COMPREHENSIVE STUDY ON BACTERIAL CONCRETE: A REVIEW

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Abstract – *Concrete is the key building material used by any constructor or builder or designer, in the civil engineering industry. The engineering industry deals with the any construction work globally. The use of concrete in any construction industry consumes high percentage of construction work rather than any materials. While constructing any structure by a builder or designer or engineer, it will be a responsibility for them to design and build any structure such that it will give service till life span of the building. In construction industry, all needs a speedy construction only. And they have been through this and a numbers of construction work in today's world has been in process of Swift only. In same process a common problem has been occurred frequently in many of constructed concrete structures in terms of crack. Despite of undertaking precaution during construction with concrete, a cracks occurs on the concrete surfaces. Crack is the major reason behind weakening the strength of the concrete. Cracks are inescapable and imparts the voids on the concrete surfaces, through which water penetrates through it and results in internal corrosion of concrete. The main target of this research work is to study the performance of types of bacteria in concrete, helping in revealing the cracks mechanism*

Key Words: **Bacterial Concrete, Bacteria, Cracks, Self-healing, Strength**

1. INTRODUCTION

Bacterial concrete is a distinct type of modified concrete, having potential to repair a crack or series of cracks on concrete surface by auto-heal process. It is also known as self-healing concrete. Different types if bacteria had been mixed to the normal dry concrete to prepare the bacterial concrete.

1.1 History

In the construction industry, common problem of cracks appearing in the surfaces of concrete had been observed. A research has been made to overcome from the crack. In 2006, for the first time the self-healing concrete was invented by Henk Jonkers, a professor and microbiologist from Delft University in the Netherlands. The experiment was made for three years and later Jonkers had found the perfect healing agent as Bacillus. [54-55]

Since Jonkers was familiar with the behavior of bacteria. He uses self-healing octopus' tentacles and plants that use offshoots to multiply itself. Based on this concept Jonkers choose Bacillus Pseudofirmus and Sporosarcina pasteurii bacteria, produces limestone and are found near volcanoes. And these bacteria consume the oxygen and prevents from internal corrosion of reinforced concrete. Moreover, these bacteria can survive for 200years and will be difficult to destroy the bacteria. Later a research had made for spores in the bacteria through which spores germinate in water and after germinating it starts multiply at very high rate. [54-55]

After finding that spores in the bacteria, three different bacteria have been developed or found as: Self-healing concrete, repair mortar and a liquid system. All forms of bacteria are having uses at different stages in construction industry. Self-Healing concrete can be used during construction in concrete. The repair mortar and a liquid system can be used in the case after the damage has occurred in the structure. [54-55]

2. EVOLUTION OF BACTERIAL CONCRETE AND ITS WORKING PRINCIPLE

Bacteria had been evolved in the Bio-Technical lab. But to use that bacteria in the re structure industry is becoming difficult with the insufficient amount of bacteria produced in the laboratory. The researchers decided to produce the bacteria in large quantity. They had produced the bacteria in high quantity in an Industrial lab. As the bacteria was very sensitive to use in the construction process, they had adopted a method of coating and produced in terms of capsule form. The coatings were provided over the capsule, which prevents from disintegration during mixture to ensure the dormant stage of bacteria until it triggered. The capsule will trigger in the presence of cracks. The bacteria will activate only when it come as contact with air and moisture. It consumes calcium lactate, converts it to calcite-an ingredient in limestone and thus helps in sealing off the cracks. This process continues for about three weeks.

The salient features of Bacterial concrete are: for length, there is no any limit for the crack, which may result in centimeters or even kilometers long but the width is restricted in such cases. As per Jonkers report, he states that the self-healing concrete will work for cracks up to one millimeter wide only. The first ever application of bacteria has been made in oil and gas industry in Canada for underground infrastructure, where repair work is extremely difficult. A professional technical service engineer Matt Dalkie in this project, explained the merit of bacterial concrete and sustainability and environment friendly. Later the use of bacterial concrete has been made in Europe in maintenance of Bridge and Tunnels. [3-8]

3. PREPARATION AND WORKING PRINCIPLE OF BACTERIA

The concrete is prepared by using the bacteria found beneath the soil and is extracted from the soil and develop the bacteria gene in the bio technological lab. The most important properties of bacterial concrete are, helps to enhance the strength of concrete. And to escalate the durability of the concrete. Formation of crack in concrete is sensitive to lower the limit of tensile strength. For this reason, the concrete work is done by embedding the reinforcement steel, which increases the tensile capacity of the concrete structure i.e. tensile loads. Here, the other function of using reinforcement bar in concrete is to prevent cracks formation. The concrete structure influence with cracks, permits the water to penetrate in through. The bacteria used while manufacturing the bacterial concrete starts showing microbial activities on contact with water and oxygen. In this process, calcite precipitation starts i.e. unhydrated calcium reacts to form calcium hydroxide produced by bacteria. Also Caco3 is developed. Caco3 solidifies on the cracks surfaces thereby sealing it up though the pores and start feeding the lime automatically and will help to heal the cracks.

