

Durability and Self- Healing Behaviour of Bacterial Impregnated Concrete

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ABSTRACT: Bacterial impregnated Concrete is a self- healing concrete in which bacteria pre added into the concrete matrix. Microbial concrete achieve more attention is because it is crack free and corrosion free inturn result in strength increment. The bacteria and its precipitates modify the microstructure of concrete thereby improve the impermeability of concrete. In this study, durability and crack healing behaviour of bacterial impregnated concrete using *bacillus subtilis jc3* bacteria was conducted. Experimental results showed a better durability performance by bacterial impregnated concrete compared to conventional M₂₅ Concrete. Bacterial concrete exhibited crack width reduction when immersed in water which strengthens self- healing property of it.

KEYWORDS: Bacterial Impregnated Concrete, Self- Healing Concrete, *Bacillus Subtilis*, Microbial Concrete, Bacterial Concrete

I. INTRODUCTION

Concrete became more versatile component of construction industry. But concrete structures shows damage before the end of their service life. Main reason behind this problem is cracking. Cracking enhance passage of deleterious substances into the concrete thereby corrosion and weakening of structure takes place. To avoid this problem, construction industries conduct regular maintenance and repairing works. Sometimes go for traditional repairing methods also eg; Epoxy based repairing methods.

Repairing at tunnel structures, nuclear power plant, marine structures etc. are very difficult to conduct and also it consumes more money and time. Traditional repairing methods also have drawbacks like cost, environmental problem and variation in thermal expansion coefficients etc. Because of these difficulties new method is needed to extend the serviceability of structures. Self-Healing concrete is a new era of construction industry and it make concrete structure crack free.

In self-healing concrete, pre-add the healing agent with in the concrete matrix thereby arresting of micro cracks takes place before they appear as large cracks. Bacterial impregnated concrete is a self-healing concrete in which bacteria act as healing agent. In bacterial impregnated concrete, bacteria incorporated at the time of mixing. When crack appear on the bacterial impregnated concrete it releases healing agent with in the concrete and flow into the cracks to seal the cracks from inside to outside. Self –healing concrete can restrain early age cracks to develop to large cracks [1].

II. LITERATURE REVIEW

For improving the strength of cement–sand mortar with microbial induced mineral precipitation, the increase in the compressive strength of cement mortar (25 %) at 28th day was observed with the addition of thermophilic and anaerobic bacteria [2].By the research on investigation of the effects of *Bacillus sp.* CT-5 isolated from cement for determining the water-absorption test and compressive strength. The result showed that the compressive strength of cement mortar increased with the addition of microbes and the treated cubes were found to absorb water six times lesser when compared to the control cubes due to the deposition of microbial calcite. This indicates that by using

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Bacillus sp. for the production of “microbial concrete” it can enhance the durability of construction materials [3]. Bacteria incorporated concrete show resistance towards the alkali, freeze-thaw and sulfate attack and drying shrinkage [4]. By the study for the assessment of durability improvement in several high strength bacterial structural concrete grades by using different type of acid, the experimental results showed that biological concrete when compared to the ordinary Portland cement without microorganism has lost less weight and strength. It was also found that maximum weight loss and compressive strength occurred during the sulphuric acid immersion as compared to hydrochloric acid immersion. It was noticeable that lesser amount of chloride and sulphur were found in the bacterial concrete immersed in sulphuric acid and hydrochloric acid. The results of this study clearly show that using suitable bacteria in concrete can increase its durability and resistance even in the presence of strong acids such as sulphuric acid and hydrochloric acid [5].

III. BIOLOGICAL SELF-HEALING PROCESS

Conventional concrete can also have the capacity to heal cracks up to the crack width of 0.2mm. Autogenous healing of conventional concrete achieved mainly by three processes 1) Swelling of C-S-H 2) Hydration of unhydrated cementitious components 3) Formation of calcite. Calcite formed by the reaction of CO_2 and $\text{Ca}(\text{OH})_2$. This healing process in conventional concrete take place in limited amount because availability of CO_2 is less within the concrete and also $\text{Ca}(\text{OH})_2$ is a soluble product which leach out with the help of ingress water [6-8].

In bacterial concrete, due to urease enzymatic activity of *Bacteria bacillus subtilis* produces urease, which catalyzes urea to produce CO_2 and ammonia, resulting in an increase of pH in the surroundings, Ca^{2+} and CO_3^{2-} ions precipitates as calcite. Calcite production also takes place due to metabolism of bacteria. For that process it consumes oxygen so that bacterial concrete is crack free. The Crystals expand until the entire gap is filled [6-10].

The microbial precipitation of CaCO_3 is determined by several factors including: the concentration of dissolved inorganic carbon, the pH the concentration of calcium ions and the presence of nucleation sites. The first three factors are provided by the metabolism of the bacteria while the cell wall of the bacteria will act as a nucleation site [9-12].

