

Effect of Bacteria on the Properties of Fly Ash Concrete

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Abstract— Today the application of concrete is rapidly increasing worldwide; it is already the most used manmade material in the world as it is relatively cheap and its basic ingredients (sand/ gravel/ water) are readily available. However, the development of a sustainable concrete is urgently needed for environmental reasons. It is clear that cement, the key binder ingredient in concrete has a high environmental impact. Presently about 10% of the total anthropogenic CO₂ is due to the cement production solely. Today innovation is leadingly being inspired by nature as a sustainable alternative. Hence, taking notes from biotechnology, investigation is being conducted to create concrete the way nature does with microorganisms. The objective here is to study the application of bacterial species i.e. Bacillus Pasteuri to improve the strength of fly ash concrete. The dormant but viable bacteria in the concrete matrix will contribute to the strength of the concrete. Water which enters the concrete will activate the dormant bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation. The spore forming Bacillus Pasteuri may be able to survive in this artificial environment and increase the strength and durability of cement concrete. We found that incorporation of this bacteria will not negatively affect the compressive and split tensile strength of the cement concrete instead induce the precipitation of calcite. Microbial Induced Calcite Precipitation is highly desirable because the calcite precipitation induced as a result of microbial activities, is pollution free and natural. Microbial calcite precipitation was visualized by Scanning Electron Microscope. The unique imaging and microanalysis capabilities of SEM established the presence of calcite precipitation inside cracks, bacterial impressions and a new calcite layer on the surface of concrete.

Key words: Bacillus pasteurii, Bacterial concrete, Fly ash, water absorption

I. INTRODUCTION

Cracking of concrete is a common phenomenon. Without immediate and proper treatments, cracks in concrete structure tend to expand further and eventually require costly repair. Though it is possible to reduce the extent of cracking by available modern technology, remediation of cracks in concrete has been the subject of research for many years. There is large number of products available commercially for repairing cracks in concrete. Surface treatments with water repellents or pore blockers can be applied. However, treatments with organic products involve some disadvantages such as the different thermal expansion coefficient of the treated layers, degradation with the age and the need for maintenance. Furthermore, the use of certain solvents contributes to pollution. Another way to clean, repair or protect concrete and mortar surfaces is to use biological

processes, which may have a more ecological character. Smart materials react to changes in stimuli (temperature, moisture or pH) and can simulate biological, human like behaviour. Humans have the ability to precipitate minerals in the form of bones and teeth continuously. This ability is not only confined to human beings; even Bacillus Pasteruii, a common soil bacterium, can continuously precipitate calcite. This phenomenon is called as microbiologically induced calcite precipitation. Microbiologically induced calcite precipitation is a technique that comes under a broader category of science called bio-mineralization. It is a process by which living organism form inorganic solids. In this method a new highly impermeable calcite layer formation takes place over the surface of the already existing cement mortar layer. Calcite has a coarse crystalline structure that readily adheres to surfaces in the form of scales. In addition to the ability to continuously grow upon itself it is insoluble in water and is pollution free and natural. Due to its inherent ability to precipitate calcite continuously bacterial concrete can be called as “Smart Bio Material”. Microbiologically induced calcite precipitation technique can be used to improve the compressive strength and stiffness of cracked concrete specimens. Considerable research on carbonate precipitation by bacteria has been performed using different bacteria. These bacteria’s are able to influence the precipitation of calcium carbonate by the production of a urease enzyme. This enzyme catalyzes the hydrolysis of urea to CO₂ and ammonia, resulting in an increase of the pH and carbonate concentration in the bacterial environment. Specifically, microbiological-induced calcite is environmentally innocuous, compared to synthetic polymers currently used for concrete repair. The highly alkaline pH of concrete is a major hindering factor to the growth of a moderate alkaliphile, B.Pasteurii, whose optimum pH for growth is around nine. B.Pasteurii however, has an ability to produce the endospore, dormant form of the cell, to endure extreme environment

Cracks in concrete significantly influence the durability characteristics of the structure. The bacterial remediation technique can be used for repairing structures of historical importance to preserve the aesthetics value, as conventional technique, such as eporus injection cannot be used to remediate cracks in those structures. This technique resists the penetration of harmful agents (chlorides, sulphates, carbon dioxide) into the concrete thereby decreasing the deleterious effects they cause. Some of the microorganisms, even though they prove to be deadly and dangerous, there are some microorganism which help the human being. There are some other microorganisms, which can even help the man made construction. They can enhance the performance of a structure by increasing its stiffness and strength for example Bascillus Pasteruii microorganism can precipitate calcite which can seal off the microcracks and macrocracks present

in the concrete structure. The study of these microorganisms, rate of precipitate, effect of pH and temperature on the rate of calcite precipitation and its effect on the concrete structure become a very important subject matter for the study. Thus, the main objective of this research is to produce a sustainable concrete using the technique of bio-mineralisation.

