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A Biological Approach On The Study Of Bacteria Based Concrete.

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ABSTRACT

Concrete used in the construction industry is sensitive to crack formation under tensile stresses which makes it ineffective and vulnerable to degradation when water and other contaminants enter into the concrete matrix through these cracks. This leads to the corrosion of steel reinforcement which ultimately makes the composite weak. The use of self- healing materials is an emerging ingenious method to improve the durability of concrete. The process of self-healing in concrete induced by microbial action is one of the evolving techniques being used in the construction industry. Therefore, this paper focuses on study of application of bacteria for the self-healing process in concrete and its improvement in strength and efficiency of concrete as a whole. The results collected from various works of literature has been used to compare.
Keywords: Self-healing concrete, bacteria, compressive strength, calcium, autonomous/engineered healing

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INTRODUCTION

Concrete is being a quasi-brittle material is susceptible to crack formation under tensile and shear stresses. This inherent brittle nature of concrete is the reason for the use of steel reinforcement in the tension cross-section which sustains the tensile loads. Concrete cracks are important to consider as it triggers the corrosion of the reinforcement within. If the cracks are within the prescribed limit, such crack openings may not lead to total collapse of the structure although it may lead to exposure of the reinforcement which leads to the degradation. Besides macrocracks, microcracks are imminent to normal concrete as it makes the concrete permeable and the reinforcement may be exposed to air. In case of a network of continuous cracks, it becomes easy for the deleterious materials to enter into the concrete and damage the reinforcement. Even though the concrete has a life span of over 50 years the cracks degrades its strength making it vulnerable to failure [1]. Repairing these cracks needs huge capital investment and time-consuming. Therefore, an effective method which will reduce the time and labor is much needed which led to the development of the use of self- healing materials in concrete.

Self-healing is a new innovative technology being improved which mimics nature's way of healing. Healing in biological tissues follows three steps: inflammatory response, cell proliferation, and tissue remodeling. The self- healing materials are designed to follow the same process to perform self- repair and self-recovery with pre-engineered properties when it is assigned in the cementitious materials. The self- healing materials act in three steps namely: actuation by triggering actions, transport of healing agents into fracture zone and chemical repair and the damage in the parent material triggers the healing process. Therefore, when concrete cracks, the self- healing materials are triggered which heals the cracks right on time [1].

Concrete self-healing is categorized into two based on the process of healing technique and the materials used. They are the intrinsic autogenous healing and the engineered/ autonomous healing. Autogenous healing is triggered without the need for any external operation but, autonomous healing is developed by adding the required engineering materials [2]. The process of autogenous healing can either be by encapsulation or by vascular system wherein the healing materials used are polymers, bacteria and chemicals. This study focuses on the biological approach of making the concrete to self-heal using bacteria.

BACTERIAL APPROACH TO SELF-HEALING CONCRETE

The application of bacteria in concrete habitat is becoming common with the need for development of cost-effective method for healing of cracks [3]. Although concrete's alkaline environment may seem hostile, bacteria seems to thrive inside rocks even at a depth of more than one km in earth crust and also in deserts [4-9]. These bacteria from spores are specialized cells has the ability to resist high mechanical and chemical stresses [10]. The spores are characterized by a low metabolism and extreme long life up to 200 years [11]. The use of bacteria had been recognized in the recent studies from surface cleaning of concrete surfaces to improvement of mortar compressive strength [12-13]. Also, bacteria have been used for treatment of degraded limestone, and also durability of concrete. with the help of bacterially controlled precipitation of dense calcium carbonate layers, crack- sealing has become significant. In the process of repair and redemption using bacteria and compounds, mineral precipitation is not triggered and were initially integrated as healing agents inside the concrete matrix. Once the crack forms, the mechanism of bacterially mediated calcite precipitation occurs which is based on the enzymatic hydrolysis of urea. The induced precipitation involves the decomposition of urea by the bacteria which its enzymes hydrolyses urea into ammonium and carbonate [14]. In the primary stage, one mole of urea is hydrolysed to one mole of ammonia and one mole of carbamate and the carbamate formed is immediately hydrolyzed which results in one mole of ammonia and one mole of carbonic acid [15].

