## INTRODUCTION

### 1.1 GENERAL

Cement can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact mass. For constructional purposes cement is restricted to the bonding material which is used with stones, sand, bricks, blocks etc. It is the most important material in construction of structures because it is used at different stages of construction in the form of various forms viz mortar, concrete, cement slurry etc.

With nearly 420 million tonnes of cement production capacity, India is the second largest cement producer in the world and accounts for 6.9 per cent world's cement output. The cement production capacity is estimated to touch 550 million tonnes by financial year 2020. Of the total capacity, 98 per cent lies with the private sector and the rest with the public sector. The top 20 companies account for around 70 per cent of the total production.

A total of 188 large cement plants together account for 97 per cent of the total installed capacity in the country, while 365 small plants make up the rest. Of the total 188 large cement plants in India, 77 are located in the states of Andhra Pradesh, Rajasthan and Tamil Nadu. Cement production in India increased from 230 million tonnes in financial year 2012 to 280 million tonnes in financial year 2017.

Dalmia Cement Ltd has become the first cement company in India to commit itself to 100 per cent renewable power. The company plans to increase its capacity from existing 2.4 to 15-20 million tonnes by 2021 by investing US$ 1.27 billion. The Government of India is strongly focused on infrastructure development to boost economic growth and is aiming for 100 smart cities. It plans to increase investment in infrastructure to US$ 1 trillion in the 12th Five Year Plan (2012–17). The government also intends to expand the capacity of the railways and the facilities for handling and storage to ease the transportation of cement and reduce transportation costs. These measures would lead to increased construction activity thereby boosting cement demand.

The production of cement releases greenhouse gas emissions both directly and indirectly: the heating of limestone releases $CO_2$ directly, while the burning of fossil fuels to heat the kiln indirectly results in $CO_2$ emissions.

The direct emissions of cement occur through a chemical process called calcination. Calcination occurs when limestone, which is made of calcium carbonate, is heated, breaking down into calcium oxide and $CO_2$.

In this project efforts are being made to reduce the cement content by using flyash enriched with bacteria . Flyash enriched with bacteria is mixed in concrete that improves the durability, compressive strength, workability, mechanical properties. Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.

The bacteria to be used as self-healing agent in concrete should be suitable for that purpose i.e. they should be able to perform long-term effective crack sealing , preferably during the total construction life time .the principle mechanism of bacterial crack healing is the bacteria themselves act largely as a catalyst, and transform a precursor compound to a suitable filler material. The newly produced compound such as calcium carbonate-based mineral precipitates should than act as a type of bio cement what effectively seals newly formed cracks. Thus for effective self-healing, both bacteria and a bio cement precursor compound should be integrated in the material matrix. However, the presence of the matrix embedded bacteria and precursor compound should not negatively affect other wanted concrete characteristics.

Bacteria that can resist concrete mixture incorporation exist in nature ,and these appear related to a specialized group of alkali-resistant spore-forming bacteria interesting feature of these bacteria is that they are able to form spores ,which are specialized spherical thick walled cells somewhat homogeneous to plant seeds .this spores are viable but dormant cells and can withstand mechanical and chemical stresses and remain in dry state visible for periods over 50 years however, when bacterial spores were directly added to the concrete mixture, their life time appeared to be limited to one-two months. The decrease in life time of the bacterial spores from several decades when in dry state to only a few months when embedded in the concrete mixture may be due to the continuing cement hydration resulting in matrix pore-diameter widths typically much smaller than the 1- m sized bacterial spores.

Another concern is whether direct addition of organic bio-mineral precursor compound to be concrete mixture will not result in unwanted loss to the other concrete properties .In the preceding study it was indeed found that various organic bio-cement precursor compound such as yeast extract, peptone and calcium acetate resulted in dramatic decrease of compressive strength. The only exception appeared to be calcium lactate what actually resulted in 10% increase in compressive strength compare to control specimens. In order to substantially increase the life time and associated functionality of concrete incorporated bacteria, the effect of bacterial spore and simultaneously needed organic bio mineral precursor compound immobilization in porous expanded clay particles was tested in this study.

It was found of the bacterial spores by immobilization inside porous expanded clay particles before addition to the concrete mixture in deed substantially prolonged their life time. Currently running viability experiments show that still after six months concrete incorporation no loss of viability is observed, suggesting that their long term viability as observed in dried state when not embedded in concrete in maintained. In subsequent experiments the expanded clay particles loaded with two component biochemical healing agent were applied as additive to the concrete mixture to test self healing potential of bacterial concrete.

