Self Healing Concrete for Sustainable and Economical Constructions – A Review

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Abstract

The rapid growth in engineering and technology has paved way for searching of innovative methods and sustainable material for construction. The economic aspects associated with deterioration of concretes accelerated the search for sustainable bacterial concretes with self-healing application. Biomineralization approach could be successfully used for tackling out the problems associated with synthetic concretes and could be exploited commercially in manufacturing industries. In spite of its immense potential this technique still remains in its ground state and need more focus for its commercialization. This work summarizes the underlying principles behind self-healing microbial concretes and their application for sustainable constructions.

Key Words: Biomineralization, concrete, encapsulation, embedment.

I. INTRODUCTION:

At present, technology has taken the standards and efficiencies of construction to a new height. Different types of processes, methods and materials are used to attain very good, sustainable and economic concrete construction. But due to human errors, incorrect handling and unskilled labour, an absolutely perfect building is impossible to make. Many problems like weathering, cracks, leaks, and bending arises after the construction. The most common problem, that is the crack may arise due to many reasons. Some reasons are: (1) Concrete expands and shrinks with temperature.(2) Due to heavy load on the building.(3) Loss of water from concrete surface encourages shrinkage.(4) Insufficient vibration at the time of laying the concrete.(5)Improper cover provided during concreting.(6)The high water-cement ratio.(7)Due to corrosion of the reinforcement steel.(8)Many mixtures with rapid setting and strength gain performance have an increased shrinkage potential.

To minimize the formation of cracks and leaks many preventive measures are followed. Some of them are: (a)Reducing water content in concrete. (b)Using the proper mixtures and quality materials.(c) Using proper finishing techniques. (d)Proper curing, placement, and vibration of concrete.

But what about the buildings that already have cracks in them. Repairing methods like stitching, sealing, muting, vacuum impregnation, and dry packing are all very expensive and provide only a brief fix until the eventual weathering and weakening of the building. Furthermore, It is estimated that cement (Portland clinker) production alone contributes 7% to global anthropogenic CO_2 emissions, what is particularly due to the sintering of limestone and clay at a temperature of 1500◦C, as during this process calcium carbonate($CaCO_3$) is converted to calcium oxide (CaO) while releasing CO_2 (Worrell et al., 2001). Therefore, from an environmental viewpoint, concrete does not appear to be a sustainable material for construction at all (Gerilla et al., 2007). Thus, it is more environmentally friendly to fix the pre-existing concrete and to make new types of concrete that are able to resist wear and tear by being able to fix itself

To this mean, plenty of research has been done in the past two decades on the use of bacteria, a promising new model of sustainable repair methodology, to fix and heal the concrete when cracks develop on them. The method focuses on the bacteria that precipitate Calcium Carbonate (CaCO3)to heal the cracks if they form on the concrete. This review tries to illuminate the various techniques and methods scientists have devised in the past two decades.

II. METHODOLOGY:

The Various Methods that were tried this past two decades are:-

1. Incorporation of Bacteria into the Concrete during its mixing
2. Incorporation of Bacterial Spores into the Concrete during its mixing
3. Applying a liquid consisting of the Bacteria or its spores in a nutrient medium directly on the cracks of a Cracked Cement Sample

All these methods use different bacteria which use different mechanisms to precipitate Calcite into the concrete. These methods are all based on Biomineralization. Biomineralization refers to the process of mineral formation by living organisms which is a widespread phenomenon in nature (Tebo et al. 2005). Biologically induced mineralization usually occurs in an open environment as an uncontrolled consequence of microbial metabolic activity (Rivadeneyra 1994).

III. CALCITE PRECIPITATION:

Calcite precipitation or Microbiologically Induced Calcite Precipitation (MICP) is a type of Biomineralization that induces the precipitation of calcium carbonate within the matrix where the microbe is located. It can be traced back to the Precambrian period, and in this precipitation three polymorphic forms of calcium carbonate may be precipitated: Aragonite, Calcite, or Vaterite. For the process of Bioremediation of concrete, researchers have tried to make sure that the Calcite form of Calcium Carbonate; the most stable form of the mineral is precipitated.