When cracks emerge on the concrete surfaces, water seep in concrete through the path of cracks known as openings also. The spores of bacteria starting shoot up and nourishing on calcium as water drizzles into the cracks. The transfiguration of soluble calcium lactate into insoluble limestone occurs and oxygen will be consumed in the chemical reaction as shown in below equation. And these insoluble limestone helps to fills up the cracks in the concrete.

$CaO + H2O = Ca(OH)2$ ……………………………(i)

$Ca(OH)2 + CO2 = CaCO3 + H2O$…………………(ii)

From the above reaction, it can be observed that lime reacts with aqua resulting the calcium hydroxide. Later, these calcium hydroxide acts with carbon dioxide results in calcium carbonate and aqua again. The aqua molecule generating again in second stage reaction helps transforming oxides of calcium into calcium hydroxide and the reaction process continues until the breakdown of all calcium oxide takes place. Based on these facts only, the research work has been carried out here.[1-12]

4. AIM & OBJECTIVE

The present research work is done to study the sorts of cracks appearing in the concrete surfaces and assimilate the different types of bacteria in the concrete surfaces to auto heal the crack mechanism. Also, the work in this paper is carried out with the aim to study about the depth of cracks healing capacity with the different uses of bacteria in the concrete and check about the strength capacity of concrete after the application of the bacteria.

5. TYPES OF BACTERIA USED IN MANUFACTURING OF BACTERIAL CONCRETE

Different types of bacteria used are:

a. Bacillus Pasteurii.
b. Bacillus Sphaericus
c. Escherichia Coli
d. Bacillus Subtilis
e. Bacillus Cohnii
f. Bacillus Pseudofirmus
g. Bacillus magaterium
h. Bacillus Flexus
i. Bacillus Cerus
j. Shwanella Species

5.1 Bacillus Subtilis:

Bacillus Subtilis is bacteria with species B. subtilis, having domain name Bacteria which is a Gram positive bacterium generally found in the soil. It is found in the roots of plants and gastrointestinal tract of ruminants and humans. The use of bacteria in concrete technology has been made with only those organisms that has been extracted from the roots of plants. It is the bacterial champions which shows the self-healing characteristics when is mixed in the concrete.

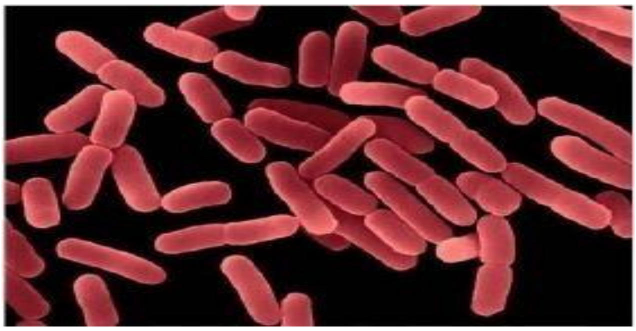

Fig 1: SEM images of Bacillus Subtilis[6]

5.2 Bacillus Pasteurii:

Bacillus Pasteuri were also known as Sporosarcina pasteurii. This is a bacteria having species of Sporosarcina pasteurii, with geneus Sporosarcina. These bacteria are a gram positive bacterium. These bacteria have a characteristic of more calcite precipitation. This bacterium also shows the spreading characteristics against the crack healing mechanism with auto heal process.

