Experimental Investigation on Development of Self Healing Mortar using Different Bacteria

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Abstract - *Concrete is most widely used construction material because of its high compressive strength & it is more sensitive to crack formation due to limited tensile strength. Crack endangers durability of concrete and cause corrosion of rebars when expose to air. Crack repair becomes very difficult when cracks are not visible or accessible. Now a day's epoxy injection technique is widely used for sealing the cracks but the biggest disadvantage of this technique is it can't seal cracks at greater depth. To overcome this problem study of self healing concrete is must. In this research work bacillus pseudofirmus and bacillus sphaericus bacteria were mixed in concrete with nutrient solution encapsulated in expanded perlite by taking different proportions (CPN:CPS) as 90:10, 80:20, 70:30, 60:40, 50:50. Concrete specimens cracked under artificial conditions and kept in humid environment for 28 days. It was found that after several days' cracks were healed by bacteria in 50:50 and 60:40 proportions rapidly. XRF analysis confirmed that bacillus pseudofirmus bacteria is more appropriate to use in self healing concrete.*

Key Words: Self-healing concrete, cracks, bacillus Pseudofirmus, bacillus sphaericus, expanded perlite

1. INTRODUCTION

Crystal formation by bacteria is a general phenomenon was discovered half century ago [1].V. Ramakrishnan proposed microbiologically induced calcite precipitation (MICP) technique for remediating cracks in concrete [19]. Effect of bacteria on various parameters of concrete proves to be beneficial development also increases compressive strength of concrete [20]. Now a day this technique is used for the crack remediation and durability improvement of concrete. In concrete, cracking is almost unavoidable due to its brittleness property and complex environment [1]. Once crack formed, due to various chemicals reinforcement bar begins to corrode. It results into decrease in structure life span [2]. The cracks may propagate at much lower stress than required to cause crack initiation. Cracking in concrete leads to several damages to the structural elements such as reduction in strength of concrete, corrosion of steel bars which result in carbonation that reduces the pH of concrete resulting in destruction of the naturally occurring passive film that protects the steel bar from moisture and oxygen causing corrosion so it is very necessary to repair the cracks.To date self healing in concrete has been achieved primarily through three different types; autogenous healing, encapsulation of polymeric material and bacterial production of caco3 [3]. The addition of expansive materials can be another method for designing a self-healing concrete [15]. Expansive materials are activated when crack formed and started to expand when triggered by water, moisture, or carbonation penetration [16]. The self healing system in concrete with microcapsule has many advantages and easy to dispersed in cementitious material [4]. Kunamineni vijay et al. suggested that encapsulation method give better result than direct application of bacterial culture and proved that use of bacteria in concrete can increase the strength and durability properties of concrete [14]. To protect the bacterial cells in harsh environment different types of carriers are used i.e Expanded clay, diatomaceous earth, hydrogel, expanded perlite, silica gel, magnetic iron oxide nanoparticles and ceramsite[5,6,7,8,9,2,10]. Expanded perlite has great absorption capacity. It absorbs water approximately 200% by its weight. Jiaguang zhang et al. provided scientific basis for potential implementation of expanded perlite as a carrier in bacteria based self healing concrete [13]. Coated expanded perlite protects bacterial spores from chemical and microbiological attack with durable potential [12]. According to Mohammed Alzhari [1] in aerobic metabolic conversion pathways bacteria produces the oxidation of an organic calcium salt, for example nutrient like calcium acetate or calcium lactate to calcium carbonate under favourable conditions. The by-products of conversion of calcium acetate to calcium carbonate are water and carbon-dioxide as follows:

$$CaC_6H_{10}O_4 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O$$

Further the water and carbon-dioxide reacts and forms weak carbonic acid which again goes into carbonation process with carbon hydroxide within the concrete to form calcium carbonate with by-product as water as shown in following reaction

$$3CO_2 + 3Ca(OH)_2 \rightarrow 3CaCO_3 + 3H_2O$$

2. MATERIALS & METHODOLOGY

2.1 Bacterial strain

Bacillus sphaericus MCC 2008 and Bacillus pseudofirmus MCC 2820 (National Centre for Microbial Resource, Pune) cultures were used in this study. Living cells were routinely cultured on nutrient agar. Spores were prepared in a sporulation media and incubated at 37ºC on an orbital shaker for 8-10 days. Spore solutions were incubated at 80ºC to ensure release of spores. Spore staining was done using Schaeffer-Fulton endospore staining method [17] to confirm sporulation. For preparation of spore solution the 10 days old culture was resuspended in 400 ml of saline. Green color spores are seen with pink/ red colored Bacillus cells.

