TO STUDY SELF-HEALING OF CONCRETE USING BACILLUS SUBTILIS BACTERIA

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Abstract: *Substances which have the incorporated capacity to fix damage brought on by mechanical use with time. The inspiration stems from biological methods, which possess the capability to cure after being injured. Initiation of fractures and other sorts of harm on a microscopic amount was demonstrated to alter electrical, thermal, and acoustical properties, and lead to entire scale collapse of this substance. Normally, fractures are fixed by hands, which can be disappointing because fractures are often difficult to discover. A substance (polymers, ceramics, etc.) which may intrinsically correct damage brought on by normal usage can lower production costs of a lot of different industrial processes during longer part-time, decrease of inefficiency over time brought on by degradation, in addition to prevent prices incurred by substance failure. For a substance to be defined rigorously as self-healing, it's crucial that the recovery process happens without human intervention. Some cases shown below, nevertheless, include therapeutic polymers that need intervention to commence the recovery procedure. Bacterial self-healing is a complex. This biotechnology enhances the durability of the construction. This caused a reduction in porosity leading to an increase of energy, dynamic modulus in addition to a decrease in water uptake, gas permeability and chloride permeation. In 44 times, 400 μm crack surface breadth has been totally filled. What's more, it's established that Eurocode two can be implemented with confidence for predicting properties of bacterial concrete.*

Keywords: Self-healing, Bacillus subtilis, Calcium carbonate, Durability, Strength

1. INTRODUCTION

Concrete is quite good substance to withstand the compressive load into a limit but in the event the load exerted on the concrete is greater than their limit of resisting load, it results in the strength loss of concrete by generating the cracks in the concrete and also the treatment of these cracks in rather pricey. A number of those property such as durability, permeability advertisement strength of the concrete construction can be diminishing. Due to Rise in the permeability of the concrete that the water easily pass through the concrete and Arrive from the touch with the reinforcement of the concrete construction and after a while corrosion begin Because of This power of the concrete construction will reduces so It'll Be necessary to repair the cracks

1. By present the germs in concrete it Creates calcium carbonate crystals that block the micro pores and cracks in the cement

2. In real micro cracks are constantly averted but to some extent they're in charge of their own collapse in strength.

Self-healing of concrete:

Self-healing materials are artificial or synthetically created substances which have the built-in ability to automatically repair damages to themselves without any external diagnosis of the problem or human intervention. Generally, materials will degrade over time due to fatigue, environmental conditions, or damage incurred during operation. Cracks and other types of damage on a microscopic level have been shown to change thermal, electrical, and acoustical properties of materials, and the propagation of cracks can lead to eventual failure of the material. In general, cracks are hard to detect at an early stage, and manual intervention is required for periodic inspections and repairs. In contrast, self-healing materials counter degradation through the initiation of a repair mechanism which responds to the micro-damage. Some self-healing materials are classed as smart structures, and can adapt to various environmental conditions according to their sensing and actuation properties.

Mechanism:

In **self-healing concrete**, formation of any cracks, leads to activation of **bacteria** from its stage of hibernation. By the metabolic activities of **bacteria**, during the process of **self-healing**, calcium carbonate precipitates into the cracks **healing** them.