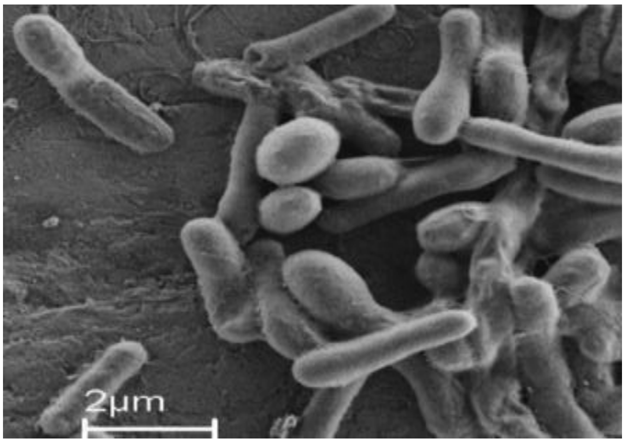

Fig 2: SEM images of Bacillus Pasteurii[6]

5.3 Bacillus Sephaericus:

Bacillus Sephaericus was also known as Lysinibacillus Sphaericus. Bacillus Sephaericus is a gram positive bacteria with strict aerobic bacterium features. Generally, the shape of this bacteria is rod in shape and found in the soil. These bacteria can be extract from the larva of mosquito but the strain obtained from the larva of mosquito can only be use for human drug research for medicine. In concrete technology, for crack healing the bacteria must be obtained from the soil.

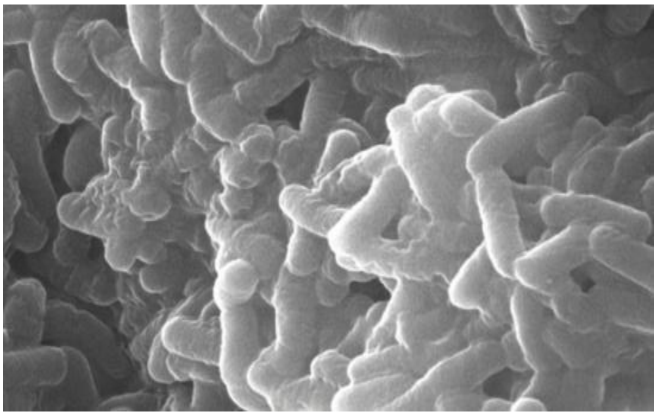

Fig 3: SEM images of Bacillus Sephaericus[6]

5.4 Bacillus Pseudofirmus:

Bacillus Pseudofirmus is a gram positive bacterium having the features of alkaliphilic and alkalitolerant an aerobic. The strain of these bacteria shows the self-healing characteristics in the concrete. It also maintains the PH value in the concrete.

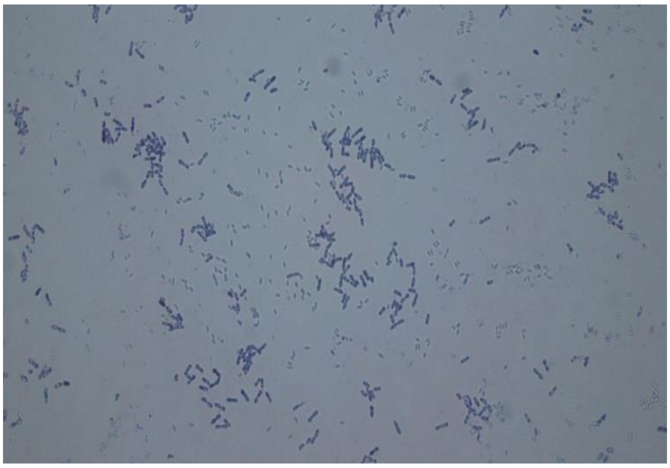

Fig 4: SEM images of Bacillus Pseudofirmus[53]

5.5 Bacillus Licheniformis:

Bacillus Licheniformis is a gram positive bacteria, generally shows mesophilic in nature. Normally these bacteria can be obtaining from the soil. But also these bacteria are available in the feathers of birds and ducks. It also shows the characteristics of self-healing, when is mixed in the concrete.

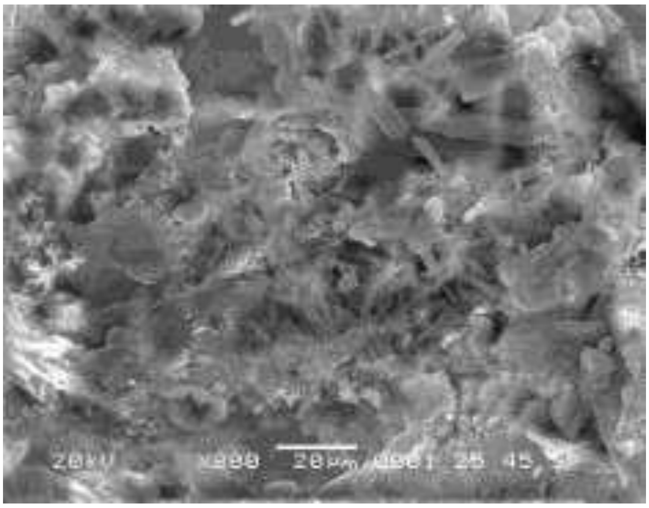

Fig 5: SEM image for Bacillus Licheniformis[4]

