Impact on Mechanical Properties of Concrete by Replacing Cement Partially By Fly Ash Enriched With Bacillus Subtilis

Aamir Nazir Lone, P. Jagannathan, K.S.Satyanarayanan

Abstract: One of the troubling issues the world presently confronting is the global warming.It is mainly due to the emission of greenhouse gases into the atmosphere by human activities. During the cement production, a huge amount of CO_2 is emitted and released into the atmosphere and in addition to that massive amount of fly ash is produced which is generally a waste product. As cement is primary binding material, our effort in this paper is to find out the best possible percentage of cement replacement with fly ash and also supplementing with microorganisms such as bacillus subtilis in order to strengthen the mechanical performance of concrete. The main aim of this paper is to strengthen the concrete with the partial replacement of cement by fly ash enriched with bacteria. From previous researches and various works of literature, we came to a conclusion of using Bacillus Subtilis with a cell concentration of 10^5 cells per 100 ml of bacterial solution. Bacillus is prepared and grown under favorable conditions before using. The mix proportion adopted is M40 for preparing the concrete mix. The samples were tested at different ages i.e. 7d, 14d, 28d, and 60d. It was seen that the strength of concrete increases considerably after using fly ash enriched with Bacillus Subtilis.

Keywords: Bacillus Subtilis, CO_2, Fly ash, C-S-H.

I. INTRODUCTION

Most of the researches focus on increasing the performance of concrete concerning both the strength and durability of concrete. As the design period of a structure is claimed to be 50 years [2], the major challenge is to propose a mechanism to increase the serviceability and lifetime of ordinary concrete. All the mechanisms either consider strength as a work factor or the ways to reduce the cement consumption in order to reduce the problems that cement poses to the environment. Concrete is mainly a porous material containinggel pores and capillary pores and due to this porous nature the concrete is highly vulnerable to acid attacks, chloride attack, and sulphate attack etc. cement is a main ingredient in the preparation of concrete. India being still a developing country produces cement in very huge quantity. It has been surveyed that India is the second largest cement producing country with nearly 420 million tonnes of cement production capacity. Interestingly, it is also 2nd largest cement consuming country. Through a comprehensive study by analysts, it has been estimated that the production capacity of cement may touch 550 million tonnes by the year 2020.

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Cement production of one tonne roughly produces carbon dioxide in same amount and the construction, on the whole, contributes 50% of the carbon dioxide emission into the atmosphere [1]. Apart from that 75 thermal power plants are present in India which produces fly ash in large quantity which is generally waste and its disposal imposes a considerable problem [10].The primary aim of using fly ash enriched with bacteria is to reduce cement consumption without affecting the strength parameters. In bacterial concrete, the main mechanism is microbial-induced calcite precipitation which induces crack healing properties and in turn enhances the mechanical properties [8, 9, 11, and 12]. In addition to this *Bacillus* is harmless and it has also been seen that with the replacement of cement by fly ash the cost has been reduced significantly [10]. Thus, this paper presents the work in which *Bacillus Subtilis* is fed to the concrete in the required proportions and results were analysed.

II. MATERIALS AND METHODS EMPLOYED

A. Bacillus Subtilis

Bacillus Subtilis, was known first by the name vibrio Subtilis and then renamed as *Bacillus Subtilis* in the year 1872, is a spore forming gram-positive bacteria normally found in soil and vegetation. The cells are rod-shaped and a decent model for cellular advancement and differentiation. It can survive in harsh conditions and can last for about 6 years if coated dust particles which protect it from UV radiations.

B. Growth of Bacillus Subtilis

The bacteria are grown in favourable conditions with a liquid base and a viable cell count. The Colony Forming Unit (CFU) is a minimum of 1 x 10^5 cells/ ml of liquid with no contamination level. The observed pH is between 6.31. The bacterial solution is directly fed to the concrete mix.

C. Cement

53 grade, Ordinary Portland cement is used in the current study and the tests on cement are carried out as per IS 8112: 1989. Table 1 lists the various properties and the results obtained from tests.

Table 1 Physical Properties of ordinary Portland cement

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Description	Test Results
Fineness	5%
Specific Gravity	3.10
Normal Consistency	31%
Initial Consistency	120 Minutes
Final Consistency	260 Minutes

D. Fly Ash

Fly ash of class F is used in the work. Fly ash is tested according to IS 3812: 1981 and results are given in Table 2.

