**SELF HEALING CONCRETE – A SUSTAINABLE FUTURE**

BY-ASHISH KATARIYA

*B. E. Civil Engineering G.H.R.C.E.M., , PUNE*

**ABSTRACT**

The cement industry is a major global contributor to world CO2 emissions (8% in 2008). A major cause of this high percentage is the durability issues associated with concrete. In recent years a new breed on concrete that has the ability to heal cracks which are a major cause of these durability issues has been developed called Self-healing Concrete. This paper will introduce this new breed of concrete in its various forms, with particular attention paid to the form which incorporates use of microbes as the healing agents.

In recent years a bacteria-based self-healing concrete is being developed in order to extend the service life. A two component healing agent is added to the concrete mixture. The agent consists of bacteria and an organic mineral precursor compound. Whenever cracks occur and water is present the bacteria become active and convert the incorporated organic compounds into the mineral calcium carbonate, known as limestone. The limestone precipitates and is able to seal and block cracks, allowing autonomous healing. This paper aims to review the development of bacteria-based self-healing concrete, introducing the proposed healing system. Different stages in the development are discussed, and some recommendations for further research are given.

**INTRODUCTION**

Concrete in most structures is designed to crack in order to let embedded steel reinforcement take over tensile stresses. Crack formation is also a typical phenomenon related to durability. Percolated cracks may lead to leakage problems or ingress of harmful materials, which can cause deterioration of the concrete matrix or reinforcement corrosion. Durability can be enhanced by preventing further ingress of water and other substances. Self-healing is characterized by regaining performance after a defect occurs. Damage targeted in bacteria-based self-healing concrete particularly relates to increased durability and leakage prevention and extending service life of concrete structures. Dr. Henk Jonker introduced a two-component healing agent to be added to the concrete mixture, consisting of bacteria and a mineral precursor compound. Upon cracking the system is activated by ingress water. Bacteria convert the mineral precursor compound into the mineral calcium carbonate, better known as limestone. Precipitation of the limestone on the crack surface enables sealing and plugging of the cracks, making the matrix less accessible to water and other deleterious materials.

**CONTENTS OF SELF‐HEALING CONCRETE**

Concrete is made of cement, usually Portland cement, water and other filling materials, like sand and grit. The concrete hardens after mixing with water, which will take about one month, because the cement hydrates with water, micro cracks in the concrete are an inevitable feature of ordinary concrete, because of the tensile strength. The tensile strength increases when there are a lot of temperature differences. These micro cracks reduce the durability of the concrete structure. Under certain circumstances, small cracks in ordinary concrete can heal themselves. When the mixture hardens, not every cement molecule reacts with water. The non‐reacting cement molecules can react with water, which flows in the concrete because of the cracks**.** Limestone will be produced, which fills the cracks. Ordinary concrete is able to heal cracks of a width of 0.20mm. If cracks become larger, the concrete will not be able to heal these cracks. 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 will change the composition of the mixture, because part of the mixture has to be replaced by the healing agent.

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 apsychrophilic 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 unfavorable 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 unfavorable 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. After filling the cracks, the circumstances will turn unfavorable again so the bacteria will form spores again.

**HOW DOES SHC WORK?**

Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures.

Specially selected types of the bacteria genus *Bacillus*, along with a calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus, are added to the ingredients of the concrete 2% by volume when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years. However, when a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria start to feed on the calcium lactate. As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralize to re-form the bone. The consumption of oxygen during the bacterial conversion of calcium lactate to limestone 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.

The two self-healing agent parts (the bacterial spores and the calcium lactate-based nutrients) are introduced to the concrete during the cement-mixing process. Only when cracks open up the pellets and incoming water brings the calcium lactate into contact with the bacteria do these become activated. Testing has shown that when water seeps into the concrete, the bacteria germinate and multiply quickly. They convert the nutrients into limestone within seven days in the laboratory. Outside in lower temperatures, the process takes several weeks.



**Figure 1: Scenario of crack-healing by concrete-immobilized bacteria (after [1]). Ingress water activates bacteria on fresh crack surfaces, bacteria multiply and precipitate calcium carbonate, eventually sealing and plugging the crack, protecting embedded steel**

**FINDING THE RIGHT BACTERIA**

The starting point of the research was to find bacteria capable of surviving in an extreme alkaline environment. Cement and water have a pH value of up to 13 when mixed together, usually a hostile environment for life: most organisms die in an environment with a pH value of 10 or above. The search concentrated on microbes that thrive in alkaline environments which can be found in natural environments, such as alkali lakes in Russia, carbonate-rich soils in desert areas of Spain and soda lakes in Egypt. Samples of Neolithic bacteria (bacteria that can live inside stones) were collected along with bacteria found in sediments in the lakes. Strains of the bacteria genus *Bacillus* were found to thrive in this high-alkaline environment. Back at Delft University the bacteria from the samples were grown in a flask of water that would then be used as the part of the water mix for the concrete. Different types of bacteria were incorporated into a small block of concrete. Each concrete block would be left for two months to set hard. Then the block would be pulverized and the remains tested to see whether the bacteria had survived. It was found that the only group of bacteria that were able to survive were the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. They would become activated when the concrete starts to crack, food is available, and water seeps into the structure. This process lowers the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated. Finding a suitable food source for the bacteria that could survive in the concrete took a long time and many different nutrients were tried until it was discovered that calcium lactate was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not interfere with the setting time of the concrete.



**Fig. 2 Electron microscope photograph of bacterial spores. Magnification 15000 x.**

**ADVANTAGES:**

* The life of the structure can be extended by 30%, the doubling in the cost of the actual concrete would still save a lot of money in the longer term.
* The corrosion of the steel is prevented due to self healing property of concrete.
* Epoxy coating is not needed to reinforcement.
* The durability of the structure is improved.
* SHC is very useful in the structures where regular maintenance is not possible or very difficult to execute.

**DISADVANTAGES:**

* The cost of self-healing concrete is about double that of conventional concrete, which is presently about €80 Euros (6720 ₹) per cubic meter
* Availability of raw material is not easy.
* Its use is costly in comparison to traditional concrete.
* It requires skilled supervision.

**APPLICATIONS –**

SHC have found use in number of large scale application in Japan, Korea, Switzerland, Australia and the U.S. these include:

* The Mitaka Dam near Hiroshima was repaired using SHC in 2003.
* The surface of the 60 year old dam was severely damaged, showing evidence of cracks, spelling and some water leakages. A 20 mm thick later of SHC was applied by spraying over the 600 m2 surface.
* An earth retaining wall in 2003, in Gifu, Japan, was repaired using SHC. OPC could not be used due to severity of the cracking in the original structure, which has caused reflective cracking. SHC was intended to minimize these damages; after one year only micro cracks of tolerable width were observed.

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**Fig. 3 Surface of a slab of self-healing concrete.**

**CONCLUSION –**

1. In this study it is concluded that over a long lifespan of the mega structures, use of SHC is economical as compared to traditional concrete.
2. Suitability of SHC is more in the parts of the structure where maintenance cannot be done easily.
3. Minimal chances of corrosion of reinforcement due to leakage proofing reducing the cost of epoxy coating.
4. Durability of the structure is increased.

**Future scope –**

* Can be used in the construction of aircraft runways, bridges and dams reducing the maintenance cost.
* Retaining wall construction.

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