curing of specimen

Figure 2: Compressive testing machine

The cube mould for each grade of concrete and containing different percentages of bacteria was loaded through Compression Testing Machine until the hairline fracture as shown in Fig. 3 was obtained on the surface of the concrete. The cube was further covered with moisture content jute bag for 30 to 40 days at room temperature for self-healing. After a span of 30-40 days, when the self-healing of the concrete was over, the compressive strength of concrete was further obtained through Compression Testing Machine. The concrete cube after self-healing is shown in Fig. 4.

Figure 3: Concrete cube after hairline fracture

Figure 4: Concrete cube after self-healing

The proportioning of materials for different grade of concrete without using bacteria is shown below in Table 3.

Table 3: Material proportions for different mix without using bacteria

Grade	Proportions			
	w/c ratio	Water (kg/m^3)	Cement (kg/m^3)	C.A. 10 (kg/m^3)
M20	0.55	7.425	13.5	40.5
M25	0.45	8.361	18.58	37.16
M30	0.40	9.144	22.86	34.30

V. Results and Discussion

Each set of 3 cubes of M20, M25 and M30 grade of concrete were tested in Compression Testing Machine with 0%, 2.5%, 5% and 10% replacement of water with bacillus subtilis bacteria to determine the compressive strength after 7, 14 and 28 days of curing. It was observed that the optimum increase in compressive strength of concrete occurred when 5% of water is replaced with B. subtilis bacteria and it ranged in between 11% to 22% for different grades of concrete. Hence, when we replace 10% of water with B. subtilis bacteria, the decrease in compressive strength of concrete upto 18% is observed, since the cement does not get sufficient amount of water for hydration which leads to the loss in compressive strength of concrete.

The compressive strength of concrete for different percentages of Bacillus subtilis in self-healing concrete is tabulated in Table 4 and shown in Fig. 5.

Table 4: Compressive strength of different grades of concrete for different percentage of B. subtilis

Mixes	Nominal Concrete (N/mm^2)	SHC 2.5% (N/mm^2)	SHC 5.0% (N/mm^2)	SHC 10.0% (N/mm^2)
M20	21.20	22.26	23.54	18.02
M25	28.60	31.46	34.90	24.60
M30	31.20	33.36	36.53	26.52

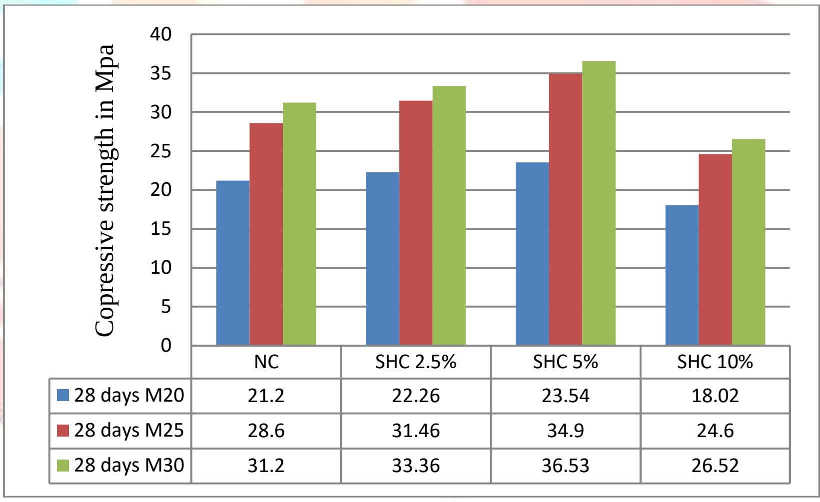

Figure 5: Compressive strength of concrete for different percentage of B. subtilis in self-healing concrete

Further, the load was applied on the concrete cubes with different bacterial cell concentration through Compression Testing Machine until a hairline fracture was obtained and then it was allowed to self heal for 30-40 days. It was observed that the concrete cubes were able to regain 65%-70% of their original strength after 30-40 days of self healing.

VI. Conclusions

In the present study, Bacillus subtilis was used as the bacteria for producing self-healing concrete. The experimental work was carried out for M20, M25 and M30 grades of concrete by replacement of water with 2.5%, 5% and 10% of Bacillus subtilis in cultured form and the following results were obtained.

1. The compressive strength of concrete increases when up to 5% of water is replaced with B. subtilis, but when 10% of water content is replaced with the bacteria then there is significant decrease in compressive strength of concrete.
2. The optimum increment in the compressive strength of concrete after 28 days of curing was found to be 11%, 22% and 17% for M20, M25 and M30 grades of concrete respectively on 5% replacement of water with B. subtilis.
3. For M20 grade of concrete, the increment of 5% and 11% and decrement of 12% in compressive strength of concrete was found on partial replacement of 2.5%, 5% and 10% of water with B. subtilis bacteria.
4. The main reason behind the fall in strength of concrete when 10% of water was replaced with bacteria is that the cement does not get the required amount of water for hydration, which leads to the decrease in compressive strength of concrete.

5. During self-healing process, when the cracks in bio-concrete come in contact of moisture and air, the bacteria feeds on the calcium lactate, joining the calcium with carbonate to form limestone, and hence fixing the crack.
6. It was also observed that the concrete cubes were able to regain 65% to 70% of their original strength within 30 to 40 days of self-healing.

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