2. LITERATURE REVIEW

1) Bacterial Concrete – A Concrete for the Future which says a common soil bacterium was used to induce calcite precipitation **(V. Ramakrishnan, R.K. Panch and S.S. Bang, 2001)**. **2)** potential application of bacteria to improve the strength of cement concrete in which the potential application of bacterial species i.e. B.sphaericus to improve the strength of cement concrete is studied **(C. Gavimath, B. M. Mali, V. R. Hooli, J. D. Mallpur, A. B. Patil, D.P.Gaddi, C.R.Ternikar,2012)**. **3)** Occurrence and Distribution of Mosquitocidal Bacillus sphaericus in Soil which says Bacillus sphaericus is one **(A. Surendran and S. John Vennison, 2011)**. **4)** Bio sealant properties of Bacillus sphaericus in which they say Bacillus spharecius was yet another partially characterized species with similar entity, having the capability of precipitating calcium carbonate **(Kantha D. Arunachalam, K.S. Sathyanarayanan, B.S. Darshan, R. Balaji Raja, 2010)**. **5)** Healing and Self-Healing of Concrete has shown during their presentation how repair and consolidation of mineral phases of building materials and the healing and self-healing of concrete with the help of bacteria is possible. Micro-organisms play a crucial role in pedogenesis, transformation of minerals and exchange of elements in structures. Dr. Nele De Belie, Ghent University, Belgium has published a paper on Healing and Self-Healing of Concrete has shown during their presentation how repair and consolidation of mineral phases of building materials and the healing and self-healing of concrete with the help of bacteria is possible. Micro-organisms play a crucial role in pedogenesis, transformation of minerals and exchange of elements in structures **(Dr. Nele De Belie, 2013)**. **6) Thirumalaichettiar** has published a paper on bacterial concrete says a novel technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite (CaCo3) precipitation is discussed. **7) Ellie Zolfagharifard** has published an article on Biological concrete could usher in a new era of self-healing civil structures says its Far better would be to use a material that heals itself just as a crack begins to appear. Existing research has focused on the use of synthetic materials that can seal up cracks as they develop. **8) At Delft University, Dr Henk Jonkers** has developed a biological concrete that uses specially selected bacteria of the genus Bacillus, alongside a combination of calcium lactate, nitrogen and phosphorus, to create a healing agent within the concrete.

3. METHODOLOGY

Materials and Specification

The following are the materials which are used in concrete: The ordinary concrete used in the test program consisted of cementing materials, mineral aggregates, and corrosion inhibitor with the following specifications:

Cement:

Ordinary Portland Cement of 53 grade is used.

Specific gravity - 3.15

Normal consistency - 32%

Initial setting time - 55 minutes

Final setting time - 258 minutes

Fine aggregate:

The fine aggregate is tested as per IS: 383-1970.

Specific gravity - 2.66

Fineness modulus - 3.22

Zone - II

Coarse aggregate

Locally available well graded granite aggregates of normal size greater than 4.75 mm and less than 16mm having the specific gravity of coarse aggregate was 2.67 and fineness modulus of 2.72 was used as coarse aggregates.

Bacteria:

1. Bacillus subtilis is the bacteria used
2. Bacteria Concentration for 1 Litre solution is 2*108 cfu/ml.
3. Bacillus subtilis is an obligate aerobe bacterium used as a larvicide for mosquito control.
4. It forms spherical endospores.
5. Bacillus subtilis is a gram-positive bacterium, with rod shaped cells that form chains-Medium sized, smooth colonies with an entire margin and also Rod-shaped cells.
6. Gram-variable, large, spore-forming rods with a diameter < 0.9 µm.
7. Catalase -positive.
8. Lecithinase-negative.
9. Does not attack sugars.
10. Growing range of Temperature: 37^0c
11. Optimum Temperature:35-37^0c.

MIX DESIGN:

The aim of studying the various properties of materials of concrete, plastic concrete and hardened concrete is to design a concrete mix for particular strength. Design of concrete mix needs complete knowledge of the various properties of the constituent material, the implications in place of change on the conditions at site, the impact of the properties of plastic concrete on the hardened concrete and the complicated inter relationship between the variables. Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The mix design procedure is explained in the following section.

Indian Standard Method Design Stipulations:

a. Concrete grade: M25

b. Exposure: Severe

c. Quality control: Good

d. Size of aggregate: 20 mm

e. Degree of workability: 0.9

f. Cement used: OPC 53 grade cement

g. Sand grading zone: II

TABLE: 3.1: Physical Properties of Materials

MATERIAL	SPECIFIC GRAVITY	BULK DENSITY (kg/m^3)
CEMENT	3.15	1450
FINE AGGREGATE	2.67	1650
COARSE AGGREGATE	2.6	1575
WATER	1	1000

The Quantity of Materials for **M25** grade are as follows:

TABLE: 3.2: Quantity of Material per m^3 of concrete

MATERIAL	WEIGHT BASIS (kg)	VOLUME (m^3)
CEMENT	410	0.130
FINE AGGREGATE	669.615	0.376
COARSE AGGREGATE	1082.141	0.624
WATER	197	.197

