Experimental Study on Strength Characteristics of Self –Healing Concrete with Fly Ash

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***Abstract*— Presence of micro cracks leads to deterioration of concrete and entrance of unwanted substances into concrete. Micro cracks also lead to the corrosion of structures eventually and the structure needs rehabilitation. Due to side effects of chemical techniques biological rehabilitation techniques have been adopted as environmental friendly methods. Certain microorganisms have been identified with the ability to deposit calcium carbonate. Bacillus subtilis bacteria present in soil is adopted for the present study due to its availability and resistance against varying pH conditions. Fly Ash is an industrial by product which is harmful for environment and need to be recycled. Studies have proved the characteristics of Fly Ash in improving the characteristics of concrete. This aim of the present study is to find the effect of bacterial concrete with Fly Ash on strength characteristics of concrete. The effect of bacteria and fly ash on the mechanical characteristics of concrete and its effect in reinforced concrete members are studied.**

Keywords*— Rehabilitation, Microorganisms, Bacillus Subtilis, Fly Ash, Mechanical Properties

I. INTRODUCTION

Concrete is one of the major construction material, and the major problem associated with concrete is that it can't take tension. Tiny cracks formed on the face of the concrete make the whole structure liable to corrosion of the steel reinforcement, thus decreasing the life span of the structure. Arresting these micro cracks helps to increase the durability of the overall structure. Due to the side effects of various chemical methods for mending the micro cracks researches have been conducted on establishing ecofriendly maintenance techniques. A technique was proposed by filling the fissures in concrete by micro biologically inducing calcite precipitation called self - healing concrete.

Self-Healing concrete is new to construction industry which aims at making the concrete structure crack free and durable. The main principle of self healing concrete is to employ calcium carbonate precipitating bacteria to heal the cracks. By adding the bacteria in concrete which produce calcium carbonate which in turn fills the pores in the concrete. The choice of the bacteria is depending on the survivability of bacteria in the alkaline environment. Most of the microorganisms perish in an environment with pH more than 10. The strains of the bacteria of species Bacillus is found to live in alkaline environment. The bacteria resist the alkaline environment by forming spores of very thick wall and they are activated when concrete start cracking and water enters into the cracks in the structure.

In concrete structures, the micro cracks up to 0.2 mm wide are healed automatically due to hydration reaction of un-reacted cement particles present in the concrete coming in contact with water. The self-healing process based on bacteria has been observed to fill cracks effectively up to 0.5 mm width. For the control concrete, $CaCO_3$ will be produced due to the reaction between CO_2 present in atmosphere with $Ca(OH0_2$ present in the concrete by to the following equation:

$$CO2 + Ca(OH)_2 \rightarrow CaCO3 + H2O$$

The Calcium Carbonate formation in this case is interrupted due to the low amount of CO_2 present. As $Ca(OH)_2$ is a soluble mineral, it gets dissolved in water and diffuse out of the crack in the form of leaching. The self-healing process by bacteria blended concrete is much more efficient due to the continuous metabolic transformation of Calcium nutrients by the bacteria present in concrete:

$$Ca(C3H5O2)2 + 7O2 \rightarrow CaCO3 + 5CO2 + 5H2O$$

Here $CaCO_3$ is formed due to microbial reaction and also indirectly due to automatic healing of concrete. This process terminates in efficient crack sealing mechanism which is bacteria based. Ureolytic bacteria, Bacillus Subtilis, can precipitate $CaCO_3$ in the alkaline environment by transforming urea to Ammonium and Carbonate. The degradation of urea increases the pH of concrete and induce the microbial precipitation of carbonate as calcite particles in a environment rich in calcium, sealing the crack and balances the pH of concrete as earlier.

In a study laboratory investigations were conducted to analyze the different features of bacterial concrete with ordinary concrete and concrete with cement was partially replaced with Fly ash and GGBS [1]. The test results show a significant improvement in strength. The strengths test results obtained from different concrete mixes indicates that it is a viable and durable material. It can be adopted as a suitable replacement for ordinary Portland cement. An undertaking is made in Bacterial concrete with non-pathogenic, spore forming, calcite forming bacterium Bacillus subtilis [3]. M20 grade concrete is prepared with different bacterial cell concentration of 10^4, 10^5 and 10^6 cells per milliliter of water and polyethylene fibre kept at constant as 0.4 %.The overall properties of self-healing concrete using Bacillus bacteria and polyethylene fibre along with durability has been observed and compared with control concrete.

