Bacterial Concrete- A Concrete Solution for Cracks - An Overview

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Abstract- *The "Bacterial Concrete" is a concrete which can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. The bacterial concrete makes use of calcite (CaCO3) precipitation by bacteria. This phenomenon is called microbiologically induced calcite precipitation. As part of metabolism, some bacterial species like Bacillus pasteurii, Bacillue sphaericus ect. produce urease, which catalyzes urea to produce CO2 and ammonia, resulting in an increase of pH in the surroundings where Ca2+ and CO32- ions precipitate as calcite. This microbiologically induced calcite precipitation is highly desirable because the calcite precipitation is pollution free and natural and can be used to improve the compressive strength of concrete specimens, repair cracks in concrete. The precipitated calcite has a coarse crystalline structure that readily adheres to the concrete surface in the form of scales. Due to this property, it can be used for repairing concrete surfaces. In addition to the ability to continuously grow upon itself, it is highly insoluble in water. It resists the penetration of harmful agents (chlorides, sulphates, carbon dioxide) into the concrete thereby decreasing the deleterious effects they cause. This paper discusses the work done on Bacterial concrete and its applications in construction.*

I. NEED FOR BACTERIAL CONCRETE

Concrete is a commonly used construction material formed by mixing cement (binder), aggregate, water and admixtures in different ratios depending on the function and strengths required. The oldest known surviving concrete is found in the former Yugoslavia and is thought to have been laid in 5600 BC using red lime as the cement. The first major concrete users were the Egyptians around 2500 BC; Egyptians used mud mixed with straw to bind dried bricks. Today the application of concrete is rapidly increasing worldwide; it is already the most used manmade material in the world as it is relatively cheap and its basic ingredients (sand/ gravel/ water) are readily available. Concrete is one of the main materials used in the construction industry, from the foundation of buildings to the structure of bridges and underground parking lots.

Concrete is an excellent material, but it is not perfect. The problem with the concrete however is the formation of cracks.

Cracking of concrete is a common phenomenon. 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 the lifespan of a structure. Without immediate and proper treatment, cracks in concrete structures tend to expand further and eventually require costly repairs. Even though it is possible to reduce the extent of cracking by available modern technology, remediation of cracks in concrete has been the subject of research for many years.

Fig. 1 Cracking of concrete

Cement, an important ingredient of concrete, is a significant source of global carbon dioxide (CO_2) emissions, making up approximately 2.4 percent of global CO_2 emissions from industrial and energy sources (Marland et al., 1989)[1]. Carbon dioxide is released during the production of clinker, a component of cement, in which calcium carbonate ($CaCO_3$) is heated in a rotary kiln to induce a series of complex chemical reactions. Presently about 10% of the total anthropogenic CO_2 is due to the cement production solely. As according to Soutsos, the thumb rule for cement production goes as for every tonne of cement made, a tonne of CO_2 is produced.

Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height.

Bacterial concrete can be one of the answers to above problems related to concrete. The concept of bacterial concrete was first introduced by V. Ramakrishnan *et al*[2]. The team at the South Dakota School of Mines and Technology developed a bacteria/glass-bead system that it believed increased the strength of concrete by 24 per cent. Unfortunately, the application of the theory was never taken forward due to a lack of interest among the commercial engineering sector at the time. The Bacterial Concrete can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation (MICP). It is a process by which living organisms or bacteria form inorganic solids. The various bacteria used in the concrete are *Bacillus pasteurii*, *Bacillue sphaericus*, *E.coli* etc. Under favorable conditions these bacteria 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”. 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. The precipitation of calcium carbonate is governed by four parameters; (1) the carbonate concentration, (2) the calcium concentration, (3) the pH of environment (which affects carbonate speciation and calcium carbonate solubility) and (4) the presence of nucleation sites (Hammes and Verstraete, 2002)[3].

II. APPLICATIONS OF BACTERIAL CONCRETE

Healing of Cracks in Concrete:

Cracks in concrete occur due to various mechanisms such as shrinkage, freeze-thaw reactions and mechanical compressive and tensile forces. Cracking of the concrete surface may enhance the deterioration of embedded steel rebars as ingression rate of corrosive chemicals such as water and chloride ions into the concrete structure is increased. Large costs are involved in maintenance and repair of concrete structures.

