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Research Paper Engineering

A Study of Performance of Bacillus Lentus on Concrete Cracks

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ABSTRACT

The objective of the present investigation is to study the performance of bacteria Bacillus Lentus to improve the strength of cracked concrete. In concrete, cracking is a common phenomenon due to the relatively low tensile strength. High tensile stresses can result from external loads, imposed deformations, plastic shrinkage, plastic settlement, and expansive reactions. Without immediate and proper treatment, cracks tend to expand further and eventually require costly repair. In this investigation, Bacillus Lentus, a common soil bacterium was used to induce calcite precipitation. This technique is highly desirable because the mineral precipitation induced as a result of microbial activities, is pollution free and natural. The effectiveness of this technique was evaluated by comparing the strength and durability of cracked specimens remediated with bacteria and those of the control specimens. Scanning electron microscope (SEM) was used to document the role of microbiologically induced mineral precipitation in improving the strength and durability of concrete.

Keywords : Bacillus Lentus; Bacterial concrete, Crack remediation, Strength study, Weight loss, Strength loss, SEM.

1. INTRODUCTION

Cracks in concrete are inevitable and are one of the inherent weaknesses of concrete. Water and other salts seep through these cracks, corrosion initiates, and thus reduce the life of concrete. Due to the negative side-effects of some of the conventional techniques, bacterial induced carbonate mineralization has been proposed as a novel and environmental friendly strategy for the protection of stone and mortar. Bacterial concrete is a material, which can successfully remediate cracks in concrete. This technique is highly desirable because the mineral precipitation ($CaCO_3$) 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. For crack repair, a variety of techniques is available but traditional repair systems have a number of disadvantageous aspects such as different thermal expansion coefficient compared to concrete and environmental and health hazards. Therefore, bacterially induced calcium carbonate precipitation has been proposed as an alternative and environmental friendly crack repair technique. In 1995, gollapudi *et al*. Were the first to introduce his novel technique in fixing cracks with environmentally friendly biological processes. The microbial precipitation of $CaCO_3$ is determined by several factors including: the concentration of dissolved inorganic carbon, the ph and the concentration of calcium ions and the presence of nucleation sites. 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.

1.1 Classification of Bacteria

- **Classification on the Basis of Shapes**

Bacteria are usually classified on the basis of their shapes. Broadly, they can be divided into Rod-shaped bacteria (Bacilli), Sphere-shaped bacteria (Cocci) and Spiral-shaped bacteria (Spirilla).

- **Classification on the Basis of Gram Strain**

This classification is based on the results of Gram Staining Method, in which an agent is used to bind to the cell wall of the bacteria; they are Gram positive and Gram-negative.

- **Classification on the Basis of Oxygen Requirement**

This classification is based on the requirement of oxygen for the survival of the bacterium. They are and Anaerobic.

1.2 Formation of carbonate ions

The bacteria used in this research produce urease which catalyzes the hydrolysis of urea ($CO(NH_2)_2$) into ammonium (nh_{4+}) and carbonate ($CO_{3\ 2-}$). First, 1mol of urea is hydrolyzed intracellular to 1mol of carbamate and 1mol of ammonia (eq. (1)). Carbamate spontaneously hydrolyses to form additionally 1mol of ammonia and carbonic acid (eq. (2)). These products subsequently form 1mol of bicarbonate and 2mol of ammonium and hydroxide ions (eqs. (3) and (4)). The last 2 reactions give rise to a ph increase, which in turn shifts the bicarbonate equilibrium, resulting in the formation of carbonate ions (eq. (5)).

$$CO(NH_2)_2+H_2O \rightarrow NH_2COOH+NH_3 \quad (1)$$
$$NH_2COOH+H_2O \rightarrow NH_2+H_2CO_3 \quad (2)$$
$$H_2CO_3 \leftrightarrow HCO^-_3+H^+ \quad (3)$$
$$2NH_3+2H_2O \leftrightarrow 2NH^+_4+2OH^- \quad (4)$$
$$HCO^-_3+H^++2NH^+_4+2OH^- \leftrightarrow CO^{2-}_3+2NH^+_4+2H_2O \quad (5)$$

Since the cell wall of the bacteria is negatively charged, the bacteria draw cations from the environment, including Ca^{2+}, to deposit on their cell surface. The Ca^{2+}-ions subsequently react with the Co_3^{2-}-ions, leading to the precipitation of caco3 at the cell surface that serves as a nucleation site (eq^n. (6) and (7)).

$$Ca^{2+} + Cell \rightarrow Cell\text{-}Ca^{2+} \quad (6)$$
$$Cell\text{-}Ca^{2+} + CO^{2-}_3 \rightarrow Cell\text{-}CaCO_3 \quad (7)$$