1. Mix proportion = cement: fine aggregate: coarse aggregate
2. Mix proportion by weight = 1:1.633:2.7:0.48
3. Mix proportion by volume = 1:2.892:4.8:1.52

Mixing of bacterial concrete:

Great concrete can be had only through and uniform mixing, better through and uniform mixing, improved through compaction and adequate healing. In the lab, the cement was mixed by hand blending. Each of the constituent substances were considered, and ironic mixing was completed for approximately 5 minutes after which water has been added. The mixing was continued until concrete of uniform consistency was got and also the specimens were compacted with table vibrator.

After 24 hours, the specimens were remolded and maintained immersed healing tank containing potable water until the required curing phase of concrete specimens. In the mix ratio 1:1.633:2.639 with water cement ratio 0.48 can be employed for other specimen and additional in cement with 10ml and 20ml proportions of germs for every specimens and suitable curing creates a considerable improvement in improving the security of embedded concrete.

Process of Manufacture of Concrete:

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad concrete. Therefore, it is necessary for us to know what the good rules are to be followed in each stage of manufacture of concrete for producing good quality concrete. The various stages of manufacture of concrete are:

1. Batching

2. Mixing

3. Placing

4. Compacting

5. Curing

Workability of Concrete:

Workability is the amount of useful internal work required to produce full compaction of concrete. It depends on

1. Types of aggregate

2. Grading of coarse and fine aggregate

3. Quantity of cement paste

4. Consistency of the cement paste

Crack Healing Analysis:

When the cracks start to form from the concrete construction water enters the cracks. After coming in contact with oxygen and water, the dormant germs become active. They multiply and germinate from the calcium established nutrient calcium lactate which may conversion of calcium lactate in to limestone by mobile reactions into blocking the fracture route by sedimentation of particles using all the surrounding cement matrix that seals the cracks.

Basic Mechanism to remediate cracks:

Microorganisms (cell surface charge is negative) draw cat ions including Ca2+ from the environment to deposit on the cell surface. The equations given below summarize the role of bacterial cell as a nucleation site.

Ca^{2+} + Cell → Cell-Ca^{2+}

Cell-Ca^{2+} +CO_3^{2-} → $CaCO_3$

The bacteria can thus act as nucleation site which facilitates for the precipitation of calcite which eventually plug the pores and cracks in concrete.

We have found out that in this observation the cracks size up to 0.8mm takes 3 weeks' time and up to 1mm size cracks takes 4weeks time to healing the crack.

MIX DESIGN PROCEDURE

(IS 10262 :2009)

GRADE OF CONCRETE M_{25}

Characteristic Compressive Strength = 25MPa

Type of Cement = OPC 53 Grade

Minimum Size of Aggregate = 20mm (Angular)

Maximum Water-Cement Ratio = 0.48

Workability = 100mm

Degree of Exposure Condition = Severe

Degree of Supervision = Good

Maximum Cement Content = 410 Kg/m3

1. **The Target Mean Strength is determined by using following relation**
   $F_{ck} = f_{ck} + (t*s)$

f'ck = Target Mean Compressive Strength at 28 days in N/mm2

fck = Characteristic Compressive Strength at 28 days in N/mm2

t = A Statistical value depending upon the results and no. of tests

s = Standard Deviation shown from IS: 10262 – 2009

Assuming not more than 5% results are expected to fall below the characteristic Compressive strength. In which case of 't 'is 1.65. Standard Deviation for M30 grade concrete is 5.

f'ck = fck+(t*S) =25 + (1.65 * 4)

= 31.6 N/mm2.

2. **Selection of Water content Ratio**
   From fig.2. IS 10262 – 2009 the water cement ratio required for the target mean strength of 31.6 N/mm2. is 0.48.
3. **Selection of water content**

From table 2, maximum water content =186 liters (for 25 to 50mm slump range) for 20 mm aggregates

Esteemed water content for 100 mm slump = 186 + 6/100*186 = 197.16 liters.

4. **Calculation of cement content**
   Water cement ratio = 0.48
   Cement content = 197.16 / 0.4 = 320 < 410Kg/m^3 Hence ok.

