ASL Pauls **C**ollege of **E**ngineering and **T**echnology

Coimbatore -642 109.

Department of **C**ivil **E**ngineering

A PAPER ON

BACTERIAL CONCRETE

BY

A.SAFATH MAIDEEN & D.RAJ KUMAR

(FINAL YEAR)

safath29@gmail.com **&** drajkumarce@gmail.com

PHONE: 9092322707,9865828830

ABSTRACT

Ability of living organisms to form minerals has lead to development of bacterial concrete. It is a biomaterial and a self repairing material it remedies cracks and fissures in concrete. Concrete with Bacillus pasteruil bacteria with filler sand has been successful this has aided restoration of historical monuments by microbial precipitation.

Bacterial have been effectively used for improving the strengths of concrete beams and other structures, which have air gaps and micro cracks. The bacterial Bacillus pasteruil in the concentration of 8.6*108 cells/ml can improve the strength of the concrete by forming a calcite layer in the crack. Thus, the strength of the beams has improved back to 81.97% of the original strength.

BACTERIAL CONCRETE

(Microbiologically Enhanced Crack Remediation Technique)

INTRODUCTION

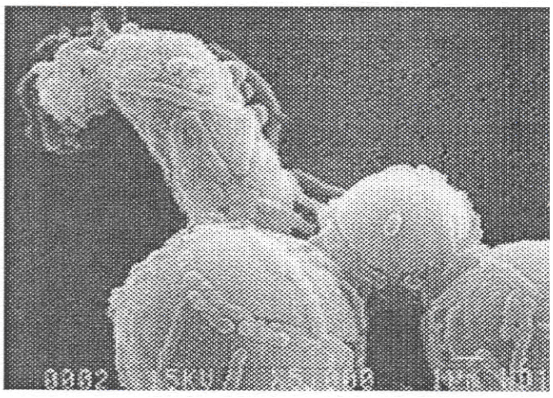
Cracking is an inevitable phenomenon in structures and is one of the inherent weaknesses. Water and other salts seep through these cracks; corrosion initiates, and thus reduces the life of structures. Any structure with cracks looses its structural integrity and, is structurally unsafe. The bacterial remediation technique can be used for repairing structures of historical importance to preserve its aesthetic value, as conventional techniques like epoxy cannot be used to remediate cracks in those structures.

This technique is highly desirable because the mineral precipitation 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: the mineral crystals grow with time and eventually plug the pores and cracks in structures.

Many types of bacteria are efficient at extracting the nitrogen they require to live from urea (the nitrogenous component of urine, produced by many microorganisms),

which process produces carbon dioxide and ammonia as byproducts. If water is also present, that ammonia will react with it to form ammonium hydroxide; if calcium is also present, that ammonium hydroxide will react with it to form crystals of calcium carbonate. Calcium carbonate (CaCO3) is better known as limestone.

Researches were done in the lab to speed up this chain reaction, which occurs in nature very slowly. This was carried by mixing two common types of soil bacteria, Bacillus pasteurii and Sporosarcina urea, with sand, and "feed" the bacteria a rich solution containing both urea and calcium chloride. After using up the supply of nutrients, the bacteria die but by that time,



This scanning electron micrograph shows spherical or oblong calcite particles formed by Bacillus pasteurii urea hydrolysis activity, shown here adhered to the particles the calcium carbonate has crystallized the sand into solid limestone. Initial experiments were done in test tubes; it has now succeeded in "growing" limestone directly within cracks in concrete blocks.

This technique is called microbiologically enhanced crack remediation (MECR). This technique comes under a broader category of science called biomineralization. It is a process by which living organisms form inorganic solids.

Calcium carbonate precipitation

In natural environments, chemical CaCO3 precipitation (Ca2+CO2- CaCO3) is accompanied by biological processes, both of which often occur simultaneously or sequentially. An endospore forming, soil microorganism, Bacillus pasteurii, is known to have an ability to precipitate calcite in the

environment. This microbiologically induced calcium carbonate precipitation (MICCP) comprises of a series of complex biochemical reactions. As part of metabolism, B. pasteurii produces urease, which catalyzed 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.

