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STUDY ON STRENGTH AND SELF-HEALING PROPERTIES OF BACTERIAL CONCRETE

P. Rajesh[1], S. Jagan[2], S.R. Ramprasanna[3] & K.S. Naresh[4]

[1]Student, School of Environmental and Construction technology, Kalasalingam Academy of Research and Education, Krishnankoi, Tamil Nadu, India– 626 126

[2]Assistant Professor, Student, School of Environmental and Construction technology, Kalasalingam Academy of Research and Education, Krishnankoi, Tamil Nadu, India– 626 126

[3]Assistant Professor, Student, School of Environmental and Construction technology, Kalasalingam Academy of Research and Education, Krishnankoi, Tamil Nadu, India– 626 126

[4]Sr. Asst Professor, Student, School of Environmental and Construction technology, Kalasalingam Academy of Research and Education, Krishnankoi, Tamil Nadu, India– 626 126

ABSTRACT

Concrete is a heterogeneous material which has the ability of accepting whatever added to it. But one such important snag is the low tensile nature of concrete which makes it more liable to cracking. Sustained loading on the crack increases the crack mouth opening which makes it prone to entry of harmful oxides and atmospheric air into concrete. This in turn reduces the durability of the concrete. This research focuses on enhancing the strength and durability of concrete by addition of bacterial species in concrete. In this research, *bacillus subtilis* cultured on *Luria Bertani* agar for 30 days was used as bacterial species. Bacterial species was added at the rate of 10ml, 20ml and 30ml in concrete. Calcium lactate was used at the rate of 0.1mol/l in concrete for the calcium mineral precipitation to fill up the cracks in concrete. Various strength studies like compressive strength, split tensile strength, flexural strength and water absorption capacity were discussed. Self-healing mechanism of concrete through calcium lactate was also discussed.

Keywords : Bacillus subtilis, Calcium lactate, Luria Bertani gar, Compressive strength, Split tensile strength, Flexural strength and self-healing.

I. INTRODUCTION

Concrete is a heterogeneous material most widely used for construction purpose. Even though good workable concrete is made, there is possibility of development of shrinkage cracks. Through this shrinkage cracks CO_2 present in the atmosphere may propagate and exert pressure on the interfacial zone, as a result of which concrete structure gets deteriorated. There are many ways to rehabilitate those concrete structures externally. But it need some extra cost, supervision and skilled workmanship. A recent innovation of inducing bacterial species in concrete overcomes the problems we face when we rehabilitate the structure externally. These Bacterial species will consume the food calcium lactite that we add while casting the concrete specimens. When the concrete specimens crack, these bacterial species consume calcium lactite and seal the cracks without any external agent support. So such bacterial concrete is popularly known as self healing concrete. The concept of bacterial concrete was first introduced by V. Ramakrishnan et al. and utilize the microbiologically induced calcite (CaCO3) precipitation the adoptednovel technique is remediating cracks and fissures in concrete. a broader category of MICP is a technique that comes under science is called bio mineralization. Microbiologically induced calcite precipitation is highly desirable because the result of microbial activities, is pollution free and natural. The technique can be used to improve the compressive strength and stiffness of cracked concrete specimens. The bacterial concrete makes use of calcite precipitation by bacteria. This is called MICP. Under favorable conditions Bacillus Subtilis, when used in concrete, can continuously precipitate a new highly impermeable calcite layer over the surface of the already existing concrete layer. The precipitated calcite has a coarse crystalline structure that readily adheres to the concrete surface in the form of scales. In addition to the ability to continuously grow upon itself, it is highly insoluble in water. It resists the penetration of harmful agents (chlorides, sulphate, and carbon dioxide) into the concrete thereby decreasing the deleterious effects they cause. Due to its inherent ability to precipitate calcite continuously, bacterial concrete can be called a ―Smart Bio Material‖ for repairing concrete. The MICP comprises a series of complex biochemical reactions. It is selective and its efficiency is affected by the porosity of the medium, the number of cells present and the total volume of nutrient added. [1] Studied the properties of bacterial concrete when cement partially replaced with fly ash and GGBS. Research was done by utilizing Bacillus Pasteurii at a rate of 10^6 in M40 grade mix. GGBS and fly ash were replaced at 10% by weight of cement. Various hardened property test such as compressive strength, indirect tensile strength and fresh property analysis were done. Research were done with various combinations like conventional concrete, concrete with bacteria, bacterial concrete with fly ash alone, bacterial concrete with GGBS and bacterial concrete with the combination of both GGBS and fly ash. Results reveal that workability gets affected by addition of pozzolanic materials than by addition of only bacteria. Addition of pozzolanic material separately increases the strength by 15% to 20%, whereas the addition of combined pozzolanic material doesn't show much improvement. [2] Studied the isolation and identification of bacteria to improve the strength of concrete. Bacillus megaterium (B.M), Bacillus licheniformis (B.L) and Bacillus flexus (B.F) were the cultured bacteria used in this research. Strength and self-healing mechanism was enhanced by calcite was analyzed by scanning electron microscope. Around 4 different mix combinations such as conventional mix (without bacteria), concrete mix with B.M, concrete mix with B.L, concrete mix with B.F were prepared. Bacterial specimens were added at a rate of 10^5 cells/ml in concrete. Results revealed that these three mix combinations showed better strength compared to conventional concrete. Width of the propagated cracks gets reduced by addition of bacterial species. This is due to the formation of calcite crystals which seals up the cracks and also it plays a major role in enhancing the strength of concrete. [3] Studied the temperature effect of various bacteria used in microbial concrete. Bacillus sphaericus and bacillus cereus collected from National collection of Industrial Microorganisms were used. These bacterial species were used at a rate of 10^0, 10^4,10^5 ,10^6 and 10^7 in concrete. By varying the temperature, compressive strength and water absorption analysis were done by using these bacteria at these levels of cell concentration. Results reveal that bacillus sphaericus can be used in concrete at lower temperature and bacillus cereus can be used in concrete at higher temperature. [4] Investigated the property of self-healing concrete. Bacillus Sphaericus were used at a rate of 10ml and 15ml/m^3 of concrete. Various tests like slump cone, compressive strength, split tensile strength and flexural strength tests were carried out to study the property of self-healing concrete. Results reveal that concrete containing 20ml of bacillus sphaericus shows better results than 10ml. Self-healing mechanism also interpreted the positive results in reducing the width of concrete by using bacillus sphaericus. [5] Studied the effect of bacteria on various cell concentrations on strength of concrete. In study M sand is also replaced with 40% by weight of river sand in concrete. E.coli was replaced at the variation of 10^5 to 10^7 cells/ml and various tests like compressive strength, indirect (split) tensile strength, flexural strength and shear strength was done. SEM analysis was also done to study the formation of calcite preparation. Results reveal that strength atthe concentration of 10^5 cells/ml with 40% M sand shows better results than at 10^5 cells/ml concentration.

