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AN EXPERIMENTAL INVESTIGATION ON THE STRENGTH PROPERTIES OF FLY ASH BASED BACTERIAL CONCRETE

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Abstract*— The present investigation deals with the influence of Bacillus Subtilis bacteria on strength properties of fly ash concrete. In fly ash concrete, cement was partially replaced with 10%, 20% and 30% with fly ash by weight and optimizes the percentage of fly ash for making bacterial concrete. The bacteria Bacillus Subtilis of different cell concentrations 10^3, 10^5 and 10^7 cells/ml were used for making bacterial concrete. The experimental investigations were carried out for 28 and 56 days. Tests conducted include Compressive strength, Split tensile strength, Flexural strength and Ultrasonic Pulse Velocity. In fly ash concrete, maximum strength properties observed for 10% replacement of cement with fly ash and the percentage of fly ash is fixed as 10% for making bacterial concrete. In bacterial concrete, maximum strength properties obtained for the bacteria cell concentration of 10^5cells/ml. The improvement in the strength properties of fly ash concrete is due to the precipitation of calcium carbonate ($CaCO_3$) in the micro environment by the bacteria Bacillus Subtilis.

***Keywords*— Fly ash, Bacillus Subtilis, Compressive strength, Split tensile strength, Flexural strength, Ultrasonic Pulse Velocity**

I. INTRODUCTION

Concrete is most widely used engineering material in construction due to its strength, durability and low cost as compared to other construction materials. The major drawback of concrete is its low tensile strength due to which micro-cracks occurs when the structure is subjected to sustained loading and exposed to aggressive environmental conditions results in to decreasing the life of the structure. Entry of harmful chemicals through these cracks may result in concrete deterioration through chemical attack and can also cause corrosion of steel reinforcement. This corrosion leads to increase in crack damage resulting in loss of strength and stiffness of concrete structures. In reinforced concrete, for both concrete and reinforcement results in high maintenance cost [1].

The “Bacterial Concrete” is a concrete which can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. A dormant (alive but not growing) and viable (capable of working successfully) bacteria of different concentration are added in concrete during mixing. Bacteria are inactive in the concrete matrix will metabolically active when revived by water and calcium media of concrete [2].

Alvin Harison [3], in his study cement has been replaced by fly ash accordingly in the range of 10% to 60% by weight of cement. Concrete mixtures were produced, tested and compared in terms of compressive strength. It was observed that 20% replacement Portland Pozzolana Cement (PPC) by fly ash strength increased marginally (1.9% to 3.2%) at 28 and 56 day respectively. It was also observed that up to 30% replacement of PPC by fly ash strength is almost equal to referral concrete after 56 d. PPC gained strength after the 56 d curing because of slow hydration process.

Navneet Chahal [4] evaluated the influence of sporoscarcina pasteurii bacteria on the compressive strength, water absorption and rapid chloride permeability of concrete without and with fly ash. Cement was replaced with 10%, 20% and 30% with fly ash by weight. Three different cell concentrations 10^3, 10^5 and10^7 of bacteria were used in making the concrete mixes. Maximum increase in compressive strength (22%) and four times reduction in water absorption was observed with 10^5 cells /ml of bacteria. This improvement in compressive strength was due to deposition of calcium carbonate within the pores. Calcite deposition in concrete observed nearly eight times reduction in chloride permeability of fly ash concrete.

Rafat Siddique [5], in his study the bacterial concentrations were optimized to 10^3, 10^5, 10^7cells/ml in concrete mix**.** Cement was replaced with fly ash, and silica fume. The percentage replacement of fly ash and silica fume was by weight of cement. The percentage use of fly ash was 0%, 10%, 20% and 30%, and that silica fume were 0%, 5% and 10%. The maximum increase in compressive strength observed after 91 days for a mixture with 10% fly ash and 10% silica fume which had 10^5 cells/ml bacterial concentrations. The increase in strength is due to the deposition of calcium carbonate on the bacteria cell surfaces within the pores. This precipitation reduced the chloride permeability in concrete with fly ash and silica fume. Ravindra Anadinni [6] investigated the influence of Bacillus pasteurii on strength properties of normal and fly ash concrete. In fly ash concrete cement was replaced with three percentages (10%, 20%, and 30%) with fly ash by weight. Different cell concentrations (0, 10^3, 10^5 and 10^7 cell/ml of mixing water) of bacteria were used in making the concrete mixes. Maximum increase in different strength properties like compressive strength, split tensile strength, flexural strength and shear strength was observed with concentration10^5 cells/ml of bacteria.

