

An Experimental Study on Performance of Bacteria in Concrete

C.Mohanasundharam, R.Jeevakkumar, K.Shankar

Abstract: Concrete is the most commonly used building material, the cracks in concrete create problem. Cracks in concrete occur due to various mechanisms such as - shrinkage, freeze-thaw reactions and mechanical compressive and tensile forces. Cracking of the concrete surface may enhance the deterioration of embedded steel bars as ingress rate of corrosive chemicals such as water and chloride ions in to the concrete structure increased. Therefore a novel technique has been developed by using a selective microbial plugging process. One such thought has lead to the development of a very special concrete known as Bacterial Concrete where bacteria is induced in the mortars and concrete to heal up the faults. In this study, *Bacillus Sphaericus* bacteria of concentration 1×10^6 cells/ml are used. The properties of control concrete and bacterial concrete are studied by conducting various tests such as compressive strength, split tensile strength, flexural test with varying grades of concrete M20, M25, M30. This study showed a significant increase in the strength was observed due to the addition of bacteria for a cell concentration of 10^6 cells per ml of mixing water and therefore calcium carbonate precipitation deposited in micro cracks.

Index Terms— *Bacillus pasteurii*, *Bacillus sphaericus*, *Escherichia coli*, *Bacillus subtilis*

I. INTRODUCTION

Bacterial concrete refers to a new generation of concrete in which selective cementation by microbiologically-induced CaCO_3 precipitation has been introduced for remediation of micro cracks. One possible mechanism is currently being investigated and developed in several laboratories. A technique based on the applications of mineral-producing bacteria. Efficient sealing of surface cracks by mineral precipitation was observed when bacteria-based mixtures were sprayed or applied onto damaged surfaces or manually inserted into cracks. As in those studies bacteria were manually and externally applied to existing structures. In several methods the possibility to using viable bacteria as a sustainable and concrete-embedded self healing agent was explored.

Manuscript received October 07,2014

C.Mohanasundharam, Assistant Professors in Civil Engineering, Muthayammal Engineering College, Rasipuram, Namakkal, Tamil Nadu, India.

R.Jeevakkumar, Assistant Professors in Civil Engineering, Muthayammal Engineering College, Rasipuram, Namakkal, Tamil Nadu, India.

K.Shankar, Assistant Professors in Civil Engineering, Muthayammal Engineering College, Rasipuram, Namakkal, Tamil Nadu, India.

In one study spores of specific alkali-resistant bacteria related to the genus *Bacillus* were added to the concrete mixture as self-healing agent.

The impermeability of the specimen improves by the precipitation of calcite. The layer formed by the *Bacillus Pasteur*, thus increasing its resistance to alkaline, sulphate and freeze-thaw attack [1].

Concrete, however, is due to its high internal pH the relative dryness and lack of nutrients needed for growth. A rather hostile environment for common bacteria but there are some extremophilic spore forming bacteria. It may be able to survive in this artificial environment and increase the strength and durability of cement concrete. The incorporation of spores forming bacteria of the species *Bacillus* will not negatively affect the compressive and split tensile strength of the cement concrete [2]. The bacteria were protected in a silical, resulting in the formation of a bio ceramic material (sol-gel or biocer) which was able to bridge the cracks completely.

The crack healing potential was illustrated by microscopic evaluations, ultrasound transmissions measurement and low pressure water permeability tests [3]. As large costs are involved in crack repairs potential of self healing of these cracks by means of calcium carbonate (CaCO_3) precipitating bacteria was investigated in this study. Growth curve for *Bacillus sphaericus* showed that the log phase was between 4-11 hours and after 21 hours the bacterial growth was inhibited. The EDTA titration was useful to find out the amount of CaCO_3 precipitate and it was highest at pH 8 [4, 5].

