An experimental studies on strength properties of bacterial concrete

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Abstract. Cement concrete is a massively used construction material throughout the world and in the process of manufacturing of one ton of cement 850 kg of CO₂ is emitted into the atmosphere. In this research, bacterial concrete was produced by replacing part of cement in controlled concrete with equal volume of class F fly ash enriched with bacteria *Bacillus sphaericus* (*B. sphaericus*) such that the strength of 28 days of bacterial concrete is at par with controlled concrete. *B. sphaericus* precipitate Calcium Carbonate while producing bacterial culture which fills the minute pores in bacterial concrete and makes it attain higher strength. Experiments were made by replacing cement from 0% to 50% with class F fly ash enriched with bacteria *B. sphaericus* and found that bacterial concrete made with of 25% replacement (M2CFB25) is suitable in fresh state and in hardened state. In fresh concrete with water cement ratio of 0.4 the compaction factor of controlled concrete (M2CC) was 0.85, fly ash concrete with 25% replacement to cement (M2CF25) was 0.84 whereas for M2CFB25 it was 0.89 which is more advantageous for M2CFB25 to get good compaction. Compressive strength of 28 days concrete M2CC, M2CF25 and M2CFB25 are 45.19 N/mm², 41.23 N/mm² and 48.11 N/mm². Similarly 28 days concrete split tensile and flexural strength of M2CFB25 is higher than M2CC and M2CF25. Fly ash concrete M2CF25 has gained less compressive strength, split tensile and flexural strength than M2CC on 28 days of curing. X-Ray diffraction test results indicated M2CFB25 have more peaks than M2CC and M2CF25 and thereby confirmed the presence of higher CaCO₃ in bacterial concrete. The usage of bacterial concrete M2CFB25 in lieu of M2CC will reduce the amount of CO₂ emitted to the atmosphere and reduce the depletion of natural resources.

1. Introduction

Concrete is a very widely used and inevitable construction material as it is very versatile and economical [1]. Concrete is a mixture of cement, coarse aggregates, fine aggregates and water in a designed proportion and is considered as a homogeneous material. Cement is the binding material in concrete, and it is produced in cement manufacturing plants. The other ingredients like water, coarse aggregate, and fine aggregate used in concrete are locally available natural resources. Aggregates are inert materials to give solid volume to the concrete and water is added for hydration of cement and in addition to give workability to fresh concrete. The strength of concrete depends on water cement ratio (w/c), the minimum water cement ratio required for 100% hydration of cement is about 0.38 [2][3], whereas excess water is added to obtain required workability of fresh concrete, results in excess voids...
and weakens the concrete [4]. In recent times bacteria are being used for self-healing of concrete [5][6], to increase the compressive strength of concrete [6][7] and to increase the concrete durability by decreasing the permeability in concrete [8][9]. Fly ash concrete is gaining less compressive strength than the controlled concrete at early ages [10]. In this research bacterial concrete was produced by replacing part of cement in controlled concrete with equal volume of class F fly-ash enriched with bacteria Bacillus sphaericus (B.sphaericus). Bacteria B.sphaericus was selected based on the research made on selection of bacteria[11]. The calcium carbonate (CaCO₃) precipitated by bacteria is insoluble in water [12] hence it improves the properties of concrete. Bacillus bacteria are Gram-positive and they are used in bacterial concretes as their cells serve as a nucleation site for CaCO₃ precipitation [13].

Bacteria are being used to repair the cracks in olden monuments as they precipitate calcium carbonate in conducive environments[14]. Bacteria added in concrete are used to precipitate calcium carbonate in the cracks once the bacteria get water and oxygen through the fresh cracks formed and cracks will be healed and this concrete is called self-healing concrete[15]. Concrete strength and durability can be enhanced by the addition of bacteria. The calcium carbonate precipitated by bacteria fills the minute pores in concrete and the compressive strength of concrete was increased by 25% to 30% when B.sphaericus was used to produce bacterial concrete. The split tensile strength of conventional M20 grade concrete at 28 days is 3.26 N/mm²[16] while bacteria B.subtilis was used the strength was 3.73 N/mm². Experiments were made with pure and mixed cultures of bacteria and found that pure culture treated concrete specimen had more pronounced decrease in uptake of water than mixed ureolytic culture[17].

