An Experimental Study on Bacterial Concrete using Bacillus Subtilis and Bacillus Megaterium

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Abstract - *Microbial induced calcium carbonate precipitation is a novel method for increasing the physical strength of the cement concrete. The objective of the present investigation is to study the incorporation of bacteria, Bacillus subtilis and Bacillus Megaterium to improve the compressive and split-tensile strength of cement concrete after comparing with conventional concrete. Conventional and bacterial concrete was prepared and its strength was evaluated using standard Indian Specifications. A significant increase in the compressive strength and split tensile strength of concrete with combination of Bacillus Subtilis and Bacillus Megaterium is found after curing for 7 and 14 days. The obtained results revealed that bacterial concreted showed more strength than the conventional concrete. Water which enters the concrete will activate the dormant bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation. The present study concludes that bacteria will not negatively affect the compressive and split tensile strength of the cement concrete.*

Key Words: Bacterial concrete, Bacillus Subtilis, Bacillus Megaterium, Fine Aggregates, Coarse Aggregates, Calcium Carbonate, Compressive strength, Split tensile strength, seepage.

1. INTRODUCTION

Concrete's versatility, durability, sustainability, and economy have made it the world's most widely used construction material. About four tons of concrete are produced per person per year worldwide. We are now at a time when the world has felt the need to live a greener and cleaner life. Having said that, the carbon footprint that goes during the production of cement is quite enormous, thereby making it a significant contributor of greenhouse gases.

Concrete, it is the most widely used material for the construction. Concrete is weak in tension and strong in compression and cracks are inevitable in concrete. Once cracks are formed in concrete it may reduce the lifespan of the concrete structures. Micro-cracks and pores are concrete are highly undesirable because they provide an open pathway for the ingress of water and deleterious substances which leads to the corrosion of reinforcement and reduces the strength and durability of concrete. Various repair techniques are available to repair the cracks, but they are highly expensive and time consuming process. There are moderate techniques to repair the cracks in concrete by itself called Self-Healing concrete. This bacterial remediation technique surpasses other techniques as it is bio-based, eco-friendly, cost-effective and durable.

Concrete is a highly alkaline material, the bacteria added is capable of withstanding alkali environment. Bacteria with calcium nutrient source are added into the concrete at the time of mixing. If any cracks will be formed in concrete, bacteria precipitate calcium carbonate. This will seal the cracks.

The development of Self-Healing Concrete (SHC) by Professor *Hendrik Jonkers of Delft Technical University in the Netherlands* has made a remarkable impact on the construction industry. The composition of Self Compacting Concrete is similar to that of Normal Concrete, that is, Cement, Fine and Coarse aggregates, Water and in addition it contains Bacteria which helps to produce calcium carbonate.

1.1 HOW DOES SELF HEALING CONCRETE WORK?

Bacterial concrete is an outcome of the reaction of a calcium based nutrient and non-reacted limestone. The cracks appear on the building are healed with the help of bacteria. Special form of bacteria belonging to "Bacillus" family, is used along with calcium lactate as a nutrient. These bacteria can be in dormant stage for approximately 200 years and after its contact with water, deposit calcite precipitate in cracks that follows process.

Once the cracks appear in the concrete, water begins to percolate in concrete through the openings. The bacterial spores germinate and start feeding on calcium as water trickles into the cracks. Conversion of soluble sodium calcium lactate into insoluble limestone takes place as the oxygen is consumed in the chemical reaction as shown in the equation. The onset of hardening of insoluble limestone fills up the cracks.

1) $CaO + H_2O \quad Ca(OH)_2$

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

The calcium oxide reacts with water, generating calcium hydroxide as the result. Reaction of this calcium hydroxide with carbon dioxide provides calcium carbonate as the end product together with egress of water. The water molecules generated in this reaction helps in converting the calcium oxide further calcium hydroxide and the reaction continues until all the available calcium oxide breaks down.

1.2 ADVANTAGES OF SELF HEALING CONCRETE.

The self-healing bacterial concrete helps in reducing maintenance and repair costs of reinforced concrete structures.

Oxygen is an agent that can induce corrosion, as bacteria feeds on oxygen tendency for the corrosion of reinforcement can be reduced.

Self-healing bacteria can be used in places where human find it difficult to reach for the maintenance of the structures. Hence it reduces risking of human life in dangerous areas and also increases the durability of the structure.

Formation of the crack will be healed in the initial stage itself thereby increasing the service life of the structure than expected life.