II. EXPERIMENTAL INVESTIGATION

In this experimental work, casting of concrete specimens were done according to IS 516-1957. Cubes, beams and cylinders were casted. The standard size of cube 150 mm, cylinder size 150 mm diameter and 300 mm height and beam of size 100 mm x100 mm x500mm were used. All materials were batched separately by weight. The materials were mixed thoroughly in mixer machine. Then concrete was poured into the mould, compacted and finished the top surface by means of a trowel. After 24 hours the specimens were removed from the mould and water curing was done for a period of 28 and 56 days and tests were conducted as per the relevant Indian standard specifications.

A. Material Details

The materials used in the investigation are:

1) *Cement : 53 Grade ordinary Portland cement conforming to IS 12269 was used in this study.*
2) *Fine Aggregate: Manufactured Sand (M-Sand) has been used in the present study. It confirms to Zone II with a specific gravity 2.62.*
3) *Coarse Aggregates: The maximum sizes of the aggregates used were 20mm and 12mm. The specific gravity of aggregate is 2.64.*
4) *Water : In the present study potable water was used for casting as well as for curing of the test specimens.*
5) *Superplasticizer : The superplasticizer used in this study was BASF Master Glenium Sky 8233.*
6) *Fly Ash : In this study, fly ash was collected from Hindustan Newsprint Limited, velloor, kottayam .The specific gravity of fly ash was 2.30. Table 1 shows the chemical composition of fly ash.*
7) *Bacterial Solution: The bacteria Bacillus Subtilis was used in this study. The pure culture of Bacillus Subtilis was collected from the department of Agricultural Microbiology, College of Horticulture, Vellanikkara, Trissur.*

TABLE 1: CHEMICAL COMPOSITION OF FLY ASH

COMPONENT	FLY ASH MASS %
SiO_2	60.5
SO_3	0.2
MgO	0.6
Na_2O	0.1

B. Mix Proportions:

Concrete grade of M30 has been designed and modified with varying percentages of fly ash (10%, 20% and30%) by weight of cement. Bacterial concrete of different concentrations (10^3,10^5 and 10^7 cells/ml of mixing water) were prepared with optimum percentage of fly ash. There were three basic mixes; fly ash concrete mixes (FC) and bacterial concrete mixes (BC). The control mix in this research is designated as normal concrete'NC'. Mix proportioning specifications are detailed in Table 2

TABLE 2: MIX PROPORTION OF M30 CONCRETE

MIX DESIGNATION	NC	FC10	FC20	FC30	BC3	BC5	BC7
FLY ASH %	0	10	20	30	10	10	10
BACTERIAL CELLS/ML	0	0	0	0	10^3	10^5	10^7
CEMENT (KG/M^3)	388	349.2	310.4	271.6	349.2	349.2	349.2
FLY ASH (KG/M^3)	0	38.8	77.6	116.4	38.8	38.8	38.8
FINE AGGREGATE (KG/M^3)	670	670	670	670	670	670	670
COARSE AGGREGATE (KG/M^3)	1200	1200	1200	1200	1200	1200	1200
WATER (KG/M^3)	167	167	167	167	167	167	167
SUPERPLASTICIZER KG/M^3)	1.3	1.3	1.3	1.3	1.3	1.3	1.3

C. *Tests on Concrete*

1) *Compressive Strength Test: Compressive strength test conducted according to IS 516:1959. The cube specimen of size 150 mm. The test was done after 28 and 56 days of water curing.*
2) *Split Tensile Strength Test: Split tensile strength test was conducted on cylinders of size 150 mm diameter and 300 mm height. Test was conducted as per IS 5816:1999.The test was done after 28 and 56 days of water curing.*
3) *Flexural Strength Test: Flexural test was conducted as per IS 516:1959 .The test was conducted on beams of size 100 mm x 100 mm x 500 mm after 28 and 56 days of water curing.*
4) *Ultrasonic Pulse Velocity: The pulse velocity can be calculated using the measured path length through the concrete as per IS 13311: 1992 (Part 1). Cube specimens of size 150mm were used. The test was done after 28 days of water curing.*