6. MATERIALS USED IN MANUFACTURE OF BACTERIAL CONCRETE

The various material used to manufacture the bacterial concrete are listed below:

- Cement
- Sand
- Coarse Aggregate
- Fine Aggregate
- Water
- Micro Organism

Ordinary Portland Cement is proposed to use while manufacturing the bacterial concrete, having the specific gravity of 3 - 3.15. The natural sand is preferred to use while manufacturing the bacterial concrete. The specific gravity of sand has to be 2.69 and the size of sand must be less than 4.75 mm. The coarse aggregate of size 20mm has to be use while manufacturing the bacterial concrete. The relative density of coarse aggregate must have to be 2.75. The aggregate may be obtained from quarries or natural resources. Water free from dirt particles and other chemicals has to be used. Different bacteria like Bacillus Subtilis, Bacillus Sphaericus and Bacillus Pastuerii are proposed to prepare a bacterial concrete.

7. COMPRESSIVE STRENGTH TEST DATA:

The use of bacteria has been made in distinct matter to manufacture the bacterial concrete with different concentration of bacteria. The following results has been recorded:

Table 1: Compressive strength test result data

Compressive strength test Result[1]				
Bacteria used	**Concentration of bacteria**	**@ 7 day's**	**@14 day's**	**@28 day's**
Bacillus Subtilis	15ml	9.17	15.89	26.27
	30ml	8.56	10.92	21.99
	45ml	7.88	10.01	17.73
	60ml	6.49	10.15	19.04
Bacillus Sphaericus	15ml	21.92	26.79	28.57
	30ml	27.48	29.61	48.43
	45ml	27.74	32.09	36.73
	60ml	24.68	35.49	30.8

From above study, it has been seen that the bacteria with 15 ml solution of Bacillus Subtilis shows the higher compressive strength test value than higher concentration of bacteria. And the compressive strength for Bacillus Sphaericus is high at 30 ml concentration of solution.[1]

Table 2: Compressive strength test result data

Compressive strength test Result[4]			
Bacteria used	**@ 7 day's**	**@ 14 day's**	**@28 day's**
Normal Mix	16.25	23	25.5
Bacillus Subtilis	17.25	24.75	27
Bacillus Lichenformis	18	25	28.75

From above table it can be observed that te compressive strength among bacteria Bacillus subtilis & Bacilus Lichenformis, the higher strength value can be obtained using Bacilus Lichenformis when is ixed in water containing calcium chloride and urea of 50ml and 20 ml per litre of water .[4]

Table 3: Compressive strength test result data

Compressive Strength Test Result for Mortar[5]			
Age (No. of Day's)	**Cell Concentration**	**Conventional concrete, N/mm2**	**Bacterial Concrete (Bacillus Subtilis)**
7	10^5 cells/ml of water	35.57	39.48
14	10^5 cells/ml of water	44.73	51.26
28	10^5 cells/ml of water	51.19	60.17
60	10^5 cells/ml of water	55.39	63.35
90	10^5 cells/ml of water	56.97	66.27
180	10^5 cells/ml of water	58.37	67.62
270	10^5 cells/ml of water	59.17	68.84
365	10^5 cells/ml of water	60.87	70.07

The results of addition of bacteria in concrete can be observed from above table, there is the gain in the compressive strength as gain in the amount of bacteria added in the concrete mix.[5]

Table 4: Compressive strength test result data

Compressive strength test results.[6]					
Bacteria used	**Concentration of bacteria**	**@ 14 day's for M30 grade**	**@ 28 day's for M 30 grade**	**@ 14 day's for M40 grade**	**@ 14 day's for M40 grade**
Bacillus Pasteurii	0 ml	4.46	5.12	4.68	5.24
	5 ml	4.62	5.2	4.84	5.34
	10 ml	4.84	5.36	4.98	5.48
	15 ml	4.74	5.22	4.88	5.26
	20 ml	4.6	5.04	4.62	5.12
Bacillus Subtilis	0 ml	4.46	5.12	4.68	5.24
	5 ml	4.96	5.22	4.96	5.62
	10 ml	5.26	5.34	5.06	5.84
	15 ml	5.16	5.24	4.96	5.72
	20 ml	5.04	5.12	4.72	5.56

