Experimental Study on Compressive Strength of M-35 Grade of Concrete and Crack-Healing in Bacteria Based Self-Healing Concrete

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Abstract
In the present scenario where the constructions are increasing, the need to find a supplementary cementing material for the improvement of strength and which has less environmental effects is of great significance. Ureolytic bacteria are the ones which can improve the strength of cement mortar by the precipitation of calcium carbonate in the presence of urea and a calcium source. In the present study Bacillus sphaericus is used to check its applicability in this regard. Various tests like consistency and initial setting time are done to find out the effect of bacterial solution on cement. Tests such as compression strength are used in the present study to identify the variation in the mechanical properties of cement concrete. To know the mineralogy and morphology of the calcium carbonate precipitated by the bacteria in compressive strength analysis are carried out It was observed that for M35 grade of bio concrete the compressive strength was nearly 14.86% more than that of conventional concrete after 3 days, nearly 25.87% after 7 days, nearly 26.32% after 14 days and 30.01% after 28 days of curing. So a maximum of 30.01% increase of compressive strength of bio-concrete was observed than that of conventional concrete.

Keywords: M-35 grade, compressive strength, calcite precipitation, cement, slump cone, bacterial concrete.

INTRODUCTION
Concrete is one of the major materials used in the construction industry. Crack initiation and further formation is a phenomenon related to durability. Cracks that go ahead to leakage problems cause harmful effect on concrete matrix. Durability can be improved by preventing further entrance of water and other substances. Self-healing phenomenon is characterized by regaining progress performance after a defect occurs. Damage targeted in bacteria-based self- healing concrete for the most part relates to enhancement of durability, leakage prevention and extend service life of concrete structures.

Effect of bacteria on various parameters of concrete proves to be beneficial development also improve compressive strength of concrete. Modern era this technique is used for the crack remediation and durability improvement of concrete. In concrete, cracking is almost inescapable due to its brittleness property and complex environment. Once crack produced, due to various chemicals reinforcement bar begins to corrode. It results into diminish in structure life span. The cracks may promulgate at much lower stress that necessary to cause crack initiation. Cracking in concrete leads as major cause to several damages to the structural elements such as reduction in strength of concrete, corrosion of steel bars which result in carbonation that diminish the pH of concrete consequential in destruction of the naturally occurring passive film that protects the steel bar from moisture and oxygen causing corrosion so it is very essential to repair the cracks. To date self-healing in concrete has been achieved primarily through three different types; autogenously healing.

2. BACILLUS SPHAERICUS

In 1995, Gollapudi et al., were the first to introduce this novel carbonate precipitation has been anticipated as an alternative and environmental friendly crack repair technique. Bacillus Sphaericus produces urease, which catalyzes urea to supply CO2 and ammonia, leading to a rise of pH value within the surroundings where ions Ca^{2+} and CO3 precipitate as CaCO3. The first three factors are provided by the metabolism of the bacteria while the cell wall of the bacteria will act as a nucleation site. Possible biochemical reactions in medium to precipitate CaCO3 at the cell surface that provides a nucleation site are often summarized as follows.

$Ca^{2+} + Cell \rightarrow Cell\text{-}Ca^{2+}$

$Cl^{-} + HCO^{3-} + NH3 \rightarrow NH4Cl + CO_3^{2-}$

$Cell\text{-}Ca^{2+} + CO3^{2-} \rightarrow Cell\text{-}CaCO3$

3. OBJECTIVE OF THE WORK

The main goal of this research project was to test the applicability of alternative metabolic mineral-producing pathways by bacteria which are truly incorporated in the concrete matrix. Such bacteria added to the concrete mixture prior to casting should remain viable for prolonged periods once integrated in the concrete matrix and be able to produce copious amounts of minerals needed to plug or seal freshly formed cracks. Integrated bacteria would thus represent an internal self-healing agent which autonomously decreases matrix permeability upon crack formation. An integrated healing agent would save manual inspection and repair and moreover increase structure durability. Addition of such an agent to the concrete mixture would thus save both money and the environment as less maintenance and use of environmental unfriendly repair material is needed.