III.RESULTS AND DISCUSSIONS

A. *Compressive Strength Test*

1) Fly Ash Concrete: The results obtained for different mixes at 28 day and 56 day are shown in figure 1.The compressive strength of normal concrete at 28 day is 39.8MPa. From the results it is observed that on addition of fly ash, 28 day strength was decreases at all replacement level. The decrease in strength may be due to slow hydration process since fly ash is a slow reactive pozzolans which delays the hydration process. It is evident that beyond 28 day, the strength increased with the addition of fly ash. The maximum compressive strength obtained at 56 day is 43.68 MPa for fly ash concrete of 10% partial replacement of cement with fly ash. The 56 day strength of fly ash concrete with 20% and 30% replacement level is lower than 10% replacement level. Therefore the fly ash percentage is optimized to 10%, for making bacterial concrete

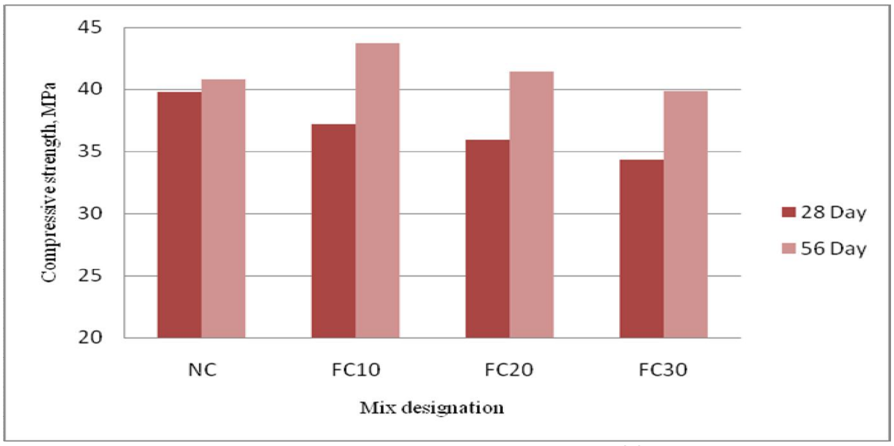

Fig. 1 28 day and 56 day compressive strength of fly ash concrete

2*) Bacterial Concrete:* The results obtained for different mixes at 28 day and 56 day are shown in figure 2. It is observed that the 28 and 56 day compressive strength of bacterial concrete with different bacteria cell concentrations are higher compared to normal concrete and fly ash concrete. Comparing the 28 day strength of fly ash concrete with bacterial concrete, strength of bacterial concrete is increased by 9-14% and the maximum strength is 42.4MPa. Compared to normal concrete strength increased by 2-7%. Comparing the 56 day strength, maximum strength obtained for the mix BC5 is 47.66MPa.

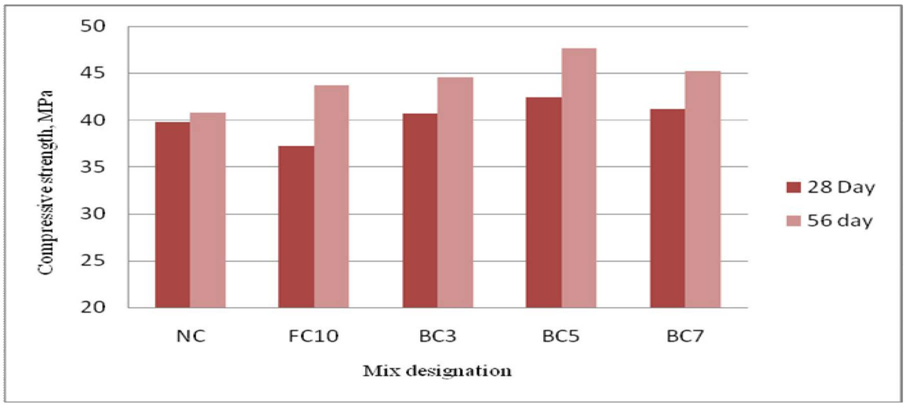

Figure .2 28 day and 56 day compressive strength of bacterial concrete

B. *Split tensile Strength Test*

1) Fly Ash Concrete: The results obtained for different mixes at 28 day and 56 day are shown in figure 3. From the test results 28 day strength of fly ash concrete decreases compared to normal concrete. The 56 day strength of fly ash concrete increased compared to normal concrete. Maximum strength 3.31MPa is obtained for the mix FC10. Beyond the 10% replacement of fly ash the 56 day strength was also decreased. Therefore the fly ash percentage is optimized to 10% for making bacterial concrete.

