International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-3, Special Issue-1, April-2015
Fifth National Conference on Innovative Practice in Construction Waste Management (IPCWM'15) On 8th & 9th April, 2015
Organized by Department of CIVIL Engineering, Sri Ramakrishna Institute of Technology, Coimbatore, India

An Experimental Investigation on Strength and Self-Healing Aspects of Fly Ash Concrete Using Bacillus Megaterium

A.Anto Edison James
PG Student,
Department of Civil Engineering,
Sri Krishna College of Technology, Coimbatore, India
antoedison07@gmail.com

V.Poornima
Assistant Professor,
Department of Civil Engineering, Sri Krishna College of Technology,
Coimbatore, India
poorni.engg@gmail.com

Dr.R.Venkatasubramani
Head of Department,
Department of Civil Engineering,
Sri Krishna College of Technology, Coimbatore, India
rvs_vlb@yahoo.com

ABSTRACT

The deterioration of reinforced concrete structures is a very common problem due to the fact that this material has a high permeability which allows water and other aggressive media to enter, thus leading to corrosion problems. The use of sealers is a common way of contributing to concrete durability. However, the most common ones are based on organic polymers which have some degree of toxicity. This paper presents the results of an experimental investigation carried out to evaluate the influence of Bacillus Megaterium bacteria on the compressive strength, splitting 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 & 40) with fly ash by 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, splitting tensile and flexural strength. This improvement in strength was due to deposition on the bacteria cell surfaces within the pores. SEM analysis performed to obtain the crystal morphology.The present work highlights the influence of bacteria on the properties of concrete made with supplementary cementing material such as like fly ash.

KEYWORDS

Bacillus Megaterium, fly ash, self-healing, compressive strength, splitting tensile strength, flexural strength, SEM.

1.INTRODUCTION

Plain concrete possesses very low tensile strength, limited ductility and little resistance to cracking. Advancement in concrete technology has been generally on the strength of concrete. Strength of concrete alone is not sufficient, the degree of harshness of the environmental condition to which concrete is exposed over its entire life is very important. Chloride ingress leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability and aesthetics 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 such as fly ash serves to refine the pore structure and the degree of hydration of the concrete. 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 and this along with the ingress of moisture and other harmful chemicals such as acids, chlorides and sulphates affect the material and seriously reduce their strength and 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 also emanate toxic gases.

A reliable self-healing method for concrete would lead to a new way of designing durable concrete structures, which is beneficial for national and global economy. The "Bacterial Concrete" can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. Calcite formation by Bacillus Megaterium is a model laboratory bacterium, which can produce calcite precipitates on suitable media supplemented with a calcium source. 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 $CaCo_3$. The favorable conditions do not directly exist in a concrete but have to 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 much calcite as needed to repair cracks.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials Used

2.1.1 Cement

Ordinary Portland cement of 53 Grade available in local market is used in the investigation. The cement used has been tested for various properties as per IS: 4031-1988 and found to be confirming to various specifications of IS: 12269-1987 having specific gravity of 3.15.

2.1.2 FlyAsh

Flyash of Class F from Mettur Thermal Power Plant (MTPP) was used. Flyash used isfound to be confirming to IS 3812-1981. Specific gravity of flyash is 2.20 and fineness modulus is 7.86.

2.1.3 Fine Aggregate

Clean and dry river sand available locally was used. Sand passing through IS 4.75 mm sieve was used for casting all the specimens.Fine aggregate used are confirming to IS 383-1970 and having a specific gravity of 2.6.

2.1.4 Coarse Aggregate

Coarse aggregate available locally and confirming to IS 383-1970 and having a specific gravity of 2.7 are used.

2.1.5 Water

Castings of specimens were done with the potable water.

2.1.6 Bacteria

The pure culture of Bacillus Megaterium a commonly available soil bacterium was obtained from biotech firm, Coimbatore.5ml of bacteria solution is adequate for per Liter of water for their efficient growth.

