RESEARCHERID
THOMSON REUTERS
[G. Divya, 8(1), Jan 2023]

ISSN : 2455-9679
SJIF Impact Factor : 6.008

ijrtsm

IJRTSM

INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

"A REVIEW ON SELF HEALING MECHANISM IN CEMENTITIOUS MATERIAL WITH BACTERIAL ASSIMILATION"

G. Divya Anusree
Assistant Professor, Department of Civil Engineering, LNCT, Bhopal, MP

ABSTRACT

Concrete is one of the most important cementitious materials used in construction industry, but it has relatively low tensile strength resulting in development of cracks, which are the inevitable and inherent weakness of concrete. Cracking of concrete is very common phenomenon without an immediate treatment, which could further expand and requires costly repairing. Also, water and other salts then seep through these cracks, initiating corrosion of the rebars and eventually reducing the life of concrete. To increase the strength and durability of the structure either the cracks that are formed should be repaired conventionally using epoxy injection or latex treatment or by providing extra reinforcement in the structure during the design phase to ensure that the crack width stays within a permissible limit. As the extra reinforcement will turn out to be uneconomical, a modern technique has been introduced which uses eco-friendly bacterial biological process that is a continuous self-remediating process for cracks and fissures in concrete and keeps the cracks width within limits. Bacterial concrete is the material used for self-healing of cracks and fissures in cementitious materials. In this paper, the treatment of cracks by using bacteria group such as Bacillus Sphaericus, Bacillus Sporosarcina pasteurii, is reviewed, which activates the self-healing mechanism in concrete and plugs the cracks and fissures that has developed. Also, the effect of the bacteria on the compressive strength and stiffness is discussed in comparison to conventional concrete along with the temperature requirement of the bacteria. Self-healing or bacterial concrete produces limestone after encountering water, using calcium lactate as food, resulting in closing of the cracks.

***Keyword**: Cracks, Bio-concrete, bacteria, microbial process, calcium lactate, compressive strength, etc.*

I. INTRODUCTION

1.1 OVERVIEW

Concrete is an important building material which is extensively used in every construction. It is most efficient when used with steel reinforcement bars, which provides adequate tensile strength to the structure. When normal stresses and tensile loads are applied to concrete, it becomes relatively brittle. Concrete's tensile strength is about one-tenth that of its compressive strength. For it to withstand tensile loads and compensate for a lack of ductility and strength, concrete members are reinforced with continuous reinforcing bars. The provision of steel reinforcement significantly increases the strength of concrete, resulting in concrete with homogeneous tensile properties; however, fracture growth in concrete buildings must be monitored. These cracks, affects the durability and strength of concrete. Large cracks may weaken structural integrity, while minor cracks impair structure durability. Cracks also increase the permeability of matrix thereby increasing the chances of corrosion in reinforcement. Therefore, the sole cause of structural fail¬ure is cracking. A structure requires frequent maintenance to decrease the chances of breakage development, which can be costly and may increase the structure's maintenance cost.

Crack may occur due to many reasons. It may occur if there is temperature difference which results in expansion and contraction of concrete members. Application of heavy loads causes large settlements and cracks are formed. When sufficient loss of water occurs, shrinkage cracks are formed. Insufficient vibration during laying of concrete or improper clear cover in concrete members is also tending to cause cracks. The workability of concrete, corrosion of reinforcement steel and high water cement ratio are also the factors causing cracks in concrete structures.

One method for limiting the expenditures of crack repairing while increasing construction durability is to employ self-healing concrete. This method was developed in a new construction material called bacterial self-healing concrete. Bacterial self-healing concrete is made up of bacteria that have been introduced into the concrete together with calcium lactate food to support those bacteria when they become active. Feeding on the supplied food source, the bacteria treat the damage and can also lessen the amount of damage experienced by the concrete structure in place.

1.2 DIFFERENT HEALING MECHANISMS OF CRACKS

There have been different healing mechanisms investigated till date for the cracks, as listed below:

(1) Concrete has an **autogenous healing** capacity as unhydrated cement is present in the matrix. When water contacts the unhydrated cement, further hydration occurs. Furthermore, dissolved CO_2 reacts with Ca^{2+} to form $CaCO_3$ crystals. These two mechanisms, however, may only heal small cracks. To enhance the healing mechanism, microfibres are added to the mixture. By mixing **microfibres** in the concrete, multiple cracking occurs. So, not one wide crack, but several small cracks are formed, which close more easily due to autogenous healing.