5. Properties of volume of Coarse aggregate and Fine aggregate content

From table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone II) for water cement ratio 0.50 = 0.62.

In the present case water cement ratio is 0.45. Therefore, the volume of water cement ratio is lower by 0.05, the proportion of volume of coarse aggregate is increased by 0.01 (at the rate of /+ 0.01 for every +/- 0.05 change in water cement ratio).

Therefore, corrected proportion of volume of coarse aggregate for the water cement ratio of 0.45 = 0.63.

Volume of coarse aggregate = 0.624

Volume of fine aggregate = 1- 0.624 = 0.376

6. Mix Calculations

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete = 1m^3
b) Volume of cement = Mass of cement/specific gravity of cement * (1/1000)
 = 410/3.15 * (1/1000)
 = 0.130m^3
c) Volume of water = Mass of water/specific gravity of water * (1/1000)
 = 197.16/1.0 * (1/1000)
 = 0.197m^3.
d) Mass of fine = (a-(b+c))
 Aggregate
e) Mass of coarse = d * Volume of coarse aggregate * specific gravity * 1000 Aggregate
 = 0.667 * 0.624 *2.6 *1000
 = 1082.141kg

7. The Quantity of Material for M$_{25}$ grade concrete are as follows:

Table: 3.3 Quantity of Material for M$_{25}$ grade concrete per m^3

Material	Weight basis (kg)	Volume (m^3)
Cement	410	0.130
Fine Aggregate	669.615	0.376
Coarse Aggregate	1082.141	0.624
Water	197.16	0.197

Mix proportions = cement: Fine aggregate: Coarse aggregate

Mix proportions by weight = 1:1.633:2.7:0.48

Mix proportion by volume = 1:2.892:4.8:1.52

4. RESULTS AND DISCUSSIONS

The test results of bio concrete and conventional concrete showed an eloquent difference. The table and charts given shows the clear information regarding compressive strength, split tensile strength and flexural strength of M25.

Compressive Strength:

S.NO	Type of bacteria	Bacterial concrete with 10ml addition of concrete		Conventional concrete	
		Compressive strength(N/mm^2)		Compressive strength(N/mm^2)	
		7days	28days	7days	28days
1	Bacillus subtills	18.45	27.89	17.89	26.17

TABLE: 4.1 Comparison between compressive strength of bacterial concrete with 10ml Addition of Bacteria and conventional concrete.

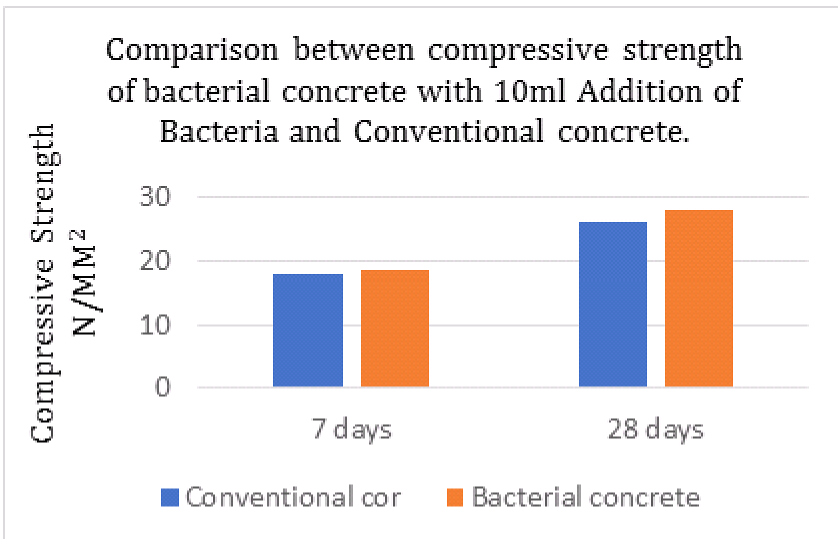

FIG. 4.1: Comparison between compressive strength of bacterial concrete with 10ml Addition of Bacteria and Conventional concrete

S.NO	Type of bacteria	Bacterial concrete with 20ml Addition of bacteria		Conventional concrete	
		Compressive strength (N/mm^2)		Compressive strength (N/mm^2)	
		7days	28days	7days	28days
1	Bacillus subtills	20.22	30.2	17.89	26.17

TABLE: 4.2 Comparison between compressive strength of bacterial concrete 20ml Addition of Bacteria and conventional concrete.

