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An Experimental Investigation on the Strength and Durability Aspects of Bacterial Concrete with Fly Ash

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Abstract

This paper presents the results of an experimental investigation carried out to evaluate the influence of Bacillus sphaericus bacteria on the compressive strength, split tensile strength, flexural strength, shear strength, water absorption and chloride permeability of concrete made without and with fly ash. Cement was replaced with two percentages (10 and 20) with fly ash by weight. Three different cell concentration (0, 10^3,10^5,10^7 cells/ml) of bacteria were used in making the concrete mixes. Tests were performed at the age of 28 days. Test results indicated that inclusion of B. sphaericus in fly ash concrete enhanced the compressive strength reduced the water absorption and chloride permeability of fly ash concrete. Maximum increase in compressive strength 15.47% was observed with 10^5cells/ml of bacteria. This improvement in strength was due to deposition on the bacteria cell surfaces within the pores.

The present work highlights the influence of bacteria on the properties of concrete made with supplementing cementing material such as like fly ash. Usage of bacteria like B. sphaericus improves strength and durability and strength of fly ash concrete through self-healing effect.
Keywords: Bacterial concrete, Bacillus sphaericus, compressive strength, water absorption, chloride penetration.

1 Introduction

Concrete is the most widely used man made construction material in civil engineering world. It has specialty of being cast in any desirable shape but plain concrete however possesses very low tensile strength, limited ductility and little resistance to cracking. As a matter of fact, advancement in concrete technology has been generally on the strength of concrete. It is now recognized that strength of concrete alone is not sufficient, the degree of harshness of the environmental condition to which concrete is exposed over its entire life is very important. Therefore, both strength and durability have to be considered explicitly at the design stage. To do this, a durable structure needs to be produced. For concrete buildings, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability and aesthetics of the structure. This may lead to early repair or premature replacement of the structure. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure by using relatively impenetrable concrete.

The inclusion of supplementary cementing materials which serve to refine the pore structure and the degree of hydration of the concrete. The highly developed pore structure occurs due to greater amount of heat of hydration which inturn depends on the age of concrete. This is especially true for concrete containing slower reacting supplementary cementing materials such as fly ash require a longer time to hydrate. Fly ash is generally used as replacement of cement, as an admixture in concrete, and in manufacturing of cement. This study explores the possibility of replacing part of cement with fly ash as a means of incorporating significant amounts of fly ash. All building materials are porous. This porosity of building material along with ingress of moisture and other harmful chemicals such as acids, chlorides and sulfates affect the material and seriously reduce their strength and life. An additive that seals the pores and cracks and thus reduces the permeability of the structure would immensely improve its life. Conventionally, a variety of sealing agents such as latex emulsions and epoxies and surface treatments with water repellents such as silanes or siloxanes are used to enhance the durability of the concrete structures. However, they suffer from serious limitations of incompatible interfaces, susceptibility to ultraviolet radiations, unstable molecular structure and high cost. They also emanate toxic gases.

In order to overcome the shortcomings of conventional sealing agents, materials with self-healing capability can be used effectively. Use of urease producing bacteria such as Bacillus sphaericus addresses these problems effectively, as these continue to survive and grow within the concrete structure after the initial use. Urease helps in mineralization of calcium carbonate, by hydrolyzing urea present in the environment. It releases carbon dioxide from urea that combines with calcium ions resulting in deposition of calcium carbonate in the form of calcite.

2 MATERIALS

2.1 Cement

In this experiment 43 grade ordinary Portland cement (OPC) with brand name JK was used for all concrete mixes. The cement used was fresh and without any lumps. The testing of cement was done as per IS: 8112-1989. The specific gravity of cement was found to be 3.15.

2.2 Fine aggregate

The sand used for the experimental program was natural river sand (Badami sand) locally procured and was confirming to zone-II of IS 383:1970. The specific gravity of fine aggregate was found to be 2.54.

2.3 Coarse aggregate

Locally available coarse aggregate having the maximum size of 20 mm and down as per IS 383:1970 were used in the present work. The specific gravity of coarse aggregate was found to be 2.78.

