Influence of Bacteria in Self – Healing 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 ashby weight. A cell concentration of 10^5 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 thebacteria cell surfaces within the pores. The present work highlights the influence ofbacteria 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

Keywords: Bacillus Megaterium, fly ash, self-healing,compressive strength, split tensile strength, flexural strength

I. 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 whichconcrete 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 aestheticsof 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 serves 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 in turn depends onthe 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 sulphates affect the material and seriously reduce their strength and life. An additive that seals the pores and cracks and thus reducing 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 alsoemanate toxic gases. 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 crackwidths. For structural reasons this extra steel has no meaning. A reliable self-healing method for concretewould lead to a new way of designing durable concrete structures, which is beneficial for national and global economy. The “Bacterial Concrete” can be made byembedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced Calcite precipitation.

Calcium carbonate precipitation, a widespread phenomenon among bacteria, has been investigated due to its wide range of scientific and technological implications. Calcite formation by Bacillus Megaterium is a model laboratory bacterium, which can produce calcite precipitates on suitable media supplemented with a calcium source. A common soil bacterium, Bacillus Megaterium was used to induce CaCo3 precipitation. The basic principles for this application are that the microbial urease hydrolyzes urea to produce ammonia and carbon di oxide and ammonia released in the surroundings subsequently increases pH, leading to accumulation of insoluble CaCo3. The favorable conditions do not directly exist in a concrete but haveto be created. A main part of the research will focus on this topic. How can the right conditions are created for the bacteria not only to survive in the concrete, but also to feel happy and produce as muchcalcite as needed to repair cracks. Furthermore the bacteria should be suspended in a certain concentration, in a certain medium before they are mixed through the concrete ingredients. Optimizationis needed here, which involves experimental testing.

II. LITERATURE REVIEW

Achal.V,et.al (2012)

Studied the results of compressive strengthof 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 10^5 cells/ml of microorganism. This improvement in compressive strength is due to deposition 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.

Sunil PratapReddy.S, et.al (2010)

studied the performance of the concrete by the microbiologically induced special growth/filler using the bacteria “Bacillus subtilis strain No.JC3” which is induced in the mortars and concrete to heal up the faults. Cement mortar cubes with four different cell concentrations were cast and control specimen were also cast and tested for compression. This study showed a significant increase in the compressive strength due to the addition of bacteria for a cell concentration of 10^5 cells per ml of mixingwater. From Scanning Electron Microscopy analysis,it is noted that pores were partially filled up by material growth with the addition of the bacteria. Reduction in pore percentage due to such material growth will obviously increase the material densityand strength. Concrete cubes with and without addition of bacteria were tested and it is observed that there is an improvement in the compressive strength for the cubes with the addition of bacteria. It is observed that there is an improvement in the Split tensile strength for the cylinders with the addition of bacteria. From the durability studies, the percentage weight loss and percentage strength loss with 5% H_2SO_4 revealed that Bacterial concrete was more durable.

SrinivasaReddy.V, et.al (2013)

conducted an experimental study on effect of calcifying bacteria on permeation properties (such as absorptivity and sorptivity) of bacterial concrete. The rate of water absorption, water absorption capacity, sorptivity and porosity tests were then performed on the samples of concrete treated with bacteria of ordinary (M20), standard (M40) and high strength (M60 and M80) grades, to assess the enhancement of permeation properties due to bio mineralization in bacterial concrete. The results showthat, absorptivity, sorptivity and porosity of bacterial concrete are much lower than the corresponding characteristics of controlled concrete. These characteristics are noticeably enhanced by the addition of bacillus subtilis JC3 to the concrete. It is also indicated from the chemical analysis that the cement-phase composition of bacterial concrete has significant amount of calcium precipitate compound.

Henk M. Jonkers,et.al (2011)

Developed a two-component self- healing system which is composed of bacteria which catalyse the metabolic conversion of organic compounds (the second component) to calcite. Both components are mixed with the fresh cement paste, thus becoming an integral part of the concrete. Experimental results show that ingress water channelled through freshly formed cracks activates present bacteria which through metabolic conversion of organic mineral-precursor compounds produce copious amounts of calcite. This new bio-based two- component system may represent a new class of self-healing mechanisms which can be applied to cement- based systems. The self-healing capacity of this system is currently being quantified what should result in an estimate of the materials durability increase. A self-healing concrete may be beneficial for both economic and environmental reasons.

