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Identification of Mechanical Properties of Bacterial Concrete with Partial Replacement of Fly Ash

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ABSTRACT

Concrete is the mostly used building material in the world. Concrete has a large load bearing capacity for the compressive loads. The application of concrete is rapidly increasing worldwide and therefore the development of sustainable concrete is urgently needed for environmental reasons and durability aspects. If a mechanism is developed that would contribute to a longer service life of concrete structures and make the material not only more durable but also more sustainable that would suffice the requirement of the durability of the concrete. One such mechanism that receives increasing attention in recent years is the ability for self repair (self healing), i.e., the autonomous healing of cracks in concrete.

Concrete is a material which takes compressive loads, but the material is weak in tension. That is why steel reinforcement bars are embedded in the material to take care of the tension. The steel bars take over the load when the concrete cracks in tension. The concrete covers and protects the steel bars from dampness etc. As the cost of the cement is going up day by day there is a need for finding an alternative to cement. For making it economical, a part of the cement by weight is replaced with a material called 'fly ash' which is cheaper in cost and abundantly available. On the other hand the cracks in concrete lead to leakage problems and there is a need to address these problems for future.

In the above context, the objective of the present investigation is to obtain the performance of the concrete by adding microbiologically induced special growth/filler and part of cement replaced by fly ash. One such thought leads to the development of very special concrete known as bacterial concrete where bacteria is induced in the concrete and part of the cement replaced by fly ash. A technique is adopted in the formation of concrete by utilizing microbiologically induced calcite ($CaCo_3$) precipitation. Microbiologically induced calcite precipitation (MICP) is a technique that comes under a broader category of science called Bio-Mineralization.

It is a process by which living organisms form inorganic solids. 'Bacillus Subtilis', a common soil bacterium can induce the precipitation of calcite. In this investigation it is to be checked by using the above technique, the possibility of improving the performance of the bacterial concrete using fly ash in longer duration. The compressive strength, tensile strength and compactness are checked on the samples of bacterial concrete by conducting the Laboratory tests like compressive test, split tensile test, pulse velocity test and diagonal tensile test in comparison with the normal concrete samples using fly ash as part replacement for cement in three different proportions.

For the experimental investigation firstly cement mortar blocks are casted using fly ash as partial replacement of cement without bacteria and also with a common soil bacterium called 'Bacillus Subtilis' of different concentrations like 10^4, 10^5, 10^6, 10^7 and 10^8 cells/ml. The cement mortar blocks are tested for 7 days and 28 days strength. Finally it is observed that the mortar blocks made with 10^5 cells/ml. concentration of 'Bacillus Subtilis' attained good strength when compared with normal mortar blocks. Therefore, for further experimental investigations 'Bacillus Subtilis' culture samples with 10^5 cells/ml. concentration are used for casting of samples of bacterial concrete using fly ash as partial replacement of cement.

Design mixes are prepared by adopting the IS code, IS: 10262-2009. To get the performance of the bacterial concrete when compared with the normal concrete 36 cubes, 36 cylinders and 36 prisms are casted with varying

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fly ash replacement for cement. And also the same numbers of samples are casted for normal concrete with varying fly ash replacements and tested for compressive strength, flexural strength, split tensile strength.

From the experimental investigations it is observed that the compressive strength, flexural strength and split tensile strength are on par with the normal concrete strength parameters. The three strength parameters of bacterial concrete are found to be higher than that of the normal concrete.

INTRODUCTION

General

The most useful construction material adopted nowadays to the tune of development of infrastructure to the continuously growing population in the world wide and their requirement for the shelter of the population is the cement concrete.

The use of concrete is increasing worldwide in a fast track and therefore the development of sustainable concrete is anticipated for environmental reasons and also for the improved strength parameters. As presently about 7% of the total anthropogenic atmospheric CO_2 emission is due to cement production. If a mechanism is developed that would contribute to a longer service life of concrete structures and make the material not only more durable but also more sustainable. One such mechanism that is anticipated in recent years is the ability for self-repair, i.e. the autonomous healing of cracks in concrete. Bacterial concrete or self healing concrete would be the correct solution for the construction activities for the durability and strength of structures. If such mixture is combined with a material called 'fly ash' the material shall become economical thus saving significant cost.

Bacterial Concrete using Fly Ash

Bacterial concrete using fly ash is a new concept in which living organism or bacteria called 'Bacillus Subtilis' is mixed in water with an ordinary Portland cement, fly ash along with fine aggregate and coarse aggregate.

Concrete with fly ash as a structural material

The most widely used construction material is concrete, commonly made by mixing Portland cement with fly ash, sand, crushed rock and water. The present consumption of concrete in the world is estimated to be around twenty thousand million metric tons every year or more than three metric tons for every living human being. The world trends indicate that man consumes no other material except water in such tremendous quantities.

The word concrete comes from a Latin term *concretus*, which means - to grow. It is because as compared to other materials, the structure, strength and other properties of concrete are not static properties of the material and keep changing with time and conditions. Concrete *solidifies* and harden after mixing with water due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone like material.

It is used to make high rise buildings, architectural structures, fly overs, road bridges, super passages, under tunnels, aqueducts, pavements and all types of foundations of structures etc.

Fly ash

This kind of ash is extracted from flue gases through electrostatic precipitator in dry form, in thermal power plants using coal as fuel. This ash is fine material and possesses good pozzolanic property. Fly ash produced in modern power stations of India is of good quality as it contains low sulphur and very low unburnt carbon i.e. less loss on ignition.