### 1.2OBJECTIVE OF THE STUDY

- To replace cement in concrete with fly without compromising in strength and durability.
- To enrich flyash with bacteria so as to achieve higher percentage of replacement to cement in concrete.
- To ensure the partial replacement of cement with flyash enriched with bacteria is having required strength and durability characteristics.
- To reduce the emission of $CO_2$ in atmosphere by reducing the requirement of cement.
- To ensure major quantity of fly ash is produce is utilized in a better way.

## 1.3 SCOPE OF THE PROJECT

- To make mix design for M40 concrete.
- Casting the specimens for durability characteristics and testing the concrete specimens for a period of 180 days.
- Comparing the bacterial concrete with control concrete.
- Tests to be conducted are RCPT, Acid Resistance, Air and Water Permeability, SEM and XRD
- Comparing the cost raw materials, electricity, water, release of carbon dioxide in atmosphere with normal concrete and concrete made with flyash enriched with bacteria.

## RESULTS AND OBSERVATIONS

### GENERAL

In this chapter we discuss about the results of conventional concrete and bacterial concrete .testing procedure are explained and result are tabulated. Compressive strength, RCPT ,Impact test , Split Test , Permeability Test , Acid Resistance Test were conducted to find the durability characteristics of concrete made with fly ash enriched with bacteria .

### COMPRESSIVE STRENGTH TEST

### 1 Test procedure for compressive strength

After curing the specimen, the specimens are taken out removed of surface dust and tested .Apply a compressive axial load to a cube specimen by macine shown if Fig. 4.1 in at a prescribed rate until failure occur .Calculate and report the compressive strength.
Compressive strength = Maximum load / cross section area of specimen

**Fig. 4.1 Compression Testing Machine**

### 2 Testing on specimen and result

The methods adopted to finding the compressive strength of concrete are as per IS 456:2000. The results of compressive strength of concrete cube of M40 design of specimens with different percentages of flyash and the value is tabulated in Table 4.1 and 4.2 for 28 days.

**Table 4.1 Compressive Strength Of Cubes**

| SPECIMEN | COMPRESSIVE STRENGTH N/mm$^2$ |
|---|---|
| CF25 | 33.76 |
| CF30 | 39.46 |
| CF35 | 35.66 |
| CF40 | 38.83 |

The graph below in Fig. 4.2 shows the compressive strength of cubes with different percentage of flyash used in concrete.

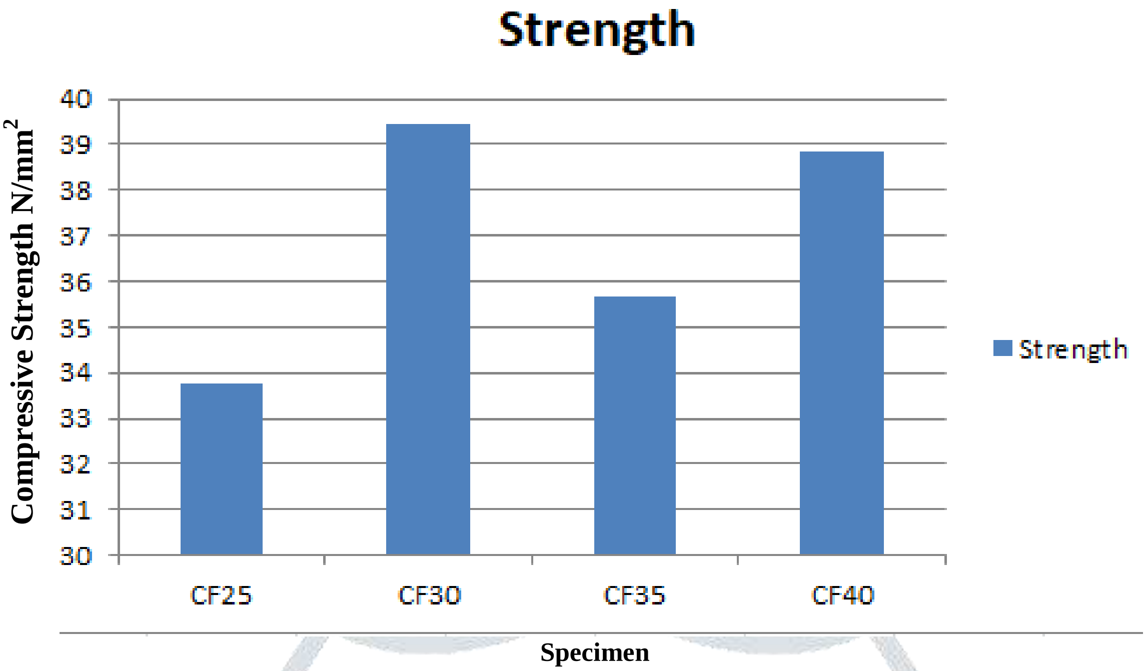


**Fig .4.2 Compressive Strength of Cubes**

These different % of flyash added is just to determine which of the composition has the maximum compressive strength, sofrom the above graph we can predict that the CF30 has the maximum compressive strength.