(2) **Superabsorbent polymers** (SAP), or hydrogels, are able to take up a large amount of fluid (up to 500 times their own weight) and to retain it in their structure without dissolving. When cracks occur, SAP are exposed to the humid environment and swell. This swelling reaction partly seals the crack from intruding potentially harmful substances. After swelling, SAP particles desorb and provide the fluid to the surrounding matrix for internal curing, further hydration and the precipitation of $CaCO_3$. In this way, cracks may close completely. Since the pH in concrete drops from 12.8 to 9-10 when a crack occurs, it is useful to investigate pH sensitive hydrogels. These will only swell when a crack occurs and fresh water penetrates.

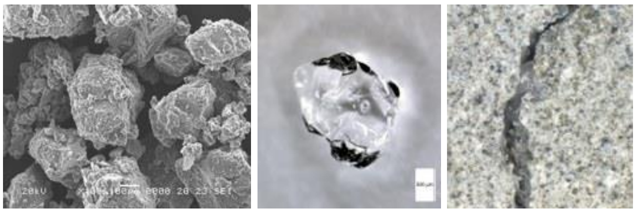

Fig. 1. Swollen SAP - Partial sealing of cracks by swelling SAP

(3) Cracks can be healed by using **calcium carbonate precipitating micro-organisms**. These organisms are embedded in the concrete matrix after immobilization on diatomaceous earth in microcapsules or in SAP, and will start the precipitation of $CaCO_3$ once a crack occurs. Through this process the bacterial cell will be coated with a layer of calcium carbonate, resulting in crack filling. The concrete thus produced is known as bio-concrete or self-healing concrete.

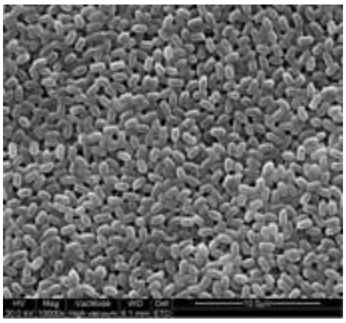

Fig.2. Bacterial spores

(4) One of the research programs considers the use of **encapsulated polymers** to obtain self-healing of concrete cracks. When a crack appears, the capsules break, and the content is released. Due to capillary action, the agent will flow into the crack. After reaction, the crack faces are bonded together, and the crack is thus healed. Depending on the required regain in properties, different healing agents have been encapsulated. To reduce the water permeability of cracked concrete, polyurethane is provided inside the capsules. When strength regain is a more important issue, methyl methacrylate is encapsulated. For structures where the aesthetic aspect is important, water repellent agents can be encapsulated.
As encapsulation material brittle glass or ceramic tubes have been used. However, since capsules have to survive the mixing process in concrete, research is currently focusing on the development of capsules with suitable properties to survive the mixing process and to release the healing agent when cracks appear in the hardened matrix.

In the case of dynamic cracks in structures under cyclic load (e.g. due to traffic or temperature variations), encapsulated elastic polymers can be used. While cracks healed with CaCO3 would reopen upon reloading and new cracks would form in the case of rigid polymers, elastic polymers should be able to bridge cracks of increasing width. Thus, for this application, strength regain is not as important as an effective sealing of cracks. Adhesive properties and strain capacity of elastic polymeric healing agents in service are assessed.

(5) While fly-ash and blast-furnace slag concrete seem to be inferior regarding the early age microstructure and strength development, their self-healing capability can be much higher, precisely because of the low hydration degree of the slag and fly-ash particles. Upon cracking, the unreacted particles can be activated again to close the crack and to regain water impermeability and strength. The suitability of different types of alkali-activators (e.g. NaOH, KOH or silicate solution) has been investigated.

1.3 SELF HEALING CONCRETE OR BIO-CONCRETE

Self-healing concrete, also known as bio-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 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 reform 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 within separate expanded clay pellets 2-4 mm wide, which ensure that the agents will not be activated 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.

It can be observed that small cracks that occur in a structure of width in the range of 0.05 to 0.1mm gets completely sealed in repetitive dry and wet cycles. The mechanism of this autogenously healing is, the width of range 0.05-0.1mm act as capillary and the water particles seep through the cracks. These water particles hydrate the non or partial reacted cement and the cement expands, which in turn fills the crack.

The development of self-healing mechanism in concrete is based on a potentially cheaper and more sustainable material then cement could thus be beneficial for both economy and environment.