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3$$
$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3$$

The products evolved as a result of hydrolyzation by the bacteria, further equilibrate in water to form bicarbonate, two moles of ammonium and two moles of hydroxide ions [16]. As the pH level increases, the bicarbonate equilibrium gets shifted.

$$H_2CO_3 \rightarrow HCO_3{}^- + H^+$$
$$2NH_3 + 2H_2O \rightarrow 2NH_4{}^+ + 2OH^-(pH\ increase)$$
$$CO_3{}^- + H^+ + 2NH_4{}^+ + 2OH^- \leftrightarrow CO_3{}^{2-} + 2NH_4{}^+ + 2H_2O$$

This leads to the production of ammonium ions which results in the emission of nitrogen oxide into the atmosphere. The ammonium ions so produced has the ability to corrode the reinforcement in the concrete or form nitric acid which in turn damages the concrete matrix [17]. In order to avoid such damages metallic conversion, aerobic method width the end result be calcium carbonate.

$$CaC_6H_{10}O_6 + 6CO_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O$$
$$5CO_2 + Ca(OH)_2 \rightarrow 5CaCO_3 + 5H_2O$$

Another way of producing calcium carbonate is by nitrate dissimilarity reduction known as denitrification. In this process, nitrate ($NO_3{}^-$) is reduced to nitrite ($NO_2{}^-$), nitric oxide (NO), nitrous oxide (N_2O), and nitrogen gas (N_2) [18]. Oxidation of organic compounds during the denitrification process results in the formation of carbon dioxide, water and nitrogen gas which ultimately leads to the formation of calcium carbonate as the final product [19].

$$Organic\ compound + NO_3{}^- + H^+ \xrightarrow{Denitrification} CO_2 + H_2O + N_2$$
$$CO_2 + 2OH^- \rightarrow CO_3{}^- + H_2O$$
$$Ca^{2+} + CO_3{}^{2-} \rightarrow CaCO_3$$

However, the electronegative charge of bacteria and its extensive surface area to volume ratio attract the calcium ions from the cementitious matrix which leads to the formation of calcium carbonate precipitation. the precipitated amount is equal or exceeds the cellular weight of the bacteria regardless of the various environments the bacteria being applied [20, 21]. When compared with metallic conversion and denitrification, the calcium carbonate produced by Ureolytic process is known to be rapid and requires less time in production as well as healing cracks [17, 22, 23].

COMPRESSIVE STRENGTH

The strength of the structural concrete has been significantly improved by the application of bacteria in concrete besides inducing the self-healing property. During the initial curing period, the bacterial cells have good nutrition as the cement matrix was absorptive. However, these cells adapt to the new environment as the cement matrix has high pH which can hinder the growth of the bacteria. During the growth process, the calcite precipitates on the surface o the cells and also in the cement matrix which is caused due to the presence of other ions in the surrounding. The formation of calcite makes the cementitious matrix to be less permeable and less porous. If the pores increase, the flow of food and oxygen to the bacterial cells stops leading to the formation of dead cells or endospores. Thus, this explains the phenomenon of increase in compressive strength in the bacteria induced concrete [24]. Various types of bacteria have been utilized for enhancing efficiency and crack healing in concrete by different researchers. Table 1 shows the different cell concentrations with regard to strength improvement as analysed by various studies.

