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Experimental Study On The Mechanical And Durability Characteristics Of Bacterial Concrete

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Abstract

This experiment was conducted to investigate the properties of Bacterial concrete for constructional purposes. In addition to concrete, bacteria named BACILLUS SUBTILIS (along with its nutrients) is added to attain more strength than conventional concrete and to improve properties of concrete. Aim of the study is to test and analyse compressive strength of concrete cubes, optimum dosage of bacteria used and to study properties of cracked specimens by introducing Bacillus Subtilis, which is uratolytic, gram positive (spore forming bacteria), and facultative aerobic. Mechanism: Bacteria convert Calcium (which is present in concrete) as Lime in the presence of oxygen and moisture content. From above mechanism, we analysed that strength of concrete cubes increases, and cracks are healed by itself i.e., it has a self-healing property due to incorporation of bacillus species.

Keywords: Bacillus Subtilis, Bacterial Concrete, Compressive Strength, Scanning Electron Microscope

I. Introduction

Concrete is a vital building material. It is most effective when reinforced by steel bar, because its tensile strength without reinforcement is considerably low relative to its compressive strength. As concrete is a high maintenance brittle material, it cracks and suffers serious wear and tear over the decades of its expected term of service.

The emerging technologies towards the evolution of concrete from ordinary concrete to different types of concrete such as high strength (HS), high performance concrete (HPC), ultra-high performance (UHPC), self-compacting (SSC), fibre reinforced concrete (FRC) etc., is developing at the faster rate to achieve the goal in terms of strength and durability. In the past few decades enormous work has been carried out in order to improve the performance by means of application of various materials and technologies.

Recently, bacterial concrete is gaining popularity due to the advantages such as self-healing property, increased durability, enhanced strength etc. When living organisms are introduced into cementitious materials, many factors are expected to influence their activity. A conducive environment such as temperature, nutrients, pH etc., is necessary for the survival and intended activity of bacteria in concrete. Among all the influential factors, nutrients for the survival of bacteria in cement mortar is considered in the study. Compressive strength is determined at various stages of curing to study the influence of bacterial activity in concrete. Microbial mineral precipitation resulting from metabolic activities of some specific microorganisms in concrete to improve the overall behaviour of concrete has become an important area. In the recent past, researchers found that compressive strength and durability of cementitious system can be improved with the inclusion of microorganisms.

II. Objectives and scope

- Develop bacterial concrete by introducing the bacteria of bacillus family
- To find optimum dosage of bacteria required for bacterial concrete.
- To increase compressive strength of concrete.
- To remediate the cracks developed in concrete.

FUTURE SCOPE

- To study the durability of concrete under various weathering conditions.
- To check the performance of bacillus subtilis by durability test.
- To verify the performance of bacillus subtilis with 1mm and 2mm crack width and 15mm, 20mm, 25mm, and 30mm crack depth.

III. Literature Review

V. Ramakrishnan [1]

The concept of bacterial concrete was first introduced by V. Ramakrishnan, (USA) a novel technique in remediating cracks in concrete by utilizing microbiologically induced calcite ($CaCO_3$) precipitation (MICP), which is highly desirable chemical reaction because the calcite precipitation induced is a result of microbial activities. The technique can be used to improve compressive strength and stiffness of cracked concrete specimens. The effect of different concentrations of bacteria on the durability of concrete was also studied by him. It was found that all the specimens with bacteria performed better than the control specimens (without bacteria). The durability performance increased with increase in the concentration of bacteria up to optimum dosage.

P. Ghosh [2]

This study describes a method of strength improvement of cement-sand mortar by the microbiologically induced mineral precipitation. A thermophilic anaerobic microorganism is incorporated at different cell concentrations with the mixing of water. The study showed that a 25% increase in 28 day compressive strength of cement mortar was achieved by adding 10^5 cells/ml of water. The strength improvement is due to growth of filler material within the pores of the cement-sand matrix as shown by the scanning electron microscopy.

IV. Methodology

Concrete contains cement, water, fine aggregate, coarse aggregate. With the normal concrete, i.e. 0.3%, 0.6%, 0.9%, 1.2% bacterial solution i.e. liquid broth is added to the conventional concrete. Then the results is compared with results from normal concrete, after gaining the highest strength we can find out the optimum dosage of bacteria we used. Six cube samples were casted on the moulds of size 15x15x15 cm. after about 24 hours the specimens were demould and keep it in water curing tank. Tests were done as per Bureau of Indian Standard codes. The test for compressive strength on cubes were measured at 7 and 28 days of curing as per IS:516-1959.