Ca^2 + Cell Cell – Ca^2+

C1- +$HCO-^3$ + NH3 NH4CI + CO_3^{2-}

Cell-Ca^2+ + CO_3^{2-} Cell-$CaCO_3$

As a microbial sealant, CaCO3 has exhibited its positive potential to selectively consolidate simulated fractures and surface fissures. Microbial calcite precipitation was quantified by X-ray diffraction (XRD) analysis and visualized by SEM.

POSSIBLE APPLICATIONS

- Monumental candidate Mount Rushmore (located not far from South Dakota school of mines and technology), which when seen close-up betrays the severe effects of rain and snow, wind, heat and cold.

ADVANTAGES:

- It is pollution-free and environment-friendly.
- It seals from the inside out (from the bottom to the top)
- It integrates with the porous concrete rather than simply filling the space in the crack.

As this concept is still in its burgeoning state, its disadvantages are yet to be known.

EXPERIMENTAL INVESTIGATIONS

The effect, B.pasteurii with various concentrations, on the modulus of rupture of the cracked cement mortar beams.

The specimens were cured in a moist cabinet for 14 days and then they were air cured for 7 days. After the specimens attained their complete strength, cracks were made in the

specimen by cracking up to half its depth on tension side. The cracked beams after remediation with bacteria were tested to determine the regain in the modulus of rupture.

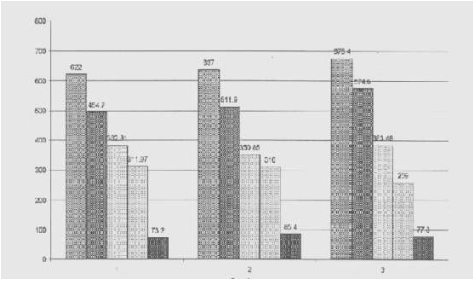
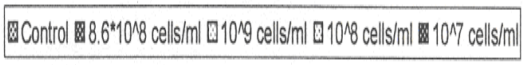


Figure 1: Compression of the modulus of repute of cracked specimens remediated with different concentrations of bacteria and uncracked specimens (Control)



A total of 15 cracked beams were made out of which 12 beams were treated with bacteria of concentration of 107 cells/ml, 109 cells/ml and 8.6 x 108 cells/ml. The other three were without bacteria (only Urea-CaC12 medium). Urea-CaC12 medium was added in each of the concentrations which served as the nutrient for the bacteria to grow in order to get the calcium carbonate precipitation. The beams were loaded centrally until it broke and the data obtained through the data acquisitions system were analyses to find the modulus of rupture of the specimens. The average values of modulus of rupture were calculated for each concentration and they were compared to that of the modulus of rupture values of the beams without pre-cracks (control). The results are shown in Figure.

1. The results are summarized as follows:

i. Cement mortar beams (with cracks) treated with a bacterial concentration of 109 cells/ml regained their strength (modulus of rupture) by 57.74% when compared to that of beams without cracks. The cracked beams with bacteria showed 90.92% greater modulus of rupture values that of cracked specimens treated without bacteria (only in Urea-Cacl2 medium).

ii. Cement mortar beams (with cracks) treated with a bacterial concentration of 8.6 x 108 cells / ml regained their strength (modulus of rupture) by 81.73% when compared to that of beams

without cracks. The cracked beams with bacteria showed 93.59% greater modulus of rupture values that of cracked specimens treated without bacteria (only in Urea-Cacl2 medium).

iii. Cement mortar beams (with cracks) treated with a bacterial concentration of 108 cells/ml regained their strength (modulus of rupture) by 45.55% when compared to that of beams without cracks. The cracked beams with bacteria showed 88.49% greater modulus of ruputer values that the of cracked specimens treated without bacteria (only in Urea-Cacl12 medium).

iv. Cement mortar beams (with cracks) treated with a bacterial concentration of 107 cells/ml regained their strength (modulus of rupture) by 12.21% when compared to that of beams without cracks. The cracked beams with bacteria showed 56.54% greater modulus of rupture values that the of cracked specimens treated without bacteria (only in Urea-Cacl2 medium).

