BEHAVIOUR OF SELF HEALING MECHANISM FOR CRACK RESISTANCE

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ABSTRACT. Crack formation is a very common phenomenon in concrete structures due to which there is ingress of water and other chemicals which hampers the durability and strength. It also affects the reinforcement when it comes in contact with water, CO2 and other chemicals. For repairing the cracks developed in the concrete, it requires regular maintenance and special type of treatment which will be very expensive. In the present project work autonomous self-healing mechanism is introduced in the concrete that helps to repair the cracks by producing calcium carbonate crystals which block the micro cracks and pores in the concrete. The selection of the bacteria was done according to their survival in the alkaline environment. Bacillus subtilis is used for this experimental study. For the growth, the bacteria were put in a medium containing different chemicals at a particular temperature and for a particular time period. From the study carried out bacteria improves the structural properties such as compressive strength and enhance the crack resisting property of the concrete. The comparative study of self-healing concrete considering compressive strength and crack resistance as the parameters was investigated and the results compared with the control concrete. It was found that with the addition of Bacteria 10^5 cells per milliliter of water i.e. at optimum dosage, there was significant increase in compressive strength of concrete as compared with the control concrete. At optimum concentration, the bacteria could heal crack width up to 1.5mm and 1.2mm for $CaCl_2$ and urea immersion and water immersion at 28 days, respectively.

Keywords: Self healing, Bacillus subtilis, compressive strength, Crack resistance.

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INTRODUCTION

Concrete is the most commonly used building material which is recyclable. It is strong, durable, locally available and versatile. It is capable to resist the compressive load to a limit but, if the load applied on the concrete is more than their limit of resisting load, it causes the strength reduction of concrete by producing the cracks in concrete and the treatment of cracks is very expensive. Cracks in concrete affect the serviceability limit of concrete. The ingress of moisture and other harmful chemicals into the concrete may result in decrement of strength and life. The ingress of sulphates and chlorides in concrete results in decrease of durability. These effects in concrete structures by cracking might be overcome by utilizing self-healing technology which has high potential to repair cracks in concrete and enhance the service life of concrete structures with a reduction of demand for repair and maintenance. Self-healing agents such as epoxy resin, bacteria, fiber, etc., are used to heal cracks in concrete. Among these, bacteria is used commonly and is found to be effective. When the bacteria is mixed with concrete, the calcium carbonate precipitate is formed and these precipitate fills the cracks and makes the concrete free from cracks. Self-healing concrete is a product, which biologically produces limestone by which cracks on the surface of concrete surface heal. Selected types of the bacteria genus Bacillus, along with calcium-based nutrient known as calcium lactate; nitrogen and phosphorous are added to the concrete when it is being mixed. The self-healing agents can lie dormant within the concrete for up to two hundred years. When a concrete structure damages and water starts to penetrate in the cracks present in it, the bacteria starts to feed on the calcium lactate consuming oxygen and converts the soluble calcium lactate into insoluble limestone. The limestone formed thus seals the cracks present. It is similar to the process of how a fractured bone gets naturally healed by osteoblast cells that mineralize to reform bone. Consumption of oxygen in the bacterial conversion has an additional advantage. Oxygen which becomes an essential element for the corrosion of steel to take place is being used in the bacterial conversion. Hence, the durability of steel in construction becomes higher. The process of bacterial conversion takes place either in the interior or exterior of the microbial cell or even some distance away within the concrete. Often, the bacterial activities trigger a change in the chemical process that leads to over saturation and mineral precipitation. Utilization of concepts of bio mineralogy in concrete lead to invention of a new material termed as Bacterial Concrete. Bacterial concrete refers to a new generation concrete in which selective cementation by microbiologically-induced $CaCO_3$ precipitation has been introduced for remediation of micro-cracks.

Table 1 Bacteria other than Bacillus which can survive in the alkaline environment

SR. NO.	APPLICATION	TYPES OF BACTERIA
1.	As a crack healer	B. Pasteuri Deleya Holophila Holomonasrurihalina Myxococcus Xanthus B. Megaterium
2.	For surface treatment	B. Sphaericus

First, 1 mol of urea is hydrolyzed intracellular to 1 mol of ammonia. Carbonate spontaneously hydrolyses to form additionally 1mol of ammonia and carbonic acid. These products subsequently form 1mol of bicarbonate and 2mol of ammonium and hydroxide ions. The last two reactions give rise to a pH increase, which in turn shifts the bicarbonate equilibrium, resulting in the formation of carbonate ions.

$$CO(NH_2)_2 + H_2ONH_2 \longrightarrow COOH + NH_3$$

$$NH_2COOH + H_2O \longrightarrow NH_3 + H_2CO_3$$

$$H_2CO_3 \longleftrightarrow HCO_3^- + H^-$$

$$2NH_3 + 2H_2O \longleftrightarrow 2NH_4^- + 2OH^-$$

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \longleftrightarrow CO_3^- + 2NH_4^+ + 2H_2O$$