Fly ash for cement concrete

Higher heat of hydration, higher water content and high porosity increases the susceptibility of concrete mass when it is exposed to a range of external and internal aggressive environment. This disturbs the soundness of the concrete and results in reduced durability. To mitigate the above problem subsequent research work was carried out which established that use of fly ash or pozzolana helps to solve all problems related to durability of concrete mass.

Reduced heat of hydration

The process is exothermic and heat is released which increases the temperature of the mass when fly ash is present in the concrete mass, it plays dual role for the strength development. Fly ash reacts with released lime and produces binder as explained above and renders additional strength to the concrete mass. The un-reactive portion of fly ash act as micro aggregates and fills up the matrix to render packing effect and results in increased strength. The large temperature rise of concrete mass exerts temperature stresses and can lead micro cracks. When fly ash is used as part of cementitious material, quantum of heat liberated is low and staggers through pozzolanic reactions and thus reduces micro-cracking and improves soundness of concrete mass.

Need for the Present Work

Natural processes, such as weathering, faults, land subsidence, earthquakes, and human activities create fractures and fissures in concrete structures. These fractures and fissures are detrimental since they can reduce the service life of the structure. Protections from cracks and resulting leak ages are critical to many structures of strategic importance and those that store hazardous chemicals. Use of synthetic agents such as epoxies for remediation of these structures introduces a different material system of doubtful long term performance and they may result in complex compatibility problems. Appearance of cracks and fissures is an inevitable phenomenon during the aging process of concrete structures when exposed to weather changes. Such cracking leads to easy passage for aggressive environment to reach the reinforcement and initiate corrosion. Many compounds, mainly polymers, are developed to seal these cracks. However, they may damage the appearance of the surface. Moreover, sometimes repair is carried out in the areas where it is not possible to shut down the plant as it is so hazardous for human beings. Hence, in such situations a way should be found out to self healing materials that seal the cracks automatically.

Objectives of the Present Work

a) To perform extensive experimentation on bacterial concrete using fly ash as partial replacement of cement by considering M20 and M40 grades of concrete (one being the normal mix and one being the standard mix).
b) To conduct compressive strength, flexural strength, split tensile strength on the samples of bacterial concrete with fly ash.
c) To compare the strength parameters of bacterial concrete samples with that parameters of normal concrete.
d) To study the results and to evaluate the performance of bacterial concrete using fly ash as partial replacement of cement.

EXPERIMENTAL PROGRAMME

General Methodology

a) The present investigation is aimed at arriving the performance of the bacterial concrete in comparison with the normal concrete using fly ash as partial replacement of cement for M20 and M40 grade concrete, after thoroughly understanding the parameters influencing the strength improvement which are designed with the help of IS:10262-2009.
b) The experimental programme is divided into four phases.
c) Phase I: Laboratory setup and procurement of materials.
d) Phase II: Mixing of cement mortar, moulding and curing of cement mortar specimens.
e) Phase III: Mixing of concrete with fly ash as partial replacement of cement, moulding and curing of concrete specimens.
f) Phase IV: Testing procedure for evaluating the strength parameters of cement mortar and concrete specimens.
g) Phase V: Evaluating test results.

Procurement of materials

The materials used for the investigative study of bacterial concrete using fly ash are given below.

- Cement
- Fly ash
- Fine aggregate
- Coarse aggregate
- Water
- Micro Organisms ‘Bacillus Subtilis’ a model laboratory bacterium is used.

Cement

Ordinary Portland cement of 53 grade confirming to IS: 12269 is used. Physical properties of cement as per IS: 12269-1999 is tested at the concrete testing Laboratory, University College of Engineering, Osmania University, and Hyderabad.

Fly ash

The fly ash of type-II confirming to IS: 3812-1981 is obtained from Kakatiya Thermal Power Station (KTPS), Bhupalapalli, Warangal District, A.P and got tested as required in an approved Laboratory in Hyderabad.

Fine aggregate

Natural sand available in the local market is used as fine aggregate. The physical properties of fine aggregate like specific gravity and fineness modulus are found.

Coarse Aggregate

Coarse aggregate of maximum size 20 mm is obtained from local market.

Water

The least expensive but the most important ingredient of concrete is water. The water which is used for mixing concrete is clean and free from harmful impurities such as oil, alkali, acid etc. Potable water is used for the mixing and curing in the present studies.

Micro organisms ('Bacillus Subtilis') cultured samples

One sample of culture 'Bacillus Subtilis' is procured from the National Collection of Industrial Micro-organisms (NCIM), National Chemical Laboratory, Pune, Maharashtra, India. After obtaining the sample of culture it is developed to the tune of requirements of investigations at Microbiology Laboratory, Osmania University, Hyderabad by giving proper feed to the micro organisms.

Culture of bacteria

The pure cultures which were obtained from NCIM, Pune, are maintained constantly on nutrient agar slants. It forms irregular dry white colonies on nutrient agar. Whenever required a single colony of the culture is inoculated into nutrient broth of 25 ml in 100 ml conical flask and the growth conditions are maintained at 37^0C temperature and placed in 125 rpm orbital shaker.

The medium composition required for growth of culture is as follows:

Peptone : 5 g/lit
Sodium chloride (NaCl) : 5 g/lit
Yeast extract : 3 g/lit

The maintenance of stock cultures and their characteristics are explained in the following sections.