From above table, it seen that the compressive strength of concrete with bacteria Bacillus Pasteurii is high at 10 ml concentration. And is same for Bacillus Subtilis also.[6]

Table 5: Compressive strength test result data

Compressive strength Test results [8]		
	Microcapsules	**Compressive Strength (MPa)**
Bacillus Sphaericus	0% (R)	75
	1%	65
	2%	60
	3%	55
	4%	50
	5%	50

Here, the Bacillus Sphaericus is used in the form of microcapsule of size 5 um. And the breaking of capsule under loading prevails the confirmation of healing of cracks. [8]

Table 6: Compressive strength test result data

Compressive Strength Test Results for Rigid Pavement [10]	
Additive	@ 28 Day's
Nano coated leaves	68 MPa

The crack appear in the rigid problem can be heal using Nano coated leaves over the concrete surfaces. From above studies, the compressive strength of hardened concrete with Nano coated leaves found is 68 MPa, which is additional compressive strength than of conventional concrete.[10]

Table 7: Compressive strength test result data

Compressive Strength test result of cube [13]			
Bacteria Types	**Cell Concentration**	**@ 7 Day's**	**@ 28 Day's**
	10^0	11.55	17.77
Bacillus Subtilis	10^3	13.33	18.67
	10^4	14.22	24.88
	10^5	14.33	25.33
	10^6	14.22	18.67

From above table it can be observed that there is a increase in the compressive strength of a concrete with addition of a bacteria with an increase of concentration of bacteria in concrete.[13]

Table 8: Compressive strength test result data

Compressive Strength test result of cement paste[14]			
Bacillus Sphaericus	**Cell concentration of bacteria**	**Cement paste**	**Cement Mortar**
Sporosarcina Pasteurii	10^6 cells/ml of water	39.8%	50%
Conventional Concrete	10^6 cells/ml of water	33.07%	28.2%
	10^6 cells/ml of water	18.3%	12.2%

It can be observed from the above the table that there is an increase in compressive strength for the cement mortar and cement paste.[14]

Table 9: Compressive strength test result data

Compressive strength of Cement Mortar with 1 OD[16]	
CM Specimen samples	**@ 28 Day's**
With Water	>33%
With Bacteria(S. Pasteurii)	About 33%

From above table it can be seen that the the specimen prepared in two manners are with water and with addition of bacteria S. Pateurii. There is increase in a compressive strength due to bacteria addition with OD concentration. The more compressive strength has been observed with 1 OD of bacteria addition than 1.5 OD.[16]

Table 10: Compressive strength test result data

Compressive strength of Bacterial Concrete[17]			
Samples	**@ 3 Day**	**@ 7 Day**	**@ 28 Day**
Conventional concrete	9.10	18.50	27.88
Bacterial Concrete (Bacillus Subtilis)	9.70	19.0	29.13

The Compressive strength has been increasing gradually in comparison of Bacterial concrete with Ordinary Concrete.[17]

Table 11: Compressive strength comparative value

S. No	**Bacteria**	**Compressive Strength results @ 28 day's**	**Water absorption results @ 28 days**	**Refrences**
1	**Bacillus Sphaericus**	30-35 % increase in strength than controlled sample	45-50 % less than controlled concrete sample	8, 34, 58,7,59,60
2	**Bacillus Subtilis**	12-17 % increase in strength than controlled sample	About 50% lesser than controlled concrete sample	61,62,63,64
3	**Bacillus magaterium**	24.2% increase in strength than controlled sample	About 46% lesser than controlled concrete sample	65
4	**Bacillus Pasteurii**	2-4 % increase in strength than controlled sample	About 50 – 70% lesser than controlled concrete sample	1,66,65,55,34,67,62,
5	**Bacillus Cohnii**	15 % increase in strength than controlled sample	About 35 % lesser than controlled concrete sample	68
6	**Bacillus Flexus**	10-18 % increase in strength than controlle	About 40% lesser than controlled concret	69

		d sample	e sample	
7	**Bacillus Cerus**	30-40 % increase in strength than controlled sample	About 50% lesser than controlled concrete sample	58, 70
8	**S. Pateurii**	18 % increase in strength than controlled sample	80-85% lesser than controlled concrete sample	71,62,7,72,73,63,74,75
9	**Shwanella Species**	25-30 % increase in strength than controlled sample	Nearly 50% lesser than controlled concrete sample	76,62,7,77

From above table, a comparative value for the compressive strength of bacterial concrete has been found for different bacteria used in the concrete and also the water absorption value for different bacteria can be observed.