4. LITERATURE REVIEW

Sujatha et al. (2017) ureolytic bacteria was isolated from ant hill and was cultured for the study. Mortar cubes of 70.6x70.6x70.6 mm was casted and bacteria was administered into the mortar through curing water. Here control specimen and one batch of bacterial where cured in tap water and another batch of bacterial cubes where cured in 1g urea/L. Compressive strength after 28 days of the bacterial cement mortar is also found to increase up to 18% when cured with water containing urea and up to 12% when cure with water.

Maheswaran et al. (2018) comparison of ureolytic activity of Bacillus cereus and Bacillus pasteurii is done here. The bacterial mortar cubes are casted by replacing entire volume of water was replaced with phosphate buffered saline (PBS) suspended bacteria. Curing of bacterial cubes where carried out in nutrient solution. The test results shows an increase of 38% compressive strength using Bacillus cereus at bacterial cell concentration of 10^6 cells/ml and 29% increase in the case of Bacillus pasteurii over the control cement mortar specimen at bacterial concentration of 10^5 cells/ml. Bacillus cereus incorporated mortar cubes show significant decrease in chloride permeability. X-ray diffraction, scanning electron microscope, thermo gravimetric analysis and Fourier transform-infrared spectroscopy are used to confirm the bacterial calcite precipitation.

Mian Luo, Chun-xiang Qian, Rui-yang Li (2019) analyzed the precipitations formed at the cracks surface of the cement paste specimens with Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray Spectrometer (EDS), and then examined by X-ray Diffraction (XRD) In conclusion, the results presented in this study show that the microbial self-healing agent can be used to achieve the goal of concrete crack self-healing. Two types of bacteria were used Type 1 - calcium lactate, Type 2 - calcium formate with bacteria spores.

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5. MATERIALS

Following are the basic tests performed on the constituent materials used, before casting concrete.

A. Cement
   1. 33 grade OPC (follows IS 269)
   2. 43 grade OPC (follows IS 8112)
   3. 53 grade OPC (follows IS 12269)

   The numbers 33, 43 and 53 represent the 28 days compressive strength of a standard cement sand mortar. This cement is very commonly used in normal concrete constructions.
   a. Fineness of cement
   b. Specific gravity of cement

B. Fine aggregate
   a. Sieve analysis of fine aggregate
   b. Specific gravity
   c. Water absorption

The size of the sand must be between 75microns to 4.75mm. That means it must completely pass through IS 4.75mm sieve and completely retained on IS 75 micron sieve

C. Coarse aggregate
   a. Sieve analysis of coarse aggregate
   b. Specific gravity
   c. Water absorption

It is generally comprises of crushed stones like granite. Sometimes gravel or broken bricks are also used as coarse aggregates. Coarse aggregate occupy the most part of the concrete matrix and contribute toward weight and strength of the hardened concrete

A. Cement

Cement is also easily available in market .It is used as binder material. It is widely used to bind sand and gravels altogether with it. It sets and gets harden with time when mixed with water. Ordinary Portland cement (OPC) has been used in the present work. It is a type of blended cement which is obtained by clinkers, gypsum materials and thoroughly mixing them in correct proportions. Portland is natural materials containing siliceous or siliceous-aluminous substance in the reactive form which, when combines with calcium hydroxide in the presence of water produces calcium silicate and aluminates hydrate compounds having cementitious properties. The testing of concrete is done according to IS Code 10262 Portland cement of 43 grades conforming to IS 8112-1989 was used. and specific gravity 3.15 was used.

Figure 1: Ordinary Portland cement.

B. Fine Aggregates (sand)

By definition, fine aggregates pass through IS sieve size 4.75 mm. Selecting fine aggregate on the basis of its zone of gradation, surface texture, water absorption, particles shape and size gives concrete better durability, strength and makes it economic. Specifications of aggregate used fulfils the requirement as per IS: 383-9170. Other properties of fine aggregate like specific gravity, water absorption, etc. satisfies IS: 2386 (part III). Calculated specific gravity and water absorption for fine aggregate was found to be 2.65 and 0.84% respectively

Figure 2: Sand Sample.