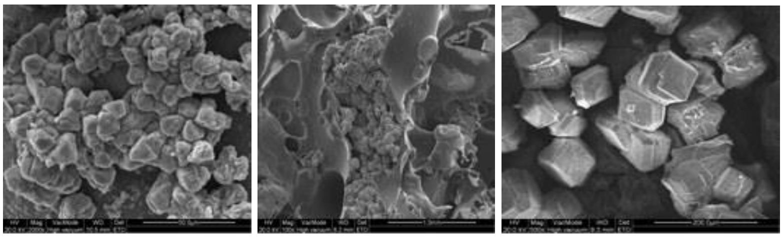

Fig.3. CaCO3 precipitation by bacteria

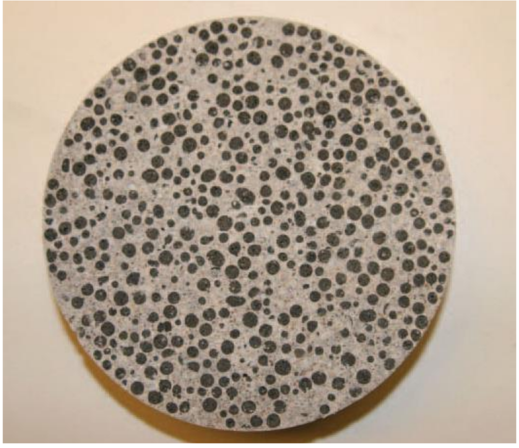

Fig.4. Bio-concrete or self-healing concrete

1.4 BACTERIA USED IN SELF-HEALING CONCRETE

Concrete being extremely alkaline in nature, the bacteria added should fit in some special norms. The added bacteria should be able to withstand the harsh environmental conditions of concrete. Concrete is a dry material and the pH value of cement and water when mixed is up to 13 which makes it confrontational as most of the organisms cannot survive in an environment having pH value higher than 10.

1.4.1 Types of Bacteria

Bacteria naturally occur in nature in various forms. They are present not only on the surface but also beneath the surface of the earth. The various bacteria that can be used in concrete are:
(i) Anaerobic Bacteria

If anaerobic bacteria like closely related specie of shewanella are added to concrete, the compressive strength increases from 25-30%.
(ii) Aerobic Bacteria

The various types of aerobic bacteria that can be used in concrete are:

- Bacillus pasteurii
- Bacillus sphaericus
- Escherichia coli
- Bacillus subtilis
- Bacillus cohnii
- Bacillus balodurans
- Bacillus pseudofirmus

1.5 FINDING THE CORRECT BACTERIA TO BE USED IN SELF-HEALING CONCRETE

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 endolithic 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 to11.5) 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.

1.6 PREPARATION OF BIO-CONCRETE

Bacterial concrete can be prepared in two ways,

- By direct application
- By encapsulation in lightweight concrete

In the direct application method, bacterial spores and calcium lactate is added into concrete directly when mixing of concrete is done. The use of this bacteria and calcium lactate doesn’t change the normal properties of concrete. When cracks are occurred in the structure due to obvious reasons. The bacteria are exposed to climatic changes. When water comes in contact with these bacteria, they germinate and feed on calcium lactate and produces limestone. Thus sealing the cracks.

By encapsulation method the bacteria and its food i.e. calcium lactate, are placed inside treated clay pellets and concrete is prepared. About 6% of the clay pellets are added for making bacterial concrete.

When concrete structures are made with bacterial concrete, when the crack occurs in the structure and clay pellets are broken and the bacteria germinate and eat down the calcium lactate and produce limestone, which hardens and thus sealing the crack. Minor cracks about 0.5mm width can be treated by using bacterial concrete.

II. LITERATURE REVIEW

2.1 GENERAL

Bio-concrete was first introduced as a way of sealing Mount Rushmore. The idea of bacteria-mediated concrete was first introduced by a US research group led by Prof Sookie Bang in the late 1990s. She had the idea of using it as a sealer on Mount Rushmore, which was subject to the effects of the climate. 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.

2.2. STUDIES ON SELF-HEALING CONCRETE

V. Ramakrishnan, R.K.Panchalan, and S.S.Bang has published a paper on Bacterial Concrete – A Concrete for the Future which says a common soil bacterium was used to induce calcite precipitation. This technique is highly desirable because the mineral precipitation induced as a result of microbial activities, is pollution free and natural. The effectiveness of this technique was evaluated by comparing the compressive strength and stiffness of cracked specimens remediated with bacteria and those of the control specimens (without bacteria). Experimental investigation was also conducted to determine the strength regaining capacity (modulus of rupture) of cracked beams remediated with different concentrations of bacteria. This paper also presents the results of a durability study on cement mortar beams treated with bacteria, exposed to alkaline, sulfate and freeze-thaw environments. Different concentrations of bacteria were used for the investigation. It was found that the use of bacteria improved the stiffness, compressive strength, modulus of rupture and durability of concrete. Scanning electron microscope (SEM) was used to document the role of microbiologically induced mineral precipitation in improving the strength and durability aspects of concrete.