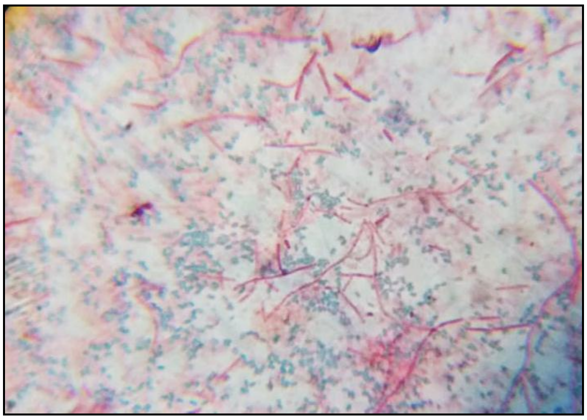

Fig -1: Microscopic view of spore solution

2.2 Bacterial strain

Growth medium consisted of three ingredients: calcium acetate and yeast extract and dextrose as the nutrients. The growth medium was buffered with tri-sodium citrate and sodium bicarbonate to provide alkaline environment the Bacillus require for growth. For each culture 1 litre nutrient solution was prepared.

Table -1: Composition of growth medium

Nutrient HiVegTM Agar w/ Manganese (Hi Media)	
Ingredients	Grams/Litre
HiVeg extract	3.0
HiVeg peptone	5.0
Manganese sulphate	0.03
Agar	15.0
Modified Growth medium	
Calcium salt (acetate/chloride)	5.0
Yeast extract	1.0
Dextrose	1.0
Buffering Components	
$Na_3C_6H_5O_7$	5.2
$NaHCO_3$	4.2

2.3 Expanded perlite

Perlite is a natural volcanic glass. It occurs naturally and has the unusual property of greatly expanding when heated sufficiently [8]. Expanded perlite has a bulk density 102 kg/m3. After encapsulation density of EP became 600kg/m3. Water absorption capacity of EP was 196% by its weight. Expanded perlite mainly used in construction, manufacturing and horticulture field.it is used in lightweight plasters, insulation, filters. It doesn't changes volume after absorption of water. It is white in color.

Fig -2: Expanded Perlite Material

2.4 Sodium Silicate

Sodium silicate, also called water glass or soluble glass, a compound containing sodium oxide (Na_2O) and silica (silicon dioxide, SiO_2) that forms a glassy solid with the very useful property of being soluble in water. Sodium silicate is sold as solid lumps or powders or as a clear, syrupy liquid. It is used as a convenient source of sodium for many industrial products, as a builder in laundry detergents, as a binder and adhesive, as a flocculent in water-treatment plants, and in many other applications. In this research work it is used as adhesive for expanded perlite coating. It works as a good insulator of heat. When pH is 7 or above it doesn't react with other materials hence it was used in work.

2.5 Encapsulation process

For encapsulation of nutrients, expanded perlite was soaked in a solution of nutrient containing calcium acetate and yeast extract. Also spore solution was completely soaked by expanded perlite. Then initial layer of sodium silicate was applied by soaking the impregnated expanded perlite in sodium silicate solution until surface of expanded perlite was completely soaked. The EP particles were then dried for 24hr at 20^{o}. Second layer of sodium silicate was then applied and instantly cement powder was applied on wet surface. Cement powder reacted with sodium silicate solution and water in the EP. The coated EP was then cured for 48h in water to become hard shell.

2.6 Preparation of mortar specimens

Mortar specimens were produced using ordinary Portland cement, natural sand and tap water. The sand to cement ratio in the control mortar was 1:3 and water to cement ratio was 0.5 by mass. Combination of CPN and CPS were added to concrete as self healing agents as a combined replacement of 20% by volume of sand. In mortar M90 to M50 combination of CPN and CPS were added in ratio of 9:1, 8:2, 7:3, 6:4 and 5:5.

Table 2: Mix design for mortar samples

Mix	CPN:CPS by volume	Constituents, g				
		Water	Cement	Sand	CPN	CPS
M90	90:10	300	600	1440	129	14
M80	80:20	300	600	1440	114	29
M70	70:30	300	600	1440	100	43
M60	60:40	300	600	1440	86	57
M50	50:50	300	600	1440	72	72

The specimens produced were disk shape with diameter 100mm and thickness 40mm. after casting specimens were placed in incubator temperature of 55^{O} C for 20 h as per accelerated curing by warm water method (IS 9013:1978) [18].

