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Self-Repairing Bio concrete: A Better Living

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Abstract: ***Concrete is one of the main materials used in the construction industry, from foundation of a building to the structures of the bridges. The concrete used has a flaw, its tensile strength is one tenth of the compressive strength and as a result it tends to crack when subjected to tension. Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Bacillus, bacteria along with calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus, are added to the ingredients of the concrete. These self-healing agents can lie dormant within the concrete for up to 200 years. The consumption of oxygen during the bacterial conversion of calcium lactate to limestone to fix cracks has an additional advantage. Oxygen is an essential element in the process of corrosion of steel and when the bacterial activity has consumed it all, it increases the durability of steel reinforced concrete constructions. Bactria improves the structural properties such as tensile strength, water permeability, durability and compressive strength of the normal concrete. Cracks of various sizes form in all concrete constructions which need to be sealed manually shortening the life of a particular construction. On the other hand, Self-healing concrete (SHC) is a revolutionary building material that has the solution to all these problems and is definitely the building material of the near future.***

Keywords: Bactteria, Bacillus pasteurii, Concrete, Bacillus sphaericus.

Introduction

The word concrete is originated from the Latin word "concretus" which means condensed and hardened [1]. Self Healing Concrete is a term that is used for cement-based materials that repair themselves after the material or structure gets damaged due to some sort of deterioration mechanism**.** The earliest use of cement is dated back to twelve million years ago [2], while the early use of concrete-like building material is dated back to 6500 BC. [3]. However, it wasn't formed as concrete until later during the Roman Empire. The world around us is covered with structures constructed with conventional concrete. Conventional Concrete is a composition of Portland cement, aggregates and water. But the Conventional Concrete has a conventional disadvantage of water permeability resulting in the seepage from the roof slabs, columns, etc.

The low level of the sustainability of concrete is a worldwide problem. As revolutionary as it was and still is, modern concrete (Lime-based) has a short lifespan caused by the formation of cracks shortening the longevity of a particular construction. In highly developed countries, there is enough money to replace concrete when it becomes too weak [4]. However, in developing countries like India there are fewer funds available to repair or replace concrete. Concrete structures are often neglected and the weakness of these constructions in developing countries can become a danger to its population or the environment. There are two ways of preparing Self-healing concrete, one is biological concrete and other is chemical method [5]. The biological concrete is a mixture of normal concrete, with the addition of bacteria and nutrients, which can fill cracks by itself. When cracks appear, the bacteria will produce limestone, which fills the cracks. This self-healing concrete now possesses the quality to repair itself and thus increase the sustainability of concrete. The strength of the Bacterial concrete will be more than the normal concrete. Strength and durability of structural concrete can be increased by a biotechnological method based on calcite Precipitation [6].

The second method of making the self healing concrete is a chemical method [7] .The healing chemicals are inserted in the capsule which breaks when cracks occurs and hence rejoins the micro cracks. Different types of healing materials have their own self healing mechanism. Different types of self healing processes are based on their design strategies.

- Biological method
- Chemical method

By direct application

The bacteria and the chemical precursor (calcium lactate) are added directly while making the concrete.

Encapsulation LAW

The part of the coarse aggregate is replaced by the light weight aggregate (LWA), which is impregnated with twice the calciumlactate solution and the spores of bacteria.

After impregnation the clay particles with 6% healing agents and the concrete is made.