Physical properties of materials used

Cement

Ordinary Portland cement of 53 grade confirming to IS: 12269-1999 is used. Physical properties of cement tested at the concrete testing Laboratory, University college of Engineering, Osmania University, Hyderabad and are presented in Table 3.1.

Table 3.1 Physical properties of Portland cement (53 grade)

S.No.	Property	Value
1	Specific gravity of cement	3.15
2	Initial setting time	35 minutes
3	Final setting time	360 minutes
4	Normal consistency	32%
5	3 days compressive strength of cement	25.81 MPa
6	7 days compressive strength of cement	36.28 MPa
7	28 days compressive strength of cement	58.51 MPa

Fly ash

The fly ash is tested as per IS 3812-1981 and the properties are tabulated in Table 3.2.

Table 3.2 Chemical requirements of fly ash

S.No.	Characteristics specified by	Present in the sample	(Requirement as per IS 3812-1981)
1	Silicon-dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus Iron oxide (Fe_2O_3) percent by mass	86.73 %	Minimum:70%
2	Silicon dioxide (SiO_2) percent by mass	62.85 %	Minimum:35%
3	Magnesium Oxide (Mg O) percent by mass	1.09%	Maximum:5%
4	Total Sulphur as sulphur trioxide (SO_3) percent by mass	1.89%	Maximum:2.75 %
5	Available alkalis as Sodium oxide (Na_2O)	0.72%	Maximum:1.5 %
6	Loss on ignition, percent bass	1.02%	Maximum:12%

Fine aggregate and Coarse aggregate

Fine aggregate used is natural sand obtained from local market. The physical properties of fine aggregate are given in Table 3.3. The details of sieve analysis are given in Table 3.4. It could be noted that the sand confirms to Zone-III as per IS: 383-1970.Coarse aggregate of maximum size 20 mm. is obtained from local market The physical properties of the coarse aggregate are given in Table 3.5 and the sieve analysis is given in Table 3.6.

Table 3.3 Physical properties of fine aggregate

S.No.	Property	Value
1	Specific gravity of fine aggregate	2.64
2	Dry unit weight	1.74
3	Fineness modulus	2.47

Table 3.4 Sieve analysis of fine aggregate (Weight of the fine aggregate sample taken = 1 kg)

S. No.	Sieve No.	Weight retained in g	% weight retained	Cumulative % weight retained	% of passing in each sieve	Remarks
1	480	4	0.40	0.40	99.60	Fine aggregate is pertaining to Zone-III as per Table 4 of IS: 383-1970
2	240	10	1.00	1.40	98.60	
3	120	144	14.40	15.80	84.20	
4	60	200	30.00	35.80	64.20	
5	30	582	58.20	94.00	6.00	
6	15	56	5.60	99.60	0.40	
7	Tray	4	0.40	100.00	0.00	

Total = 247.00
Fineness modulus = 2.47

Table 3.5 Physical properties of coarse aggregate

S. No	Sample	Specific gravity	Bulk density (loose) Kg	Bulk density (compacted) Kg	Water absorption	Free (surface) moisture
1	2	3	4	5	6	7
1	Coarse aggregate	2.65	1348	1485	0.50 %	Nil

Table 3.6 Sieve analysis of coarse aggregate (Weight of the coarse aggregate sample taken=5 kg)

S. No.	Sieve No.	Weight retained in g	% weight retained	Cumulative % weight retained	% of passing in each sieve	Remarks
1	80	0	0	0	99.60	Reference code is IS: 383-1970
2	40	0	0	0	98.60	
3	20	1598	31.96	31.96	84.20	
4	10	3310	66.20	98.16	64.20	
5	4.80	92	1.84	100.00	6.00	
6	2.40	0	0	100.00	0.40	
7	1.20	0	0	100.00	0.00	
8	0.60	0	0	100.00	0.00	
9	0.30	0	0	100.00	0.00	
10	0.15	0	0	100.00	0.00	

Total = 730.12
Fineness modulus = 7.30

Bacteria

The bio-chemical characteristics of bacteria 'Bacillus Subtilis' are shown in Table 3.7 below.

Table 3.7 Biochemical characteristics of pure culture of 'Bacillus Subtilis'

Shape, size, gram stain	Long rods, 0.6-0.8 µm in width and 2.0 - 3.0 µm in length, gram positive
Colony morphology (on nutrient agar plate)	Irregular, dry, white, opaque colonies
Fermentation	Not applicable
Lactose	No acid, No gas
Dextrose	No acid, No gas
Sucrose	Acid and gas

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H2S production	-
Nitrate reduction	-
Indole production	-
Vogesproskauer test	-
Citrate utilization	-
Catalase activity	+
Gelatin liquefaction	+
Starch hydrolysis	+
Lipid hydrolysis	+

Note: '+':- Present, '-':- Absent

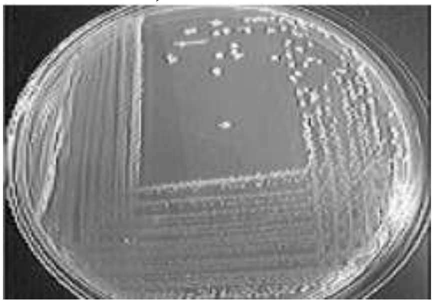

Plate 3.1 Colony morphology of 'Bacillus Subtilis' on agarplate (Irregular, dry, white, opaque colonies)