2.7 Crack creation and healing

After curing specimens were dried at room temperature for 24 h and perimeter of each specimen was wrapped with carbon fiber polymer strip to control creation of crack width to be generated without falling apart. Cracks on specimens were created on compression testing machine by applying point load. Widths of cracks were measured by using digital microscope of zooming capacity 1000X. The size of crack is important factor to check the ability of bacterial precipitation [11]. After crack formation, specimens were placed in humid environment for 30 days and water was sprinkled on specimens.

2.8 Observation of crack filling

Using digital microscope (1000X) visualization of crack healing was performed. Detection of calcium carbonate was carried out using X-Ray Diffraction test.

3. RESULTS AND OBSERVATIONS

3.1 Percentage of calcium by XR-F test.

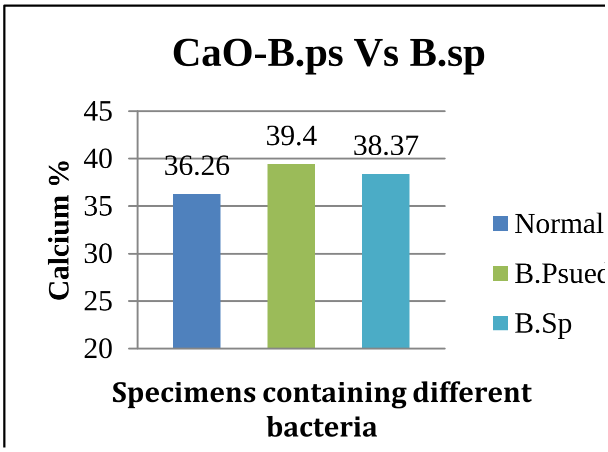

Chart -1: Calcium percentage of mortars

Percentage of calcium in normal mortar, mortar with B. Pseudofirmus & mortar with B sphaericus are 36.26, 39.4 & 38.37% respectively. Percentage of calcium in B. Psuedofirmus is 39.4% which is greater than normal mortar confirmed formation of calcium carbonate in cracks. Percentage of calcium in B.Pseudofirmus is 39.4% which is greater than percentage of calcium in B. sphaericus shows B. Pseudofirmus has more growth than B.sphaericus.

3.2 Element composition of specimen

Following graphs represent percentage of various elements in mortar with different bacteria.

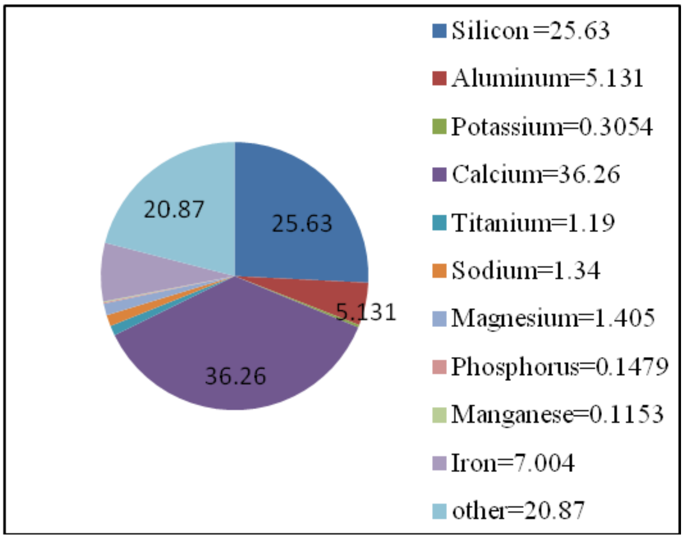

Chart -2: Elemental composition of normal mortar

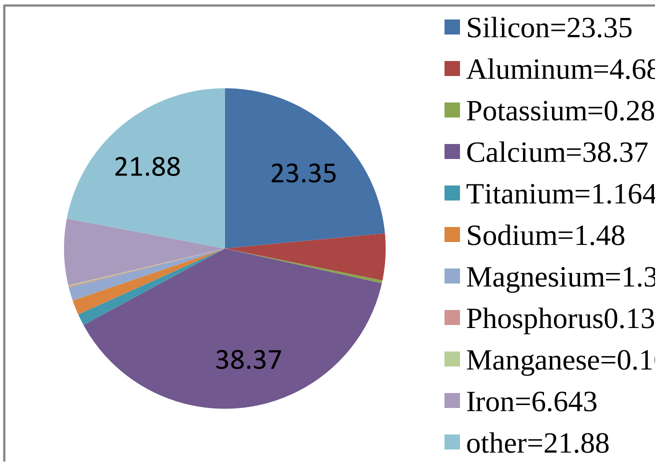

Chart -3: Elemental composition of mortar with B.Sp.