2.4 Fly ash

Fly ash has been shown to be an effective addition for concrete providing increased cohesion and reduced sensitivity to changes in water content. Fly ash used in the experiment was obtained from Raichur (Karnataka). The class c type of fly ash is used.

2.5 Water

Clean water available in the laboratory, was used for the preparation of specimens and for the curing of specimens.

2.6 Bacteria

The pure culture of Bacillus sphaericus NCIM NO 2478 was obtained from National Collection of Industrial Microorganisms, Pune. The sub culture of Bacillus sphaericus was made in a laboratory of Department of Biotechnology.

3 Results and discussion

3.1 Compressive strength

Effect of Bacillus sphaericus bacteria on the 28-day compressive strength of all concrete is given in Table 7.13 and graphically represented in Fig. 7.1. It is observed that compressive strength of normal concrete and fly ash concrete increased with increase in bacteria cell concentration up to 10^5cells/ml and then there was reduction in the strength at 10^7cells/ml. Maximum compressive strength was achieved at 10^5cells/ml for normal and all fly ash concretes. For reference concrete (0% fly ash) with 10^5cells/ml bacterial cells, there was 15.47% improvement in the compressive strength (40.37 MPa) with respect to compressive strength (34.96 MPa) of reference concrete without bacteria cells. In fly ash bacterial concrete, there was 11.16% and 11.26% improvement in compressive strength of concrete (10% and 20% fly ash) with the inclusion of 10^5cells/ml bacterial cells. The improvement in compressive strength by B. sphaericus is probably due to deposition of $CaCO^3$ on the microorganism cell surfaces and within the pores, which plug the pores within the binder matrix. The results from the study showed that due to inclusion of bacteria in normal and fly ash concrete, compressive strength was improved which would in-turn increase the overall durability performance of the concrete. The increase in compressive strengths is mainly due to filling of the pores inside the cement mortar cubes with microbiologically induced calcium carbonate precipitation.

A Bacillus sphaericus bacterium for a cell concentration of 10^5 cells per ml of mixing water is obtained in the time range of 18-22 hours. At this stage it is growth phase hence it is active and precipitate more calcite. Bacterial concentration 10^7 cells per ml of mixing water are obtained in the range between 22-24 hours. At this stage, microbes are entering the death phase. Hence the microbes are not active and they do not precipitate much calcite.

Table 1: Effect of bacteria (B. sphaericus) on compressive strength of fly ash concrete

Description of concrete	Bacteria concentration (cells/ml)	Average compressive strength (Mpa)
Concrete with 0% fly ash	0	34.96
	10^3	38.59
	10^5	40.37
	10^7	39.19
Concrete with 10% fly ash	0	33.85
	10^3	36.48
	10^5	37.63
	10^7	36.67
Concrete with 20% fly ash	0	32.22
	10^3	33.41
	10^5	35.85
	10^7	34.22

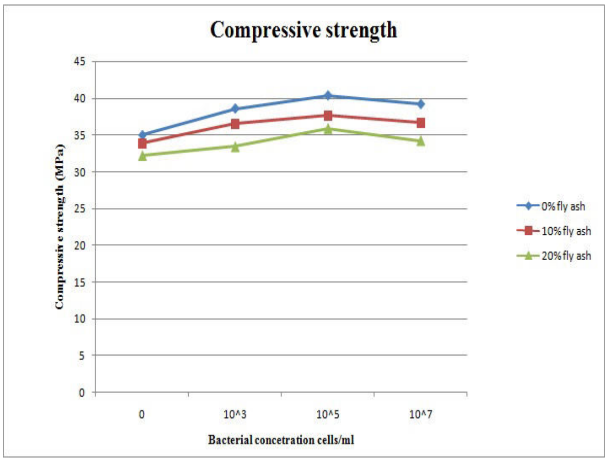

Fig 1: Effect of bacteria (B. sphaericus) on compressive strength of fly ash concrete