Table 2. Physical properties of fly ash

Physical properties	Test values
Specific Surface Area	1.240 m^2/g
Specific Gravity	2.20
Moisture Content	0.200
Wet Density	1.75 g/cc
Turbidity (NTU)	459
pH	7.1

E. Fine Aggregate

River sand, passing through 4.75 IS sieve is used. The tests are conducted as per IS 383: 1970. The sand conforms to zone II as per IS code. The value of specific gravity for fine aggregate is found as 2.65.

F. Coarse Aggregate

Coarse aggregate having size 20mm and down size is taken and tested for physical properties according to IS 383: 1970. The results are shown in the Table 3.

Table 3Physical properties of Coarse Aggregate

Name of the Test	Test values
Impact Test	16.66%
Water Absorption	0.5%
Specific Gravity	2.66

G.Mix Design and Determination of Proportions

Mix design is prepared as per IS 10262:2009 for M40 grade of concrete. Water/cement ratio adopted is 0.40. However, in bacterial concrete total water content is divided into 60% water and 40% bacterial solution. The concrete specimens are prepared as per guidelines specified in IS codes for various proportions to specify the benefits of using fly ash enriched with bacteria as a partial replacement to cement described below:

i) Conventional concrete (CC) specimens.

ii) Concrete containing bacterial solution instead of water and no added fly ash (CCB)

iii) Concrete with partial replacement of cement by Class F fly ash added in 25% (CF25), 30% (CF30), and 35% (CF35).

iv) Similarly. preparation of concrete by partially replacingthe cement with class F fly ash enriched with bacteria with 25% (CFB25), 30% (CFB25) and 35% (CFB25) as a replacement to cement. The bacteria is added to concrete in place of water

Samples are cast and demolded after 1 day of casting and kept in water for curing prior to testing. In bacterial concrete, the concrete mix contains 70% water and 30% bacterial solution containing *Bacillus Subtilis*. The specimens are taken out of curing tank, surface dried, weighed and measured before carrying out tests.

III. GENERAL PROCEDURE

In order to investigate the mechanical properties of the concretes under study, minimum of three samples including cubes with dimensions 100 mm x 100 mm x 100 mm, cylinders 200mm long and 100mm diameter, and beams of size 100mm x 100mm x 500mm are cast for every mix proportion and tested for compressive strength, split tensile strength, flexural strength, rebound hammer, and ultrasonic pulse velocity test, at different ages. The results are compared and a conclusive conclusion is drawn.

A. Compressive Strength Test

These tests are conducted to find out the compressive strength of conventional concrete (CC), concretewith fly ash in various percentages (CF), concrete with fly ash and bacteria (CFB), and concrete with bacteria only and no added fly ash (CCB). The casting of specimens is carried out as per IS 516-1959. The specimens are cast and demolded after 24 hours and kept for curing. The specimens are taken out and wiped with a clean cloth to make it surface dry. Then, taken for testing in compression testing machine. The specimen is centrally placed and the load is applied at a constant rate of 2.5 kN/s.

The arrangement is shown in the Figure 1.

Figure 1 compression testing machine

B. Split Tensile Strength Test

Specimens for split tensile strength are cast in cylindrical moulds 200mm long and 100mm diameter. Casting and testing of the specimens are done as per the specification specified by IS: 5816-1999. The specimens are made surface dry before carrying out a test.

Testing is done in a compression testing machine. The sample is placed horizontally and tightened between the bearing plates. A constant rate at 1.00 kN/s of load is applied. As soon as the sample forms the crack the machine automatically stops and the readings are noted.
The arrangement for split tensile test is shown in figure 2.

Figure 2 split tensile test arrangement

C. Flexural Strength Test

The specimensemployed for flexural strength tests arehaving size of 100mm x 100mm x 500mm. The tests are carried out as per IS specifications. The casting of specimen is carried out and demolded after 48 hours before immersing in water for curing, maintaining a temperature of 30^0C to 32^0C. Testing is done after 28 days of curing. Testing is carried out in a compression testing machine. Flexure apparatus consisting of a steel loading pad and roller supports. The load is three-point loading. The arrangement is shown in the Figure 3.