The main groups of Bacteria found to be able to precipitate calcium carbonate are cyanobacteria, and Sulphate-reducing Bacteria. Two different pathways through which Calcium Carbonate is precipitated have been identified. They are

1) Autotrophic Pathway: There are three kinds of Autotrophic pathways and each of lead to the production carbonate autotrophically from carbon from gases or dissolved carbon dioxide.
2) Heterotrophic Pathway: In this pathway, there is crystal precipitation due to heterotrophic growth. Based on the nutrients and ions available in the matrix that these heterotrophic microbes live in, they produce crystals that are precipitated out. With the proper nutrient medium, Calcium Carbonate crystals are precipitated

There are several mechanisms which explain the process of carbonate precipitation, but three of them: Ureolysis, Denitrification, and metabolic conversion of organic acids have been exploited for bioremediation of concrete.

A) The Autotrophic Pathway:

This pathway takes place in autotrophic microbes who convert atmospheric or dissolved Carbon Dioxide (CO_2) into carbonate. There are 3 possible ways which this can be accomplished. They are-

a) Methanogenesis:

Done by Methanogenic Archaea. This autotrophic pathway converts CO_2 and H_2 to Methane (CH_4)

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

$$CH_4 + SO_4^{2-} \longrightarrow HCO_3^- + HS^- + H_2O$$

$$Ca^{2+} + 2HCO_3^- \longrightarrow CaCO_3 + CO_2 + H_2O$$

The Equations show the anaerobic oxidation of methane by electron acceptors such as Sulphate ion (as in Sulphur Bacteria) and production of bicarbonate (Castainer et. al 2000). The produced bicarbonate ions form calcium carbonate ions if calcium ions are present in the matrix where the bacteria is present.

b) Oxygenic and Anoxygenic Photosynthesis:

Photosynthesis is also a pathway which can give rise to the precipitation of calcium carbonate in presence of calcium ions. There are two types of photosynthetic bacteria, Oxygenic photosynthetic bacteria whose examples are Cyanobacteria, and Anoxygenic photosynthetic bacteria whose examples are purple bacteria. Both oxygenic and anoxygenic photosynthesizing microbes utilize different mechanisms to produce

Methanal (HCHO). Carbon dioxide (CO_2) is removed from bicarbonate solutions during microbial photosynthesis forming Carbonate (CO_3^{2-}). This leads to the increase of local pH and finally Calcium carbonate precipitation in the presence of Calcium ions (Hammes and Verstraete 2002).

$CO_2 + H_2O \longrightarrow HCHO + O_2$ (Oxygenic Photosynthesis)

$CO_2 + H_2S \longrightarrow HCHO + 2S + 2H_2O$ (Anoxygenic Photosynthesis)

$2HCO_3^{2-} \leftrightharpoons CO_2 + CO_3^{2-} + H_2O$

$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3$

From these reactions we can see that this pathway is only possible when the bacteria are exposed to sunlight and carbon dioxide in the surrounding environment, this pathway is not suited for the bioremediation of concrete even though it may help to reduce CO2 levels and help combat Global Warming.

B) The Heterotrophic Pathway:

Microbial communities precipitate crystals of different carbonates in different nutrient media consisting of different metal ions. For example of the media contains Calcium ions then the crystal precipitated will be Calcium carbonate, similarly of the media contains magnesium ions, the crystals precipitated will be Magnesium Carbonate. The bacteria form Carbonate ions by using various organic acids (acetate, Lactate, citrate, succinate, oxalate, malate, etc.) as sources of energy and these carbonate ions react with the metal ions in solution to the form the corresponding carbonate. Calcium carbonate precipitation through use of organic acid has been widely documented in different substrate environments, including caves, marine environment, lakes and soil. It was found that heterotrophic bacterial communities (*Arthrobacter* and *Rhodococcus*) isolated from stalactites in the cave could produce calcium carbonate in the presence of calcium acetate (Rusznyák et al. 2011; Groth et al. 2001). Cacchio et al. (2003) also found that *Bacillus* and *Arthrobacter* species are capable of precipitating calcium carbonate under alkaline carbonate medium.

The main advantages of this pathway are that Organic acids act as the sole energy source for these microbes and the proteins and Extra polymeric Substances (EPS) on their cell wall act as nucleation sites. With each type of cell wall, different polymorphs or Calcium Carbonate may be precipitated, from Aragonite (Needle-like crystals) to Calcite (Rhombic Crystals). Thus with this pathway, specific strains of bacteria can be chosen to precipitate a specific type of Calcium Carbonate.