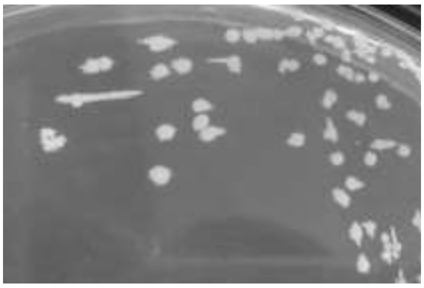

Plate 3.2 Phase contrast micro photograph of 'Bacillus Subtilis' (Long rods, 0.6-0.8μm in width and 2.0-3.0 μm in length, gram positive)

Plate 3.3 Microscopic photograph of multiple 'Bacillus Subtilis' cultured at Microbiology Department, Osmania University, Hyderabad (View 1)

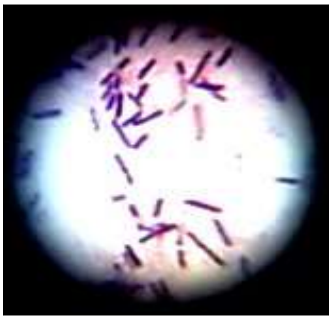

Plate 3.4 Microscopic photograph of multiple 'Bacillus Subtilis' cultured at Microbiology Department, Osmania University, Hyderabad (View 2)

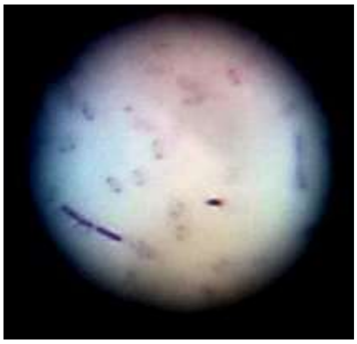

Plate 3.5 Microscopic photograph showing the culture of 'Bacillus Subtilis' cultivated at Microbiology Department, Osmania University, Hyderabad (View 1)

Plate 3.6 Microscopic photograph showing the culture of 'Bacillus Subtilis'cultivated at Microbiology Department, Osman University, Hyderabad(View 2)

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Figure 3.1 Liquid form of bacteria 'Bacillus Subtilis'

Phase II

Mixing of cement mortar

The following mix cases are considered for both normal cement mortar and bacterial cement mortar using fly ash as partial replacement of cement. The mix proportion adopted is 1: 3.

Case 1 : Normal or control cement mortar mix with fly ash.

Case 2 : Cement mortar mix with fly ash with 10^4 cells/ml. bacterial solution.

Case 3 : Cement mortar mix with fly ash with 10^5 cells/ml. bacterial solution.

Case 4 : Cement mortar mix with fly ash with 10^6 cells/ml. bacterial solution.

Case 5 : Cement mortar mix with fly ash with 10^7 cells/ml. bacterial solution.

Case 6 : Cement mortar mix with fly ash with 10^8 cells/ml. bacterial solution.

Age of curing

The specimens are cured for 7 days and 28 days. A total of 18 specimens for each period of curing for each mix cases is tested and the results are recorded. The details of the testing procedure and the results are given in the following sections.

Phase III

Mixing of concrete with fly ash

Two mixes of M20 and M40 grades of concrete are considered for both normal concrete and bacterial concrete using fly ash as partial replacement of cement of 10%, 20% and 30%. The mix design is adopted as per IS: 10262-2009 and mixes are as follows.

- Normal mix of concrete with fly ash for M20 and M40 grade as per IS: 10262-2009.
- Bacterial mix of same concrete using 10^5cells/ml of 'Bacillus Subtilis' culture for M20 and M40 grade as per IS: 10262-2009.

Tests on fresh concrete with fly ash

Slump test

The slump test is perhaps the most widely used because of the simplicity of the apparatus required and the test procedure. The slump test indicates the behavior of the compacted concrete cone under the action of gravitational forces. The test is carried out with a mould called the slump cone. The slump cone is placed on a horizontal and a non-absorbent surface and filled in three equal layers of fresh concrete, each layer being tamped 25 times with a standard tamping rod. The top layer is struck off level and the mould is lifted vertically without disturbing the concrete cone. The subsidence of the concrete in millimeters is termed as 's***lump'***.

Compaction factor test

This test is also used to assess the workability of the concrete mix. The degree of compaction called the '*compaction factor*' is measured by the density ratio, i.e., the ratio of the density actually achieved in the test to the density of the same concrete fully compacted. Based on the compaction factor the workability of the mix is evaluated. This test is also performed for all the mixes. Figure 3.3 shows the sample test of compaction factor being indicated.

Workability

The workability tests are conducted using slump and compaction factors as shown in the Figures 3.2 and 3.3 respectively. A slump of 30 mm to 100 mm and percentage of compaction of 0.90 approximately shows the medium workability conditions. However the workability is within the limit as specified above and it is found that there is no difference in the workability aspects during the formation of normal and bacterial concrete with fly ash. The details of workability for both normal or control concrete with fly ash and bacterial concrete with fly ash are tabulated in Table 3.8 and Table 3.9 respectively.

Figure 3.2 Slump of concrete being measured in Laboratory

Figure 3.3 Compaction factor of concrete being measured in the Laboratory

Table 3.8 Average workability of control concrete with fly ash

Grade of concrete	Slump in mm	% of compaction	Degree of workability
M20 grade	73.00	86.83	Medium
M40 grade	87.00	90.51	Medium

Table 3.9 Average workability of bacterial concrete with fly ash

Grade of concrete	Slump in mm	% of compaction	Degree of workability
M20 grade	75.00	87.63	Medium
M40 grade	97.00	91.50	Medium

Table 3.10 shows the variation of slump and compaction factors for M20 grade concrete and the same is depicted in the graphs 3.4 and 3.5 respectively.