The addition of bacteria to the fresh concrete results in the formation of CaCO3 precipitation that can be observed through the naked eye as shown in Fig. 3.9. Fig. 3.9 presents photographs of typical RCA concrete with *B. Subtilis* and *B. sphaericus* (106 cells/ml), RCA control and NCA concrete without bacteria. White foam like material can be visualised in the outer surface of the bacterial concrete sample (Figs. 3.9a and 3.9b) which are absent in other two

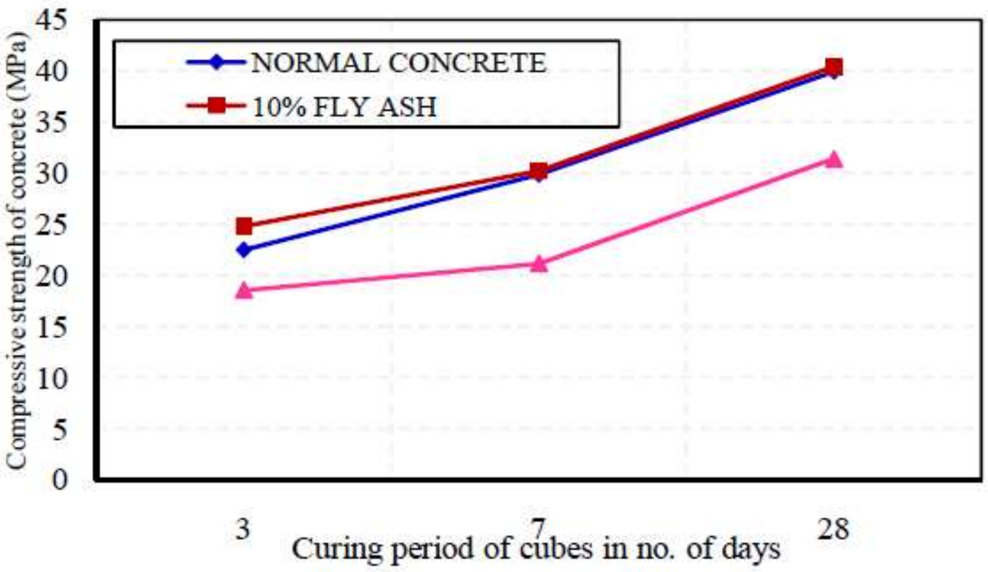


**Fig: 4.3 (A) Compressive strength result without bacterial solution**

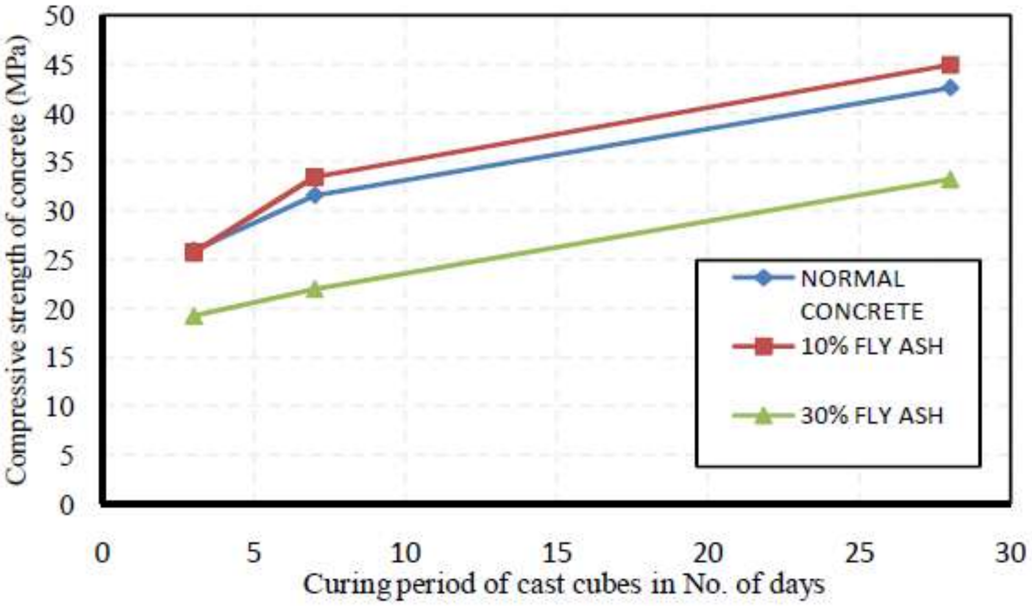


**Fig 4.3 (B) Compressive strength result with bacterial solution**

The mean compressive strength for specimens with different concentration of bacteria at 7 days and 28 days are presented in Table 3.14. It is observed that the compressive strength of bacterial concrete increases with the increase of cell concentration for both 7 days and 28 days strength. However, after cell concentration of 106 cells/ml the trend reverses. The same results are plotted in Figs. 3.10 and 3.11 for *B. subtilis* and *B. sphaericus*. The maximum increment of 28 days compressive strength of RCA concrete is found to be 