Bacterial Concrete - A Review Paper

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Abstract-Concrete is a composite and brittle material. Cracks formation in concrete is a common thing. These cracks are harmful for concrete and the reinforcement concrete also. Repairing of the cracks are costly and it is need skilled labour too. In this condition bacterial concrete will be a good solution for it. Bacteria, which are mix with the concrete, produce calcium carbonate that will fill the cracks and heal the cracks of concrete. Here, in this paper, we will discuss about, types of bacteria, methodologies, advantages & disadvantages, and will give a overview of Bacterial Concrete.

Index Terms: Bacterial Concrete, Bacteria, Modern Concrete Technology, Self-Healing Concrete.

I.INTRODUCTION

Concrete is a modern construction material. Concrete is used widely from the Industrial-Age, e.g. middle of seventeenth century. Concrete is a composite material, which is mainly mixture of cement, sand, stone chips (coarse aggregate) and water. Though concrete is a brittle material, cracks are common facts in concrete. There are various reasons to develop the cracks in concrete. The factors affecting the development of cracks in concrete, are, Water-Cement Ratio, Tension in concrete, Freeze-Thaw Action, Shrinkage etc. These cracks are harmful for concrete structure. It reduces the strength of concrete, increases the water seepage in concrete. Again this water is harmful for the reinforcement of concrete. So, repair of the cracks is very essential.

There are some common and conventional methods to repair the cracks. The methods are, Epoxy Injection, Grouting and Sealing, Grouting, Stitching, Drilling and Plugging, etc. These methods are cost effective, and need skilled labours. These methods also have environmental issues.

A new technique has come out in the modern era, to repair the cracks, biologically. This technique is Bacterial Concrete. In this method, bacteria are used as a crack filling agent. Many scientists have used different types of bacteria in their experiment. The bacteria can be active up to 200 years in the concrete. When water enters through the cracks, the bacteria become active, and they took nutrients which are soluble, and produce Calcium Carbonate, which is insoluble in water. This Calcium Carbonate stored and solidified and fills the concrete cracks. This method is environment friendly and cheap also. It gives positive impact in concrete.

II. LITERATURE REVIEW

A. What is Bacterial concrete: - Bacterial Concrete is a concrete that can heal its cracks autonomously, by Calcium Carbonate, which is produced by the bacteria.

B. Mechanism of Bacterial Concrete:

Bacteria, used for the manufacturing of concrete, should be able to give a long-term performance, so that the concrete will heal autonomously through its life time.

Main mechanism of the self-healing process is that, the bacteria transform the soluble Calcium Lactate to insoluble Calcium Carbonate, which seal the concrete cracks.

$$Ca(C_3H_5O_2) + 7O_2 \longrightarrow CaCO_3 + 5CO_3 + 5H_2O.$$

Where as in control specimen (concrete without bacteria) of the concrete, Carbon-Di-Oxide, reacts with Calcium Hydroxide, and produce Calcium Carbonate.

$$Ca(HO)_2 + CO_2 \longrightarrow CaCO_3 + H_2O.$$

Though the Carbon-Di-Oxide is not sufficiently present in concrete, so there is limited production of Calcium Carbonate. But in case of bacterial concrete, there is active production of calcium Carbonate, by metabolic action of gram-positive bacteria, which is sufficient to repair the cracks.

C. Types of Bacteria Used in Bacterial Concrete:

- Bacillus Pasteurizing.
- Bacillus Cohnii.
- Escherichia Coli.

- Bacillus Sphaericus.
- Bacillus Subtilis.
- Bacillus Cereus.
- Protius Vulgarius.

This bacterium is Gram-Positive bacteria, which is harmless in nature. These bacteria are activated at average temperature of 40° C.

We can't mix those bacteria directly in concrete. We have to culture the bacteria to create spore, so that it can survive in concrete for long time.

D. Review of Research Paper:

H.M. Jonkers [1], publish a research paper on "Bacteria-Based Self Healing Concrete". In this experiment they create the concrete specimen, using concrete materials and the 2-4 mm size particles are replaced by oven dried clay particles mix with bio-chemical bacterial agent, which is 50% of the fine aggregate. The bacterial density was $5X10^7$ spore $d.m^{-3}$. After 28 days curing, they got that, there is 50% decrease in compressive strength, due to the replacement of the concrete aggregate. Also after 56 days water curing study, on pre-cast concrete, there is 100% healing of cracks in sample specimen, where 33% healing in control specimen.