Table 3.10 Workability of M20 concrete (slump and compaction factors)

% fly ash replacement	Water cement ratio	Super plasticizer	Slump in mm		Compaction factor in mm	
			Without bacteria	With bacteria	Without bacteria	With bacteria
10	0.5	0	68	71	0.862	0.871
20	0.5	0	72	73	0.870	0.878
30	0.5	0	78	80	0.873	0.880

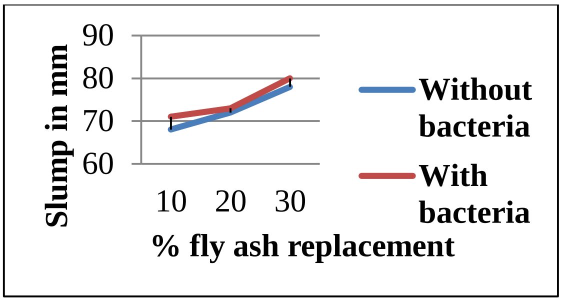

Figure 3.4 Variation of slump for M20 grade concrete

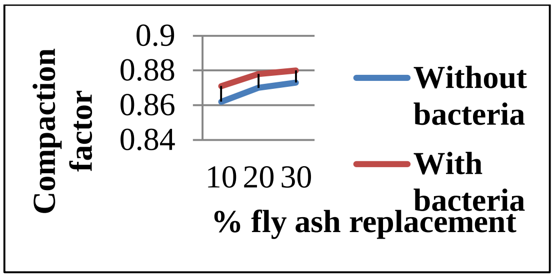

Figure 3.5 Variation of compaction factor for M20 grade concrete

From the Figures it can be ascertained that as the fly ash replacement increases, the slump and compaction factors increases gradually for M20 concrete.

Table 3.11 shows the variation of slump and compaction factors for M40 grade concrete and the same is depicted in the graphs 3.6 and 3.7 respectively.

Table 3.11 Workability of M40 concrete (slump and compaction factors)

% fly ash replacement	Water cement ratio	Super plasticizer	Slump in mm		Compaction factor in mm	
			Without bacteria	With bacteria	Without bacteria	With bacteria
10	0.35	0.8	91	90	0.895	0.910
20	0.35	0.8	102	100	0.905	0.915
30	0.35	0.8	104	102	0.915	0.920

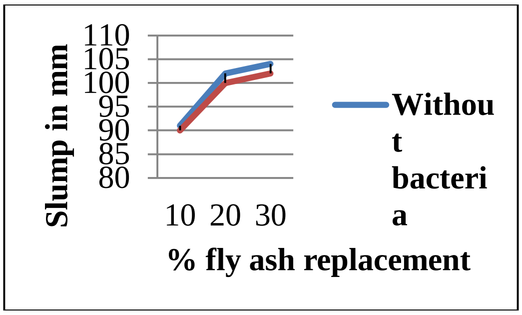

Figure 3.6 Variation of slump for M40 grade concrete

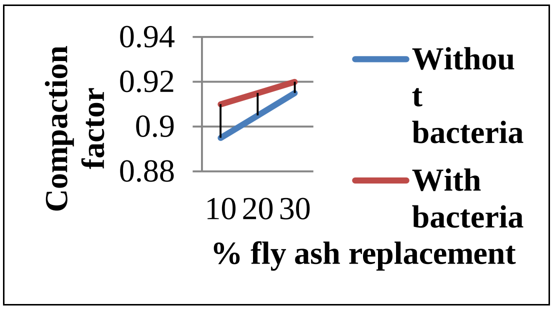

Figure 3.7 Variation of compaction factor for M40 grade concrete

From the Figures it can be ascertained that as the fly ash replacement increases, the slump and compaction factors increases gradually for M40 concrete also.

3.4.5 Concrete Mix Properties

The M20 mix design done as per IS:10262:2009 as explained below in Table 3.12. The same procedure is adopted for other mix proportions and the results are mentioned in Table 3.13.

Table 3.12 Mix design for M20 grade concrete

Grade Designation	M 20	
Type of cement	OPC 53 grade conforming to IS :12269	
Maximum nominal size of aggregate	20 mm	
Minimum cement content	300 kg/cum for Mild exposure as per Table 5 of IS:456-2000	
Maximum water cement ratio	0.5	
Workability	Medium	
W/C ratio arrived	0.5	
Max water content for 20 mm metal as per Table 2 of IS:10262:2009	186	lit
Arrived water content for 20 mm metal	176	lit
Cement content =Water/water cement ratio	352.00	kg/cum
Max cement content as per IS 456-2000	450.00	kg/cum
Volume of CA per unit volume of total aggregate (For 20 mm metal and Zone II sand) for W/C ratio 0.5 as per Table. 3 of IS 10262:2009	0.620	
Corrected volume of CA per unit volume of total aggregate (For 20 mm metal and Zone II sand) Volume of CA	0.620	
Note: If the water cement ratio differs from 0.5, then the ratio of coarse aggregate per unit volume of total aggregate is required to be adjusted. The proportion of volume of coarse aggregate per unit volume of total aggregate has to be adjusted at the rate of (-)/(+) 0.01 for every (+)/(-) 0.05 change in water cement ratio .		
Volume of FA= 1- Volume of CA	0.380	
Volume of Concrete	1	cum
Volume of cement=(Mass of cement/specific gravity of cement) x1/1000	0.1117	kg/cum
Volume of water=(Mass of water/specific gravity of water) x1/1000	0.176	kg/cum
Volume of super plasticizer	0	
Volume of All in Aggregate= Volume of concrete-(Volume of cement + Volume	0.7123	kg/cum

of water + Volume of admixture if any)		
Proportioning		
Cement	352.00	kg/cum
Weight of FA=Volume of all in aggregate x Volume of FA x Specific gravity of FA x 1000	714.53	kg/cum
Weight of CA=Volume of all in aggregate x Volume of CA x Specific gravity of CA x 1000	1170.23	kg/cum
Water	176	Lit