VirginieWiktor, et.al(2011)

Studied the crack-healing potential of a specific and novel two-component bio-chemical self- healing agent embedded in porous expanded clay particles, which act as reservoir particles and replace part of regular concrete aggregates. Upon crack formation the two-component biochemical agent consisting of bacterial spores and calcium lactate arereleased from the particle by crack ingress water. Subsequent bacterially mediated calcium carbonate formation results in physical closure of micro cracks. Experimental results showed crack-healing of up to 0.46 mm-wide cracks in bacterial concrete but only up to 0.18 mm-wide cracks in control specimens after 100 days submersion in water. That the observed doubling of crack-healing potential was indeed due tometabolic activity of bacteria was supported by oxygen profile measurements which revealed O_2 consumption by bacteria-based but not by control specimens.

Gerard Muyzer, et.al (2008)

Investigated the potential of bacteria to act as self-healing agent in concrete, i.e. their ability to repair occurring cracks. A specific group of alkali- resistant spore-forming bacteria related to the genus Bacillus was selected for this purpose. Bacterial spores directly added to the cement paste mixture remained viable for a period up to 4 months. A continuous decrease in pore size diameter during cement stone setting probably limited life span of spores as pore widths decreased below 1m, the typical size of Bacillus spores. However, as bacterial cement stone specimens appeared to produce substantially more crack-plugging minerals than control specimens, the potential application of bacterial spores as self-healing agent appears promising.

Willem De Muynck, et.al (2007)

proposed bacterial induced carbonate mineralization as a novel and environmental friendly strategy for the protection of stone and mortar. This paper reports the effects of bacterial $CaCO_3$ precipitation on parameters affecting the durability ofconcrete and mortar. Pure and mixed cultures of ureolytic bacteria were compared for their effectiveness in relation to conventional surface treatments. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas. This bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surfaces. The type of bacterial culture and medium composition had a profound impact on $CaCO_3$ crystal morphology. The use of pure cultures resulted in a more pronounced decrease in uptake of water, respectively less pronounced change in the chromatic aspect, compared to the use of mixed ureolyticcultures as a paste. The results obtained with cultures of the species Bacillus sphaericus were comparable to the ones obtained with conventional water repellents.

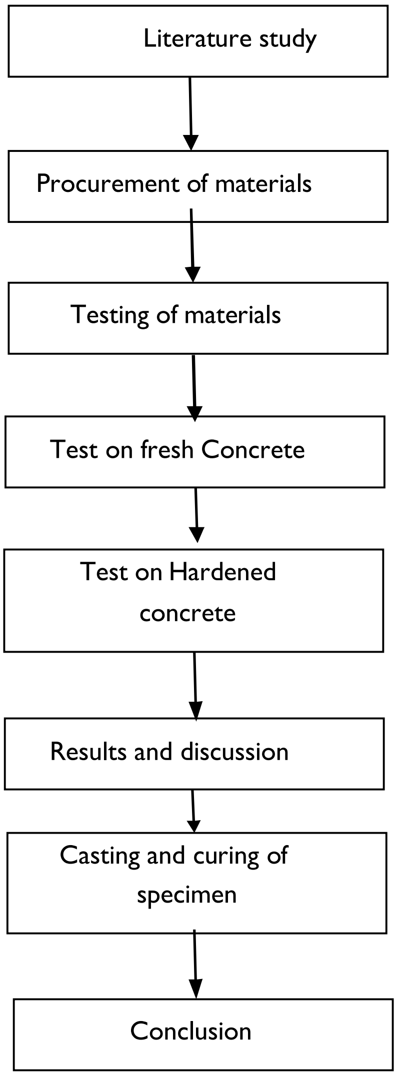
Kim.H.K, et al (2012)

