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Studies on Split Tensile, Flexural, Compressive Properties of Quatenary Blended Bacterial Self Compacting Concrete

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ABSTRACT
Concrete is the foremost building material broadly used in building construction, but cracks in concrete are inevitable and are one of the inherent weakness of the concrete. The major downside of concrete is its low tensile strength due to which micro crack occurs when the load applied is more than its limit and this paves way for the seepage of water and other salts. This initiates corrosion and makes the whole structure vulnerable and leads to the failure of structure. To remediate this types of failure due to cracks and fissures, an approach of using biomineralization in concrete has evolved in recent years. In this method, of enhancing the performance of concrete, the calcite precipitating spore forming bacteria is introduced into concrete. When water enters through the cracks, it reacts with bacteria and forms precipitates of calcium carbonate, as a by-product, which fills the cracks and makes crack free concrete. This type of concrete prepared with bacteria is called as Bacterial Concrete. Therefore, an attempt has been made to study SCC(self-compacting concrete) with a quaternary blend of 40% cement, 25% fly ash, 25% GGBS, 10% micro silica with Bacillus Subtilis, a non-toxic soil bacterium. Water binder ratios of 0.3 and 0.4 were used. Thus, this project is an attempt to define Bacterial Concrete like how it is different from other materials, its ingredients, the factors influencing its various properties, the method by which it can be used in concrete etc. As Bacterial Concrete has remarkable advantages over ordinary concrete in self repairing itself when cracked, it proves to be an environmentally safe material to be used. It is therefore important to encourage the ongoing researches to further enhance the properties and also to bring out the initiative to lay a standard for the usage of these bacteria based material.

KEYWORDS: Quaternary, blended, SCC, bacteria ,concrete,CaCO3,repair,cracks

I. INTRODUCTION

About 7% of the total worldwide carbon-dioxide emissions is due to the production of cement. One of the ways to reduce cement consumption is to use blended cements i.e., replace maximum percentage of cement with mineral admixtures like fly ash, ground granulated blast furnace slag (GGBS), micro silica etc. use of blended cements can reduce Carbon-dioxide emissions by 13-22%. Further, use of blended cement is not only an economical and environmental friendly way of using concrete but also has several advantages like it reduces water-cement ratio, improves workability, reduces permeability, reduces alkali-aggregate reactions, prevents sulphate attack, there by enhances durability of concrete.

On the other hand, formation of micro-cracks in concrete is unavoidable. The micro-cracks may be due to its low tensile strengths, increase in water-cement ratio, due to creep and shrinkage, or it may be as a natural part of hydration process. These micro-cracks may affect the durability of concrete.

Several external chemical treatment methods are available to solve this problem. Self-healing of cracks in concrete using bacteria is an innovative and an eco-friendly way of fixing the cracks with out the use of chemicals, By this, the cracks can be fixed internally and immediately, when it is formed.

The bacteria along with the calcium source (which acts as a nutrient for its growth) is included with the other usual ingredients of concrete. When cracks occur oxygen and moisture seeps into the concrete, the bacteria which is in the spore form until then, gets activated consuming the oxygen, moisture and the nutrient. As a part of its metabolism, the bacteria produces calcium carbonate (CaCO3) which seals the cracks of the concrete and ensures the durability of the concrete.

But, the disadvantage is that the bacterial spores may get damaged due to the mechanical forces applied on the concrete while preparing it. Self-compacting concrete (SCC) is one which does not require any compaction by mechanical vibrations and compacts itself under its own weight. Since this concrete eliminates compaction, the problem of bacterial spores getting damaged by mechanical vibrations can be avoided when it used in SCC. In turn, drawback of SCC like formation of plastic and drying shrinkage cracks can be well taken care by the bacteria.

But, SCC mix should be designed in such a way that it should be flowable enough to fill up the formwork, at the same time, it should neither segregate nor bleed. In order to make SCC resistance to segregation, usually mineral admixtures are being used, i.e., blended cements can be effectively used in SCC.

Thus an attempt has been made to study the combined effect of blended cements, self-healing by bacteria and self-compaction in concrete, so as to acquire a more efficient, economical and technically sound concrete for the construction industry.

II. LITERATURE REVIEWS

SakinaNajmuddinSaifee , published a paper on Critical appraisal on Bacterial Concrete. In this paper they discussed about the different types of bacteria and their applications. The bacterial concrete is very much useful in increasing the durability of cemetous materials, repair of limestone monuments , sealing of concrete cracks to highly durable cracks etc.It also useful for construction of low cost durable roads , high strength buildings with more bearing capacity, erosion prevention of loose sands and low cost durable houses. They have also briefed about the working principle of bacterial concrete as a repair material. It was also observed in the study that the metabolic activities in the microorganisms taking place inside the concrete results into increasing the overall performance of concrete including its compressive strength. This study also explains the chemical process to remediate cracks.

Meera C M and Dr Subha, have published a paper on Strength And Durability assessment Of Bacteria Based Self-Healing Concrete. In this paper they have discussed about the effect of Bacillus subtilis JC3 on the strength and durability of concrete. They used cubes of sizes 150mm x 150mm x 150mm and cylinders with a diameter of 100mm and a height of 200mm with and without addition of micro organisms, of M20 grade concrete. For strength assessments, cubes were tested for different bacterial concentrations at 7 days and 28 days and cylinders were tested for split tensile strength at 28 days. It was observed that the compressive strength of concrete showed significant increase by 42% for cell concentration of 105 of mixing water. And also, with the addition of bacteria there is a significant increase in the tensile strength by 63% for a bacteria concentration of 105cells/ml at 28 days. For durability assessment, acid durability test, chloride test and water absorption test were done. From the results it could be inferred that the addition of bacteria prevents the loss in weight during acid exposure to a certain limit, proving the bacterial concrete to have higher Acid Attack Factor. The Water Absorption Test, showed a lesser increase in weight of bacteria concrete sample than control, from which it could be reckoned that the concrete will become less porous due to the formation of Calcium Carbonate, due to which it resulted in lesser water absorption rate. Chloride test results showed that the addition of bacteria decreases weight loss, due to Chloride exposure and enhances the Compressive Strength.

Chitra P Bai & Shibi Varghese, have published a paper on an experimental investigation on the strength properties of fly ash based Bacterial concrete. In this paper, The bacteria Bacillus Subtilis was used for study with different cell concentrations of 103, 105 and 107 cells/ml for preparing the bacterial concrete. Cement was partially replaced by 10%, 20% and 30% of fly ash by weight for making the bacterial concrete. Concrete of grade M30 was prepared and tests such as Compressive strength, Split tensile strength, Flexural strength and Ultrasonic Pulse Velocity were conducted after 28 and 56 days of water curing. For fly ash concrete, maximum compressive strength, split tensile strength, flexural Strength and Ultrasonic Pulse Velocity values were obtained for 10% fly ash replacement. For bacterial concrete maximum compressive strength, split tensile strength, flexural strength, and UPV values were obtained for the bacteria cell concentration of 105cells/ml. The improvement in the strength properties of fly ash concrete is due to the precipitation of calcium carbonate (CaCO3) inthe micro environment by the bacteria Bacillus Subtilis.

