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Strength Characteristics of Bacterial Concrete

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***Abstract*— 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. 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**

***Index Terms*— Self Healing, Microbiologically Induced Calcite Precipitation (MICP), Bio Mineralization, 'Bacillus Subtilis'**

I. INTRODUCTION

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 formatter will need to create these components, incorporating the applicable criteria that follow. 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.

II. MATERIALS.

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.

III. A 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.

The bacterial concrete with fly ash helps in preventing the development of cracks in concrete and improves the strength parameters. This in turn increases the durability of the structure. Also the bacterial concrete with fly ash is eco friendly and therefore it is necessary to go for the present work. Therefore the investigative experimentation is needed on bacterial concrete using fly ash samples so as to find out the strength parameters in comparison with the normal concrete with fly ash.

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III B 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.
To study the results and to evaluate the performance of bacterial concrete using fly ash as partial replacement of cement

III C Cases of cement mortar mix using fly ash

Case 1: Normal or control cement mortar using fly ash mix.
Case 2: Cement mortar (fly ash) mix case added with 10^4 cells/ml. bacterial solution.
Case 3: Cement mortar (fly ash) mix case added with 10^5 cells/ml. bacterial solution.
Case 4: Cement mortar (fly ash) mix case added with 10^6 cells/ml. bacterial solution.
Case 5: Cement mortar (fly ash) mix case added with 10^7 cells/ml. bacterial solution.
Case 6: Cement mortar (fly ash) mix case added with 10^8 cells/ml. bacterial solution.

The above mix cases have been considered for both normal cement mortar and bacterial cement mortar with part replacement of cement by fly ash. The mix proportion adopted is 1: 3.

III D **Specimens moulded**

Cube specimens:
Cube size: cube moulds of 150 x 150 x 150 mm size.Number of cubes: 3 for normal + 3 for bacterial concrete for each age of curing for each variation of fly ash replacement of 10%, 20% and 30%.
Total number of cubes casted: 36.
Cylinder specimens:
Cylinder size: cylinder moulds of 150 mm diameter x 300 mm length.
Number of cylinders: 3 for normal + 3 for bacterial concrete for each age of curing for each variation of fly ash replacement of 10%, 20% and 30%.
Total number of cylinders casted: 36.
Prism specimens:
Prism size: prism moulds of 100 mm x 100 mm x 500 mm size.
Number of prisms: 3 for normal + 3 for bacterial concrete for each age of curing for each variation of fly ash replacement of 10%, 20% and 30%.
Total number of prisms casted: 36.

IV A Laboratory set up

The Concrete Technology Laboratory at University College of Engineering, Osmania University is used for this project. Universal testing machine and compression testing machine are used to test all the concrete specimens. The curing of the concrete specimens is done by submerging the specimens in storage tanks.

IV B 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

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

Table 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

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Table 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%

Table 3: 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
H2S production	-
Nitrate reduction	-
Indole production	-
Vogesproskauer test	-
Citrate utilization	-
Catalase activity	+
Gelatin liquefaction	+
Starch hydrolysis	+
Lipid hydrolysis	+

Figure 1 Liquid form of bacteria 'Bacillus Subtilis'

IV C 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.

V A 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 'slump'. The slump value gives the measure of the consistency or the wetness of the mix. This test is performed for all the mixes. Figure 3.2 shows the sample of the slump of concrete being measured.

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.

Figure 2 Slump of concrete being measured in Laboratory.

Table 4 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 5 Average workability of control 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

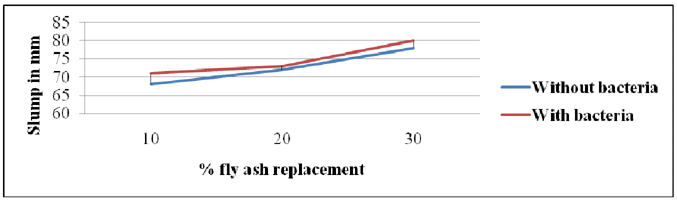

Figure 3 Variation of slump for M20 grade concrete

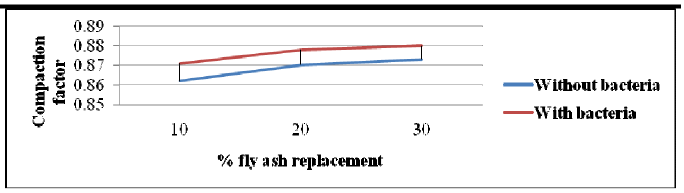

Figure 4 Variation of compaction factor for M20 grade concrete.

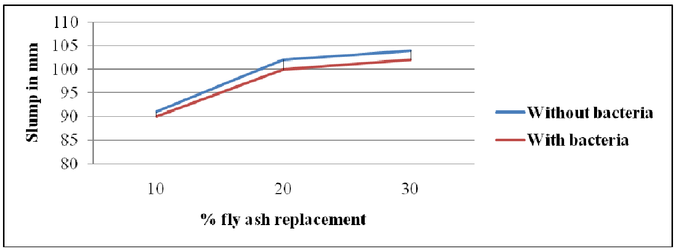

Figure 5 Variation of slump for M40 grade concrete

Figure 6 Moulds of cement concrete cubes being casted in the Laboratory

Figure 7 Compression testing at concrete Laboratory at UCE,OU.

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V B Ultrasonic Pulse Velocity Tests

Pulse velocity tests
28 days pulse velocity test

(a) Normal or control concrete using fly ash for various proportions of mix with M20 grade is as follows:

The cube specimens subjected to submerged curing with 10% fly ash have attained an average pulse velocity of 4390m/sec (Good).

The cube specimens subjected to submerged curing with 20% fly ash have attained an average pulse velocity of 4260m/sec (Good).

The cube specimens subjected to submerged curing with 30% fly ash have attained an average pulse velocity of 4100m/sec (Good).

(b) Bacterial concrete using fly ash as partial replacement in various proportions of mix with M20 grade:

The cube specimens subjected to submerged curing with 10% of fly ash have attained an average pulse velocity of 4410/sec (Good).

The cube specimens subjected to submerged curing with 20% fly ash have attained an average pulse velocity of 4350m/sec (Good).

The cube specimens subjected to submerged curing with 30% fly ash have attained an average pulse velocity of 4230m/sec (Good).

(c) Normal or control concrete using fly ash in various proportions mix with M40 grade:

The cube specimens subjected to submerged curing with 10% fly ash have attained an average pulse velocity of 4490m/sec (Good).

The cube specimens subjected to submerged curing with 20% fly ash have attained an average pulse velocity of 4380m/sec (Good).

The cube specimens subjected to submerged curing with 30% fly ash have attained an average pulse velocity of 4310m/sec (Good).

(d) Bacterial concrete with fly ash mix with M40 Grade:

The cube specimens subjected to submerged curing with 10% fly ash have attained an average pulse velocity of 4550m/sec (Good).

The cube specimens subjected to submerged curing with 20% fly ash have attained an average pulse velocity of 4470m/sec (Good).

The cube specimens subjected to submerged curing with 30% fly ash have attained an average pulse velocity of 4410m/sec (Good).

The results are also tabulated in Table 4.4 given below

V C Conclusions

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.

Scope for Future Work

Further studies may be conducted on

- Bacterial concrete using GGBS.
- Bacterial concrete in its carbonation in aggressive chemical environment.
- Bacterial concrete on corrosion of steel reinforcement in aggressive environments.
- Bacterial concrete performance in flexure.
- Bacterial concrete using rice husk ash.
- Bacterial concrete using lime surki mortar.

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