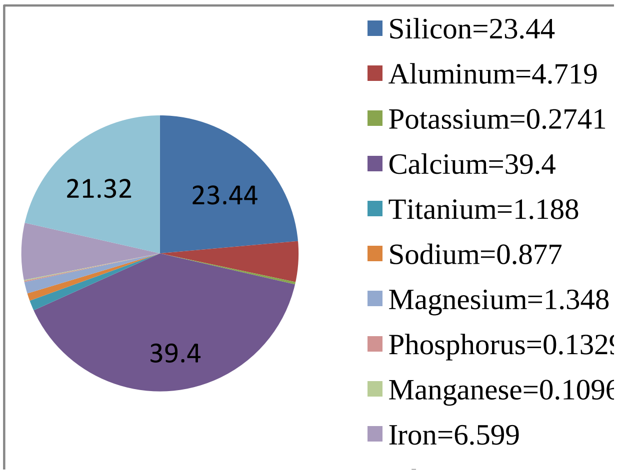

Chart -4: Elemental composition of mortar with B. Pseudo.

The fig 4 confirms increase in the calcium carbonate at cracks after application of water and nutrient on surface of cracks. The fig 2 shows elemental composition of normal mortar containing 36.26% calcium. The fig 3 & 4 shows 3% & 2% increment in the percentage of calcium compared to other elements in mortar of B. Pseudofirmus and B. Sphaericus respectively.

3.3 Measurement of crack widths

The following table shows measurement of crack widths of mortar specimens.

Table 3: Measurement of crack widths

proportion	sample no.	Crack width(mm)	Crack healing remark
Bacillus Psuedofirmus			
CPN:CPS		26-Apr	28-may
50:50	1	0.4	Partially healed
	2	0.3	Partially healed
	3	0.2	Fully healed
60:40	1	0.4	Not healed
	2	0.2	Partially healed
	3	0.2	Partially healed
70:30	1	0.3	Not healed
	2	0.1	Partially healed
	3	0.2	Partially healed
80:20	1	0.2	Not healed
	2	0.2	Not healed
	3	0.6	Not healed
90:10	1	0.3	Not healed
	2	0.1	Not healed
	3	0.2	Not healed
Bacillus sphaericus			
50:50	1	0.4	Partially healed
	2	0.2	Fully healed
	3	0.2	Fully healed
60:40	1	0.5	Not healed
	2	0.2	Partially healed
	3	0.1	Fully healed
70:30	1	0.3	Not healed
	2	0.1	Partially healed
	3	0.1	Partially healed
80:20	1	0.1	Not healed
	2	0.2	Not healed
	3	0.2	Not healed
90:10	1	0.2	Not healed
	2	0.074	Not healed
	3	0.08	Not healed

Above table shows crack healed of width 0.2 mm in 50:50 proportion of B. pseudofirmus mortar.In B. Sphaericus width of 0.1 mm & 0.2 mm cracks healed in 50:50 & 60:40 proportions. Above table shows cracks are not healed in proportions 70:30, 80:20, 90:10 of B. Sphaericus. Proportion 70:30 of B. pseudofirmus mortar showed comparative healing of cracks after specimens kept in humid environment.

3.4 Image analysis of various proportions

Mortar Containing 50:50 B. Pseudo. Bacteria.

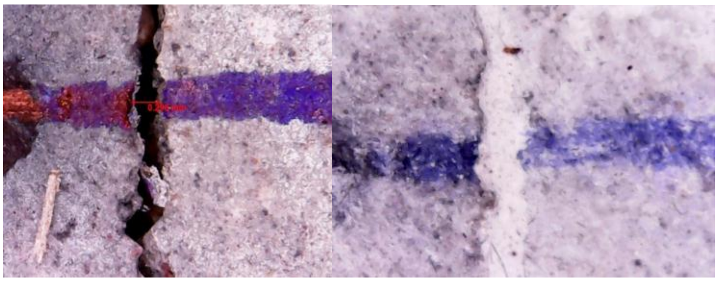

Fig -3: 50:50 B.Pseudofirmus

Figure 3 shows artificial crack formation and crack healed after curing. After keeping in humid condition for 28 days B.Pseudofirmus precipitated calcium carbonate to seal the crack of width 0.2 mm. In 50:50 proportion due to more concentration of spores crack healed completely of width less than 0.2 mm. Cracks of width greater than 0.2 mm are not healed completely.