2. Materials and Methods
The materials used in production of bacterial concrete are described here with.

2.1 Ordinary Portland cement
Ordinary Portland cement 53 grade conforming to Bureau of Indian Standards (IS:12269-2013) [18] was used for this research. Tests were conducted for specific gravity, setting time, fineness, compressive strength, loss on ignition and insoluble residue. The results fulfill the requirements of Indian Standards and hence the same was used to produce bacterial concrete.

2.2 Fine and coarse aggregates
Fine aggregate used in this research is river sand free from impurities and the specific gravity of sand was found to be 2.6. Tests were made to find the fineness modulus of fine aggregate and it is confirmed that the sand belongs to Zone II as per IS 383 -1970[19]. Air dried fine aggregate free from dampness is stored and used to cast concrete specimens. Water absorption of sand is found to be 0.5% as per IS 2386 (Part III) – 1963.

Coarse aggregates were obtained by crushing the black granite stones which were passing through 20 mm, angular and the specific gravity was found to be 2.7. The tests were conducted for crushing, impact and abrasion as per IS 2386 (Part IV) – 1963[20]. The results indicate the average of crushing values was 27, impact value was22 and Los Angeles abrasion value was 28. Test results confirmed that the aggregates were very good quality and the same was used for research work. The sizes of coarse aggregates used to produce concrete were 1) 50% of the aggregate used in concrete was passing through 20 mm sieve and retained on 10 mm sieve. 2) Balance 50% of the aggregate was passing through 10 mm and retained on 4.75 mm sieve.

2.3 Fly ash
Fly ash for this research work was procured from coal based Ennore thermal power station and stored in a dry place by packing in polyethylene bags. The test results of fly ash are shown in table 1 and it conforms to class F fly ash[21].
| Sl No | Properties                              | Units | Experimental results |
|-------|-----------------------------------------|-------|----------------------|
| 1     | The specific gravity                    | ------| 2.12                 |
| 2     | Particle size (Retained on 45 micron)   | %     | 31.0%                |
| 3     | Loss on Ignition                        | %     | 1.52                 |
| 4     | SiO₂                                    | %     | 56.77                |
| 5     | Al₂O₃                                   | %     | 31.83                |
| 6     | Fe₂O₃                                   | %     | 2.82                 |
| 7     | CaO                                     | %     | 0.78                 |

2.4 Bacteria

Bacteria required for producing bacterial concrete need to be non-pathogenic bacteria, capable of producing calcium carbonate in a conducive environment. Bacillus bacteria are non-pathogenic, Gram-positive and they are used in bacterial concretes as their cells serve as a nucleation site for CaCO₃ precipitation [13]. Bacteria *B.sphaericus* was selected based on literature review and the experiments conducted on bacterial concrete [11]. *B.sphaericus* culture was obtained from The Microbial Type Culture Collection and Gene Bank, Institute of Microbial Technology (IMTECH), Chandigarh. To culture the bacteria *B.sphaericus* was grown in petri plates in nutrient agar at 37°C for 24 hours is shown in figure 1.

![Figure 1. Growth of bacteria *B.sphaericus* in petri plates.](image)
The Bacteria was cultured at Center for Environmental Nuclear Research, SRM IST, Kattankulathur, Tamil Nadu, India by using Bioreactor. The optimum temperature maintained for growth of bacteria is 37°C for 24 hours. The Bioreactor functioning set up is shown in figure 2, where it is possible to control temperature, revolution per minute, air flow and it protects the bacterial culture from contamination.