This study showed a significant increase in the compressive strength was observed due to the addition of bacteria for a cell concentration of 10^5 cells per ml of mixing water. From the durability studies, the percentage weight loss and percentage strength loss with 5% H_2SO_4 revealed that Bacterial concrete has less weight and strength losses than the conventional concrete and it also revealed that bacterial concrete is more durable in terms of "Acid Durability Factor" and "Acid Attack Factor" than conventional concrete [6]. *Bacillus flexus* the isolated species was found to perform better when compared to that of *Bacillus pasteurii* and *Bacillus sphaericus* [7, 1].

The present investigation demonstrates that *Bacillus flexus* have better potential of calcite production than other species; hence this species could be effectively used in MICP. The microbial mineral precipitation was a result of metabolic activities of concrete microorganisms was used to improve the overall behaviour of concrete. It

An Experimental Study on Performance of Bacteria in Concrete

was predicted that bacterial calcium carbonate (CaCO_3) precipitation occurs as a by product of common metabolic processes such as urea hydrolysis. ureolytic bacteria that were capable of precipitating calcium carbonate were isolated and further their urease activity was tested based on the production of urease.

Scanning electron microscopy (SED) analysis revealed the direct involvement of these isolates in calcium carbonate precipitation. The production of the calcite was further confirmed by x-ray diffraction (XRD) and energy-dispersive x-ray (EDX) analysis [8]. *Bacillus sphaericus* is one of the effective biolarvicides to control *Culex* species and the monitoring of larval susceptibility is essential to avoid resistential development. Mosquito larvicidal activity is *B. Sphaericus* was assessed by isolating them from ecologically different soil habitats. The isolates of *B. sphaericus* showed a significant level of variation in their larvicidal activity [9].

II. BACTERIAL CONCRETE

Bacterial concrete refers to a new generation of concrete in which selective cementation by microbiologically-induced CaCO_3 precipitation has been introduced for remediation of micro cracks. As in those studies bacteria were manually and externally applied to existing structures, this mode of repair cannot be categorized as truly self healing. In several follow up studies there is possibility is to use viable bacteria is sustainable and concrete embedded self healing agent was explored.

Need For Bacterial Concrete

The ongoing research in the field of concrete technology has lead to the development of special concrete considering the speed of construction, the strength of concrete, the durability of concrete and the environmental friendliness with industrial material like fly ash, blast furnace slag, silica fume, metakeolin etc. The process can occur inside or outside the microbial cell or even some distance away within the concrete of a bacterial activity is simply trigger a change in solution chemistry that leads to over saturation and mineral precipitation.

Self Healing Property of Concrete

Smaller cracks typically with a crack width smaller than 0.2mm are generally considered as unproblematic. Although such micro cracks do not affect strength properties of structures they do on the other hand contribute to material porosity and permeability. Ingress of an aggressive chemical such as chlorides, sulphates and acids may result on the longer term in concrete matrix degradation and premature corrosion of the embedded steel reinforcement and thus hamper the structures' durability on the long term. Particularly mixtures based on a high binder content show remarkable crack-healing properties what is due to delayed (secondary) hydration of matrix embedded non-hydrated cement and binder particles upon reaction with crack ingress water.

Reason for Bio-Mineralisation Method:

Autogenously self-healing of cracks in traditional but also high-binder content mixtures appear limited to cracks with a width smaller than 0.2 mm. This somewhat limited effectiveness appears largely due to the restricted expansive potential of the small non-hydrated cement particles lying exposed at the crack surfaces. Another limitation of application is highbinder content mixtures solely for the purpose of increasing self-healing capacities are current policies which advocate sparse use of cement in concrete for sustainability reasons as current cement production contributes about 7% to global anthropogenic CO_2 emissions. For latter reasons, alternative and more sustainable self-healing mechanisms are therefore wanted.

