Influence of Bacteria on Strength And Self-Healing Characteristics of Fly Ash Concrete

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Abstract*- Traditional concrete is considered brittle, rigid and susceptible to cracks. Synthetic polymers used for the repair of cracks are susceptible to ultraviolet radiations, high cost and emanate toxic gases. This project presents the results of an experimental investigation carried out to evaluate the influence of Bacillus Megaterium bacteria on the compressive strength, split tensile strength, flexural strength and self-healing characteristics of concrete made without and with fly ash. Cement was replaced with four percentages (10, 20, 30 and 40) with fly ash by weight. A cell concentration of 105 cells/ml of bacteria was used in making the concrete mixes. Tests were performed at the age of 28 days. Test results indicated that the inclusion of Bacillus Megaterium in fly ash concrete enhanced the compressive, split tensile and flexural strength. 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 supplementary cementing material such as like fly ash. Usage of bacteria like Bacillus Megaterium improves strength and durability of fly ash concrete through self-healing effect.

I. INTRODUCTION

Concrete is the most widely used man made construction material in civil engineering world. It has specialty ofbeing 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.

If a method could be developed to automatically repair cracks in concrete this would save an enormous amount of money, both on the costs of injection fluids for cracks and also on the extra steel that is put in structures only to limit crack widths. For structural reasons this extra steel has no meaning. A reliable self-healing method for concrete would lead to a new way of designing durable concrete structures, which is beneficial for national and global economy.

II. LITERATURE REVIEW

To provide a detailed review of the body of literature related to Bacterial concrete and fly ash concrete would be too immerse to address in this thesis. However, there are many good references that can be used as a starting point for this project. This literature review and introduction will focus on recent contributions related to the needs of the present work.

Achal.V,et.al (2012) studied the results of compressive strength of cement mortars incorporating microorganism. The effect of addition of microorganism, Bacillus megaterium, on the compressive strength of cement mortar cube has been studied. Ordinary Portland cement (OPC) was used to prepare mortar with different cell concentration of microorganism in the mixing water. A significant increase in the compressive strength of cement mortar cube at different ages (3, 7, 14 and 28 days) was achieved with the addition of B. megaterium. Increases in compressive strength were observed maximum in case of 105 cells/ml of microorganism. This improvement in compressive strength isduetodeposition on the microorganism cell surfaces and within the pores of cement-sand matrix.

SeshagiriRao.M.V, et.al (2013) studied the applicability of specifically calcite mineral precipitating bacteria for concrete repair and plugging of pores and cracks in concrete has been recently investigated and the possibility of using specific bacteria as a sustainable and concrete embedded self-healing agent was studied and results from on-going studies are discussed. Synthetic polymers such as epoxy treatment currently being used for repair of concrete are harmful to the environment, hence the use of a biological repair technique in concrete is focused. Thus an attempt is made to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength and durability 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. Concrete, due to its high internal pH, relative dryness and lack of nutrients needed for growth, is a rather hostile environment for common bacteria, but there are some extremophilic spore forming bacteria may be able to survive in this environment and increase the strength and durability of cement concrete.

III. METHODOLOGY AND MATERIALS UTILISED

GENERAL

In this chapter the materials which are used for investigations to make the self-healing fly ash concrete and their physical and chemical properties were explained.

FLY ASH

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash, which does not rise, is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata.

Class F Flyash

Class F fly ash is available in the large quantities and is produced when either anthracite, bituminous with pozzolanic properties and Cao content < 5 percent is burned. It contains a greater combination of silica, alumina and iron (greater than 70 per cent) than class C fly ash. Fly ash (Class – F) was obtained from Mettur Thermal Power Plant (MTPP). For same reason, Class F is the solution to a wide range of summer concreting problems. It provides sulphide and sulphate resistance equal or superior to type C. Class F is often recommended for use where concrete may be exposed to sulphate ions in soil and ground water.

Figure.Fly ash

Table 1.Physical properties of fly ash

Properties	Values
Finesses modulus (passing through 45 micro meter)	7.86
Specific gravity	2.2

Table 2.Chemical Properties of fly ash

Chemical properties Min% by mass	**IS:3812-1981**	**Fly ash MTTP**
Sio2+Al2O3+Fe2O3	70	90.5
SiO2	35	58
CaO	5	3.6
SO3	2.75	1.8
Na2O	1.5	2
L.O.I	12	2
MgO	5	1.91

Advantages of Fly Ash

Fly ash use creates significant benefits for our environment. Fly ash use conserves natural resources and avoids landfill disposal of ash products. By making concrete more durable, life cycle costs of roads and structures are reduced. Furthermore, fly ash use partially displaces production of other concrete ingredients, resulting in significant energy savings and reductions in greenhouse gas emissions. The reuse of fly ash as an engineering material primarily stems from its pozzolanic nature, spherical shape, and relative uniformity.

