INT. J. BIOL. BIOTECH., 15 (4): 801-813, 2018.

BIO CONCRETE: AN OVERVIEW

Shumaila Jawaid[1], Kashif Ahmed[1*] and Muhammad Aslam Bhutto[2]

[1]*Department of Chemistry, N.E.D. University of Engineering & Technology, Karachi, Pakistan.*
[2]*Department of Civil Engineering, N.E.D. University of Engineering & Technology, Karachi, Pakistan.*
*E-mail Kashif25473@yahoo.com

ABSTRACT

This is the review based study which is beneficial and development step that include bacteria, types of bacteria on the basis of classification and effects of microbes on different conditions in concrete on the basis of its properties like strength, durability, absorption of water, insertion of chloride and mineral precipitates of bacteria are good techniques for the development of bio concrete. This also includes the harmful effects of bio-concrete and the diseases which are caused by microorganisms. The self-healing ability is not comprehensively tested or analyses at micro, macro and Nano scale. In macrostructure, self-healing ability is based upon durability criteria of absorption of water, resistance with chloride and acid. Microstructure level's tests are done to maximize the validity of consequences. Nanostructure based study is few but it's important to review that all the ways of self-healing efficiency of cement depending material is for developing the new and fresh experimental techniques. Effective self-healing is usually occurred due to the use of polymers, microorganism and additional cementing material. It is the key issue to find out the self-healing efficiency's effect to sealing the crack width successfully. It is reported so far that at least crack of 0.97 mm is healed. Only in one paper it is reported that the depth of healing of maximum size of crack is 5 mm.

Keywords: Bio concrete, Self-healing concrete, Bio sealant.

INTRODUCTION

Concrete is world-wide used construction material for making different buildings, roads, dams, bridges, storage tank and many other purposes. Concrete is usually a combination of cement, coarse particles (Crash and Sand) and water. It is used to design and improve the infrastructures. Concrete has many advantages and disadvantages. Due to the strength, durability and permeability of concrete, its demand is increasing year by year (Talaiekhozan *et al*., 2014). Its demand also increases due to availability, low price and possibility to make the desired size and shape. Concrete has an age of about 50 year normally, after that because of the effect of weather (effect of sunlight and rain) it forms cracks. It is impossible to prevent the cracks formation. These cracks allow different chemicals to entered or penetrate in its structure. In the result of cracks, it loses its durability. Cracks are seen in both plastic and hardened conditions. In plastic state, cracks are due to shrinkage, settlement and rapid loss of water while in hardened state, it is due to weather effects, thermal effect and absence of water content (dryness) and many other reasons (Samani and Attard, 2014; Achal *et al*., 2011; Warscheid and Braams, 2000; Le Métayer-Levrel *et al*., 1999)

The bacterial self-healing efficiency of concrete material has an important topic for researchers in biotechnology and civil engineering (Balazs, 2007; Nosonovsky and Bhushan, 2008). In 1980s, there are few article related to the concrete self-healing property but after 1990s, a series of papers were published. There are two types of cracks repairing including active and passive. In Passive treatment only outer surface cracks are sealed while in active treatment, both outer and inner cracks are healed (Pacheco-Torgal and Labrincha 2013). Chemical compound used as sealers, such as waxes, siloxane, chlorinated rubbers, polyurethane, epoxy resins and acrylics. These sealers have some limitations which are as follows; weather effects resistant (moisture sensitivity, poor heat resistant), weak bonding with concrete material and thermal coefficient between sealers and concrete (Dhami *et al*., 2012; Van Tittelboom *et al*., 2010; De Muynck *et al*., 2010;De Muynck *et al*., 2008). Self-healing techniques or active treatment was occurring independently or spontaneously in many conditions according to crack's position. It has a capability of rapid activation upon crack's formation and its sealing. Bacterial self-healing efficiency of concrete by the production of calcium carbonate ($CaCO_3$) and for the bacterial self-healing efficiency, there are three main themes which are as follows;

i. Bacterial production of calcium carbonate
ii. Autogenous action.
iii. By the encapsulation of polymeric compounds (Wu *et al*., 2012).

Autogenous action is the natural process by which cracks are repaired by water or moisture content. Cracks are healed by hydration of cemented material or carbonation of calcium hydroxide (Edvardsen, 1999; Ramm and

Biscoping, 1998). Cracks of about 0.1 to 1.3 mm can be healed by this treatment (Qian *et al*., 2010; Ahn and Kishi, 2009; Şahmaran *et al*., 2008; Reinhardt and Jooss, 2003; Clear, 1985). When calcium oxide is mixed with water it forms calcium hydroxide which will react with atmospheric carbon dioxide and forms calcium carbonate as shown in equations (1) and (2) which is the greatest source for crack's healing.