Types of Bacteria in The Concrete:

- i) *Bacillus pasteurii*
- ii) *Bacillus sphaericus* (used in the present study)
- iii) *Escherichia coli*
- iv) *Bacillus subtilis*

Survival of Bacteria in Concrete

The starting point of the research was to find bacteria capable of surviving in an extreme alkaline environment. Cement and water has a pH value of more than 13. When mixed together, usually a hostile environment for his life. Most organism die in environment with a pH value of 10 or above. The search concentrated on microbes that thrive in alkaline environments which can be found in natural environments, such as alkali lakes in Russia, carbonate-rich soils in desert areas of Spain and soda lakes in Egypt. Samples of endolithic bacteria (Bacteria that can live inside stones) were collected along with bacteria found in sediments in the lakes. Strains of the bacteria genus *Bacillus* were found to thrive in this high alkaline environment. Different types of bacteria's are incorporated into a small blocks of concrete. Each concretes block would be lefts to two month to set hard. Then the block would be pulverized and the remains tested to see whether the bacteria had survived. It was found that the only group of bacteria that were able to survive were the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. Further it would become activated at the time of cracking, food is available and water seeps into the structure. This induces low pH value of highly alkaline concrete of the range (pH 10 to 11.5).

III. MATERIAL PROPERTIES

A. *Bacillus Sphaericus*:

Bacillus sphaericus is strictly aerobic gram positive rod shaped bacterium. It is an insecticide against certain strains of diseased mosquitoes. *Bacillus Sphaericus* are pore forming bacterium, dormant for several years and would be able to withstand extreme temperature.

B. Cement

Portland Pozzolana Cement (PPC) was used in casting the specimens. PPC is manufactured by the inter grinding of OPC clinker with 10 to 25 percent of Pozzolanic material.

Properties of Cement

- a. Specific Gravity of Cement
- b. Fineness of Cement (Sieve Analysis)
- c. Consistency of Cement
- d. Initial Setting Time

C. Coarse Aggregate

Hard granite broken stones of less than 20mm size were used as coarse aggregate. The specific gravity, fineness modulus, water absorption and bulk density of the coarse aggregate were tested.

Properties of Coarse Aggregate

- a. Specific Gravity
- b. Bulk Density
- c. Water Absorption
- d. Fineness Modulus

D. Fine Aggregate

River sand size less than 4.75 mm size were used as fine aggregate. The specific gravity, fineness modulus, water absorption and bulk density of the fine aggregate were tested.

Properties of Fine Aggregate

- a. Specific Gravity
- b. Bulk Density
- c. Water Absorption
- d. Fineness Modulus

E. Water

Portable water in laboratory with pH value of not less than 6 and the requirement of IS 456-2000 was used for mixing concrete and curing the specimen.

IV. MIX DESIGN

The process of selecting suitable ingredients of concrete and determining their relative proportion with the object of producing concrete of certain minimum strength as economically as possible is known as Mix Design. The mix design is carried out to achieve specified age, workability of fresh concrete and durability requirements by using IS 10262-2009. The following data are required for mix proportioning of a particular grade of concrete.

Grade designation	25 N/mm ²
Type of cement	OPC 53 Grade Cement
Maximum nominal size of aggregate	20 mm
Specific gravity of fine aggregate	2.69
Specific gravity of coarse	2.75

aggregate	
Degree of workability	0.90 compaction factor
Maximum water-cement ratio	0.375
Exposure conditions	mild
Type of aggregate	Crushed angular aggregate

Table.1 Grade of Mix Concrete

Target Mean Strength:

The target mean strength is determined by using the relation $f_t = f_{ck} + kS$

Where f_t - target mean compressive strength at 28 days

f_{ck} - characteristic compressive strength at 28 days

S - Standard deviation

K - Statistical coefficient

$$f_t = 25 + 4.6 (1.64) = 32.54 \text{ N/mm}^2$$

Water-cement ratio:

Corresponding to this target mean strength, the water cement ratio is read from the appropriate curve in IS10262. Hence a water-cement ratio of 0.44 is accepted.