Many of the physical and chemical deterioration mechanisms of concrete are related to aggressive substances present in aqueous solution. An important measure to protect concrete against damage is then diminishing the uptake of water. Surface treatments play an important role in limiting the infiltration of water and consequently of detrimental components into concrete. Nowadays a broad array of organic and inorganic products is available on the market for the protection of concrete surfaces, such as a variety of coatings, water repellents and pore blockers. These conventional means of protection show, however, beside their favourable influences also a number of disadvantageous aspects such as:

i) Different thermal expansion coefficient of the treated layers;
ii) Degradation over time
iii) The need for constant maintenance.
iv) Furthermore the use of certain solvents contributes to environmental pollution.

2. MATERIALS AND METHODS

CEMENT: Ordinary Portland cement of 53 grade used for all tests is from the same batch. The cement used has been tested for various properties as per IS: 4031-1988 and found to be conforming to various specifications of IS: 12269-1987.

SAND: Locally available Sand is used to find the compressive strength of cement mortar cubes and concrete beams.

FINE AGGREGATE: The locally available aggregate is used as fine aggregate in the present investigation. The cleaned fine aggregate is chosen between sizes 4.75 mm to 10mm in accordance with IS: 2386-1963.

WATER: Water used for mixing and curing is fresh potable water, conforming to IS:3025–1964 part 22, part 23 and IS: 456 – 2000.

BACTERIA: Bacillus Lentus, a laboratory cultured bacterium is used.

2.1 MORTAR SAMPLES FOR COMPRESSIVE STRENGTH STUDY: Total 84 Mortar samples were made by using ordinary Portland cement, locally available river sand and potable water. The composition of the mortar Mix is shown in Table 2.1.1. Cement and sand ratio is used as 1:3 (by weight). Moulds with dimensions of 70.6 mm× 70.6 mm× 70.6 mm. After casting, all moulds were placed in a normal temperature of room with a relative humidity of more than 90% for a period of 24h. After demoulding, the specimens were placed for the curing for 28 days.

Material	Weight per cube
Sand	600 mg
Cement	200 mg
Water	83 ml

Table 2.1.1: Composition of Mortar cubes

2.2.1 CREATION OF CRACKS: Standardized cracks were realized in mortar samples with dimensions of 70.6 mm×70.6 mm× 70.6 mm. the crack was developed by marble cutter on the upper surface, with a depth of 15, 20 mm or 25 mm and a width of 1 mm and 2mm.

2.1.3 INSERTING BACTERIA IN TO CRACKS: The cracks in specimens were filled with a mixture of sand and Bacillus Lentus. The sand mixed with bacteria suspension to a final concentration of 10^9 cells/ml was forced into the crack with a knife-edge.

Fig 2.1.1 The mixture of sand and B. Lentus

Fig 2.1.2 Inserting bacteria in to cracks

Liquid media consist of (Nutrient Broth + $NaHCO_3$ + urea) is given for 1 month to bacteria to produce calcite during this period as a food at interval of every 6 hours.

2.1.4 TESTING PROCEDURE: 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 28 days and 56 days is determined and Scanning Electron Microscopy (SEM) analysis is made on the broken sample of 56 days cube specimen.

2.2 CONCRETE SAMPLES FOR FLEXURAL STUDY: The investigation is carried to study the flexural behaviour of concrete. 42 simply supported beams consisting of balanced section are cast and tested. Concrete samples were made by using ordinary Portland cement. The composition of the concrete mix is shown in Table 2.2.1. Moulds with dimensions of 500 mm×100 mm ×100 mm. After casting, all moulds were placed in a normal temperature of room with a relative humidity of more than 90% for a period of 24h. After demoulding, the specimens were placed for the curing for 28 days.

MATERIAL	Weight per cmt
Sand	546 kg.
Aggregates (grit)	475 kg.
Aggregates (kapchi)	713 kg.
Cement	383 kg.
Water	191.6 lts.

Table 2.2.1: Composition of concrete mix

2.2.1 CREATION OF CRACKS: Standardized cracks were realized in concrete beams with dimensions of 100 mm×100 mm× 500 mm. the crack was developed by marble cutter on the upper surface, with a depth of 15, 20 mm or 25 mm and a width of 3 mm. There were 7 sets of beams each containing 3 samples selected for 3mm width and depth combination, so total 42 numbers of concrete beams were cast for 28 days test results and for 56 days of results. The procedure of Bacteria application on cracks and food application are same as in procedure of same in mortar cubes.