Table 3.13 Constituents of M20 and M40 mixes Per cum

Mix	Mix with fly ash replacement	Mix design	W/C ratio	Cement Kg	Fly ash Kg	Fine aggregate Kg	Coarse aggregate Kg	Water Litre	Superplasticizer
M20	10%	M1	0.5	316.8	35.20	714	1170	176	0
	20%	M2	0.5	281.6	70.4	714	1170	176	0
	30%	M3	0.5	246.4	105.6	714	1170	176	0
M40	10%	M4	0.35	397.8	44.20	711	1170	146	0.8
	20%	M5	0.35	353.6	88.4	711	1170	146	0.8
	30%	M6	0.35	309.4	132.6	711	1170	146	0.8

The concrete cubes are casted for both M20 and M40 grades as shown in Figure 3.8.

Figure 3.8 Moulds of cement concrete cubes being casted in the Laboratory

Phase IV

Phase IV deals with the testing procedures for evaluating the strength parameters of cement mortar specimens using fly ash and concrete specimens with fly ash with and without bacteria.

Testing procedure

The concrete specimens considered in this investigation programme are subjected to the following tests.

Compression test

Compression test is conducted confirming to IS 516-1959, on the concrete specimens, on the Universal Testing Machine (200 MT). In this test, cube is placed with the cast faces not in contact with the platens of testing machine i.e., the position of the cube when tested is at right angles to that as cast. Load is applied at a constant rate of stress equal to 15 MPa/min according to relevant IS code and the load at which the specimen failed is recorded.

Figure 3.9 Compression testing at concrete Laboratory at UCE, OU

Flexural strength test

The flexural strength test is conducted confirming to IS: 516-1959 and the code specify two point loading. In this test, the test specimens are stored in water at a temperature of 24^0C to 34^0C for 48 hours before testing. They are tested immediately on removal from the water whilst they are still in a wet condition, the dimensions of each specimen should be noted before testing.

Cylinder splitting tension test

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This test is also sometimes referred as, 'Brazilian test'. The test is developed in Brazil in 1943. At about the same time this was also independently developed in Japan. The test is carried out by placing a cylinder specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder along the vertical diameter.

Ultrasonic pulse velocity test

Ultrasonic pulse velocity test is a non destructive test. Ultrasonic pulse velocity method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete to be tested. The pulse generator circuit consists of Electron circuits for generating pulses and a transducer for transforming these Electron pulses into mechanical energy having vibration frequencies in the range of 15 to 50 kHz. The time of travel between initial onset and the reception of the pulse is measured electronically.

Table 3.14 Pulse velocity ratings

Pulse velocity (m/sec)	Concrete rating
4575	Excellent
3660 – 4575	Good
3050 – 3660	Questionable
2135 - 3050	Poor
2135	Very poor

ANALYSIS OF TEST RESULTS AND OBSERVATIONS

Strength Characteristics

Preliminary remarks

This chapter deals with the analysis of experimental tests conducted on hardened mortar specimens and concrete specimens which are casted using fly ash, after attaining the desired age of curing with respect to its compressive strength, flexural strength split tensile strength and pulse velocity. The results are precisely and systematically compiled and presented. They are also represented in graphs for its critical analysis and interpretations.

Properties of Cement Mortar using Fly Ash

Compressive strength

The most common of all the parameters is the compressive strength of cement mortar because it is a desirable characteristic of concrete. The compressive strength of cement mortar is quantitatively related to the compressive strength of concrete.

Table 4.1 Compressive strength of M20 and M40 concrete at 7 and 28 days (in MPa)

Concrete grade	% fly ash replacement	Without bacteria		With bacteria		% increase in strength of bacterial fly ash concrete than normal fly ash concrete	
		7 days	28 days	7 days	28 days	7 days	28 days
M20	10	16.41	26.90	17.55	30.10	6.95	11.90
	20	12.90	19.20	13.75	21.45	6.59	11.72
	30	10.34	17.82	11.08	20.01	7.16	12.29
M40	10	29.45	48.30	31.85	52.85	8.15	9.42
	20	21.84	36.40	23.35	40.40	6.91	10.99
	30	18.90	31.50	20.12	33.80	6.46	7.30