V Srinivasa Reddy, M V Sheshagiri Rao & S. Sushma, have published a paper on Feasibility

Study on Bacterial Concrete as an innovative self-crack healing system. This paper describes 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. This shows that the Improvement in compressive strength reaches a maximum at about 105/ml cell concentration. The cost of using microbial concrete compared to conventional concrete which is critical in determining the economic feasibility of the technology, is also studied. The cost analysis showed anincrease in cost of 2.3 to 3.9 times between microbial concrete and conventional concrete with decrease of grade. And nutrients such as inexpensive, high protein-containing industrial wastes such as corn steep liquor (CSL) or lactose mother liquor (LML) effluent from starch industry can also be used, so that overall process cost reduces dramatically. Precipitation of these crystals inside the gel matrix also enhances the durability of concrete significantly. Furthermore, this analysis has shown an increase in the cost of production and a significant decrease in carbon footprint compared to conventional concrete.

Mohith Goyal & P. Krishna Chaitanya , published a paper on Behaviour of Bacterial Concrete as Self-Healing Material. In this paper they have carried out laboratory investigations to compare the different parameters of bacterial concrete with ordinary concrete and concrete, in which 70% cement was partially replaced with 30% of Fly Ash and 30% of GGBS. In this paper, Bacillus pasteurii, is used to prepare M25 concrete. Various tests such as slump flow test, compressive strength, flexural strength and split tensile strength were conducted for different specimens of, bacterial concentrations of 40ml, 50ml and 60 ml for each specimen. In order to identify atomic and molecular structure and to check the presence of formation of calcium carbonate X- Ray diffraction test was conducted. There was significant improvement of compressive strength by 30% in concrete mix with bacteria and more than 15% in fly ash and 20% in GGBS. It was observed that bacterial concrete achieves maximum split tensile strength and flexural strength when 40 ml and 50 ml bacterial solution was used but loses this trend after 14 days with 60ml bacterial solution when flexural strength test was performed. Also, 50ml bacterial solution proved to be effective in increasing the split tensile strength, compressive strength and flexural strength of the specimen as compared to 40ml and 60 ml bacterial solution. Also, from the XRD analysis, it is proven that the presence on bacteria is contributing to CaCO3 production, which has reduced the percentage of air voids, thus, increasing the strength of the structure considerably.

N. Ganesh Babu & Dr.S.Sidddi Raju , has published a paper onan experimental study on strength and fracture properties of self-healing concrete. In this paper they have made an attempt is made to arrest the cracks in concrete using bacteria and calcium lactate. The percentages of bacteria selected for the study are 3.5% and 5% by weight of cement. In addition, calcium lactate was used at 5% and 10% replacement of cement by weight. Bacteria produce calcium carbonate crystals which blocks the micro cracks and pores in the concrete after reacting with calcium lactate. Bacillus pasteurii is used for different bacterial concentrations for M40 grade of concrete. Various tests such as compressive strength, elastic modulus and fracture of concrete were analysed. The cubes of dimensions of 100x100x100 mm were used for compressive strength test. It was observed that compressive strength for controlled concrete using calcium lactate, at 7 days and 28 days were 19.8 MPa and 40.53 MPa respectively. With the addition of calcium lactate, there is considerable decrease in compressive strength. Compressive strength of concrete with 5% bacteria was found to be 49.5 M pa at 28 days, which is more than controlled concrete. With the addition of calcium lactate at 10% (optimum percentage) and bacteria to concrete, there is considerable increase in compressive strength. Hence calcium lactate along with 3.5% and 5% bacteria can be used as an effective self-healing agent.

III. MATERIALS

Cement

Locally available 53 grade of Ordinary Portland Cement (Ultra Tech Brand.) confirming to IS: 12269 was used in the investigations. It has specific gravity of 3.15. Table 4.1 gives the physical properties of OPC used in the present investigation and they conform to IS specifications. Table 4.1 gives properties of cement.

Flyash

Class F fly ash of specific gravity 2.18 was used. Table 4.2 gives the properties of fly ash.

GGBS (Ground Granulated Blast Furnace Slag)

GGBS of specific gravity 2.92 was used. Table 4.3 gives properties of GGBS.

Micro Silica

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The Micro Silica obtained from ' Oriental Trexim Pvt Ltd '. Micro Silica conforming to a standard approved by the deciding authority may be used as part replacement of cement provided uniform blending with the cement is ensured. The Micro Silica (very fine non-crystalline silicon dioxide) is a by-product of the manufacture of silicon, ferrosilicon or the like, from quartz and carbon in electric arc furnace.It has specific gravity 2.63

Table 4.4 gives properties of Micro Silica. The chemical composition of Micro Silica is rich in silica.

Coarse Aggregate

Rounded aggregates of maximum size 20mm from local source is used.

Fine Aggregate

Locally available clean, natural river sand is used.

Super Plasticiser

A two in one super plasticiser including VMA(Master Glenium Sky 8662) was used for the study .

Bacterial Culture

The bacteria which we used in the project is Bacillus Subtilis. Bacillus Subtilis is a non-toxic, gram positive and rod shaped soil bacterium which can grow at Ph = 12 and temperature 30 degree Celsius was selected for the study. The pure culture of B. Subtilis (MCC 2183) was obtained from the Microbial Culture Collection (MCC), Pune in a freeze dried condition. The pure culture formed irregular dry white colonies on nutrient agar medium.

The bacterial growth curve using UV visible spectrophotometer at wavelength 600nm showed that maximum growth of bacteria occurred at 24th hour. The bacteria was preserved on nutrient agar slants (solid medium) for future use.

Whenever required a single colony of culture is inoculated into an autoclaved nutrient broth (liquid medium) of 100ml in 500ml conical flask and kept in shaking incubator (to ensure uniform growth) at 37 degree Celsius for 24 hours to ensure maximum growth. The nutrient agar / nutrient broth medium required for the growth of bacteria contains peptone, NaCl and beef / yeast extract.

Calcium Lactate

Calcium Lactate was used as nutrient for Bacillus Subtilis in concrete since it does not interfere with the setting time of the concrete. A 1% solution of calcium lactate was used as a calcium source for bacillus subtilis in the concrete.

SCC mix design

The SCC mix proportion is designed using Nan su method but the cement has been replaced by 25% fly ash , 25% GGBS, & 10% Micro Silica I.e., the binder consists of 40% cement , 25% flyash,25% GGBS & 10% micro silica. Materials required for 1 m3 QBBSCC(Quaternary Blended Bacterial Self Compacting Concrete) is given in table 4.7 .