C. Coarse Aggregate

By definition, coarse aggregates get retained on IS sieve size 4.75 mm. Construction aggregates which makes bulk of the concrete adds strength to the overall composite materials. Aggregates used in the testing and casting should be free from dust particles, mud or any other impurities. In this thesis work, machine crushed basalt stones of maximum 20 mm size are used. Specifications of aggregate used fulfils the requirement as per IS: 383-1970. Some tests were performed to determine the properties of coarse aggregate as per IS: 2386 (part III). Calculated specific gravity of coarse aggregate used in the experiment was found to be 3.125. Testing for the water absorption of coarse aggregate was performed and the calculated result was 2.0%.

Figure3: Course Aggregate Sample.

D. Water

Water is easily available and inexpensive but the most important ingredient of concrete. The water must be free from impurities like oil, alkali, acid etc which is used for mixing concrete. Water is essential material of concrete which gets combined with cement to form a cement paste by the process of hydration. Then this cement paste adheres to aggregates and fills the voids to get better strength and bond among constituent materials. Water used was natural potable which satisfies the provisions of IS 456:2000.

E. Bacillus Sphaericus

Concrete is a very essential building material since it is very brittle, so it is expected to crack with time. So to prevent concrete from cracks, self-healing agents are used. The objective of this study to use Bacillus Sphaericus in the concrete mix which produces the calcium precipitate which is useful in dealing with the situation of crack. The studies and results from various surveys have given an idea about bacterial concrete.

Figure 4: Cell structure of Bacillus sphearicus.

F. Calcium lactate

In this thesis work, calcium lactate is used as nutrient food for bacillus sphaericus. It's another name is calcium salt pentahydrate ($C_6H_{10}CaO_6$).When lactic acid reacts with calcium hydroxide, calcium lactate forms. Calcium lactate is used as calcium source or food for the bacteria to produce calcium carbonate which decides compressive strength of the concrete. Calcium source is added externally to the dry mix of concrete prepared. This additional nutrient source helps to improve compressive strength, self-healing property and durability of the concrete. Different proportions of calcium lactate are added to the dry mix with respect to the weight of cement to be added. Generally, 0.25 % of the weight of the cement is taken for the study.

Table 1: Size of the specimen.

Grade of concrete	Name of the specimen	Name of the test	Size of the specimen (in mm)	Number of specimen
M-35	Concrete cubes for conventional concrete	Compression	150 x 150 x 150	12
M-35	Concrete cubes for bio-concrete	Compression	150 x 150 x 150	12
Total Cubes				24

6. RESULTS

Compressive Strength Test on concrete cubes For M35 grade of concrete

Table 2: Properties of grade M35 mix design concrete.

S.No.	Materials and other properties	Quantity/Proportions
1.	Ratio of Cement: Fine aggregate. Coarse aggregate	1: 1.296 : 2.33
2.	Cement	478.75 Kg/m^3
3.	Fine aggregate (sand)	620.57 Kg/m^3
4.	Coarse aggregate	1117.52 Kg/m^3
5.	Water	204.5 L/m^3
6.	Water-Cement ratio	0.427
7.	Slump	75 mm

1.1.1

1.1.2 M35 Conventional concrete

- ▶ Target mean strength (Design strength), f_t = 43.25 N/mm^2
- ▶ Percentage of compressive strength, concrete achieves at different stages of curing are-
  - At 3 days = 40 % of design strength
  - At 7 days = 65 % of design strength
  - At 14 days = 90 % of design strength
  - At 28 days = 99 % of design strength
- ▶ Check = Calculated compressive strength ≥ Target mean strength

Table 3: Compressive strength of M35 grade of conventional concrete.