2. LITERATURE REVIEW

V Srinivasa Reddy, M V Seshagiri Rao and S Sushma, described in their paper about the effect of bacterial cell concentration of Bacillus Subtilis JC3, on the strength by determining the compressive strength of standard cement mortar cubes of different grades, incorporated with various bacterial cell concentrations. The cost of using microbial concrete compared to conventional concrete which is critical in determining the economic feasibility of the technology, is also studied.[9]

A.T. Manikandan, A.Padmavathi, have published a paper on *An Experimental Investigation on Improvement of Concrete Serviceability by using Bacterial Mineral precipitation.* In this paper, the bacteria Bacillus subtilis strain 121 was from Microbial Type Culture Collection and Gene Bank, Chandigarh. Samples were prepared in sets of three for a water cement ratio of 0.5 by mass for conventional concrete and a water cement ratio of 0.25 and bacterial culture of 0.25 for bacterial concrete by mass.[1]

Department of Biotechnology and environmental sciences, Thapar University (2011), reported on influence of bacteria on the compressive strength, water absorption and rapid chloride permeability. Influence of sporoscarcina pasteurii bacteria on the compressive strength and rapid chloride permeability of concrete. Concrete cubes were prepared with different concentration of Sporoscarcina pasteurii. The cell concentration was determined from the bacterial growth curve made by observing optical density at 600mm.[4]

3. PROBLEM STATEMENT

The major aim of the present work is to study the Compressive and tensile strength of a typical M_{25} grade bacterial concrete mix.

3.1OBJECTIVES

- ✓ To study the variation of compressive strength and split tensile strength of the concrete with Bacteria Subtilis and conventional concrete.
- ✓ To study the variation of compressive strength and split tensile strength of the concrete with Bacteria Megatarium and conventional concrete.
- ✓ To study the variation of compressive strength and split tensile strength of the concrete with combination of Bacteria Subtilis and Bacillus Megaterium and conventional concrete.
- ✓ To determine the average time for seepage in the slabs designed with Bacillus Subtilis and Bacillus Megaterium and their combination.
- ✓ To measure the length of the cracks filled in the concrete with bacteria.

3.2 METHODOLOGY

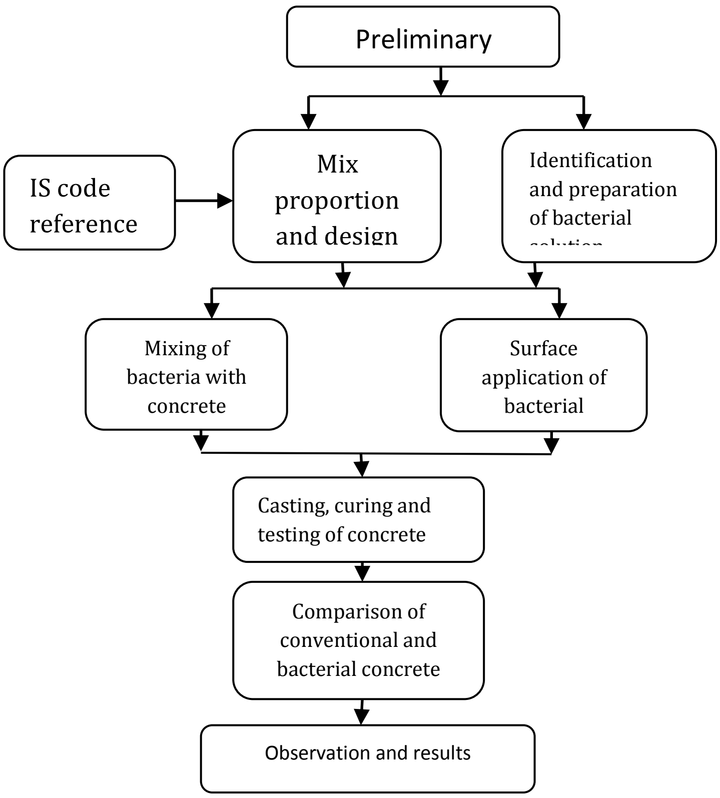

Fig 1 Methodology

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 08 | Aug 2020 www.irjet.net p-ISSN: 2395-0072

4. MATERIALS

4.1 CEMENT

For the present investigation, ZUARI grade-53 OPC confirming to BIS: 12269-1987 was used. The cement sample was dried, powdered and free from lumps.

4.2 COARSE AGGREGATES

The coarse aggregate chosen for concrete is typically round in shape, is well graded, and smaller in maximum size than that used for conventional concrete. Normally conventional concrete could have a maximum aggregate size of 40 mm or more. Typically, the maximum size of coarse aggregate used in SHC ranges from approximately 10 mm to 20 mm. Generally, aggregates occupy 70% to 80% of the volume of concrete and have a natural rock (Crushed stone, or natural gravels) and sands, although synthetic materials such as slag and Expanded clay or shale are used to some extent, mostly in lightweight concretes (Miness et al., 2003).

