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An Attempt to Enhance the Properties of Concrete using Bacteria

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Abstract

Concrete is the most widely used construction material for infrastructure but most concrete structures are prone to cracking. Tiny cracks on the surface of the concrete make the whole structure vulnerable because water seeps in to degrade the concrete and corrode the steel reinforcement greatly reducing tsshe lifespan of a structure. As current crack filling material in concrete proved harmful and toxic. It can be replaced by recent innovative, eco-friendly material – Bacteria. Huge diverse bacterial species can participate in precipitation of mineral carbonate, even in many diverse conditions. Lots of work has been done for Bacillus Sphericus. So through this project we want to show the role of Bacillus Sphericus as crack- healing material in concrete to improve mechanical performance & its effect on various parameters of concrete.
Keyword- Bacillus sphericus, Compressive strength, Concrete, Crack

I. INTRODUCTION

Concrete is still one of the main materials used in the construction industry. Concrete will continue to be the most important building material for infrastructure. The quality of concrete structures depends majorly on three parameters: compressive strength, permeability, & corrosion. So, most concrete structure is prone to cracking. Small cracks on the surface of the concrete make the whole structure vulnerable. In the case of historic buildings and monuments, these cracks are inevitable and destroy the structure. Water and other salts seep through these cracks, corrosion initiates, and thus reducing the lifespan of concrete. Use of synthetic agents such as epoxies for remediating these structures will reduce the aesthetic appearance of the structures; a novel strategy to restore or remediate such structures is bio mineralization of calcium carbonate using microbes such as Bacillus species. Bacterial concrete refers to a new generation of concrete in which selective cementation by microbiologically-induced (CaCO3) precipitation has been introduced for remediation of micro cracks. The technique is called Microbiologically Enhanced Crack Remediation (MECR). The mineral precipitation (CaCO3) induced as a result of microbial activities is pollution free and natural. As the cell wall of bacteria is anionic, metal accumulation (calcite) on the surface of the wall is substantial, thus the entire cell becomes crystalline and they eventually plug the pores and cracks in concrete. The technique can be used to improve the compressive strength and stiffness of cracked concrete specimens.

The Bacterial concrete‖ can be prepared by adding spore forming bacteria in the concrete that are able to continuously precipitate calcite, this process of production of calcite precipitation is called Microbiologically Induced Calcite Precipitation (MICP). Bacteria used to induce calcite precipitation in concrete. The basic principle for this process is that the microbial urease hydrolyzes urea to produce ammonia and carbon dioxide and the ammonia released in surrounding subsequently increases pH, leading to accumulation of insoluble calcium carbonate. Bacterial cultures improve the strength of cement sand mortar and crack repair on surfaces of concrete structures. Calcium carbonate precipitation, a metabolic process which occurs in some bacteria, has been investigated due to its wide range of scientific and technological implications. Calcite formation by Bacillus species is used in making bio concrete, which can produce calcite precipitates on suitable media supplemented with a calcium source. Some bacteria have the ability to produce endospores to endure an extreme environment, as observed by the studies. The technique can be used to improve the compressive strength and stiffness of cracked concrete specimen.

In this experiment the study of compressive strength of bacterial concrete using different concentrations of bacteria are carried out. The bacteria used in the experiment are bacillus sphericus. Concrete cubes are prepared. The compressive strength test carried out on the cracked cubes. The cracks are filled using bacteria and rise husk ash. Cubes with three different cell concentrations are prepared and the compressive strength for each 14days and 28days is carried out. The results are compared with the control specimens to see the variation in the strengths. And the results are compared to find the optimum amount of bacteria to be added to the concrete to get the maximum compressive strength The crack healing efficiency and the effect of this combination of bacteria and rise husk ash on the crack is analysed using SEM (SCANNING ELECTRON MICROSCOPE).