investigated the characteristics of microbiological precipitation of calcium carbonate on normal and lightweight concrete by two types of bacteria, Sporosarcinapasteurii and Bacillus sphaericus.Concrete specimens were treated by pure water, a cell-free medium, and medium with cells; and a macrographic study of the distribution of calcium carbonate precipitation on the concrete specimens was carried out using a conventional digital camera to investigate the effects of the addition of bacteria. As a micrographic study, scanning electron microscope (SEM) images and energy dispersive spectroscopy (EDS) spectra were used to observe the shapes and distributions of the calcium carbonate crystals at a microscale level. The X-ray diffraction (XRD) analysis was carried out to characterize the crystalline phases of the calcium carbonate crystals formed in liquid medium with and without cells. In addition, a capillary water absorption test of the concrete specimens was conducted to evaluate the effects of microbiological precipitation of calcium carbonate on the properties of moisture transport, which may affect the durabilityof the concrete. It was found that Bacillus sphaericus precipitated denser calcium carbonate crystals than Sporosarcinapasteurii.

III. MATERIAL AND METHODS:

CEMENT

Cement is the most important ingredient in concrete. Some of the important factor that play a vital role in selection of cement are compressive strength at various ages, fineness, heat of hydration, alkali content, tri calcium aluminate (C_3A) content, tri calcium silicate (C_3S) content, di calcium silicate (C_2S) content, etc. It is also necessary to ensure compatibility of the chemical and mineral admixtures with cement. Ordinary Portland Cement (OPC) is now available in three grades namely 33, 43 and 53 grades. The number indicating the compressive strength of standard cement sand mortar cubes in MPa after 28days of curing. For the present investigation, OPC 53 grade confirming to IS 12269- 1987 was selected. It was dry, powdery and free of lumps. While storing cement, avoid all possible contact with moisture. Store the cement away from exterior walls, off damp floors and stacked close together to reduce air circulation.



Properties	Values
Fineness of Cement	7.5%
Specific gravity	3.15
Grade of Cement	53

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 knownas 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 calciumoxide (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).

Physical Properties of Fly ash

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

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

Chemical Properties of Fly ash

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 foruse where concrete may be exposed to sulphate ions in soil and ground water.

FINE AGGREGATE

Fine aggregate used for cement mortar usedbe properly graded to give minimum void ratio and be free from deleterious material like clay, silt content and chloride contamination, etc. Grading of fine aggregate should be such that it does not cause increase in water demand for the concrete and shouldgive voids so that the fine cementitious particles fill the voids.

Physical Properties of River Sand

Hence it is desirable to use coarser variety of fine aggregate having a high fineness modulus for making workable and strong concrete. The optimum gradation of fine aggregate is determined more by its effects on water requirements that on physical packing, ACI committee reports that sand with fineness modulus below 2.5 gives a sticky consistency, making it difficult to compact and sand with fineness modulus of about 3 gives the best workability and compressive strength. Properties such as void ratio, gradation and density have to be accessed to design a dense mix with optimum cement content and reduced mixing water for the present investigation, locally available sand confirming to IS:383-1970 was used.

COARSE AGGREGATE

Coarse aggregate is the strongest and the least porous component in concrete. It is also chemically stable material. Presence of coarse aggregate reduces drying shrinkage and other dimensional changes occurring on account of movement of moisture. Coarse aggregate contributes to impermeability concrete provided that graded and the mix is suitably designed. Ordinary blue granite crushed stone aggregate confirming to IS: 383-19970 was used as a coarse aggregate in concrete. Optimum size of the coarse aggregate in most situations about 20mm was adopted. They generally possess all the essential qualities of a good building stone showing very high crushing strength, low absorption value and least porosity. Various tests were carried out as per IS: 2386-1968 Part III.

- Specific gravity
- Sieve analysis
- Fineness modulus

Figure : Coarse Aggregate

Physical Properties of Coarse Aggregate

Proportion	Value
Specific gravity	2.7
Finesses modulus	7.00

Properties	Values
Specific Gravity	2.6
Fineness Modulus	2.25

WATER

Water is an important ingredient of concrete as it actively participates in chemical reactions with cement to form the hydration products, calcium- silicate-hydrate (C-S-H) gel. The strength of the cement concrete depends mainly from the binding action of the hydrate cement paste gel. A higher water binder ratio will decrease the strength, durability, water tightness and other related properties of concrete. The water used for making concrete should be from desirable salts that may react with cement. Silts and suspended particles are undesirable as they interfere with setting, hardening and bond characteristics. Algae in mixing water may cause marked reduction in strength of concrete either by combining with cement to reduce the bond or by causing large amount of air entrainment in concrete. Water confirming to the requirements of IS:456-2000, is found to be suitable for making concrete. It is generally stated that the water fit for drinking is fit for making concrete. In this present study, casting and curing of specimens were done with the portable water, i.e., available in the collegepremises.