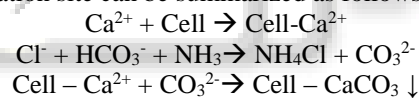
II. METHODOLOGY

A. Bio-Concrete:

“Bacterial Concrete” can be made by embedding bacteria in concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation.

In nature 3 groups of organisms can induce MCP:

- 1) Photosynthetic organisms- such as cyanobacteria and algae that remove CO₂,
- 2) Sulphate reducing bacteria- that is responsible for dissimilator reduction of sulphates
- 3) Organisms that are involved in the nitrogen cycle either ammonification of amino acids/ nitrate reduction/ hydrolysis of urea among the above, hydrolysis of urea by the enzyme urease is the simplest of all the MCP mechanisms stated. This method presents several advantages too; it is robust hence easily controllable and has the potential to produce high amounts of carbonate within a short period of time. Also, in the presence of a calcium source, calcium carbonate is readily precipitated under these conditions. Urease activity is widespread amongst bacteria. As such, the use of ureolytic bacteria for precipitation of carbonate is the most commonly used approach among MCP for production of calcium carbonate. Possible biochemical reactions in medium to precipitate CaCO₃ at the cell surface that provides a nucleation site can be summarized as follows.



As in those studies bacteria were manually and externally applied to existing structures, this mode of repair cannot be categorized as truly self healing. In several follow up studies therefore, the possibility to use viable bacteria as a sustainable and concrete-embedded self healing agent was explored. In one study spores of specific alkali-resistant bacteria related to the genus *Bacillus* were added to the concrete mixture as self-healing agent. These spores germinated after activation by crack ingress water and produced copious amounts of crack-filling calcium carbonate based minerals through conversion of precursor organic compounds which were also purposely added to the concrete mixture. However, in that study it was found that the bacteria-based self-healing potential was limited to relatively young (7-days cured) concrete only, as viability and related activity of bacterial spores directly (unprotected) embedded in the concrete matrix was restricted to about two months. The present paper builds further on results reported in latter research paper. Here, bacterial spores and organic mineral precursor compounds are packed in porous expanded clay particles prior to addition to the concrete mixture. It is hypothesized that protection of bacterial spores within porous light weight aggregates extends there viability period and

thus concrete self healing functionality when embedded in the material matrix.

- Classification on the Basis of Shapes: Bacteria are usually classified on the basis of their shapes. Broadly, they can be divided into
 - 1) Rod-shaped bacteria (Bacilli).
 - 2) Sphere-shaped bacteria (Cocci).
 - 3) Spiral-shaped bacteria (Spirilla).

- Classification on the Basis of Gram Strain: This classification is based on the results of Gram Staining Method, in which an agent is used to bind to the cell wall of the bacteria, they are Gram-positive and Gram-negative.

B. *Bacillus Pasteurii*:

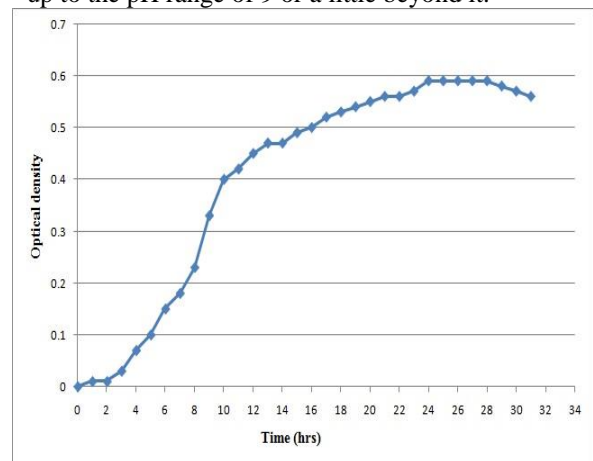
- Selection of bacteria: The reason for selecting *Bacillus Pasteuri* is that it's a common soil bacteria which can be easily extracted from soil, its non pathogenic and the growth conditions required are easily achievable. The details of the morphology of this species are mentioned below.