4.3 FINE AGGRERATES

Manufactured sand (MS) is a term used for aggregate materials less than 4.75mm which are processed from suitable source material (crushed rock or gravel). Production generally involves crushing, screening and possibly washing. Crushing of stones into aggregates by VSI, then fed to rotopactor to crush aggregates into sand to required grain sizes (as fines). Screening is done to eliminate dust particles and Washing of sand eliminates very fine particles present within. The end product will satisfy the requirements of IS: 383-1970 and can be used in Concrete & construction.

4.4 BACILLUS SUBTILIS

Bacillus Subtilis can be either cultured or is available in emulsion form as bio-fertilizer.

Fig 1 Bacillus Subtilis Bio fertilizer

4.5Bacillus Megaterium

Bacillus megaterium can be either cultured or is available in emulsion form as bio-fertilizer. Bacillus Megaterium is a rod like, gram positive, mainly aerobic spore forming bacterium found in widely diverse habitats. With a cell length of up to 4 micro meter. Bacillus Megaterium is amongst the biggest known bacteria. The cells often occur in pairs and chains, where the cells are joined together by polysaccharides on the cell walls.

Fig 2 Bacillus Megaterium Bio fertilizer

5. TEST RESULTS OF COARSE AGGREGATES

Sl. No.	Characteristics	Unit	Value	IS: 383-1970
1	Fineness Modulus	%	3.6	6.5-8
2	Specific Gravity		2.64	2-3.5
3	Loose density of CA	Kg/m^3	1450	1200-1750
4	Water Absorption	%	0.5	Maximum-0.6

Table 1 Test results of coarse aggregates

5.1Results on Tests conducted on Fine Aggregate

Sl. No.	Characteristics	Unit	Value	IS: 383-1970
1	Fineness Modulus	%	3.33	2-4.0
2	Specific Gravity		2.61	2.5-2.9
3	Loose density of FA	Kg/m^3	1463	1200-1750
4	Water Absorption	%	0.5	Maximum-0.6

Table 2 Test results of fine aggregates

5.2Results on Tests conducted on Cement

Sl. No.	Characteristics	Unit	Value	I.S.8112-1989
1	Fineness	%	6	Maximum-10
2	Standard Consistency	%	33	Maximum-31.5
3	Soundness 3.1 Lechatelier Method	mm	6	Maximum-10
4	Setting Time 4.1 Initial Setting Time 4.2 Final Setting Time	minutes minutes	35 600	Minimum-30 Maximum-600

5	Specific Gravity Value		3.15	Maximum-3.19

Table 3 Test results of cement

6. MIX DESIGN

Sl.no.	Materials	Conventional concrete kg/m³	Bacterial concrete kg/m³
1.	Cementitious materials		
	• Cement	426	426
2.	Aggregates		
	• Fine Aggregate	685.06	685.06
	• Coarse Aggregate	1083.79	1083.79
3.	Water Content	192	192
4.	Bacteria	Not Used	5ml per liter of water

Table 4 Mix design

7. RESULTS AND DISCUSSION

7.1 Compressive strength of M-25 conventional concrete and Bacillus Subtilis – 7 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm²)	AVERAGE STRENGTH (N/mm²)
1.	25	Conventional concrete	0	382.5 390 370	17 17.33 16.44	16.92
2.	25	Bacillus Subtilis	20	406 398 410	18.04 17.68 18.22	17.98

Table5 Compressive strength of M-25 conventional concrete and Bacillus Subtilis – 7 days

The above table graphically represented in fig as shown below. It can be seen that the average compressive strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus subtilis. The average compressive strength of bacterial concrete with bacillus subtilis is 6.26% greater than conventional concrete.

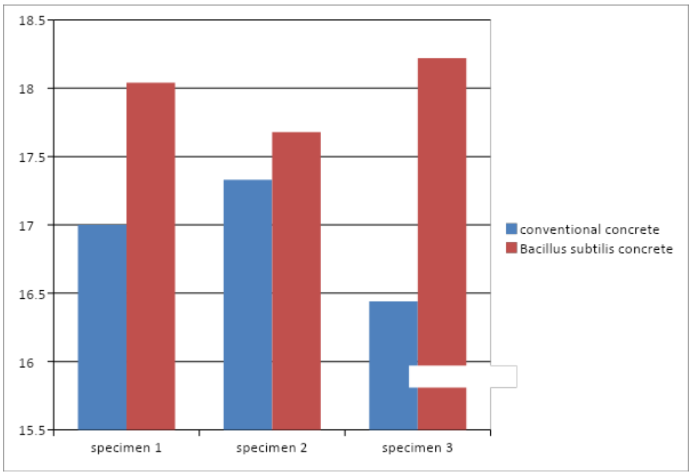

Chart 1 Graphical representation of 7-day compressive strength of conventional concrete and bacillus subtilis