Two water binder ratios of 0.3 and 0.4 were used for the study. After several trials of the fresh properties of the concrete satisfying the requirements of EFNARC 2005, for w/b ratio 0.3,the super plasticizer dosage is taken as 1.8% of binder and for w/b ratio 0.4,the SP dosage is taken as 1.6%.

Water

Water is the least expensive but most important ingredient of concrete. Fresh potable water is used for making concrete, which is clean and free from harmful impurities such as oil, alkali, acid, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. In general the water which is portable for drinking should

Locally available potable water conforming to IS 456-2000 was used.

IV. TESTS CONDUCTED

Workability tests

Slump flow test

Assessment of Slump Flow Test

This is a simple, rapid test procedure, though two people are needed if the T50 time is to be measured. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential.

It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without booking, but may give some indication of resistance to segregation.

It can be argued that the completely free flow, unrestrained by any foundries, is not representative of what happens in concrete construction, but the test can be profitably be used to assess the consistency of supply of supply of ready-mixed concrete to a site from load to load.

L-box test

This test for self-compacting concrete is based on a Japanese design for underwater concrete, has been described by Peterson. The test assesses the flow of the concrete and also the extent to which it is subjected to blocking by reinforcement. The apparatus is shown in the figure.

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The apparatus consist of rectangular section box in the shape of an 'L', with a vertical and horizontal section, separated by a movable gate, in front of which vertical length of reinforcement bar are fitted. The vertical section is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section.

When the flow has stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section. It indicates the slope of the concrete when at rest. This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted.

The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as the T20 and T40 times and are an indication for the filling ability.

The section of bar con be of different diameters and are spaced at different intervals, in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate. The bar can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete.

Assessment of test:

This is a widely used test, suitable for laboratory and perhaps site use. It asses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section.

Unfortunately there is no arrangement on materials or dimensions or reinforcing bar arrangement, so it is difficult to compare test results. There is no evidence of what effect the wall of the apparatus and the consequent 'wall effect' might have on the concrete flow, but this arrangement does, to some extent, replicate what happens to concrete on site when it is confined within formwork. Two operators are required if times are measured, and a degree of operator error is inevitable.

Interpretation of the result:

If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1=1. Therefore the nearest this test value, the 'blocking ratio', is unity, the better the flow of concrete.

The EU research team suggested a minimum acceptable value of 0.8. T20 and T40 time can give some indication of ease of flow, but no suitable values have been generally agreed. Obvious blocking of coarse aggregate behind the reinforcement bars can be detected visually.

V-Funnel Test:

The equipment consists of V-shaped funnel section is also used in Japan. The described V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 20mm.

The funnel is filled with about 12 litre of concrete and the time taken for it to flow through the apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increases significantly.

Assessment of test:

Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result if, for example there is too much coarse aggregate.

High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. While the apparatus is simple, the effect of the angle of the funnel and KYthe wall effect on the flow of concrete is not clear.

Interpretation of result:

This test measures the ease of flow of concrete, shorter flow time indicates greater flow ability. For SCC a flow time of 10 seconds is considered appropriate.

The inverted cone shape restricts the flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 minutes of settling, segregation of concrete will show a less continuous flow with an increase in flow time.

Compressive strength of specimen

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates.

Compressive Strength Formula:

Compressive strength formula for any material is the load applied at the point of failure to the cross-section area of the face on which load was applied.

Compressive Strength = Load / Cross-sectional Area

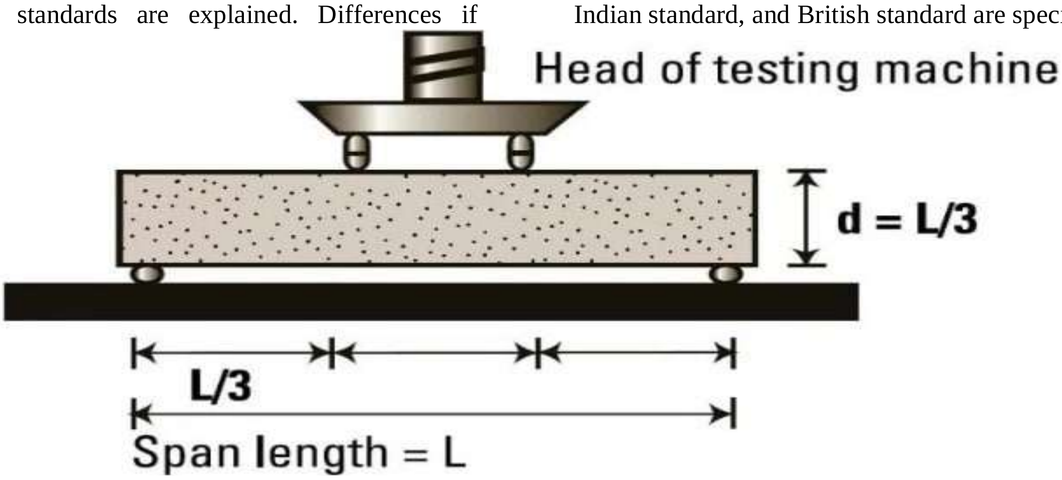
Compressive Strength of Concrete at Various Ages

The strength of concrete increases with age. Table shows the strength of concrete at different ages in comparison with the strength at 28 days after casting.

Age	Strength percent
1 day	16%
3 days	40%
7 days	65%
14 days	90%
28 days	99%

Flexural strength:

Flexural test on concrete based on the ASTM standards are explained. Differences if present in specification or any other aspects of flexural test on concrete between ASTM standard, Indian standard, and British standard are specified



Flexural Test on Concrete

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending.

The results of flexural test on concrete expressed as a modulus of rupture which denotes as (MR) in MPa or psi.The flexural test on concrete can be conducted using either three point load test (ASTM C78) or centre point load test (ASTM C293). The configuration of each test is shown in Figure-2 and Figure-3, respectively. Test method described in this article is according to ASTM C78.