2.1.7 Bacterial Treatment Solution

The concrete cubes were wiped with a blotting paper to remove any surface bacteria and cured in corresponding calcite precipitation media of Calcium chloride 50 g/Lt + Urea 20g/Lt at room temperature.

2.2 Concept of Bacterial Concrete

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

$$Ca^{2+} + Co_3^{2-} \rightarrow CaCo_3\downarrow \qquad (1)$$

The solubility of $CaCo_3$ is a function of pH and affected by ionic strength in the aqueous medium (Stumm and Morgan, 1981). In urea-$Cacl_2$ medium that supports microbial growth, NH_4^+ and Cl^- also reacts with OH^- and H^+ respectively, at different pH, further interfering with chemically-induced $CaCo_3$ precipitation. Microbiologically-induced $CaCo_3$ precipitation occurs via far more complicated processes then chemically-induced precipitation. The bacterial cell surface with a variety of ions could non-specifically induce mineral deposition by providing a nucleation side. Especially, Ca^{2+} is not likely utilized by microbial metabolic processes, rather accumulates outside the cell. In medium, it is possible that individual microorganisms produce ammonia as a result of enzymatic urea hydrolysis to create an alkaline micro-environment around the cell.

The high pH of these localized areas without a significant increase in pH in the entire medium at the beginning apparently commences the growth of $CaCo_3$ crystals around the cell.

Possible biochemical reaction in urea-$CaCl_2$ medium to precipitate $CaCo_3$ at the cell surface can be summarized as follows.

$$Ca^{2+} + \text{cell} \rightarrow \text{Cell-}Ca \qquad (2)$$

$$Cl^- + HCO_3^- + NH_3 \rightarrow NH_4Cl + Co_3^{2-} \qquad (3)$$

$$\text{Cell} - Ca^{2+} + Co_3^{2-} \rightarrow \text{Cell} - CaCo_3\downarrow \qquad (4)$$

In addition, the results of kinetic studies render an explanation that the rate of $CaCo_3$ precipitation correlates with the cell growth and urease executes higher enzymatic activities and stronger affinity to urea at higher pH levels (pH 8-9) where calcite precipitation is favorable.

The role of the microbial urease was defined from the data that the calcite precipitation B.Pasteurii and E.coli expressing B. Pasteurii urease was inhibited in the presence of a urease inhibitor and a significant amount of calcite precipitation was induced by E.coli, whereas little was induced by E.coli lacking urease genes. These observations support our assumption that the urease enzyme is a primary factor that initiates microbiologically-induced calcite precipitation. In detail, reaction 1 produces calcium carbonate and proteins in aqueous medium where Co_3^{2-} primarily stays as HCO_3^-.

$$Ca^{2+} + HCO_3^- \rightarrow CaCo_3 + H^+ \, (5)$$

In biological systems, many calcareous organisms couple classification to their metabolic assimilation processes to scavenge protons. In urease-based reactions, NH_3 released by the enzymatic hydrolysis of urea uses the protons generated from the calcite precipitation to produce NH_4^+.

$$NH_3 + H^+ \rightarrow NH_4^+ (6)$$

The subsequent increase of pH in surrounding medium due to the presence of ammonia ions and the additional release of Co_2 from the enzymatic urea hydrolysis further accelerate the rate of the urease-induced calcite precipitation. Thus, an active participation of urease is of essence in biochemical calcite precipitation.

2.3 Mix Proportion

A mix M25 grade was designed as per IS 10262:2009 and the same was used to prepare the test samples. M1 is the conventional mix and M2, M3, M4 and M5 are obtained by replacing cement with fly ash in the range of 10%, 20%, 30% and 40% by weight of cement.