A. Microbiological Calcite Precipitation

Humans have the ability to precipitate minerals in the form of bones and teeth continuously. This ability is not only confined to human beings; even Bacillus sphaericus, a common soil bacterium can continuously precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. Under favourable conditions Bacillus sphaericus when used in concrete can continuously precipitate a new highly impermeable calcite layer over the surface of the already existing concrete layer. Calcite has a coarse crystalline structure that readily adheres to surfaces in the form of scales. In addition to the ability to continuously grow upon itself it is highly insoluble in water. Due to its inherent ability to precipitate calcite continuously bacterial concrete can be called as a ―Smart Bio Material‖. Cracks in concrete significantly influence the durability characteristics of the structure. The bacterial remediation technique can be used for repairing structures of historical importance to preserve the aesthetics value, as conventional technique, such as epoxy injection cannot be used to remediate cracks in those structures.

B. Process of Healing Cracks by Bacteria

First of all, germination of germs by spores and swarming occurs and the bacteria's grows with the help of proper media in large quantity in particular time. From the metabolism process, the levans glue, filamentous cell formation is produced along with precipitation of CaCO3. These materials combine with each other making a cementations material. CaCO3 precipitation is a chemical process which is govern by generally by four factors:

1) The calcium concentration.
2) The dissolved inorganic carbon concentration (DIC).
3) The pH.
4) Availability of nucleation site.

In natural environments, chemical CaCO3 precipitation (Ca2++ CO32-→ CaCO3↓) is accompanied by biological processes, both of which often occur simultaneously or sequentially. This microbiologically induced calcium carbonate precipitation (MICCP) comprises of a series of complex biochemical reactions. As part of metabolism, B. sphaericus produces urease, which catalyzes urea to produce CO2 and ammonia, resulting in an increase of pH in the surroundings where ions Ca2+ and CO32- precipitate as CaCO3. Possible biochemical reactions in medium to precipitate CaCO3 at the cell surface that provides a nucleation site can be summarized as follows.

Ca2+ + Cell → Cell-Ca2+ . . . . (1)
Cl- + HCO3- + NH3 → NH4Cl + CO32- . . (2)
Cell - Ca2+ + CO32- → Cell – CaCO3↓ . . . (3)

Earlier it was reported that sand consolidation by B.sphaericus reduced porosity by up to 50% and permeability by up to 90% in the areas where the cementation took place. Microbial calcite plugging was selective and its efficiency was affected by the porosity of the medium, the number of cells present and the total volume of nutrient added. The sand column loaded with bacteria was so tightly plugged that the column was fractured with a mechanical knife for examining. In a study conducted by Zhong, an average crack width of 2.7 mm and a mixture of silica fume (10%) and sand (90%) showed the highest compressive strength in the microbial remediation of granite. Concrete crack remediation by microorganisms was significantly different from that of granite remediation, mainly due to the fact that concrete maintained high levels of pH. An extreme alkaline environment of pH around 12 is the major hindering factor for growth of B. pasteurii, whose optimum pH for growth is around 9. However, B. pasteurii has the ability to produce endospores to endure an extreme environment**.**

C. Maintenance of Stock Cultures

Pure cultures of Bacillus sphaericus were maintained on nutrient agar slants and were preserved under refrigeration (4^{0} C) until further use, sub-culturing was carried out for every 30 days. Contamination from other bacteria was checked periodically by streaking on nutrient agar plates. Whenever required, few colonies of the pure culture is inoculated into nutrient broth of 25ml in 100ml conical flask and the growth condition are maintained at 37°C temperature and placed in 125 rpm orbital shaker. The growth medium used with the composition of nutrient agar is:

- Beef extract : 3.0g
- Peptone : 10.0g
- NaCl : 5.0g
- Distilled water : 1000 ml
- pH : 7.4

D. Media Preparation

Nutrient broth (1000 ml) and nutrient agar

Ingredients	*Amount*	*Broth*
Peptone	*10 gm.*	*10 gm.*
Meat/ Beef Extract	*3 gm.*	*3 gm.*
Sodium chloride	*5 gm.*	*5 gm.*
Distilled water	*1000 ml*	*1000 ml*
Aar	*250 ml*	-

pH	*7.4*	*7.4*

Table 1: Amount of Ingredients Used For Preparing Media

II. MATERIALS AND METHODS

Materials The following are the details of the materials used for concrete cubes.