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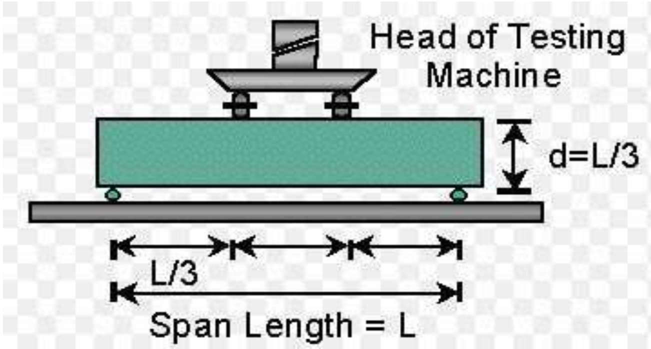


Fig.2: Three-Point Load Test (ASTM C78)

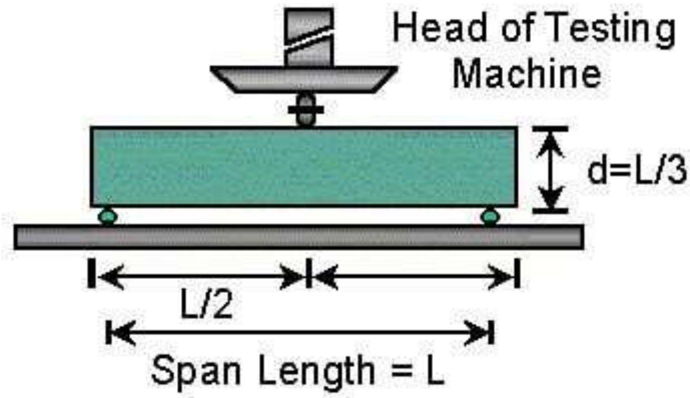


Fig.3: Centre Point Load Test (ASTM C293)

It should be noticed that, the modulus of rupture value obtained by centre point load test arrangement is smaller than three-point load test configuration by around 15 percent.

Moreover, it is observed that low modulus of rupture is achieved when larger size concrete specimen is considered.

Furthermore, modulus of rupture is about 10 to 15 percent of compressive strength of concrete. It is influenced by mixture proportions, size and coarse aggregate volume used for specimen construction.

Finally, the following equation can be used to compute modulus of rupture, but it must be determined through laboratory test if it is significant for the design:

$$f_r = 7.5\sqrt{f'_c} \quad \rightarrow \text{Equation-1}$$

Where:

f_r: Modulus of rupture

f_c': concrete compressive strength

Split tensile strength:

The tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures.

Moreover, the concrete is very weak in tension due to its brittle nature. Hence. it is not expected to resist the direct tension. So, concrete develops cracks when tensile forces exceed its tensile strength.

Therefore, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack.

Furthermore, splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete.The procedure based on the ASTM C496 (Standard Test Method of Cylindrical Concrete Specimen) which similar to other codes like IS 5816 1999.

Calculations

Calculate the splitting tensile strength of the specimen as follows:

T= 2P/ pi LD

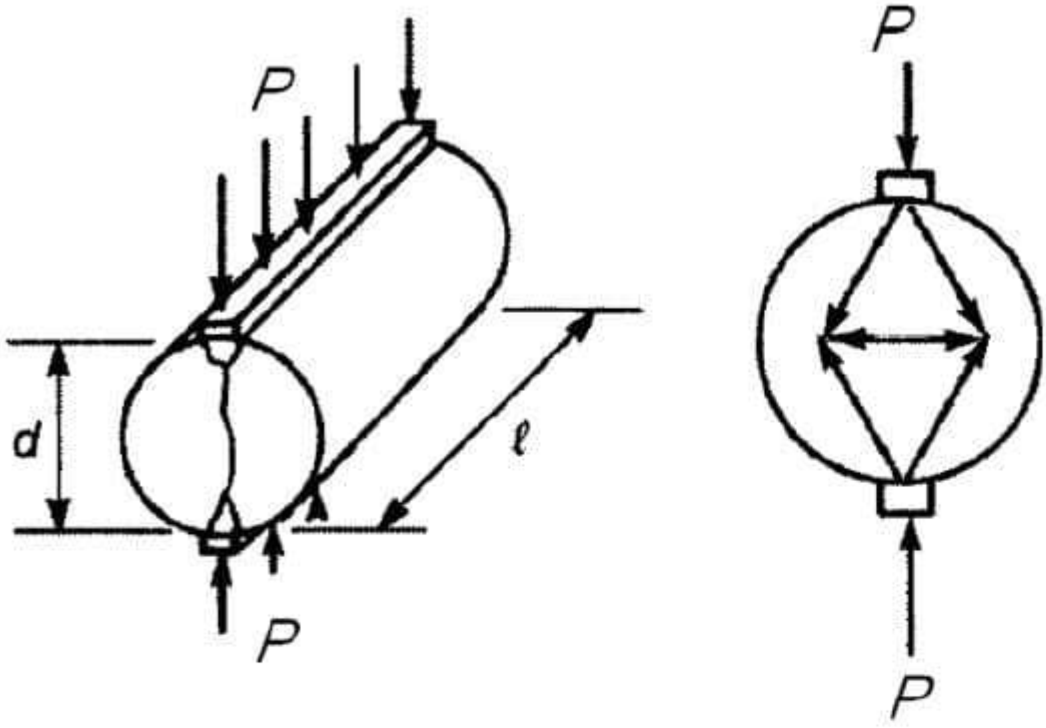
Where:

T = splitting tensile strength, MPa

P: maximum applied load indicated by the testing machine,N

D: diameter of the specimen, mm

L: length of the specimen,mm



PROPERTIES

1 Cement

Table 4.1.1.Physical Properties of Ordinary Portland Cement

S.no	Property	Test Results
1	Normal Consistency	32%
2	Initial Setting time	90 min
3	Final Setting time	250 min
4	Specific Gravity of Cement	2.95
5	Compressive strength(at 28 days)	56.3N/mm^2

2 Properties of Fly ash

Table 2.1Typical Oxide Composition of Indian Fly Ash (Hyderabad Industries LTD, Telangana)

S.no	Constituents	Percentage (%)
1	Silica, SiO_2	60.9
2	Alumina, Al_2O_3	31.01

3	Iron Oxide, Fe_2O_3	3.99
4	Lime, CaO	0.7
5	Magnesia, MgO	1.50
6	Sulphur Trioxide, SO_3	0.85
7	Loss on ignition	0.2
8	Surface Area m^2/kg	236
9	Drying Shrinkage	0.012

3 GGBS

Table 3.1 chemical composition of GGBS

S.no:	Constituents	Percentage
1	Calcium oxide(cao)	40%
2	Silica(sio_2)	35%
3	Alumina(Al_2o_3)	13%
4	Magnesia(Mgo)	8%

Table 3.2 Physical properties

colour	Off white
Specific gravity	2.92
Bulk density	1200Kg/m^3
Fineness	350m^2/Kg

4.Micro silica

Table 4.4.1 composition of micro silica

S.no	constituents	Percentage(%)
1	SiO_2	94.35
2	LOI	2.35
3	Na_2o	0.33
4	Fe_2O_3	0.04
5	K_2O	0.56
6	MgO	0.24
7	CaO	0.09

5 Coarse Aggregate

Table 5.1 Physical properties of coarse aggregate

S.no	property	Test results
1	Fineness modulus	7.17
2	Specific gravity	2.70
3	Bulk density	
A	Loose	1390 kg/m^3
B	Dense	1560kg/m^3
4	Flakiness index	24.1%
5	Elongation index	12.8%