Figure Potable Water

MICRO-ORGANISMS

Bacillus Megaterium, a commonly availablesoil 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 environmentwith a pH value of 10 or above.
- ❖ Bacillus Megaterium can withstand pHvalue above 12.

Biochemical characteristics of the pure cultureBacillus Megaterium

Characteristics	Bacillus Megaterium
Shape, size, gram strain	Long rods, 0.6-0.8 m in width and length,gram positive
Colony morphology (On nutrient agar plates)	Irregular, dry, white
Fermentation:	
Lactose	No acid, no gas
Dextrose	No acid, no gas
Sucrose	Acid and gas
H2S production	-
Nitrate reduction	-
Indole production	-
Methyl red test	-
Vogesproskauer test	-
Citrate utilization	-
Catalase activity	+
Gelatin liquefaction	+

Note: "+" :- Present "-":- Absent

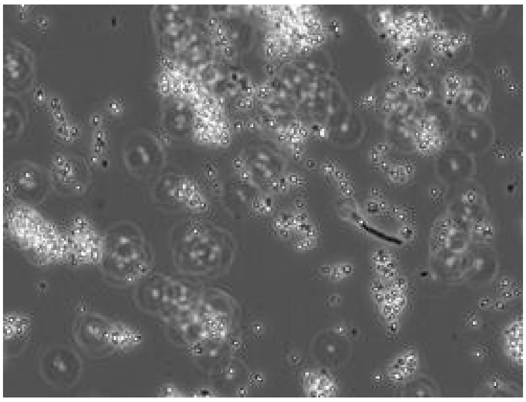


Fig Phase contrast Microphotograph

2. MIX DESIGN:

STIPULATIONS FOR PROPORTIONING:-

a) Grade designation : M25
b) Grade of cement : OPC 53 grade
c) Max. nominal size of c. agg :20mm
d) Minimum cement content : 250 Kg/m^3
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/m^3

TEST DATA FOR MATERIALS:

a) Cement used : OPC 53 grade
b) Fly ash : Confirming to IS3812
c) Specific gravity of cement : 3.15
d) Specific gravity of water 1
e) Specific gravity of fine aggregate: 2.6
f) Specific gravity of coarse aggregate: 2.7
g) Specific gravity of fly ash : 2.2

3) Selection of water content:-

From Table 2 of IS 10262:2009,
Maximum water content for 20mmaggregate = 186litres,

Estimated water content for 75mm slump(186+186X3%) = 192 litres,
Increase by 3% for every additional 25mm(clause 4.2 of IS 10262)

4) Calculation of cement and fly ash content:-

W/C ratio = 0.45
Cementitious material content = (192/0.45) 3
= 427 Kg/m
From Table 5 of IS 456, Minimum cement content for 'Severe' 3
Exposed condition = 250 Kg/m 3 3
427 Kg/m >250Kg/m
Hence OK.
Fly ash at 10% of total cementitiousmaterial content = 427 X 10%

STEPS FOR DESIGN PROCEDURE:-

1) Determination of Target Mean Strength:-

f'ck=fck + 1.65s
Where, Cement (OPC)
= 427 - 42.7
= 384.3 Kg/m^3
fck= Characteristic compressive strength at 28 dayStandard deviation, S= 5
f'ck = 25 + 1.65(4)2
= 31.6 N/mm

2) Selection of water - cement ratio:-

From Table 5 of IS 456:2000
Max water - cement ratio = 0.50 Adopted water - cement ratio = 0.450.45< 0.50, Hence OK.
Saving of cement using fly ash
= 43 Kg/m^3
Fly ash being utilised
= 42.7 Kg/m^3