It was found that bacillus subtilis was more applicable bacteria for self-healing concrete when matched to other bacterias from bacillus family [4]. The compressive strength of concrete having bacteria count 10^6 was increased by 52.71% however for compressive strength was increased from 24% to 33% for diluted bacteria count. Surface velocity remains consistent of bacteria impregnated concrete before the crack was induced and after it's healing. The bacteria and its byproducts alter the pore structure of concrete thereby increase the impermeability of concrete [5]. In this study, crack healing behavior of bacterial concrete using bacillus bacteria and its durability study was conducted. Experimental results indicated a better durability performance for bacterial concrete matched to conventional M25 Concrete. Bacterial concrete show crack width decrease when placed in water which provides self- healing property to it. An experimental investigation was done to inspect the self- healing of cracked conventional mortar made with OPC and with fly ash mortar [6]. 20% OPC has been replaced by class F fly ash for cement - fly ash mortar. The compressive strength & ultrasonic pulse velocity, sorptivity tests on mortar specimens indicates the self-healing of cementitious particles in terms of complete recovery of its properties. The self- healing ability is more extrusive for mortar having Fly Ash.

Effectiveness of Bacteria and bagasse ash of sugar cane as a substitute for cement in concrete is examined [7]. It was concluded that sugarcane bagasse ash is a low weight material and 10% and 20% replacement of bagasse ash along with bacteria improves the durability of the concrete. The rapid chloride test indicates that the chloride permeability index is comparatively low for all the concrete specimens with bacteria and bagasse ash.

II. EXPERIMENTAL INVESTIGATION

A. *Materials and Properties*

The main components of concrete are cement, aggregates and water. In this study class F fly ash is to be used as a substitute for cement partially. The specific gravity of Fly ash was found to be 2.7 and fineness value as 5%. The bacteria of species Bacillus Subtllis is selected. Firstly, tests were done to evaluate the properties of individual materials. The material properties of cement are given in table1. Secondly, a mix M25 was adopted as it is one of the commonly adopted mix nowadays in normal construction works. Next, a water-cement ratio of 0.5 was adopted by carrying out repeated workability tests. Cubic specimens of size 150mm were casted to find out the 7 and 28-day compressive strength.

Table1 . Material properties of cement

Material Property	Value
Specific Gravity of Cement	3.12
Standard consistency of cement	32%
Initial setting time	34 min
Fineness cement	7%

Sieve analysis was conducted out to find the particle size distribution of fine aggregates. The size of fine aggregates used was below 4.75 mm. Specific gravity of fine aggregate was obtained as 2.6 and 2.9 for coarse aggregate. As per sieve analysis results the fine aggregate is confined to zone II.

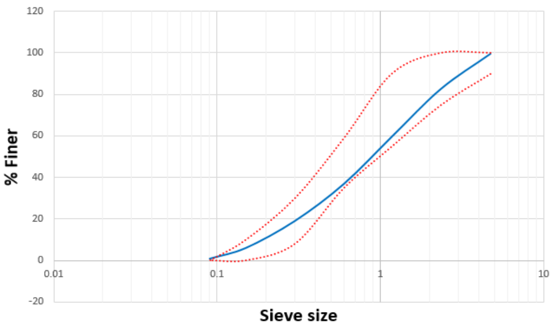

Fig 1. Particle size distribution of fine aggregates

Fig 2. Particle size distribution of coarse aggregates

Bacillus subtilis, which is also known as grass bacillus, is one of a Gram-positive bacterium, found in soil and the intestines of organisms. It is a member of the species Bacillus, and has a tough, protective spore, giving it the ability to resist extreme environmental conditions. The shape of the cells are typically rod-like, and are about 4-10 micrometers in length and 0.25 to 1.0 micrometer in diameter. This species is seen on the top of the soil. As it possesses fermentation properties, it is used to manufacture various enzymes, and is used in horticulture and agriculture. Fly ash is a waste product after burning coal in electric power plants. It is a puzzolana, substance that contains alumina and silica materials which when added with lime and water it forms a compound identical to Portland cement. Fly Ash is classified as two types as Class F and Class C.