6 Fine Aggregate

Table 6.1Physical properties of fine aggregate

s.no	Property	Test results
1	Fineness modulus	2.48
2	Specific gravity	2.53
3	Bulk density	
A	Loose	1600kg/m^3
B	Dense	1720kg/m^3

7.Mix design

Table 7.1 materials required for one m^3 of QBBSCC

%Of Admixtures	W/b ratio	Super plasticizer dosage	cement	sand	C.A	Flyash	GGBS	Micro silica
40% OPC,25% flyash, 25% GGBS ,10% microsilica	0.3	1.8%	172	851	793	107	107	43
	0.4	1.6%						

8.Workability

Table 8.1 Fresh properties of QBBSCC

	w/b ratio 0.3	w/b ratio 0.4
Slump-flow (mm)	590	700
V-funnel(sec)	8.69	2.46
T-500(sec)	12.09	5.88
L-Box	0.82	0.97

9.Compressive Strength Results:

Table 9.1 :Compressive Strength of Quaternary Blended Bacterial Self-Compacting Concrete at 7, 28, 90 days of w/b 0.3

Concentration of Bacteria (no. of cells/ml of water)	Compressive Strength with w/b 0.3		
	7 days (N/mm^2)	28 days (N/mm^2)	90 days (N/mm^2)
0	24.19	39	52.20
10^3	32.65	44.58	49.03
10^4	21.97	44.93	54.36
10^5	24.62	47.55	57.35
10^6	33.42	50.95	58.89

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Table 9.2 :Compressive Strength of Quaternary Blended Bacterial Self-Compacting Concrete at 7, 28, 90 days of w/b 0.4

Concentration of Bacteria (no. of cells/ml of water)	**Compressive Strength with w/b 0.4**		
	7 days (N/mm^2)	28 days (N/mm^2)	90 days (N/mm^2)
0	21.17	33.91	41.60
10^3	26.02	42.19	51.05
10^4	27.09	42.71	51.17
10^5	23.59	43.91	51.23
10^6	27.27	45.02	51.54

10 Split tensile strength results

Table 10.1 Split Tensile Strength of Quaternary Blended Bacterial Self-Compacting Concrete at 7, 28, 90 days of w/b 0.3

Concentration of Bacteria (no. of cells/ml of water)	**Split Tensile Strength with w/b 0.3**		
	7 days (N/mm^2)	**28 days (N/mm^2)**	**90 days (N/mm^2)**
0	**1.46**	**2.19**	**3.75**
10^6	**2.43**	**3.67**	**5.87**

Table10.2 Split Tensile Strength of Quaternary Blended Bacterial Self-Compacting Concrete at 7, 28, 90 days of w/b 0.4

Concentration of Bacteria (no. of cells/ml of water)	**Split Tensile Strength with w/b 0.4**		
	7 days (N/mm^2)	28 days (N/mm^2)	90 days (N/mm^2)
0	1.231	2.328	3.04
10^6	2.32	3.46	4.51

10.2 Split Tensile Strength of Quaternary Blended Bacterial Self-Compacting Concrete at 7, 28, 90 days of w/b 0.4

Concentration of Bacteria (no. of cells/ml of water)	**Split Tensile Strength with w/b 0.4**		
	7 days (N/mm^2)	28 days (N/mm^2)	90 days (N/mm^2)
0	1.231	2.328	3.04
10^6	2.32	3.46	4.51

11.Flexural strength results

Table 11.1 Flexural Strength of Quaternary Blended Bacterial Self-Compacting Concrete at 7, 28, 90 days of w/b ratio 0.3

Concentration of Bacteria (no. of cells/ml of water)	**Flexural Strength with w/b 0.3**		
	7 days (N/mm^2)	**28 days (N/mm^2)**	**90 days (N/mm^2)**
0	**4.18**	**5.36**	**6.52**
10^6	**4.83**	**6.24**	**7.61**

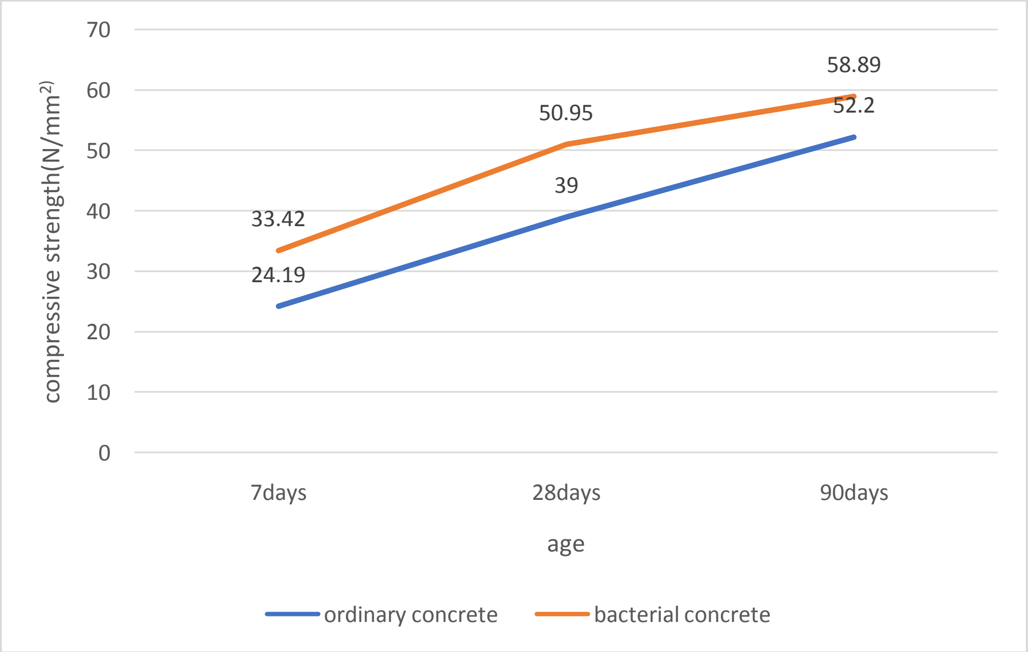
Table 11.2 Flexural Strength of Quaternary Blended Bacterial Self-Compacting Concrete at 7, 28, 90 days of w/b ratio 0.4

Concentration of Bacteria (no. of cells/ml of water)	Flexural Strength with w/b 0.4		
	7 days (N/mm^2)	28 days (N/mm^2)	90 days (N/mm^2)
0	3.6	4.88	5.94
10^6	4	5.52	6.73

