Influence of Bacteria on Durability of Concrete by Bacterial Mineral Precipitation

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Abstract— Most of the world population is getting urban centric and as a result the use of concrete is swiftly increasing worldwide, however is that its immense production exerts adverse impact on the environment. An innovative approach to reinstate or remediate such structures is bio mineralization of calcium lactate to calcium carbonate using microbes, such as Bacillus species (viable but dormant bacteria). The present study investigated the effects of Bacillus pasteurii on compressive strength, flexural strength, water permeability and rapid chloride penetration test on three samples having different proportions. The results indicated a maximum of 12.67% increase in initial compressive strength, 10.54% in final compressive strength and 18.67% increase in flexural strength of cement mortar cubes. Minimum depth of water penetration was found to be 20.43mm while the chloride penetration of concrete changed from "moderate" to "low" when compared with controlled cubes for M40 grade of concrete. The results clearly showed microbially induced calcium carbonate precipitation can be applied for several building materials for enrichment of durability.

Key words: Bacterial Mineral, Bacteria on Durability

I. Introduction

Concrete is a strong and relatively cheap construction material and its basic ingredients (cement, water, aggregates) are readily available. It has specialty of being cast in any desired shape but plain concrete however possesses very low tensile strength, limited ductility and little resistance to cracking. One drawback, however is that its massive production exerts negative impact on the environment. However, durability of concrete may be meet halfway due to many man-made factors and natural consequences. It is most effective when reinforced by steel bars, mainly because its tensile strength is substantially low related to its compressive strength. It is also a very brittle material with low tolerance for strain. The deterioration of concrete structures usually comprises of movement of aggressive gases and/or liquids from surrounding environment into the concrete, followed by physical and/or chemical reactions within its internal structure, possibly leading to irreversible damage [1] Normally these cracks can occur at any phase of its life and mostly begin internally where they cannot be observed for years until major repairs are required. Thus inspection and maintenance practices for concrete structures have received considerable attention. Constant examination and maintenance is challenging due to the cost and the amount of labor hours are required.

For concrete buildings, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and subsequent reduction in the strength, serviceability and aesthetics of the structure. The pore structure on concrete allows permeation of harmful chemicals. Progressive dissolution of the mineral matrix as a consequence of weathering leads to an increase of the porosity and as result, the mechanical features decrease [2]. Concrete is also susceptible to cracking due to a number of factors such as shrinkage, excessive heating and water, freeze thaw, tensile stress and creep. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure by using relatively impenetrable concrete. Sometimes repairs cannot be carried out in the areas where it is not possible to shut down the plant. An autogenously healing system that remediates cracks with materials similar to that of concrete and goes deeper inside the crack rather than the surface treatment would be of great benefit.

Concrete constructions are currently designed according to set norms that allow cracks to form up to 0.2 mm wide. Such micro cracks are generally acceptable, as these do not directly impair the safety and strength of a construction. Autogenous crack healing capacity of concrete has been recognized in several recent studies [4]. A number of studies reported that under certain circumstances, small cracks in concrete can heal [3].This phenomenon is known as 'Autogenous healing or self-healing' of concrete. As regular maintenance and repair of the concrete is costly and in some cases not at all possible, inclusion of an autonomous self-healing repair mechanism would be highly beneficial as it could both reduce maintenance and increase material durability. Microbially induced calcium carbonate precipitation is a naturally occurring biological process that has various applications in remediation and restoration of range of building materials [5]. A novel strategy to restore or remediate such structures Bacillus species (viable but dormant bacteria).

II. Experimental procedure

A. *Materials and Methods*

Ordinary Portland cement 53 grade was used as per IS 12269(1987). Course aggregates of 20mm and 10mm retained at 4.75 mm and crushed sand for fine aggregates were used. Physical and chemical properties are listed in table 1 and 2.