The burning of older bituminous coal typically produces Class F fly ash. This fly ash is puzzolanic in nature, and contains less than 7% lime. Fly ash of Class C is produced from the burning of younger coal, it also has some self-cementing properties. Class C fly ash generally contains more than 20% lime.

B. *Mix Design*

A mix M25 was adopted as it is one of the commonly adopted mix nowadays in normal construction works. Trial mixes were conducted to get the desired workability based on fresh concrete tests. Cubes of size 150mm were casted for each trials conducted. Dalmia OPC 53 cement was used for the study and water cement ratio of 0.5 was adopted. The details of mix design calculations are provided in table 2.

Table 2: Mix Design Calculations

Material	Cement	Fine agg.	Coarse agg.	Water
Mass : Kg/m^3	394.32	668.33	1216.27	197.16

C. Experimental Programme

The tests conducted on fresh concrete are slump test and compaction factor test. The mechanical characteristics of concrete studied are compressive strength, split Tensile strength and flexural strength. Compressive strength test were conducted on cubes of side 150mm, split tensile on cylinder of 150mm dia and 300mm height and flexural strength on beam of size 100mm x 100mm x 500mm. Flexural study is conducted on reinforced beam of size 230 mm x 300mm x 1500mm, Beams were casted by replacing the amount of cement by appropriate concentration of Bacteria and Fly Ash. The reinforced beams with and without bacteria were casted and cured for 28 days. Reinforcement details of the beams are given in Fig3. 3 Nos of 16mm Ø bars were given as main bottom reinforcement and 2 Nos of 12 mm Ø bars were laid as top reinforcement. 2 legged 10mm Ø stirrups @ 120mm centre to centre were provided as shear reinforcement.

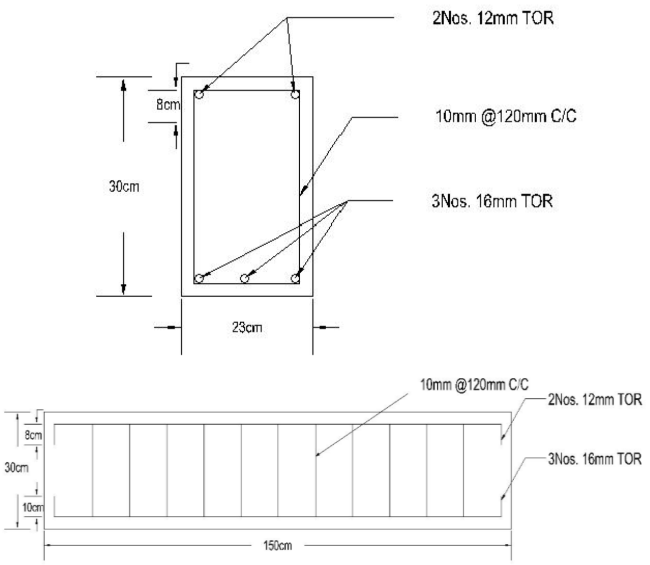

Fig 3. Reinforcement details of beam

D. Test Setup for Flexural Study

Flexural study of reinforced beam is carried on Loading Frame of 50T capacity keeping the ends simply supported. Two point loading is applied at the flexural span. Dial gauges with least count 0.01mm and maximum range of 10mm were used to note the deflection values. Mechanical strain gauge and steel discs are used to calculate the strain values. Test setup arrangement is shown in Fig 4.

Fig 4. Test Setup

III. RESULTS AND DISCUSSIONS

A. Tests on Fresh Concrete

Slump test and compaction factor test were conducted on fresh concrete. The slump value obtained for control mix was 70mm and for bacterial concrete with fly ash was 85mm. The values of compaction factor test results for control mix and concrete with bacteria and fly ash are 0.88 and 0.93 respectively.

B. Tests on Haardened concrete

Compressive strength & split tensile strength are conducted on CTM and Flexural strength on Flexural testing machine. Based on compressive strength test, the favorable concentration of Bacillus Subtilis was found as 6x10^6 Cells /ml. and the optimum percentage of cement that can be replaced with Fly Ash was found out to be 25%. These tests are conducted after 28 days curing, for control mix, concrete with optimum percentage of bacteria and concrete with optimum percentage of bacteria with Fly ash. The results of these tests are tabulated in table 3. It has been seen that there is increase in the properties of the mix with bacteria and fly ash.