The Sulphur and Nitrogen cycle are the two other methods that can be used for calcium carbonate precipitation. Sulphur cycle follows by dissimilatory reduction of sulphate. In this process, calcium carbonate is produced if calcium source, organic matter and sulphate are present in the medium. The increase in pH as a result of degasification of hydrogen sulphide shifts the reaction towards precipitation of calcium carbonate (Castainer et al.1999). One of the ways sulphur bacteria produce calcium carbonate is,

$$CaSO_4 + 2HCHO \longrightarrow CaS + 2CO_2 + 2H_2O$$

$$CaS + H_2O \longrightarrow Ca(OH)_2 + H_2S$$

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$Ca(OH)_2 + H_2CO_3 \longrightarrow CaCO_3 + H_2O$$

Using the Nitrogen Cycle, there are 3 main pathways for Calcium Carbonate Precipitation. They are (1) Ureolysis (2) Ammonification of amino acids and (3)Nitrate reduction. As a result of the nitrogen cycle, calcium carbonate is precipitated upon the presence of sufficient calcium ion in the medium (Castainer et al. 1999).

(a) Ureolysis:

Microorganisms such as *Bacillus sphaericus* and *Bacillus pasteurii* are able to produce biominerals through metabolic reaction in the presence of calcium source (Wang et al., 2012b).

In Ureolysis, Urease positive bacteria convert Urea into Carbamic Acid which in turn converts into Ammonia by reacting with H_2O.

$$CO(NH_2)_2 + H_2O \xrightarrow{urease} NH_2COOH + NH_3$$

$$NH_2COOH + H_2O \longrightarrow NH_3 + H_2CO_3$$

The H_2CO_3 formed can dissociate into carbonate ions (CO_3^{2-}).

$$2NH_3 + 2H_2O \longrightarrow 2NH_4^+ + 2OH^-$$

$$2OH^- + H_2CO_3 \longrightarrow CO_3^{2-} + H_2O$$

These carbonate ions can react with the Calcium ions if present in the environment to precipitate as Calcium carbonate.

$$Ca^{2+} + Cell \longrightarrow Cell\text{-}Ca^{2+}$$

$$Cell\text{-}Ca^{2+} + CO_3^{2-} \longrightarrow Cell\text{-}CaCO_3$$

For the last reaction the calcium ion can be provided either by internal sources that are available in the cement structure or by adding chemicals such as calcium chloride, calcium nitrate or calcium lactate externally (Stuckrath et al. 2014). However calcium chloride as a calcium source may cause chloride ion attack and thus may degrade the reinforcement bars. Thus, application of calcium nitrate or calcium lactate is recommended.

The disadvantages, however of this method is that the ammonium ions (NH_4^{+}) produced through ureolysis results in the emission of NO. It is also found that remediation of 1 m^2 of concrete needs 10 g/L of urea which produces 4.7g of nitrogen. This amount is about one-third of the nitrogen that is produced by each person everyday (De Muynck et al. 2010). Also, the presence of excessive ammonium in the concrete matrix leads to degradation of the reinforcement bars.

(b) Metabolic conversion of organic acid salts to carbonate

Another pathway to precipitate is the metabolic conversion of organic acid salts to carbonate. This carbonate then reacts with the calcium ions in the cement matrix to give calcium carbonate (Jonkers et al. 2010; Wiktor and Jonkers 2011; Sierra-Beltran et al. 2014; Jonkers 2011). Here aerobic oxidation of organic acids leads to the formation of CO2, which in alkaline environment converts to carbonate ions. The carbonate ions react with the calcium ions in the cement matrix to precipitate as calcium carbonate.

The reaction for calcium lactate to calcium carbonate is given below,

$$CaC_6H_{10}O_6 + 6O_2 \longrightarrow CaCO_3 + 5CO_2 + 5H_2O$$

A reaction between the produced water and carbon dioxide and the available calcium oxide in the concrete matrix contributes to the increase of autogenous healing (Achal et al. 2011; Achal and Pan 2011; Van Tittelboom and De Belie 2013). Compared to the ureolysis pathway, this pathway is much more sustainable as no nitrogen compounds are being formed through this method, also since O2 is being used in this reaction the reinforcement bars in the concrete are also protected from corrosion. Compatibility with concrete composition, protection of reinforcement bars and high calcium carbonate precipitation are among the main advantages of this method.