5) Proportion of volume of coarse aggregate andfine aggregate content:-

From table 3, IS 10262:2009, Volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate(zone I) for W/C ratioof 0.5 = 0.60
In the present case W/C ratio is 0.45.
Therefore, volume of coarse aggregate is required tobe increased to decrease the fine aggregate content. As the water cement is lower by 0.05 the proportionof volume of coarse aggregate is increased by 0.01
Volume of Coarse aggregate for the W/Cratio of 0.45 = 0.61
Volume of fine aggregate = 1-0.61 = 0.39

6) Mix calculation:-

a) Volume of Concrete = 1m
b) Volume of Cement
Mass of cement x (1/1000)(Specific Gravity of Cement)
= (384.3/3.15) x (1/1000)
= 0.122m
c) Volume of fly ash
Mass of fly ash x (1/1000)(Specific Gravity of fly ash)
= (42.7/2.2) x (1/1000)
= 0.019 m^3
d) Volume of Water
(Mass of water) x (1/1000)(Specific Gravity of water)
= (192/1) x (1/1000)
= 0.192 m
e) Volume of all in aggregates
[a-(b + c + d)]
= [1-(0.122+ 0.192 + 0.019)]
= 0.667m
e) Mass of coarse aggregate
e x volume of coarse aggregate x Specificgravity of coarse aggregate x 1000
= 0.667 x 0.61 x 2.7 x 1000
= 1100Kg
f) Mass of fine aggregate
d x volume of fine aggregate x Specificgravity of coarse aggregate x 1000
= 0.667 x 0.39 x 2.6 x 1000
= 677Kg

Required materials for 1m concrete:-
CEMENT = 427 Kg/m
WATER = 192 litres
FINE AGGREGATE = 677Kg/m
COARSE AGGREGATE = 1100Kg/m
W/C ratio = 0.45

Table 4.1 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

Quantity of Bacteria

As per the past research by the Delft University, 5ml of bacteria solution is adequate for per Liter of water for their efficient growth.

MIX PROPORTIONS

The identification, mix proportion and quantity of material taken for one meter cube of fly ash concrete mixes are given in Table 4.2.The mixM1 is the control mix and mixes M2,M3,M4 andM5 were obtained by replacing fly ash with10%, 20% and 30% of weight of cement respectively.

Table 4.2 Mix Proportions for Different Mixes

MIX	% FLYASH	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

Table 4.3 Mix Proportions Per m^3

MIX	CEM ENT Kg)	FLYASH Kg)	FINEAGGREGATE (Kg)	COARSE AGGREGATE (Kg)	WATER (lit)
M1	427	0	683	1109	192
M2	384.3	42.7	677	1100	192
M3	341	86	671	1089	192
M4	298.9	128.1	664	1079	192
M5	256.2	170.8	659	1071	192

IV.EXPERIMENTAL TESTS

TESTS ON FRESH CONCRETE

SLUMP TEST

The slump test was performed as per IS 1199 -1959. The slump test is the most well-known and widely used test to characterize the workability of fresh concrete. The inexpensive test, which measures consistency, is used on job sites to determine rapidly whether a concrete batch should beaccepted or rejected.

The slump test result is a measure of the behavior of a compacted inverted cone of concreteunder the action of gravity. It measures the consistency or the wetness of concrete.

The apparatus for conducting the slump test consists of a metallic mould in the form of a cone having the following dimensions.

Bottom diameter : 20 cm
Top diameter : 10 cm
Height : 30cm

The procedure of slump cone test is as follows

- The test is carried out using a mould known as a slump cone
- The cone is placed on a hardnon-absorbent surface.
- This cone is filled with freshconcrete in three stages, eachtime it is tamped using a rod of standard dimensions.
- At the end of the third stage, concrete is struck off flush tothe top of the mould.
- The mould is carefully liftedvertically upwards, so as notto disturb the concrete cone.
- Concrete subsides. This subsidence is termed as slumpand is measured in terms of mm.

Fig Slump Cone

TESTS ON HARDENED CONCRETE

Testing of hardened concrete plays an important role in controlling and conforming the quality of cement concrete work. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable part of any quality control program for concrete, which helps to achieve higher efficiency of the material used and greater assurance one will not come to know, the actual strength of concrete for some time. This is an inherent disadvantage in conventional test. But, if strength of concrete is to be known at an early period, accelerated strength test can be carried out to predict 28 days strength. Tests are made by casting cubes, cylinders, prisms.

