Nano World Journal

https://doi.org/10.17756/nwj.2024-s1-039

Research Article

Open Access

Durability Studies on Self-compacting Concrete - Bacterial Concrete

C. Vaidevi[1*], S. Monisha[1], P. Gomathi Nagajothi[2] and P. Amsayazhi[3]

[1]Department of Civil Engineering, Aarupadai Veedu Institute of Technology, Vinayaka Misson's Research Foundation (Deemed to be University), Chennai, Tamil Nadu, India
[2]Department of Civil Engineering, Dr. M.G.R. Educational and Research Institute (Deemed to be University), Chennai, Tamil Nadu, India
[3]Saveetha Engineering College, Chennai, Tamil Nadu, India

[*]Correspondence to:
C. Vaidevi
Department of Civil Engineering,
Aarupadai Veedu Institute of Technology,
Vinayaka Misson's Research Foundation
(Deemed to be University),
Chennai, Tamil Nadu, India.
E-mail: vaiducivil@gmail.com

Received: January 03, 2024
Accepted: March 14, 2024
Published: March 19, 2024

Citation: Vaidevi C, Monisha S, Nagajothi PG, Amsayazhi P. 2024. Durability Studies on Self-compacting Concrete - Bacterial Concrete. *NanoWorld J* 10(S1): S218-S222.

Published by United Scientific Group

Abstract

Self-compacting concrete (SCC) is a homogenous concrete having good workability conditions with less water-powder ratio and this concrete eliminates the vibration during the placement. Concrete faces many environmental impacts on the surface or to a certain depth which affects the structure and the reinforcement. This paper shows the durability tests on SCC bacterial concrete such as a water permeability, acid attack, sulfate attack, and pH tests. Bacteria-cultured water is mixed for making the bacterial concrete and then the cube is moulded to conduct the test with different bacteria species. Due to chemical curing of 60 days done after the normal curing of 28 days in a cube size 150 x 150 x 150 mm, it is found to be the strength of bacterial concrete. And the pH value shows the base in nature. The permeability of the concrete also tested. The compressive strength decreased for some species of bacteria and for some species the values are merely equal to conventional SCC concrete. Finally, the SCC bacterial concrete holds good results in durability concerns. This is happened due to nano size of the bacteria mixed with concrete increases the efficiency and life period.

Keywords

Bacteria, Self-compacting concrete, Durability, Water permeability, Chemical attack

Introduction

Self-healing concrete with bacteria produces limestone that heals cracks which appears on the surface of concrete structures [1, 2]. Certainly, the field of nanoscience has contributed significantly to the development of self-healing materials, particularly in the construction industry. The use of various nanomaterials as healing agents in concrete is a promising advancement. Let's delve into some of the key nanomaterials such as nano-clays, nano-calcium carbonate, nano-silica, carbon nanotubes, and many other nanosized materials [3]. Bacteria, polymers, nanomaterials, and other minerals encapsulated provide autonomous healing in concrete [4]. The nutrient added with bacteria is known as calcium lactate which nitrogen and phosphorous mixed and that sustains the bacteria for up to 200 years and self-heals the concrete. The cracks appear in the concrete when the concrete structure is damaged and water starts to seep through it, when the water gets contaminated and nutrients spores of the bacteria, the bacteria start to feed on the calcium lactate [5, 6]. The soluble calcium lactate is converted to insoluble limestone when the bacteria feed oxygen and by sealing it up the limestone solidifies the cracked surface [7]. Bacteria mixed concrete not only heal the micro cracks it also heals the nano cracks.

The corrosion of the embedded reinforcement cause due to the bacteria meets the oxygen and increases on the surface of durability of the steel, the reaction of carbon dioxide (CO_2) present with calcium hydroxide ($Ca(OH)_2$) which forms calcium carbonate ($CaCO_3$) in the concrete matrix according to the following reaction [8, 9].

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

Nanomaterial based design improves self-healing performances and used in several applications for sustainable construction which plays vital benefits in future [10].