2.2.2 TESTING PROCEDURE: After the required period of curing the beam specimens are removed from the curing tank and cleaned. A set of beams are tested for flexural strength at 28 days and 56 days. The beam is placed on two roller supports, resting on cast iron blocks, placed on the wing table of the Universal testing machine. The load is from the fixed cross head of the machine as two point loading, on the two rollers placed 165 mm apart, by a loading beam of sufficient stiffness. Testing is performed under third point loading under controlled deflection The test is conducted as per IS : 516-1999.

2.3 MORTAR SAMPLES FOR DURABILITY STUDY: The investigation is carried out to study the durability aspect of Bacterial concrete. For long term durability of concrete structures, it is essential that the environmental factors capable of adversely affecting their service life can be given proper consideration. Chemical attack by aggressive water is one of the factors responsible for damage to concrete. Frequently it is the presence of sulphate ions in water that accounts for

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its aggressive behaviour to concrete because certain constituents of cement paste can enter into deleterious soluble alkali sulphates and many industrial waters contain enough sulphate to potentially damage the Ordinary cement concrete.

A total of 21 sets of cubes of size 70.6 mm x 70.6 mm x 70.6 mm are cast and cured. After 28 days of curing and 28 days of to allow bacteria to produce calcite. cubes are immersed in 3.5% concentrated $MgSo_4$. The percentage weight loss, percentage compressive strength loss is taken for a set of cubes at 56 days.

2.3.1 TESTING PROCEDURE: After 28 days of casting, each cube is tested for weight An accelerated experimental test program is conducted on ordinary Portland cement concrete. Specimens are subjected to 3.5% solutions of $MgSo_4$. Cubes are continuously immersed in solution. The specimens are arranged in such a way that the clearance around and above the specimen is not less than 30 mm. The solution has been changed for an interval of every 15 days after taking the measurements. Before testing, each specimen is removed from the tubs, and brushed with a soft nylon brush and rinsed in tap water. This process removes loose surface material from the specimens. The percentage weight loss, percentage compressive strength loss is taken for a set of cubes at 56 days.

3. TEST RESULTS

3.1 COMPRESSIVE STRENGTH: The investigation is carried out to study the strength of cement mortar cubes. The results of the cement mortar strengths at 28 days and 56 days at various crack depth and width are shown in graph below.

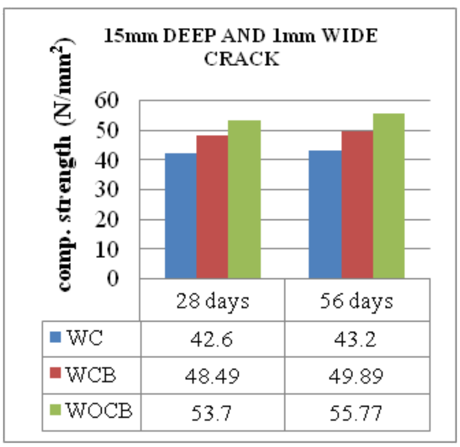

Fig.3.1.1 Graph showing Variation of Compressive Strength of 15 mm depth at different days

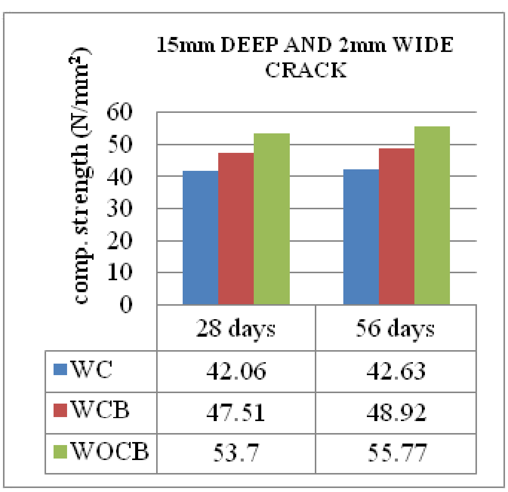

Fig.3.1.2 Graph showing Variation of Compressive Strength of 15 mm depth at different days

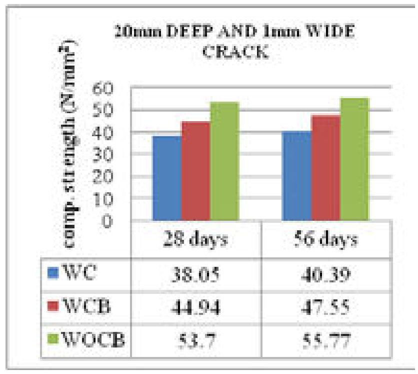

Fig.3.1.3 Graph showing Variation of Compressive Strength of 20 mm depth at different days