Water cement ratio= 0.375

For mild exposure, w/c=0.55

The lesser is 0.375

The water content is = 188.80 litres/m³

The cement content works out to be 188.8/0.375 = 503.00 kg/ m³

Determination of coarse and fine aggregates:

Now the quantities of coarse and fine aggregates are worked out per m³ of concrete as given below:

Volume of concrete = 1 - 0.02 (Entrapped air)

$$= 0.98 \text{ m}^3 = 980 \text{ liters}$$

The quantity of fine aggregate is found using the equation

$$V = (w + \frac{c}{s_c} + \frac{1}{p} \frac{fa}{s_{fa}}) \frac{1}{100}$$

$$0.98 = (188.79 + \frac{503}{3.15} + \frac{1}{0.35} \times \frac{fa}{2.68})$$

$$f_a = 673.27 \text{ kg/m}^3$$

Similarly, for coarse aggregates,

$$V = (w + \frac{c}{s_c} + \frac{1}{(1-p)} \frac{ca}{s_{ca}}) \frac{1}{100}$$

$$0.98 = (188.79 + \frac{503}{3.15} + \frac{1}{(1-0.35)} \frac{ca}{2.68}) \frac{1}{100}$$

$$c_a = 1250.27 \text{ kg/m}^3$$

V. EXPERIMENTAL RESULTS

A. Tests On Fresh Concrete

Fresh concrete or plastic concrete is a freely mixed material which can be moulded into any shapes. The relative quantities of cement, aggregates and water mixed together, to control the properties of cement in wet and the hardened state.

An Experimental Study on Performance of Bacteria in Concrete

a. Slump Test

Slump test is the most commonly used method of measuring workability of concrete. The apparatus for conduction the slump test consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as follows

Bottom Diameter = 20 cm

Top Diameter = 10 cm

Height = 30 cm

b. Compaction Factor test:

The sample of concrete to be tested is placed on the top hopper upto the brim. The trap door is opened so that the concrete falls into the lower hopper. Then the trap door of the bottom hopper is opened and the concrete is allowed to fall into the cylinder.

Compaction Factor =

Weight of partially compacted concrete

Weight of fully compacted concrete

Casting of Test Specimens

S.No	Name of Specimen	Grade of concrete		
		M20	M25	M30
1	Cubes	6	6	6
2	Cylinder	6	6	6
3	Prism	6	6	6
4	Slab	3	3	3

Table.2 Control concrete

Bacterial concrete

S.No	Grade of concrete	Grade of concrete		
		M20	M25	M30
1	Cubes	6	6	6
2	Cylinder	6	6	6
3	Prism	6	6	6
4	Slab	3	3	3

Table 3: Bacterial concrete



Fig 1: Casted specimens

B. Tests On Hardened Concrete

a. Compressive Strength

Compressive test are made at recognized ages of the test specimens. Least three specimens, preferably from different batches shall be made for testing at each selected age. The load is applied at the rate of 140 kg/cm²/min (approximately) until the failure of the specimen.

Compressive strength, $F_c = P/A$

Where,

F_c = Compressive Strength (N/mm²)

P = Ultimate Load (N) and

A = Loaded Area (150mm x 150mm)



Fig 2: Compressive Testing machine

b. Split Tensile Strength Test

Tensile strength of concrete is determined by splitting the cylinder across the vertical diameter. Split tensile strength is an indirect method of finding out the tensile strength of concrete.

The splitted tensile strength is calculated using the formula,

$$F = 2P / \pi dL$$

Where P = applied load

D = diameter of the specimen

L = length of the specimen



Fig 3: Split tensile Test

c. Flexural Strength Test

The standard size of the specimens 10 x 10 x 50 cm is used. The mould should be made of metal or cast iron, with sufficient plate thickness to prevent spreading or warping. The testing machine may be of sufficient capacity for the testing and rate of loading as specified. The load is applied through the roller placed at middle(central point load). The flexural strength of specimen is expressed as modulus of rupture, f_b .

$$\text{Flexural strength, } f_b = P \times l / (bd^2)$$

Where,

P = Applied load

l = Length of specimen

b,d=Cross section dimensions of specimen.

d. Two point loading:

The specimen is placed in such a manner that the load is applied to the uppermost surface as cast in the mould, along two lines spaced 40 cm apart. The axis of the specimen is carefully aligned with the axis of loading material. The load is applied without a shock and increasing continuously at a rate such that the extreme fibre stresses increasing gradually. The load is increased until the specimen fails, and the maximum applied during the test is recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure is noted.