Materials and Method

Materials and its properties

Cement

It is a binding material used in bonding sand and the aggregate, where OPC 53 grade available in local market is used. Laboratory tests are conducted as per IS 12269 (2013), the cement should be dark with a light greenish shade, free from lumps [11].

Fine aggregate

The river sand locally available and size less than 4.75 mm is used [12].

Coarse aggregate

The size of the aggregates, limited to 10 mm and 12.5 mm is used.

Fly ash

The mineral admixture called 'pulverized fuel ash' and class C is used [13].

Water

The pH range of water should be 6 to 8.5, are used which is free from impurities like leaves, shells, papers, etc. [14].

Admixtures

Superplasticizer is a water reducing agent which is used for this research as named modified polycarboxylic ether.

Viscosity modifying agent

It is used to modify the cohesiveness without altering the fluidity in concrete called viscosity modifying agents, master matrix SDC 150 is used.

Bacteria

The bacteria are purchased from MTCC and was cultured in biotechnology lab [15, 16]. The two species of bacteria is used for testing (Figure 1). Size of the bacteria is less than 1000 nm.

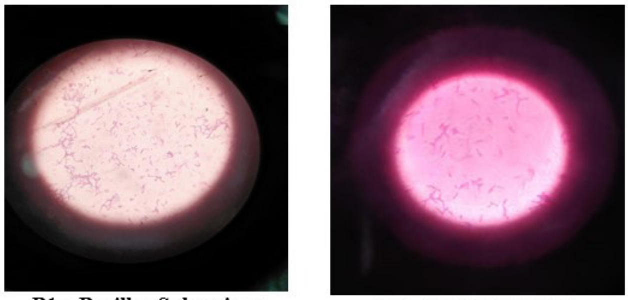

Figure 1: Bacteria.

Water permeability test

The permeability of concrete depends on the pores or voids present in the concrete. In a mixture of cement, sand and coarse aggregate material combined altogether has pores and contains voids in it [17]. Due to this the interconnected and continuous link between the materials in concrete is prone to permeate fluid or gases and deleterious materials are like water, CO_2, sulfur dioxide (SO_2) and chloride (Cl) through the pores in the concrete which reacts with reinforcement and forms rust and corrosion and increases the volume of the reinforcement which damages the structure in the form of surface cracking and collapse. The coefficient of permeability represents the rate of flow of water which transmitted through the saturated concrete specimen under the maintained hydraulic gradient. It is inversely linked to the durability of concrete. When concrete permeability value is less, the durability of concrete is more and there is rapid growth in nanoscience and a nanotechnology which creates self-repairable materials such as particles size less than 500 nm. With the trigger of temperature this repair progress called non-autonomic self-healable systems [18].

The water permeability test is conducted with code [IS 3085 (1965)] and German standard code [DIN 1048 (1991)], three samples of concrete cubes of specimen's size 150 x 150 x 150 mm were casted and tested. The test was conducted for 3 days (72 h) by applying 5 N/mm^2 or 5 bar constant water pressure were maintained throughout the study period. The water pressure applied to the concrete cube was by means of an arrangement consisting of air compression connected to the water tank through the valve to adjust the pressure. The water percolating depth during the test period is noted until the steady state is reached. The test was carried out at a temperature of 27 ± 2 °C [19]. The test is shown in figure 2, figure 3, table 1 and table 2.

The factors depend on the durability of concrete such as the water content, amount of cementitious material, aggregate size, compaction, and on curing efficiency.

The water permeability coefficient is recommended by IS 3085 (1965) and the maximum permissible value is 15 x 10^{-12} m/s for a conventional concrete. The coefficient of permeability (K) is calculated by equation 2.

$$K = D2P/2TH \quad (2)$$

Where 'D' is depth of penetration (mm), 'P' is porosity of concrete measured as fraction, 'T' is time in seconds, and 'H' is pressure head (1.5 m).