20.93% for *B. Subtilis* (B-3a) and 35.87% for *B. sphaericus* (B-3b) with respect to RCA control mix with an optimum cell concentration of 106 cells/ml. The same trend is also reported for bacterial NCA concrete in the literature [Chahal *et al.* 2012a, 2012b]. This increase of compressive strength may be due to the precipitation of CaCO3 by bacteria on the micro-organism cell surfaces and within the inner side of the concrete which is confirmed in the microstructure analysis (refer section 3.4.3.5 and 3.4.3.6). The compressive strength is improved by the microbiological precipitation of CaCO3 in the micro pores of concrete. Since the cell concentration of 106 cells/ml yields maximum compressive strength of RCA concrete the further investigation on bacterial concrete are conducted only considering this cell concentration for both the two selected bacteria (B-3a and B-3b).

**(a) Concrete with *B. subtilis* (B-3a)**

**(b) Concrete with *B. sphaericus* (B-3b)**

**(c) Concrete without bacteria (Control)**

**(d) Concrete without bacteria**

**Fig: 4.4 Photographs of fresh concrete specimens**

## Split Tensile Strength Results

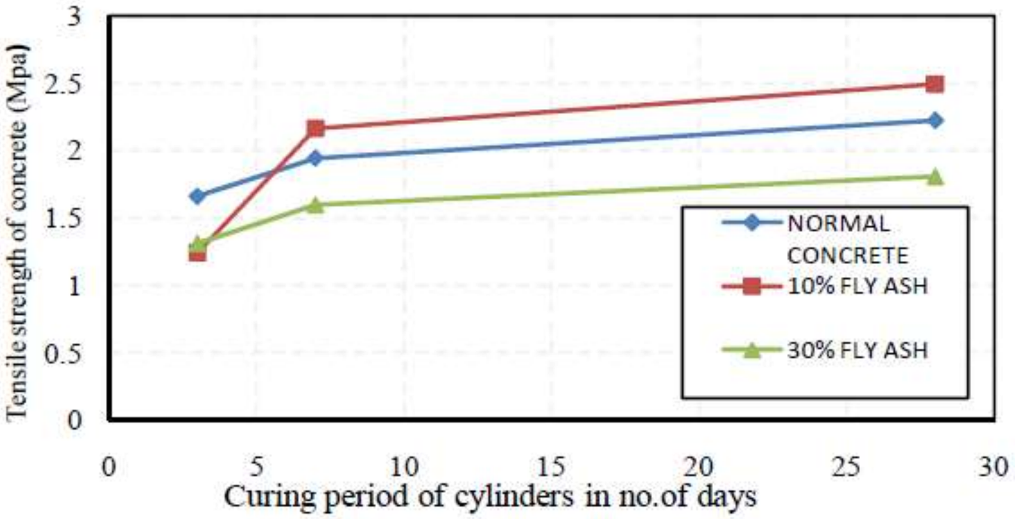
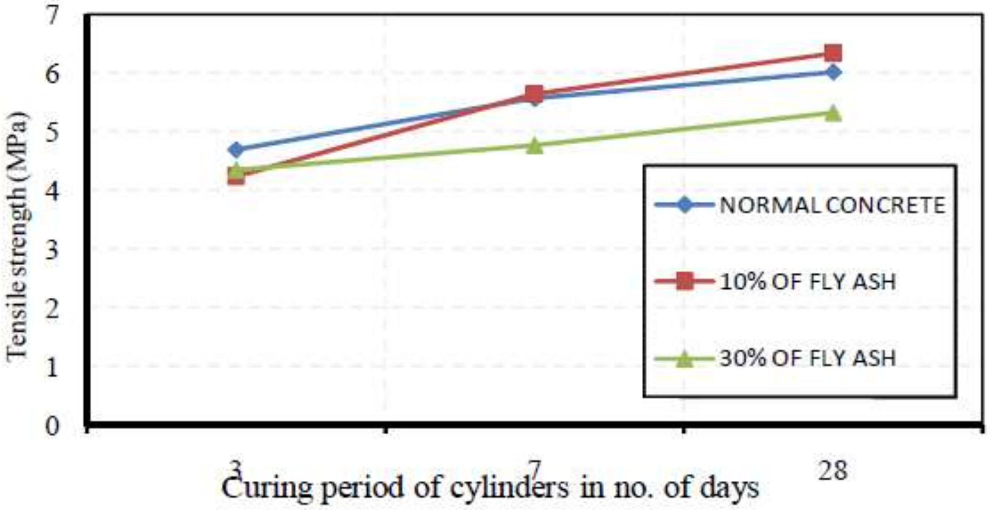