COMPRESSIVE STRENGTH TEST

Compression test is the most common test conducted on hardened concrete, partly because it is easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. Thecompression test is carried out on specimens cubicalor cylindrical in shape. The cube specimen is of the size 150 x 150 x 150mm. Due to compression load, the cube or cylinder undergoes lateral expansion owing to poisons ratio effect.

Test procedure

Fig Testing of Cubes in CTM

The cube-compressive test was conducted in compression testing machine as shown in Fig.3.6. The load was applied as per IS 516-1964. Concrete specimen of 150 x 150 x 150 mm cubes were cast with different proportion of concrete. After 24 hours the specimen aredemoulded and subjected to curing for 28 days in ordinary tap water. After 28 days of curing, the cubes are then allowed to become dry for some hours .For each proportions triplicate specimen were cast .The cubes are tested in compressive – testing machine. The load was applied at the rate of 140 kN/min. The ultimate loads at which the cube fails were taken. The performance of concrete with regard to strength. The test methods should be simple, direct and convenient to apply. One of the purposes of testing hardened concrete is to confirm that the concrete used at site has developed the required strength. As the hardening of the concrete takes time,

4.2.2. SPLIT TENSILE STRENGTH TEST

It is a method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. It is expressed as the minimum tensile stress (force per unit area) needed to split the material apart. A cylindrical specimen of size 150x300 mm is used. The specimen if loaded until failure occurs and failure load is noted. The main advantage of this method is that the same type of specimen and the same testing machine as are used for the compression test can be employed for the test. The splitting test is simple to perform and gives more uniform results than other tension tests. Strength determined in the splitting test is believed to be closer to the true tensile strength of concrete, than themodulus of rupture. Splitting strength gives about 5 - 12% higher value than the direct tensile strength.

Test procedure

The split tension test is a method of determining the tensile strength of concrete. The testis carried out according to IS: 516-1970.The experiment consists of casting and testing of cylinder, 150mm diameter and 300mm height. Specimens were cured for 28 days under water prior to testing. Compression testing machine having 2000kN is used for loading. Load at a constant stoke rate, is applied through two hardwood strips of 25mm wide, 3mm thick and 300mm long. The load was applied until the cylinder splits across the diametric plane connecting the loading strips. Thefailure of Cylinder Specimen is shown in Figure 3.6

2*P*P= Compressive Load inkNL=Length in m D=Diameter in mm

5.2.3FLEXURAL STRENGTH TEST

A beam specimen is casted to test the flexural strength of the concrete. The standard specimen size is 100x100x500 mm. A UTM machineis used for the testing of these specimens. The testingmachine shall be set to any reliable type of sufficient capacity for the test. Permissible errors should not begreater than ±0.5%. The bed of the machine should be provided with two steel rollers, of 38 mm diameter, on which the specimen is supported. The test specimen should be casted and cured for 28 daysand tested for maximum load.

Test procedure

The flexural strength of concrete prism wasdetermined based on IS: 516 –1959.Beam specimensof size 100x100x500 mm were casted and placed in UTM and tested for flexural strength. The specimensare placed on two point loading setup and rollers above the specimens. Place the specimen in the machine in such a manner that the load is applied to the upper most surface as cast in the mould along two lines spaced 13.3cm a part. Apply load without shock and increase continuously at a rate of 180 kg/min andit is increased until the sample fails. Measure the distance between the line of fracture and nearest support. Testing of Prism for Flexural strength is shown in Fig.3.7

If a > 13.3cm,then

P x l

sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selectedarea of the surface of the sample, and a 2- dimensional image is generated that displays spatial variations in these properties. Areas ranging from approximately 1 cm to 5 microns in width can be

imaged in a scanning mode using conventional SEM

techniques (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50 to

If a < 13.3 $fb = \frac{}{b \times d^2}$

If a < 11, Discard the specimen

P = Maximum load applied to thespecimen in kN.

L= Supported Length in mm.

d = Depth of the specimen mm, and

a = Distance of the crack from the nearest

100 nm). The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions (using EDS), crystalline structure, andcrystal orientations (using EBSD).

support


Fig 5.7 Testing of Prism for Flexural Strength inUTM

4.2.4. SCANNING ELECTRON MICROSCOPY

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solidspecimens.