Table 1: Improvement in compressive strength of cementitious materials

S. no	Bacteria used	Cell concentration	Efficiency %	Standard Deviation	Ref
1.	Bascillus sphaericus and Bascillus licheniformis	-	15	4.55	[25]
2.	Bascillus sp. CT-5	-	29	5.35	[26]
3.	Sporosarcina pasteurii	-	24	1.82	[27]
4.	Bascillus megaterium and Lysinibacillus sphaericus	-	14.8 34.6	4.69 9.31	[28]
5.	Bascillus subtilis	-	18	2.43	[29]
6.	Bascillus subtilis	2.2 x 10^6 cells/m^3	30	6.06	[30]
7.	Bascillus sphaericus	-	32.21	7.62	[31]
8.	Bascillus sphaericus, Bascillus subtilis and Sporosarcina pasteurii	6.6 x 10^6 cells/ml, 4.9 x 10^5 cells/ml and 9 x 10^7 cells/ml	2.26	13.56	[32]
9.	Sporosarcina pasteurii	10^3 cell/mL	22	0.40	[33]
10.	Bascillus sp. CT-5	Optical density (OD_{600} of 1)	36.15	10.41	[34]
11.	Bascillus Magaterium	30 x 105 cell/ml	24	1.82	[35]
12.	Bascillus sphaericus	-	11.2	7.23	[36]
13.	Bascillus sphaericus	-	14.3	5.04	[37]
14.	Shewanella	10^5 cell/ml	25.3	2.74	[38]
15.	Arthrobacter crystallopoietes and Lysinibacillus fusiformi	-	8.9 4.5	8.86 11.97	[39]
16.	Bascillus subtilis	10^5 cell/ml	19.2	1.58	[40]
17.	Sporosarcina pasteurii	-	33	8.18	[41]
18.	Bascillus subtilis	0.33 mg/ml	14.8	4.69	[42]
19.	Bascillus cereus Bascillus pasteurii	10^6 cell/ml and 10^5 cell/ml	38 29	11.72 5.35	[43]
20.	Bascillus subtilis	2.8 x 10^8 cell/ml	12	6.67	[44]

The sign "-' indicates a study where the cell concentration was not given clearly

From the table it can be observed that in general Bascillus sphaericus has enhanced the compressive strength of the concrete to a greater extent compared to the other species. Also, the cell concentration used in the concrete plays a major role in influencing the compressive strength of concrete.

EXPERIMENTAL PROGRAM

Bascillus Megaterium with different cell concentrations was used in this study. The purpose of different cell concentrations was to obtain significant improvement in strength of concrete. the bacteria used in this study was directly isolated from soil and were extracted by the process of serial dilution.

Preparation and testing of specimens

Five different cell concentrations from 10 x 10^5 cfu/ml to 50 x 10^5 cfu/ml were introduced in concrete of strength 40 MPa. The mix design for concrete was done as per the code IS 10262 [45]. Twelve cubes of dimensions 150mm x 150mm were cast and cured for 7 days and 28 days respectively and tested for compressive strength. In the current study, the bacterial concrete was prepared by mixing the bacteria in the eater used for concrete. This is the easiest way to generate bio- mineralization specifically for calcite precipitation in cementitious materials. The cured specimens were tested using the standard compressive testing machine.

RESULTS AND DISCUSSION

The cured specimens were tested using the standard compressive testing machine. The results were tabulated as shown in Table 2 and the graph (Fig. 1) shows the variation of compressive strength with respect to the cell concentration.

Table 2: Compressive strength

Cell concentration (cfu/ml)	Compressive strength MPa	
	7 days	28 days
Control	24.0	42.4
10×10^5	24.8	43.8
20×10^5	25.3	44.6
30×10^5	28.4	46.9
40×10^5	26.5	45.2
50×10^5	25.7	43.6