7.2 Tensile strength of M-25 conventional concrete and Bacillus Subtilis – 7 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	TENSILE STRENGTH (N/mm²)	AVERAGE STRENGTH (N/mm²)
1.	25	Conventional concrete	0	50.89 51.42 50.01	2.88 2.91 2.83	2.87
2.	25	Bacillus Subtilis	20	52.48 51.95 52.66	2.97 2.94 2.98	2.96

Table 6 Tensile strength of M-25 conventional concrete and Bacillus Subtilis – 7 days

The above table graphically represented in fig 7.2 as shown below. It can be seen that the average tensile strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus subtilis. The average tensile strength of bacterial concrete with bacillus subtilis is 3.13% greater than conventional concrete.

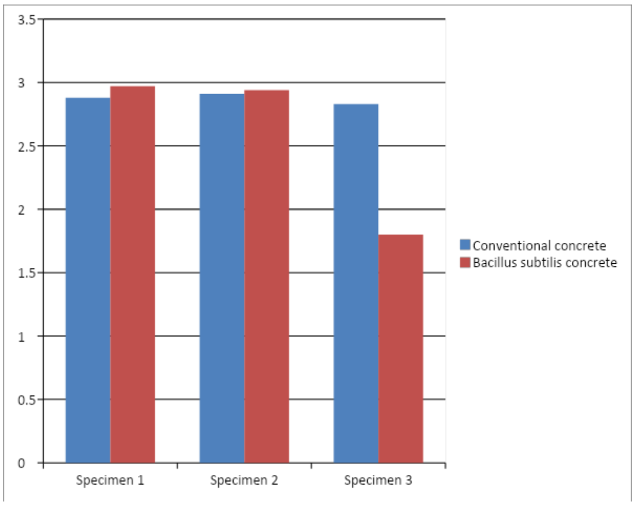

Chart 2 Graphical representation of 7-day tensile strength of conventional concrete and bacillus subtilis

7.3 COMPRESSIVE STRENGTH OF M-25 CONVENTIONAL CONCRETE AND BACILLUS MEGATERIUM – 7 DAYS

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm^2)	AVERAGE STRENGTH (N/mm^2)
1.	25	Conventional concrete	0	382.5 390 370	17 17.33 16.44	16.92
2.	25	Bacillus Megaterium	20	385 388 381	17.11 17.24 16.93	17.09

Table 7 COMPRESSIVE STRENGTH OF M-25 CONVENTIONAL CONCRETE AND BACILLUS MEGATERIUM – 7 DAYS

The above table graphically represented in fig as shown below. It can be seen that the average compressive strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus Megaterium. The average compressive strength of bacterial concrete with Bacillus Megaterium is 1.004% greater than conventional concrete.

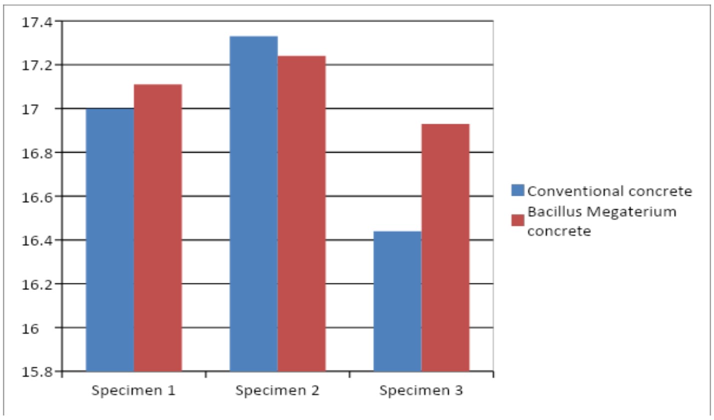

Chart 3 Graphical representation of 7-day compressive strength of conventional concrete and bacillus Megaterium.

7.4 Tensile strength of of M-25 conventional concrete and Bacillus Megaterium – 7 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	TENSILE STRENGTH (N/mm^2)	AVERAGE STRENGTH (N/mm^2)
1.	25	Conventional concrete	0	50.89 51.42 50.01	2.88 2.91 2.83	2.87
2.	25	Bacillus Megaterium	20	51.07 51.24 50.89	2.89 2.90 2.88	2.89

Table 8 Tensile strength of of M-25 conventional concrete and Bacillus Megaterium – 7 days

The above table graphically represented in fig as shown below. It can be seen that the average tensile strength of conventional concrete is less than the average tensile strength of bacterial concrete with bacillus Megaterium. The average tensile strength of bacterial concrete with Bacillus Megaterium is 0.69% greater than conventional concrete.