G. Adhithya Vijay, R. Tamilarasan, C. Yaswanath, and E. Arunachalam [2], published research paper on, "Experimental Investigation on Self-Healing Concrete, Using E.Coli Bacteria". They used E.Coli bacteria as self-healing bacterial agent. In this experiment they made 150 X 150 X 150 mm^3 M-20 grade concrete blocks, where they used 5%, 10%, & 15% bacterial solution respectively. Their main focus is to observe the changes on compressive strength and split tensile strength on the bacterial concrete, beside the self-healing capacity of the bacterial concrete. As a result they got that the bacteria repaired the cracks, with calcium carbonate and the maximum compressive strength of the concrete developed was 15.96 N/mm^2, 20.03 N/mm^2 , 25.36 N/mm^2, for the bacterial solution 5%, 10%, 15%, for 7, 14, & 28 days, respectively which is more than conventional concrete. The split tensile strength also became better than the conventional concrete.

B.R. Gautam [3], published a paper on, "Bacteria Based Self-Healing Concrete - A Bacterial approach". In this experiment their main objective was to study on the effectiveness in crack repairing, and the development in compressive strength & flexure strength of concrete. They used 6% of bacteria mix clay pallets to make the bacterial concrete block. As a result they got, bacteria heals the crack by depositing calcium carbonate, and in 28 days compressive strength of bacterial concrete was 38.95 N/mm^2, where in conventional concrete was 30 N/mm^2, and in case of flexure strength of bacterial concrete in 28 days was 7.80 N/mm^2, whereas in conventional concrete the strength was 7.05 N/mm^2.

Lagazo Magil A., Noriesta, Carla Pamela D., Montecalvo, Marlou A., P. Alviar [4], published research paper on, "Experimental Research Using Bacteria (Bacillus Subtillis) As a Self-Healing Concrete : A basis for Strengthening Infrastructure In The Philipine Setting". The main aim of the experiment was to find, the effectiveness of Bacteria in compressive, split tensile strength, flexure strength, water absorption and effectiveness to seal the cracks in concrete. In this experiment, concrete mix used as 1:2.5:5, and water cement ratio as 0.45. Bacillus Subtilis used as bacterial spore and 30ml of bacterial solution add in the concrete mix. As a result they got, this bacteria is safe for human being, because it's bio safety level is one. They also found that, the compressive strength of bacterial concrete was increased by 35.15%, split tensile strength increased by 32.26%, flexure strength increased by 17.24%, and there was a decrease in water absorption. They came in conclusion that the bacterial concrete not only healed the cracks, but it improves strength of concrete too, in low cost.

Pawar Bhagyashri, Magdum Archana, Bhosale Megh, Pol Sayalia [5], published paper on "Bacterial Concrete". In this experiment they made two concrete blocks of M-25 grade, with mix proportion 1:1.13:2.72 and water cement ratio as 0.42. As a result they got, 25% increase in compressive strength, in 28 days, when the bacterial solution is, 10^5 cells/ml. Enhancement in compressive strength, reduction in permeability, and water absorption was seen in this experiment.

Kusuma K., Amit Kumar Rai, Prasant Kumar, Harini K., Harshita M.N. [6], published paper on "Self-Healing Concrete". They used 53 grade OPC, 4.75 mm river sand, Coarse aggregate whose max size 20mm, having ratio 1:1.93:3.93, and water cement ratio as 0.51, bacterial concentration as 10^5 cells/ml of water, and metal sheet to create cracks in concrete 0.3 mm thick and 20mm deep. In this

experiment they found that, there was an increase in compressive strength by 11.96%, decrease in water absorption by 0.45% and decrease in water permeability, in 28 days result, as compared to conventional concrete. They also found that self-healing capacity increased in 28 days and there was good response in self crack healing. They added that self healing concrete will be high quality concrete with eco-friendly, cost effective concrete.