- Cement: Ordinary Portland cement of grade 53available in local market is used in the investigation having specific gravity of 2.92.
- Fine aggregate: River sand well graded passing through 4.75mm sieve was used. Specific gravity was found to be 2.635(white sand), water absorption 0.9% and confirming to zone II.
- Coarse aggregate: Crushed aggregate is with a maximum size of 20 mm and normal continuous grading. Coarse aggregate (grit) of 10 mm size are also used. The specific gravity of the coarse aggregates (20 mm) of 2.85 and specific gravity of the fine aggregate (10 mm) of 2.80 were used.
- Bacterial strains: The bacteria used in the present works are:
- When bacteria + rice husk ash applied on the cracks after casting: Rice husk ash is used with Bacillus sphaericus for healing the cracks on concrete cubes and beams and various properties of concrete are checked.

III. PREPARATION OF SPECIMEN FOR COMPRESSIVE STRENGTH TEST

Concrete samples were made by using OPC (ordinary Portland cement) of grade 53. . Standardized cracks were realized in concrete samples with dimensions of 150 mm × 150 mm × 150 mm. After casting, all moulds were placed in a normal room temperature for a period of 24hrs. After de-moulding, the specimens were placed for the curing for 28 days in local available water.

A. Creation of Cracks

After completion of 28 days curing standardized cracks were created in concrete specimen by marble cutter on the upper surface, having a depth of 15mm and width of approximate 3 mm.

Fig. 1: Crack made of 15 mm depth

Fig. 2: Paste of bacteria mixed of rise Husk ash

Paste of bacteria mixed with rise husk ash and Insertion of bacteria paste in crack surface

P-Urathine as a food was given, on filled crack with bacteria, at every six hours interval and up to 7 days to produce calcite in crack.

Fig. 3: Crack filled by bacteria

IV. TESTING METHODOLOGY

The testing has been done as per IS: 516-1999. After the required period of curing the cubes are removed from the curing tank and tested for compressive strength. The compressive strength of the mortar cubes at 14 days and 28 days is determined and Scanning Electron Micrograph (SEM) analysis is to be done on treated surface with bacteria and rise husk ash.

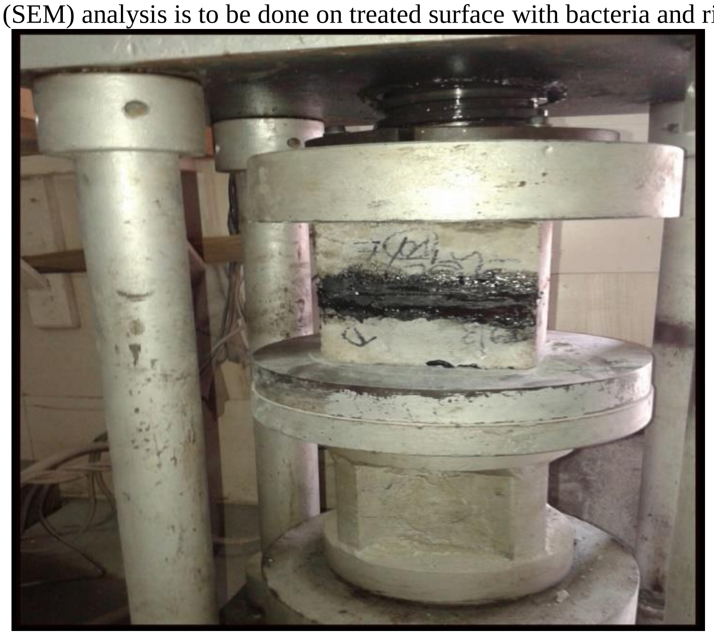

Fig. 4: Compression test on concrete cube after filling crack with bacteria + rise husk ash

V. RESULTS

Compressive Strength Test		
Cell concentration/ml of mixing water	*Average Compressive Strength of Concrete (N/mm^2)*	
	14 days	*28 days*
Nill (specimen without crack)	*56.86*	*65.28*
Nil (specimen with crack)	*42.01*	*46.56*
10^5	*43.21*	*47.80*
10^7	*45.40*	*51.90*
10^9	*48.60*	*55.60*