Table 1. Mix Proportion

Mix	**Cement (Kg/m^3)**	**Fly Ash (Kg/ m^3)**	**Fine Aggregate (Kg/ m^3)**	**Coarse Aggregate (Kg/m^3)**	**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

3. RESULTS AND DISCUSSION

Concrete cubes of 150x150x150 mm, cylinders of 150 mm diameter x 300 mm height and prism of 100x100x500 mm were cast with the ratio provided. After casting and demoulding, the specimens were cured in bacterial medium. The compressive,splittingtensile and flexural strength tests were performed at 7, 14 & 28 days.

3.1 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.

Table 2. Slump Cone Result

Mix	**Fly Ash Content**	**Slump (mm)**
M1	0%	75
M2	10%	82
M3	20%	85
M4	30%	90
M5	40%	90

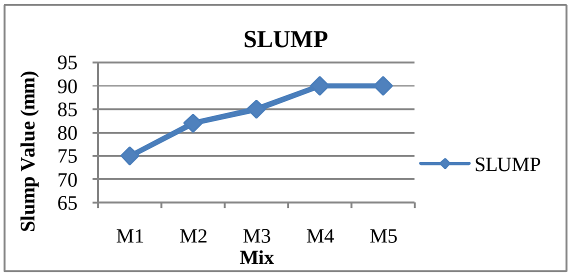

Figure1. Slump Cone Results

3.2 Compressive Strength

Compressive strength test is a mechanical test measuring the maximum amount of compressive load a material can bear before failure. Due to compression load, the cube undergoes lateral expansionowing to poisson's ratio effect.

Compressive strength = Maximum Load / Cross sectional Area N/mm^2

Table 3. Compressive Strength Result

Mix	Fly Ash by % of Cement	Average Compressive Strength MPa		
		7 Days	*14 Days*	*28 Days*
M1	0	16.75	23.00	27.20
M2	10	17.20	23.50	27.62
M3	20	18.00	23.87	28.05
M4	30	18.12	24.05	28.65
M5	40	18.05	23.90	28.40

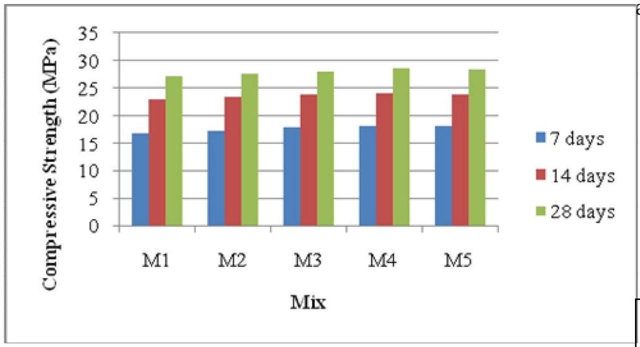

Figure2. Compressive Strength Results

3.3 Splitting Tensile Strength

The splitting test is easy to perform and procure uniform results when compared to other tension tests. Strength determined is much closer to the true tensile strength. It provides 5-12% higher value than the direct tensile strength.

$$\text{Splitting Tensile Strength} = \frac{2P}{\pi LD} \; N/mm^2$$

P= Compressive Load in kN
L=Length in m
D=Diameter in mm

Table 4. Splitting Tensile Strength Result

Mix	Fly Ash by % of Cement	Average Splitting 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

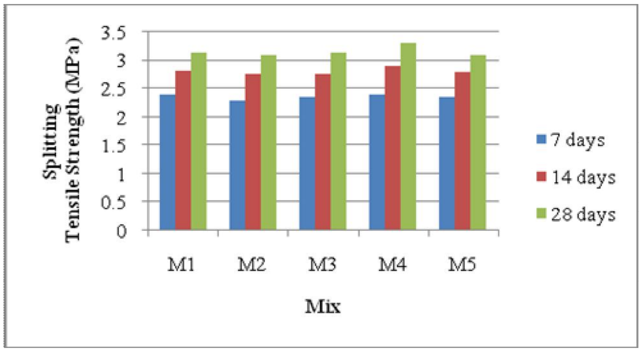

Figure 3. SplittingTensile Strength Results

3.4 Flexural Strength

The flexural strength of concrete prism was determined based on IS: 516 –1959.Beam specimens of size 100x100x500 mm were casted and placed in UTM and tested for flexural strength. The specimens are placed on two point loading setup and rollers above the specimens.