(c) Dissimilatory Nitrate reduction

Denitrification is the process through which Nitrate (NO3-) is reduced to nitrite (NO2-), nitric oxide (NO), and nitrogen (N2). The most direct application of this pathway is that it can be applied to the anaerobic place. Denitrification is carried out by denitrifying bacteria. The microorganisms that are involved in the denitrification process are facultative anaerobes, mainly *Denitrobacillus*, *Thiobacillus*, *Alcaligenes*, *Pseudomonas*, *Spirillum*, *Achromobacter* and *Micrococcus* species (Karatas 2008). Due to organic denitrification CO_2, H_2O and N_2 are produced. In the reaction, H+ is consumed thus increasing the pH of the matrix. This increase in pH leads to the conversion of CO_2 to carbonate, which in turn reacts with the calcium ions in the matrix to precipitate as calcium carbonate.

$$\text{Organic compound} + a\ NO_3 + b\ H^+ \longrightarrow c\ CO_2 + d\ H_2O + e\ N_2$$

$$CO_2 + 2OH^- \longrightarrow CO_3^{2-} + H_2O$$

$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3$$

This process, however, is slower compared to ureolysis. Urea hydrolysis occurs in a short period of time. Therefore, calcium carbonate precipitation through ureolysis pathway is the fastest approach among calcium carbonate biomineralization processes (De Muynck et al. 2010).

Since Biomineralization is a slow process, chemicals that hasten it are in high demand. Also, bacteria that are low-risk and precipitate a high amount of Calcium carbonate are in demand, however, care is to be taken that the selected bacteria does not form a biofilm which leads to uneven and undesirable patches on the concrete (Ghaz-Jahanian et al. 2013).

Table 1. Over view of microorganism and nutrients which have been used to produce calcium carbonate in concrete matrix

Mechanism of Precipitation	Microorganism	Nutrient	Embedment in Concrete	References
Bacterial Metabolic Conversion of Organic acid	*B. pseudofirmus*	Calcium lactate, calcium glutamate, yeast extract and peptone	Direct	Jonkers and Schlangen (2009)
	B. pseudofirmus	Calcium lactate, calcium acetate, yeast extract and peptone	Direct	Jonkers et. al (2010)
	B. cohnii	Calcium lactate, calcium acetate, yeast extract and peptone	Direct	Jonkers et.al (2010)
	B. cohnii	Calcium lactate and yeast extract	Immobilized	Sierra-Beltran et al. (2014)
	B.alkalinitrilicus	Calcium lactate and yeast extract	Immobilized	Wiktor and Jonkers (2011)
Ureolysis	*B.sphaericus*	Urea, calcium nitrate and yeast extract	Immobilized	Wang et. al (2014b)
	B.sphaericus	Urea and Calcium Chloride	Direct	Achal et al. (2013)
	B.sphaericus	Urea, calcium nitrate and yeast extract	Immobilized	Wang et al. (2012a)
	B.sphaericus	Urea and Calcium Chloride	Direct	Achal et al. (2011)
	B.sphaericus	Urea, calcium nitrate and yeast extract	Immobilized	Wang et al. (2010)

	B.sphaericus	Urea, Calcium chloride, calcium nitrate and yeast extract	Immobilized	Van Tittelboom et al. (2010)
	B.sphaericus	Urea, calcium nitrate and yeast extract	Immobilized	Wang et al. (2014c)
	B.sphaericus	Urea, Calcium Chloride and Calcium Acetate	-	De Muynck et al. (2008a)
	B.sphaericus	Urea, calcium nitrate and yeast extract	Direct	Wang et al. (2012b)
	S.pasteruii	Urea and Calcium Chloride	Direct	Ramachandran et al. (2001)
	Pseudomonas aeruginosa	Urea and Calcium acetate	Direct	Ramachandran et al. (2001)
	B.sphaericus	Urea and Calcium acetate	Direct	Kim et al (2013)
	S.pasteruii	Urea, calcium chloride	Direct	Kim et al (2013)
	S.pasteruii	Urea and Calcium Chloride	Immobilized	Bang et al (2001)
	S.pasteruii	Urea, calcium nitrate and calcium chloride	-	Qian et al (2010b)
	S.pasteruii	Urea, and Calcium nitrate	-	Chunxiang et al (2009)
	S.pasteruii	Urea, and calcium chloride	Immobilized	Bang et al. (2010)
	S.pasteruii	Urea, nutrient broth and calcium chloride	Direct	Maheswaran et al. (2014)
	B.cereus	Urea, nutrient broth and calcium chloride	Direct	Maheswaran et al. (2014)
	B.amyloliquefaciens	Urea, calcium acetate, yeast extract and glucose	-	Lee (2003)
	Sporosarcina soli	Urea and calcium chloride	Direct	Park et al. (2010)
	B. massiliensis	Urea and calcium chloride	Direct	Park et al (2010)
	Arthrobacter crystallopoietes	Urea and calcium chloride	Direct	Park et al (2010)
	Lysinibacillus	Urea and calcium	Direct	Park et al. (2010)