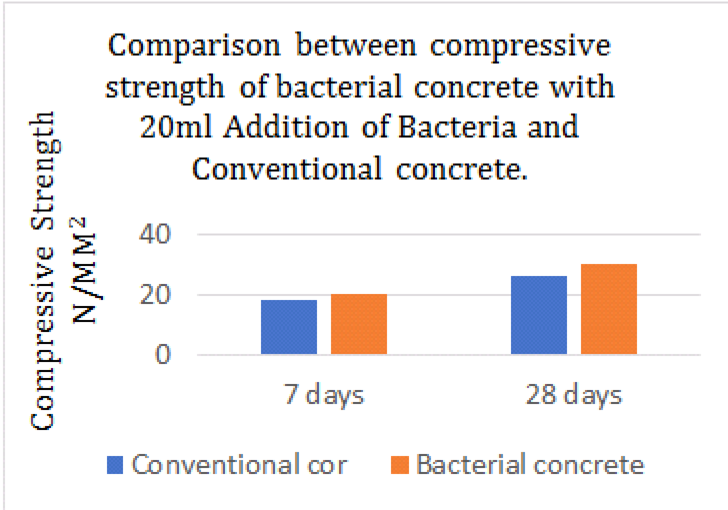

FIG. 4.2: Comparison between compressive strength of bacterial concrete with 20ml Addition of Bacteria and Conventional concrete.

DISCUSSIONS:

When we compare Bacterial concrete with conventional concrete, we have found out that the increase in compressive strength of the Bacterial concrete with 20ml of addition of bacillus subtilis for 7 days, 28 days as 13.02% and 15.39% respectively.

Split Tensile Strength:

TABLE: 4.3Comparison between split tensile strength of bacterial concrete with 10ml Addition of Bacteria and Conventional concrete.

S.NO	Type of bacteria	Bacterial concrete 10ml Addition of Bacteria		Conventional concrete	
		Split tensile strength (N/mm^2)		Split tensile strength (N/mm^2)	
		7days	28days	7days	28days
1	Bacillus subtilis	2.32	3.48	2.216	3.27

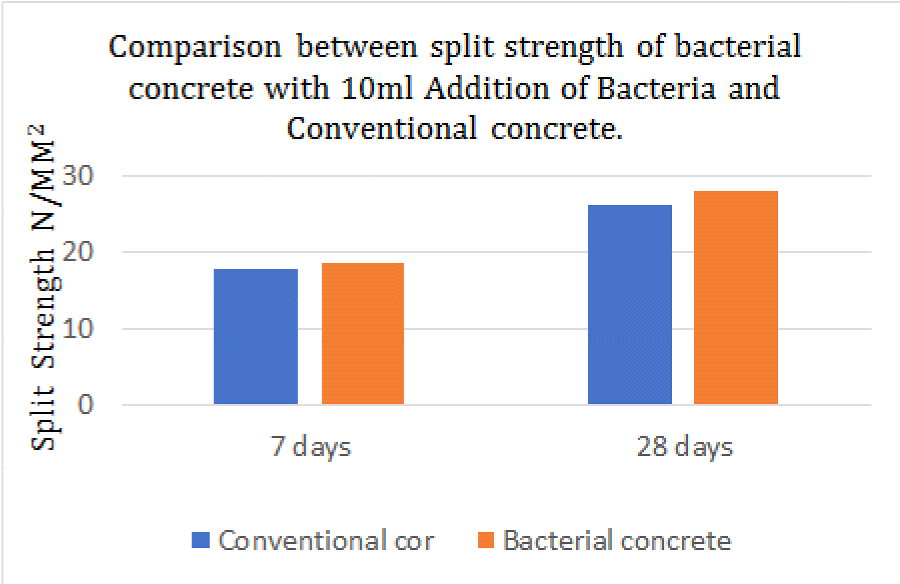

FIG.4.3: Comparison between split tensile strength of bacterial concrete 20ml Addition of Bacteria and conventional concrete.