Fly ash recycling can be done by including its usage in:

- Portland cement and grout
- Embankments and structural fill
- Waste stabilization and solidification
- Raw feed for cement clinkers

- Mine reclamation
- Stabilization of soft soils
- Road sub base
- Aggregate
- Mineral filler in asphaltic concrete
- Other applications include cellular concrete, geopolymers, roofing tiles, paints, metal castings, and filler in wood and plastic products.
- Low hydraulic conductivity
- Little expansion with hydration of the layer
- Resistant to the impact of freeze/thaw cycles
- Resistant to wet/dry cycles
- Reduced acidity, sulphate content and metal content of water flowing out from the site
- To reduce acid mine drainage (AMD)

Disadvantages

- Injected grout would dissolve with time
- Long-term stability and shrinkage of grout used as a capping layer is unknown
- Flexibility of the grout decreases with the addition of lime (lime is added to stabilize type F fly ash)

MICRO-ORGANISMS

Bacillus Megaterium, a commonly available soil bacterium is used.

Finding the Right Organisms

- Normally cement and water has pH value up to 12 when mixed together.
- Most organisms die in an environment with a pH value of 10 or above.
- Bacillus Megaterium can withstand pH value above 12

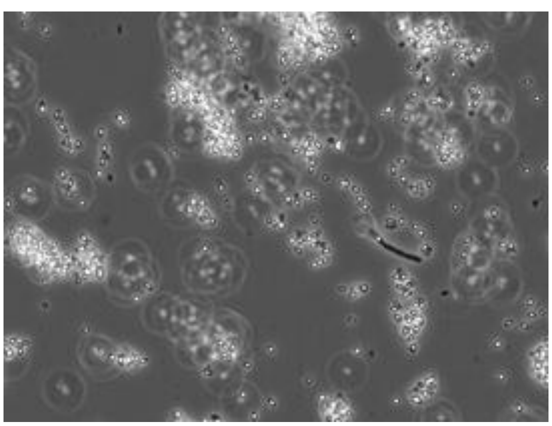


Figure Phase contrast Microphotograph

Location

- Bacillus Megaterium frequently lives in water, soil, air and decomposing plant residue.
- It also present at the root-soil interface.
- It can also grow without oxygen in the presence of nitrite.

CONCEPT OF BACTERIAL CONCRETE

The overall equilibrium reaction of calcite precipitation can be described below.

$$Ca2+ + Co32- \rightarrow CaCo3\downarrow \qquad \rightarrow \text{Eqn } 3.1$$

The solubility of CaCo3 is a function of pH and affected by ionic strength in the aqueous medium (Stumm and Morgan, 1981). In urea –Cacl2 medium that supports microbial growth, NH4+ and Cl- also reacts with OH- and H+ respectively, at different pH, further interfering with chemically-induced CaCo3 precipitation. Microbiologically-induced CaCo3precipitation occurs via far more complicated processes then chemically-induced precipitation. The bacterial cell surface with a variety of ions could non-specifically induce mineral deposition by providing a nucleation side. Especially, Ca2+ is not likely utilized by microbial metabolic processes, rather accumulates outside the cell. In medium, it is possible that individual microorganisms produce ammonia as a result of enzymatic urea hydrolysis to create an alkaline micro-environment around the cell.

The high pH of these localized areas without a significant increase in pH in the entire medium at the beginning apparently commences the growth of CaCo3 crystals around the cell.

Possible biochemical reaction in urea-CaCl2 medium to precipitate CaCo3 at the cell surface can be summarized as follows.

$$Ca2+ + cell \rightarrow Cell- Ca \rightarrow \text{Eqn } 3.2$$
$$Cl- + HCO3- + NH3 \rightarrow NH4Cl + Co32- \rightarrow \text{Eqn } 3.3$$
$$Cell – Ca2+ + Co32- \rightarrow Cell – CaCo3 \downarrow \rightarrow \text{Eqn } 3.4$$

In addition, the results of kinetic studies render an explanation that the rate of CaCo3 precipitation correlates with the cell growth and urease executes higher enzymatic activities and stronger affinity to urea at higher pH levels (pH 8-9) where calcite precipitation is favorable.

