- Bacterial Concrete

A novel technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite (CaCo3) precipitation is discussed. Microbiologically induced calcite precipitation (MICP) is a technique that comes under a broader category of science called biomineralization. It is a process by which living organisms form inorganic solids. Bacillus Pasteruii, a common soil bacterium can induce the precipitation of calcite. As a microbial sealant, $CaCO_3$ exhibited its positive potential in selectively consolidating simulated fractures and surface fissures in granites and in the consolidation of sand. MICP is highly desirable because the calcite precipitation induced as a result of microbial activities, is pollution free and natural. The technique can be used to improve the compressive strength and stiffness of cracked concrete specimens. A durability study on concrete beams treated with bacteria, exposed to alkaline, sulfate and freeze-thaw environments were also studied. The effect of different concentrations of bacteria on the durability of concrete was also studied. It was found that all the beams with bacteria performed better than the control beams (without bacteria).

The durability performance increased with increase in the concentration of bacteria. Microbial calcite precipitation was quantified by X-ray diffraction (XRD) analysis and visualized by SEM. The unique imaging and microanalysis capabilities of SEM established the presence of calcite precipitation inside cracks, bacterial impressions and a new calcite layer on the surface of concrete. This calcite layer improves the impermeability of the specimen, thus increasing its resistance to alkaline, sulfate and freeze-thaw attack.

Introduction

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 Pasteruii, a common soil bacterium, can continuously precipitate calcite . This phenomenon is called microbiologically induced calcite precipitation. Under favorable conditions Bacillus Pasteruii 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 . In natural environments, chemical $CaCO_3$ precipitation (Ca^{2+}+

CO_3^{2-}→ $CaCO_3$↓) 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. pasteurii produces urease, which catalyzes urea to produce CO_2 and ammonia, resulting in an increase of pH in the surroundings where ions Ca^{2+} and CO_3^{2-} precipitate as $CaCO_3$. Possible biochemical reactions in medium to precipitate $CaCO_3$ at the cell surface that provides a nucleation site can be summarized as follows.

Ca^{2+} + Cell → Cell-Ca^{2+} . . . . (1)

Cl^- + HCO_3^- + NH_3 → NH_4Cl + CO_3^{2-} . . (2)

Cell-Ca^{2+} + CO_3^{2-} → Cell-$CaCO_3$↓ . . . (3)

Earlier it was reported that sand consolidation by B. pasteurii 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 and Islam, 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

Objectives

The objectives of the investigation were:

• To study the effect of different concentrations of bacteria on the durability of concrete.

• To study the efficiency of bacteria when suspended in different mediums (water, phosphate-buffer and urea-$CaCl_2$) on the durability of concrete.

Experimental Program

The effect of bacteria suspended in different mediums on the alkali aggregate reactivity of concrete beams In this study bacteria were first suspended separately in three different mediums (water, phosphate-buffer and urea-$CaCl_2$) to obtain a final concentration of 1 x 108 cells/ml. A total of 12 concrete beams of dimensions 285.75 x 25.4 x 25.4 mm (11.25 x 1 x 1 in) were made. Three beams for each type of medium (with bacteria) and three beams without bacteria (control) were made. The molds were placed in the moist curing cabinet for 24 ±2 hrs and after demolding they were placed in urea-$CaCl_2$ solution and cured for 7 days. The test was done as per the requirements of ASTM C1260 (Standard test method for potential alkali aggregate reactivity of aggregates mortar bar method). The specimens were transferred into a plastic container containing tap water and were immersed completely.

They were placed in an air tight container and kept in an oven at 80 2°C (176 3.6°F) for 24 hrs, later removed one at a time and the zero readings were taken using the length comparator. After the zero readings were taken the specimens were placed in a container containing 1N NaOH (40 g of sodium hydroxide in 1000 ml of distilled water) and were placed in the oven. Readings were taken at 3, 7, 11 and 14 days. At the end of 14 days beams made with bacteria suspended in water, urea-CaCl±±2 and phosphate-buffer had 7%, 18% and 30% less mean expansions respectively than that of the control beams. 3.2 The effect of different concentrations of bacteria (1 x 107 cells/ml, 1 x 108 cells/ml and 1 x 109 cells/ml) suspended in phosphate-buffer on the alkali aggregate reactivity of concrete beams. A total of 12 beams with dimensions 285.75 x 25.4 x 25.4 mm (11.25 x 1 x 1 in) were made in this study. Three beams for each concentration of bacteria and three beams without bacteria (control) were made. The test was done as per the requirements of ASTM C1260 as explained earlier. At the end of 14 days the beams with bacterial concentration of 1 x 107 cells/ml, 1 x 108 cells/ml, 1 x 109 cells/ml had 13%, 21%, and 32% less mean expansions respectively than that of the control beams.

Discussion

The effects of the following parameters on the durability of concrete were investigated:

- Bacteria suspended in water (BW).
- Bacteria suspended in urea-$CaCl_2$ (BU).
- Bacteria suspended in phosphate buffer (BP) and
- Different concentrations of bacteria.

All the test results were compared with that of the control concrete. It was found that all the beams made with bacteria performed better when compared to the control concrete with one exception (BW). The beams made with bacteria suspended in water (BW) performed as bad as the control concrete. Because of a difference in osmotic pressure, bacteria cannot survive in water and they will eventually lyse. The following major reasons are attributed to the better performance of the bacterial concrete: Formation of a new additional layer on the surface of the already existing concrete layer. This new additional calcite layer formed by bacteria is highly insoluble and increases the impermeability of the specimen. Thus it resists the penetration of harmful solutions into the concrete (alkali, sulfate etc.…) thereby decreasing the deleterious effects they may cause.

The compressive strength of concretes made with BW, BU and BP were determined. It was found that concretes made with BU and BP had marginal (5 to 10%) increase in the strength whereas the concrete made with BW had marginal decrease in strength (10%) when compared to control concrete. This increase in the matrix strength (for concrete made with BU & BP) would have resulted in lesser mean expansion and would have eventually increased the overall durability performance of the concrete. The higher the bacterial dosage, the better was the durability performance. Further tests are planned for determining the optimum concentration of bacteria in increasing the durability performance of concrete.