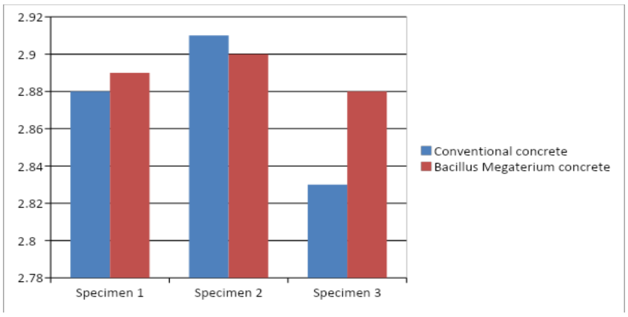

Chart 4 Graphical representation of 7-day tensile strength of conventional concrete and bacillus Megaterium

7.5 Compressive strength of M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 7 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm²)	AVERAGE STRENGTH (N/mm²)
1.	25	Conventional concrete	0	382.5 390 370	17 17.33 16.44	16.92
2.	25	Combination of Bacillus Subtilis and Bacillus Megaterium	20	419.5 415 416	18.64 18.44 18.48	18.52

Table 9 Compressive strength of M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 7 days

The above table graphically represented in fig as shown below. It can be seen that the average compressive strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus subtilis and bacillus Megaterium. The average compressive strength of bacterial concrete with Bacillus subtilis and Bacillus Megaterium is 9.45% greater than conventional concrete.

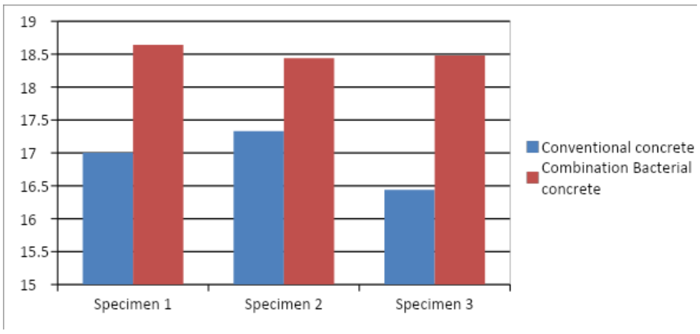

Chart 5 Graphical representation of 7-day compressive strength of conventional concrete and combination of bacillus subtilis and bacillus megaterium

7.6Tensile strength M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 7 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	TENSILE STRENGTH (N/mm²)	AVERAGE STRENGTH (N/mm²)
1.	25	Conventional concrete	0	50.89 51.42 50.01	2.88 2.91 2.83	2.87
2.	25	Combination of Bacillus Subtilis and Bacillus Megaterium	20	53.36 53.10 53.17	3.02 3.005 3.009	3.011

Table 10 Tensile strength M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 7 days

The above table graphically represented in fig 7.6 as shown below. It can be seen that the average tensile strength of conventional concrete is less than the average tensile strength of bacterial concrete with bacillus subtilis and bacillus Megaterium. The average tensile strength of bacterial concrete with Bacillus subtilis and Bacillus Megaterium is greater than 4.912% conventional concrete.

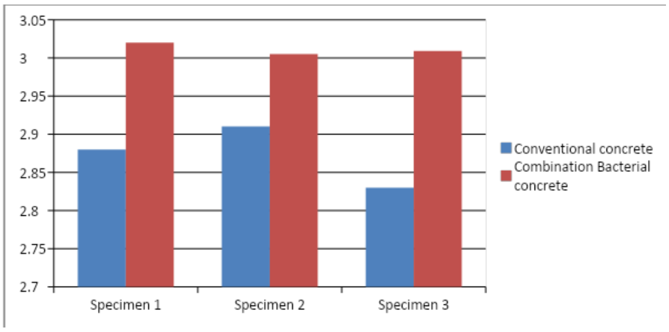

Chart 6 Graphical representation of 7-day tensile strength of conventional concrete and combination of bacillus subtilis and bacillus megaterium

7.7 Compressive strength of M-25 conventional concrete and Bacillus Subtilis -14 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm^2)	AVERAGE STRENGTH (N/mm^2)
1.	25	Conventional concrete	0	506.2 510 504	22.5 22.66 22.4	22.52
2.	25	Bacillus Subtilis	20	515 513 520	22.88 22.80 23.11	22.93

Table 11 Compressive strength of M-25 conventional concrete and Bacillus Subtilis -14 days

The above table graphically represented in fig as shown below. It can be seen that the average compressive strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus subtilis. The average compressive strength of bacterial concrete with bacillus subtilis is 1.82% greater than conventional concrete.