Sr No.	Test conducted	Results	Requirements as per IS 12269:2013
1	Consistency	29%	Not specified
2	Initial Setting Time	170 minutes	Shall not be less than 30 minutes
3	Final Setting Time	275 minutes	Shall not be more than 600 minutes
4	Compressive Strength at 28 days	60 Mpa	Shall not be less than 53 Mpa
5	Fineness Test (by Blain's air permeability method)	292m^2/Kg	Shall not be less than 225m^2/Kg

6	Soundness Test (by Le-Chatelier's Test)	0.50 mm	Shall not be more than 10 mm
7	Soundness Test (by Autoclave expansion method)	0.14%	Shall not be more than 0.8%
8	Density	3.15 gm/cc	Not specified

Table 1: Physical Properties of Cement

Sr No.	Test conducted	Results	Requirements as per IS 12269:2013
1	Lime Saturation Factor	0.90	Shall lie between .80-1.02
2	Ratio of percentage of Alumina to that of Iron Oxide	1.40	Shall not be less than 0.66
3	Insoluble Residue (% by mass)	1.20	Shall not be more than 4.0
4	Magnesia (% by mass)	1.20	Shall not be more than 6.0
5	Sulphuric An hydrate (% by mass)	1.85	Shall not be more than 3.5
6	Total loss on Ignition %	1.10	Shall not be more than 4.0

Table 2: Chemical Properties of Cement

B. Microorganism, Growth Conditions and Culture Medium

The strain *Bacillus pasteurii*, American type culture collection, ATCC 11859 is procured from National Chemical Laboratory under Council of Scientific and Industrial Research, Pune having NCIM Accession no. -2477, propagation medium 41 and propagation temperature 30°C.

Selected culture medium is *Nutrient Broth* which were cultured to check their morphology on Nutrient Agar. Final pH (at 25°C) 7.4±0.2.

The general composition of a medium is as follows:

1) Nutrient Broth: Which contains
   Peptic digest of animal tissue-5g/l,
   Sodium chloride-5g/l,
   Beef extract-1.5g/l,
   Yeast extract-1.5g/l.
   The desired culture medium is obtained from HIMEDIA Laboratory, Mumbai.
2) Calcium Chloride: CaCl2.10H2O
3) Urea: NH2.CONH2,
   Molecular Weight- 60.06
   Assay- min 90%
   Melting Point- 131-134 °C
   Sulphated ash- <0.1%
   Chloride- <0.002%
   Sulphate- <0.05%

In this experimental work the microbial culture are made in three different proportions.

Type A	Nutrient Broth + Live cells of *B.pasteurii*	13gm of nutrient broth into 1000ml + 10^7 cell concentration of Live cells.
Type B	Nutrient Broth + Urea + calcium chloride + Live cells of *B.pasteurii*	8gm of nutrient broth into 1000mL + 2% urea + 25mM of calcium chloride + 10^7 cell concentration of Live cells.
Type C	Nutrient Broth + Urea + Endospore of *B.pasteurii* + calcium chloride.	8gm of nutrient broth into 1000mL + 2% urea + 25mM of calcium chloride + 10^7 cell concentration endospores.

Table 3: Types of Mix

C. Compressive Strength Test

The cubical moulds of size 150mm x 150mm x 150mm were cleaned and checked against the joint movement. A coat of oil was applied on the inner surface of the moulds and kept ready for the concreting operation. Meanwhile the required quantities of cement, sand and aggregate for particular mix were weighed and accurately added. The bacterial culture or water-to-cement ratio was 0.42. Fine aggregates and cement were thoroughly mixed in pan mixer and then rotated until uniform mixture was obtained. Then, calculated quantity of bacterial solution and water was added and mixing was continued for about 3-5 minutes to get a uniform mix. The wet concrete was then poured into moulds and for every 2-3 layers were well compacted. Level the surface and mark indications over them and then the cubes were tested for 3,7,14 and 28 days in compressive testing machine.