C. C. Gavimath, B. M. Mali, V. R. Hooli, J. D. Mallpur , A. B. Patil , D.P.Gaddi, C.R.Ternikar has published a paper on potential application of bacteria to improve the strength of cement concret in which the potential application of bacterial species i.e. B.sphaericus to improve the strength of cement concrete is studied. Here they have made an attempt to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength of the concrete. Water which enters the concrete will activate the 5 dormant bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation. Concrete, however, is due to its high internal pH, relative dryness and lack of nutrients needed for growth, a rather hostile environment for common bacteria, but there are some extremophilic spore forming bacteria may be able to survive in this artificial environment and increase the strength and durability of cement concrete. In this study they found that incorporation of spore forming bacteria of the species Bacillus will not negatively affect the compressive and split tensile strength of the cement concrete.

A. Surendran and S. John Vennison has published a Journal on Occurrence and Distribution of Mosquitocidal Bacillus sphaericus in Soil which says Bacillus sphaericus is one of the effective biolarvicides to control Culex species and the monitoring of larval susceptibility is essential to avoid resistance development. Mosquito larvicidal activity of B. sphaericus was assessed by isolating them from ecologically different soil habitats in and around Devakottai of Tamil Nadu inSouth India. The isolated organisms were confirmed as Bacillus sphaericus based on biochemical characterization and microscopic observations.

Thirumalaichettiar has published a paper on bacterial concrete says a novel technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite (CaCo3) precipitation is discussed. Microbiologically induced calcite precipitation (MICP) is a technique that comes under a broader category of science called biomineralization. It is a process by which living organisms form inorganic solids. Bacillus Pasteruii, a common soil bacterium can induce the precipitation of calcite. 6

Ellie Zolfagharifard has published a article on Biological concrete could usher in a new era of self-healing civil structures says its Far better would be to use a material that heals itself just as a crack begins to appear. Existing research has focused on the use of synthetic materials that can seal up cracks as they develop. But the work by Delft and Ghent universities is unique in that they plan to use living bacteria to achieve what they hope will be better results. At Delft University, Dr Henk Jonkers has developed a biological concrete that uses specially selected bacteria of the genus Bacillus, alongside a combination of calcium lactate, nitrogen and phosphorus, to create a healing agent within the concrete. If untouched, these agents can remain dormant in the concrete for centuries. But if water begins to seep into the cracks, the spores of the bacteria 7 start to germinate and feed on the calcium lactate. This consumes oxygen, which in turn converts the calcium lactate into limestone that solidifies and seals the surface. The removal of oxygen also improves the durability of the steel reinforcement.

Dr. Nele De Belie, Ghent University, Belgium has published a paper on Healing and Self-Healing of Concrete has shown during their presentation how repair and consolidation of mineral phases of building materials and the healing and self-healing of concrete with the help of bacteria is possible. Micro-organisms play a crucial role in pedogenesis, transformation of minerals and exchange of elements in structures. This also includes transformation of hard rocks to soft soil, which supports plant growth and is a positive process in nature. However, when this rock is used as a building block or a constituent of concrete, this biodegradation process is far from positive. The building materials may be protected by traditional systems such as coatings and hydrophobic sealers or with organic dispersions. In the bacterial treatment, the solution medium used was of equimolar concentration of urea (20g/l) and CaCl2 or Ca(NO3)2 for 3 days and thereafter dried for 3 days at 28oC. The bacteria used were B. Sphaericus(BS). But to protect these bacteria from the strong alkaline environment in concrete, they were immobilized in Silica Sol-gel. The treatments were applied by placing the samples on plastic rods in the treatment solution, where the liquid level was 10 mm above their lower side. Remediation of cracks could be possible by formation of biocers.

Kantha D.Arunachalam , K.S. Sathyanarayanan , B.S. Darshan, R.Balaji Raja has published a article on Biosealant properties of Bacillus sphaericus in which they say Bacillus sphaercius was yet another partially characterized species with similar entity, having the capability of precipitating calcium carbonate. Earlier researchers have shown very less implementation of the 8 organism in remediation aspect. Bacillus sphaercius was sub cultured and temperature, pH were optimized at 7.4 and 37°C. Growth curve for Bacillus sphaercius showed that the log phase was between 4-11 hours and after 21 hours the bacterial growth was inhibited. EDTA titration was performed to find out the amount of CaCO3 precipitate and it was highest at pH 8. The broth culture was subjected to Atomic Force Microscope studies. The analysis confirmed the presence of calcite in both the bacterial solution and dry scrapes. Optimum nickel ion concentration for calcium carbonate precipitation was found to be 80µm. The cubes were treated for 5 days in laboratory scale and to pilot scale in the second phase for 25 days. At the end of the study, the potential of Bacillus sphaercius in Bio-concrete was well established.