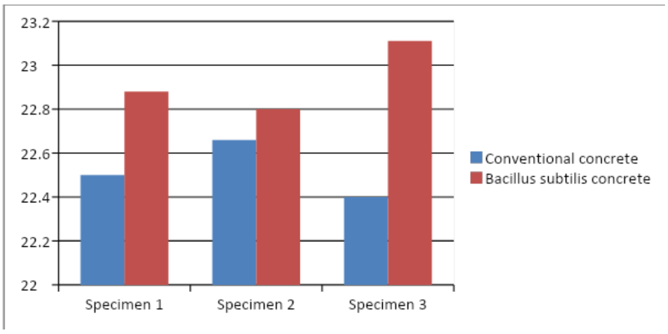

Chart 7 Graphical representation of 14-day compressive strength of conventional concrete and bacillus subtilis

7.8 Tensile strength of M-25 conventional concrete and Bacillus Subtilis-14 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	TENSILE STRENGTH (N/mm^2)	AVERAGE STRENGTH (N/mm^2)
1.	25	Conventional concrete	0	58.66 58.84 58.54	3.32 3.33 3.313	3.321
2.	25	Bacillus Subtilis	20	59.02 59.05 59.37	3.34 3.342 3.36	3.347

Table 11 Tensile strength of M-25 conventional concrete and Bacillus Subtilis-14 days

The above table graphically represented in fig as shown below. It can be seen that the average tensile strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus subtilis. The average tensile strength of bacterial concrete with bacillus subtilis is 0.78% greater than conventional concrete.

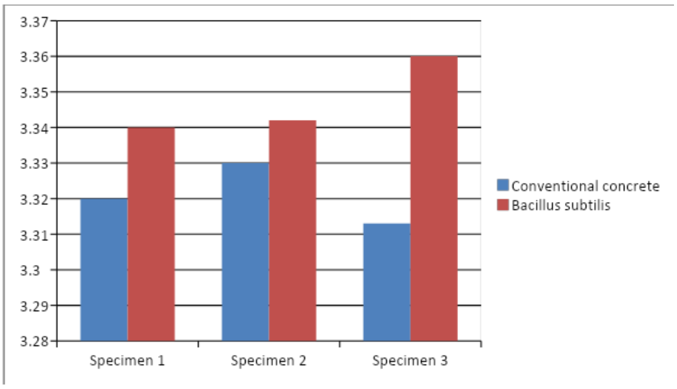

Chart 8 Graphical representation of 14-day tensile strength of conventional concrete and bacillus subtilis

7.9 Compressive strength of M-25 conventional concrete and Bacillus Megaterium -14 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm^2)	AVERAGE STRENGTH (N/mm^2)
1.	25	Conventional concrete	0	506.2 510 504	22.5 22.66 22.4	22.52
2.	25	Bacillus Megaterium	20	511.5 512 510	22.73 22.75 22.66	22.71

Table 12 Compressive strength of M-25 conventional concrete and Bacillus Megaterium - 14 days

The above table graphically represented in fig as shown below. It can be seen that the average compressive strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus Megaterium. The average compressive strength of bacterial concrete with Bacillus Megaterium is 0.843% greater than conventional concrete.

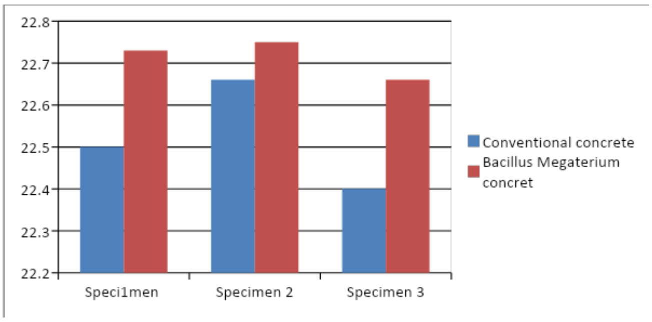

Chart 9 Graphical representation of 14-day compressive strength of conventional concrete and bacillus Megaterium

7.10 Tensile strength of of M-25 conventional concrete and Bacillus Megaterium – 14 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	TENSILE STRENGTH (N/mm²)	AVERAGE STRENGTH (N/mm²)
1.	25	Conventional concrete	0	58.66 58.84 58.54	3.32 3.33 3.313	3.321
2.	25	Bacillus Megaterium	20	58.84 58.91 58.88	3.33 3.338 3.332	3.33

Table 13 Tensile strength of M-25 conventional concrete and Bacillus Megaterium – 14 days

The above table graphically represented in fig as shown below. It can be seen that the average tensile strength of conventional concrete is less than the average tensile strength of bacterial concrete with bacillus Megaterium. The average tensile strength of bacterial concrete with Bacillus Megaterium is 0.27% greater than conventional concrete.