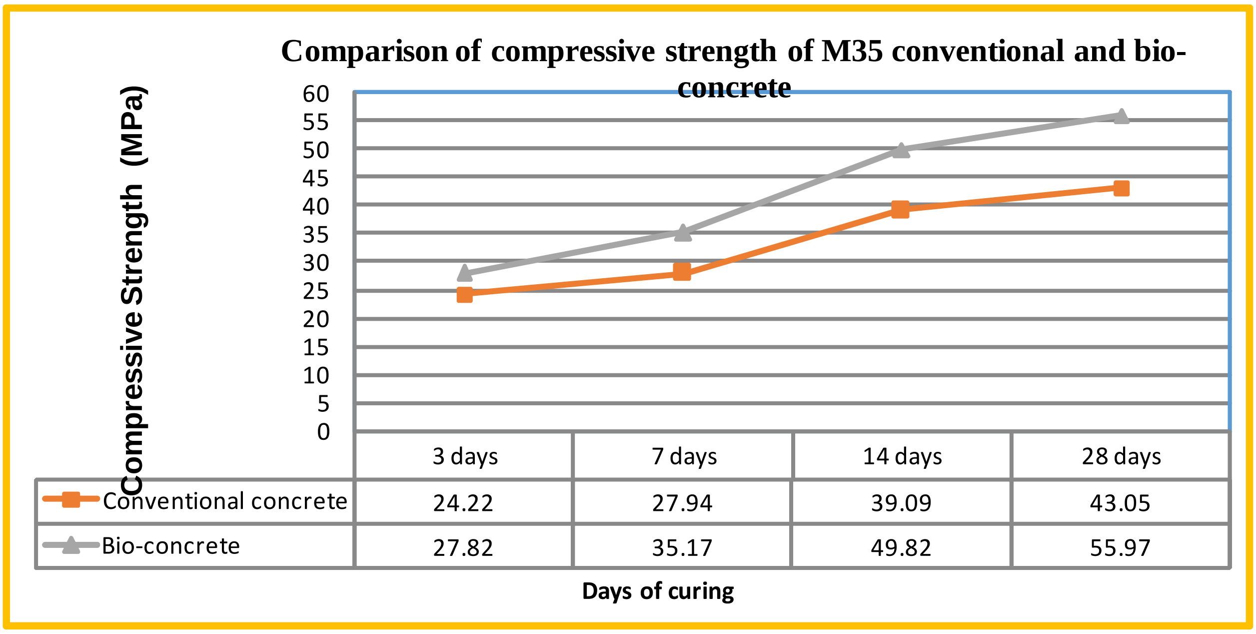
Cubes No.	Load (KN)	Load(N)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Target mean strength at different stages of curing (N/mm^2)	No. of Days
1	554.63	554625	24.65	24.22	17.30	3 days
2	515.7	515700	22.92			
3	564.53	564525	25.09			
4	614.93	614925	27.33	27.94	28.12	7 days
5	636.53	636525	28.29			
6	634.5	634500	28.20			
7	873.9	873900	38.84	39.09	38.93	14 days
8	888.08	888075	39.47			
9	876.83	876825	38.97			
10	969.3	969300	43.08	43.05	42.81	28 days
11	972.23	972225	43.21			
12	968.63	968625	43.05			