Biological METHOD

Researchers have shown that it is possible to mix special bacteria, which releases self healing chemicals, into concrete before it is poured. These bacteria keep the concrete healthy till they are alive. The major advantage of adding the bacteria is it closes the cracks by precipitating in the calcite with calcium carbonate. Recently, in experiments, bacterial spores and nutrients and calcium lactate have been used as self healing agents [8-10]. The bacteria and calcium lactate are both embedded in capsules, to prevent interaction before cracks appear. Concrete with added healing agents is called self healing concrete. The addition of those capsules although changes the composition of the mixture, because part of the mixture has to be replaced by the healing agent. Per cubic metre concrete, 15kg healing agent has to be added, which means that 15 kg cubic metre concrete material has to be removed. This will decrease the strength of the concrete. There are several useable bacteria which can be added to the concrete. Usually, the Bacillus alkali nitrulicus, an alkali resistant soil bacterium, is added. Alkali resistant bacteria live in extreme alkaline circumstances. Ph values range from 9 to 11. Their temperature range reaches from 10 till 40 degrees Celsius. There is another possible bacterium which can be added. This is a psychrophilic bacterium. This bacterium also lives in extreme circumstances with the same pH range but an optimum temperature close to freezing point [11-13].

Bacterias used for preparation of SHC

Bacteria are relatively simple, single celled organisms. The bacteria used were Bacillus Pasteurii, Bacillus Cohnii, and Bacillus Filla etc. It is a bacterium with the ability to precipitate calcium carbonate in the presence of any carbonate source. The bacterium is used for the same and for the improvement in the strengths of the concrete test specimens were observed. The microbes are a bacillus species and are completely not harmful to human beings. They precipitate inorganic crystals hence the healing of the cracks takes place in the concrete and it can withstand any temperature conditions.

- Most of the Bacteria belongs to genus bacillus are fulfilling the required criteria discussed above.

- The suitable chemical precursor found to be most suitable is "calcium lactate" Ca (C3H5O2)2.

Bacterial based healing Process

Concrete already has a built-in healing mechanism due to ongoing chemical, physical and mechanical processes. Most significant is precipitation of calcium carbonate (Edvardsen 1999). Average limit for which healing can still occur is a crack width of 0.2 mm. Carbonation reaction lies at the base of the calcium carbonate production, where diffused carbon dioxide reacts with the hydration product calcium hydroxide as can be seen in Equation 1.

$CO2 + Ca(OH)2 \rightarrow CaCO3 + H2O$ (1)

The principle of microbial healing also lies in the precipitation of calcium carbonate (Jonkers et al. 2010). Ingress water activates dormant bacteria. Dense layers of calcium carbonate are produced by bacterial conversion of an incorporated mineral precursor compound [14]. In case of calcium lactate the reaction is as given in Equation 2, where bacteria only act as a catalyst.

$Ca(C3H5O2) + 7O2 \rightarrow CaCO3 + 5CO2 + 5H2O$ (2)

From the metabolic conversion of calcium lactate carbon dioxide is produced, which further reacts with the calcium hydroxide from the concrete matrix according to the chemical reaction in Equation 1, producing additional calcium carbonate. Massive production of large, over 100 μm sized (Van der Zwaag et al. 2009), crystalline calcium carbonate precipitates seal and block cracks, preventing further ingress of water and possible other substances that may attack the concrete matrix or embedded reinforcement, see Figure 2.

The pathway that has been studied most for engineering purposes is probably the decomposition of urea by bacteria, with the aid of the bacterial urease enzyme. As a component of metabolism,bacteria species gives urease, that catalyzes urea to carbonate and ammonium that results in an increase of pH and carbonate concentration in the bacterial surroundings [15]. These components further hydrolyze to ammonia (NH_4^+) and carbonic acid ($CO_3^{\;2-}$) that leads to the formation of calcium carbonate. The process of making urease for the hydrolysis of urea CO $(NH_2)_2$ into carbonate (CO_3^{--}) and ammonium (NH_4^+) is be as follows [16].