	fusiformis	chloride		
Denitrification	*Diaphorobacter nitroreducens*	Urea, calcium formate, calcium nitrate and yeast extract	Immobilized	Erşan et al (2015a)
	B.sphaericus	Urea, calcium formate, calcium nitrate and yeast extract	Immobilized	Erşan et al (2015a)

(Table credits bioconcrete: next generation of selfhealing concrete, Mostafa Seifan et al.)

IV. EMBEDMENT OF MICROBES IN CONCRETE MATRIX:

The microorganism or the healing agent can be inserted into the concrete by three methods-

(1) Vascular network method

This method is by the supplies of the healing agent from the outside of the structure through the pre-constructed vascular network during concrete preparation. The healing agent movers through the vascular network due to the pressure gradient created. This method seems to be quite impractical due to several short-coming like the healing agent must have constant viscosity throughout its life to maintain the easy flow of the healing agent. If the agent is more than the crack capacity it can cause aesthetic problems. It is difficult to distribute vessels throughout the structure. And the incorporation of the vascular network inside concrete could decrease the bond between the concrete composition which will lead to structural delamination.

(2) Direct Embedment

Bacteria directly are embedded into the concrete mixture during preparation. The healing agent is dissolved in water and then added to cement and sand. Alkaliphilic and spore-forming bacteria is the most suited due to their tolerance to extreme environment. The incorporation of the microorganism into concrete can influence the metabolic activity due to high pH condition and harsh environment where the cell is vulnerable to death due to the dry condition. Studies have also shown a decrease in the number of viable bacteria over time indicating that bacterial cell can be viable only for up to 4 months (135 days), (Jonkers et al. 2010). Therefore we need to use immobilized spore-forming bacteria to maintain the bacteria in concrete for a long period of time.

(3) Encapsulation

The bacteria are protected by a protective material such as diatomaceous earth, hydrogel and porous expanded clay particles. It can increase the viability of the bacteria for a long period of time inside the capsule which will mechanically break open when the cracks are formed. It is found that filling by microcapsule will create large pores which are the space that appears after microcapsule rupture. (Van Tittelboom et al. 2011; Van Tittelboom and De Belie 2013). So encapsulation efficiency depends on capsule size and their distribution.

V. PREPARATION OF THE CONCRETE:

Encapsulation

- The concrete sample can be made by normal Portland cement CEM152.5N and $CaCO_3$ precipitating bacteria like *Bacillus sphaericus* with a purified strain of LMG 222 57 isolated from calcareous sludge from biocatalytic ureolytic calcification reactor. The bacteria were immobilized in silica gel to protect from extreme alkali condition. The bacterial treatment was done in ways as follows:

(1) *Bacillus sphaericus* in sol-gel with $CaCl_2$:

1.2g of NaCl added to 10ml demineralized water and the mixture was vortexed. 50ml of an overnight grown centrifuged culture at 7000rpm for 5min at 4°C. The pellet was suspended and vortexed after that 40ml levasil sol added and vortexed again. The obtained suspension was bought into the crack by a syringe and repeated until the entire crack was filled after hardening of sol into gel the sample was immersed in an equimolar solution of urea and $CaCl_{2}.2H_2O$ for 3 days.

(2) Sol-gel:

1.2g of NaCl added to 10ml demineralized water and the mixture was vortexed for 30 seconds. Then, 40ml of Levasil sol added and vortexed again by means of a syringe, the suspension was bought into filling the entire crack.

(3) *Bacillus sphaericus* with $CaCl_2$:

The sample immersed in *B. sphaericus* for 24h. The growth medium consists of 20g/L yeast extract and 20g/L urea. The surface of the sample is wiped with a paper towel to remove some bacteria from the surface so the ureolytic activity occurs inside the cracks. Then the sample was immersed in an equimolar solution of urea.