V. ANALYSIS OF RESULTS:

- Table 4.8. summarizes the fresh properties of QBBSCC. The fresh properties of QBBSCC were found to satisfy the requirements of EFNARC 2005
- Table 4.9. summarizes the compressive strength test values of QBBSCC at 7 and 28 days containing different concentration of B. Subtilis for w/b 0.3 and 0.4. It is found that the compressive strength is maximum i.e., 33.42 N/mm2 and 50.95 N/mm2 for w/b 0.3 and 27.27 N/mm2 and 47.02 N/mm2 for w/b 0.4 at 7 and 28 days respectively, when the addition of bacteria was 106 no. of cells/ml of water compared to the reference and other concentrations of bacteria. Thus the bacterial concentration was optimized to 106 no. of cells/ml of water. Also the graph shows more compressive strength for bacterial concrete compared to ordinary concrete.
- Table 4.10. summarizes the split tensile strength test values of QBBSCC at 7 and 28 days for w/b 0.3 and 0.4. The split tensile strength of QBBSCC with bacterial concentration 106 no. of cells/ml of water is found to be more than the reference.
- Table 4.11. summarizes the flexural strength test values of QBBSCC at 7 and 28 days for w/b 0.3 and 0.4. The flexural strength of QBBSCC with bacterial concentration 106 no. of cells/ml of water is found to be more than the reference.

Graphs
Compressive strength
(w/b ratio of 0.3)



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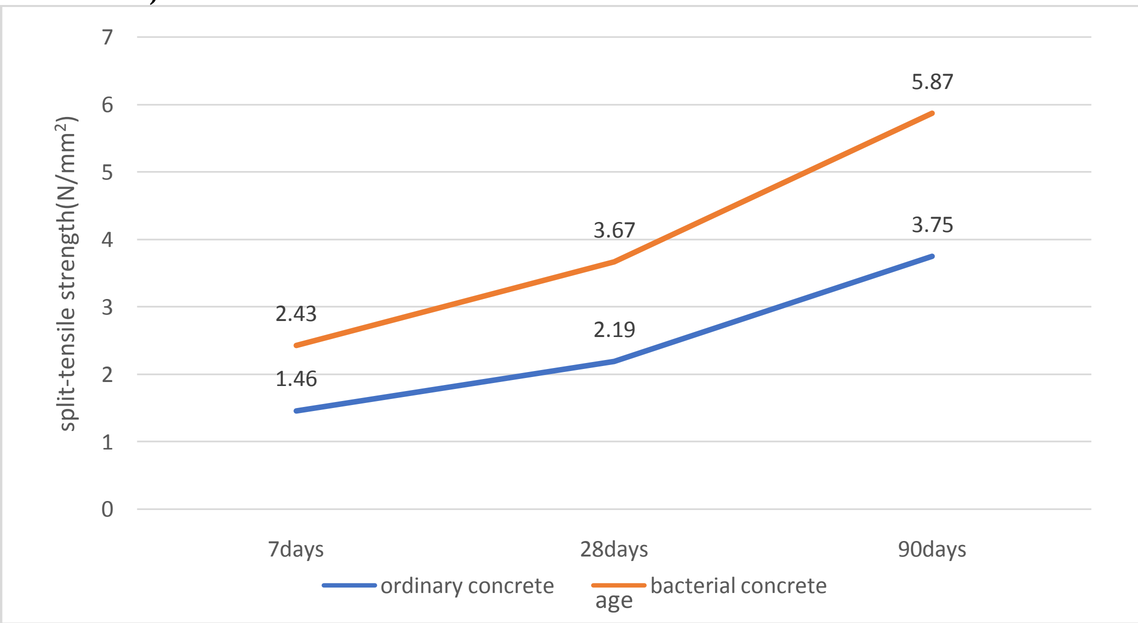
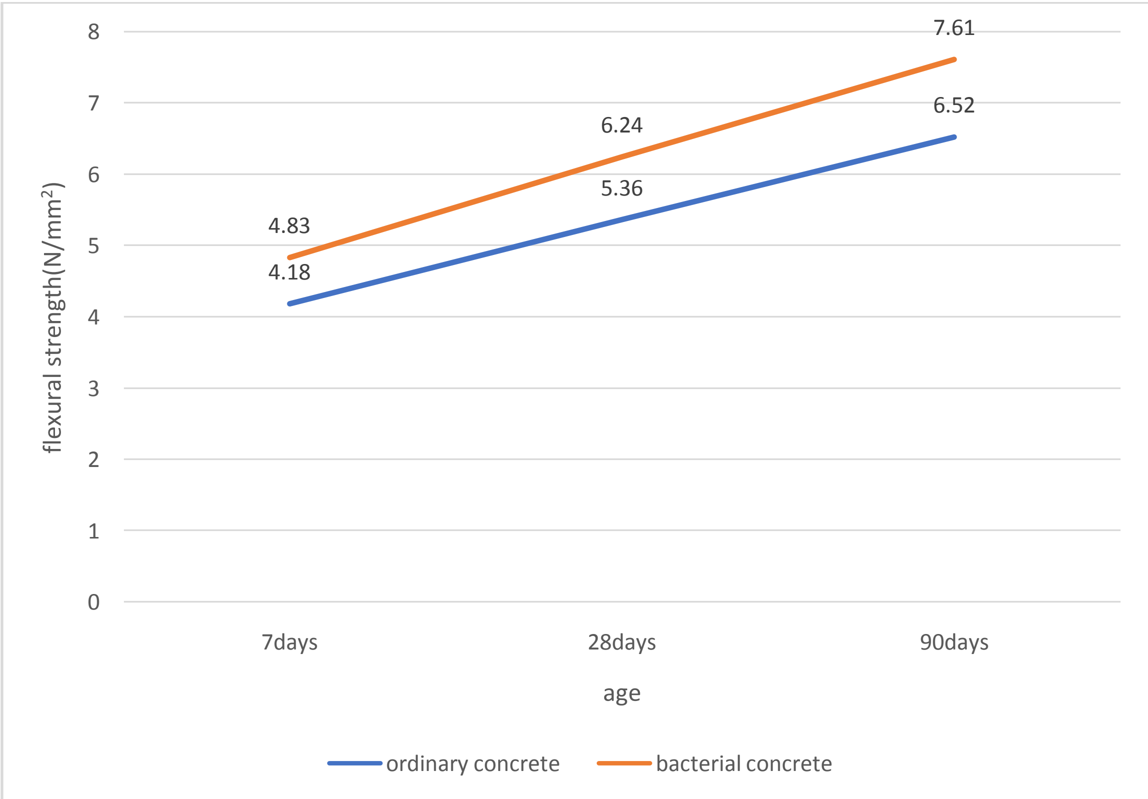
Split-tensile strength (w/b ratio of 0.3)



Flexural strength (w/b ratio of 0.3)