V.TEST RESULTS

5.1.SLUMP CONE TEST

Table 6.1 Slump Cone Result

MIX	FLY ASH CONTENT	SLUMP (mm)
M1	0%	75
M2	10%	82
M3	20%	85
M4	30%	90
M5	40%	90

5.2. COMPRESSIVE STRENGTH

Table 6.2 Compressive Strength Test Result

MIX	FLY ASHBY % OFCEMENT	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

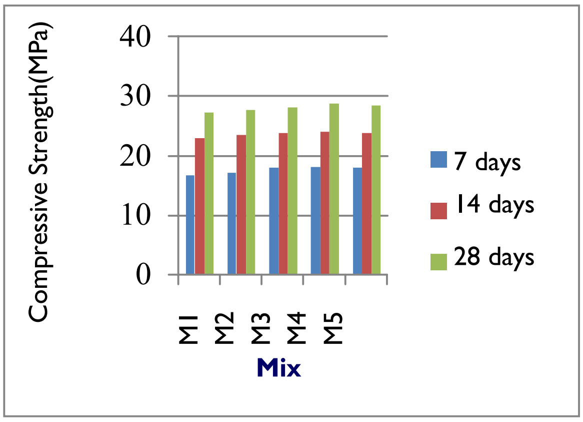


Fig 6.2 Compressive Strength Results

SPLIT TENSILE STRENGTH

Table 6.3Split Tensile Strength Test Result

MIX	FLY ASHBY % OFCEMENT	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

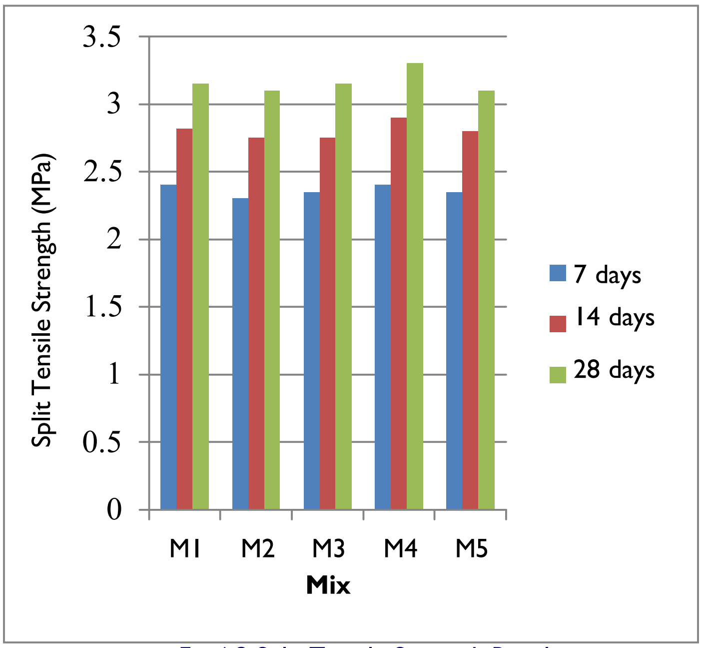


Fig 6.3 Split Tensile Strength Results

The tensile strength of the specimens is seento 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.