IV. PREPARATION OF BACTERIAL CONCRETE

Bacteria are added at the time of mixing which is in suspension form. *Bacteria bacillus subtilis* have the ability to withstand hostile environment of concrete. The thick cell membrane of *bacteria bacillus subtilis* helps to offer resistance against high pH. Therefore *bacillus* genus bacteria could remain hibernated within the concrete for 200 years until it gets the suitable environment. When crack appear on concrete structure which help the ingress of water and air so that pH of concrete environment reduce and bacteria become activate. Peptone based nutrients added along with bacterial content which enhance the calcite production.

V. PROCESS MATERIAL AND MIX PROPORTION

a) Materials

- Ordinary Portland cement (OPC)

For the experimental works Ordinary Portland cement of 53 grade having specific gravity of 3.15 was used. Which found to be confirming to IS:12269-1987.

- Aggregates

Locally available crushed angular granite metal of 20 mm and down size having the specific gravity of 2.81 and manufactured sand having the specific gravity of 2.737 and confirming to IS:383 zone II was used for the experimental works, tested as per IS:2386-1963

- Bacterial Strains

The bacterial strains were collected from Kerala Agricultural College, Mannuthy. The bacteria used in this study is *Bacillus Subtilis jc3*.

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Table 1: Characteristics of *Bacillus Subtilis* JC3 bacteria [11]

Characteristics	Bacillus Subtilis JC3
Shape, size, gram strain	Long rods, 2.0 to 3.0 μm in length and 0.6-0.8 μm in width gram positive
Colony morphology (on nutrient agar plate)	Irregular, dry, white, opaque colonies
Dextrose	No acid, no gas
Sucrose	No acids, no gas
H ₂ S production	Acids and gas
Nitrate reduction	-
Indole production	-

Bacillus subtilis is a Gram positive, rod shaped bacteria, commonly found in soil(table 1). *Bacillus subtilis* is an endospore forming bacteria, and the endospore that it forms allows it to withstand extreme temperatures as well as dry environments. *Bacillus subtilis* is considered and obligate aerobe, but can also function anaerobically when in the presence of nitrates or glucose. *Bacillus subtilis* is not considered pathogenic or toxic and is not a disease causing agent

- Water

Locally available water confirming to IS 456 is used. Water used for mixing and curing was clean and free from injurious amounts of oil, acid, alkali, salts, sugar, organic materials or other substances that may be deleterious to concrete.

b) Mix Proportions

By adopting mix proportion as 1:1:2 for M₂₅ mix with W/C ratio 0.44 Slump obtained is 105mm and 7th day compressive strength is 17.48 N/mm² and 28th day compressive strength 26.07 N/mm².

VI. TEST ON CONCRETE

a)Durability Assessment

An experimental program was conducted on M₂₅ grade concrete cubes of size 100×100×100 mm with and without addition of *b.subtilis*. For salt and acid durability test, specimens were immersed in 5% solution of NaCl and 5% solution of H₂SO₄. Tests were carried out at regular intervals of 7 days for a period of 28 days. The solutions are replaced at regular intervals to maintain concentration of solution throughout the test period. The evaluations were conducted after 14, & 28 days from the date of immersion. After removing the specimens from the solution, the surfaces were cleaned and weighed.

b) Water Absorption Assessment

Saturation water absorption test was conducted at the age of 28 days on 100mm cubes in accordance with IS 2185-1979. The water absorption percentage of conventional concrete compared with bacterial concrete. The specimen were weighted before drying in hot air oven 105⁰C. The drying process was continued until the difference in mass between two successive measurements at 24hours interval closely agreed. The dried specimens were cooled at room temperature and then immersed water. The specimens were taken out at regular intervals of time, surface dried and weighed. The difference between the saturated mass and the oven dried mass expressed as the percentage of oven dried mass gives the saturated water absorption. For good concrete the increase in masses should be less than 10% by initial masses

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c) Self-Healing Assessment

To study the crack healing capacity of bacterial concrete cubes with different crack width (0.1mm, 0.22mm, 0.3mm, 0.4mm, 0.45mm and 0.5mm) were casted for this study. Continuous examination carried out to identify the healing capacity. Bacteria (*Bacillus subtilis*) were added along with the water in the concentration 10^5 cells/ml at the time of mixing. Different crack width was made by using feeler gauge blades of required thicknesses. After casting, the specimens were demoulded after 24 hours and at the same time feeler gauge blades removed then immediately submerged in clean fresh water for 100 days. Continuous examination carried out to identify the healing capacity of bacterial concrete.

VII. RESULTS AND DISCUSSIONS

Weight change of Bacterial concrete on exposure with salt water was studied using cubes in accordance with ASTM C267. The weight change percentage was compared for Bacterial Concrete Specimens and Control Specimen.