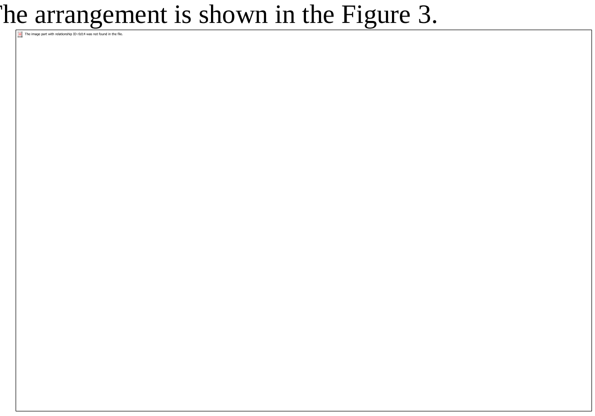

Figure 3 loading arrangement for flexure test (source internet)

D. Rebound Hammer Test and Ultrasonic Pulse Velocity (UPV) test

These tests are non-destructive in nature,cast-off to determine the strength, uniformity and quality of concrete in relation to the standard requirements. The rebound hammer consists of mass controlled by spring that slides on a plunger within a tubular housing. Tests are done as per IS 13311(Part 1 and Part 2) 1992. The results are then compared with the standard values.UPV also helps to determine the homogeneity in concrete and quality of concrete with respect to standard requirement. It is also used to determine voids, cracks and imperfections in the concrete. The apparatus comprises of an electronic pulse generator, one pair of transducers, an electronic timing device, and anamplifier. The tests are carried out on concrete samples with direct transmission. The time taken is noted and pulse velocity is calculated. The velocity is compared with the standard values as per IS code.

Table 4 Velocity Criterion for Concrete Quality Grading

Si No.	Pulse Velocity by Cross Probing (km/s)	Concrete Quality
01	Above 4.5	Excellent
02	3.5 to 4.5	Good
03	3.0 to 3.5	Medium
04	Below 3.0	Doubtful

IV. RESULTS AND DISCUSSION

The samples are cast forCC, CF and CFB.

A. Workability

According to ACI standard 116R-90 workability is described as simplicity through which concrete is mixed, placed, compacted and finished. It is a fresh concrete property. Workability is controlled by water-cement ratio which directly affects the strength of concrete. More the water/cement ratio less the strength and vice versa. In this research, water/cement ratio of 0.40 is adopted for M40 grade of concrete in accordance with IS: 456-2000. The workability of each mix proportion was determined after mixing and the values are tabulated.

Table 5Workability of Different Mix Proportions

Mix Proportion	Slump value (mm)
CC	5
CF25	4
CF30	3
CF35	2
CCB	10
CFB25	8
CFB30	6
CFB35	5

Table 5 above clearly shows that with the addition of bacterial solution in concrete the workability considerably increases. So in order to match the water-cement ratio to that of conventional concrete the water-cement ratio for bacterial concrete was reduced to 0.30 instead of 0.40.

B.Compressive Strength Test

The tests are carried out at different ages of curing. Samples are taken out from curing tub and wiped with clean cloth. It is kept in atmosphere for some time to dry and then taken for testing. At every age three samples are tested and average result is taken as shown in Table 6.

Table 6Average Compressive Strength of CC, CF and CFB at Different Ages

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Mix Proportion	Average compressive strength (N/mm^2)		
	7TH day testing	14th day testing	28th day testing
CC	26	37.8	45.1
CF25	23	26	33.3
CF30	17.8	24	32.6
CF35	13.6	20.2	28
CCB	27.1	38.5	46.2
CFB25	29.8	40.2	48.5
CFB30	23	32.6	41.5
CFB35	17.8	27.1	39.2

From Table 6 it is clear that the compressive strength of fly ash concrete i.e. CF25, CF30 and CF40 is less than conventional concrete CC. while as, bacterial concrete CFB25 after 28 days achieves 1.07 times of conventional concrete. It can also be seen that CCB is having less strength than CFB25, as the pores are filled more due to very fine nature of fly ash.

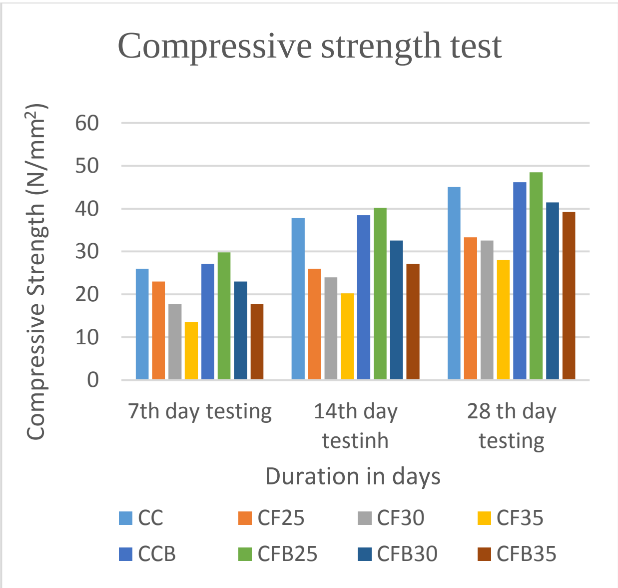

Figure 4 Compressive Strength

The graph in Figure 4 comparesthecompressive strength of different proportions at different ages.