(4) *Bacillus sphaericus* with sol-gel and with $CaCl_2$:

Sample treated with sol-gel as mentioned above (2) and then when it hardened, the sample was subjected to Bacillus sphaericus + $CaCl_2$ treatment.[Kim Van Tittelboom, Nele De Belie, Willem De Muynck, Willy Verstraete].

Use of silica gel or polyurethane

Concrete, being an important construction material is bound to cracks due to many reasons which in turn reduce the life of it. Therefore, the use of bacterial as self-healing came up. But due to the extreme alkali condition of the environment (pH>12) reduce its bacterial activity. The bacterial might also get destroyed in the process of hydration. Therefore a suitable carrier is required for the survival and immobilization of the bacteria. So, silica gel or polyurethane was used as a carrier. Silica gel is a popular carrier as it has good properties of mechanical, thermal and photochemical stability. The silica sol and bacteria suspension were injected into the crack by syringe. When gel formation takes place it is repeated until the cracks are filled. The specimen is immersed in a medium of urea and Ca+ then $CaCO_3$ precipitation occurs. The encapsulation is in the glass tube which is incorporated during casting when cracks occur the glass capsule break and bacterial flow into the crack the silica gel form in situ when silica sol meets Ca+. at the same time bacterial cells meet with urea and Ca+, $CaCO_3$ precipitates. Polyurethane (PU) is used as a waterproof material. The PU foam with the bacterial cell was cut into equal size pieces then the PU foam strips were placed into the cracks of mortar specimen. The specimen was incubated in a Urea-CaCl2 medium at room temperature. As a result, $CaCO_3$ precipitation occurs and the compressive strength of the crack was higher than the control specimen [Jianyun Wang, Kim Van Tittelboom, Nele De Belie, Willy Verstraete].

Direct Embedment

- The sample can be made with IS 12269-1987 with local natural river sand conforming to IS 383-1970. with Bacillus sp. Of CT-5 isolate which is commercially available cement isolated from an enrichment culture technique of nutrient broth and nutrient broth-urea medium for the isolate. This Bacillus sp. CT-5 grown in nutrient broth-urea(NBU) was used in the cement mortar with a cement to sand ratio of 1:3(by weight) and bacterial culture or water to cement at 0.47. after demolding its cured in NBU medium at room temperature. Then a compression test is done by automatic compression-testing machine(COMPTEST 3000 at AIML Ltd, New Delhi) [Varenyam Achal; Abhijit Mukherjee; and M. Sudhakara Reddy]
- A mixture of calcium lactate and bacterial spore embedded in clay particle. Spores that were isolated from alkaline lake soil (Wadi Nature, Egypt) were used as the self-healing agent and sequence analysis of 16S rRNA gene of the bacteria show a 98.7% homology to *Bacillus alkalinitrilicus* as alkali-resistant bacteria. This culture was washed by repeated centrifugation and resuspension to

harvest the vegetative cells and spore. Then it is heated to inactivate the vegetative cells for 30min at 80°C. The mortar was prepared from Portland cement (CEMI 42.5N, ENCI,) fine sand and LWA with bacterial spore (bacterial specimen) or without spore (control specimen). After 56 days the specimen was stretched with a computer controlled application for crack formation. Two crack specimens were prepared with a high number of cracks was immersed in water. Later, on exposure to the atmosphere for diffusion of gases over air-water interface for the bacterial spore to activate and precipitate the required $CaCO_3$ based material for the healing of cracks. [Virginie Wiktor, Henk M. Jonkers].

Vascular network

This method is inspired by the nature of bones and the complexity of its healing mechanism. To create network concrete porous concrete cylinder were used as core based on work by (Yang 2002, Mahboub 2009), the material was gravel(1513 kg/m3), Portland cement CEM I 42.5,(355 kg/m3), Pulverized Fly Ash (22kg/m3) and super-plasticizer (1.4 l/m3) with 0.28 water-cement ratio. Porous concrete cylinders of 35mm diameter and 130 mm height were cast in PVC then all samples were covered with plastic. Demoulded after 24h the cured in curing chamber for 7 days. The taken out it was allowed to achieve saturation surface dry condition for 24h. one sample was covered in PVA water-soluble plastic and one sample was not covered. Then the porous cylinder was put into a 56 diameter PVC mould then cast around the cylinder core. After 7 days the porous network was taken out and dried in an oven at 35°C for 24h and tensile stress applied to create a crack. The healing agent was injected into the sample using syringe through the top end. Epoxy was the healing agent to seal the crack consisting of epoxy resin Conpox Harpiks BY 158(liquid) and hardener Haerder HY 2996 with a weight ratio of 0.3 with a fluorescent dye.