Since the cell wall of the bacteria is negatively charged, the bacteria draw cations from the environment, including Ca^{2+}, to deposit on their cell surface. The Ca^{2+}-ions subsequently react with the CO_3^{2-}-ions, leading to the precipitation of $CaCO_3$ at the cell surface that serves as a nucleation site.

$$Ca^{2+} + \text{cell} \longrightarrow \text{cell-}Ca^{2+}$$

$$\text{Cell-}Ca^{2+} + CO_3^{2-} \longrightarrow \text{cell-}CaCO_3 \downarrow$$

MATERIALS AND METHODOLOGY

Ordinary Portland cement of 43 grade was used for all concrete mixes in this experimental work. The cement used was fresh and without any lumps. Of all the materials that influence the behavior of concrete, cement is the most important constituent, because it is used to bind sand and aggregate and it resists atmospheric action. Portland cement is a general term used to describe hydraulic cement. The testing of cement was done satisfying the specification as per IS: 8112-1989.

Table 2 Physical properties of cement (IS: 8112-1989)

PROPERTY OF CEMENT	VALUE
Grade of cement	43 grade
Specific gravity of cement	2.9

Crushed angular stone aggregate obtained from the local quarry has been used. In this experimental work, coarse aggregates used are of 20mm and 10mm down size, tested as per IS:2386-1963 (I, II and III) specifications and mixed in the ratio of 60:40.

Table 3 Physical properties of coarse aggregate (IS: 2386-1963)

PROPERTIES	RESULTS	PERMISSIBLE LIMIT AS PER IS:2386-1963
Specific Gravity	2.73	In between range 2.6-3.0
Water absorption	1.0%	-

The aggregates smaller than 4.75 mm size is called fine aggregates. Natural sand is generally used as fine aggregate. In this experimental work, the sand confirming to grading Zone III of IS: 383 – 1970 was used as fine aggregates.

Table 4 Physical properties of fine aggregate

PROPERTIES OF FINE AGGREGATE	VALUE
Grade	Zone III
Specific gravity	2.6
Water absorption	1.0%

Water used for mixing and for curing of concrete throughout the experimental work was clean portable water free from oil, organic content, turbidity and salts that may be deleterious to concrete.

Bacterium named Bacillus Subtilis (B.S.), procured from the microbiology laboratory of Parvatibai Chowgule College of Arts and science was used in this investigation. This bacterium is rod-shaped, gram-positive and anaerobic bacteria and the most important thing is that it doesn’t have any health hazards to humans and animals.

Principle of preparation of bacteria

The growth of an organism on a media is called culture. The food base that supports the growth of an organism is called culture media. The culture media is devised in such a way that the organism should get all the nutritional requirements. The culture media are prepared in laboratory by weighing and dispensing the individual ingredients or procured ready-made media from the market. Generally, the common media contain both organic and inorganic nutrients but of the cultivation of many microorganisms specialized media are prepared. If solidification of media is required, agar is mixed with other ingredients.

Concentration of cells is measured by Haemocytometer and Gram staining method is used to determine the morphology of the bacterial strains.

Table 5 Various tests on bacteria

TEST	TO DETERMINE	RESULT
Haemocytometer Test	Cell Concentration	10^5 cells/mL of bacterial solution
Gram staining	Morphology	Gram positive
Urease test	Calcite precipitation	Color change –yellow to pink
$CaCO_3$ test	Quantity of Calcite precipitation	3mg/L

Details of specimen

About 24 cubes of size 150 mm x 150 mm x 150 mm were cast to test the compressive strength after 7 and 28 days.

Table 6 Details of concrete cube specimen

SR. NO.	MIX	DESCRIPTION
1	CC	Control Concrete
2	SHC1	Bacteria 10^4 cells per milliliter of water
3	SHC2	Bacteria 10^5 cells per milliliter of water
4	SHC3	Bacteria 10^6 cells per milliliter of water

RESULTS

Compressive Strength Test

The results showed that, the strength of self-healing concrete has marginally higher than the control concrete. The maximum strength is obtained for SHC2 concrete. The increment in strength is due to the growth of filler material within the concrete and the dead cells present in the concrete. The presence of dead cells also reduces the porosity and crack formation in concrete.

Table 7 Compressive strength of concrete cubes after 7 days

MIX	7 Days COMPRESSIVE STRENGTH (N/mm^2)				
	1	2	3	AVERAGE	% INCREASE IN STRENGTH
CC	13.6	13.9	13.7	13.73	-
SHC 1	17.3	15.9	17.6	16.94	23.37
SHC 2	20.8	19.4	19.35	19.85	44.57
SHC 3	18.5	16.42	17.6	17.50	27.45

Table 8 Compressive strength of concrete cubes after 28 days

MIX	28 Days COMPRESSIVE STRENGTH (N/mm^2)				
	1	2	3	AVERAGE	% INCREASE IN STRENGTH
CC	21.9	23.5	22.16	22.52	-
SHC 1	24.6	25..3	25.5	25.13	11.58
SHC 2	27.5	25.41	29.5	27.47	21.98
SHC 3	26.8	24.6	24.1	25.2	11.90