The calculation was done using equation 2; the decreased value of concrete shows permeability resistance to re-satura-

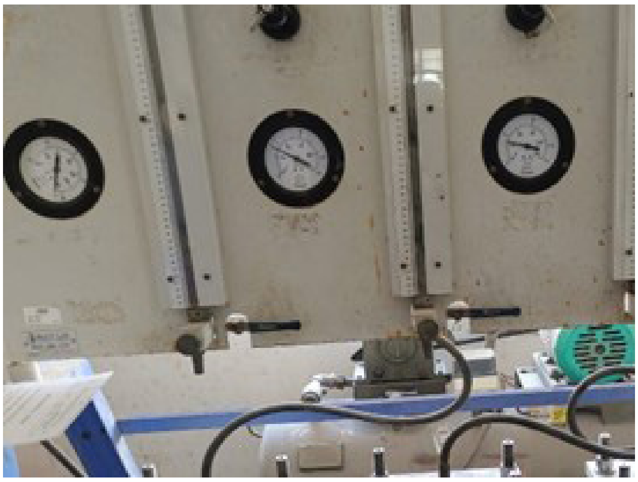

Figure 2: Water permeability test on cube.

Figure 3: Water penetration measurement.

Table 1: Water penetration depth on SCC with bacteria.

Mix	Water penetration depth (mm) 28 curing days	
Curing days	Before	After crack healed
SCC	55	-
SCC + B1	38	7
SCC + B2	62	8
SCC + B1 + B2	48	15

Note: B1 – *B. sphaericus* and B2 – *B. subtilis*.

tion, sulfate, acid - chemical attacks, and chloride ion penetration. The nanoparticles present in the concrete which is liberated by bacteria reduces the concrete crack size, were it increase the impermeability [20].

The above test shows that crack-healed concrete is impermeable with less porousness than normal curing concrete. The moisture makes the concrete more permeable than conventional concrete. Due to calcite precipitation, the pores are closed. More curing increases the impermeability of concrete with bacteria [21, 22].

Results and Discussion

Chemical attack test

Sulfate attack

A sodium sulfate (Na_2SO_4) 5% solutions are prepared by taking a weight of sodium sulfate was mixed with water. A 28-day age of concrete specimens are immersed in the sulfate solution for 60 days. The chemical curing of sample exposure to the solution is taken out and surface dried. Then compressive strength test was done [19]. The test is shown in figure 4 and table 3.

The strength of the concrete for mixes was not much affected by sulfate curing, *Bacillus sphaericus* comes down below the target mean strength, and both mixes were not more affected when compared to conventional SCC.

Acid attack

The test is called acid ponding test because the concrete cube has been kept under the acid mixed water. The specimen cube is immersed in 5% of hydrochloric acid mixed water for 60 days, after curing for 28 days in normal water then it is cured in acid solution. After this, the cube is tested to find the compressive strength of concrete and that is compared with the normal curing concrete. The age of 28 days samples is taken for this test [19].

The bacterial concrete mixes are affected by the acid attack but not much when compared with conventional SCC. By mixing both bacteria species that are not much affected by acid and maintained the same reaction in sulfate attack. The test is shown in figure 5 and table 4.

Nanotechnology improves the properties of concrete because nanoparticles are small and have wide surface area,

Table 2: Co-efficient of water penetration test results on SCC with bacteria.

Mix	Average penetration depth	Co-efficient of permeability	Average penetration depth	Co-efficient of permeability
	mm	(cm/sec)	mm	(cm/sec)
	28 days		After crack healed	
SCC	55	3.416×10^{-11}	-	-
SCC + B1	38	1.683×10^{-11}	7	0.954×10^{-10}
SCC + B2	62	3.725×10^{-11}	8	1.253×10^{-10}
SCC + B1 + B2	48	2.026×10^{-11}	15	4.253×10^{-10}

Note: B1 – *B. sphaericus* and B2 – *B. subtilis*.

Figure 4: Sulfate attack test.

Table 3: Sulfate attack.

Mix	Compression strength before chemical curing	Compression strength after chemical curing 60 days
SCC	65 N/ mm²	62 N/mm²
SCC + B1	61 N/mm²	56 N/mm²
SCC + B2	72.1 N/mm²	64.5 N/mm²
SCC + B1 + B2	63.5 N/mm²	60 N/mm²

Note: B1 – *B. sphaericus* and B2 – *B. subtilis*.