Table 2: Effect of Bacteria (*B.Subtilis*) on Salt Test

Type of Concrete	Weight Of Cube(Kg)			Percentage Increase In Wt.(28 th day)	Percentage Increase In Wt.(28 th day)
	Initial Wt.	14 th Day Wt.	28 th Day Wt.		
Conventional concrete	2.587	2.598	2.609	0.425	0.85
Bacterial Concrete	2.532	2.535	2.541	0.118	0.36

By immersing the conventional concrete cube specimen in salt water percentage weight increase occurred is 0.85% while for bacterial impregnated concrete is 0.36%. Result obtained is shown in table (2).

Loss of weight of Bacterial concrete on exposure with sulfuric acid was studied using cubes in accordance with ASTM C267. The weight change percentage was compared for Bacterial Concrete Specimens and Control Specimen.

Table 3: Effect of Bacteria (*B.Subtilis*) on Acid Test

Type Of Mix	Weight Of Cube(Kg)			Percentage Loss In Wt.(14 th day)	Percentage Loss In Wt.(28 th day)	Percentage loss in compressive strength
	Initial Wt.(kg)	14 th Day Wt.(kg)	28 th Day Wt.(kg)			
Conventional Mix	2.579	2.5663	2.5537	0.327	0.99	38.71
Bacterial concrete	2.556	2.5496	2.5392	0.25	0.66	14.28

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By immersing the conventional concrete cube specimen in sulphuric acid percentage weight loss occurred is 0.66% while for bacterial impregnated concrete is 0.99%. Result obtained is shown in table (3). Due to the effect of acid 38.71% reduction in compressive strength occurred in case of conventional concrete while for bacterial concrete is only 14.28%.

Saturation water absorption test was conducted at the age of 28 days on 100mm cubes in accordance with IS 2185-1979. The water absorption percentage of conventional concrete compared with bacterial concrete.

Table 5: Effect of Bacteria (*B.Subtilis*) on Water Absorption Test

Type of concrete	Weight of specimen		Water absorption percentage
	Saturated	dried	
Conventional concrete	2.541	2.51	1.24%
Bacterial Concrete	2.52	2.515	0.19%

Conventional concrete shown 1.24% water absorption while for bacterial concrete was 0.19% (table 5). Results showed that bacterial concrete is denser and more durable than the control mix. In bacterial impregnated concrete its pore spaces filled by the bacteria itself or by the bacterial precipitates ie, CaCO_3 . It has the good adhesion between cement and aggregates and by that narrowing of interfacial transition zone takes place which is the weakest zone in concrete. Even dead cells acts like organic fibers with in the concrete matrix.

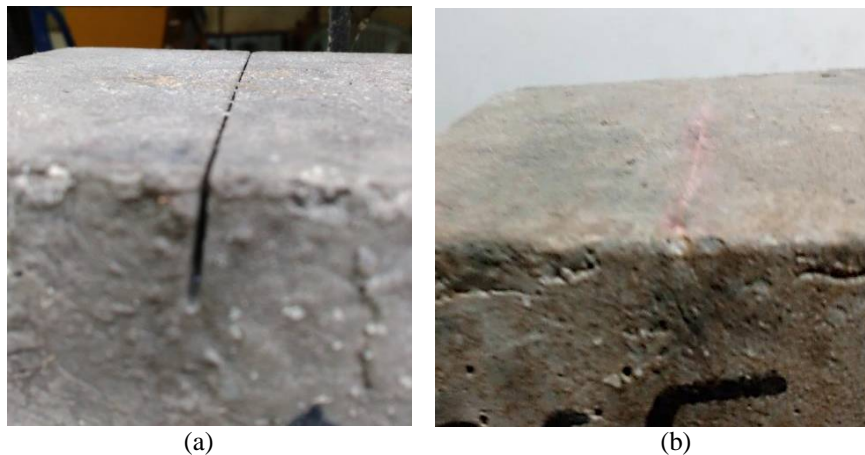


Fig 1: a) Cube with 0.1mm crack width before curing b) Complete healing of crack width 0.1mm after 100 days of curing

After 100 days of curing 0.1mm crack width healed completely (Fig.1) whereas 0.5 mm crack width reduced to 0.42mm, 0.45mm to 0.4mm and 0.22mm to 0.15mm. The self-healing process seems like slow process but it is more sustainable and also it provides long term efficiency. After 100 days of curing specimen with 0.1mm crack width healed completely.

The permeability of concrete depends not only on mix proportion, compaction, and curing but also on micro cracks caused by ambient temperature and humidity cycles. Bacterial impregnated concrete which has the ability to heal micro cracks before they appear as large cracks. Thereby increase the durability of the structure. Self-healing process of bacterial concrete is a slow process but it has long term efficiency compared to other crack arresting methods.

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VIII. CONCLUSION

- After 100 days of curing specimen with 0.1mm crack width healed completely.
- From durability studies, bacterial concrete is denser and more durable than the control mix.

Bacterial impregnated concrete is a special concrete which has the ability to heal cracks and which in turn result in increase in durability properties.

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