ROLE OF THE MICROBIAL UREASE IN CALCITE PRECIPITATION

The role of the microbial urease was defined from the data that the calcite precipitation B.Pasteurii and E.coli expressing B. Pasteurii urease was inhibited in the presence of a urease inhibitor and a significant amount of calcite precipitation was induced by E.coli, whereas little was induced by E.coli lacking urease genes. These observations support our assumption that the urease enzyme is a primary factor that initiates microbiologically-induced calcite precipitation. In detail, reaction 1 produces calcium carbonate and proteins in aqueous medium where Co32- primarily stays as HCO3-.

$$Ca^{2+} + HCO_3^- \rightarrow CaCo_3 + H^+ \rightarrow \text{Eqn 3.4}$$

In biological systems, many calcareous organisms couple classification to their metabolic assimilation processes to scavenge protons. In urease-based reactions, NH3 released by the enzymatic hydrolysis of urea uses the protons generated from the calcite precipitation to produce

$$NH_4^+. NH_3 + H^+ \rightarrow NH_4^+ \rightarrow \text{Eqn 3.5}$$

The subsequent increase of pH in surrounding medium due to the presence of ammonia ions and the additional release of Co2 from the enzymatic urea hydrolysis further accelerate the rate of the urease-induced calcite precipitation. Thus, an active participation of urease is of essence in biochemical calcite precipitation.

MIX DESIGN

Mix design is the process of selecting suitable ingredients of concrete and determines their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The first object is to achieve the stipulated minimum strength. The second object is to make the concrete in the most economical manner. Coat wise all concrete depends primarily on two factors, namely cost of materials and cost of labour. Labour cost by the way of formworks, batching, mixing, transporting and curing is nearly same for good concrete and bad concrete. Therefore attention is mainly on directed to the cost of the materials. Since the cost of cement is many times more than the cost of their ingredients, optimum usage of cement is sought out by designing the mix.

DESIGN OF CONCRETE MIX FOR M25 GRADE

STIPULATIONS FOR PROPORTIONING:-

a) Grade designation	: M25
b) Grade of cement	: OPC 53 grade
c) Maximum nominal size of coarse aggregate	: 20mm
d) Minimum cement content	: 250 Kg/m3
e) MaximumW/C ratio	: 0.50
f) Workability slump	: 75 mm
g) Exposure condition	: Severe
h) Method of placing	: Hand placed
i) Maximum cement content	: 450 Kg/m3

TEST DATA FOR MATERIALS:

Cement used	: OPC 53 grade
Fly ash	: Confirming IS3812
Specific gravity of cement	: 3.15
Specific gravity of water	: 1
Specific gravity of fine aggregate	: 2.6
Specific gravity of coarse aggregate	: 2.7
Specific gravity of fly ash	: 2.2

EXPERIMENTAL PROGRAMME

This paper presents the experimental investigation carried out on the test specimen to study the strength related properties of the concrete containing Bacillus Megaterium.

The experimental tests for the strength properties of concrete are compressive strength, split tensile strength and flexural strength of concrete. Based on the test procedure given in IS 516-1959 code tests were conducted on specimens. Also the self-healing capacity of concrete is analysed and SEM analysis is carried out to study the morphology.

SAMPLING OF MATERIALS

Representative samples of the materials of concrete for use in the particular concrete construction work shall be obtained by careful sampling. Test samples of cement shall be made up of small portion taken from each one of a number of bags on the site. Test samples of aggregate shall be taken from larger lots by quartering.

PREPARATION OF MATERIALS

All materials shall be brought to room temperature, preferably 270 – 300 C before commencing the tests. The cement samples, on arrival at the lab shall be thoroughly mixed dry either by hand or in suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material, care being taken to avoid the intrusion of foreign matter. The cement shall then be stored in a dry place, preferably in air tight containers. Samples of aggregates for each batch of concrete shall be of desired grading and shall be in air dried condition. In general the aggregate shall be separated into fine and coarse fractions and recombined for each concrete batch in such a manner as to produce desired grading. IS sieve 480 shall be normally used for separating the fine and coarse fractions but where special gratings are being investigated, both fine and coarse fractions shall be further separated into different sizes.

PROPORTIONING

The proportioning of the materials including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work. Where the proportions of the ingredients of the concrete as used on the site are to be specified by volume they shall be calculated from the proportions by weight used in the test cubes and the unit weights of the materials.