3.2 Water absorption

The influence of bacteria on the water absorption of concrete is given in Table 7.65 and graphically represented in Fig. 7.5. It can be seen from this figure that with the inclusion of bacteria, water absorption capacity of normal and fly ash concretes decreased with the increase in bacteria concentration. Maximum reduction in water absorption was observed with 10^5cells/ml for all normal and fly ash concretes. However, concrete with 10% fly ash concrete give 5.20 water absorption (minimum). The presence of bacteria resulted in a significant decrease in the water uptake compared to control specimens. The deposition of a layer of calcium carbonate on the surface and inside pores of the concrete specimens resulted in a decrease of water absorption and permeability. Once the pores are sealed, reduction in water ingress is observed. This bacterial action deposition can seal the pores, voids and micro cracks, where other sealants are unable to work through. Hence, from this experiment, it is clear that the presence of a layer of carbonate crystals on the surface by bacterial cells has the ability to improve the resistance of cementitious materials towards degradation.

Bacterial concentration 10^7 cells per ml of mixing water is obtained in the range between 22-24 hours. At this stage, microbes are entering the death phase. Hence the microbes are not active and they do not precipitate much calcite.

Table 2: Effect of bacteria (B. sphaericus) on shear strength of fly ash concrete

Description of concrete	Bacteria concentration (cells/ml)	Average water absorption
Concrete with 0% fly ash	0	6.63
	10^3	6.39
	10^5	5.83
	10^7	6.35
Concrete with 10% fly ash	0	5.76
	10^3	5.53
	10^5	5.20
	10^7	5.27
Concrete with 20% fly ash	0	6.15
	10^3	5.76
	10^5	5.46
	10^7	5.65

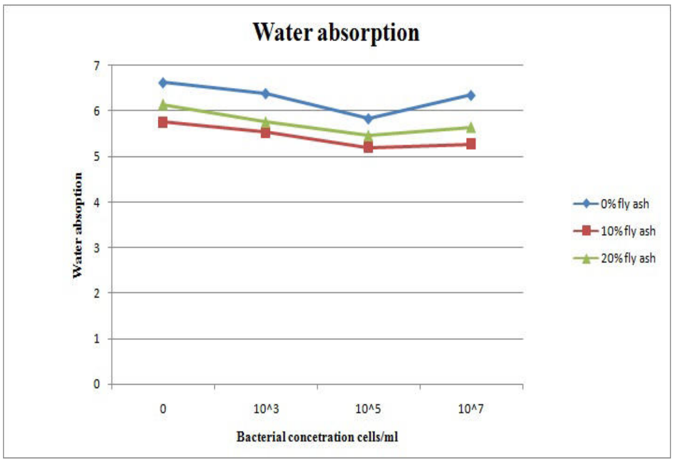

Fig 2: Effect of bacteria (B. sphaericus) on water absorption of fly ash concrete

3.3 Chloride penetration test

The influence of bacteria on the chloride penetration of concrete is given in Table 7.91 and graphically represented in Fig. 7.7. It can be seen from this figure that with the inclusion of bacteria, chloride penetration capacity of fly ash concretes decreased with the increase in bacteria concentration. Maximum reduction in chloride penetration was observed with 10^5cells/ml for all normal and fly ash bacterial concretes. However, concrete with 20% fly ash bacterial concrete gave 277.33 mg/lit chloride penetration (minimum). The presence of bacteria resulted in a significant decrease in the chloride uptake compared to control specimens. The deposition of a layer of calcium carbonate on the surface and inside pores of the concrete specimens resulted in a decrease of water absorption and permeability. Once the pores are sealed, reduction in water ingress is observed. This bacterial action deposition can seal the pores, voids and micro cracks, where other sealants are unable to work through. Hence, from this experiment, it is clear that the presence of a layer of carbonate crystals on the surface by bacterial cells has the ability to improve the resistance of cementitious materials towards degradation.