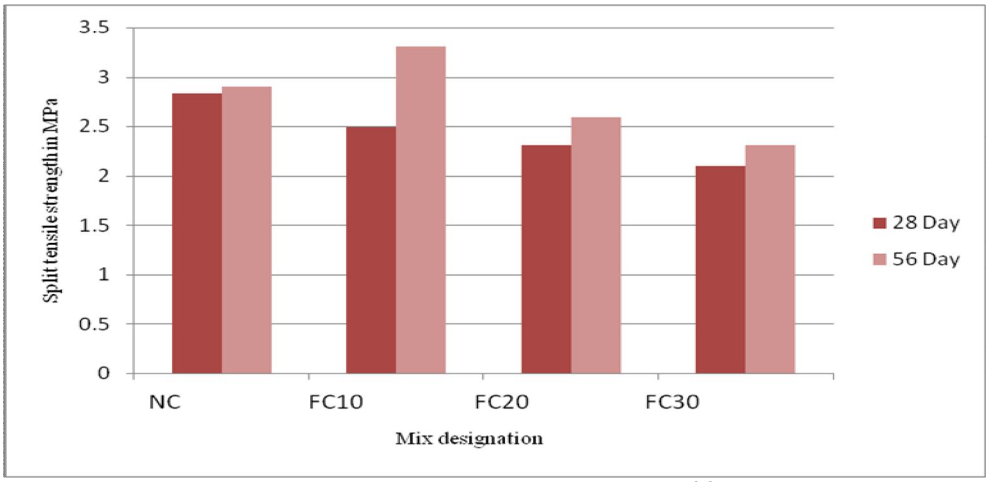

Fig.3 28 day and 56 day split tensile strength of fly ash concrete

2*) Bacterial Concrete:* The results obtained for different mixes at 28 day and 56 day are shown in figure 4. It is observed that 28 and 56 day split tensile strength of bacterial concrete is higher compared to normal concrete and fly ash concrete. At 28 day maximum strength obtained is 3.24MPa and for 56 day it is 4.28MPa. Maximum strength obtained for the mix BC5. In bacterial concrete minimum strength obtained for the mix BC3.

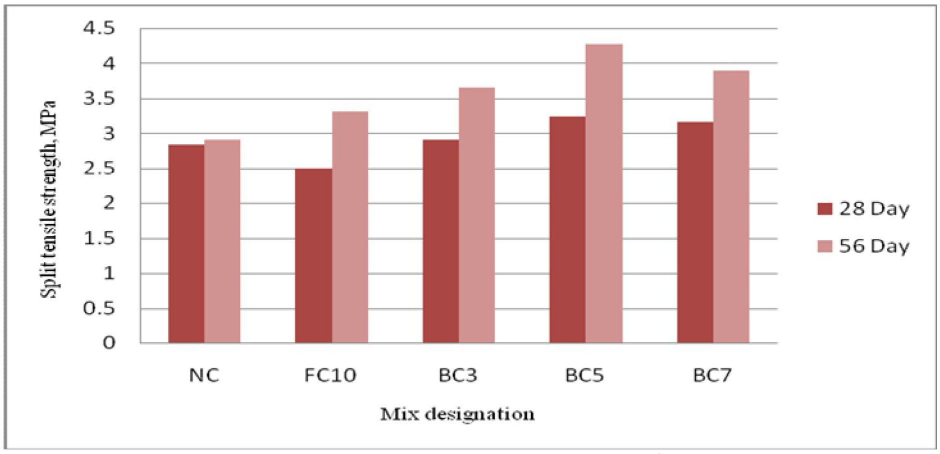

Fig.4 28 day and 56 day split tensile strength of bacterial concrete

C. *Flexural Strength Test*

1) Fly Ash Concrete: The results obtained for different mixes at 28 day and 56 day are shown in figure 5.Comparing 28 day flexural strength of fly ash concrete with normal concrete the strength decreases with increase in percentage of fly ash. The decrease in strength may due to slow hydration process since fly ash is a slow reactive pozzolans which delays the hydration process. Maximum flexural strength at 56 day is 5.60MPa obtained for the mix FC10. Therefore the fly ash percentage is optimized to 10% for making bacterial concrete of varying concentrations.