P S Tan, M Q Zhang, D Bhattacharyya has published a article on Processing and Performance of Self-Healing Materials says Two self-healing methods were implemented into composite materials with self healing capabilities, using hollow glass fibres (HGF) and microencapsulated epoxy resin with mercaptan as the hardener. For the HGF approach, two perpendicular layers of HGF were put into an E-glass/epoxy composite, and were filled with coloured epoxy resin and hardener. The HGF samples had a novel ball indentation test method done on them. The samples were analysed using micro-CT scanning, confocal microscopy and penetrant dye. Micro-CT and confocal microscopy produced limited success, but their viability was established. Penetrant dye images showed resin obstructing flow of dye through damage regions, suggesting infiltration of resin into cracks. Three-point bend tests showed that overall performance could be affected by the flaws arising from embedding HGF in the material. For the microcapsule approach, samples were prepared for novel double-torsion tests used to generate large cracks. The samples were compared with pure resin samples by analysing them using photoelastic imaging and scanning electron microscope (SEM) on crack surfaces. Further double-torsion testing showed that healing recovered approximately 24% of material strength. Self-healing materials are materials designed to recover strength from low-level damage done to the material over the course of its service lifetime. The self-healing technique is particularly useful when applied to composite materials, since composites have low damage detectability and is susceptible to sudden and brittle failure. This study is aimed at two self-healing methods that had been implemented into composite materials with self-healing capabilities, that is: (1) using embedded hollow glass fibres (HGF) storing epoxy resin and hardener, and (2) using microencapsulated epoxy resin with 2- methylimidazole/CuBr2 as the hardener. Current methods of evaluating the performance of self-healing polymer composites involve inducing some form of damage into the material.

Michelle Pelletier from the University of Rhode Island (URI) announced that she has developed a self-healing concrete that would be inexpensive to produce.Michelle Pelletier, collaborating with URI Chemical Engineering Professor Arijit Bose, created a concrete matrix that was embedded with a micro-encapsulated sodium silicate healing agent. When cracks formed in the concrete, the capsules ruptured and released the agent into the adjacent area. The sodium silicate reacted with the calcium hydroxide already present in the concrete, and formed a calcium-silica-hydrate gel that healed the cracks and blocked the concrete's pores. The gel hardened in about one week.When Pelletier's concrete was stress-tested to the point of almost breaking, it proceeded to recover 26% of its original strength. By contrast, conventional concrete only recovers 10%. Pelletier believes that she could boost the strength of her mix even higher, by increasing the quantity of the healing agent. Refer Figure 3.

Researchers at Northumbria University in the U.K. are developing a "self-healing" concrete. **Dr Alan Richardson**, a Senior Lecturer in Construction in the School of the Built and Natural Environment is using ground-borne bacteria – bacilli megaterium – to create calcite, a crystalline form of natural calcium carbonate. This can then be used to block the concrete's pores; keeping out water and other damaging substances to prolong the life of the concrete.The bacteria is grown on a nutrient broth of yeast, minerals and urea and is then added to the concrete. With its food source in the concrete, the bacteria breeds and spreads, acting as a filler to seal the cracks and prevent further deterioration. It is hoped the research could lead to a cost-effective cure for 'concrete cancer' and has enormous commercial potential. While further research is needed, Dr Richardson is hopeful that the repair mortar will also be effective on existing structures. So-called 'concrete cancer' may be caused by the swelling and breaking of concrete and is estimated to cost billions of pounds worth of damage to buildings .Dr Richardson said: "This project is hugely exciting. The potential is there to have a building that can look after itself."

At Delft University, **Dr. HenkJonkers** is developing a biological concrete that uses specially selected bacteria of the genus Bacillus, alongside a combination of calcium lactate, nitrogen and phosphorus, to create a healing agent within the concrete.If untouched, these agents can remain dormant in the concrete for centuries. But if water begins to seep into the cracks, the spores of the bacteria start to germinate and feed on the calcium lactate. This consumes oxygen, which in turn converts the calcium lactate into limestone that solidifies and seals the surface. The removal of oxygen also improves the durability of the steel reinforcement. They are using clay pellets that are around 2-4mm wide to make sure that the agents are not activated during the mixing process. The problem with this is there is need to use relatively high volumes of this porous aggregate within the concrete mix which results in gain of self-healing but lose of strength of the concrete. The clay pellets make up 20 per cent of the volume of the concrete that would otherwise be made of a harder material. This is estimated to weaken the concrete by around 25 per cent, which is far too much for applications that require high compressive strength. Jonkers is now working on using a compressed powder instead of pellets that will hold the self-healing agent in less than one per cent of the volume of the concrete.