Fig:4.5 (A) Tensile strength result without bacterial solution

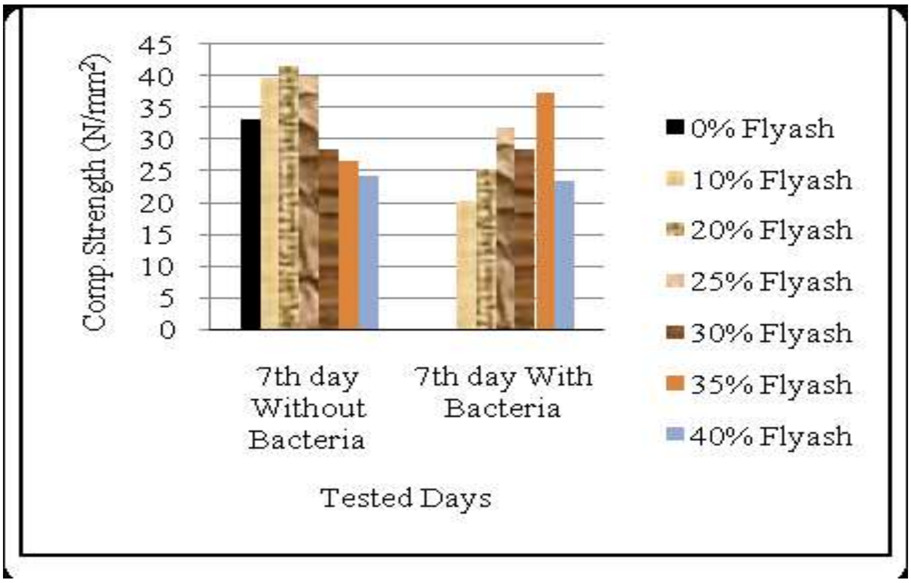


Fif:4.5(B) Tensile strength result with bacterial solution

## Flexural strength results

Table 4.2Flexural Strength Of Beams

| SPECIMEN | FLEXURAL STRENGTH N/mm$^2$ |
|---|---|
| CF25 | 3.2 |
| CF30 | 4 |
| CF35 | 4.8 |
| CF40 | 4.4 |
| | |



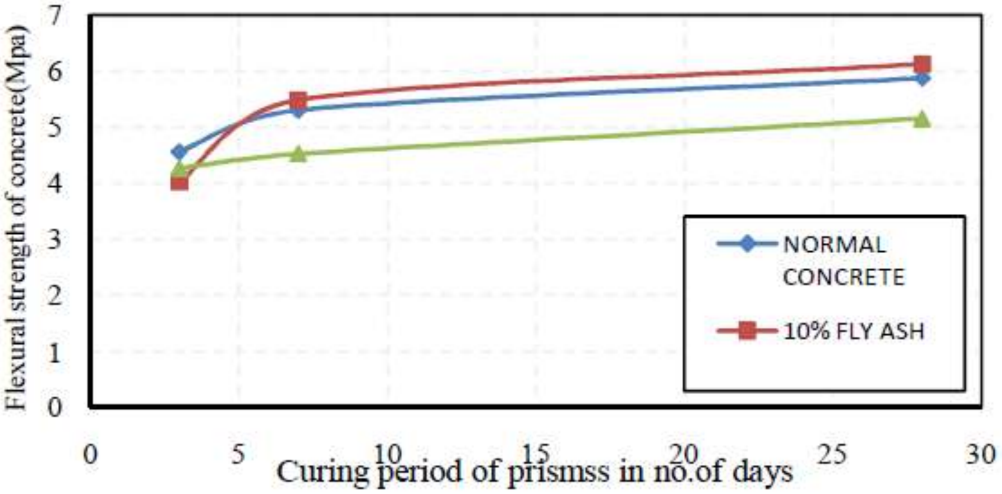


Fig:4.6 (A) flexure strength without bacteria

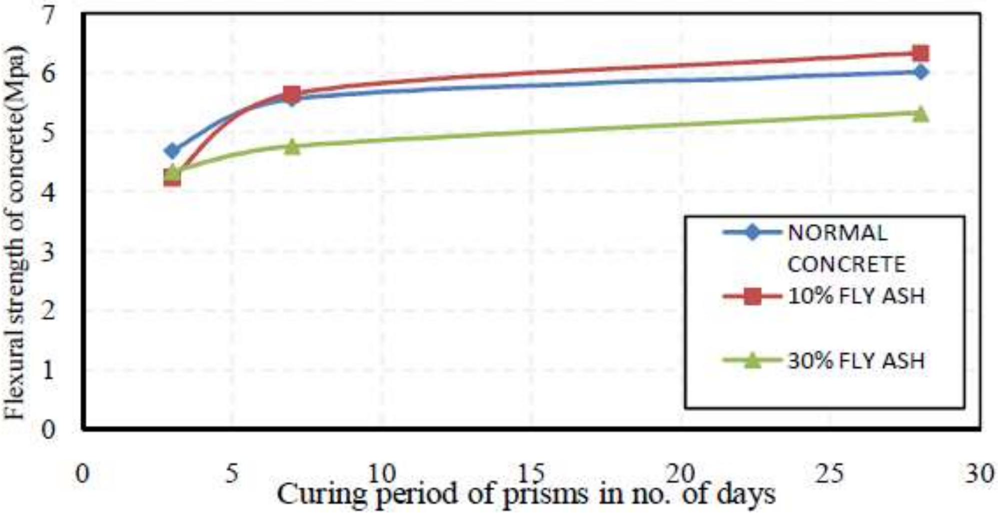


Fig:4.6 (B) flexure strength with bacteria

**Fig. 4.7 Flexural Test On Beam**

Flexural strength of beams as shown in Fig.. 4.4got increased in CF35 and then it is getting reduced as the amount of flyash is added more. As the aim of this research is to replace higher percentage of cement from concrete, the specimen with more % of flyash with bacterial concrete will be added and then all the test will be done and compared to get the best composition with better results.

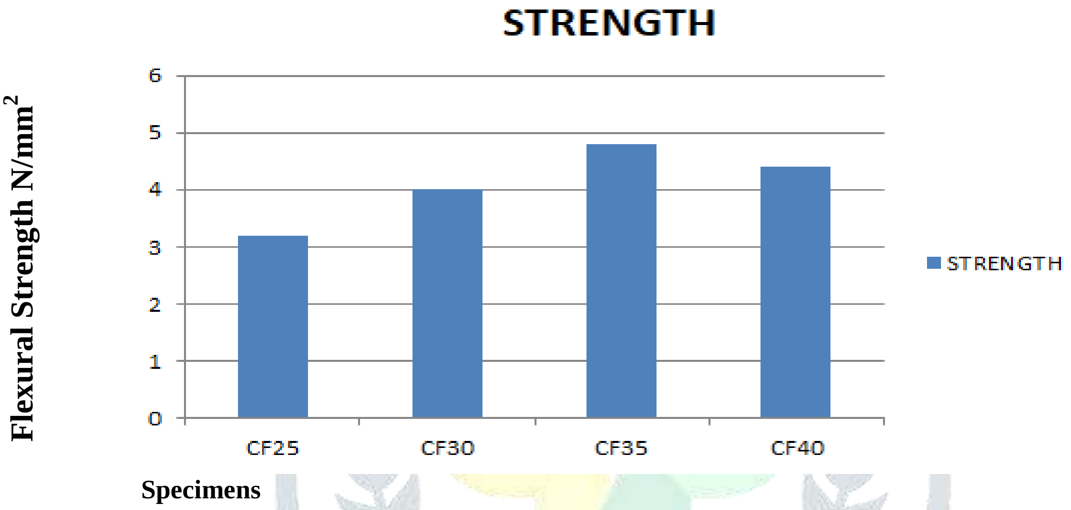


**Fig 4.8 Flexural Strength of Beams**

Unlike a compression test or tensile test, a flexure test does not measure fundamental material properties. When a specimen is placed under flexural loading all three fundamental stresses are present: tensile, compressive and shear and so the flexural properties of a specimen are the result of the combined effect of all three stresses as well as (though to a lesser extent) the geometry of the specimen and the rate the load is applied.

The most common purpose of a flexure test is to measure flexural strength and flexural modulus. Flexural strength is defined as the maximum stress at the outermost fiber on either the compression or tension side of the specimen. Flexural modulus is calculated from the slope of the stress vs. strain deflection curve. These two values can be used to evaluate the sample materials ability to withstand flexure or bending forces.

Water absorption results

The influence of bacteria on the water absorption of fly ash concrete is given in Table 4.3 and shown in Fig. 4.9. Water absorption test at 7-days was conducted as per ASTM C 642 [19]. It can be seen from this figure that with the inclusion of bacteria, water absorption capacity of fly ash concretes decreased with the increase in bacteria concentration. Maximum reduction in water absorption was observed with 105 cells/ml for all fly ash concretes; however, concrete with 10% fly ash concrete gave 3.25% water absorption (minimum).