M35 Bio-concrete

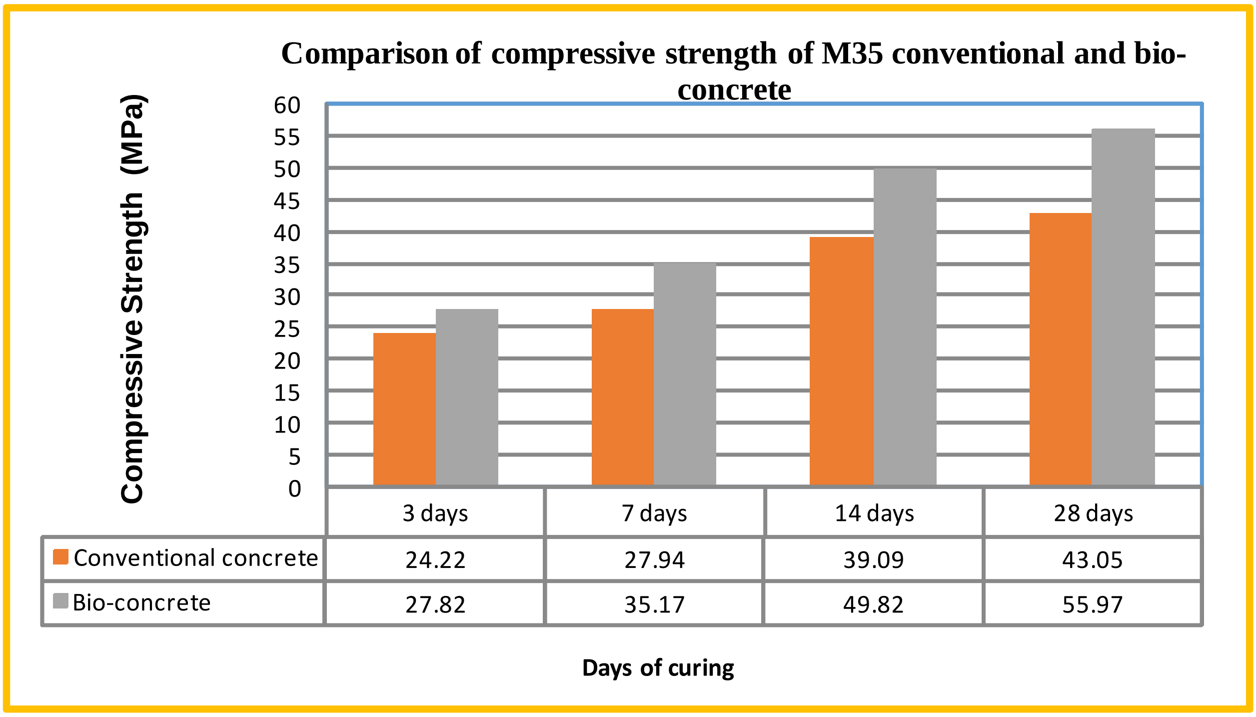
- Amount of bacillus sphaericus = 0.25 % of the weight of cement used
- Amount of calcium lactate = 0.50 % of the weight of cement used

Table 4: Compressive strength of M35 grade of bio-concrete **M35 Bio-concrete.**

Cubes No.	Load (KN)	Load(N)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Target mean strength at different stages of curing (N/mm^2)	No. of Days
1	614.03	614.03	27.29	27.82	24.22	3 days
2	630.90	630.90	28.04			
3	633.15	633.15	28.14			
4	783.00	783.00	34.80	35.17	27.94	7 days
5	792.00	792.00	35.20			
6	798.75	798.75	35.50			
7	1121.18	1121.18	49.83	49.82	39.09	14 days
8	1141.65	1141.65	50.74			
9	1100.03	1100.03	48.89			
10	1285.20	1285.20	57.12	55.97	43.05	28 days
11	1236.38	1236.38	54.95			
12	1256.18	1256.18	55.83			



Graph 1: Graphical representation of comparison of compressive strengths of M35 conventional and bio-concrete.



Graph 2: Graphical representation of comparison of compressive strengths of M35 conventional and bio-concrete.

From the above graph, it is clear that there is enhancement in compressive strength of bio- concrete as compared to the conventional one. There is about 14-30 % of improvement in compressive strength for all the stages of curing. Maximum enhancement in compressive strength could be observed after 28 days of curing is 30.01% increment in bio- concrete. Enhancement in compressive strength increases with the grade of concrete.

7. Self-Healing Performance of Bacterial Concrete or Bio-Concrete:

Bacterial concrete shows self-healing property when a load of 70 % of the failure load obtained at 28 days of curing is applied to it, followed by curing that loaded moulds for next 28 days. When the concrete moulds get loaded, it develops cracks on its surface. That loaded concrete moulds then put for curing for the next 28 days where bacillus sphaericus and calcium lactate reacts with water and starts healing concrete by forming a white cast of calcium carbonate precipitate over the cracks, thus sealing the cracks and improving the compressive strength of bio-concrete.