Researchers at Ghent University are using the micro-organism Bacillus sphaericus with urea as a nutrient source to create calcium carbonate. Researcher **Dr. Nele De Belie** said they have first discovered the bacterium as it was causing problems closing up water pipes. They realised the same bacteria could help enhance the durability of concrete. Instead of using a porous aggregate to hold the self-healing agent, the Ghent team opted to place the material in a hollow glass capsule with an internal diameter ranging from 0.8 to 4mm. As the concrete cracks, the capsules break, releasing the self-healing agent. This method eliminates the need for porous aggregates and retains the strength of the concrete. During the course of its research, the team found that the bacteria struggled to fill cracks of more than 300mm. It has since developed a solution that is purely synthetic, by using polyurethane capsules, which foam in moist environments, and an accelerator that shortens the reaction time. Initial tests have shown that the foam can expand 25-30 times more than a bacterial solution. But the team hasn't given up on biological process yet..

III. PROBLEM FORMULATION: NEED AND SIGNIFICANCE OF PROPOSED RESEARCH WORK

Concrete will continue to be the most important building material for infrastructure but most concrete structures are prone to cracking. 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. Concrete can withstand compressive forces very well but not tensile forces. When it is subjected to tension it starts to crack, which is why it is reinforced with steel; to withstand the tensile forces.

Structures built in a high-water environment, such as underground basements and marine structures, are particularly vulnerable to corrosion of steel reinforcement. Motorway bridges are also vulnerable because salts used to de-ice the roads penetrate into the cracks in the structures and can accelerate the corrosion of steel reinforcement. In many civil engineering structures tensile forces can lead to cracks and these can occur relatively soon after the structure is built. 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.

3.1 OBJECTIVES

Cracks in concrete structures can shorten their service life by primarily exposing the reinforced steel within the concrete to carbon dioxide and chlorides and thus leading to corrosion. To overcome this drawback, self-healing technology is being developed. Self-healing in concrete is defined as the ability for the concrete to detect its damage and restore its degraded properties using inherently available resources within the concrete matrix. The overall objective of this study is to produce a state-of the report on this technology to identify areas of needed research, thereby increasing the uptake of this technology, which will increase the service time and durability of the concrete works, by reducing the material loss, and to build environmental friendly civil works.

IV. PROPOSED METHODOLOGY DURING THE RESEARCH PLANNING OF THE WORK

The method of using microbes in bacterial concrete is known as microbial Induced Calcium Carbonate Precipitation (MICCP) or bio mineralization. Bio mineralization is a biological precipitation in which organisms create a local micro environment by providing chemical precipitation of mineral phases extracellularly. Some usually occurring metabolic processes including sulphate reduction, photosynthesis and urea hydrolysis end up in giving CaCO3 as there by product. Various bacteria can precipitate calcium carbonate in both natural and laboratory conditions. Calcium carbonate precipitation is mainly governed by following factors

- pH value
- Calcium concentration
- DIC (Dissolved Inorganic Carbon) concentration
- Nucleation sites

The main mechanism behind making a self-healing concrete is that the bacteria should be able to convert the soluble organic nutrients into insoluble inorganic calcite crystals which seals the cracks. The self-healing agent that is applied to the concrete consists of two components, bacteria which acts as a catalyst and calcium lactate i.e. the mineral precursor which is converted to calcium carbonate mineral. The presence of CO2 and calcium hydroxide within the concretion of calcium carbonate in control concrete as shown in the reaction given below:

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

The calcium carbonate is formed due to the presence of limited CO2. Calcium hydroxide being soluble in nature dissolves in excess water and comes out from cracks as leaching. In self-healing concrete active metabolic conversion of calcium nutrients takes place due to the presence of bacteria10.

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

There are two pathways of calcium precipitation done by microorganisms:

- It involves Sulphur cycle in which Sulphur reducing bacteria carry out Sulphur reduction in anoxic environment.
- It involves nitrogen cycle, explicitly the amino acid oxidative deamination and urea or uric acid degradation using ureolytic bacteria in aerobic environment and in anaerobic conditions nitrate reductions.