Bacterial concentration 10^7 cells per ml of mixing water is obtained in the range between 22-24 hours. At this stage, microbes are entering the death phase. Hence the microbes are not active and they do not precipitate much calcite.

Table 3: Effect of bacteria (B. sphaericus) on chloride penetration of fly ash concrete

Description of concrete	Bacteria concentration (cells/ml)	Chloride content at 30mm depth (mg/lit)
Concrete with 0% fly ash	0	509.33
	10^3	466.00
	10^5	340.33
	10^7	409.67
Concrete with 10% fly ash	0	436.00
	10^3	406.33
	10^5	307.00
	10^7	350.33
Concrete with 20% fly ash	0	416.00
	10^3	387.00
	10^5	277.33
	10^7	317.00

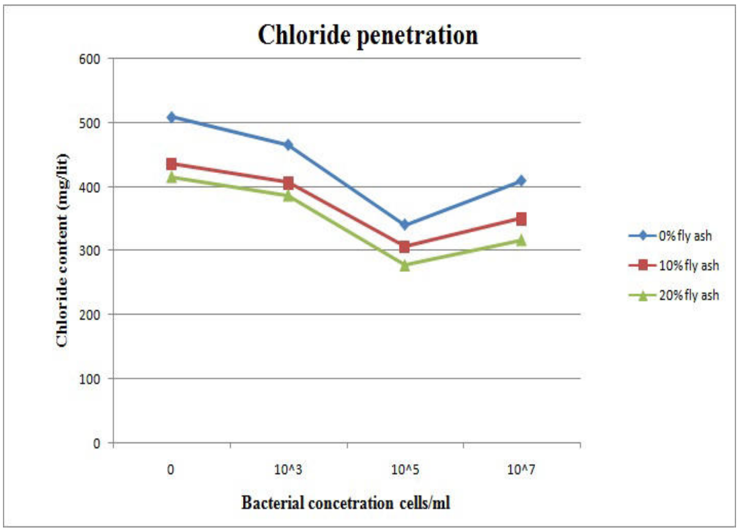

Fig 3: Effect of bacteria (B. sphaericus) on chloride penetration of fly ash concrete

3.4 Scanning electron microscopy

Calcite precipitation in concrete was carried out by SEM analysis. The specimens with bacteria did not develop any micro cracks, as they did not expand much unlike reference specimens. Furthermore, many calcite crystal faces show hollow, rod-like impressions of B. Sphaericus, 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 concrete. Fig.4 shows the SEM picture of normal concrete, where in, pores can be easily seen inside it. Fig.5 and fig.6 shows the presence of crystalline calcium carbonate associated with bacteria. The SEM analysis of concrete with Bacillus Sphaericus has revealed distinct calcite crystals embedded in concrete. High calcium amounts in it confirmed that calcite was present in the form of calcium carbonate due to bacteria. The deposition of calcite serves as barrier to harmful substances and thus improves impermeability.