2.5 Bacterial concrete
In bacterial concrete part of cement was replaced with equal volume of fly ash enriched with bacteria B.sphaericus. In the process of enriching the fly ash with B.sphaericus, the uniform mixture of fly ash with bacterial solution possessing the precipitated CaCO$_3$ was ensured. In bacterial concrete CaCO$_3$ fills the minute pores in concrete and thereby makes the bacterial concrete to attain higher strength, more durability with less permeability[22][23].

2.6 Concrete proportions
In this research mix design was made to prepare M40 concrete (M2). Test specimens were made for controlled concrete (M2CC), fly ash concrete (M2CF) and bacterial concrete with B.sphaericus (M2CFB). Fly ash concrete with different proportions were made by replacing 10%, 20%, 25%, 30%, 35%, 40%, 45% and 50% of cement with equal volume of fly ash and they are designated as M2CF10, M2CF20, M2CF25, M2CF30, M2CF35, M2CF40, M2CF45 and M2CF50 respectively. Similar percentages of cement were replaced in bacterial concretes (M2CFB) made with fly ash enriched with bacteria B.sphaericus and they are designated as M2CFB10, M2CFB20, M2CFB25, M2CFB30, M2CFB35, M2CFB40, M2CFB45 and M2CFB50.

2.7 Tests Performed
The tests performed to establish the strength properties of bacterial concrete are 1) Compressive strength 2) Split tensile strength 3) Flexural strength and 4) X-Ray diffraction test (XRD). Compressive strength of concrete was obtained by testing concrete cubes of size 100 mm $\times$ 100 mm $\times$100 mm. Split tensile strength of concrete was obtained by testing concrete cylinders of size 100 mm diameter and 200 mm long. Flexural strength of concrete was obtained by testing concrete beams of size 100 mm $\times$ 100 mm $\times$500 mm. These tests were performed by using Digital Compression Testing Machine at Concrete and Highway lab at SRM Institute of Science and Technology at Kattankulathur, Tamil Nadu, and India. Concrete cylinders were cured for 28 days and a thin layers were cut from it and small chips of each concrete is taken and made very smooth and polished by rubbing with
grinding stones, sand paper and they were tested for X-Ray diffraction at Nano laboratory of SRM Institute of Science and Technology. Figure 3 showing the Digital Compression Testing Machine.

Figure 3. Digital Compression Testing Machine.

3. Results and discussion
The results of compressive strength, split tensile strength, flexural strength and X-Ray diffraction test of concrete specimens of M2CC, M2CF and M2CFB are discussed herewith. The test results of compressive strength, split tensile strength, flexural strength of concrete were obtained by testing three samples and the average strength and standard deviations are given in the figures and tables. In each proportion tests were conducted after curing for a period of 7 days, 14 days, 28 days, 56 days, 90 days and 180 days.

3.1 Compressive Strength of Concrete
Concrete cubes of size 100mm × 100 mm ×100 mm were cast for M2CC, M2CF and M2CFB. The compressive strength with error bar of controlled concrete M2CC and fly ash concrete M2CF10 to M2CF50 are shown in figure 4.
Figure 4. Compressive strength of fly ash concrete.

The controlled concrete M2CC has gained higher strength than fly ash concrete of all proportions from 10% to 50% on 28 days of curing. Fly ash concrete has gained higher strength during extended curing time. Testing was done on 7 days, 14 days, 28 days, 56 days, 90 days and 180 days. The compressive strength of 28 days M2CC was 45.19 N/mm$^2$ and fly ash concrete M2CF10 was 43.20 N/mm$^2$ and for M2CF50 was 33.47 N/mm$^2$. The compressive strength of 28 days fly ash concrete vary from 0.96 times to 0.74 times of M2CC. The fly ash concrete gained higher compressive strength on extended curing period. It is found that fly ash concrete M2CF45 and M2CF50 on 180 days of curing had gained 0.99 times and 0.97 times of M2CC cured for 28 days. The other proportions of fly ash concretes M2CF10 to M2CF40 had gained higher compressive strength on 180 days of curing than M2CC on 28 days.