VI. PERFORMANCE OF SELF HEALING CONCRETE:

Self-healing concrete is significant for its high compressive strength and durability through biomineralization. The durability of concrete can be improved by reducing absorption, permeability and diffusion of fluids and gases. The permeability of the specimen with polyurethane immobilized bacteria decreased by six times compared to the control and water absorption has decreased due to its bio-based agent, in both microencapsulated bacteria and non encapsulated one too. The encapsulated ones had a healing ratio ranging from 48%- 80%, on the other hand, non encapsulated ones had a ratio of 18%-50% by the means of Bacillus sphaericus LMG 22557(J.Y. Wang, H. Soens, W.Verstraete, N. De Belie)

Table 2. Performance effect of self healing concrete

Microbe	Effect on compression strength		Effect on durability		Reference
	Effect	Time (day)	Permeability	Water absorption	
Bacillus Sphaericus	-	28	+	Nil	Wang et al (2014c)
	-	90			
	+	3	Nil	P	Achal et al (2011)
	+	7			
	+	21			
	Nil	Nil	Nil	P	Wang et al (2012b)
	+	7	+	Nil	Achal et al (2013)
	+	28			
	Nil	Nil	+	Nil	Wang et al (2014b)
	Nil	Nil	+	Nil	Wang et al (2012a)
S. pasteurii	+	7	Nil	Nil	Bang et al (2010)
	+	28			
	+	28	Nil	+	Chahal et al (2012)
Bacillus cohnii	+	7	Nil	Nil	Sierra-Beltran et al (2014)
	+	28			
	+	56			
B. pseudofirmus	-	3	Nil	Nil	Jonkers et al (2010)
	-	7			
	-	28			
Diaphrobactor nitroreducens	-	7	Nil	Nil	Erşan et al. (2015a)
	-	28			

+ positive effect, - negative effect

The water absorption test to demonstrate the absorption rate for mortar cubes showed that over a period of 168h, the cubes treated with Bacillus sp. Nearly absorbed six times less water compared to the control mortar specimen. The deposition of $CaCO_3$ resulted in a decrease in the sorptivity as a result reduced intake of a harmful substance that could reduce the life of the concrete

However, there are contradicting results where the use of bio-based healing agent through the process of encapsulation of *B. sphaericus* in mortar resulted in a decrease in the compression strength by 15%- 34% (Wang et al. 2014b) whereas the cube mortar of *B. sphaericus* the compressive strength (Achal et al.2013). There was a positive influence on compressive strength for less concentration of cells at 5x 106cells/ mm^3 and a reduction compressive strength in the mortar with 5x 108 cells/ mm3. There are other studies showing that by *Sporosarcina pasteurii* as healing agent increased the compressive strength of the mortar as the higher the concentration of immobilized bacteria increased the compressive strength by 24%. There was improved compressive strength with improved cell concentration from 6.1x 107 cells/cm3 compared to 3.1x

109 cells/cm3(Bang et al. 2010). There are studies indicate that *B. sphaericus* that were immobilized, ureolytic and denitrifying bacteria in concrete decreased compressive strength. But the use of *Diaphorobacter nitroreducens* in clay activated carbon marginally enhanced compressive strength. However, immobilization of *B. sphaericus* in metakaolin and zeolite has an adverse effect on compressive strength. All this contradiction in the results of different researches is mainly due to the different culture media and nutrient source as well as environment condition. The biomineralization can plug the porosities and void inside the concrete too. Therefore the application of microbes that can produce small bio-minerals for the healing of cracks.

VII. CONCLUSION:

Application of self-healing approach over the existing method of construction is capable to fill microcracks and restrict crack development, which can reduce labor and maintenance cost. (Jonkers et al 2010). It can reduce CO2 emission for cement industries due to decreased cement production(De Muynck et al., 2008; Berenjian et al.2016). Reduction in porosity, rendering concrete watertight, compatibility between $CaCO_3$ and concrete composition and favorable thermal expansion are the other advantages of using self-healing concrete

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