FLEXURAL STRENGTH

Table 6.4 Flexural Strength Test Result

MIX	FLY ASHBY % OFCEMENT	AVERAGE FLEXURALSTRENGTH 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

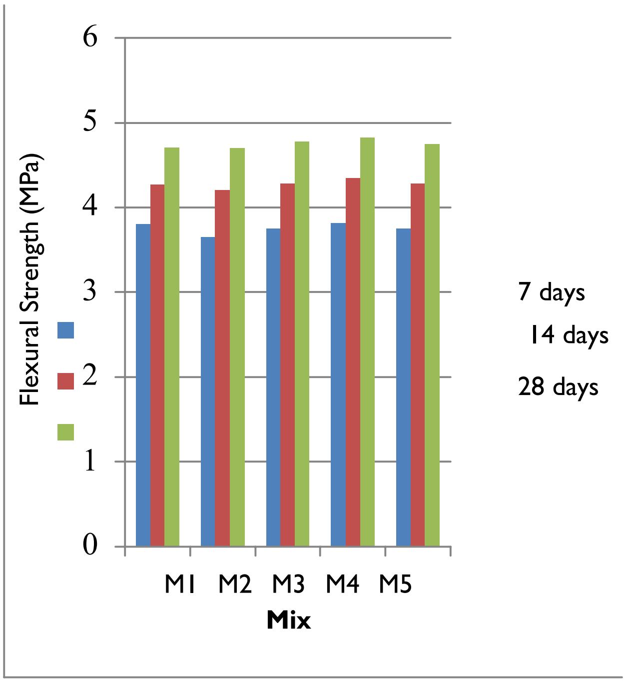


Fig 6.4 Flexural Strength Results

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

VI. 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 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.

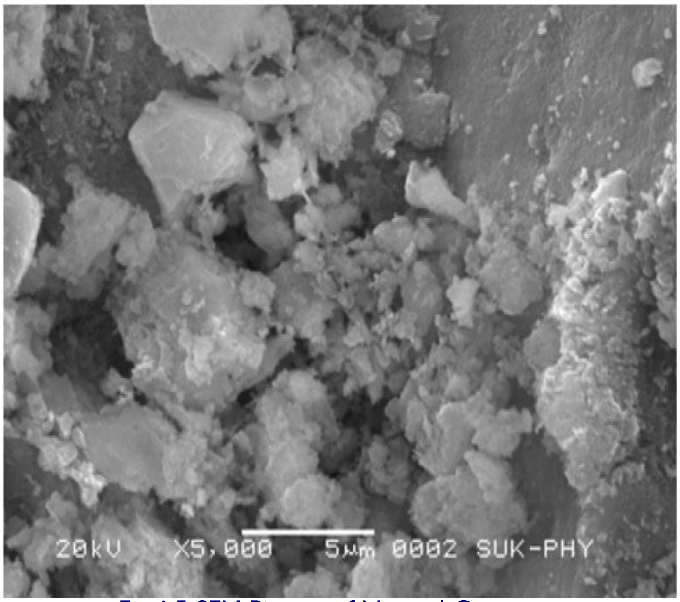


Fig 6.5 SEM Picture of Normal Concrete

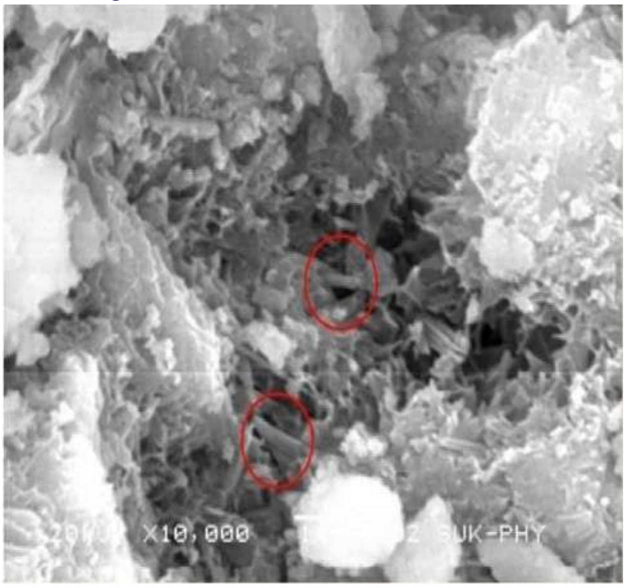


Fig 6.7 SEM Picture of Fly Ash Concrete ShowingBacterial Induced Calcite Deposition in Micro Cracks

6.1. SELF-HEALING CAPACITY

Self-healing capacity of the concrete is analysed using sample with cracks due to manual external loading. It is then cured for about 28 days. After the curing period about 90% of the crack is arrested due to the deposition of calcite crystals owing to the presence of Bacillus Megaterium.

VII. CONCLUSION

As per the guidelines given in IS 10262:2009 the mix design for M25 grade concretewas designed and bacteria was added.

- 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 gradeself-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 strengthby 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.
- Durability properties like porosity, water absorption and sorptivity to know the effect of addingfly ash can be carried out.
- This study could also be conducted for othertypes of concrete.
- Performance of the bacterial concrete in pavements where the prevalence of cracks will be more can be investigated

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