II. EXPERIMENTAL INVESTIGATION:

Around 24 specimens were casted for the research in which it includes 12 cubes of size 150mm*150mm*150mm, 6 cylinders of size 150mm*300mm and 6 prisms of size 500mm*150mm*150mm. M50 grade concrete of mix ratio 1:0.82:2.5:0.45 with bacillus subtilis at the rate of 10ml,20ml and 30ml were prepared. OPC of 53 grade, fine aggregate passing through 4.75mm sieve, coarse aggregate of 20mm size and water specifying the requirements of IS456:2000 were used as ingredients to prepare the concrete mix. Concrete mix were prepared as per standards and specimens were casted and allowed to dry for 24 hours. Dried specimens were then cured for 28 days and tests were carried as per Indian Standards.

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FIGURE 1. Casting of Concrete Specimens

III. RESULTS AND DISCUSSION

3.1 Slump Cone Test:
Slump test was done as per IS 1199 to check the workability of concrete. Slump cone apparatus comprises of a cone shaped structure with height of 30cm, top diameter of 10cm and bottom diameter of 20cm. Based on the results, nature of slump is decided as true, collapse or shear and presented in table 1.

TABLE 1. Slump Test for M50 Grade

	Amount of Bacteria (ml)	Value of Slump (mm)	Nature of Slump
1	0	119mm	True Slump
2	10	125mm	True Slump
3	20	127mm	True Slump
4	30	131mm	True Slump

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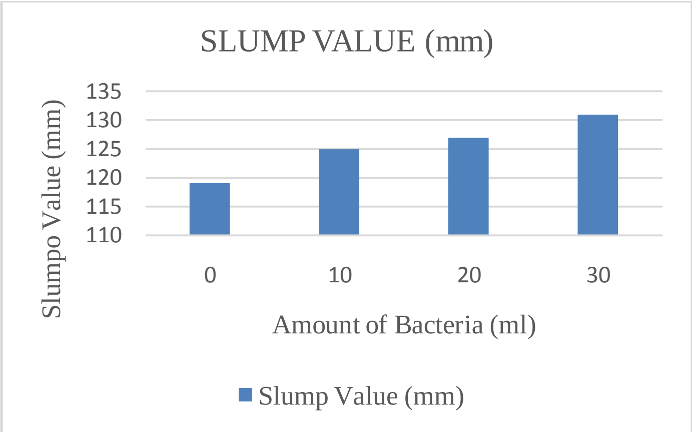

FIGURE 2. Slump Value for M50 Grade

3.2 Compressive Strength Test:

Compressive strength test was done on 150mm*150mm*150mm specimen specifying the requirements of IS516. The test was carried on cube specimens using Compression Testing Machine and results were obtained and given in table 2.