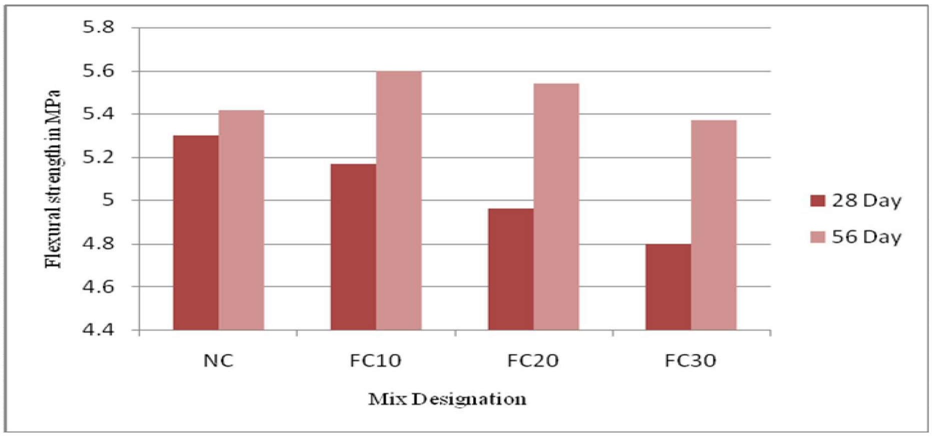

Fig. 5 28 day and 56 day flexural strength of fly ash concrete

2*) Bacterial Concrete:* The results obtained for different mixes at 28 day and 56 day are shown in figure 6. It is observed that the flexural strength of bacterial concrete at 28 and 56 day is increased compared to normal concrete and fly ash concrete. Maximum strength at 28 and 56 day is 5.68MPa and 7.44MPa. The maximum strength obtained for the bacterial cell concentration of 10^5cells/ml.

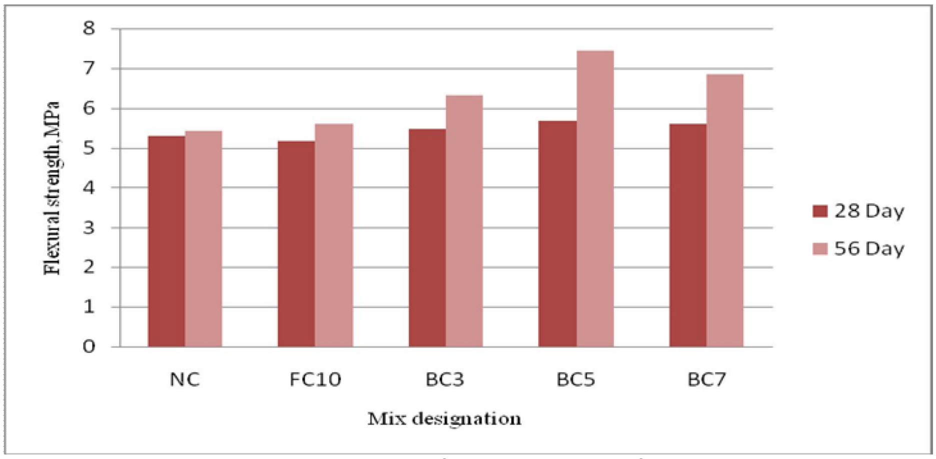

Fig. 6 28 day and 56 day flexural strength of bacterial concrete

D. *Ultrasonic Pulse Velocity Test*

The results obtained for different mixes at 28 day are shown in figure 6.The ultrasonic pulse velocity of fly ash concrete decreases with increase in fly ash percentages compared with the normal concrete. Decrease in velocity value indicates the voids in the concrete. Bacterial concrete shows higher values compared to normal and fly ash concrete at 28 days. The maximum value 4.98 km/sec is obtained for bacterial concrete with 10^5 cell/ml concentration. UPV value of mix FC30 is 4.48 km/sec and it is comes under 'Good' category. All other mixes have UPV value greater than 4.5 km/sec therefore the mixes are 'Excellent' category.