CS-Control Specimen, BC- Bacterial Concrete, BCFA-Bacterial Concrete with Fly Ash.

Table 3: Mechanical properties test results

Sl N0	Specimen Details	Compressive Strength	Split Tensile strength	Flexural strength
1	CS	31.11 N/mm^2	3.53 N/mm^2	3.2 N/mm^2
2	BC	34.76 N/mm^2	3.74 N/mm^2	3.5 N/mm^2
3	BCFA	36.44 N/mm^2	3.89 N/mm^2	3.7 N/mm^2

C. Results of Flexural Study

Reinforced concrete beam is tested on loading frame by applying load in tones using hydraulic force. The results of the flexural test on reinforced beam is tabulated in table 4.

Table 4: Experimental test results for Beam Specimens

Specimen Label	Initial crack Load	Ultimate Load	Deflection
Control Beam (B1)	150 KN	330 KN	5.16 mm
Beam with bacteria and Fly Ash (B2)	175 KN	385 KN	4.65 mm

Deflection values are taken with the help of dial gauges and strain values are calculated using demountable strain gauges. Load v/s deflection graph is shown in Fig 5 and Load v/s strain graph is shown in Fig 6.

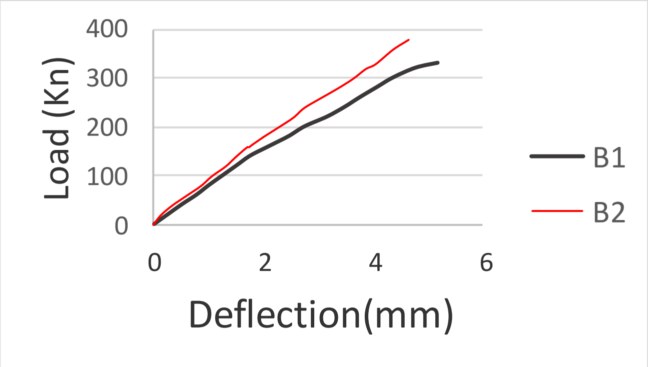

Fig 5. Load v/s Deflection Curve

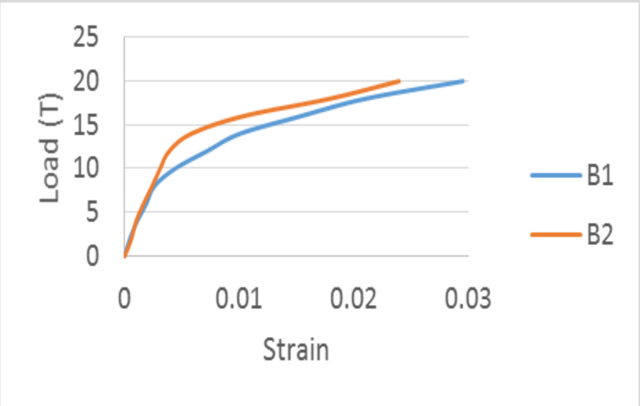

Fig 6. Load v/s Strain Curve

IV. CONCLUSIONS

In this study tests are conducted to find the favorable concentration of Bacillus Subtillis Bacteria and Fly Ash in self healing concrete with fly ash. The effect of bacteria and fly ash in concrete on the mechanical characteristics of concrete and the strength characteristics of reinforced concrete beams are evaluated. The following conclusions are drawn out from the study:

- The apt Concentration of Bacteria was found to be 6x 10^6 cells/ml and percentage of cement that can be replaced with Fly Ash to be 25%.
- Addition of Fly ash and Bacillus Subtilis bacteria at optimum concentration has improved mechanical characteristics of concrete compared to normal mix.
- The ultimate Load carrying capacity of beam with Bacteria and fly ash (B2) is 16.6% more compared to control beam (B1).
- There is a 9.88 % reduction in deflection for beam B2 compared to control beam B1.
- The Strain values at mid span for Beam B2 with BCFA is lesser compared to the control beam.

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