Figure 5: Acid attack.

Table 4: Acid attack.

Mix	Compression strength before chemical curing	Compression strength after chemical curing
SCC	65 N/mm²	42.4 N/mm²
SCC + B1	61 N/mm²	52 N/mm²
SCC + B2	72.1 N/mm²	50.2 N/mm²
SCC + B1 + B2	63.5 N/mm²	59.1 N/mm²

Note: B1 – *B. sphaericus* and B2 – *B. subtilis*.

which is highly reactive to reduce permeability, increase the strength and dense the microstructure [20].

pH test

Normally, pH value will be approximately 12 to 13 for new concrete; this is mostly due to presence of $Ca(OH)_2$, which is a byproduct of cement hydration. As a concrete surface were reacts with CO_2 in air, which reduces the pH value about 8.5 through a process called carbonation. So, the test is conducted to find the pH value of the bacterial concrete.

The *Bacillus subtilis* compressive strength is higher than the other species of bacteria even more than the conventional SCC. The mixing of both bacteria also gives mere equal compressive strength, but all mixes satisfy the target strength and grade of concrete. The test is shown in figure 6 and table 5.

The pH value of all mix ratios is maintained as concrete is an alkaline in nature. Due to carbonation the value may change. The bacteria present in concrete forms calcite deposition which heals the nano/micro cracks which were tested using chemical investigations. The *B. subtilis* bacteria produces more $CaCO_3$ for healing structural and non-structural cracks [21, 22].

Conclusion

As the durability concern, the bacterial concrete holds better results when compared with conventional concrete. The porosity also reduced in concrete and not much affected by the acid and sulfate so chemical attack tests for the bacterial concrete is good enough and can be used for the construction. The *B. sphaericus* have more durability when compared with *B. subtilis* and but both bacteria species mixing concrete holds good in chemical attack test. The CH bond is changed into

Figure 6: pH test.

Table 5: pH test.

Mix	Mean - pH value
SCC	10.7
SCC + B1	10.24
SCC + B2	12.5
SCC + B1 + B2	10.5

Note: B1 – *B. sphaericus* and B2 – *B. subtilis*.

CSH bond is a nanostructured material which increases the strength of concrete. High-performance nanomaterials make sustainable concrete which is done through self-healing technology because it protects the nanostructures.

Acknowledgments

We would like to express our sincere gratitude to our institution, Aarupadai-Veedu Institute of Technology, Vinayaka Mission's Research Foundation (Deemed to be University) for the funded support under the seed money project scheme, project ID - "VMRF/SeedMoney-Phase2/2020-10/AVIT-Kanchi/5" for executing the project. We would also like to thank Dr. S.A.V. Satya Murty, Director Research-VMRF, Dr. G. Selva Kumar, Principal AVIT, Dr. S.P. Sangeetha (VP Academics), Head of Civil Engineering, Dr. R. Divahar, and Head of Biotechnology, Dr. R. Devika for their assistance.

Conflict of Interest

None.