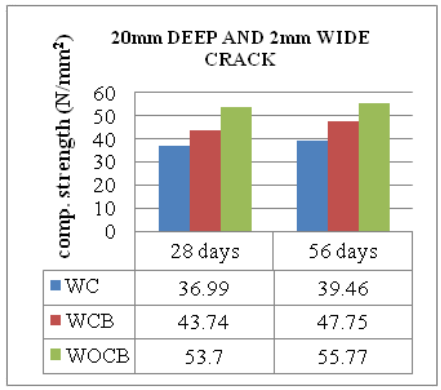

Fig.3.1.4 Graph showing Variation of Compressive Strength of 20 mm depth at different days

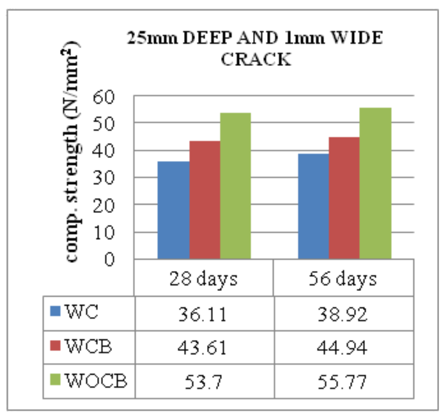

Fig.3.1.5 Graph showing Variation of Compressive Strength of 25 mm depth at different days

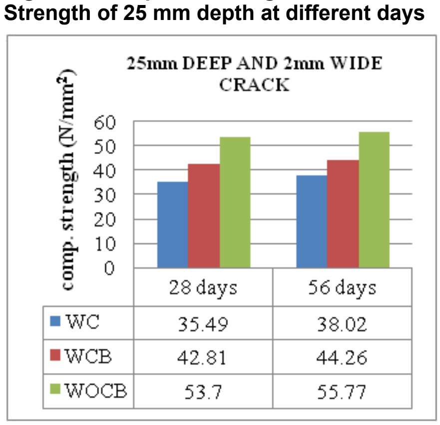

Fig.3.1.6 Graph showing Variation of compressive Strength of 25 mm depth at different days

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3.2 FLEXURAL BEHAVIOR OF CONCRETE: The investigation is carried to study the flexural behaviour of concrete. 42 simply supported beams consisting of cross section 100mm x 100mm x 500mm.

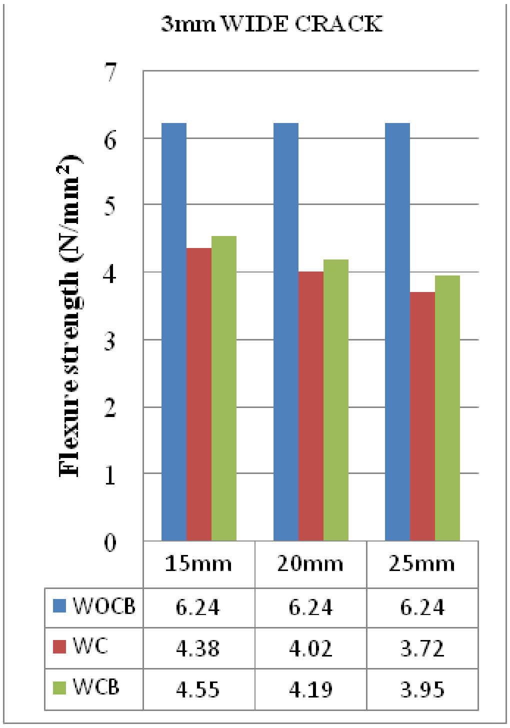

Fig.3.2.1 Graph showing Variation of flexural strength at 28th day

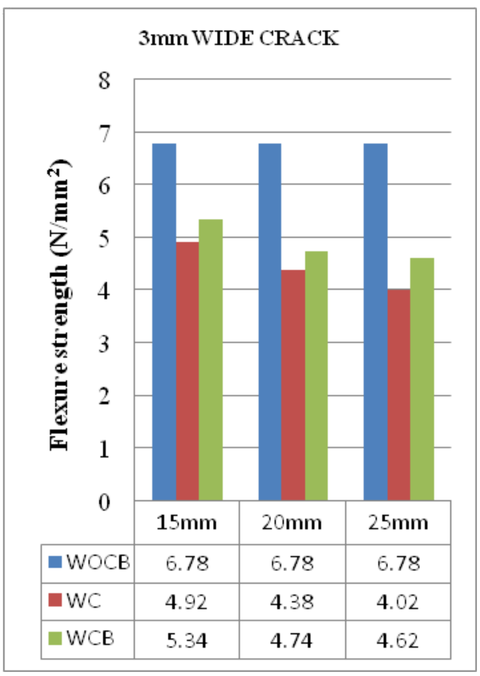

Fig.3.2.2 Graph showing Variation of flexural strength at 56th day

3.3 THE STRENGTH LOSS, WEIGHT LOSS OF CONCRETE: The investigation is carried out to study the durability aspect of Bacterial concrete. After 28 days of curing in water 18 sets of cubes are immersed in 3.5% concentrated $MgSO_4$. The results of the percentage weight loss and percentage compressive strength loss of concrete are shown in graph below.