The presence of bacteria resulted in a significant decrease in the water uptake compared to control specimens. The deposition of a layer of calcium carbonate on the surface and inside pores of the concrete specimens resulted in a decrease of water absorption and permeability. Once the pores are sealed, reduction in water ingress is observed. This bacterial action deposition can seal the pores, voids and microcracks, where other sealants are unable to work through. Nemati and Voordouw noticed a decrease in the permeability of sandstones cores after injecting calcium carbonate forming reactants. Hence, from this experiment, it is clear that the presence of a layer of carbonate crystals on the surface by bacterial cells has the ability to improve the resistance of cementitious materials towards degradation.

| Mixture no. | Bacteria concentration (cells/ml) | | | |
|---|---|---|---|---|
| | 0 | $10^3$ | $10^5$ | $10^7$ |
| M-1 (0% fly ash) | 17.7 | 14 | 13 | 13.7 |
| M-2 (10% fly ash) | 14 | 4 | 3.25 | 3.7 |
| M-1 (20% fly ash) | 16 | 6.9 | 5.2 | 7 |
| M-1 (30% fly ash) | 17.4 | 7.8 | 6.9 | 8 |

**Table 4.3 Effect of bacteria on water absorption of fly ash concrete**

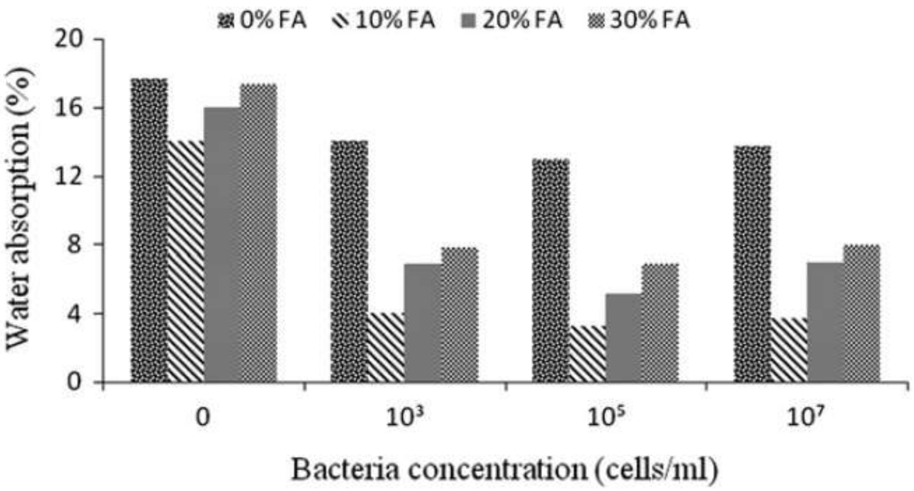
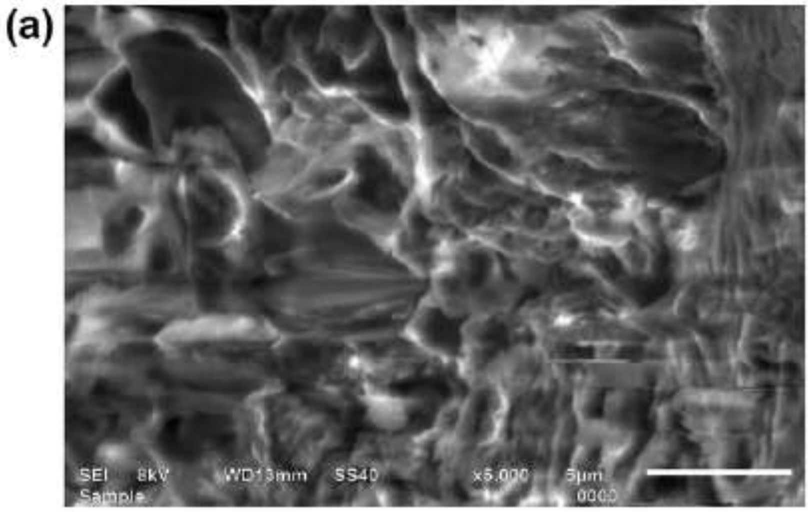


**fig:4.9 Effect of bacteria on water absorption of flyash concrete at 7days**

**Scanning Electron microscopy results**

Calcite precipitation in fly ash concrete was carried out by SEM analysis. Fig. 4.10 (a) shows the SEM picture of control concrete, wherein, pores can be easily seen inside it. The SEM analysis of fly ash concrete with S. bacillus 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. Fig. 4.10b shows the presence of crystalline calcium carbonate associated with bacteria. The deposition of calcite serves as barrier to harmful substances and thus improves impermeability