Fly ash concrete has loses its strength gradually when percentage of percentage of fly ash increased to replace cement in concrete irrespective of curing period. Compressive strength of controlled concrete cured for 28 is 45.19 N/mm$^2$ when 10% to 50% fly ash is used to replace cement compressive strength is reduced from 4.40% to 25.93%. Adesanya has stated that when corn cob ash was used to prepare blended concreto from 0% to 25% it is found that compressive strength was gradually reduced as percentage of replacement for a period up to 60 days. Higher compressive strength was obtained for replacement of 5% to 10% on 120 days and 180 day than control concrete[24].

The compressive strength with error bar of controlled concrete M2CC and bacterial concrete M2CFB10 to M2CFB50 are shown in figure 5.
Figure 5. Compressive strength of bacterial concrete.

The controlled concrete M2CC has gained compressive strength of 45.19N/mm$^2$ on 28 days of curing. The compressive strength of 28 days cured bacterial concrete were made with replacement of cement with fly ash enriched bacteria from 10% to 40% had gained higher strength than M2CC, and strength varies from 1.11 times to 1.02 times of M2CC. Bacterial concrete mixes M2CFB45 and M2CFB50 had gained higher strength than M2CC (45.19N/mm$^2$) on 90 days and 180 days of curing. Using bacterial concrete up to 40% of cement can be replaced without any loss of compressive strength on 28 days of curing.

Nosouhian has made research in bacterial concrete and found that the compressive strength of 270 days bacterially treated specimen gained 25.42% higher compressive strength than Controlled concrete (28 days strength)[13].

3.2 Split Tensile Strength of Concrete

Concrete cylinders were cast for controlled concrete (M2CC) as per mix design M2, fly ash concrete were made by replacing part of cement with class F fly ash. The percentages of replacement of cement were 10, 20, 25, 30, 35, 40, 45 and 50. The specimens used for this test are cylinders of were 100 mm diameter and 200 mm long. The split tensile strength of concrete is obtained by testing three samples and the average of split tensile strengths with standard deviations are given in table 2.

The split tensile strength of M2CC on 28 days is 4.35 N/mm$^2$ and of fly ash concrete M2CF10 to M2CF50 have attained lesser split tensile strength than M2CC and they were in the range of 0.92 to 0.58 times of M2CC. Fly ash concrete mixes M2CF25 to M2CF50 have not gained the split tensile strength of M2CC (4.35N/mm$^2$) even after 180 days of curing and they are in the range from 0.99 to 0.68 times of M2CC.

Hefni did research with fly ash concrete by activating with different chemicals. It is found that split tensile strength of controlled concrete was not achieved by fly ash concrete till 56 days and when fly ash was activated with Aquis Na$_2$SiO$_3$ split tensile strength was higher than controlled concrete on respective curing periods starting from third day.
### Table 2. Split tensile strength of fly ash concrete with standard deviation.

| Days | M2C | M2CF | M2CF | M2CF | M2CF | M2CF | M2CF | M2CF | M2CF |
|------|-----|------|------|------|------|------|------|------|------|
|      | 7   | 14   | 28   | 56   | 90   | 180  |      |      |      |
|      | 3.23| 3.82 | 4.35 | 4.53 | 4.56 | 4.63 |      |      |      |
|      | 2.94| 3.52 | 4.02 | 4.28 | 4.41 | 4.51 |      |      |      |
|      | 2.85| 3.41 | 3.94 | 4.07 | 4.24 | 4.41 |      |      |      |
|      | 2.77| 3.37 | 3.82 | 3.95 | 4.18 | 4.29 |      |      |      |
|      | 2.43| 2.96 | 3.43 | 3.64 | 3.75 | 3.85 |      |      |      |
|      | 2.09| 2.58 | 2.91 | 3.02 | 3.24 | 3.29 |      |      |      |
|      | 1.91| 2.45 | 2.72 | 2.85 | 2.92 | 3.18 |      |      |      |
|      | 1.73| 2.34 | 2.59 | 2.73 | 2.75 | 3.07 |      |      |      |
|      | 1.65| 2.21 | 2.53 | 2.65 | 2.76 | 2.96 |      |      |      |