C.Split Tensile Strength

The tests for split tensile strength are carried out on cylindrical specimens and the results are shown in Table 7.

Table 7Average Split Tensile strength of CC, CF and CFB at Different Ages

Mix Proportion	Average Split Tensile Strength (N/mm^2)		
	7TH day testing	14th day testing	28th day testing
CC	1.94	2.55	3.26
CF25	1.06	1.37	1.73
CF30	0.67	1.22	1.47
CF35	0.58	1.07	1.28
CCB	2.02	2.74	3.33
CFB25	2.29	2.96	3.85
CFB30	1.18	2.06	2.78
CFB35	0.98	1.8	2.17

The Table 7 shows the result of split tensile strength on various proportions. It can be seen that bacterial concrete with fly ash 25% achieves higher strength than CC and all proportions of CF. CFB25 achieves split tensile strength1.18 times of CCafter 28 days of curing.

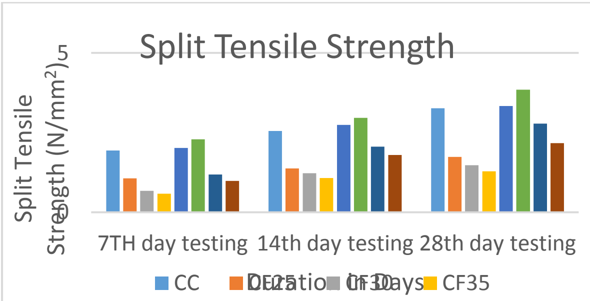

Figure 5 Split Tensile Strength

Figure 5 shows the graph comparingsplit tensile strength of different proportions at different ages.

D. Flexural Strength

Flexural Strength test results are shown in Table.

Table 8Average Flexural strength of CC, CF and CFB at Different Ages

Mix Proportion	Average Flexural Strength (N/mm^2)
	28TH day testing
CC	6.57
CF25	4.12
CF30	3.89
CF35	3.54
CCB	6.98
CFB25	7.5
CFB30	6.23
CFB35	5.85

The Table 8 shows the result of flexural strength test on various proportions. It can be seen that bacterial concrete with fly ash 25% achieves higher strength than CC and all proportions of CF. CFB25 achieves flexural strength 1.14 times of CCafter 28 days of curing.

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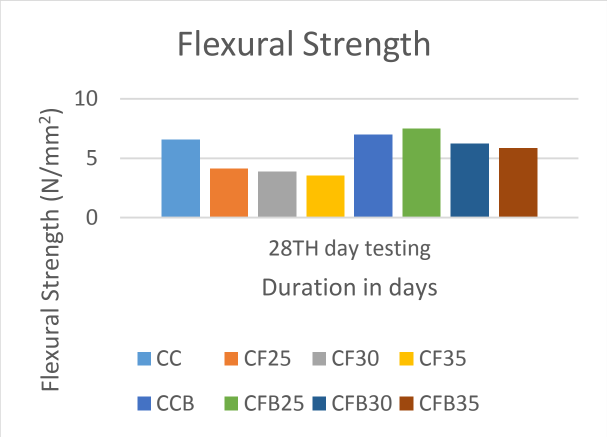

Figure 6 Flexural Strength

Graph in Figure 6depicts the comparison of flexural strength of different proportions at different ages.

E. Rebound Hammer Test

The rebound hammer test results are shown in table 9. The testing is performed on samples kept for 28 days of curing. One face of specimen is taken and the impact is made at nine places 20mm from the edges and the average result is taken.

Table 9 Rebound Hammer Values after 28 days

Mix Proportion	Average Rebound Hammer Test Values
	28^{TH} day testing
CC	36.61
CF25	34.5
CF30	30.61
CF35	29.8
CCB	41.44
CFB25	46.27
CFB30	40.83
CFB35	38.9

The rebound hammer results indicate that the quality of flyash concrete enriched with bacteria has high impact value as compared to control concrete. CFB25 has the highest value indicating good uniformity and good quality of concrete.