DISCUSSIONS:

When we compare Bacterial concrete with conventional concrete, we have found out that the increase in split tensile strength of the Bacterial concrete with 20ml of addition of bacillus subtilis for 7 days, 28 days as 12.8% and 14.37% respectively.

Flexural Strength:

TABLE: 4.4 Comparison between flexural strength of Bacterial concrete with10ml Addition of Bacteria and Conventional concrete.

S.NO	Type of bacteria	Bacterial concrete 10ml Addition of Bacteria		Conventional concrete	
		Flexural strength (N/mm²)		Flexural strength (N/mm²)	
		7days	28days	7days	28days
1	Bacillus subtilis	7.2	9.74	6.91	9.08

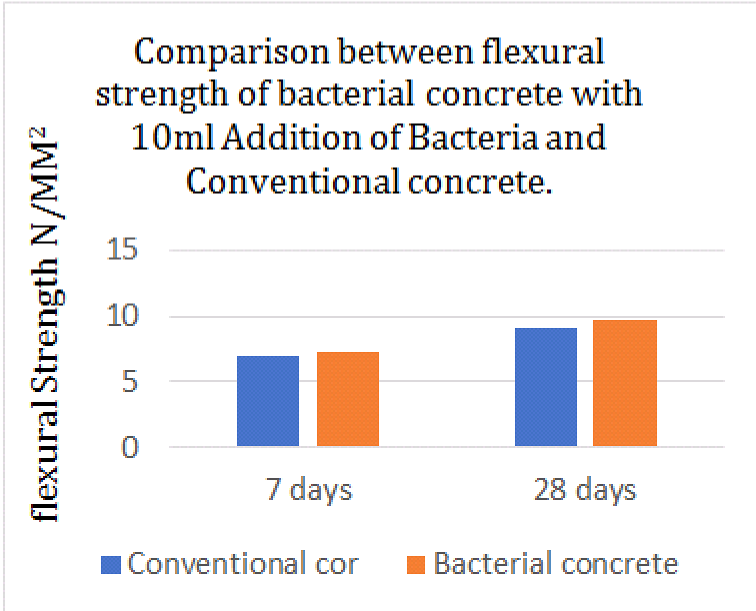

FIG.4.4: Comparison between flexural strength of bacterial concrete with 10ml Addition of Bacteria and Conventional concrete.

DISCUSSIONS:

When we compare Bacterial concrete with conventional concrete, we have found out that the increase in flexural strength of the Bacterial concrete with 20ml of addition of bacillus subtilis for 7 days, 28 days as 4.2% and 7.26% respectively.

TABLE: 4.5 Comparison between flexural strength of bacterial concrete with 20ml Addition of Bacteria and conventional concrete.

S. NO	Type of bacteria	Bacterial concrete 20ml Addition of Bacteria		Conventional concrete	
		flexural strength (N/mm^2)		flexural strength (N/mm^2)	
		7days	28days	7days	28days
1	Bacillus subtilis	7.5	10.27	6.91	9.08