V. Properties of materials

Cement: Ordinary Portland Cement of 53 Grade referring to 8112-1989

Fine Aggregate: Natural river sand conforming to Zone 2 grading as per IS: 383-1987

Coarse Aggregate: 20 mm Maximum size conforming to IS: 383-1970

Water: Free from physical impurities, with respect to IS: 10500-1963

SELECTION OF BACTERIA:

We have selected Bacillus Subtilis, since it produces Calcium Carbonate and due to ease of availability. It is also known as Hay Bacillus or Grass Bacillus, is a gram-positive, Catalane-positive bacterium, found in soil and the gastrointestinal tract of ruminants and humans. A member of the genus Bacillus, B. Subtilis is rod-shaped, and can form a tough, protective endo-spores, allowing it to tolerate extreme environmental conditions. This bacterium is considered as the best studied Gram-Positive bacterium and a model organism to study bacterial chromosome replication and cell differentiation.

EXPERIMENTAL PROCEDURE FOR CULTURAL GROWTH OF BACTERIA:

Bacillus subtilis is a common soil bacterium, which can produce calcite precipitates on suitable media supplemented with a calcium source. The bacteria were cultured in liquid medium according to the supplier's recommendations. The medium used to grow bacteria consisted of 5.0 g peptone, 3.0 g meat (beef) extract, per litre of distilled water; to which 1.5% agar was added to obtain a solid medium for the stock culture. This medium was supplemented with 0.01 g $MnSO_4$ .H_2O to enhance sporulation and pH was adjusted to 7.0 using 1 N HCl. The mixture was first sterilized by autoclaving for 20 minutes at 121 degrees Celsius, allowed to cool to room temperature (25oC). B. Subtilis culture were obtained through activation of lyophilized bacteria whereas for all later experiment's cultures were obtained through sub culturing. Note that the whole culturing process was performed under sterile condition. Then, cultures were incubated at 30oC on a shaker incubator at 130 rpm for 72 hours. Afterward, bacterial cells were harvested by centrifuging the 72 h old grown culture.

Figure: 1. Bacillus subtilis solution

Table 1 Properties

S. No	Description	Result
1	Fineness of Cement	94%
2	Normal Consistency	30%
3	Initial Setting Time	30 minutes
4	Final Setting Time	10 hours
5	Specific gravity	3.15

Table 2 Properties of Fine Aggregate

S. No	Description	Result
1.	Sand zone	Zone-II
2.	Specific gravity	2.64
3.	Water absorption	1.2%
4.	Bulk density	1560
5.	Fineness modulus	3.2
6.	Moisture content	2.0%

Table 3 Properties of Coarse Aggregate

S. No	Description	Results
1.	Specific Gravity	2.78
2.	Impact Value	5.7%
3.	Water Absorption	1.0%
4.	Crushing Value	18.72%
5.	Bulk Density	1935.3kg/m3

VI. Mix Design

Concrete mix design is defined as the appropriate selection and proportioning of constituents to produce a concrete with pre-defined characteristics in the fresh and hardened states.

Mix design was carried out as per IS: 10262-1982 with respect to the design stipulations and data mentioned.

Step 1: Target mean strength of concrete

$f'_{ck} = f_{ck} + (t \times S)$

Where,

f'_{ck} = target average compressive strength at 28 days

f_{ck} = characteristic compressive strength at 28 days

S = Standard deviation

$f'_{ck} = 30 + (1.65 \times 6)$

$= 39.9$ MPa

For S refer IS 10262:1982 Cl 3.2.1.2 Table No: 2

Step 2: Selection of Water-Cement ratio

The maximum water cement shall be taken from table of IS: 456:2000

From table of IS 456, maximum water cement ratio = 0.45

Adopt w/c ratio 0.4

0.4<0.45, hence O.K.

Step 3: Selection of Water content

Referring to IS 10262 Cl 4,

For 20 mm nominal maximum size of aggregates water content is 186 litres for 25 to 50 mm slum range.

Estimated water content for 25 to 50 slump is 186 litres.

Step 4: Calculation of Cementitious content

Water Cement ratio = 0.4

Water content = 186 litres

186/0.4 = 465 kg/m^3

Therefore, provided Cement = 465 kg/m^3

Which is greater than the minimum cement content of 300 kg/m^3 for moderate exposure condition as per IS 456.

Step 5: Proportion of volume of course and fine aggregate content

Volume of C.A. corresponding to 20 mm size aggregate and sand conforming to zone II for w/c ratio of 0.5 is 0.62

In present case w/c ratio is 0.4. Therefore, volume of C.A. is required to be increased for decrease in F.A. content.