Fig 4: Flexure test – two point load

VI. CONCLUSION

The examinations of the control concrete and bacterial concrete cubes are done to determine the mechanical properties. The results reveal that the bacteria incorporated concrete specimens shows better compressive strength after 7th and 28th days of curing than control concrete. The percentage of increase in compressive test at 7 days of curing are 6.22%, 4.23% and 4.85% for M20, M25 and M30 grade of concrete respectively. Similarly, at 28 days of curing, are found to be 7.62%, 5.02%, 6.92% for M20, M25 and M30 grade of concrete respectively. The split tensile strength of cylindrical specimens at the end of 7 days and the percentage increase are found to be 9.04%, 13.62%, 10.73% for M20, M25 and M30 grade of concrete respectively. Similarly, for 28 days of curing are to be 3.07%, 1.41%, 1.82% for M20, M25 and M30 grade of concrete respectively. The flexural strength of prismatic beam specimens at the end of 7 days and the percentage

increase are to be 12.12%, 15.29%, 6.89% for M20, M25 and M30 grade of concrete respectively. Similarly, for 28 days are to be 4.58%, 2.09%, 1.91% for M20, M25 and M30 grade of concrete respectively.

From the above results, due to the incorporation of bacteria the compressive strength of concrete increases remarkably. The split tensile strength and flexural strength were increases for 7 days of curing. But after 28 days, very small amount of strength is increased. The bacteria incorporated R.C.C. slab specimen withstands more load before starts yielding than that of control concrete slab specimen.

REFERENCES

- [1] International Journal Of Advanced Biotechnology And Research, ISSN 0976-2612, VOL 3, ISSUE 1, 2012, PP 541-544, "Potential Application Of Bacteria To Improve The Strength Of Cement Concrete", Author: C. C. Gavimath, B. M. Mali, V. R. Hooli, J. D. Mallpur, A. B. Patil, D. P. Gaddi, C.R.Ternikar.
- [2] "Improvement Of Concrete Durability By Bacterial Mineral Precipitation", V. Ramakrishnan, Ramesh K. Panchalan & Sookie S. Bang.
- [3] Concrete Repair, Rehabilitation And Retrofitting Ii, Isbn 978-0-415-46850-3 "Crack Repair In Concrete Using Biodeposition", N. Debelie & W. De Muynck.
- [4] Second International Conference On Sustainable Construction Materials And Technologies, June 28-30, 2010. "Potential Of Applying Bacteria To Heal Cracks In Concrete", J.Y. Wang, K. Van Tittelboom, N. De Belie And W. Verstraete.
- [5] International Journal Of Engineering Science & Technology, Vol. 2(3), 2010, 270-277. "Studies On The Characterisation Of Biosealant Properties Of Bacillus Sphaericus", Author:Kantha D.Arunachalam, K.S.Sathyarayanan, B.S.Darshan, R.Balaji Raja.
- [6] Asian Journal Of Civil Engineering (Building And Housing) Vol. 11, No. 1 (2010) Pages 43-55 "Performance Of Standard Grade Bacterial (Bacillus Subtilis) Concrete", S. Sunil Pratap Reddy, M.V. Seshagiri Rao, P. Aparna And Ch. Sasikala.
- [7] International Journal Of Advances In Engineering & Technology, March 2013. "Bio Mineralisation Of Calcium Arbonate By Different Bacterial Strains And Their Application In Concrete Crack Remediation", Jagadeesha Kumar B G, R Prabhakara, Pushpa.
- [8] African Journal Of Biotechnology, Vol. 10(42), Pp. 8359-8372, 8 August, 2011, "Calcium Carbonate Precipitation By Different Bacterial Strains", Navneet Chahal, Anita Rajor And Rafat Siddique.
- [9] Academic Journal Of Entomology 4(1): 17-22, 2011, Issn 1995-8994, "Occurrence And Distribution Of Mosquitocidal Bacillus Sphaericus In Soil", A. Surendran And S. John Vennison.