### Table 3. Split tensile strength of bacterial concrete with standard deviation.

| Days | M2CC | M2CFB | M2CFB | M2CFB | M2CFB | M2CFB | M2CFB | M2CFB | M2CFB |
|------|------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 7    | 14    | 28    | 56    | 90    | 180   |      |      |      |
|      | 3.23 | 3.82  | 4.35  | 4.53  | 4.56  | 4.63  |      |      |      |
|      | 3.14 | 3.95  | 4.56  | 4.97  | 5.03  | 4.97  |      |      |      |
|      | 3.02 | 3.87  | 4.43  | 4.81  | 5.03  | 4.84  |      |      |      |
|      | 2.98 | 3.76  | 4.38  | 4.77  | 4.78  | 4.58  |      |      |      |
|      | 2.91 | 3.64  | 4.20  | 4.48  | 4.58  | 4.55  |      |      |      |
|      | 2.88 | 3.59  | 4.16  | 4.43  | 4.55  | 4.48  |      |      |      |
|      | 2.83 | 3.45  | 4.05  | 4.43  | 4.48  | 4.40  |      |      |      |
|      | 2.69 | 3.31  | 3.62  | 3.94  | 4.05  | 4.05  |      |      |      |
|      | 2.43 | 2.92  | 3.29  | 3.66  | 3.72  | 3.74  |      |      |      |

The results show that the bacterial concrete, enriched with \textit{B. Sphaericus}, achieved higher tensile strength compared to the controlled concrete. The percentages of replacement of cement were 10, 20, 25, 30, 35, 40, 45, and 50. The specimens used for this test were cylinders of 100 mm diameter and 200 mm long.

The split tensile strength of 28 days controlled concrete M2CC was 4.35 N/mm$^2$ and bacterial concrete M2CFB10 to M2CFB25 have gained higher strength than controlled concrete as the calcium carbonate precipitated by bacteria were able to fill the pores and they are in the range of 1.05 times to 1.01 times of M2CC and other proportions from M2CFB30 to M2CFB50 have gained strength in the range of 0.97 times to 0.76 times of M2CC. The M2CFB30 to M2CFB40 have gained higher split...
tensile strength than M2CC (4.35\,N/mm$^2$) on 56 days of curing and they are in the range of 1.04 times to 1.00 times of M2CC. Even on 180 days of curing the other proportions of bacterial concrete M2CFB45 and M2CFB50 have not attained the strength of M2CC (4.35\,N/mm$^2$) and they are only in the range of 0.89 times to 0.86 times of M2CC. In this research M2CFB25 could achieve 1.01 times of M2CC in 28 days of curing.

Sunil has found that split tensile strength of 28 days controlled concrete was 4.51\,N/mm$^2$ and bacterial concrete using $B$. subtilis was 1.18 times of controlled concrete when there is no fly ash was added\cite{25}.

3.3 Flexural Strength of Concrete

Concrete beams were cast for controlled concrete (M2CC), fly ash concrete with 10, 20, 25, 30, 35, 40, 45 and 50 percentages of replacement to cement with class F fly ash and the concrete beams specimens are of size 100 mm $\times$ 100 mm $\times$ 500 mm. The flexural strengths of concrete proportions were obtained by testing three specimens and the averages of the flexural strengths are given in table\textbf{4}.