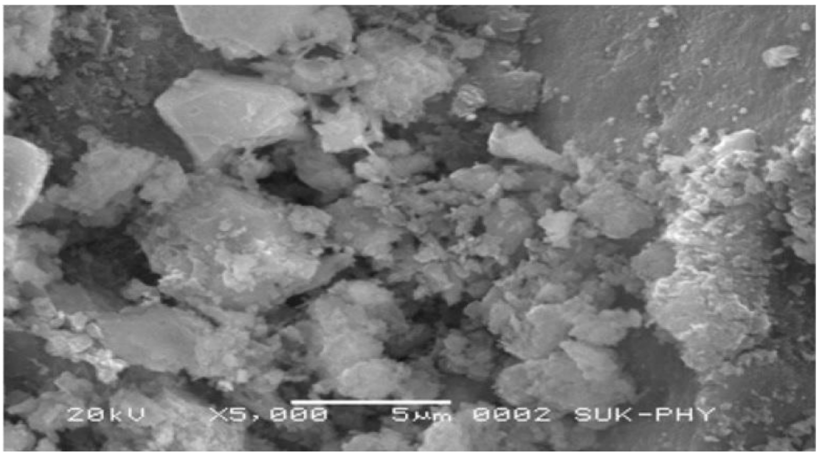

Figure 4: SEM picture of normal concrete

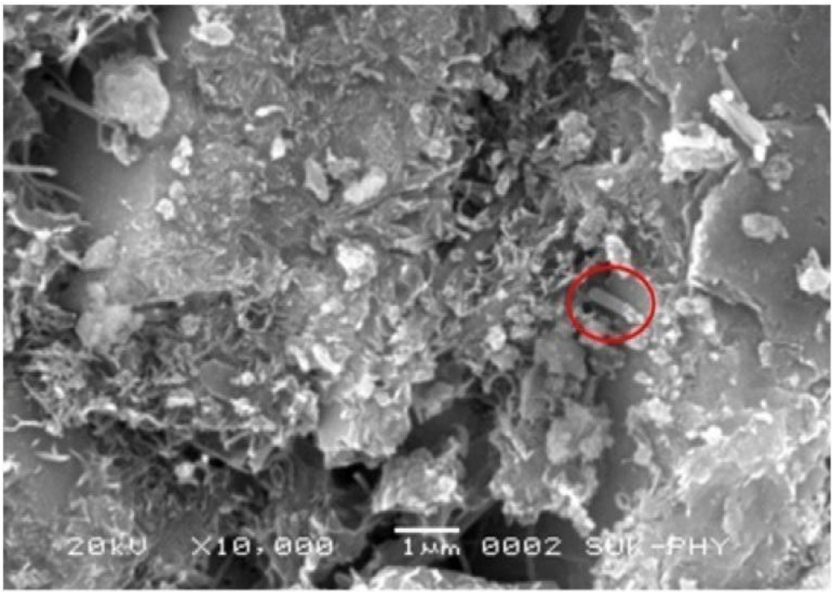

Figure 5: SEM picture of Concrete showing bacterial induced calcite deposition in micro cracks

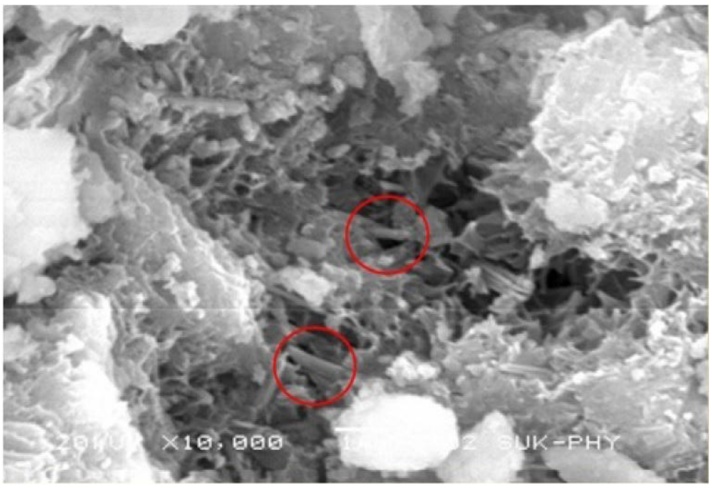

Figure 6: SEM picture of Concrete showing bacterial induced calcite deposition in micro cracks

4. Conclusions

- Bacteria Bacillus sphaericus plays a significant role in increasing the compressive strength of normal concrete by up to 15.47% and fly ash concrete up to 11.16% and 11.26% for 10% and 20% fly ash as replacement of cement respectively as compared to reference concrete at a particular cell concentration i.e. at 10^5 cells/ml.
- The increase in compressive strength is mainly due to consolidation of the pores inside the normal and fly ash concrete with bacteria induced calcium carbonate precipitation.
- Bacillus sphaericus causes reduction in water absorption, and chloride penetration which could in turn increase durability of concrete structures.

5. Suggestions for future research

- This study could also be conducted for other types of cement.
- Long term investigation of the properties could also be carried out. For which, investigations are already in progress and would be communicated in future publications.

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