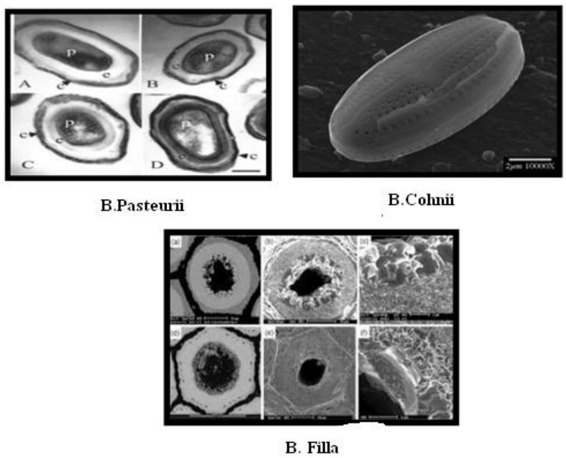


Fig.1 Different Bacteria used for study

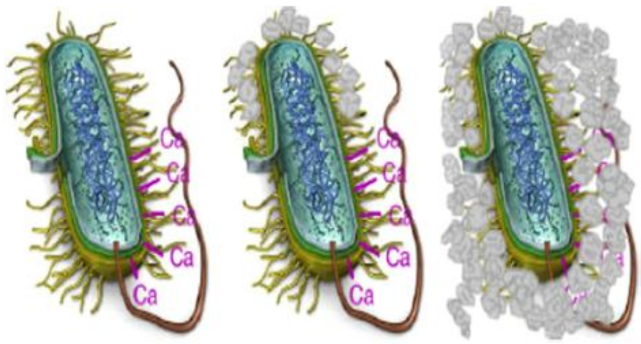
$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3 \quad (1)$$

$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3 \quad (2)$$

$$H2CO_3 \leftrightarrow HCO_3^- + H^+ \quad (3)$$

$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \quad (4)$$

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2O \quad (5)$$



The cell wall of the bacteria is negatively charged, the bacteria draw cations from the environment, together with $Ca^{2+,}$ to deposit on their cell surface. The Ca^{2+} ions react with the CO_3^{2-} prime to precipitation of calcium carbonate at the cell surface that serves as a nucleation site. Fig. 1 shows the image of calcium carbonates precipitation on bacterial cell wall.

$$Ca^{2+} + Cell \rightarrow Cell - Ca^{2+}$$

$$Cell - Ca^{2+} + CO_3^{2-} \rightarrow Cell - CaCO_3 \downarrow$$

Several micro organisms have the ability to precipitate calcium carbonate by means of urealysis. A thorough review of literature has revealed certain applications of bacteria. The Bacillus Subtilis bacteria can increase the strength of the concrete with lightweight aggregate and graphite nanoplatelets [17]. Bacillus Aerius bacteria in rice husk ash concrete was investigated and it was observed that the durability of concrete has been increased [18]. Bacillus Megaterium bacteria were used in concrete and results shows 24% increase in compressive strength [19]. The deposition of calcium carbonate in concrete by Bacillus Sphaericus improves the durability of concrete [18]. The Sporoscarcina Pasteurii bacteria used in fly ash concrete has shown improvement in strength and durability of fly ash concrete through self-healing effect [19]. The Sporoscarcina Pasteurii bacteria used in silica fume concrete, it was found that here is an improvement in strength and durability of silica fume concrete through self-healing effect [19]. Bacillus Sphaericus bacteria was used in concrete to check the surface treatment and the results reveal that bacterial carbonate precipitation can be used as an alternative surface treatment for concrete.

Fig 2. Formation of Calcium carbonate on bacterial cell wall

II. Chemical Method

From recent experiment, by Chan-Moon Chung, it is quite evident that, when two substances methacryloxypropyl determinated polydimethylsiloxane and benzoyl isobutyl-ether are mixed in the presence of sunlight, they transform into waterproof polymer that sticks to concrete. Now this balm is put inside tiny capsules made of Urea and formaldehyde,which keeps the chemical mixture isolated from sunlight.When due to external conditions the cracks occur , the capsule
breaks and the balm comes out . These capsules are made by stirring together a solution of water, urea, ammonium chloride and a benzene derivative called resorcinol that encourages capsule formation. Then methacryloxypropyl-terminated is added with polydimethylsiloxane, benzoin isobutyl ether and formaldehyde, and cooked the mixture for 4½ hours at 55°C. This process causes the urea and the formaldehyde to form, as desired, capsules containing the two concrete-healing chemicals. The mixture is mixed with liquid polymer and sprayed the mixture on to some concrete blocks, each weighing two-thirds of a kilo, and allowed the resulting film to solidify. Then cracked each block in turn, by applying pressure, and put the blocks out in the sun for four hours.