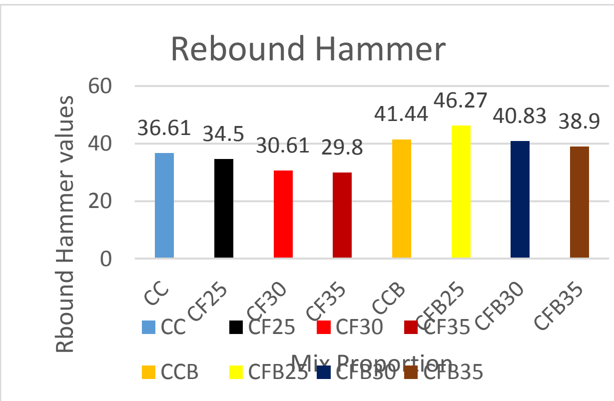

Figure 7 Rebound Hammer Value Comparison for Different Proportions

F. Ultrasonic Pulse Velocity test

The tests are done as per codal provisions and the test is carried on cubes kept for curing for 28 days. Three specimens are tested and 12 readings for each specimen is taken to fet the average result, which is tabulated in table 10 below.

Table 10 Ultrasonic Pulse Velocity test Values after 28 days of Curing

Mix Proportion	Average UPV Values
	28^{TH} day testing
CC	6.01
CF25	5.84
CF30	4.53
CF35	3.28
CCB	5.77
CFB25	6.4
CFB30	6
CFB35	5.65

UPV results also makes it quite clear that the quality of concrete with flyash enriched with bacteria is homogeneous and excellent quality of concrete.

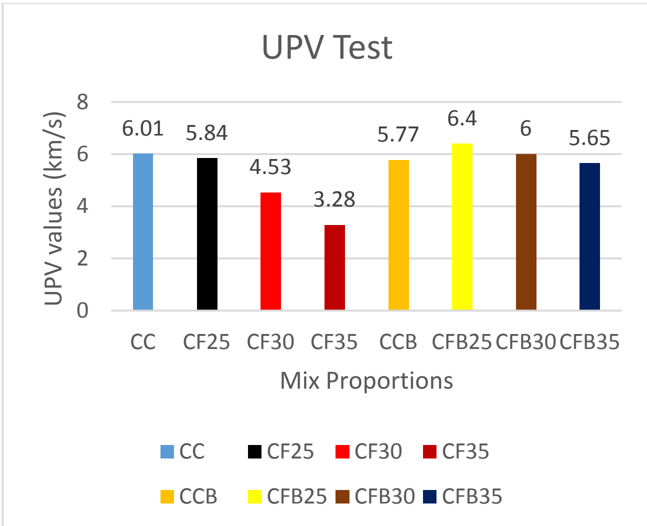

Figure 8 UPV value comparison for different proportions

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V. CONCLUSION

- On addition of bacterial solution in the concrete matrix, the workability of concrete at the same water-cement ratio increases. Thus, for the same grade of concrete the water/cement ratio is reduced to 0.30 instead of 0.40 adopted earlier for conventional concrete (CC).
- On 28 days of continuous curing, the compressive strength of concrete increased 1.07times of conventional concrete (CC) when it is induced with the bacterial solutioncontaining fly ash 25%.
- Also for the same proportion of bacterial concrete (CFB25) the Split tensile strength at 28 daysis1.18 of Conventional Concrete (CC).
- Flexural strength test reveals that the concrete with the bacterial solution and flyash 25% (CFB25) at 28 days attain highest strength. The flexural strength of CFB25 at 28 days is 1.14 times of Conventional concrete.
- Rebound hammer tests indicate that the quality of concrete made by partially replacing cement with flyash enriched with bacterial solution attain high impact values i.e. above 40, which says that the quality of concrete is good. However the concrete with only fly ash as partial replacement has low impact value and the quality is medium. CFB25 attains highest impact value and is 1.26 times of Conventional concrete.
- UPV results shows that the pulse velocity for all proportions in general is above 3.5 and above 4.5 for control concrete and concrete with fly ash admixed with bacteria in particular.
- It can be seen that the strength of CCB is more than CC but less than CFB25. It can be due to the fact that in flyash particles are very fine and fill the gaps more as compared to CCB.

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