8. Bacterial Concrete Moulds after Crack Formation

Bacterial concrete moulds develop cracks when subjected to a load of 70 % of the failure load is applied to it. Minor cracks approximately up to 0.2 mm in the concrete get healed autogenously. This step of developing cracks is necessary to check whether concrete shows healing property or not. For any grade of concrete, procedure is same to develop cracks. Some images of cracks formed in the bio-concrete is shown below. Now these moulds will be put again for curing for next 28 days to check its healing property. The width of cracks can be measured with the help of microscope and further studies could be carried out. These cracks degrade the quality and compressive strength of concrete, that's why, it is required to make bacterial concrete purposely.

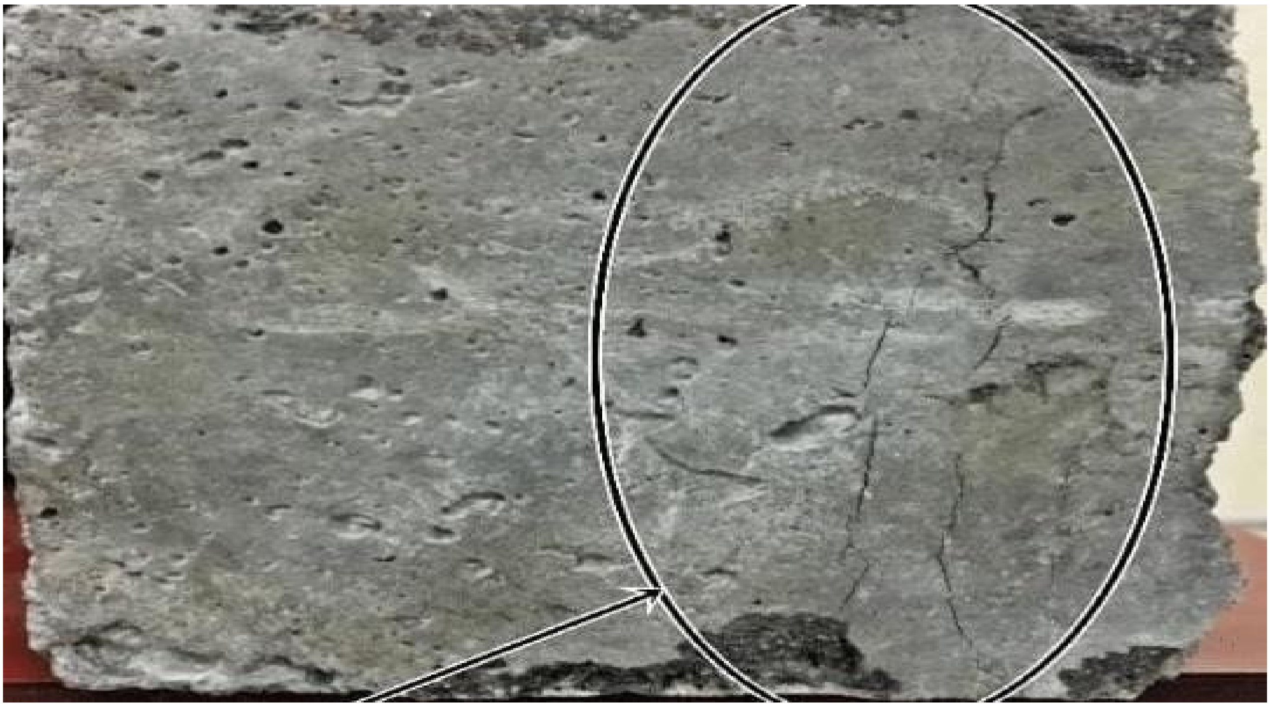


Figure 5: Cracks formation.