Observations

The cracks in the concrete propagated into the polymer film containing the capsules, and cracked some of the capsules open too, releasing their contents. These then set, on exposure to the sun, into a waterproof layer—a fact proved by immersing the blocks in water. After 24 hours immersion he weighed the blocks, to see how much water they had soaked up. On average, untreated concrete accumulated 11.3 grams of water. Concrete coated with capsule-free polymer took in 3.9 grams. But concrete covered with a polymer layer containing capsules absorbed just 0.4 grams.

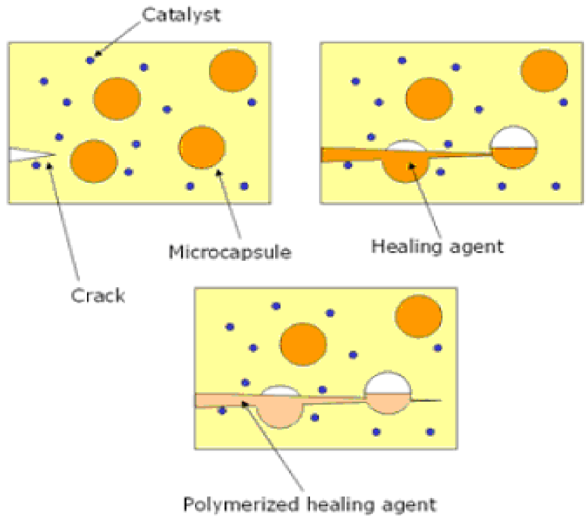


Figure2. Concept of embedded microcapsules of healing agent, based on the figure from White et al.. From left to right: micro-structure with embedded catalyst and microcapsules of healing agent (polymer precursor), crack ruptures microcapsules and healing agent coats crack surfaces via capillary action, catalyst cross-links healing agent.

V. Advantages and Disadvantages

The Self Healing Concrete has comparatively very less permeability, more durability and strain bearing capacity than the conventional concrete. A potential drawback of this reaction mechanism is that for each carbonate ion two Ammonium ions are simultaneously produced which may result in excessive environmental nitrogen loading.

VI. Future perspectives

Currently a fully functional bacteria-based self-healing concrete system using LWA as storage reservoir is available on the laboratory scale. On-going studies in our laboratory investigate the possibility to use this system in practical applications.

A next step towards widening application possibilities is the development of a more efficient and economical agent that does not negatively affect concrete strength properties. Possibility for easy application and production on industrial scale at low costs should be considered. Next to healing capacity, long-term behaviour and improvement of durability characteristics of the bacteria-based self-healing concrete material need to be determined, such as resistance to chloride penetration and freeze-thaw cycles. Long-term monitoring of larger scale experiments executed in the outdoors environment may reveal material behaviour in practice. Feasibility of implementing the material in the market should then finally be determined by a full cost-benefit analysis.

VII. CONCLUSIONS

- While most healing agents are chemically based, more recently the possible application of bacteria as self-healing agent has also been considered. In a number of published studies the potential of calcite precipitating bacteria for concrete or limestone surface remediation or durability improvement has been investigated.
- Metabolically active bacteria consume oxygen; the healing agent may act as an oxygen diffusion barrier protecting the steel reinforcement against corrosion. So far, bacteria

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have never been used to remove oxygen from the concrete matrix to inhibit reinforcement corrosion and further studies are needed to quantify this potentially additional beneficial process.

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