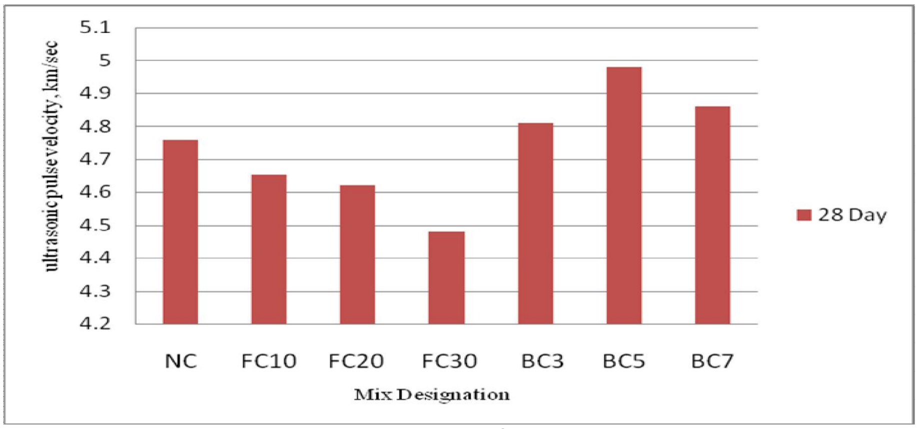

Fig. 7 Comparison of 28 day UPV values

IV. CONCLUSIONS

The following results were obtained from the experimental study on fly ash based bacterial concrete.

1) *Compressive strength of fly ash concrete is increased at 56 day compared to 28 day. The later strength of fly ash is due to the pozzolanic action. The maximum strength obtained for the 10% replacement of fly ash and the strength increased by 7% compared to 56 day strength of normal concrete.*
2) *Compressive strength of bacterial concrete at 28 day is increased by 2-7% and 9-14% compared to normal and fly ash concrete. The maximum strength for 28 and 56 day obtained for the mix BC5 and the 56 day strength of is increased 9% and 17% compared to fly ash and normal concrete.*
3) *Split tensile strength of fly ash concrete increased at 56 day. The maximum strength obtained for the 10% replacement of fly ash and it is increased by 13%* compared to *normal concrete. For mixes FC20 and FC30 strength decreases.*
4) *The split tensile strength of bacterial concrete at 28 day is increased by 3-14% and 17-30% compared to normal and fly ash concrete. The maximum strength for 28 and 56 day obtained for the mix BC5. The 56 day strength of bacterial concrete is increased by 9% and 17% compared to fly ash and normal concrete.*
5) *The maximum flexural strength of fly ash concrete at 56 day is obtained for 10% replacement of fly ash. Compared to normal concrete the strength increased by 3%. Beyond 10% fly ash replacement the strength decreases.*
6) *Flexural strength of bacterial concrete at 28 and 56 day is higher compared to normal and fly ash concrete. Maximum strength obtained for the bacteria cell concentration of* 10^5*cells/ml and the 28 day strength increased by 7% and 10% compared to normal and fly ash concrete. The 56 day strength is increased by 13% and 17% compared to fly ash and normal concrete.*
7) *Maximum UPV value obtained for the bacteria cell concrete of* 10^5*cell/ml. UPV value of mix FC30 is comes under 'Good' category. All other mixes are in 'Excellent' category.*
8) *Comparing all the test results of fly ash concrete, maximum compressive strength, split tensile strength, flexural strength, and UPV value obtained for 10% fly ash replacement.*
9) *For bacterial concrete maximum compressive strength, split tensile strength, flexural strength, and UPV value obtained for the bacteria cell concentration of* 10^5*cells/ml. The increase in strength is due to the deposition of calcium carbonate* ($CaCO_3$) *in the pores.*

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