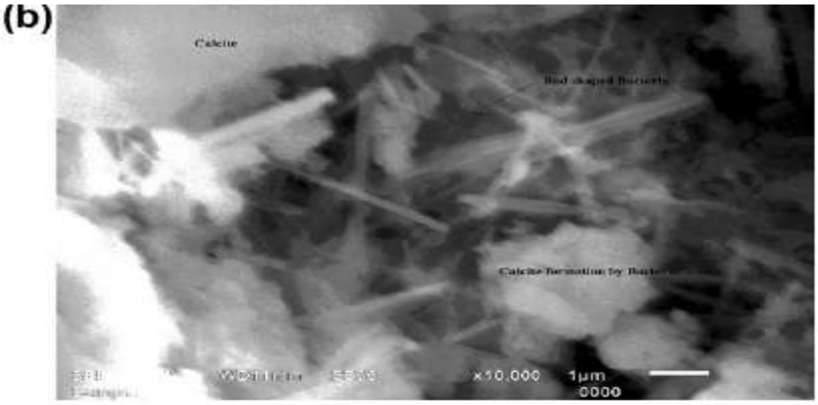


**Fig 4.10 SEM images of (A) control concrete (B) flyash concrete (containing 10% flyash + 10^5 cell/ml of bacteria) showing induced calcite deposition in microcracks**

## Rapid chloride permeability test results

Results of the effect of bacteria on the rapid chloride permeability of fly ash concrete at the age of 28 days, is given in Table 10 and shown in Fig. 4. It is clear from this figure that with the inclusion of bacteria, chloride ingress capacity of fly ash concretes decreased with the increase in bacteria concentration. Maximum reduction in chloride ions was observed with 105 cells/ml for all fly ash concretes; however, concrete with 30% fly ash concrete gave 762 coulombs penetration which is considered to be very low. The ability of concrete to resist the penetration of chloride ions is a critical parameter in determining the service life of concrete structures exposed to deicing salts or marine environments. The concrete containing fly ash along with optimized dose of bacteria (S. bacillus) showed good resistance towards rapid chloride penetration.

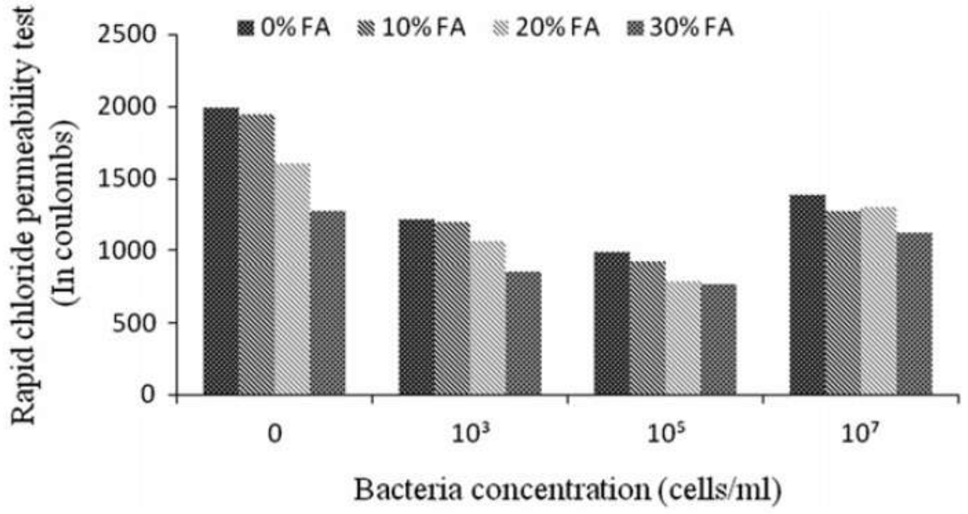


**Fig 4.11 Effect of bacteria on the rapid chloride permeability of fly ash concrete at 28 days**

| Mixture no. | Bacteria concentration (cells/ml) | | | |
|---|---|---|---|---|
| | 0 | $10^3$ | $10^5$ | $10^7$ |
| M-1 (0% fly ash) | 1988 | 1210 | 989 | 1382 |
| M-2 (10% fly ash) | 1943 | 1189 | 915 | 1268 |
| M-1 (20% fly ash) | 1604 | 1062 | 789 | 1293 |
| M-1 (30% fly ash) | 1266 | 853 | 762 | 1120 |

**Fig 4.12 Effect of bacteria on the rapid chloride permeability of fly ash concrete**