Self Healing Concrete

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***Abstract*— 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.** Possible causes of self-healing are formation of calcium carbonate or calcium hydroxide, sedimentation of particles, continued hydration and swelling of the cement matrix. Usually SHC consists of Portland cement, water and other filling materials, like sand and grit. Calcium hydroxide is a reaction product of the hydration of concrete. For calcium carbonate, the water in the crack has to contain dissolved carbon dioxide. The anhydrated cement in the vicinity of the crack hydrates and the hydration product fill the crack. There is increasing interest in the phenomenon of mechanical property recovery in self healed concrete materials because self-healing concrete could solve the problem of concrete structures deteriorating before the end of their service life. For cement based materials, there are two type of method-
The first is using Bacteria to precipitate calcite in cracks in concrete. Second is adhesive method. Bacteria are able to form spores which produces calcium carbonate directly and also indirectly via the reaction of on-site produced CO2 with $Ca(OH)_2$ from the cracked surface. As a result, the durability of the structure is enhanced. However, this method does not lead to strength improvement of structure. However the cost of self-healing concrete is about double that of conventional concrete. The dynamic modulus measurements provide a quick means to evaluate the presence of self-healing. There are many possibilities of applying self-healing concrete in everyday constructions, like bridges and buildings.

***Keywords*— Cracks; Bacteria; Chemical Methods; Physical Methods; Capsule Formation**

I. INTRODUCTION

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-water permeability resulting in the seepage from the roof slabs, columns, etc.

The low level of the sustainability of concrete is a worldwide problem. This is often caused by cracks in the concrete. When cracks appear, the quality of the concrete will deteriorate due to water leakage and corrosion. The concrete becomes weak and there is a high risk of collapse, so parts of the concrete construction often need replacing. In highly - developed countries, there is enough money to replace concrete when it becomes too weak. However, in developing countries 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. Self - healing concrete is a normal concrete mixture, 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. Consequently, this concept will save a lot of money, keeping in mind the 80 years future prospectus. This technique is well experimented and is also called Bioconcrete.

The second method of making the self healing concrete is a chemical method .The healing chemicals are inserted in the capsule which breaks when cracks occurs and hence rejoins the micro cracks.

The structures where this technique plays and would play a significant role are- structures which remain submerged like the canals, Dams, roads in highlands like Cherrapunjee and high rise buildings where earthquake risk is more.

II. CHEMICAL METHOD

From recent experiment, by Chan-Moon Chung, it is quite evident that, when two substances methacryloxypropyle-terminated polydimethylsiloxane and benzoyl isobutyl-ether are mixed in the presence of sunlight, they transform into water-proof 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.

III. BIOLOGICAL METHOD

Research at Delft University of Technology, has 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.

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, 15 kg 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 alkalinitrulicus, 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.

The bacteria are added to the concrete mixture as spores. Spores are inactive cells with a high survival rate. They are proof against unfavourable circumstances like temperature fluctuation and moisture. The spores become active when getting into contact with water. When the alkali - bacteria grow active, they can make limestone out of calcium lactate . When the living conditions become unfavourable again, the active bacteria will form spores. The added capsules tear open when cracks appear in the self - healing concrete. Water will leak inside, which will activate the bacteria. The bacteria, which will be in contact with the released nutrient, calcium lactate, will produce limestone. Limestone will fill the cracks and there is no possibility for water to leak into the concrete anymore. These bacteria are able to heal cracks of a width of 0.80 mm within circa 100 days. After filling the cracks, the circumstances turns unfavourable again so the bacteria will form spores again.

$$5CO2 + 5Ca(OH)2 \rightarrow 5CaCO3 + 5H2O \quad [1]$$

Carbon Dioxide + Calcium Hydroxide → Limestone + Water

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

Calcium Lactate + Oxygen → Limestone + Carbon Dioxide + Water

TABLE I
COST OF 1 CUM OF BIOLOGICAL CONCRETE

Font Size	**Appearance (in Time New Roman or Times)**			
	Unit	**Quantity**	**Cost/Unit**	**Total Cost**
1	Bag Cement	1	400	400
2	Self Healing Agent	5	100	500
3	Concrete Mixer(rent)	1	2400	2400
4	Bucket	80	10	800
5	Concrete Vibrator	1	2400	2400
6	Grit and Sand			1500
	Total		For 1cum	Rs.8000

IV. RESULTS

Fig1.Shows direct stereomicroscopic observation of cracks from control and bacteria-based specimens before and after 100 days of immersion in tap water. Width of completely healed cracks was significantly larger in bacteria-based specimens (0.46 mm) compared to control specimens (0.18 mm).