Table Mix proportion

Water	Cement + Fly Ash	Fine aggregate	Coarse aggregate
192 Liters	427 Kg	677 Kg	1100 Kg
0.45	1	1.58	2.57

Table of Mix Proportion for Bacterial solution

MIX	% FLY ASH	BACTERIAL SOLUTON	MIX PROPORTIONS
M1	0	5 ml/ litre	1:1.6:2.6:0.45
M2	10	5 ml/ litre	1:1.58:2.57:0.45
M3	20	5 ml/ litre	1:1.57:2.55:0.45
M4	30	5 ml/ litre	1:1.55:2.52:0.45
M5	40	5 ml/ litre	1:1.54:2.51:0.45

IV. RESULTS AND DISCUSSIONS

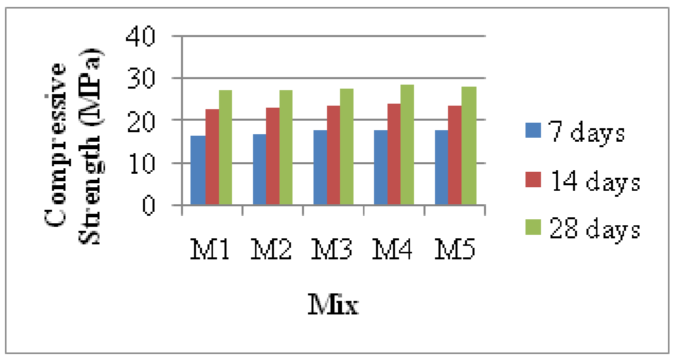
This chapter deals with the result and discussions of the experimental investigation carried out to study the mechanical properties of concrete. The basic strength properties namely compressive strength, split tensile strength and flexural strength were studied. Self-healing capacity of concrete as well as SEM analysis were also carried out.

COMPRESSIVE STRENGTH

The compressive strength results are shown in. The compressive strength was measured in terms of MPa. Fig shows the results of the compressive strength.

The compressive strength increases as the curing period increases. This improvement in compressive strength by Bacillus Megaterium is probably due to deposition ofCaCO3 on the microorganism cell surfaces and within the pores, which plug the pores within the binder matrix. The curing media also contributes to the increase in strength.

MIX	FLY ASH BY % OF CEMENT	AVERAGE COMPRESSIVE STRENGTH MPa		
		7 days	14 days	28 days
M1	0	16.75	23.00	27.20
M2	10	17.20	23.50	27.62
M3	20	18.00	23.87	28.05
M4	30	18.12	24.05	28.65
M5	40	18.05	23.90	28.40

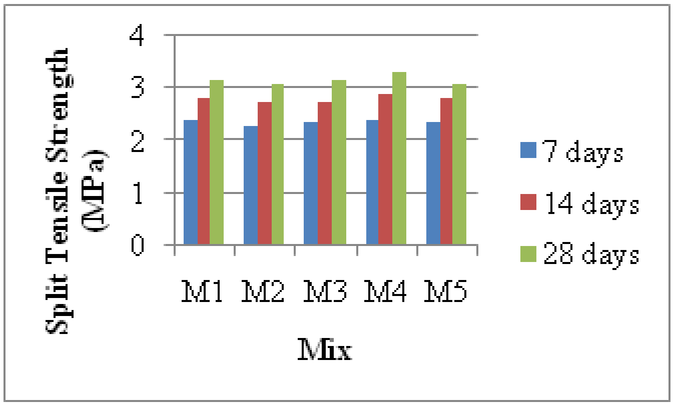


SPLIT TENSILE STRENGTH

The Split tensile strength results are shown in. The split tensile strength was measured interms of MPa. Fig shows the results of the split tensile strength.

The tensile strength of the specimens is seen to increase with age. At early ages of curing the tensile strength decreases with increase in fly ash content in concrete. However the rate of decrease diminished with increasing age of curing.

MIX	FLY ASH BY % OF CEMENT	AVERAGE SPLIT TENSILE STRENGTH MPa		
		7 days	14 days	28 days
M1	0	2.40	2.82	3.15
M2	10	2.30	2.75	3.10
M3	20	2.35	2.75	3.15
M4	30	2.40	2.90	3.30
M5	40	2.35	2.80	3.10

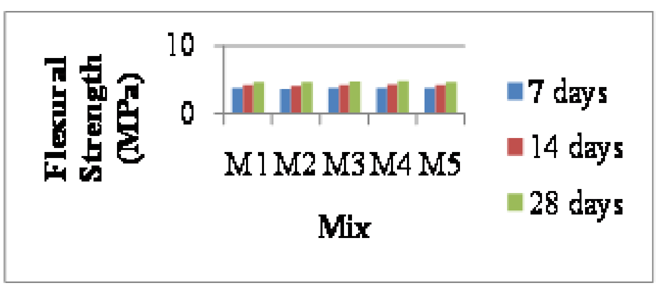


FLEXURAL STRENGTH

The Flexural strength results are shown in. The Flexural strength was measured interms of MPa. Fig shows the results of the Flexural strength.