The effect of B. pasture on the alkali aggregate reactivity

A set of 10 beams were made, out of which 5 were made with bacteria and five were made without bacteria, using water. The specimen moulds were placed in a moist cabinet for about 24+2 hrs and after they were demoded they were placed in Urea CaCl2 and cured for 7 days. The specimens were transferred into a plastic container containing tap water and were immersed completely. They were sealed and placed in oven at 80+2.00C (176+3.60F) for 24hrs, later removed one at a time and the reading was taken. After the zero readings were placed in the oven. The process of drying the specimens and taking the reading was done in 15+5 sec after removing the specimens from the container. After each specimen was measured they were left on a towel (for drying until the length comparator readings were taken for all the remaining bars. Reading swerve taken at every 3, 5, 7, 11 and 14 days.

It was observed that the mean expansion of beams made with bacteria was less than the mean expansion of cement mortar beams made without bacteria. From the results it is concluded that cement mortar beams made with bacteria reduced the mean percentage expansion by 19.98%. This reduction is due to the formation of calcite in the specimen due to the metabolic activities of the bacteria which makes the cement mortar beam more compact by filling the voids and less permeable thus a voiding the penetration of deleterious fluids into the specimen.

The effect of B. pasteurii on the sulfate attack resistance with the optimum concentration of bacteria (8.6 x 108 cells/ml).

A total of 8 beams were made out of which 4 were made with water and 4 were

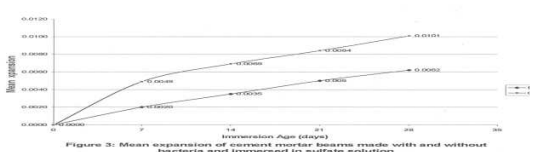


Figure 3: Mean expansion of cement mortar beams made with and without bacteria and immersed in sulfate solution

made with bacteria. The specimens were cured in Urea-CaCl2 medium for 7 days. Zero reading (initial readings) was taken before placing the specimens in 0.35 M sodium. sulfate solution. Additional readings were taken using a length comparator at every 7,14, 21 and 28 days after placing them in sodium sulfate solution.

Cement mortar beams were made with and without bacteria; it was observed that bacteria remediate specimens had 38.62% less mean expansion than the mean expansion of the control specimens. The corresponding graphs are shown in Figure 3.

The effect of different concentrations of bacteria on the freeze thaw durability.

A total of 8 beams were made. Two beams were made without bacteria (control) and two beams were made for each concentration of bacteria. After the specimens were remolded they were cured in Urea-CaCl1 media for 7 days and then were air cured for 14 days. Freezing and thawing test was done by alternately lowering the temperature of the specimens form 4.4^0C to – 17.8^0C

(40^0 F to 0^0F) and raising it form – 17.8^0C to 4.4^0C (0^0F to 40^0F). The specimens were removed and were tested for pulse velocity, length change and weight change.

The results were summarized as follows:

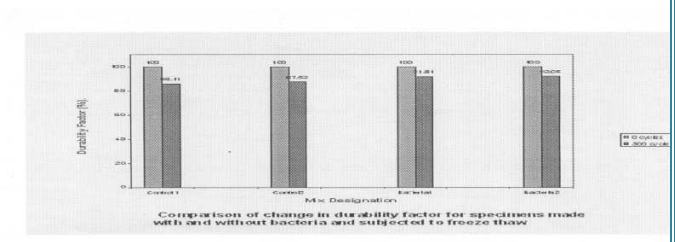
i. The mean expansion at the end of 210 cycles were 0.19% for control beam, 0.083%, 0.079% and 0.064% respectively for 1 x 106 cells/ml, 1 x 107 cells/ml and 8.6 x 108 cells/ml bacterial beams.

ii. The reduction in weight after 210 cycles were 14% for control beams, 5%, 3% and 1% respectively for 1 x 106 cells, 1 x 107 cells / ml, and 8.6 x 108 cells / ml bacterial beams.

iii. The average durability factor after 210 cycles were 71% for control beams, 74%, 82% and 89% respectively for 1 x 106 cells / ml, 1 x 107 cells / ml and 8.6 x 108 cells / ml bacterial beams.