8. CRACK FORMATION:

The different bacteria are used in the concrete to heal the cracks. The various stages of crack healing with the use of bacteria are shown below:

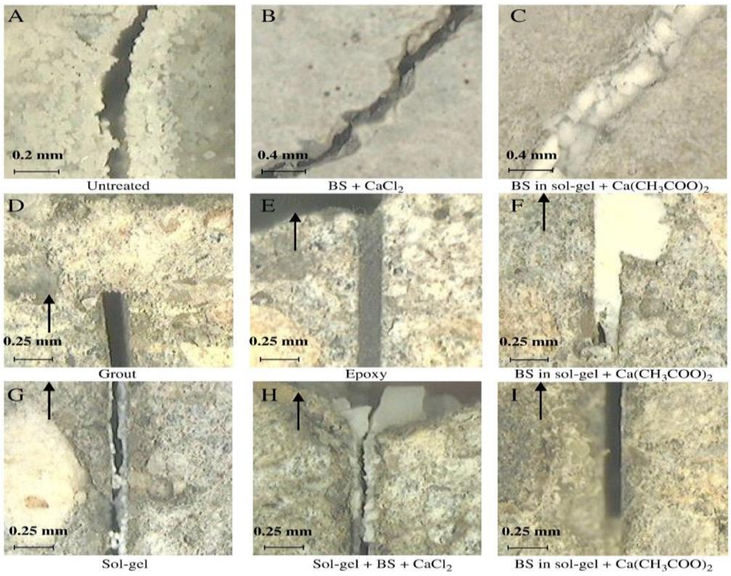

Fig 6: Images of cracks present in the concrete and healing depth due to bacteria[28].

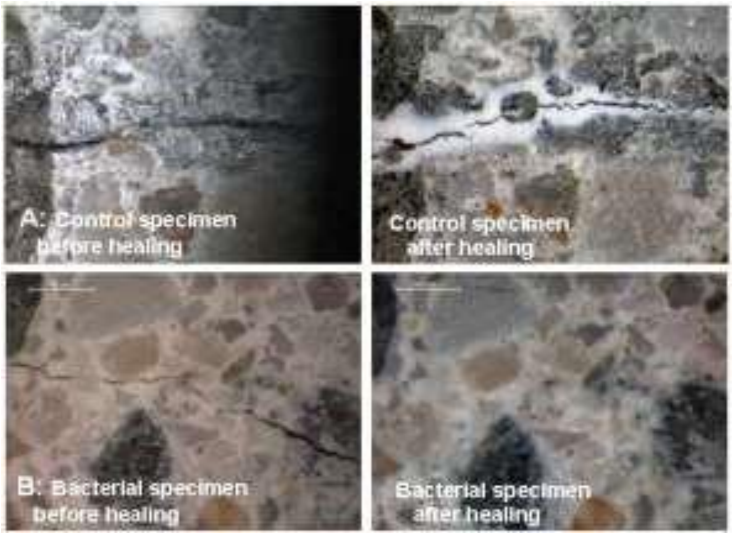

Fig 7: self-healing admixtures composed of clay pellets[31]

9. COMPRESSIVE STRENGTH, FLEXURAL STRENGTH & SEALING OF CRACKS:

The crack healing depth after the use of bacteria in the concrete: are shown below with the images.