TABLE 2.Compressive Strength at the Age of 7 Days and 28 Days

S. No	Amount of bacteria (ml)	Compressive Strength (Mpa)	
		7 Days	28 Days
1	0	32.15	50.71
2	10	40.14	59.43
3	20	42.07	62.65
4	30	45.53	68.19

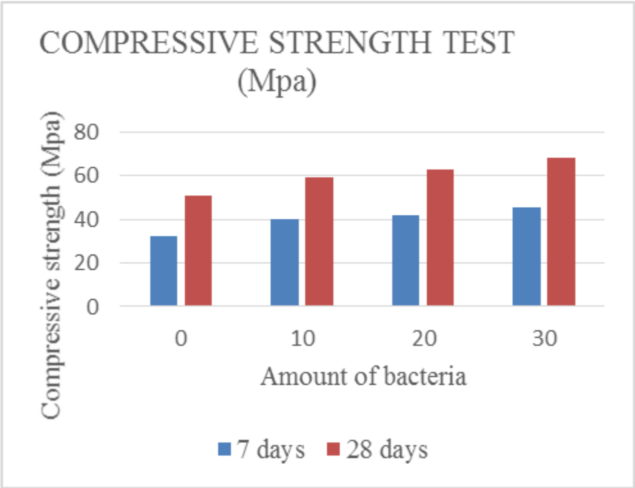

FIGURE 3. ***Compressive strength at the age of 7 days and 28 days***

3.3 Split Tensile Strength Test:

Split tensile strength test was done at 150mm*300mm cylindrical specimens specifying the requirements of IS 516. Cylindrical specimens were casted meeting the requirements of IS 10262 and surface dried for 24 hours and cured for 28 days. The test was conducted on cylindrical specimens using Universal Testing Machine and results were obtained and presented in table 3.

TABLE 3.Split Tensile Strength at the age of 7 Days and 28 Days

S. No	Amount of bacteria (ml)	Split tensile strength (Mpa)	
		7 Days	28 Days
1	0	3.024	4.514
2	10	3.271	4.883
3	20	3.491	5.120
4	30	3.625	5.317

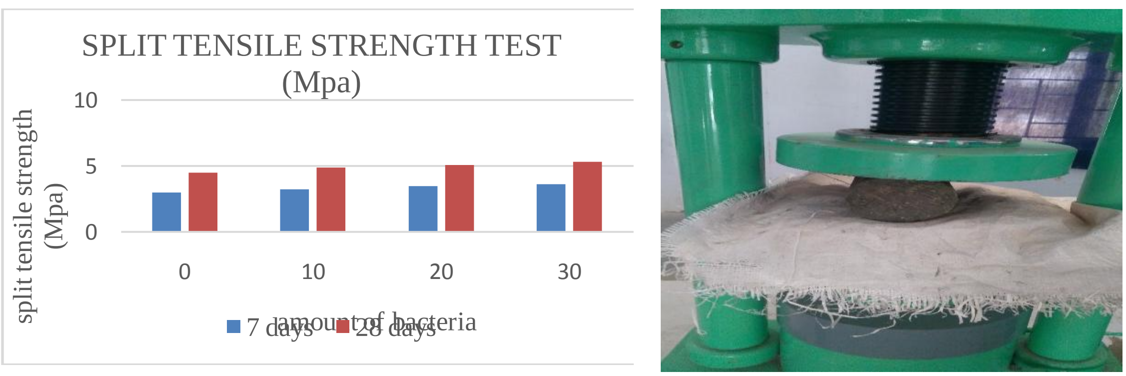

FIGURE 4. Split tensile strength at the age of 7 and 28 Days

3.4 Flexural Strength Test:

Flexural strength test was done at 500mm*100mm*100mm beam specimens specifying the requirements of IS 516. Beam specimens were casted meeting the requirements of IS 10262 and surface dried for 24 hours and cured for 28 days. The test was conducted on beam specimens using Flexural Testing Machine and results were obtained and presented in table 4.

TABLE 4. Flexural strength at the age of 7 Days and 28 Days

S. No	Amount of bacteria (ml)	Flexural strength Test (Mpa)	
		7 Days	28 Days
1	0	5.006	7.473
2	10	5.515	8.232
3	20	5.809	8.671
4	30	6.074	9.067