\begin{table}[h]
\centering
\caption{Flexural strength of fly ash concrete with standard deviation.}
\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|c|}
\hline
Days & M2CC & M2CF10 & M2CF20 & M2CF25 & M2CF30 & M2CF35 & M2CF40 & M2CF45 & M2CF50 \\
\hline
\hline
7 & 4.98 & 4.03 & 3.91 & 3.74 & 3.41 & 3.10 & 2.84 & 2.52 & 2.38 \\
14 & 6.05 & 5.36 & 5.16 & 4.78 & 4.39 & 4.15 & 3.96 & 3.65 & 3.42 \\
28 & 6.97 & 6.34 & 6.27 & 6.04 & 5.76 & 5.23 & 4.94 & 4.62 & 4.35 \\
56 & 7.28 & 6.74 & 6.56 & 6.32 & 6.05 & 5.51 & 5.26 & 4.96 & 4.64 \\
90 & 7.45 & 7.06 & 6.87 & 6.66 & 6.41 & 6.03 & 5.67 & 5.31 & 5.05 \\
180 & 7.75 & 7.39 & 7.37 & 7.20 & 6.93 & 6.33 & 6.13 & 5.77 & 5.40 \\
\hline
\end{tabular}
\end{table}

The flexural tensile strength of M2CC on 28 days is 6.97\,N/mm$^2$ and of fly ash concrete M2CF10 to M2CF50 have attained lower strength than M2CC and they were in the range of 0.91 to 0.62 times of M2CC. Fly ash concrete M2CF10 has gained higher flexural strength than M2CC (6.97\,N/mm$^2$) on 90 days of curing and it was 1.01 times of M2CC. Fly ash concrete M2CF20 and M2CF25 have gained higher flexural strength than M2CC (6.97\,N/mm$^2$) on 180 days of curing and it ranged from 1.06 to 1.03 times of M2CC. Even after 180 days of curing M2CF30 to M2CF50 have not gained the flexural strength of M2CC (6.97\,N/mm$^2$) and they were in the range of 0.99 to 0.77 times of M2CC. Similar trend was observed by Hefni that flexural strength of 28 days controlled concrete was 2.81\,N/mm$^2$ and fly ash was 2.41\,N/mm$^2$. In another observation by Huang has found that early age flexural strength of controlled concrete was better than fly ash concrete\cite{26}. Values of flexural strength of bacterial concrete are given in table\textbf{5}.
Table 5. Flexural strength of bacterial concrete with standard deviation.

| Days | M2CC | M2CFB 10 | M2CFB 20 | M2CFB 25 | M2CFB 30 | M2CFB 35 | M2CFB 40 | M2CFB 45 | M2CFB 50 |
|------|------|----------|----------|----------|----------|----------|----------|----------|----------|
| 7    | 7.98 | 4.60     | 4.27     | 4.10     | 3.96     | 3.84     | 3.80     | 3.59     | 3.45     |
| 14   | 6.05 | 6.23     | 5.98     | 5.80     | 5.47     | 5.37     | 5.17     | 4.96     | 4.65     |
| 28   | 6.97 | 7.51     | 7.33     | 7.14     | 6.98     | 6.88     | 6.67     | 6.11     | 5.94     |
| 56   | 7.28 | 8.04     | 7.90     | 7.72     | 7.56     | 7.37     | 7.16     | 6.66     | 6.55     |
| 90   | 7.45 | 8.25     | 8.23     | 8.06     | 7.81     | 7.72     | 7.41     | 7.03     | 6.89     |
| 180  | 7.75 | 8.43     | 8.34     | 8.26     | 8.07     | 7.88     | 7.55     | 7.43     | 7.13     |

| Standard deviation (N/mm²) |
|---------------------------|
| 7 | 0.45 | 0.64 | 0.94 | 0.64 | 0.89 | 0.89 | 0.77 | 0.51 | 0.23 |
| 14 | 0.56 | 0.70 | 0.48 | 0.70 | 0.75 | 0.78 | 1.09 | 0.78 | 0.45 |
| 28 | 0.34 | 0.80 | 0.44 | 0.80 | 0.72 | 0.99 | 0.91 | 0.99 | 1.00 |
| 56 | 0.43 | 1.38 | 0.58 | 1.40 | 0.92 | 0.85 | 0.83 | 0.85 | 0.62 |
| 90 | 0.49 | 0.97 | 1.03 | 0.97 | 1.14 | 1.09 | 1.10 | 1.09 | 1.14 |
| 180 | 0.45 | 1.05 | 1.26 | 1.05 | 1.04 | 1.19 | 0.96 | 1.19 | 0.78 |