- Morphology:
 - 1) Gram positive bacteria but easily decolorized and motile.
 - 2) Spores are spherical or slightly oval.



Fig. 1: The pure culture of *Bacillus pasteurii*

- Growth Conditions Required:
 - 1) Temperature range of 30-40 degree Celsius suits the best.
 - 2) Have the ability to grow up to highly alkaline mediums up to the pH range of 9 or a little beyond it.



Graph 1: Growth curve of bacteria

- Fly Ash Concrete: The use of bituminous or sub-bituminous coal increasing day by day as large number of thermal power plants are being constructed, leading to increase of the production of fly ash. Fly ash is the finely divided residue, resulting from the combustion of ground or powdered coal and transported by the flue gases of boilers fired by the pulverized coal. It's

available in large quantities as a waste product from a thermal power and industrial plants.

• **Materials:**

Almost all the objectives of the research work are experimental oriented. Therefore the research work is basically experimental oriented. Following methodology is adopted for the research work.

- 1) Ordinary Portland cement
- 2) Fly ash
- 3) Microorganism : Bacillus pasteurii

• **Tests:**

The cubes and cylinders have been tested as per IS specifications. The compressive test and water absorption tests were carried out both on conventional and bacterial concrete specimens. The conventional and bacterial concrete cube specimen after casting were cured for 7 and 28 days and tested in compression testing machine. From the tests, it was observed that the concrete specimen prepared by incorporating the micro-organisms yielded higher strength as compared to the conventional concrete.

• **ADVANTAGES & DISADVANTAGES:**

1) **Bioconcrete:**

Advantages:

- 1) Considerable increase in Compressive Strength.
- 2) Eco-friendly behaviour.
- 3) Self healing of Cracks.

Disadvantages:

- 1) Demands large sterile medium to manage micro organisms.

2) **FLY ASH CONCRETE:**

Advantages:

- 1) Highly economic.
- 2) Reduces permeability to water and aggressive chemicals.
- 3) Smooth concrete surface.

Disadvantages:

- 1) Slower strength gain.
- 2) Environmental hazard.

C. **Sem Investigations:**

Microbial calcite precipitation was quantified by visualized by SEM. The specimens with bacteria did not develop any micro cracks, as they did not expand much unlike control specimens when subjected to alkali aggregate reactivity, sulfate attack, drying shrinkage and freeze-thaw. Figure 1 shows that a new layer (Surface II) was formed over the surface of the cement mortar beam (Surface I) Magnified image of calcite crystals found on the surface. Bacteria were found in intimate contact with the calcite crystals (Figure 3). Rod-shaped impressions, consistent with the dimensions of *B. pasteurii* were found in the calcite crystals, which formed on the surface of the specimens in. It was found that all the specimens with bacteria had a layer of calcite at the surface, thus improving its impermeability and its resistance to alkaline environment, sulfate attack and freeze-thaw.

Furthermore, many calcite crystal faces show hollow, rod-like impressions of *B. pasteurii*, where bacteria in contact with the calcite interfered with normal crystal growth. These microscopic observations serve to confirm the mechanism of microbial calcite precipitation in cement.