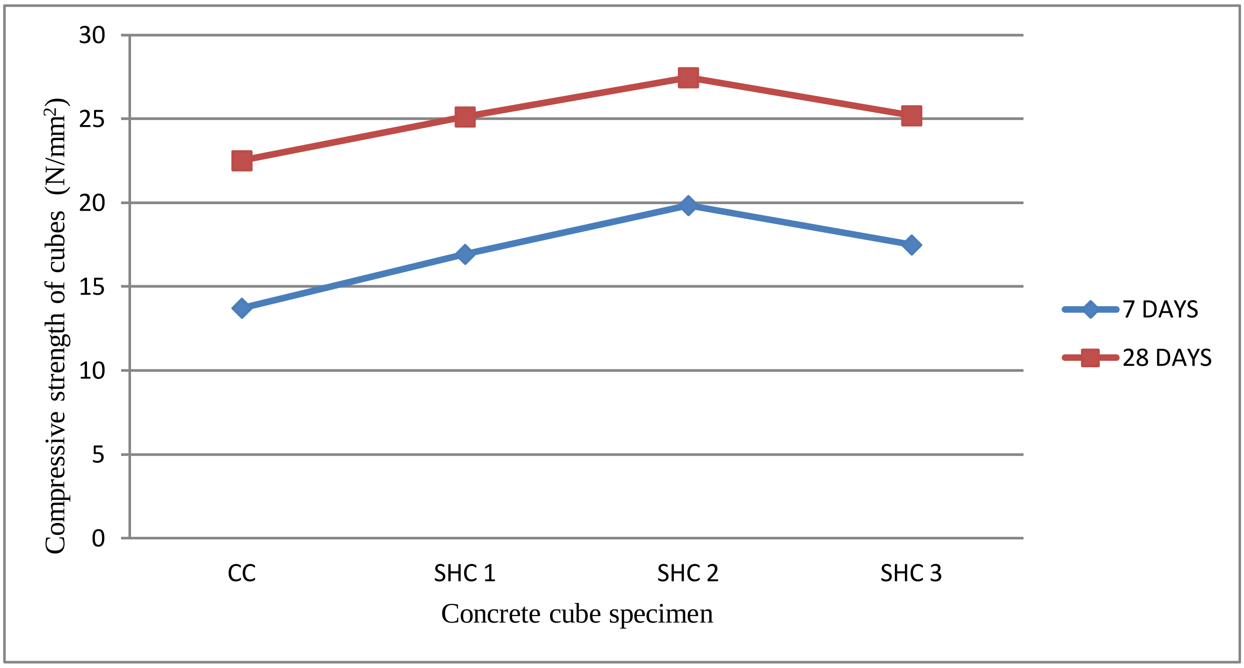

Figure 1 Variation of Compressive strength of concrete

Visual Evaluation of Crack Filling

After creating cracks, the cubes were placed in three different exposures for treatment, which were:

a) $CaCl_2$ + urea immersion
b) Water immersion
c) Air exposure

The crack width ranges were measured using vernier caliper before and after 28 days of treatment in different exposure. The studied crack widths were mainly below 3mm and the time set for healing was 28 days.

Table 9 Crack width ranges of concrete blocks before and after 28 days treatment

TYPE	CRACK WIDTH RANGES (INITIAL) (mm)			CRACK WIDTH RANGES(AFTER 28 DAYS) (mm)		
	$CaCl_2$ + Urea	Water	Air	$CaCl_2$ + Urea	Water	Air
B.S.10^4 cells/mL	0.5-1.5	0.4-2.8	0.2-0.8	0-0.3	0-1.8	0.2-0.8
B.S.10^5 cells/mL	0.9-2.2	0.2-1.4	0.8-1.2	0-0.7	0-0.2	0.8-1.2
B.S.10^6 cells/mL	1.4-2.8	1.2-3.0	0.8-1.6	0.2-1.7	0.4-1.9	0.8-1.6

The results were classified on the type of exposure. During immersion in $CaCl_2$ and urea solution and water, bacteria started to precipitate $CaCO_3$ resulting in partially filling the cracks. At the optimum concentration of bacteria, it has been observed the filling was only feasible for 1.5mm and 1.2mm wide cracks for $CaCl_2$ and urea immersion and water immersion at 28 days respectively. It has been seen that, air exposure was unable to fill the crack. This may be due to the absence of water, as for bio-assisted healing, bacterial spores need water to revive their activities to precipitate $CaCO_3$. Therefore, for self-healing activity water is essential in the cracking zone.

CONCLUSION

- Microbial concrete technology has proved to be better than many conventional technologies because of its eco-friendly nature, self-healing abilities and increase in durability of various building materials.
- The overall development of compressive strength and crack resistance of Self-healing concrete by using Bacillus subtilis bacteria has been investigated and compared with control concrete.
- Optimum compressive strength was obtained for SHC2 concrete specimen. Bacillus subtilis has improved the characteristics of concrete specimen.
- Optimum dosage of bacterial solution was found to be 10^5 cells/mL.
- The self-healing effect was found to be effective with more $CaCO_3$ precipitation. It was observed that the $CaCO_3$ precipitation was directly proportional to the concentration of bacteria and Ca^{2+}.

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