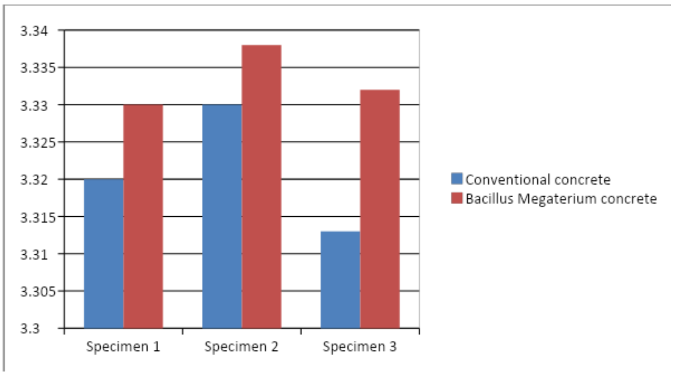

Chart 10 Graphical representation of 14-day tensile strength of conventional concrete and bacillus Megaterium

7.11 Compressive strength of M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 14 days

Sl.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	COMPRESSIVE STRENGTH (N/mm²)	AVERAGE STRENGTH (N/mm²)
1.	25	Conventional concrete	0	506.2 510 504	22.5 22.66 22.4	22.52
2.	25	Combination of Bacillus Subtilis and Bacillus Megaterium	20	540 536 548	24 23.82 24.35	24.05

Table 14 Compressive strength of M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 14 days

The above table graphically represented in fig as shown below. It can be seen that the average compressive strength of conventional concrete is less than the average compressive strength of bacterial concrete with bacillus subtilis and bacillus Megaterium. The average compressive strength of bacterial concrete with Bacillus subtilis and Bacillus Megaterium is 6.79% greater than conventional concrete.

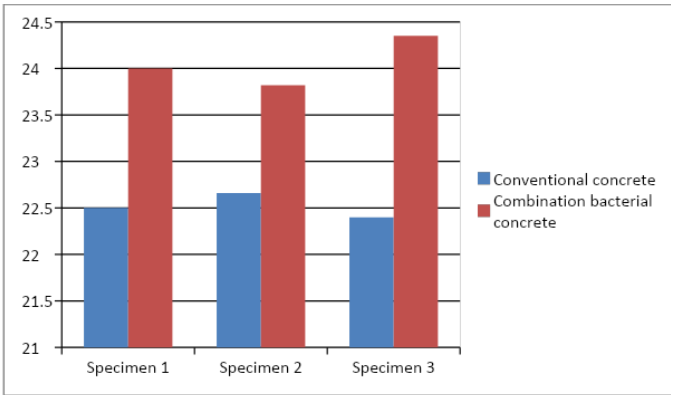

Chart 11 Graphical representation of 14-day compressive strength of conventional concrete and combination of bacillus subtilis and bacillus megaterium

7.12 Tensile strength M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 14 days

S.NO.	GRADE (M)	NAME	PROPORTION (ml)	LOAD (KN)	TENSILE STRENGTH (N/mm²)	AVERAGE STRENGTH (N/mm²)
1.	25	Conventional concrete	0	58.66 58.84 58.54	3.32 3.33 3.313	3.321
2.	25	Combination of Bacillus Subtilis and Bacillus Megaterium	20	60.59 60.36 61.03	3.429 3.416 3.454	3.433

Table 15 Tensile strength M-25 conventional concrete and combination of Bacillus Subtilis and Bacillus Megaterium – 14 days

The above table graphically represented in fig 7.12 as shown below. It can be seen that the average tensile strength of conventional concrete is less than the average tensile strength of bacterial concrete with bacillus subtilis and bacillus Megaterium. The average tensile strength of bacterial concrete with Bacillus subtilis and Bacillus Megaterium is greater than 3.372% conventional concrete.