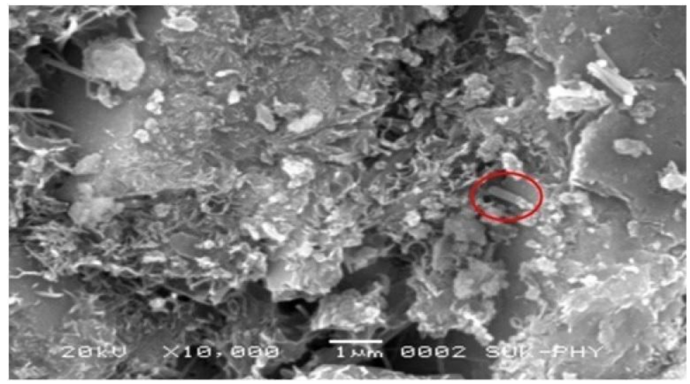
The flexural strength of the specimens is seen to increase with age. At early ages of curing the flexural strength decreases with increase in fly ash content in concrete. However the rate of decrease diminished with increasing age of curing.

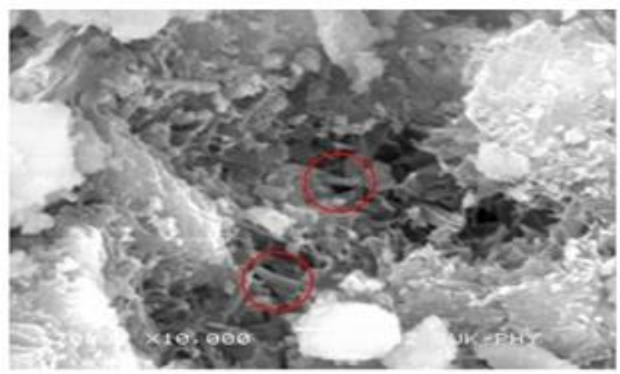
MIX	FLY ASH BY % OF CEMENT	AVERAGE FLEXURAL STRENGTH MPa		
		7 days	14 days	28 days
M1	0	3.80	4.27	4.71
M2	10	3.65	4.20	4.70
M3	20	3.75	4.28	4.78
M4	30	3.82	4.35	4.82
M5	40	3.75	4.28	4.75

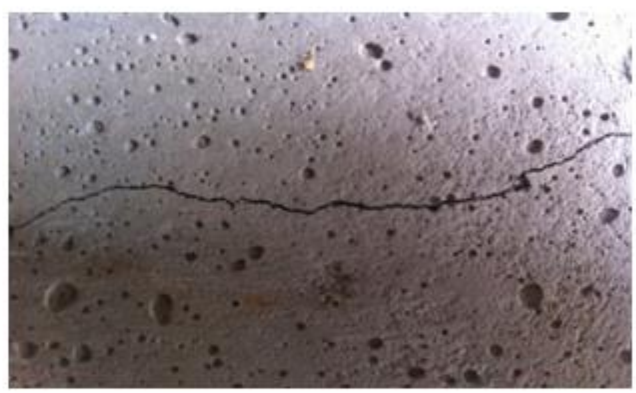


SCANNING ELECTRON MICROSCOPY

Calcite precipitation in concrete was carried out by SEM analysis. Many calcite crystal faces show hollow, rod-like impressions of Bacillus Megaterium, 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 6.5 shows the SEM picture of normal concrete, where in, pores can be easily seen inside it. Fig 6.6 and Fig 6.7 shows the presence of crystalline calcium carbonate associated with bacteria. The SEM analysis of concrete with Bacillus Megaterium has revealed distinct calcite crystals embedded in concrete. High calcium amounts in it confirmed thatcalcite was present in the form of calcium carbonate due to bacteria. The deposition ofcalcite serves as barrier to harmful substances and thus improves impermeability.







V. CONCLUSION

- Addition of fly ash leads to an increase in compressive strength, split tensile strength and flexural strength.
- Incorporating bacteria heals the micro cracks within and at the surface of concrete by CaCo3 precipitation.

- Maximum compressive stress, Split tensile and Flexural strength develop in M-25 grade self-healing concrete by adding 30% fly ash.
- Addition of fly ash increases compressive strength by about 6%, the split tensile strength by about 4.7%, the flexural strength by about 2.5%.
- Use of fly ash reduces the amount of cement content as well as heat of hydration in the concrete mix. Thus, the construction work with fly ash concrete becomes environmentally safe and also economical.
- SEM analysis confirms the mechanism of microbial calcite precipitation in concrete due to presence of Bacillus Megaterium.
- The analysis of self-healing capacity proves to show that 90 % of the crack is arrested.

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