References

1. Jonkers HM, Thijssen A, Muyzer G, Copuroglu O, Schlangen E. 2010. Application of bacteria as self-healing agent for the development of sustainable concrete. *Ecol Eng* 36(2): 230-235. https://doi.org/10.1016/j.ecoleng.2008.12.036
2. Khaliq W, Ehsan MB. 2016. Crack healing in concrete using various bio influenced self-healing techniques. *Constr Build Mater* 102: 349-357. https://doi.org/10.1016/j.conbuildmat.2015.11.006
3. Goyal R, Verma VK, Singh NB. 2023. Nanomaterials based self-healing concrete. *Mater Today Prc* 1-6. https://doi.org/10.1016/j.matpr.2023.03.553
4. Amran M, Onaizi AM, Fediuk R, Vatin NI, Muhammad Rashid RS, et al. 2022. Self-healing concrete as a prospective construction material: a review. *Materials* 15(9): 3214. https://doi.org/10.3390/ma15093214
5. Meera CM, Subha V. 2016. Strength and durability assessment of bacteria based self-healing concrete. *J Mech Civil Eng* 1-7.
6. Kannan N, Likhit ML. 2014. Self-healing material bacterial concrete. *Int J Res Eng Technol* 3(3): 656-659.
7. Gowda MR, Naveen KS, Laxmisagar HK. 2020. Development of self compacting concrete using silica fume. *Int J Sci Res Develop* 4(11): 36-38.
8. Seifan M, Samani AK, Berenjian A. 2016. Bioconcrete: next generation of self-healing concrete. *Appl Microbiol Biotechnol* 100: 2591-2602. https://doi.org/10.1007/s00253-016-7316-z
9. Jonkers HM. 2011. Bacteria-based self-healing concrete. *In Genium* 56(1): 84-93.
10. Shah KW, Huseien GF. 2020. Biomimetic self-healing cementitious construction materials for smart buildings. *Biomimetics* 5(4): 47. https://doi.org/10.3390/biomimetics5040047
11. Depaa RB, Kala TF. 2015. Experimental investigation of self healing behavior of concrete using silica fume and GGBFS as mineral admixtures. *Indian J Sci Technol* 8(36).
12. Manikandan AT, Padmavathi A. 2015. An experimental investigation on improvement of concrete serviceability by using bacterial mineral precipitation. *Int J Res Sci Innov* 2(3): 48.
13. Xu J, Yao W. 2014. Multiscale mechanical quantification of self-healing concrete incorporating non-ureolytic bacteria-based healing agent. *Cem Concr Res* 64: 1-10. https://doi.org/10.1016/j.cemconres.2014.06.003
14. Wang JY, Snoeck D, Van Vlierberghe S, Verstraete W, De Belie N. 2014. Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. *Constr Build Mater* 68: 110-119. https://doi.org/10.1016/j.conbuildmat.2014.06.018
15. Sahoo KK, Sathyan AK, Kumari C, Sarkar P, Davis R. 2016. Investigation of cement mortar incorporating *Bacillus sphaericus*. *Int J Smart Nano Mater* 7(2): 91-105. https://doi.org/10.1080/19475411.2016.1205157
16. Wang J, Jonkers HM, Boon N, De Belie N. 2017. *Bacillus sphaericus* LMG 22257 is physiologically suitable for self-healing concrete. *Appl Microbiol Biotechnol* 101: 5101-5114. https://doi.org/10.1007/s00253-017-8260-2
17. Chahal N, Siddique R, Rajor A. 2012. Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete. *Constr Build Mater* 28(1): 351-356. https://doi.org/10.1016/j.conbuildmat.2011.07.042
18. Wang J, Van Tittelboom K, De Belie N, Verstraete W. 2012. Use of silica gel or polyurethane immobilized bacteria for self-healing concrete. *Constr Build Mater* 26(1): 532-540. https://doi.org/10.1016/j.conbuildmat.2011.06.054
19. Vaidevi C, Kala TF, Kalaiyarrasi AR. 2020. Mechanical and durability properties of self-compacting concrete with marble fine aggregate. *Mater Today Proc* 22: 829-835. https://doi.org/10.1016/j.matpr.2019.11.019
20. Plassard C, Lesniewska E, Pochard I, Nonat A. 2004. Investigation of the surface structure and elastic properties of calcium silicate hydrates at the nanoscale. *Ultramicroscopy* 100(3-4): 331-338. https://doi.org/10.1016/j.ultramic.2003.11.012
21. Achal V, Mukerjee A, Reddy MS. 2013. Biogenic treatment improves the durability and remediates the cracks of concrete structures. *Constr Build Mater* 48: 1-5. https://doi.org/10.1016/j.conbuildmat.2013.06.061
22. Achal V, Mukherjee A, Reddy MS. 2011. Microbial concrete: way to enhance the durability of building structures. *J Mater Civil Eng* 23(6): 730-734. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000159