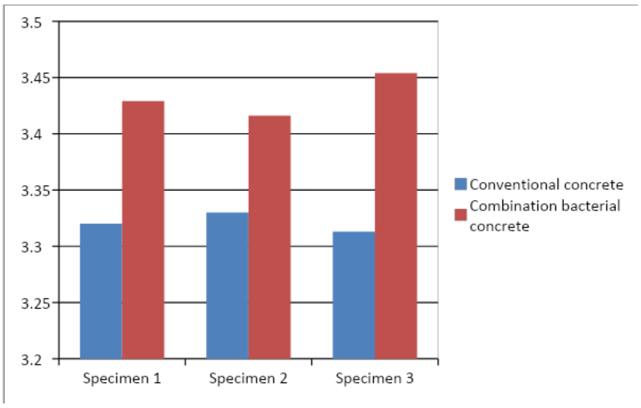

Chart 12 Graphical representation of 14-day tensile strength of conventional concrete and combination of bacillus suubtilis and bacillus megaterium

7.13 RESULTS FOR SEEPAGE TEST PERFORMED ON CONCRETE SLABS-

Sl. NO	Slab No.	Type of top coat	Average total time for seepage in mi
1	Slab 1	Conventional	96
2	Slab 2	Conventional	100
3	Slab 3	Bacillus Subtilis	110
4	Slab 4	Bacillus Subtilis	108
5	Slab 5	Bacillus Megaterium	140
6	Slab 6	Bacillus Megaterium	150
7	Slab 7	Combination	350
8	Slab 8	Combination	353

Table 16 Results for Seepage Test

The above table shows the seepage test results, the seepage time of combination slab with Bacillus Subtilis and Bacillus Megaterium is 258.67% greater than conventional concrete. The seepage time of Bacillus subtilis is 11.2% greater than conventional slab. The seepage time of Bacillus Megaterium is 47.95% greater than conventional concrete.

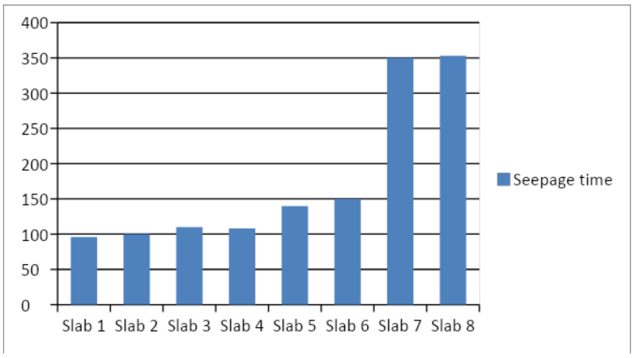

Chart 13 Seepage test results

8. CONCLUSIONS

- ✓ The value of slump increases with increasing the bacteria content in concrete. Whereas the value of compaction factor decreases with increasing the bacteria content in concrete.
- ✓ The optimum content of bacteria used in the concrete is 20 ml.
- ✓ The compressive strength of bacterial concrete with Bacillus Subtilis for 7 days is 6.26 % greater than conventional concrete.
- ✓ The compressive strength of Bacterial concrete with Bacillus Megaterium for 7 days is 1.0048 % greater than conventional concrete.
- ✓ The compressive strength of bacterial concrete with Bacillus Subtilis and Bacillus Megaterium for 7 days is 9.45 % greater than conventional concrete.
- ✓ The tensile strength of bacterial concrete with Bacillus Subtilis for 7 days is 3.13 % greater than conventional concrete.
- ✓ The tensile strength of Bacterial concrete with Bacillus Megaterium for 7 days is 0.69 % greater than conventional concrete.
- ✓ The tensile strength of bacterial concrete with Bacillus Subtilis and Bacillus Megaterium for 7 days is 4.912 % greater than conventional concrete.

- ✓ The compressive strength of bacterial concrete with Bacillus Subtilis for 14 days is 1.82 % greater than conventional concrete.
- ✓ The compressive strength of Bacterial concrete with Bacillus Megaterium for 14 days is 0.843% greater than conventional concrete.
- ✓ The compressive strength of bacterial concrete with Bacillus Subtilis and Bacillus Megaterium for 14 days is 6.79% greater than conventional concrete.
- ✓ The tensile strength of bacterial concrete with Bacillus Subtilis for 14 days is 0.78% greater than conventional concrete.
- ✓ The tensile strength of Bacterial concrete with Bacillus Megaterium for 14 days is 0.27 % greater than conventional concrete.
- ✓ The tensile strength of bacterial concrete with Bacillus Subtilis and Bacillus Megaterium for 14 days is 3.372 % greater than conventional concrete.
- ✓ From the above test results we can conclude that the combination bacterial concrete with Bacillus Subtilis and Bacillus Megaterium gives us more compressive and tensile strength.
- ✓ From the seepage test results table, we can observe that the seepage time of slab for slab 7 and slab 8 are greater than all the remaining slab. Hence seepage results suggest that the concrete with Bacillus subtilis and Bacillus Megaterium helps in self-healing of concrete.

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