9. Bacterial concrete moulds after 28 days of curing

These cracked moulds when put for curing undergone chemical reaction with water. Bacillus sphaericus and calcium lactate reacted with water to form calcium carbonate precipitate in the form of white cast over cracks. This white cast shows the healing property of bacterial concrete. Other form of calcium source can be added in the concrete. Calcium source makes the bacteria to accelerate or retard the setting time of the concrete. Healing of crack helps concrete to reduce its permeability and water absorption simultaneously. Here, direct method is opted for adding healing agent, but after analyzing papers, encapsulation method is more effective than others for better results. Below are some images of the bacterial concrete after curing process. These concrete moulds should be allowed to rest in sunlight for some time after taking them from water to get the better view of healed cracks.

Figure 6: Self-healing of cracks developed.

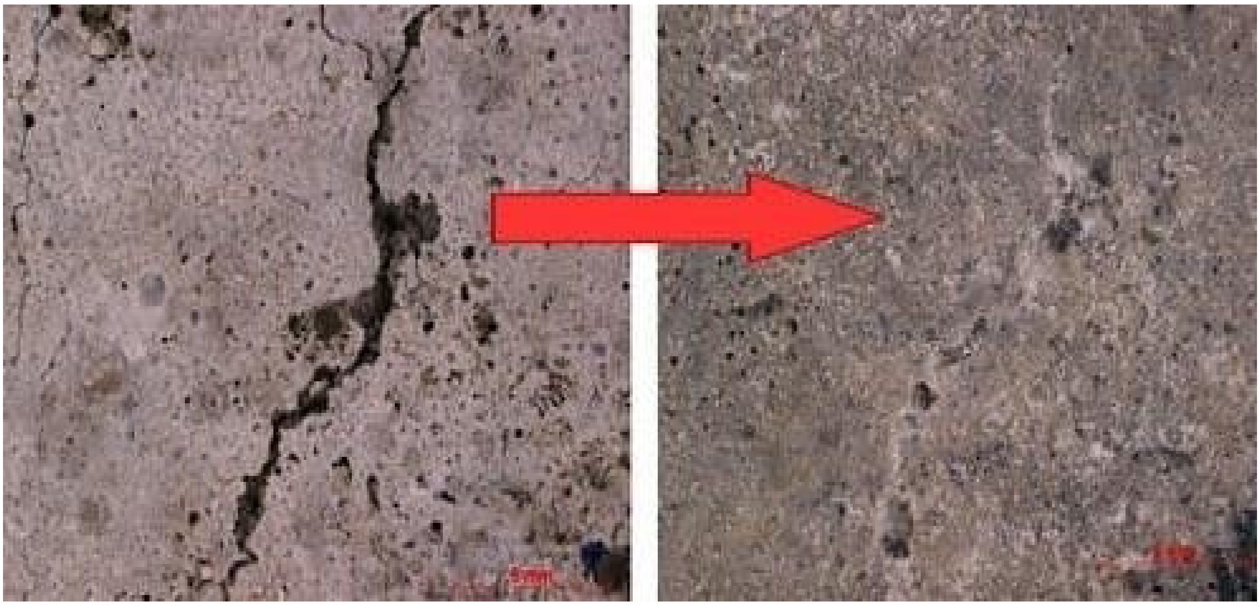


Figure 7: White cast showing calcium carbonate precipitate.

10. CONCLUSION

The thesis work is for improvement of the compressive strength of concrete by self-healing property. We used Bacillus sphaericus as bacteria and calcium lactate as nutrient. We used M35 grade of concrete for the work. We can make following conclusions according to our work:-

It was observed that for M35 grade of bio concrete the compressive strength was nearly 14.86% more than that of conventional concrete after 3 days, nearly 25.87% after 7 days, nearly 26.32% after 14 days and 30.01% after 28 days of curing.

So a maximum of 30.01% increase of compressive strength of bio-concrete was observed than that of conventional concrete.

As a data from some previous research it is obtained that concrete with the addition of Bacillus sphaericus gives slightly higher strength than Bacillus pasteurii.

Because of its self-healing and eco-friendly property they are way better than the conventional concrete.

Bacterial concrete are more durable and environment friendly.

According to previous research some bacteria are dangerous for human health but bacillus sphaericus is not harmful for human health.

Due to use of bacteria and its nutrient the initial cost of the concrete is increased but the maintenance cost is reduced.

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