If a > 13.3cm, then

$$\text{Modulus of rupture } f_b = \frac{P \times l}{b \times d^2}$$

$$\text{If } a < 13.3 \qquad f_b = \frac{3P \times a}{b \times d^2}$$

If a < 11, Discard the specimen

Table 5. Flexural Strength Result

Mix	Fly Ash by % of Cement	Average Flexural Strength MPa		
		7 Days	*14 Days*	*28 Days*
M1	0	3.80	4.27	4.71
M2	10	3.65	4.20	4.70
M3	20	3.75	4.28	4.78
M4	30	3.82	4.35	4.82
M5	40	3.75	4.28	4.75

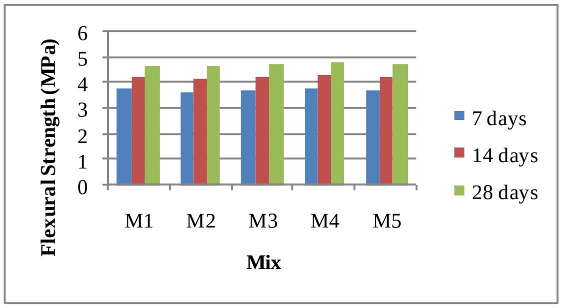

Figure. 4. Flexural Strength Results

The tests to evaluate the strength properties were carried out which clearly describes that Mix 4(M4) shows required result when compared to others mixes and the reference mix. It shows that as the percentage of fly ash increases it gradually increases the compressive,splitting tensile and flexural strength, which beyond 40% decreases gradually.

3.5 SEM Analysis

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample.

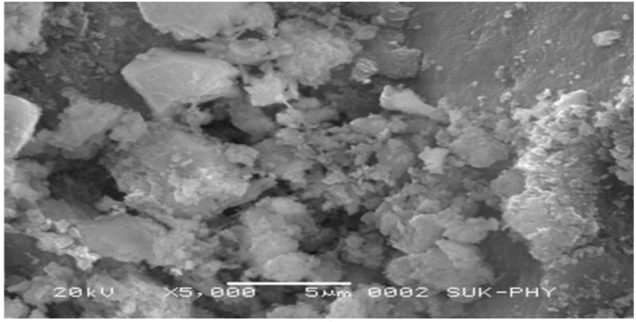

Figure 5. SEM Picture of Normal Concrete

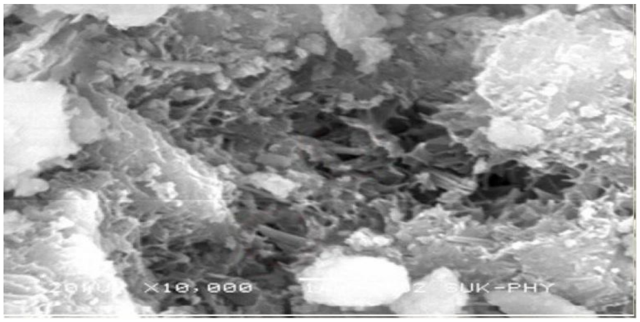

Figure6. SEM Picture of Fly Ash Concrete Showing

Bacterial Induced Calcite Deposition in Micro Cracks

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.

3.6 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.