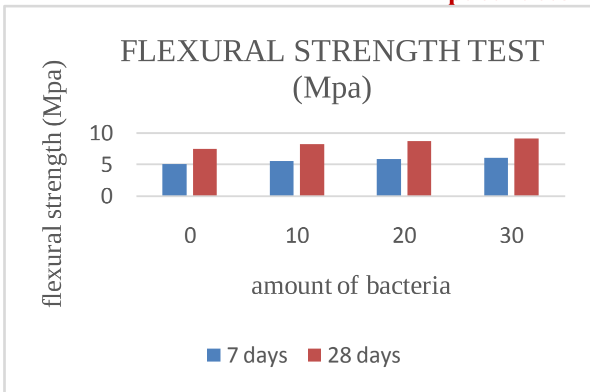

FIGURE 5. Flexural strength at the age of 7 days and 28 days

3.5 Water Absorption:

Water absorption test was done on cube specimens of size 150mm*150mm*150mm to evaluate the rate of permeability of water meeting the standards of ASTM D570. After measuring the initial weight of specimen, the specimens were immersed in water for 28 days. Resulting weight will give the rate of permeability of water through the specimen. The test was conducted and results were obtained and presented in table 5.

TABLE 5. Water absorption after 28 Days

S. No	Amount of bacteria (ml)	Water Absorption after 28 days (%)
1	0	2.26
2	10	1.78
3	20	1.53
4	30	1.25

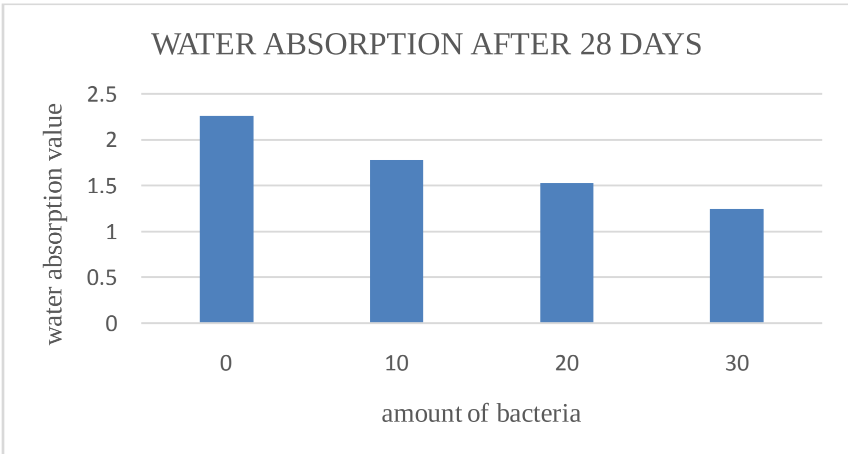

FIGURE 6. Water Absorption at the age of 28 Days

3.6 Self-Healing Mechanism:

Cracks develop in concrete by various means such as improper casting, curing and external loading etc. So to overcome such cracks bacteria along with calcium lactate was added in concrete while casting. This bacteria will be dormant for around 200 years leading to the precipitation of $CaCO_3$ which involves in the process of sealing up the cracks in concrete. Small cracks in concrete may vary from 0.05mm to 0.1mm Cracks were created manually on cube specimens of size 150mm*150mm*150mm by using aluminum plate on the top surface after 28 days of curing. The depth of the crack varies from 10mm to 30mm at an interval of 10mm each and width of the crack varies from 1mm to 3mm at an interval of 1mm each

(A) Before Self-Healing

(B) After Self- Healing

FIGURE 7. Self-Healing Mechanism

IV. CONCLUSION

- From the experimental investigation it is clear that the optimum level of replacement of bacillus subtilis in concrete is around 30ml. Compressive strength for Bacillus subtilis impregnated concrete of around 30ml shows increase in compressive strength of around 25.63% than conventional concrete at 28 days. This is due to the formation of calcite crystal which plays a major role in strength improvement of concrete.
- Split tensile strength of concrete containing 30ml of bacillus subtilis shows 15.10% increase compared to conventional concrete, 8.162% compared to 10ml addition of bacteria and 3.70% compared to 20ml addition of bacteria at the age of 28 days. As discussed earlier this strength gain is also due to the formation of calcite crystals.
- Flexural strength of concrete containing 30ml of bacillus subtilis shows 17.58% increase compared to conventional concrete, 9.21% compared to 10ml addition of bacteria and 4.37% compared to 20ml addition of bacteria at 28 days. Increase in strength is observed at only marginal rate as a result of calcite formation.
- Water absorption results interpret bacillus subtilis shows higher resistance to water absorption than conventional concrete at 28 days. The Water absorption for 30ml addition of bacteria is 44.7% lesser than the conventional concrete. This in turn will enhance the concrete strength and will pave way for improving more durability properties of concrete. This is mainly due to the precipitated calcite in coarse crystalline form which make the concrete less susceptible to entry of water as well as other harmful agents into the concrete.
- Experiments conducted by creating manual cracks of varying sizes revealed that bacillus subtilis act as a proper self-healing agent in remediation of cracks in concrete. Reduction in size of cracks were clearly observed at the age of 28 days. This is due to the precipitated calcite crystal fill up the cracks on the top surface and thereby reducing the cracks in concrete

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