Mortar Containing 60:40 B. Pseudo. Bacteria.

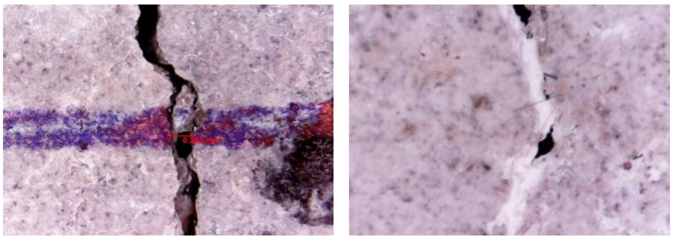

Fig -4: 60:40 B.Pseudofirmus

In proportion of 60:40 fig 4 shows crack healed comparatively. In this proportion crack width greater than 0.1mm are comparatively healed. This proportion contains 60% nutrient with 40% spore solution. Due to less percentage of spores compared to nutrient solution it formed less amount of calcium carbonate to heal the cracks. In remaining proportions, 70:30, 80:20, 90:10 no healing capacity was observed. May be due to insufficient amount spores of bacteria no calcium carbonate precipitation seen on the surface of specimens.

Mortar Containing 50:50 B. Sphaericus Bacteria

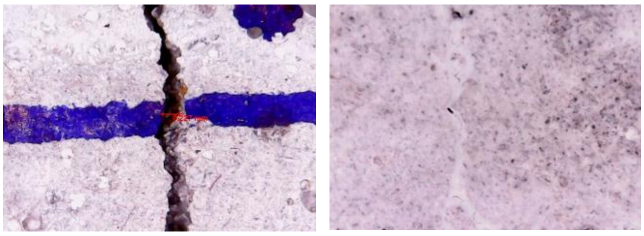

Fig -5: 50:50 B. Sphaericus

Fig 5 shows crack healed after curing in mortar specimens containing B.Sphaericus bacteria. After keeping in humid condition for 28 days B. Sphaericus precipitated calcium carbonate to seal the crack of width 0.2 mm. In 50:50 proportion due to more concentration of spores crack healed completely of width less than 0.2 mm. Cracks of width greater than 0.2 mm are not healed completely.

Mortar Containing 60:40 B. Sphaericus Bacteria

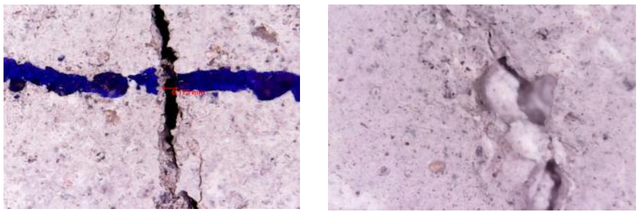

Fig -6: 60:40 B. Sphaericus

In 60:40 proportion of B.Sphaericus crack healed comparatively. In this proportion crack width up to 0.1mm are completely healed. This proportion contains 60% nutrient with 40 % spore solution. Cracks containing width above 0.1mm are comparatively healed. In 70:30 proportion 0.1mm crack width healed comparatively. Above 0.1mm width no healing capacity observed in 70:30 proportion. In both bacteria's 80:20 & 90:10 proportion, due to less spores no cacium carbonate precipitation observed.

3.5 Healing conditions

In this work samples are placed in humid condition for 28 days. Cracked mortars were maintained. Routinely water was sprinkled on the cracked mortar to create suitable environment for growth of bacteria.

4. CONCLUSION

1) X-RF test confirmed formation of calcium carbonate in the cracks by B. Pseudofirmus and B. Sphaericus bacteria which shows B.Pseudofirmus bacteria have more growth than B. sphaericus.
2) It is observed that B. Pseudofirmus bacteria is suitable to fill the cracks and ratio 50:50 (CPN:CPS) of B.

pseudofirmus shows more growth of bacteria in the cracks.

3) It reveals that more the number of spores results into maximum formation of calcium carbonate.
4) In B. Pseudofirmus bacteria approximate healing period 28 days is observed for less than or equal to 0.2mm crack width.
5) Bacteria seal early cracks (<200µm) which results into prevention of initial cracking.

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