Subham Ajay Puranik, Siddharth Jain, G. Sritam, Sayali Sandbhor [7], published paper on "Bacterial Concrete - A Sustainable Solution for Concrete Maintenance". They used the concrete grade M-20, and the bacterial spore, Bacillus Subtilis (B1) and Bacillus Sphaericus (B2). They made total 8 blocks of concrete, among those blocks four are for B1 and other four blocks are for B2. On those four blocks for B1 and B2 both different bacterial solutions were added, that is, 15ml, 30ml, 45ml, and 60ml. For seepage check, they create eight concrete slabs. Among those slabs three for B1, other three for B2, and another two is for conventional concrete slab. After experiment they arrived at a result that, in case of compressive strength 15ml solution of Bacillus Subtilis gave good result in 7 & 28 days compressive strength, and 30ml solution of Bacillus Sphaericus gave the best result in 7 & 28 days compressive strength. In case of seepage protection, they found, Bacillus Spaericus is better than Bacillus Subtilis. After the test and results, they concluded that, for M-20 grade concrete 30ml Bacillus Spaericus gave better compressive strength than conventional concrete and as a waterproofing material, seepage control, and self healing capacity, this bacteria works better than Bacillus Subtilis.

N.Sudha,T.Gowsalaya,A.Hemavarshini, S. Gokula Lakshmi [8], published a paper on "Experimental Investigation on Strength Properties of Self-healing Bacterial Concrete Using M-Sand". In this experimental investigation they used M-25 grade concrete, where they used M-Sand as fine aggregate. M-Sand is termed as Manufacturing Sand, which is sieved and free from pebbles. They used B.Cereus bacteria as self-healing agent. In this investigation they found that, addition of 30ml bacterial solution, gave more effectiveness to increase the compressive strength, flexure strength and spilt tensile strength in 28 days. They concluded that, this bacterial concrete not only enhance the self-healing capacity of concrete, but it also increases the strength of concrete and the bacteria used in the bacterial concrete, is safe and economical.

Harshali J., Mitali S., Neha A., Pragati B. [9], published paper on "Bio Concrete and Bacteria Based Self Healing Concrete". In their experiment they used the combination of two bacteria, Bacillus Spericus, and Protius Vulgarius (in total 10ml bacterial solution, there is 5ml Bacillus Spericus and 5ml Protius Vulgarius). They choose M-25 grade concrete for this experiment, with, 150mm X 150mm X 150mm, concrete cubes and total 6 no.s cubes casted (three conventional concrete cube and three is bio concrete). After 28 days, they got results like, 15.80% increase in compressive strength, 5.18% increase in flexure strength, water absorption decreased by 3.83%, and sorptivity decreased by 6.89%, than the conventional concrete. They concluded that, the bacteria repair and heal the concrete cracks by calcium carbonate and also improve the properties of concrete.

Gaurav Agarwal, Rahul Kadam [10], published paper on "Bacterial Concrete - A Solution to Crack Formation". For this experiment they choose Bacillus Subtilis. Through this experiment they not only studied the self-healing capacity of bacterial concrete, but also studied the changes in compressive strength, flexure strength, and split tensile strength in bacterial concrete. They observed the bacterial movement through S.E.M. (Scanning Electron Microscope). After the experiment and observing the result, they came to a conclusion that, the average increase in compressive strength in concrete is 19.41%, and increase in flexure strength is by 22.07%, compared to the conventional concrete. By the bacterial action, the Calcium Carbonate was deposited which fills the cracks, and seal the cracks. It also reduces the rate of water absorption and permeability in concrete. 10^5 cells of bacteria (24ml of bacteria in 1000ml) gave a good result. The bacterial spore can live in concrete for 100 years.

E. Summary of Literature Review:

After studying different research papers, it is observed that, the bacteria used in bacterial concrete, is mainly Gram-Positive bacteria, that means those bacteria is harmless bacteria, and it can remain active in average temperature of 40^0 C. Result of the experiments says that, the bacterial concrete not only has self-healing property, but it also improves

the strength of concrete. In case of Bacillus bacteria, it gives good effectiveness when its cell concentration is 10^5 cells/ml, of mixing water. Proper mixing and proper choosing of bacteria give better result in compressive strength in concrete that can be increased to 20-25% on an average and it also increases split tensile strength, flexure strength, and decreases water seepage and permeability, compared to the conventional concrete. There is no need of regular observation and maintenance in Self-Healing Bacterial Concrete.

F. Application: -

1. Used in low cost concrete construction.
2. We can use it in concrete pavement in suitable weather.
3. Used in water retaining concrete structure.
4. This is very useful in sewage system.
5. We can use it in roof also.

G. Advantage: -

- It can heal the cracks (upto 0.5mm cracks) by its own.
- It has better compressive strength.
- This concrete has low permeability and low water absorption.
- This concrete gives a good resistance to freeze-thaw action.
- Corrosion of reinforcement will be reduced, by using this concrete.
- It has low maintenance cost.

