A Study on Strength Characters of Bacterial Concrete

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Abstract:
Concrete is unique in all construction material because it is specifically designed for civil engineering purpose. It plays a critical role in the construction of the nation’s infrastructure. The cracks in concrete whether major or minor are one of the weakness of concrete. These cracks will be developed over a period of time which adversely affect its strength and durability. Hence an attempt is made here using bacteria belongs to bacillus family used to heal minor cracks in concrete. These types of bacteria were introduced externally to improve the process of Microbiologically Induced Calcite Precipitation (MICP) in concrete. It (MICP) is a technique that comes under the study of science called bio mineralization. Bacillus subtilis, one of the soil bacterium can induce the Precipitation of calcite. The present work is to study the potential application of bacterial species bacillus subtilis in healing the minor cracks there by improving the strength of cement concrete. Here M20 grade of concrete was used for the study. The concrete mix was prepared as per IS specifications. Testing on specimens for compression was carried out after 28 days of curing using both CTM and NDT equipment’s and results are tabulated. Minor cracks less than one millimeter are induced artificially in concrete and the broth solution having bacterial culture in it are injected along the crack pattern. After healing, compressive strength was tested using NDT equipment and was found a marginal improvement in the strength criteria.

Key words: bacillus subtilis, MICP, minor cracks, NDT, CTM

1. Introduction:
Concrete is used widely as construction material globally. Cracks in concrete is one of the major issue to address immediately. Based on the research carried out globally, numerous attempts were to overcome the deficiencies of cement concrete [1]. Due to the results obtained from researchers on concrete, we end up with the following on special concrete (a) the durability and strength of concrete (b) the speed of construction and (c) the environmental friendliness of alternative materials used in concrete. In addition it was found that mineral precipitation using microbes can improve the overall behavior of concrete [3]. This can be achieved by injecting bacteria from a broth solution externally on the concrete which can able to precipitate calcite. Thus the process of calcite precipitate is known as microbially induced calcite precipitation. In this study bacteria Bacillus subtilis JC3 is used to induce CaCO₃ precipitation [4]. The encouraging conditions will not directly exist in concrete. The objective of the work is to focus on how to create a encouraging condition for the bacteria to be alive in the concrete to produce as much calcite as needed to repair minor cracks.

2. Materials and Method:
The cement used was Zuari OPC 53 grade of specific gravity 3.14. With this the Coarse
aggregates specified in IS10262:2009 was adopted. Here specific gravity of 2.77 coarse aggregate was used. The specification confirming to IS10262:2009 for fine aggregate (FA) was also adopted by replacing M sand of specific gravity 2.6 with Zone II was used as FA, the locally available potable water used for mixing without any additives. Apart from this Bacillus Subtilis JC3 was cultured in nutrient agar broth and was maintained in a temperature bath. The test program consist of casting and followed by testing of concrete specimen of cubes (150x150x150 mm) to determine the compressive strength using CTM and UPV test equipment’s. The specimens are casted for M20 mix using ordinary Portland cement with M sand as fine aggregate and coarse aggregate of maximum size 20mm. The specimen are allowed for a curing period of 28 days and test was conducted as per IS code provisions.

2.1 Growth of Bacteria:

Bacteria was identified from soil and it was isolated. The isolated bacteria was cultured in the facility available at the Department of microbiology, Faculty of Agriculture.

![Bacillus subtilis culture](image)

The culture is maintained on nutrient agar solution which forms a dry white colonies in the agar solution. As per requirement single colony of the culture is inoculated into nutrient broth of 200ml in 500 ml conical flask and the growth condition are maintained at orbital shaker. There required medium composition for the growth of culture is glucose 1gm, peptone 1gm, beef extract 0.15 gm, and NACI 1gm are mixed with 200 ml distilled water.
2.2 Development of bacterial solution:

After the pure culture was developed, the amount of required solution was prepared. This broth solution is produced according to the formula from APHA and AOAC, the concentration of the solution on analysis is obtained as $10^5$ cells/ml of solution.
3. Result and Discussion:

3.1. Compressive Strength Test:

Here the cube specimen is placed CTM platform, in such a way that opposite sides are get loaded. The load is applied without shock and increased gradually until its resistance breaks down and no greater load can be sustained. The maximum load to the specimen is then recorded. The compressive strength test and the crack pattern of the casted cube specimen obtained during the testing are shown in fig 4.

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\text{compressive strength} = \frac{\text{ultimate load}}{\text{area of specimen}}
\]

Table 1. Compressive strength test of conventional concrete cubes

| Sl.no. | Size of specimen (mm) | Ultimate load (kN) | Compressive strength (N/mm\(^2\)) | Average compressive strength(N/mm\(^2\)) |
|--------|------------------------|--------------------|-----------------------------------|---------------------------------------|
| 1      | 150x150x150            | 636                | 28.266                            | 27.5                                  |
| 2      | 150x150x150            | 543                | 24.13                             |                                       |
| 3      | 150x150x150            | 679                | 30.17                             |                                       |

3.2. Creating crack pattern for bacterial applications:

Initiating the crack pattern for bacterial applications,
3.3. Injecting bacteria in to the concrete:

Cultured bacteria in the liquid form is injected (applied) on the initiated micro crack pattern on the cubes.

![Injecting bacteria on cracked surface](image)

3.4. Healing of Crack:

Here cracks are healed due to the precipitation formed by the microorganism. These microorganisms placed in the concrete after immobilization, and will form the precipitation of CaCO$_3$ once a crack occurs. By this process the cube crack will be coated with a layer of calcium carbonate. This test carried out by the initiation of minor cracks of less than 1mm on the cube and exposing them to the atmosphere for a period of 9 weeks.
3.5 Ultrasonic pulse velocity test:

This test is done to assess the quality of concrete using ultrasonic pulse velocity method as per IS: 13311 (Part 1) – 1992. The test was conducted on control concrete and bacterial concrete using the model RTULx4600 of accuracy 0.1µs and frequency 60kHz by direct method of testing.
The UPV results are a direct indication of the density of concrete and it reflects the quality of the concrete specimen too.

Table 2. Velocity Criterion for Concrete Quality Grading as per IS 13311-part 1 (1992)

| Sl.No. | pulse velocity by cross section probing ( km/s ) | Concrete quality grading |
|--------|-----------------------------------------------|--------------------------|

Fig 8. Pulse Velocity Testing Equipment

Fig 9. Transmitter and receiver ends
Table 3. Ultrasonic Pulse Velocity

| Concrete type                | 28\textsuperscript{th} day km/s | Concrete quality grading |
|------------------------------|---------------------------------|--------------------------|
| conventional concrete        | 4.37                            | Good                     |
| Healed concrete 10\textsuperscript{5} cells/ml | 4.46                            | Good                     |

3.6 SEM image of conventional and bacterial concrete:

Scanning Electron Microscopy (SEM) is used for analysis. SEM can achieve resolution better than 1 manometer, specimens can be observed in high vacuum, in low vacuum and (in environmental SEM) in wet conditions. Following are some of the SEM images obtained.

Fig 10. SEM image of conventional concrete
Fig 11. SEM image of bacterial concrete
4. Conclusion:
It was concluded that the study on strength characters of bacterial concrete was found to be good when compared to other methods. Based on UPV test results and SEM analysis carried out on the healed specimens the micro crack pattern comes close together and making it denser, the compression strength was marginally increased when compared with conventional specimen. The optimum concentration of cells is found to be $10^5$ cells/ml from the experiments result. This was not harmful for human. Further this work can be extended for other structural elements such as beams, slabs, and columns.

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