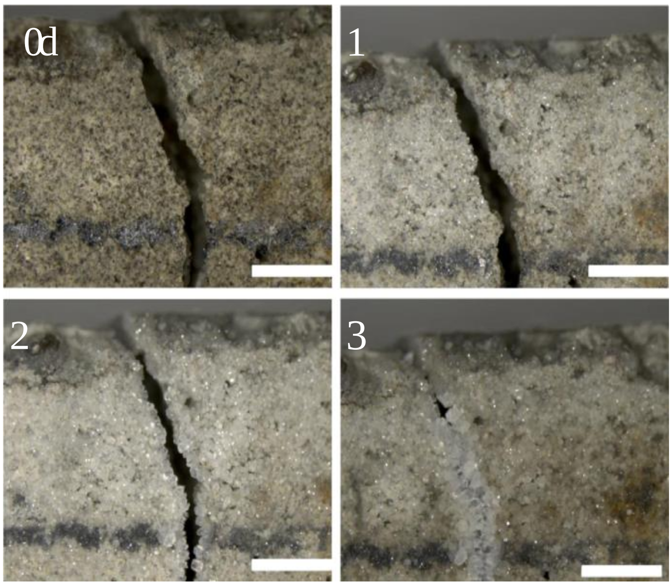

Fig 8: An example of a crack healing completion proces[8]

Table 12: Split Tensile strength test result

Split tensile strength result		
Bacteria Type	**Split tensile strength for cylinders (Refrence)**	**Remarks**
Bacillus Subtilis	1,5,13,15	More than conventional concrete
Bacillus Licheniformis	1	More than conventional concrete
Bacillus Pasteurii	16,19	More than conventional concrete

Table 13: Crack Heal measurement

Bacteria Type	**Crack Heal Measurement**	**Refrence No**	
Bacillus Sphaericus	Cracks in the concrete with bacteria gets reduced to minimum , compare to conventional concrete	1,2,6,8,28,33,34,35,36	
Bacillus Subtilis	The crack present in concrete cure at 28 days gets reduced to minimum.	1,2,4,5,6,13,15,17,24,30,37,38,39,40	
Basillus Licheniformis	The crack present in concrete cure at 28 days gets reduced to minimum .	4,41	

Bacillus magaterium	The crack present in concrete cure at 28 days gets reduced to minimum.	14,30,41	
Bacillus Pasteurii	Cracks(of different pattern) in the concrete with bacterial concrete gets closure to vanish the cracks than conventional concrete.	6,14,16,19,21,30,33, 38,41,42,43	
Bacillus Cohnii	Cracks in the concrete with bacteria gets reduced to	44	
	minimum , compare to conventional concrete		
Bacillus Flexus	Cracks in the concrete with bacteria gets reduced to minimum , compare to conventional concrete	34,46	
Bacillus Cerus	Cracks in the concrete with bacteria gets reduced to minimum , compare to conventional concrete	31,34,46	
S. Pateurii	Cracks in the	32,38,39,47,48,49,50	

	concrete with bacteria gets reduced to minimum , compare to conventional concrete		
Shwanella Species	Cracks in the concrete with bacteria gets reduced to minimum , compare to conventional concrete	38,51,52	
Sporoscarcina Pasteurii	Cracks in the concrete with bacteria gets reduced to minimum , compare to conventional concrete	20	
Bacterium Powder	Cracks in the concrete with bacteria gets reduced to minimum , compare to conventional concrete	25	

10. APPLICATION:

The following conclusion can be drawn from above:

- Due to its calcite precipitation properties of bacteria in the concrete, can be used for the treatment of cracks for historical monuments with limestone.
- It is effective to use to repair the cracks in the Rigid (R.C.C) pavement.
- Bacterial Concrete is helpful to seal the cracks in special structures like Bridge Deck, Pier etc by preventing the steel to corrode due to seepage of water.

11. CONCLUSION:

The variation of compressive strength test results has been noted in the above table [1-10] i.e. for different bacteria, different value of strength has been seen. With the addition of bacteria in the concrete there is the increase in compressive strength values. Thus, we can say that the use of bacteria in concrete enhance the compressive strength of concrete. The enhancing of strength value in concrete, shows the least permeability i.e. reduction of water content in the concrete than conventional concrete. This method is eco-friendly and conventional to use. Bacteria also helps in increasing the durability of the concrete. It helps to reduce the cost of maintenance in the building. Due these features in bacterial concrete, it increases the workability of concrete and imparts the great role in construction industry as a remedy of cracks. These bacteria can also be use with addition of other admixtures like plasticizer and superplasticizer, helps to increase the compressive strength of concrete. It ensures the quality of construction and saves the environment from being polluted from construction industries. The method is cheaper than others crack treatment methods.

It is also seen that the cracks have been healed in variation as varies according to the use of types of bacteria respectively. The different bacteria show different characteristics in path of healing the cracks of different pattern of cracks. The cracks have been healed upto 5 μm, 7 μm, 0.2 mm, 0.25mm, 0.3mm, 0.4mm etc.

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