D. Flexural Strength Test

Beam of size 700mm x 150mm x 150mm has been casted, So the moulds were cleaned and the joints between the sections of moulds shall be thinly coated with mould oil and similar coating of mould oil has been applied between the contact surfaces of the moulds and the base plate in order to ensure that no water escapes during filling. The interior faces of the assembled moulds shall be thinly coated with oil to prevent adhesion of the concrete. Meanwhile the required quantities of cement, sand and aggregate for particular mix were weighed and accurately added. The bacterial culture or water-to-cement ratio was 0.42. Fine aggregates and cement were thoroughly mixed in pan mixer and then rotated until uniform mixture was obtained. Then, calculated quantity of bacterial solution and water was added and mixing was continued for about 3-5 minutes to get a uniform mix. The wet concrete was then poured into moulds and for every 2-3 layers were well compacted. Level the surface and mark indications over them and then the beam were tested for 28 days.

E. Rapid Chloride Ion Penetration Test ASTM C 1204-94

The tests were performed using 2 in. (51 mm) long, 3.75 in. (95 mm) diameter cylindrical specimens cut from cores obtained with a diamond-dressed coring bit (alternatively, tests are performed using 4 in. (100 mm) diameter cast cylinders, and the test values are normalized using the ratio of the standard to the actual cross-sectional areas). After the curved surface of a test specimen is coated with epoxy, the specimen is vacuum saturated with water and then soaked for 18 hours. The specimen then placed in the testing apparatus where one end of the specimen is exposed to a solution containing sodium chloride (NaCl) and the other end is exposed to a solution containing sodium hydroxide (NaOH). To increase the rate of chloride penetration into the specimen, thus speeding up the test, a constant 60 V potential is applied across the specimen. The current across the specimen is measured at least every 30 minutes during the 6-hour test.

F. Water Permeability Test (Din 1048: Part 5)

This test gives a measure of the resistance of concrete against the penetration of water exerting pressure. It shall normally be carried out when the age of the concrete is 28 days. For this test, controlled and bacteria treated specimens are casted and placed inside the permeability cell at age 28 days, the water is introduced on the top of the cell and the pressure of 0.5 N/mm2 is applied in way to force the water to penetrate through the sample. The measurement of the permeability is carried out by a method based on water penetration depth after 96 hrs. Water with a colour indicator is used, which helps to determine the border of penetration depth. If water penetrates through to the underside of the specimen, the test may be terminated and the specimen rejected as failed. The mean of the maximum depth of penetration from three specimens thus tested shall be taken as the test result.

G. Results and Discussions

1) Compressive Strength Test: - Cube mould size 150 X 150 mm

	Controlled MPa	Type A MPa	Type B MPa	Type C MPa	Max % increase
3Days	26.84	29.19	30.24	29.54	12.67
7 Days	37.76	40.07	41.75	38.74	10.56
14Days	45.42	47.89	49.85	48.05	9.75
28Days	55.97	57.09	61.87	59.62	10.54

Table 4: Results of Compressive Strength Test

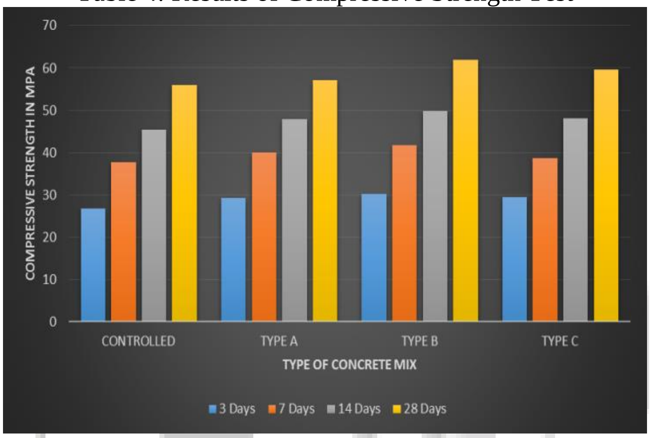

Fig. 1: Graph Representation of Compressive Strength Test

Graph 1 summarizes the 3, 7, 14, 28 days compressive strength of different concrete mix. The compressive strength had significantly increased for the specimen that contained microbial cells. The highest compressive strength was obtained from Type B specimen on 28 days test (61.87 Mpa). The maximum increase in compressive strength was found to be 12.67% for 3 days test and 10.54% for 28 days test.