Correction to be made at the rate of ± 0.01 for every ± 0.05 change in w/c ratio.

Therefore, corrected proportion of volume of C.A. for the w/c ratio 0.4 is 0.015

Volume of C.A. = 0.635

Volume of F.A. = 1-0.635= 0.365

Step 6: Mix proportions

a) Volume of concrete = 1m^3
b) Volume of Cement = (mass of cement/specific gravity of cement) x (1/1000)
   = (465/3.15) x (1/1000)
   = 0.1476 m^3
c) Volume of water = (mass of water/specific gravity of water) x (1/1000)
   = (186/1) x (1/1000)

= 0.186 m^3

d) Volume of all aggregate = [a-(b+c)] = [1-(0.1476+0.186)]
= 0.6664 m^3

e) Mass of C.A. = [d] x vol of C.A. x specific gravity o C.A. x 1000
= 0.6664 x 0.635 x 2.78 x 1000
Mass of C.A. = 1176.39 kg

f) Mass of F.A. = [d] x vol of F.A. x specific gravity of F.A. x 1000
= 0.6664 x 0.365 x 2.64 x 1000
= 642.14 kg

Step 7: Mix proportions

Cement	=	465 kg/m^3
Water	=	186 kg/m^3
F.A.	=	642.14 kg/m^3
C.A.	=	1176.39 kg/m^3

Proportion of cement: sand: aggregate = 1:1.38:2.53

VII. Experimental methods and tests

Compressive strength of cubes:

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. In our investigation we have made M30 grade of concrete as per IS 10262. Further, we have poured the concrete in the cube moulds and five different samples were made which are as follows.

1. Conventional concrete of grade M30
2. Concrete with 15 ml bacterial solution
3. Concrete with 30 ml bacterial solution
4. Concrete with 45 ml bacterial solution
5. Concrete with 60 ml bacterial solution

There are different methods of mixing the bacterial solution in the concrete which are

a. Direct mixing
b. Indirect mixing
c. Injection method

In our investigation we have adopted the direct method mixing. The compressive strength is determined using compressive testing machine.

Scanning Electron Microscope:

SEM is essentially a high magnification microscope, which uses a focused scanned electron beam to produce images of the sample, both top-down and cross-sections. To investigate the morphology and chemical constituents of self-healing products and to observe the self- healing process, selected specimens are examined by Scanning Electron Microscope (SEM) Energy Dispersive Spectroscopy (EDS). SEM is a powerful instrument which permits the characterization of heterogeneous materials and surfaces.

After four months of healing in water, the selected specimens of each mixture was subjected to Scanning Electron Microscopy observation (SEM, JOEL JSM-6380LV, 20V). Back scattered electron imaging (BES) was used for electron micrography. Crack healed samples into small cubes and were completely dried at 50˚ C in an oven for three days before the SEM observation. An Energy Dispersion Spectrometer (EDS) connected with SEM was used to detect the components of precipitation. All the selected samples were gold coated with a Denton vacuum Desk-IV coating system prior to examination. An energy dispersive spectrometer (EDS) connected with SEM was used simultaneously to detect the components of the precipitation.

- SEM analysis reveals the direct involvement of the isolated ureolytic bacteria in calcium carbonate precipitation and the production of calcite was confirmed by X Ray Diffraction (XRD) and Energy-Dispersive X-Ray Analysis (EDX).
- In EDX analysis, the spectra of CaO and $CaCO_3$ were noted for all the mixtures for 28 days. It was observed that the spectra of $CaCO_3$ increased after 28 days. The concrete specimen without bacteria was also analysed and it was observed that it showed minor or no signs of $CaCO_3$ crystals. Hence it was concluded that $CaCO_3$ spectra increased due to the presence of bacteria.