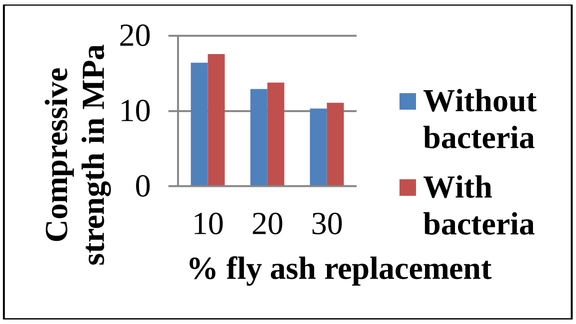

Figure 4.1 Compressive strength of M20 concrete at 7 days

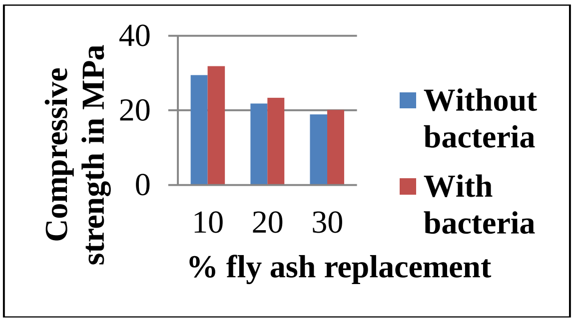

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Figure 4.2 Compressive strength of M40 concrete at 7 days

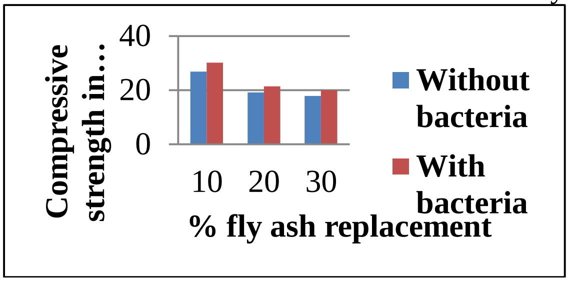

Figure 4.3 Compressive strength of M20 concrete at 28 days

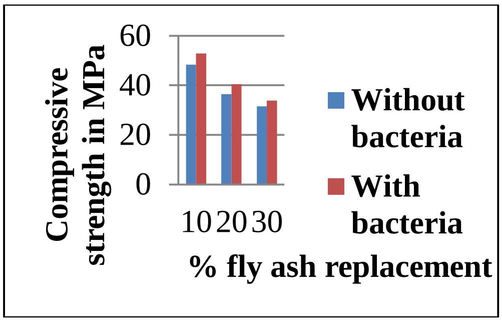

Figure 4.4 Compressive strength of M40 concrete at 28 days

Flexural strength (or) Modulus of rupture of concrete using fly ash

One of the important and useful parameters of concrete is the flexural strength.

Table 4.2 Flexural tensile strength of M20 and M40 concrete at 7 and 28 days (in MPa)

Concrete grade	% fly ash replacement	Without bacteria		With bacteria		% increase in strength of bacterial fly ash concrete than normal fly ash concrete	
		7 days	28 days	7 days	28 days	7 days	28 days
M20	10	3.56	3.6	3.90	4.01	9.55	11.39
	20	3.26	3.31	3.48	3.68	6.75	11.18
	30	3.04	2.92	3.24	3.25	6.58	11.30
M40	10	3.39	4.84	3.75	5.47	10.62	13.02
	20	3.12	4.61	3.38	5.15	8.33	11.71
	30	2.95	4.24	3.19	4.64	8.14	9.43

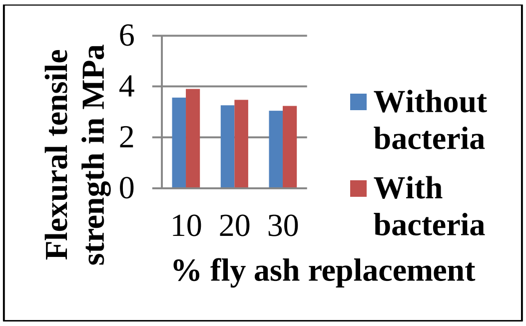

Figure 4.5 Flexural tensile strength of M20 concrete at 7 days

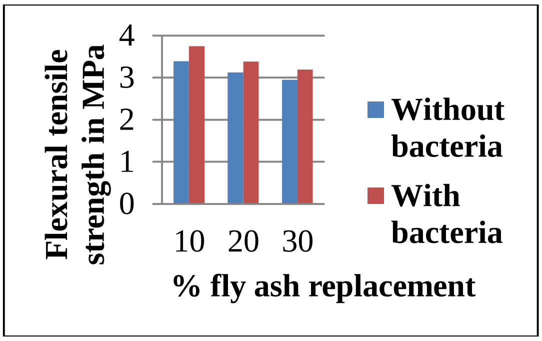

Figure 4.6 Flexural tensile strength of M40 concrete at 7 days

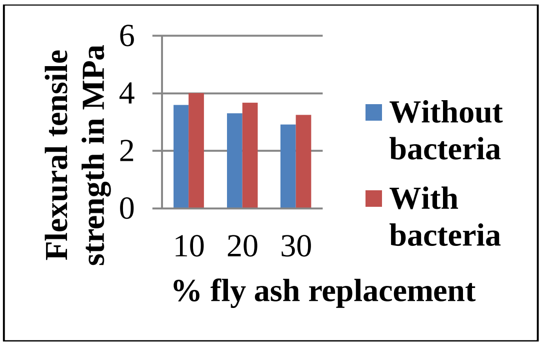

Figure 4.7 Flexural tensile strength of M20 concrete at 28 days

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			.6	24	81	23	8

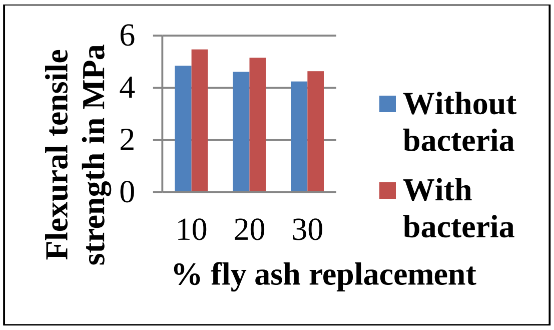

Figure 4.8 Flexural tensile strength of M40 concrete at 28 day

Split tensile strength of concrete using fly ash

Split tensile strength is observed by indirect method called cylinder split method which is one of the useful parameters of concrete.