2) Flexural Strength Test: - Beam of 700 X 150 X 150 mm

	Controlled N/mm^2	Type A N/mm^2	Type B N/mm^2	Type C N/mm^2	Max % increase
28Days	5.14	5.91	6.10	5.88	18.6

Table 5: Results of Flexural Strength Test

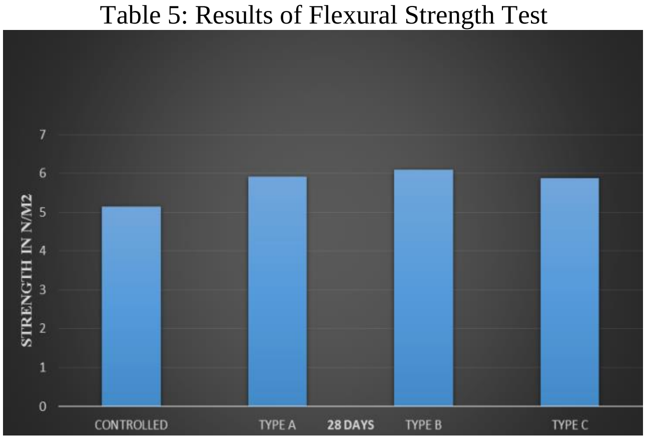

Fig. 2: Graph Representation of Flexural Strength Test

Graph 2 summarizes the 28 days Flexural strength of different concrete mix. The Flexural strength had significantly increased for the specimen that contained microbial cells. The highest flexural strength was obtained from Type B specimen on 28 days test (6.10 N/mm^2). The maximum increase in flexural strength was found to be 18.6% for 28 days test.

3) Rapid Chloride Ion Penetration Test ASTM C 1204-94

	Controlled	Type A	Type B	Type C
28 Days	3450	2508	1892	1979

Table 6: Results of Rapid Chloride Ion Penetration Test ASTM C 1204-94

4) Charge Passed (In Coulombs)

Charge (Coulombs)	>4000	2000 to 4000	1000 to 2000	100 to 1000	<100
Chloride Penetrability	High	Moderate	Low	Very Low	Negligible

Table 7: Results of Rapid Chloride Ion Penetration Test ASTM C 1204-94

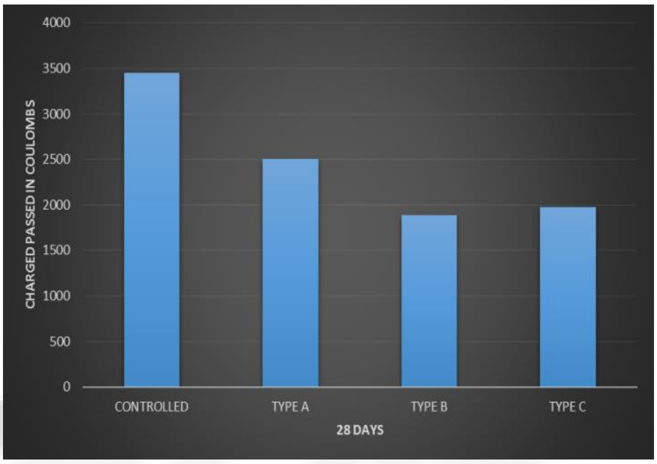

Fig. 3: Graph Representation of Rapid Chloride Ion Penetration Test

Graph 3 summarizes the 28 days Rapid Chloride Ion Penetration Test of different concrete mix. The Rapid Chloride Ion Penetration Test had significantly decreased for the specimen that contained microbial cells. The lowest Chloride Ion Penetration t was obtained from Type B specimen on 28 days test (1892 Coulombs). The Rapid Chloride Ion Penetration Test showed the result where chloride penetration of concrete changed from “Moderate” to “Low”.