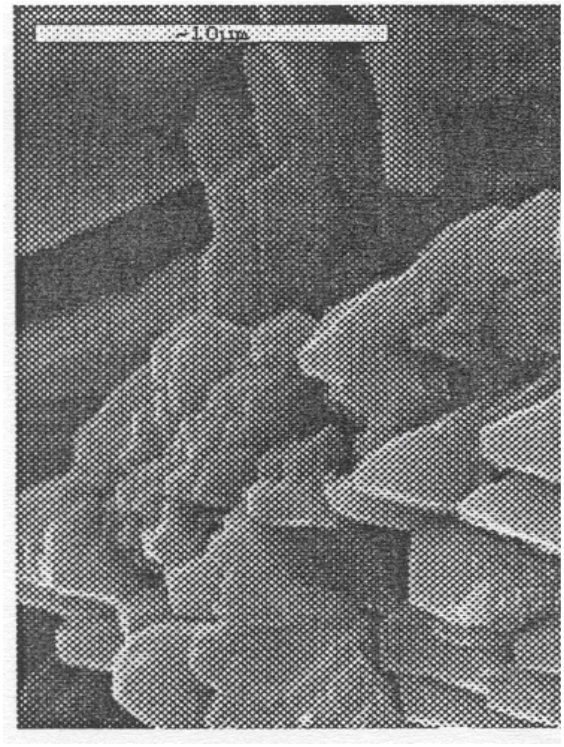
iv. From the results, it is evident that cement mortar with all bacterial concentrations perform better than the beams without bacteria when subjected to freeze-thaw.

v. The higher the bacterial dosage, the better was the performance.



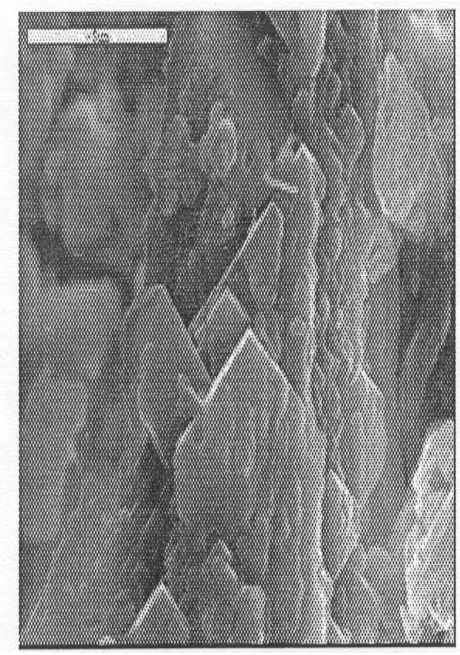
Scanning Electron Microscope (SEM) Examination:

Scanning electron microscope (SEM) is one of the most versatile instruments available for examination and analysis of macro structural characteristics of solid objects. The primary reason for SEM's usefulness is the high resolution that can be obtained when bulk objects are examined.



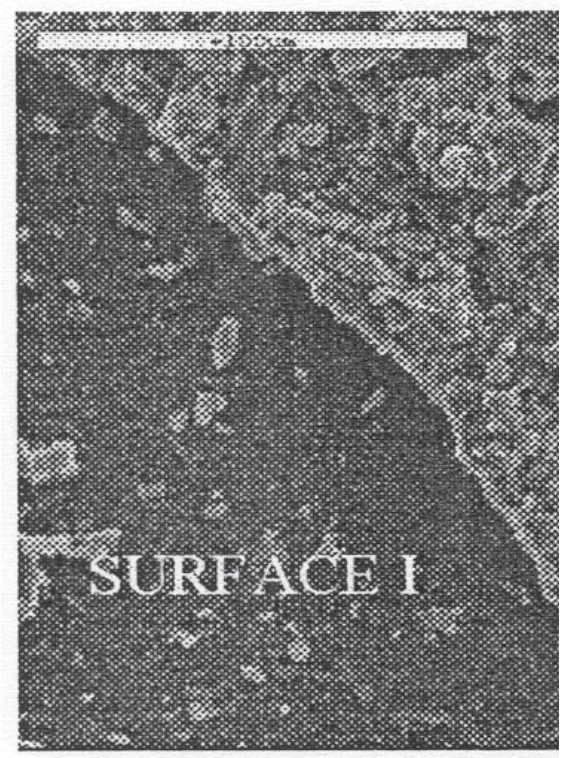
Micrograph 1: Magnified image of full-grown calcite crystals in interior surface of the crack.