Figure7. Sample with Cracks Due to Manual External Loading

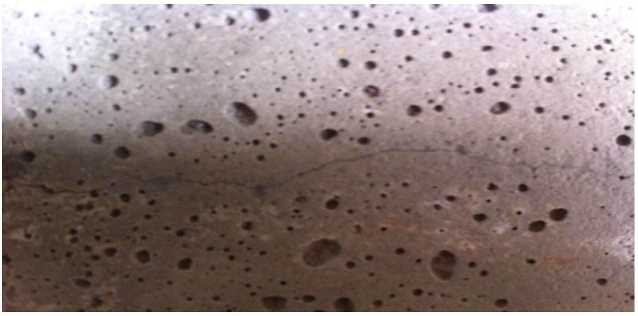

Figure8. Sample Taken After 28 Days Curing

4. CONCLUSION

i. Addition of fly ash leads to an increase in compressive strength, splitting tensile strength and flexural strength.
ii. Incorporating bacteria heals the micro cracks within and at the surface of concrete by $CaCo_3$ precipitation.
iii. Maximum compressive stress, Splitting tensile and Flexural strength develop in M-25 grade self-healing concrete by adding 30% fly ash.
iv. Addition of fly ash increases compressive strength by about 6%, the splitting tensile strength by about 4.7%, the flexural strength by about 2.5%.
v. SEM analysis confirms the mechanism of microbial calcite precipitation in concrete due to presence of Bacillus Megaterium.
vi. The analysis of self-healing capacity proves to show that 90 % of the crack is arrested.

5. SCOPE FOR FUTURE WORK

1. Durability properties like porosity, water absorption and sorptivity to know the effect of adding fly ash can be carried out.
2. This study could also be conducted for other types of concrete.
3. Performance of the bacterial concrete in pavements where the prevalence of cracks will be more can be investigated.

REFERENCES

[1] Henk M. Jonkers and Erik Schlangen, (2009) ‘A two component bacteria-based self-healing concrete’ ISBN 978-0-415-46850-3

[2] Jagadeesha Kumar B G and R Prabhakara, Pushpa H, (2013) ‘Effect of Bacterial Calcite Precipitation on Compressive Strength of Mortar Cubes’ ISSN: 2249 – 8958,Volume-2,Issue-3

[3] Jayeshkumar Pitroda, Dr. L.B.Zala, Dr.F.S.Umrigar (2012) ‘Experimental Investigations on Partial Replacement of Cement with Fly Ash in Design Mix Concrete’ E-ISSN 0976-3945

[4] Moinul Islam and Saiful Islam (2010) ‘Strength Behaviour of Mortar Using Fly Ash as Partial Replacement of Cement’ Concrete Research Letters-Vol. 1(3) 2010

[5] Oguzhan Copuroglu, Erik Schlangen, Henk M. Jonkers, Arjan Thijssen, Gerard Muyzer, (2008) ‘Application of bacteria as self-healing agent for the development of sustainable concrete’ Ecological Engineering 36 (2010) 230–235

[6] Pacheco-Torgal.F, J.A. Labrincha, (2013) ‘Biotech cementitious materials: Some aspects of an innovative approach for concrete with enhanced durability’ Construction and Building Materials 40 (2013) 1136–1141

[7] Seshagiri Rao M.V, V. Srinivasa Reddy, M. Hafsa, P. Veena and P. Anusha, (2013) ‘Bioengineered Concrete - A Sustainable Self-Healing Construction Material’ ISSN 2278 – 9472 Vol. 2(6), 45-51

[8] Srinivasa Reddy V, Jyothi Kumar K S, Seshagiri Rao M V, Sasikala Ch, (2013) ‘Studies on Permeability of Self-Healing Built-In Bacteria Concrete’ ISSN: 2277-3878, Volume-1

[9] Sunil Pratap Reddy.S, M. V. Seshagiri Rao, P. Aparna and Ch. Sasikala (2010) ‘Performance of Ordinary Grade Bacterial (Bacillus Subtilis) Concrete’ ISSN 0974-5904, Vol. 03

[10] Virginie Wiktor and Henk M. Jonkers, (2011) ‘Quantification of crack-healing in novel bacteria-based self-healing concrete’ Cement & Concrete Composites 33 (2011) 763–770

[11] Willem De Muynck, Kathelijn Cox, Nele De Belie, Willy Verstraete, (2007) ‘Bacterial carbonate precipitation as an alternative surface treatment for concrete’Construction and Building Materials 22 (2008) 875–885