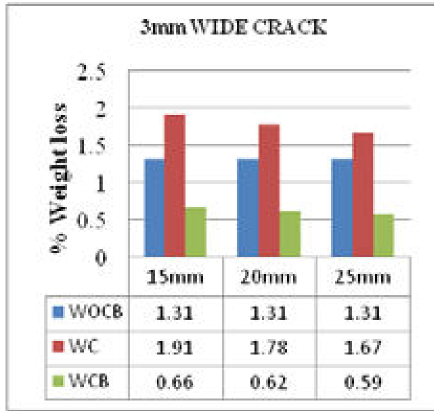

Fig.3.3.1 Graph showing Variation of % weight loss at 56th day

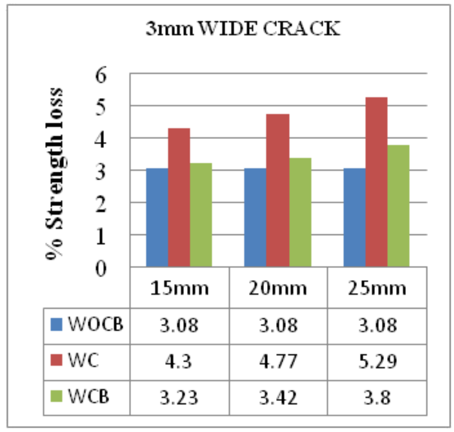

Fig.3.3.2 Graph showing Variation of % strength loss at 56th day

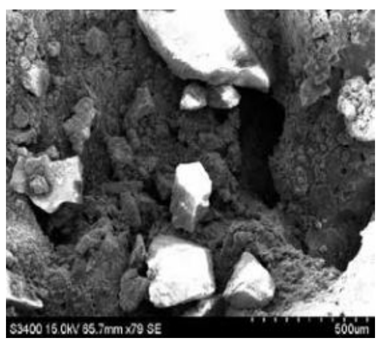

Fig. 3.3.1 Cracked specimens

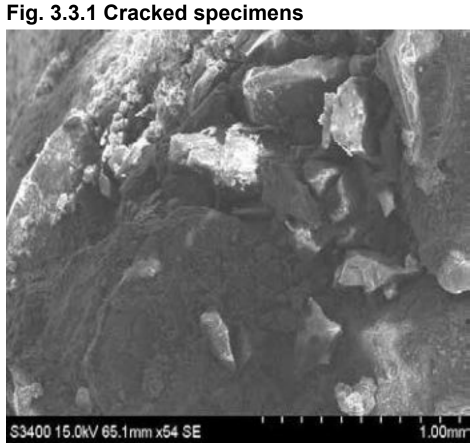

Fig. 3.3.2 Calcified regions of bacterial concrete

4. CONCLUSIONS

The following conclusions are drawn from the detailed experimental investigations conducted on the behavior of ordinary grade conventional concrete.

- The addition of bacteria Bacillus Lentus in cracks improves the compressive strength around 17.3% at 28th day and 17.6% at 56th day.
- The experiment on concrete beams shows that not much improvement in flexural strength because of proper bond not create between calcite and concrete in 56 days. It might take more than 6 month to create good bond between them.
- From the durability studies, in WOCB, WC and WCB cubes immersed in 3.5% $MgSO_4$. The percentage weight loss respectively in WOCB, WC-15, WCB-15, WC-20, WCB-20, WC-25 and WCB-25 are 1.31%, 1.95%, 0.66% 1.78%, 0.62%, 1.67% and 0.59%. It shows that weight loss percentage in WCB is less compared to WOCB and WC.
- The percentage strength loss respectively in WOCB, WC-15, WCB- 15, WC-20, WCB-20, WC-25 and WCB-25 are 3.07%, 4.31%, 3.22%, 4.77%, 3.42%, 5.29% and 3.79%. It shows that strength loss percentage in WCB is less compared to WC but larger than WOCB.
- Bacillus Lentus is a soil bacterium.
- Bacillus Lentus can be produced in the laboratory which is proved to be safe and cost effective.

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