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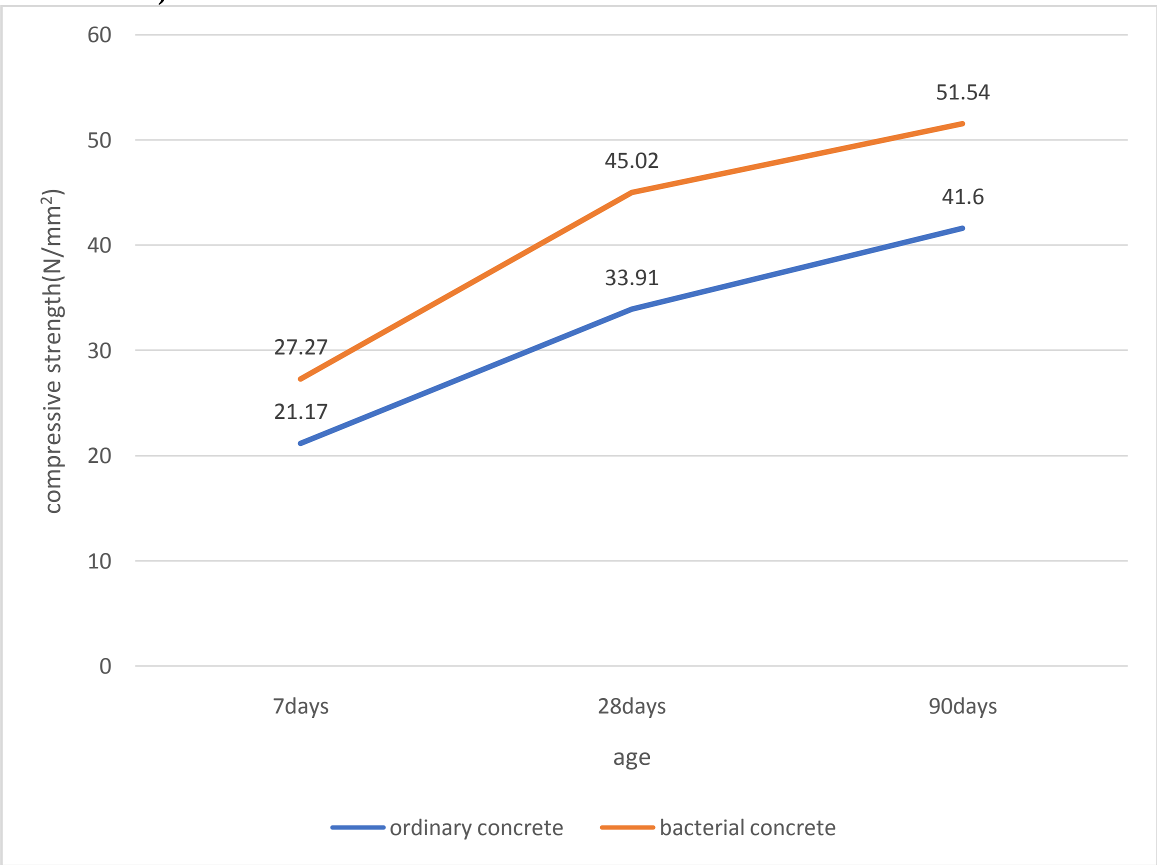
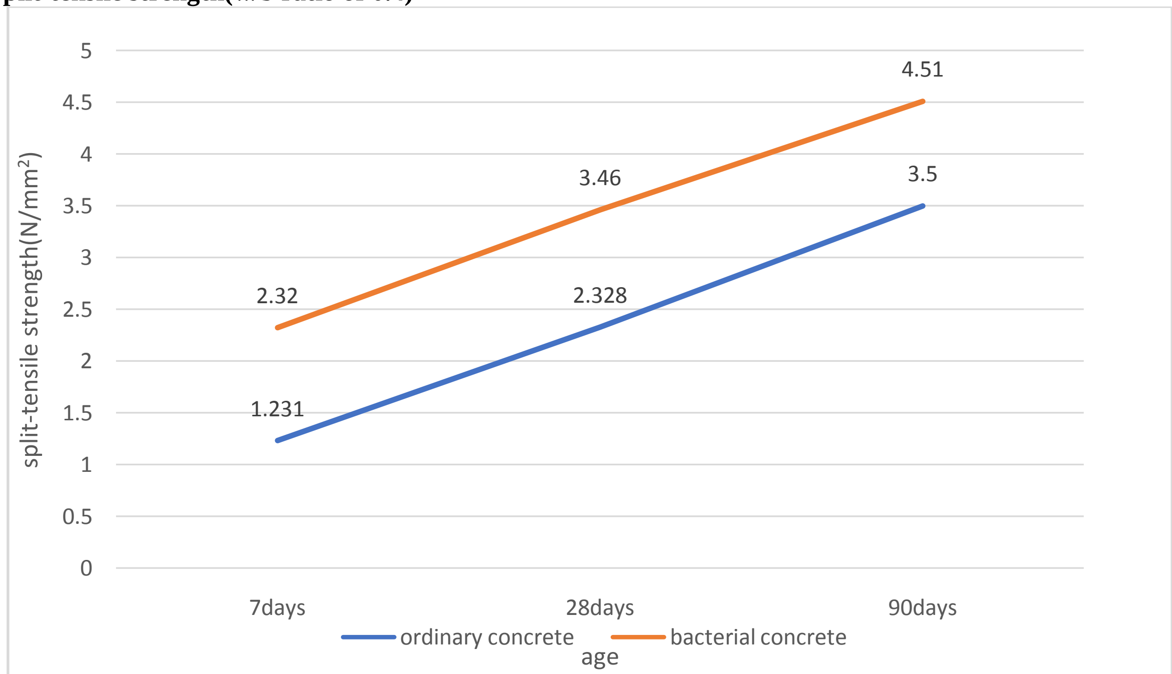
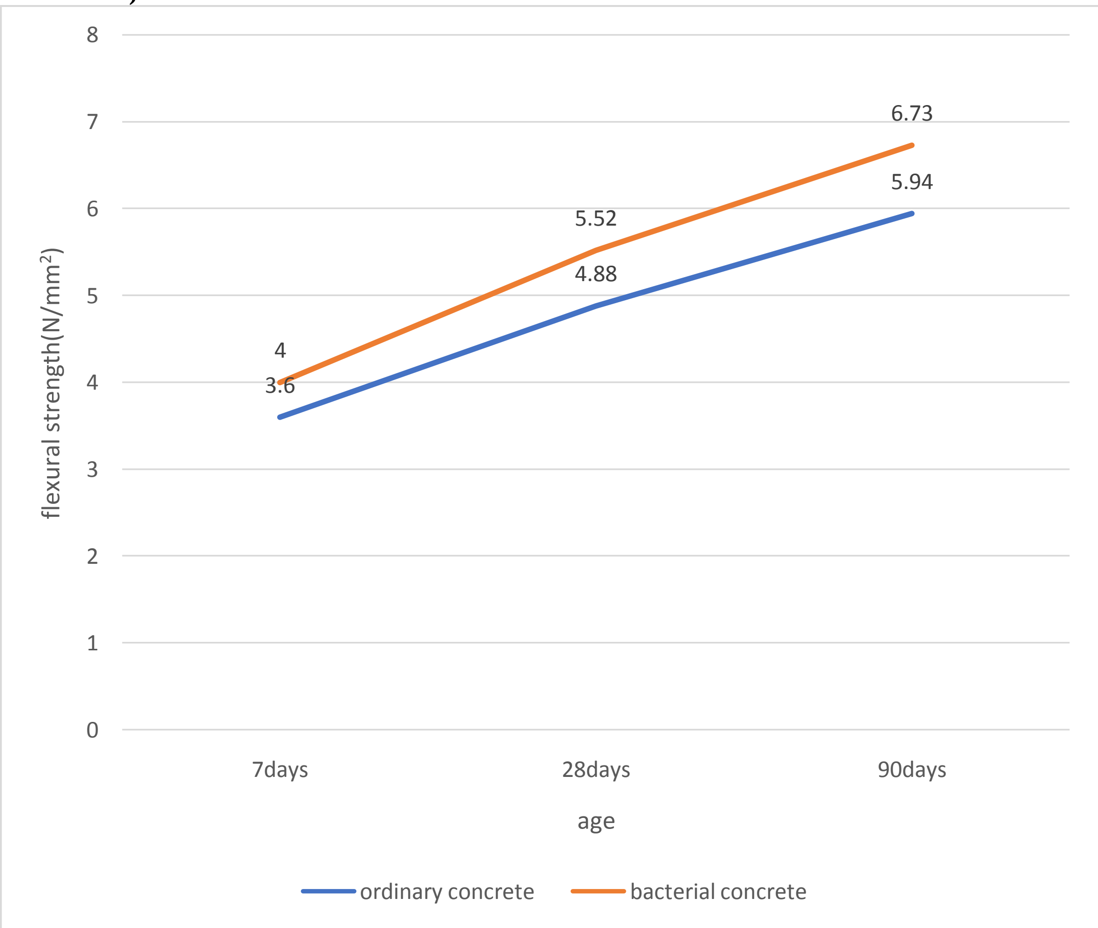
Compressive strength
(w/b ratio of 0.4)