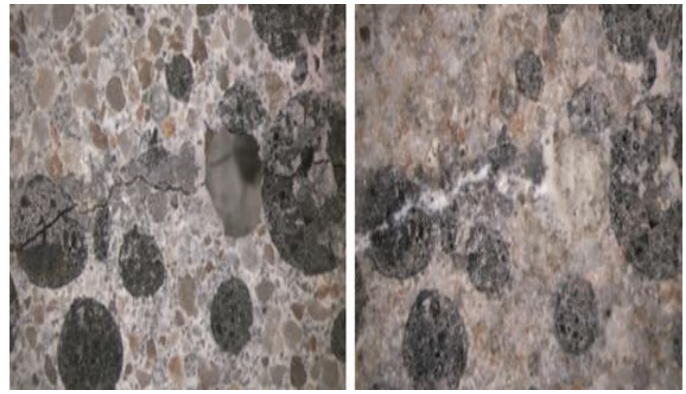

Fig.2 Crack Healing in Concrete

Bacterial concrete is a material, which can successfully remediate cracks in concrete. Use of microbial concrete has exhibited high potential for remediation of cracks in various structural formations such as concrete and granite (Gollapudi et al., 1995 [4] Stocks-Fisher et al., 1999)[5]. Microbiologically enhanced crack remediation has been reported by Bang and Ramakrishnan (2001) [6] where Bacillus pasteurii was used to induce calcium carbonate precipitation. Ramachandran et al (2001) [7] proposed microbiologically enhanced crack remediation (MECR) in concrete. Specimens were filled with bacteria, nutrients and sand. Significant increase in compressive strength and stiffness values as compared to those without cells was demonstrated. The presence of calcite was limited to the surface areas of crack because bacterial cells grow more actively in the presence of oxygen. Extremely high pH of concrete germinated the need for providing protection to microbes from adverse environmental conditions. Polyurethanes were used as vehicle for immobilization of calcifying enzymes and whole cells because of its mechanically strong and biochemically inert nature (Klein & Kluge 1981[8] Wang & Ruchenstein, 1993[9]). Bang et al (2001)[10] investigated the encapsulation of bacterial cells in polyurethanes and reported positive potential of microbiologically enhanced crack remediation by polyurethane immobilized bacterial cells. They also studied the effect of immobilized bacterial cells on strength of concrete cubes by varying the concentration of immobilized cells per crack. Encapsulated healing agents were dispersed through the concrete matrix. Once a crack appears, the capsules break and the healing agents are released into the crack, resulting crack repair. The other method of crack healing is introducing healing agents in glass tubes dispersed through the concrete matrix. Cracks form in the concrete matrix wherever damage occurs and subsequently these cracks break the glass tubes, releasing both components of the healing agent into the crack plane through capillary action. When both components come into contact, the polymerization reaction is triggered and the crack faces are bond together.

Improvement in compressive strength of concrete:

Compressive strength is one of the most important characteristic of concrete durability. It is considered as an index to assess the quality of concrete. More is the compressive strength, more is the durability of concrete specimen. Compressive strength test results are used to determine that the concrete mixture as delivered meets the requirements of the job specification. So, the effect of bacterial concrete on compressive strength of concrete and mortar was studied and it was observed that significant enhancement in the strength of concrete and mortar can be seen upon application of bacteria. The applicability of microbial concrete to affect the compressive strength of mortar and concrete was done by several studies (Bang et al., 2001[10], Ramachandran et al., 2001[7], Ghosh et al., 2005[11], De Muynck et al 2008[12]. Where different microorganisms have been applied in the concrete mixture. Ramchandran et al (2001)[7] observed the increase in compressive strength of cement mortar cubes at 7 and 28 days by using various concentrations of Bacillus pasteurii. They found that increase of strength resulted from the presence of adequate amount of organic substances in the matrix due to microbial biomass. Ghosh et al (2005)[11] studied the positive potential of Shewanella on compressive strength of mortar specimens and found that the greatest improvement was at cell concentration of 105 cells/ ml for 3, 7, 14 and 28 days interval. They reported an increase of 17% and 25% after 7 and 28 days.

Restoration of Historical Buildings:

Degradation of historical buildings is mainly due to the intrusion of water which is the main factor of pollutants. Bacterially induced carbonate precipitation has been proposed as an environmentally friendly method to protect decayed ornamental stone. 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. This technique is known as biodeposition. Biodeposition is an organic originated and highly compatible method for restoration and conservation of porous stone materials, especially porous limestone or lime-bound sandstone. It results in a deposition of a carbonate layer on the surface, and in a depth of a few centimetres under the surface of porous materials. Crystals produced during the precipitation integrate themselves into the matrix of the stone material in a high extent. This method was first used for conservation purposes by a French research group (Le Metayer-Levrel et al. 1999)[13].

Reduction in Permeability

The most common cause of deterioration in reinforced concrete is the transport of aggressive gases and/or liquids into concrete from the surrounding environment followed by physical and/or chemical reactions within its internal structure, possibly leading to irreversible change (Claisse et al. 1997[14], Khan 2002[15]). Therefore, the permeation properties, rather than mechanical properties, are the important factors to study in relation to concrete durability. Permeability is another important characteristic of concrete that affects its durability. Permeation is required for controlling the ingress of moisture, ionic and gaseous species into the concrete. Achal, V et al. 2011[16] studied the effect of calcite precipitation induced by Sporosarcina pasteurii (Bp M-3) on parameters affecting the durability of concrete or mortar. An inexpensive industrial waste, corn steep liquor (CSL), from starch industry was used as nutrient source for the growth of bacteria and calcite production, and the results obtained with CSL were compared with those of the standard commercial medium. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in substantial decrease of water uptake, permeability, and chloride penetration compared with control specimens without bacteria.

III. CONCLUSIONS

Bacterial concrete technology has proved to be better than many conventional technologies because of its eco-friendly nature, self healing abilities and increase in durability of various building materials. Work of various researchers has improved our understanding on the possibilities and limitations of biotechnological applications on building materials. Enhancement of compressive strength, reduction in permeability, water absorption, reinforced corrosion have been seen in various cementitious and stone materials. Cementation by this method is very easy and convenient for usage. This will soon provide the basis for high quality structures that will be cost effective and environmentally safe but, more work is required to improve the feasibility of this technology from both an economical and practical viewpoints. The presence of bacteria in concrete can increase the resistance of concrete towards alkali, sulfate, freeze-thaw attack and drying shrinkage. Finding a way of prolonging the lifespan of existing structures means we could reduce this environmental impact and work towards a more sustainable solution. This could be particularly useful in earthquake zones where hundreds of buildings have to be flattened because there is currently no easy way of repairing the cracks and making them structurally sound. The new concrete would be perfect for structures which are difficult to maintain, like underground buildings, motorways or oil rigs.

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