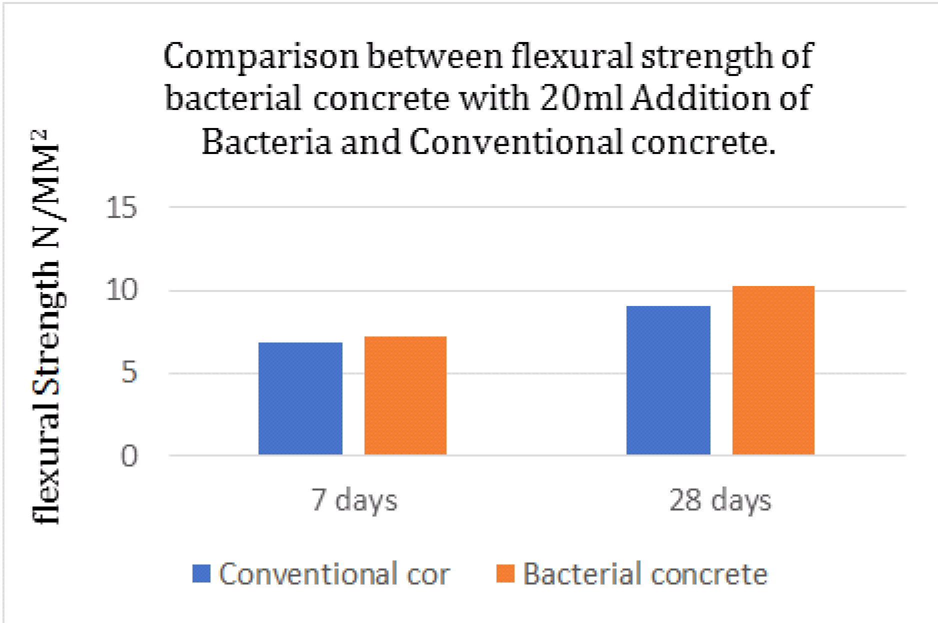

FIG: 4.5 Comparison between flexural strength of bacterial concrete with 20ml Addition of Bacteria and conventional concrete.

DISCUSSIONS:

When we compare Bacterial concrete with conventional concrete, we have found out that the increase in flexural strength of the Bacterial concrete with 20ml of addition of bacillus subtilis for 7 days, 28 days as 8.5% and 13.12% respectively.

5. Conclusions

1. The Compressive, split tensile and flexural strength of M25 bio-concrete is found to be higher than M25 conventional concrete.

2. A Self-Healing Concrete with microbial activities is pollution free and natural.

3. The workability test of the bacterial concrete resulted in 90mm of slump value.

4. We have found out that the compressive strength of the bacterial concrete with 10ml and 20ml of addition of bacillus subtilis as 27.89 and 30.2 respectively.

5. Same way we have found out that the split tensile strength of the bacterial concrete with 10ml and 20ml of addition of bacillus subtilis as 6.42 and 14.37 respectively. We have also found out that the flexural strength of the bacterial concrete with 10ml and 20ml of addition of bacillus subtilis as 7.26 and 10.27 respectively.

6. Finally we have casted a cube of size 150mm x 150mm x 150mm with 20ml addition of bacillus subtilis and made some tiny cracks by giving little load and the observation of the healing process of the crack is going on.

REFERENCES

1. **V. Ramakrishnan, R. K. Panchalan and S. S. Bang** ; ''Improvement of concrete durability by bacterial mineral precipitation ''; Proceedings of 24th International Conference of Cement Microscopy, San Diego, California; Vol. 4234 (2001); 13-15 December 2000; pp. 168-176.

2. **C. C. Gavimath, B. M. Mali, V. R. Hooli, J. D. Mallpur , A. B. Patil , D. P. Gaddi, C. R. Ternikar'';** Potenial application of bacteria to improve the strength of cement concrete''; International Journal of Advanced Biotechnology and Research; Issue 1 ISSN 0976-2612; Vol 3; 2012; pp 541-544.
3. **Kantha D. Arunachalam , K. S. Sathyanarayanan, B. S. Darshan, R. Balaji Raja;** ''Studies on the characterisation of Bio sealant properties of Bacillus sphaericus''; International Journal of Engineering Science and Technology; ISSN: 0975-5462; Vol. 2(3);2010; pp 270-277.
4. **Surendran and S. John Vennison**; ''Occurrence and Distribution of Mosquitocidal Bacillus sphaericus in Soil''; Academic journal of Entomology 4 (1); ISSN 1995-8994; 2011; pp 17-22.
5. **Dr. Nele De Belie, Kim Van Tittelboom**; ''Self-Healing in Cementitious Materials- A Review''; International Journal of 3 R; Issue no. 10.3390/ma6062182; ISSN 1996-1944; 27 May 2013; pp 2182-2217.
6. IS: 10262 – 1982 "Recommended guidelines for concrete mix design".
7. "CONCRETE TECHNOLOGY" Theory and practice by **M.S. SHETTY**.
8. **Thirumalaichettiar** has published a paper on bacterial concrete says a novel technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite (CaCo3) precipitation is discussed.
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