5) Water Permeability Test (Din 1048: Part 5)

	Controlled	Type A	Type B	Type C
28 Days	23.12	24.23	21.18	20.43

Table 8: Results of Water Permeablity Test

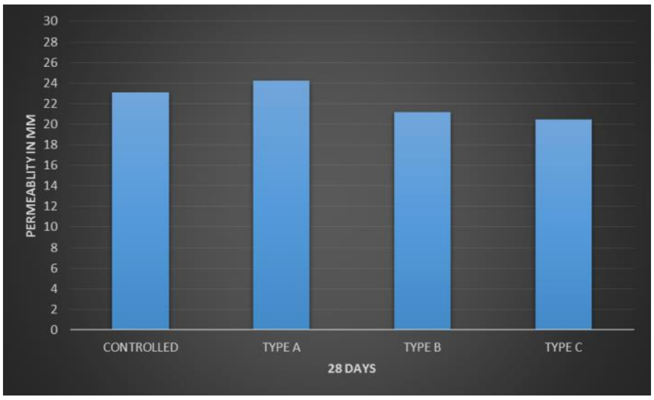

Fig. 4: Graph Representation of Water Permeability Test

Graph 4 summarizes the 28 days Water permeability test of different concrete mix. The Water permeability test had significantly decreased for the specimen that contained microbial cells. The lowest Water permeability was obtained from Type C specimen on 28 days test (20.43 mm). The Water permeability test showed the result where Water permeability of concrete is acceptable.

III. Conclusion

The addition of Bacillus pasteurii in concrete mix improves the compressive strength by an increment of 12.67% for 3 days test and 10.54% for 28 days test when compared with controlled mix which gives us the indication about the benefits of adding this microorganism.

The addition of Bacillus pasteurii in concrete mix also increases the flexural strength by an increment of 18.6 % for 28 days test when compared with controlled mix.

These two tests showed the benefit of adding Bacillus pasteurii for strength characteristics and results shows it can be used to increase the strength.

Now taking the durability factor into account The Rapid Chloride Ion Penetration Test showed the result where chloride penetration of concrete changed from “Moderate” to “Low” and lowest water permeability in treated cubes when compared with controlled ones which shows that this microorganism also plays key role in durability factor along with strength.

References

[1] Claisse, E, P. A., Elsayad, H. A., and Shaaban, I.G (1997). “Absorption and sorptivity of cover concrete.” J. Mater. Civ. Eng., 9(3), 105-110.

[2] Tiano, P., Biagiotti, L., and Mastromie, G. (1999).”Bacterial bio-mediated calcite precipitation for monumental stones conservations: methods of evaluation.” J. microbial. Methods, 36(1-2).133-145.

[3] Aldea, C., Song, W., Popovics, J., and Shah, S. (2000). “Extent of Healing of Cracked Normal Strength Concrete.” J. Mater. Civ. Eng., 10.1061.

[4] Neville AM (2002) Autogenous healing- A concrete miracle? Concrete Int 24(11):76-82.

[5] P. Ghosh ., S Mandal., B.D. Chattopadhyay (2005): “Use of Microorganism to improve the strength of cement mortar” Cement and Concrete Research 35(2005) 1980-1983.

[6] HenkM.Jonkers& Erik Schlangen (2008): “Development of a bacteria-based self-healing concrete” Tailor Made Concrete Structures- Walraven & Stoelhorst.

[7] Henk M.Jonkers “Application of bacteria as self-healing agent for the development of sustainable concrete” Ecological Engineering 36(2010)230-235.

[8] Varenyam Achal , Abhijeet Mukherjee, and M.S. Reddy “Microbial concrete: Way to enhance durability of building structures”. Journal of material in civil engineering © ASCE/JUNE 2011/731. DOI: 10.1061/ (ASCE) MT.1943-5533.0000159.

[9] Achal V., Mukherjee A., Reddy M. S., (2013) Biogenic treatment improves the durability and remediates the cracks of concrete structures, J Construction and Building Materials.

[10] Ravindranatha, N. kanan, Likhit M.L: “Self-Healing material bacterial concrete” 2014 Eissn: 2319-1163. International Journal of Research in Engineering and Technology.