VII. Results

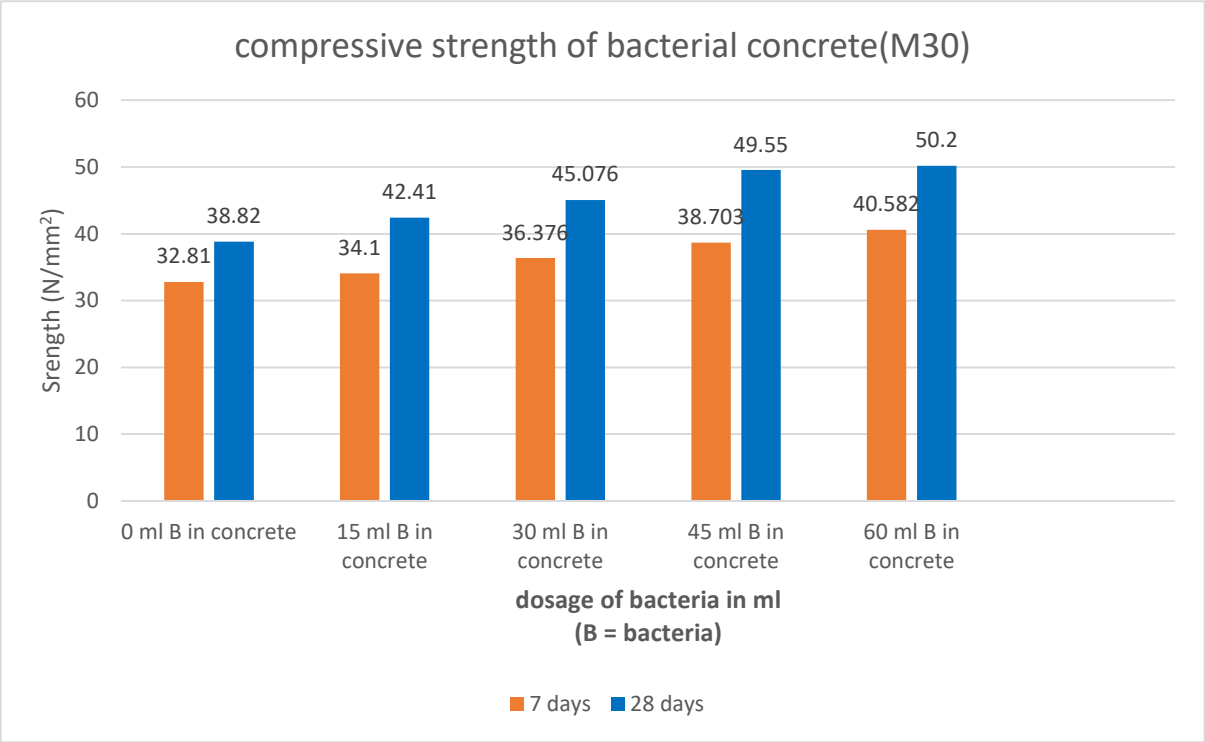
Compressive strength for M30 grade of bacterial concrete. Bacteria is mixed in concrete as 0%, 0.3%, 0.6%, 0.9% and 1.2% i.e., as 0 ml, 15 ml, 30 ml, 45 ml and 60 ml.

Effect of bacterial concrete is shown in the graph below. With increase in ml of bacteria in concrete, compressive strength of cubes increases and maintains constant value from the optimum value. Hence the optimum value is considered as 45 ml of bacteria in concrete.

Table 4 Compressive strength values: Various mix proportions at 7 & 28 days

Mix	Specimen No.	Compressive strength at 7 days (FA)			Fresh Weight	Hardened Weight	Compressive strength at 28 days (FA)		
		Load (KN)	Stress (N/mm^2)	Avg			Load (KN)	Stress (N/mm^2)	Avg
0 ml	1	801	35.6	32.81	8.41	8.49	841	37.37	38.82
	2	710	31.55		8.37	8.39	866	38.48	
	3	704	31.28		8.41	8.58	914	40.62	
15 ml	1	775.8	34.48	34.1	8.61	8.69	941.2	41.83	42.4
	2	779.2	34.63		8.79	8.81	960	42.66	
	3	745.2	33.12		8.71	8.77	958	42.57	
30 ml	1	840	37.33	36.37	8.62	8.63	1015	45.11	45.07
	2	777.7	34.56		8.65	8.71	1014	45.06	
	3	704	37.24		8.62	8.75	1014	45.06	
45 ml	1	864	38.4	38.70	8.81	8.83	1102	48.97	49.55
	2	898.7	39.94		8.71	8.78	1146	50.93	
	3	850	37.77		8.79	8.89	1094	48.75	
60 ml	1	892	39.64	40.58	8.67	8.79	1143	50.8	50.2
	2	945.6	42.02		8.61	8.84	1128	50.13	

	3	902	40.08		8.69	8.79	1121	49.82	



VIII. Conclusion

- The compressive strength was found to increase with bacterial addition and this increase is mainly due to deposition of microbial induced calcium carbonate precipitation on the microorganism cell surfaces and within the pores of the mortar. It was noticed that in normal mortar, the compressive strength was increased with the increase in bacterial cell concentration up to 10^{6} cells/ml. Maximum increase in compressive strengths was achieved at 10^{6} cells/ml.
- The percentage increase in compressive strength of 45ml and 60ml bacterial concrete using B. Subtilis for 7 days is higher than conventional concrete.

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