Table 4.3 Split tensile strength of M20 and M40 concrete at 7 and 28 days (in MPa)

Concrete grade	% fly ash replacement	Without bacteria		With bacteria		% increase in strength of bacterial fly ash concrete than normal fly ash concrete	
		7 days	28 days	7 days	28 days	7 days	28 days
M20	10	2.75	3.65	2.97	4.10	8.00	12.33
	20	2.69	3.1	2.89	3.41	7.43	10.00
	30	2.28	2.85	2.41	3.15	5.70	10.53
M40	10	3.72	3.72	4.03	4.21	8.33	13.17
	20	3.35	3.05	3.61	3.38	7.76	10.82
	30	3.05	2	3.	2.	6.	8.0

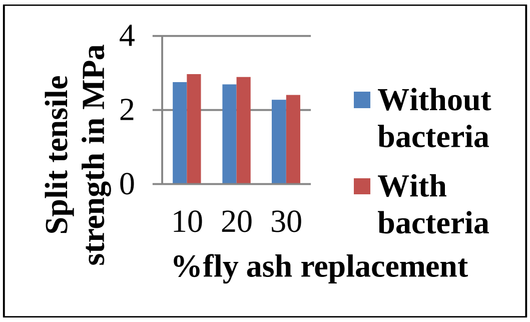

Figure 4.9 Split tensile strength of M20 concrete at 7 days

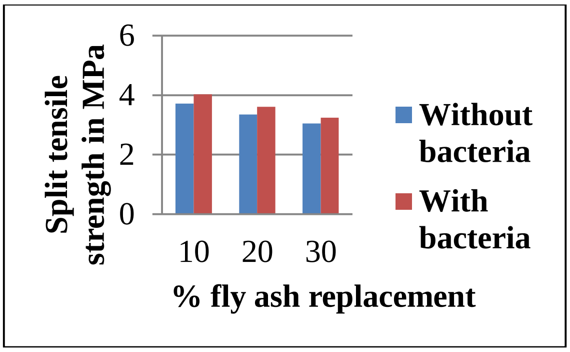

Figure 4.10 Split tensile strength of M40 concrete at 7 days

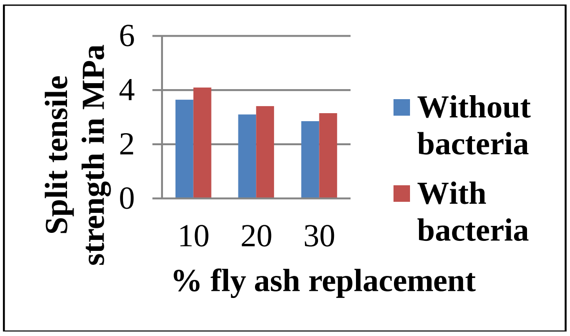

Figure 4.11 Split tensile strength of M20 concrete at 28 days

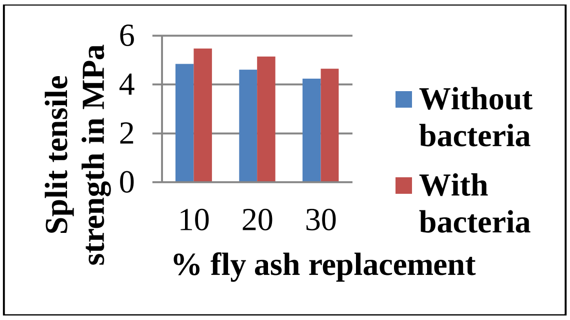

Figure 4.12 Split tensile strength of M40 concrete at 28 days

Ultrasonic Pulse Velocity Tests

Pulse velocity tests

Table 4.4 Pulse velocity of concrete using fly ash after 28 days curing

Mix	% of fly ash	Pulse velocity in m/sec.			
		Without bacteria	Rating	With bacteria	Rating
M 20	10	4390	Good	4410	Good
	20	4260	Good	4350	Good
	30	4100	Good	4230	Good
M 40	10	4490	Good	4550	Good
	20	4380	Good	4470	Good
	30	4310	Good	4410	Good

conclusion

Based on the present experimental investigations, the following conclusions are drawn.

- 'Bacillus Subtilis' can be produced from laboratory which is proved to be a safe and cost effective.
- The addition of 'Bacillus Subtilis' bacteria improve the hydrated structure of cement mortar.
- The compressive strength of cement mortar using fly ash is maximum with the addition of 'Bacillus Subtilis' bacteria for a cell concentration of 10^5 cells/ml of mixing water. Therefore, bacteria with a cell concentration of 10^5 cells/ml of mixing water are used in the present investigations.
- The addition of 'Bacillus Subtilis' and fly ash do not affect the workability aspects of concrete and there is no change in the workability aspects of bacterial concrete when compared to normal concrete without bacteria.
- The addition of 'Bacillus Subtilis' increases the compressive strength without bacteria for M20 and M40 grade concrete with fly ash, the compressive strength increases up to 7.5% for M20 and 8.00% for M40 grade at 28 days age.

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