Fig. 1

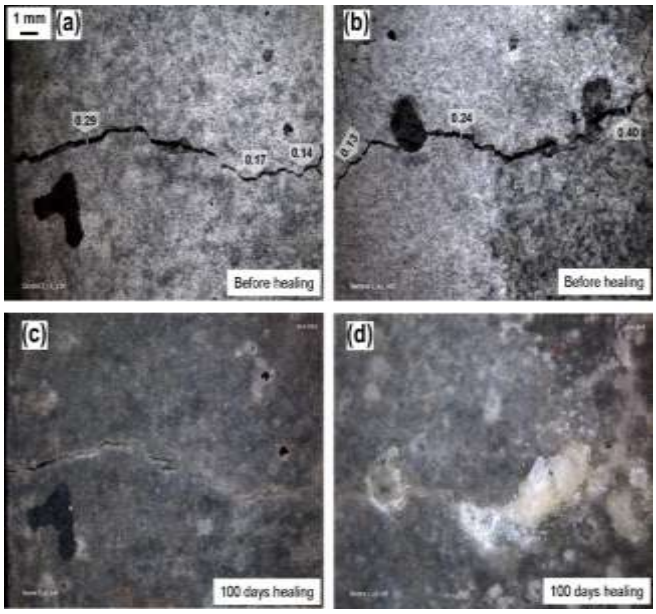

Fig. 2

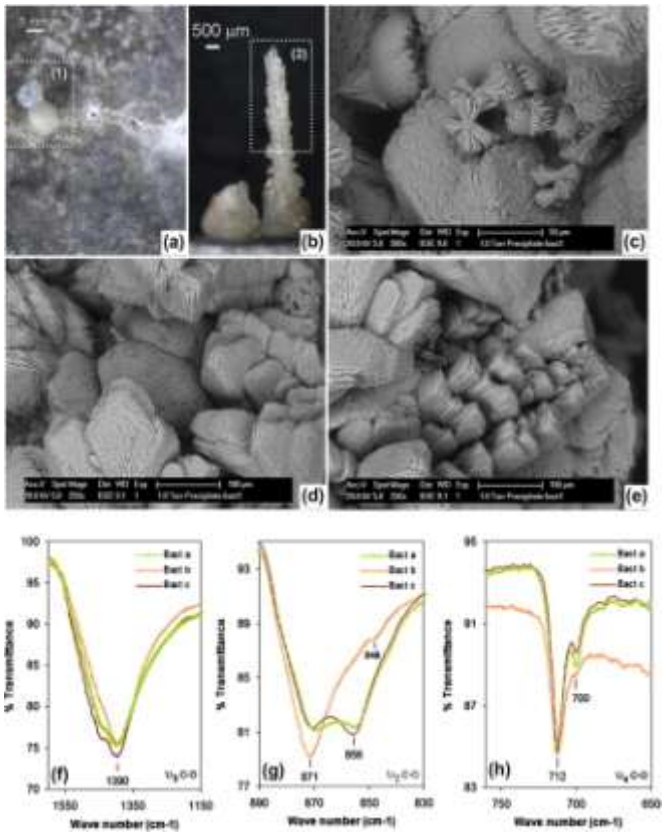

Fig.2. Microscopic images of crack-filling precipitates after crack-healing (water submersion) of a bacteria-based specimen. (a) Stereomicroscopic overview image of crack with specific detail (massive columnar precipitate) indicated by dotted square, seen from above. (b) Stereomicroscopic close-up image of massive columnar precipitate (a1) seen from lateral side. (c–e) ESEM images of top part of massive columnar precipitate indicated in image (b2) by dotted square. (f) Details of the FT-IR spectra obtained from three different samples (a–c) of massive columnar precipitate observed on the cracks surface of bacteria-based specimen: C–O asymmetric stretching vibration (υ_3). (g) Details of the out of plan bending vibration $\upsilon_2 CO_3^{2-}$. (h) Details of bands of the planar bending vibration $\upsilon_4 CO_3^{2-}$.

V. ADVANTAGES AND DISADVASNTAGES

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. 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 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.

- While, in this study many features of Self Healing Concrete have been quantified but the life of bacteria, cost of construction and efficiency still needs a separate study.

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