H. Disadvantages: -

- Growth of bacteria is not good for any atmosphere or any media.
- Cost of the concrete is higher than conventional concrete.
- There is no proper code or guideline for this Bacterial Concrete.

III. CONCLUSION

Through this paper we conclude that, the bacteria present in self healing concrete (Bacterial Concrete), can seal the micro cracks (up to 0.5mm), by producing Calcium Carbonate and through this process it improves the strength of concrete also. Micro Bacteria fill the concrete voids by producing Calcium Carbonate ($CaCo_3$), which decreases the water permeability and seepage in concrete and for this compressive strength also improves. Not only compressive strength, it improves overall strength of concrete in 28 days.

Maintenance cost of the concrete will be less compared to the conventional concrete, but the manufacturing cost of the concrete is high. As per future perspective, we need to focus on more research and more study on this topic, so that we can develop a proper code or a proper guideline on the Bacterial Concrete. Also, we have to think about large scale production of the bacterial spore, that can help us in large production of this concrete which will eventually also reduce some cost of the concrete.

After resolving these kinds of problems, the bacterial concrete will play a major role in future construction which will create a new direction in concrete technology, future construction and sustainable development.

REFFERENCE

[1] H.M. Jonkers, "Bacteria-Based Self-Healing Concrete", in the *HERON Vol. 56 (2011) No. 1*/2, page. 1-12, 2011.

[2] G. Adhithya Vijay, R. Tamilarasan, C. Yaswanath, and E. Arunachalam, "Experimental Investigation on Self-Healing Concrete Using E.Coli Bacteria", in the, International Journal of Trend in Research and Development, Volume 6(2), ISSN: 2394-9333, Page. 155-161, Mar – Apr 2019.

[3] B.R. Gautam, "Bacteria Based Self-Healing Concrete - A Bacterial approach", in the, The International Journal of Engineering and Science (IJES), ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805, PP. 57-61, 2018.

[4] Lagazo Magil A., Noriesta, Carla Pamela D., Montecalvo, Marlou A., P. Alviar, "Experimental Research Using Bacteria (Bacillus Subtillis) As a Self-Healing Concrete: A basis for Strengthening Infrastructure in the Philippine Setting", in the International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume-8, Issue-1S4, Page. 125- 129, June 2019.

[5] Pawar Bhagyashri, Magdum Archana, Bhosale Megh, Pol Sayalia, "Bacterial Concrete", in the JOURNAL OF INFORMATION, KNOWLEDGE AND RESEARCH IN CIVIL ENGINEERING, ISSN: 0975 – 6744, Volume 4, Issue 2, page. 393-397, NOV 16 TO OCT 17.

[6] Kusuma K., Amit Kumar Rai, Prasant Kumar, Harini K., Harshita M.N., "Self-Healing Concrete" in the, International Research Journal of Engineering and Technology (IRJET), e-

ISSN: 2395-0056, p-ISSN: 2395-0072, Volume: 05 Issue: 05, page. 3817-3822, May-2018.

[7] Subham Ajay Puranik, Siddharth Jain, G. Sritam, Sayali Sandbhor, "Bacterial Concrete - A Sustainable Solution for Concrete Maintenance", in the, International Journal of Innovative Technology and Exploring Engineering (IJITEE), ISSN: 2278-3075, Volume-8, Issue-11S, page. 227- 232, September 2019.

[8] N. Sudha, T. Gowsalaya, A. Hemavarshini , S. Gokula Lakshmi, "Experimental Investigation on Strength Properties of Self-healing Bacterial Concrete Using M-Sand", in the, International Journal of Advance Research and Innovation, ISSN 2347 - 3258, Volume 6, Issue 4 (2019) 1-4, page. 1-4, 2019.

[9] Harshali J., Mitali S., Neha A., Pragati B., "Bio Concrete and Bacteria Based Self-Healing Concrete", in the International Journal of Research in Engineering and Technology, eISSN: 2319-1163 | pISSN: 2321-7308, Volume: 05 Issue: 05, page. 95- 99, May-2016.

[10] Gaurav Agarwal, Rahul Kadam, "Bacterial Concrete - A Solution to Crack Formation", in the International Journal of Innovative Research in Advanced Engineering (IJIRAE), ISSN: 2349-2163, Issue 10, Volume 4, page. 1-6, October 2017.

[11] Google.com.