Table 2: 14th & 28th day test results of compressive strength test in (N/mm^2) for 15 mm depth of crack

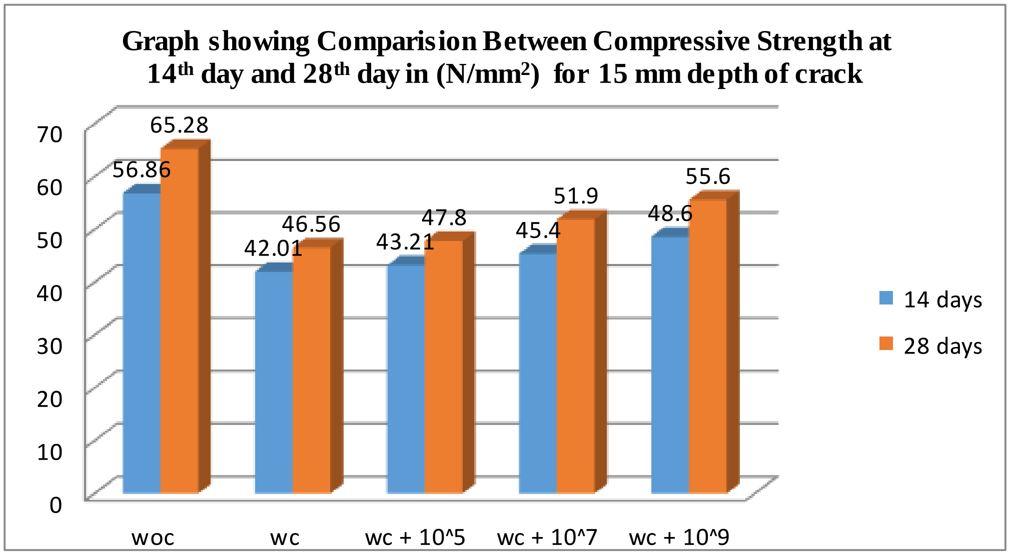

Fig. 5: Graph 1: showing Comparison between Compressive Strength at 14th day and 28th day in (N/mm^2) for 15 mm depth of crack

A. SEM (Scanning Electron Microscope) Results

Fig. 6: Scanning Electron Microscope

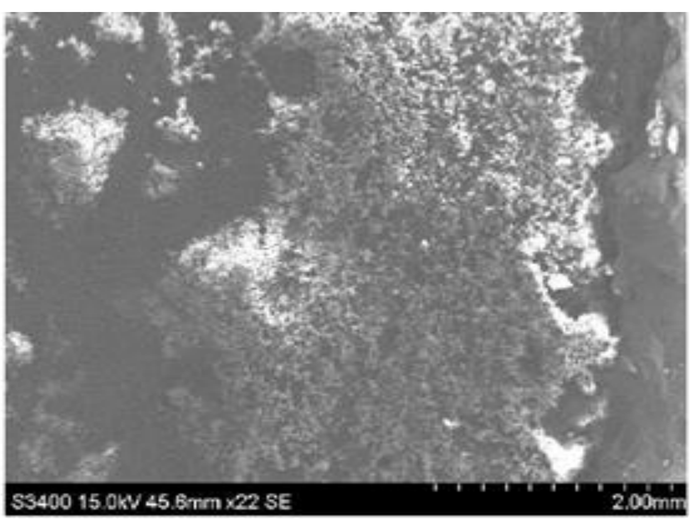

Fig. 7: Magnified image of rise husk ash Specimen. Scale bar is 2.0 mm

VI. CONCLUSION

- Bacillus sphaericus in cracks improves the compressive strength. This reveals the fully grown calcite crystal with distinct and sharp edges all over the surface of the crack act as an agent for an eventual plugging and remediation. The use of this biological repair technique is highly desirable because the mineral precipitation induced as a result of microbial activities is pollution free and natural.
- The unique imaging and microanalysis capabilities of SEM established the presence of calcite precipitation inside cracks. The development of the microbial concrete will provide alternative solution for chemical sealant. So, it will be cost effective and environmentally safe.

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