The flexural strength on 28 days of curing of M2CC was 6.97 N/mm² and bacterial concrete M2CFB10 to M2CFB30 have gained higher strength than M2CC and other proportions from M2CFB35 to M2CFB50 have not attained the strength of M2CC and the bacterial concrete M2CFB10 to M2CFB30 attained the strength in the range of 1.08 times to 1.00 times of M2CC. Other proportions from M2CFB35 to M2CFB40 had gained higher strength on 56 days of curing and it was in the range of 1.06 times to 1.03 times of M2CC. The M2CFB45 and M2CFB50 have gained higher flexural strength on 90 and 180 days of curing. Similar trend was observed by researcher Kannan that flexural strength of B.pasteurii treated concrete was 7.85 N/mm² and that of controlled concrete was 7.06 N/mm².

3.4 X-Ray diffraction test

Concrete is tested using X-Ray diffraction (XRD) to find ensure higher amount of CaCO₃ present in bacterial concrete than fly ash concrete of same proportion. Since M2CFB25 was selected based on test results concrete samples of M2CC, M2CF25 M2CFB25 were tested for XRD and the results are shown in figures. XRD results were analyzed using high score Plus software to identify the compounds present. By using this software the compound for each peak and corresponding to 2θ (2theta) values were obtained. For each compound it gives the intensity of peak, crystal system and mineral names. By transferring the values of X-axis and Y-axis to origin a similar graph is obtained were the peaks are marked with compound name. The graph obtained from origin is given in figure 6 for M2CC, figure 7 for M2CF25 and figure 8 for M2CFB25.2
Figure 6. Graph showing the XRD result of control concrete M2CC.

Figure 7. Graph showing the XRD result of fly ash concrete M2CF25.

Figure 8. Graph showing the XRD result of bacterial concrete M2CFB25.
The intensity of CaCO$_3$ available in M2CFB25 is higher and number of peaks for calcium also higher than M2CF25. Peaks of CaCO$_3$, SiO$_2$, Fe$_2$O$_3$ and Al$_2$O$_3$ were shown in the graph. It is clear from the graph that M2CFB25 is having higher amount of CaCO$_3$ than M2CF25. This is due the addition of CaCO$_3$ precipitated by B.sphaericus. Due to the addition of calcite the pores in concrete were sealed and their by the strength of concrete has increased.

4. Conclusions
Usage of fly ash to replace part of cement in concrete is not gaining importance in construction industry as fly ash concrete is not gaining equal strength of cement concrete in 28 days. The compressive strength of fly ash concretes mixes on 28 days of curing were not at par with controlled concrete and there are in the range of 0.96 to 0.74 times of M2CC. Similarly split tensile strength are in the range of 0.92 to 0.58 and flexural strength of fly ash concrete are in the range of 0.91 to 0.62 times of M2CC on 28 days of curing.

In this research bacterial concrete is produced by replacing cement with fly ash is enriched with bacteria B.sphaericus and it has given higher strength properties in 28 days than cement concrete even after replacing cement upto 25% with fly ash enriched with bacteria.

The compressive, split tensile, flexural strength of M2CFB25 have attained 1.06, 1.01 and 1.02 times of M2CC respectively on 28 days curing.

The optimum percentage of bacterial concrete is M2CFB25 as it attains higher mechanical properties than M2CC. Calcium carbonate precipitated fills the pores in the concrete and make it as a suitable proportion to replace M2CC. Bacterial concrete is very advantages as it reduces the pollutions and saves natural resources and electrical energy.

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