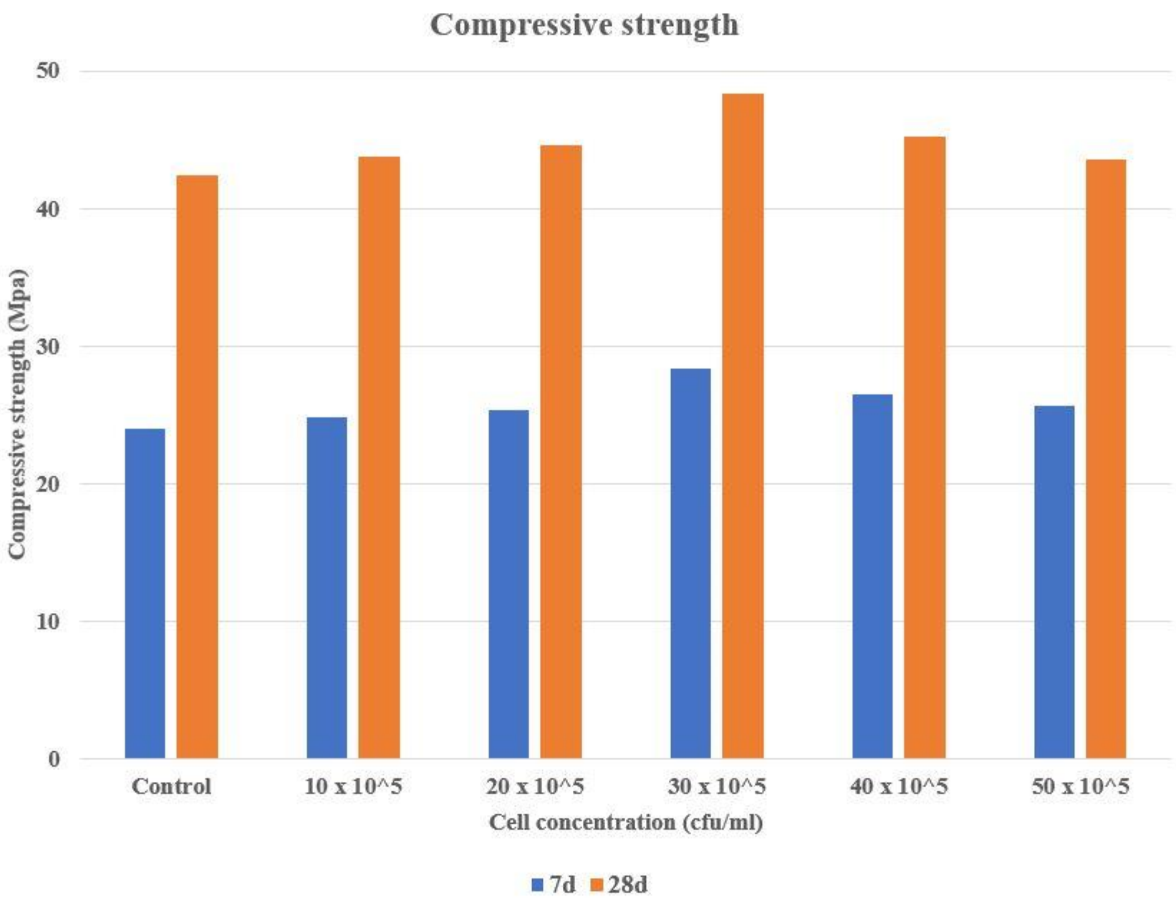

Fig. 1 Effect of different cell concentration of bacterial cells on the compressive strength of concrete

It can be inferred from the graph that the compressive strength of concrete has been enhanced by the microbial concentration with highest compressive strength at 30×10^5 cfu/ml cell concentration in 7 days and 28 days respectively. Beyond 30×10^5 cfu/ml cell concentration, for both 40×10^5 cfu/ml and 50×10^5 cfu/ml, a decrease in compressive strength was observed. This decrease in compressive strength was due to the high population of bacteria making it competitive for the nutrient at higher concentrations than 30×10^5 cfu/ml. Also, simple statistical standard deviation (Table 1) was taken comparing the mean compressive strength of the current study and previous literatures to analyse the variation in compressive strength due to Bascillus Megaterium and other bacterial species.

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CONCLUSION

The main objective of this work is to understand the utilization of urea producing bacteria such as Bascillus pasteruri, Bascillus subtilis and other bacterial species in healing of concrete cracks and also improving the compressive strength. The study helped to identify the bacteria that has positive effect on the compressive strength of concrete which thereby improves the durability and helps in production of high quality, environment friendly and cost- effective concrete.

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