One of the most commonly used methods applied for MICCP is hydrolysis of urea through the urease enzyme in an environment in which calcium is in abundance. This method results in the hike in the dissolved carbon (inorganic) concentration and pH. Urease propels the hydrolysis of urea in bacterial environment to ammonia and CO2, resulting in pH and carbonate concentration increase. 1 mol of urea forms 1 mol of ammonia and 1 mol of carbonate by intracellular hydrolyzation, which in turn forms additional 1 mole of ammonia and carbonic acid spontaneously. The flow chart below shows the chemical process behind the bio-mineralization process:

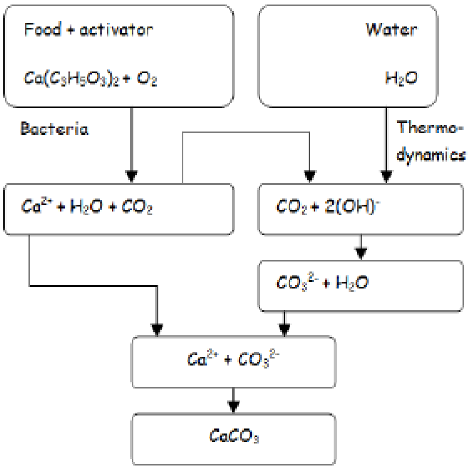

Fig.5. Chemical flow-chart of self-healing process by bacteria

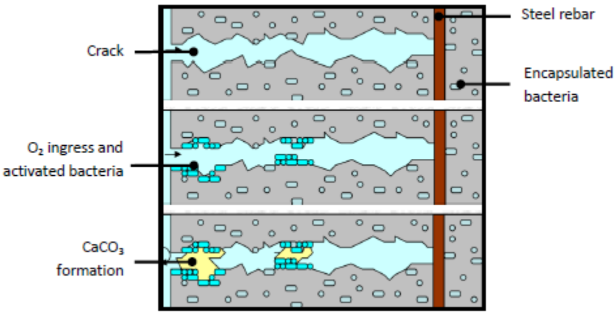

Fig.6. Schematic representation of self-healing by bacteria.

The experimental study carried out on the self-healing concrete consists of following steps:

1. Process of manufacture of concrete
2. Weight batching
3. Hand mixing
4. Placing
5. Compaction
6. Curing
7. Workability of concrete
8. Slump test
9. Mixing, compaction and curing

V. PREPARATION OF BACTERIA

In this study the effect of Bacillus Sphaericus in concrete is studied. Bacteria added in concrete of mix proportion M20(1:1.5:3) with 10ml and 20ml proportions and proper curing makes a substantial improvement in enhancing the protection of embedded in concrete. The bacteria is firstly prepared in following steps:

1. Mixing of bacteria
2. Preparation of nutrient agar
3. Processing of bacteria
4. Culturing and isolation
5. Ability of bacterial concrete to repair cracks
6. Processing of bacteria

Concrete could soon be healing its own hairline cracking. Holes and pores of wet concrete are healed. Combined calcium with oxygen and carbon dioxide to form calcite is essential for healing tiny cracks which arrest the seepage of water.

5.1 TESTS TO BE CONDUCTED

The tests to be conducted on self healing concrete in this study are:

1. Compressive strength
2. Split tensile strength

VI. CONCLUSIONS

Concrete plays a major role in the construction industry. For a durable structure, good quality concrete must be used. A Self Healing Concrete for the Future which says a common soil bacterium was used to induce calcite precipitation which is highly desirable because the mineral precipitation induced as a result of microbial activities is pollution free and natural.

1. The compressive and slit tensile strength of M20 bio-concrete is found to be higher than M20 conventional concrete.

2. The workability test of the bacterial concrete resulted in 90mm of slump value.
3. We have found out that the compressive strength of the bacterial concrete with 10% and 20% of addition of bacillus sphaericus as 13.07% and 13.75 % respectively.
4. Same way we have found out that the split tensile strength of the bacterial concrete with 10% and 20% of addition of bacillus sphaericus as 3.15% and 7.25% respectively. We have also casted a beam of size 500mm x 100mm x 100mm with 20% addition of bacillus sphaericus and made some tiny cracks by giving little load and the observation of the healing process of the crack is going on.
5. It reduces the chances of defects that can take place in a structure like corrosion of reinforcement and cracks.
6. Bacteria can be further used in mortar and bricks to improve their properties.

The conclusion of the study is that the proposed biochemical healing agent composed of bacteria represents a promising bio-based and thus sustainable alternative to strictly chemical or cement based healing agents.

.