Split-tensile strength(w/b ratio of 0.4)



Flexural strength (w/b ratio of 0.4)



VI. CONCLUSION

The review provides the following conclusions based on the experimental investigations of various researchers:

1. Soil bacterium is proved to be safe, non-pathogenic and cost effective and can be safely used in crack remediation of concrete structure.

2. Some researchers say bacteria like B. Sphaericus and Sporosarcina Pasteurii can increase the strength and durability of cement composites. On the controversy, some researchers say bacteria like B. Pasteurii is effective in crack remediation but not in strength enhancement of cement mortar mixture.

3. Microbiological remediation is more efficient in shallow cracks than in deeper cracks because microorganisms grow more actively in the presence of oxygen.

4. Large cracks in reinforced concrete can also be filled using MICP technique. It does not lead to strength improvements of the structure, but by filling the crack, the path to reinforcement is blocked. This application can be used in water retaining structures, where cracks can be filled and leakages can be stopped and in underground structures, where repair is difficult.

5. In bacteria-based systems for the repair of damaged concrete structures, alkaliphilic bacteria can be applied to relatively new concrete structures whereas denitrifying bacteria can be applied to old or highly carbonated concrete.

6. The surface deposition of $CaCO_3$ using B. Sphaericus decreased water absorption with 65 - 90% depending on the porosity of the specimens. As a result, the carbonation rate and chloride migration decreased by about 25 – 30% and 10 – 40% respectively.

7. Use of consortium of bacteria in concrete had 8.34% and 13.1% strength increase at 7 days and 28 days respectively when compared to concrete with B. Subtilis alone, which makes the consortium technique more acceptable.

8. There was a significant improvement of compressive strength by 30% in concrete mix with bacteria and more than 15% in flyash and 20% in GGBS. From XRD analysis, it is proven that the

presence of bacteria is contributing to CaCO3 production, which has reduced the percentage of air voids, thus increasing the strength of the structure considerably.

9. Bacterial treated concrete samples gave the lower sorptivity and porosity values compared to control concrete. This means that the time taken for the water to rise by capillary action in bacterial concrete are longer and thus proved that these concrete are less porous compared to the control concrete. The possible reason for this is calcite mineral precipitation in the pores due to the microbial activities. Also, in bacterial concrete, interconnectivity of pores is disturbed due to plugging of pores with calcite crystals.

Thus, bacterial concrete appears to be a promising solution in reducing the high maintenance and repair cost of concrete infrastructure. It will soon offer a source for high quality structures that will be cost effective and environmentally friendly. More researches have to be made to improve the feasibility of the use of this technology and to establish a standard method for bacterial concrete from both economical and practical point of view.

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ANNEXURE-1

Illustrative example for Mix design

Design for the concrete mix by the method of “Bureau of Indian Standard Method”

Test data for materials:

Packing factor = 1.12
Specific gravity of cement = 3.15
Specific gravity of coarse aggregate = 2.68
Specific gravity of fine aggregate = 2.68
Specific gravity of fly ash = 2.18
Specific gravity of GGBS = 2.92
Specific gravity of micro silica = 2.63
Bulk density of loose coarse aggregate = 1416 kg/m^3
Bulk density of loose fine aggregate = 1520 kg/m^3
Ratio of coarse aggregate and fine aggregate =1:1
Air content = 1.5%

Determination of fine aggregate and coarse aggregate content

Amount of coarse aggregate = 1.12*1416*0.5
= 792.96 kg/m^3
Amount of fine aggregate= 1.12*1520*0.5
= 851.2 kg/m^3

Determination of amount of binder

Assuming each kg of cement can provide a compressive strength of 0.14 M pa for SCC at 28 days
Amount of binder = 60/0.14 = 429 kg/m^3
Cement content = 40% of 429 = 171.6 kg/m^3
Fly ash content = 25% of 429 = 107.25 kg/m3
GGBS content = 25% of 429 = 107.25 kg/m^3
Micro silica content = 10% of 429 = 42.9 kg/m^3
Super plasticizer for 0.3 = 1.8% of 429 = 7.722 lit/m^3
Super plasticizer for 0.4 = 1.6% of 429 = 6.864 lit/m^3
Quantity of water for w/b ratio 0.3 =0.3*429 =130 lit/m^3
Quantity of water for w/b ratio 0.4 =0.4*429 = 171.6 lit/m^3