Sample were taken from the surface of the crack to determine whether there was any bacteriogenic mineral precipitation, which contributed to the bond and regaining strength of the already cracked beam. It was found that full-grown calcite crystals, with distinct and sharp edges (Micrograph i) had grown all over the surface of the crack, thus acting as an agent that eventually plugged and remediate the cracks.



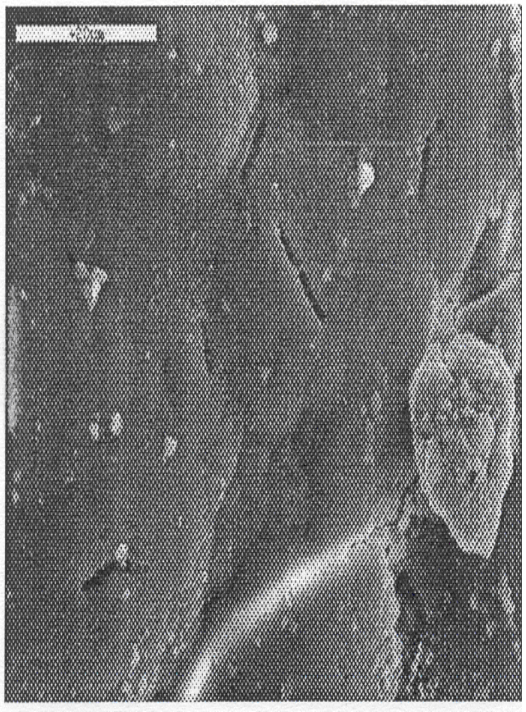
Micrograph 2: Magnified image of calcite crystals developed on the surface of the cement mortar beams

On further investigation rod-shaped objects were found dispersed in the crystals. These objects measure 1-3 m in length and 0.5 m or less across, consistent with the dimensions of B. Pasteurii. Micrograph 2 shows magnified image of calcite crystals. Developed on the surface of cement mortar beams with bacteria, subjected to alkali aggregate reactivity.



Micrograph 3: This picture shows a new layer (Surface II) formed over the surface of the cement mortar beam (Surface I)

Micrograph 3 shows that a new layer (Surface I). The elemental composition of surface I, was found to be characteristic of cement material, and the elemental composition of surface II, was found to be predominantly calcite material, which formed an impermeable layer and increased the freeze thaw durability. Rod-shaped impressions, consistent with the dimensions of B. Pasteurii were found in the calcite crystals, which formed on the surface of the specimens subjected to sulfate attack



Micrograph 4: Rod-shaped impressions, consistent with the dimensions of B. It was found that all the specimens with bacteria had a layer of calcite at the surface, thus improving its impermeability and its resistance to alkaline environment, sulfate attack and freeze-thaw.

CONCLUSIONS:

- The microbial remediation of cracks in cement mortar specimens increased the compressive strength, stiffness and modulus of rupture.
- Durability characteristics improved with the addition of bacteria.
- Microbiologically induced calcite precipitation is effective in remediation of cracks.
- Calcite layer improves the impermeability of specimen, thus increasing its resistance to alkaline, sulfate and freeze-thaw attack.
- Cracked cement mortar beams remediate with bacteria of concentration 8.6 x 108 cells/ml regained its strength by 81.97% of its original (uncracked) strength.
- Higher concentration of bacteria reduced the regaining strength of the beams.
- The presence of bacteria had reduced the effects of sulfate attack.
- The presence of bacteria had reduced the mean expansion by 45.37%, when compared to the control specimens without bacteria, when subjected to freezing and thawing.
- Bacteria remediate specimens had a better durability factor than specimens made without bacteria.