.REFERENCES

[1] Dr. Nele De Belie, Ghent University, Belgium, “Self-Healing of Concrete”.
[2] Dr. Fixit Institute of Structural Protection and Rehabilitation.
[3] Self Healing Concrete – A Sustainable Future by Simon Dunn, BEng (hons), Cardiff University.
[4] Tomoya Nishiwaki, Marina Koda, Makoto Yamada, Hirozo Mihashi, Takatsune Kikuta, Journal of advanced concrete technology, volume 10 (2012), Pp.195-206.
[5] Studies on the characterisation of Biosealant properties of Bacillus sphaericus by Kantha D. Arunachalam, K.S. Sathyanarayanan , B.S. Darshan, R. Balaji Raja.
[6] IS : 10262 – 1982 “Recommended guidelines for concrete mix design”.
[7] “CONCRETE TECHNOLOGY” Theory and practice by M.S.SHETTY
[8] Bang SS, Galinat JK, Ramakrishnan V (2001) Calcite precipitation induced by polyurethane-immobilized Bacillus pasteurii. Enzyme and Microbial Technology28:404–409.
[9] DeGraef B, deWindt W, Dick J, Verstraete W, deBelie N (2005) Cleaning of concrete fouled by lichens with the aid of Thiobacilli. Materials and Structures 38(284):875–88.
[10] DeMuynck W, deBelie N, Verstraete W (2007) Improvementof concrete durability with the aid of bacteria. Proceedingsof the First International Conference on Self HealingMaterials 18–20 April 2007, Noordwijk aan Zee, The Netherlands.Edvardsen C (1999)
[11] Water permeability and autogenoushealing of cracks in concrete. ACI Materials Journal96(4): 448–454. Jonkers HM (2007) Self healing concrete: a biological approach. In S. van der Zwaag (ed.) *Self healing materials—An alternative approach to 20 centuries of materials science*. Springer, The Netherlands; pp: 195–204.
[12] Li VC, Yang E (2007) Self healing in concrete materials. In S. van der Zwaag (ed.) *Self healing materials—An alternative approach to 20 centuries of materials science*. Springer, The Netherlands; pp: 161–194.
[13] Neville AM (2002) Autogenous healing—A concrete miracle? *Concrete Int* 24(11):76–82.
[14] Ramachandran SK, Ramakrishnan V, Bang SS (2001) Remediationof concrete using micro-organisms. ACI Materials Journal 98:3–9.
[15] Reinhardt HW, Jooss M (2003) Permeabilitiy and Self-healingof cracked concrete as a function of temperature and crack width. Cement and Concrete Res 33:981–985. Schlegel HG (1993) General microbiology, 7th edition, Cambridge University Press.
[16] Soundharya S, Nirmal KK. Strength improvement studies on self-healing characteristics of bacterial concrete. International Journal of Engineering Science Invention Research and Development. 2014 Oct; I(IV):162–4.
[17] Navneet C, Anita R, Rafat S. Calcium carbonate precipitation by different bacterial strains. African Journal of Bio Technology. 2011 Aug; 10(42):8359–72.
[18] Kavia K, Hema C. Dressing of structural cracks using Bio Concrete. Indian Journal of Science and Technology. 2015 Nov; 8(32):1–4.

[19] Vekariya M, Jayesh K, Pitroda. Bacterial concrete: new era for construction industry. International Journal of Engineering Trends and Technology. 2013 Sep; 4(9):4129–33.

[20] Jonkers HM. Self-healing concrete: A biological approach, in self-healing materials. Springer. 2011; 56:1–12.

[21] Henk MJ, Schlangen E. Development of a bacteria-based self-healing concrete. Taylor and Francis Group, London; 2008. p. 425–30.

[22] Jonkers HM, Schlangen E. A two component bacteria-based self-healing concrete. Concrete Repair, Rehabilitation and Retrofitting II. Taylor & Francis Group, London; 2009. p. 213–6.

[23] Noraisyah N, Leong SW, Praveen R. A Review on the compressive strength of bio mineralized mortar. In the 3rd National Graduate Conference (NatGrad2015), University Tenaga Nasional, Putrajaya Campus; 2015 Apr 8–9. p. 235–6.

[24] Manikandan AT, Padmavathi A. An experimental investigation on improvement of concrete serviceability by using bacterial mineral precipitation. International Journal of Research and Scientific Innovation (IJRSI). 2015 Mar; 2(3):48.

[25] Maheswaran S, Dasuru SS, Murthy ARC, Bhuvaneshwari B, Kumar VR, Palani GS, Iyer NR, Sarayu KM, Sandhya S. Strength improvement studies using new type wild strain Bacillus cereus on cement mortar. Current Science. 2014 Jan; 106(1):50.

[26] Beena K. Microbial concrete: a multi-purpose building material-an overview. International Journal of Advances in Engineering and Technology. 2015 Jan; 7(6):1608–19.