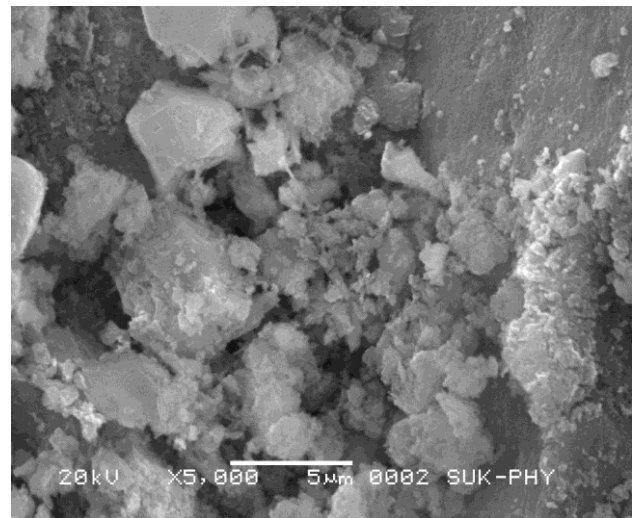


Fig. 2: Normal Concrete

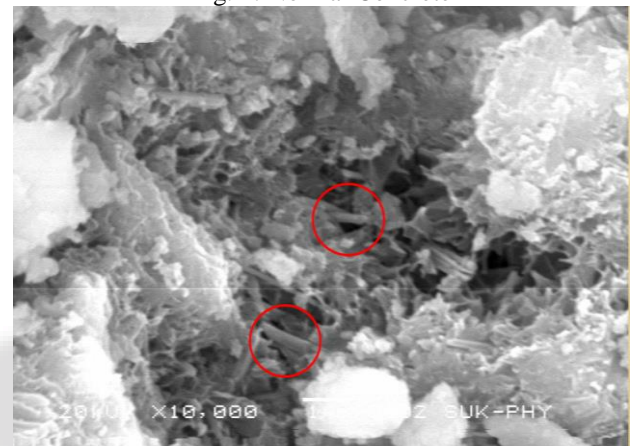


Fig. 3: With Bacteria & Calcite Precipitation

D. **Mix design calculation:**

Mix design was done as per IS10262-2007. M25 grade of concrete was designed by this method.

Step 1: Target strength for mix proportioning as per table-1 of IS10262-2007

Target strength = characteristic strength + (1.65 x standard deviation)

$$= 25 + (1.65 \times 4) = 31.6 \text{ N/mm}^2$$

Step 2: Selection of water cement ratio as per table-5 of IS456-2000

W/C ratio = 0.50

Step 3: Selection of water content as per table-2 of IS10262-2007

For 20 mm aggregates maximum water content = 186 kg/m³

We consider here 185 kg/m³

Step 4: Calculation of cement content

$$= 185 / 0.50 = 370 \text{ kg/m}^3$$

Step 5: Volume of coarse aggregate as per table-3 of IS10262-2007

Volume of 20 mm size coarse aggregate = 0.62

Step 6: Mix calculation

Volume of concrete = 1 m³

Volume of cement = (mass of cement/specific gravity of cement) x (1/1000)

$$= (370 / 3.15) \times (1 / 1000) = 0.117 \text{ m}^3$$

Volume of water = (mass of water/specific gravity of water) x (1/1000)

$$= (185 / 1) \times (1 / 1000) = 0.185 \text{ m}^3$$

Quantity of total aggregate = $(1 - 0.117 - 0.185) = 0.698 \text{ m}^3$

Here out of 0.698 m^3 , 62% will be coarse aggregate therefore fine aggregate will be 38%.

Therefore mass of fine aggregate = $0.698 \times 0.38 \times 2.62 \times 1000 = 694.93 \text{ kg/m}^3$

Therefore mass of coarse aggregate = $0.698 \times 0.62 \times 2.90 \times 1000 = 1255 \text{ kg/m}^3$

Step 7: Following table gives the mix proportion

Mix proportion

W/C ratio	Cement	Fine aggregate	Coarse aggregate
185	370 kg/m ³	694.93 kg/m ³	1254.3 kg/m ³
0.50	1	1.88	3.39

Table 1:

III. RESULT AND DISCUSSION:

A. Overall Test Results of Compressive Strength:

Description of concrete	Bacteria concentration (cells/ml)	Average compressive strength(MPa)	Percentage increase in Compressive strength w.r.t reference mix
Concrete with 0% fly ash as replacement of cement	0	33.33	Reference
	10 ³	36.88	10.65
	10 ⁵	40.14	20.43
	10 ⁷	38.21	14.64
Concrete with 10% fly ash as replacement of cement	0	31.84	Reference
	10 ³	34.59	8.63
	10 ⁵	37.40	17.46
	10 ⁷	36.07	13.28
Concrete with 20% fly ash as replacement of cement	0	30.59	Reference
	10 ³	32.81	7.40
	10 ⁵	35.18	15
	10 ⁷	33.55	9.67
Concrete with 30% fly ash as replacement of cement	0	29.18	Reference
	10 ³	30.59	4.83
	10 ⁵	32.21	10.38
	10 ⁷	31.70	8.63

Table 2:

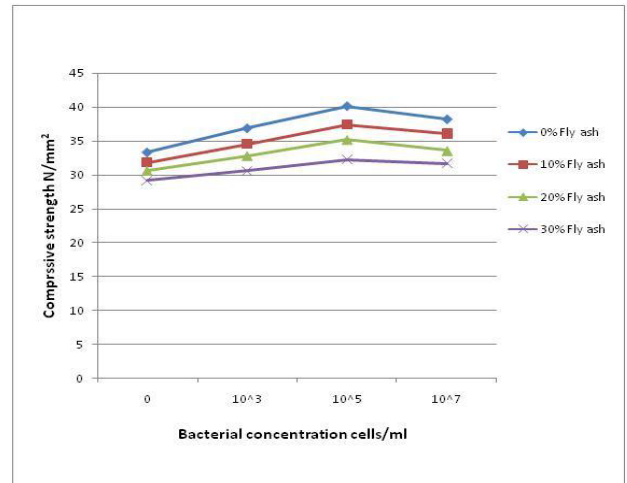


Fig. 4:

B. Overall Test Results of Split Tensile Strength:

Description of concrete	Bacteria concentration (cells/ml)	Average split tensile strength(MPa)	Percentage increase in split tensile strength w.r.t reference mix
Concrete with 0% fly ash as replacement of cement	0	3.72	Reference
	10 ³	4.17	12.09
	10 ⁵	4.40	18.27
	10 ⁷	4.31	15.86
Concrete with 10% fly ash as replacement of cement	0	3.48	Reference
	10 ³	3.81	9.48
	10 ⁵	4.03	15.80
	10 ⁷	3.91	12.35
Concrete with 20% fly ash as replacement of cement	0	3.29	Reference
	10 ³	3.53	7.29
	10 ⁵	3.72	13.06
	10 ⁷	3.61	10.03
Concrete with 30% fly ash as replacement of cement	0	2.92	Reference
	10 ³	3.11	6.50
	10 ⁵	3.25	11.30
	10 ⁷	3.13	7.19

Table 3:

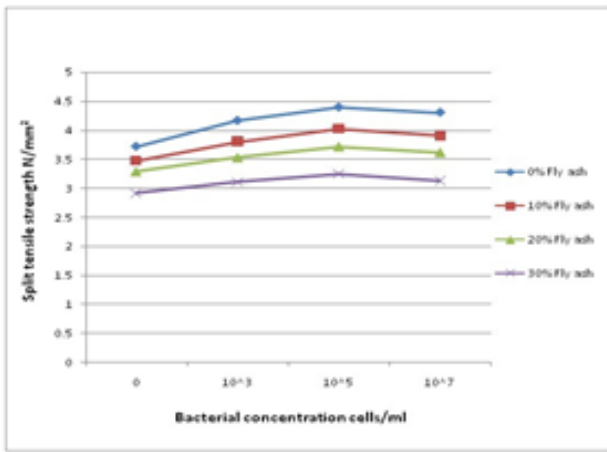


Fig. 5:

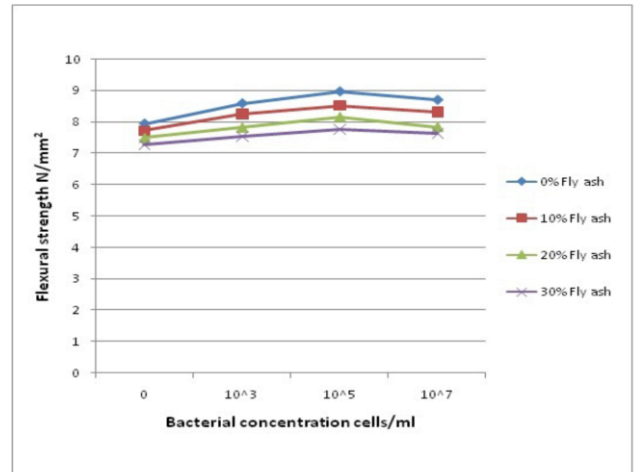


Fig. 6:

C. Overall Test Results of Flexural Strength:

Description of concrete	Bacteria concentration (cells/ml)	Average Flexural strength(MPa)	Percentage increase in Flexural strength w.r.t reference mix
Concrete with 0% fly ash as replacement of cement	0	7.93	Reference
	10 ³	8.58	8.19
	10 ⁵	8.96	12.98
	10 ⁷	8.69	9.58
Concrete with 10% fly ash as replacement of cement	0	7.73	Reference
	10 ³	8.25	6.72
	10 ⁵	8.52	10.21
	10 ⁷	8.32	7.63
Concrete with 20% fly ash as replacement of cement	0	7.49	Reference
	10 ³	7.82	4.40
	10 ⁵	8.16	8.94
	10 ⁷	7.84	4.67
Concrete with 30% fly ash as replacement of cement	0	7.28	Reference
	10 ³	7.54	3.57
	10 ⁵	7.77	6.73
	10 ⁷	7.64	4.94

Table 4:

D. Overall Test Results of Shear Strength:

Description of concrete	Bacteria concentration (cells/ml)	Average Shear strength(MPa)	Percentage increase in Shear strength w.r.t reference mix
Concrete with 0% fly ash as replacement of cement	0	6.75	Reference
	10 ³	7.40	9.62
	10 ⁵	7.86	16.44
	10 ⁷	7.59	12.44
Concrete with 10% fly ash as replacement of cement	0	6.47	Reference
	10 ³	6.75	4.32
	10 ⁵	7.21	11.43
	10 ⁷	7.03	8.65
Concrete with 20% fly ash as replacement of cement	0	6.01	Reference
	10 ³	6.38	6.15
	10 ⁵	6.66	10.81
	10 ⁷	6.56	9.15
Concrete with 30% fly ash as replacement of cement	0	5.27	Reference
	10 ³	5.55	5.31
	10 ⁵	5.83	10.62
	10 ⁷	5.64	7.02

Table 5:

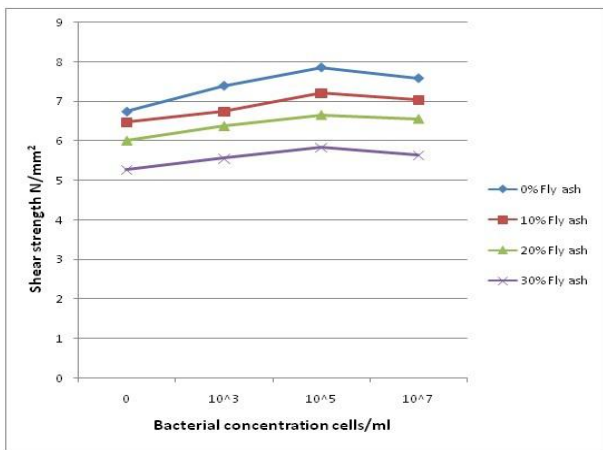


Fig. 7:

E. Overall Test Results of Water Absorption:

Description of concrete	Bacteria concentration (cells/ml)	Average Water absorption (MPa)
Concrete with 0% fly ash as replacement of cement	0	6.55
	10 ³	6.35
	10 ⁵	5.83
	10 ⁷	6.31
Concrete with 10% fly ash as replacement of cement	0	5.68
	10 ³	5.45
	10 ⁵	5.12
	10 ⁷	5.30
Concrete with 20% fly ash as replacement of cement	0	5.96
	10 ³	5.68
	10 ⁵	5.39
	10 ⁷	5.58
Concrete with 30% fly ash as replacement of cement	0	6.40
	10 ³	6.12
	10 ⁵	5.62
	10 ⁷	5.97

Table 6:

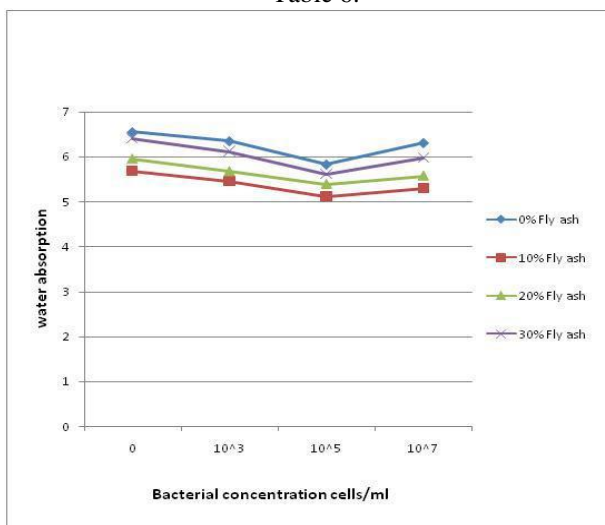


Fig. 8:

F. Overall Test Results of Sorptivity:

Description of concrete	Bacteria concentration (cells/ml)	Average Sorptivity (MPa)
Concrete with 0% fly ash as replacement of cement	0	5.33
	10 ³	4.77
	10 ⁵	4.04
	10 ⁷	4.47
Concrete with 10% fly ash as replacement of cement	0	3.95
	10 ³	3.50
	10 ⁵	3.18
	10 ⁷	3.59
Concrete with 20% fly ash as replacement of cement	0	4.42
	10 ³	3.95
	10 ⁵	3.56
	10 ⁷	4.10
Concrete with 30% fly ash as replacement of cement	0	4.83
	10 ³	4.51
	10 ⁵	3.93
	10 ⁷	4.21

Table 7:

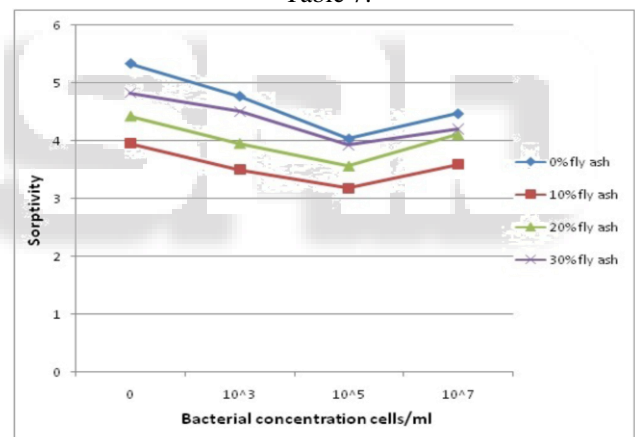


Fig. 9:

IV. CONCLUSION

- Microbial concrete technology has proved to be better than many conventional technologies because of its eco-friendly nature, self healing abilities and increase in durability of various building materials.
- From the growth curve we can conclude that the maximum growth for Bascillus Pasteruii is in the range of 24-26hrs i.e. 10⁵ cells/ml.
- From the SEM analysis carried out, the difference between the normal concrete and bacterial concrete is clearly visible.
- Precipitation of calcite takes place at highest concentration i.e. 10⁵ cells/ml (from the growth curve).
- Compressive strength reduces when cement replaced fly ash. As fly ash percentage increases compressive strength and split strength decreases.

- Bacillus pasteurii causes reduction in water absorption which could in turn increase durability of concrete structures.
- Use of fly ash in concrete can save the coal & thermal industry disposal costs and produce a 'greener' concrete for construction.
- The cost analysis indicates that percent cement reduction decreases cost of concrete, but at the same time strength also decreases.
- This research concludes that fly ash can be innovative supplementary cementitious Construction Material but judicious decisions are to be taken by engineers.
- Fly Ash: The use of these by-products offers environmental advantages by diverting the material from the waste stream reducing the energy investment and allaying pollution.

- As a construction material

The use of biocementation through MICP with bacteria for variety of applications seems to be a compatible alternative to cement. In particular this method used for consolidation of sand (aggregate) and the attainable strengths, make it a practicable alternative to concrete. Bioconcrete is being commercialised on a small scale for moulded products, bricks or blocks and instant pavements. However, at large scales uniform distribution of strengths is yet to be mastered. No investigation has been carried out so far to check the durability of this material. However, if problems do appear in the future, some of the applications of MICP are that of crack remediation and self-healing of existing concrete. Therefore, the possibility of healing future damages in bioconcrete.

- As an alternative to concrete

By means of an LCA the environmental impact of bioconcrete is proven to be half that of concrete, even though the production of the inputs in bioconcrete are double that of concrete. This is mainly due to the possibility of bioconcrete being able to be recycled and re-used to produce bioconcrete hence forming a closed loop by closing its cycle.

- Scope for further study

The following experimental works can be conducted in future:-

- 1) Long term investigation of strength and durability properties need to be studied.
- 2) The performance of other kinds of bacteria and their comparison in improving the concrete properties can be assessed.
- 3) The work can be extended to higher concrete grades.
- 4) The present work forms a basis for developing bacterial concrete by using various other mineral admixtures like silica fume, metakaolin etc.

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