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad \textbf{(1)}$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad \textbf{(2)}$$

BIOMINERALIZATION

It is a phenomenon in which living organism produce mineral ions to stiffen or harden the existing tissues. These tissues are known as mineralized tissue. Examples are carbonate produced from invertebrates, silicate from algae and calcium carbonate and phosphate from vertebrates. This process is occurred through biologically controlled mineralization, it proceed in open environment as a result of bacterial metabolic activity. Biominerals are produced by the combination of microbial metabolic waste and surrounding environment as shown in Fig 1. (Rivadeneyra *et al*., 1994).

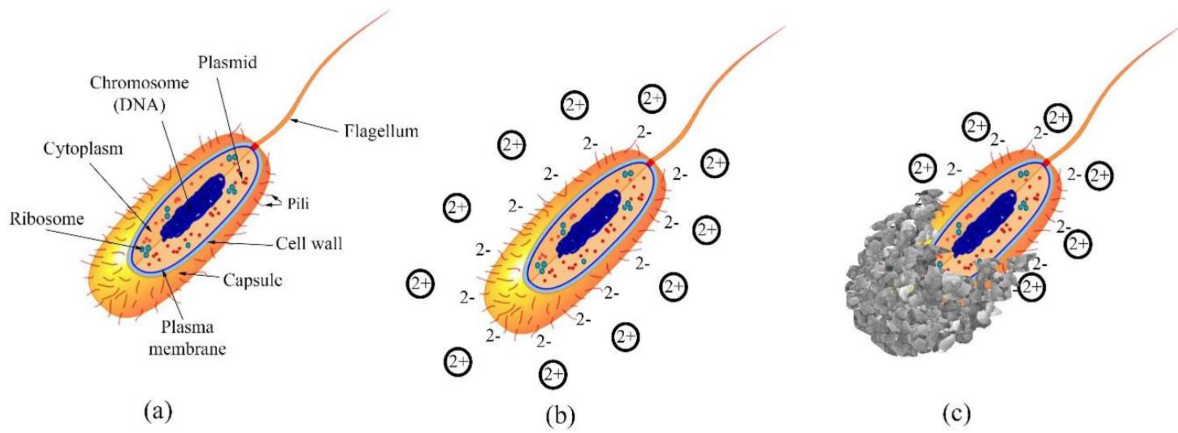

Fig 1. (a) bacterial Structure. (b) cell membrane (Negatively charged) surrounded by cell wall (positively charged). (c) Production of bio minerals by combination of cell wall ions and surrounding ions (Rivadeneyra *et al*., 1994).

Bio mineralization takes place in anaerobic conditions or in oxic-anoxic surface. It is highly affected by temperature, nucleation site, concentration of inorganic carbon (dissolved) and Hatree energy (E_h). It was noted that the production of precipitates of calcium carbonate is interested because of its effective capacity of bonding with concrete material (Barton and Northup, 2011; Hammes and Verstraete, 2002).

UREOLYTIC EFFECTS AND REMEDIATION OF BACTERIA

The ureolytic effect of bacteria is involved in bio mineralization. Biologically induced mineral precipitation resulting from metabolic activity plays a vital role in improving the behavior of concrete material. The process of precipitation of carbonate is quiet clear but all bacteria have an ability to produce the precipitates of calcium carbonate (Boquet *et al*., 1973). It is the unique technique for improvement of formation of structural damages in concrete by injecting or insertion of selective bacteria, by which precipitation of calcium carbonate enhanced in the form of calcite (which is produced by metabolic activity of bacteria). Bio mineralization is best technique for remediation (improvement) of cracks in concrete used for building material. The metabolic processes involve in precipitation occurred are urea hydrolysis, photosynthesis and sulfate reduction (Hammes *et al*., 2003). Hydrolysis of Urea, which is biologically controlled reaction that produce carbonate ion without generating protons, is controlled with the help of enzyme urease. Solid crystalline material is formed when the urea hydrolysis is occurred in calcium carbonate precipitates. The bonding capability of calcium carbonate precipitated crystals are depending upon the rate of formation of carbonate and also depend upon the appropriate conditions which is possible to control the reaction or to produce tight bonding of calcite with concrete (biocement or bioconcrete). Ureolysis is influenced in the presence of urea in laboratory conditions and (Urea amido hydrolase, EC 3.5. 1.5) is used as a urease enzyme (Jugnia *et al*., 2008). Following are steps, (Siddique and Chahal, 2011).

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

2. $NH_2COOH+H_20 \rightarrow H_2CO_3+NH_3$.
3. $H_2CO_3 \rightarrow HCO_3^{-}+H^{+}$.
4. $2NH_3+2H_20 \rightarrow 2NH_4+2OH^{-}$ (pH INCREASED).
5. $HCO_3+H^{+}+2OH^{-} \rightarrow CO_3^{2-}+2H_2O$.
6. $CO_3^{2-}+Ca^{2+} \rightarrow CaCO_3$ (Carbonate ppt).
7. $CO(NH_2)_2+2H_20+Ca^{2+} \rightarrow 2NH_4^{+}+CaCO_3$ (OVERALL REACTION)

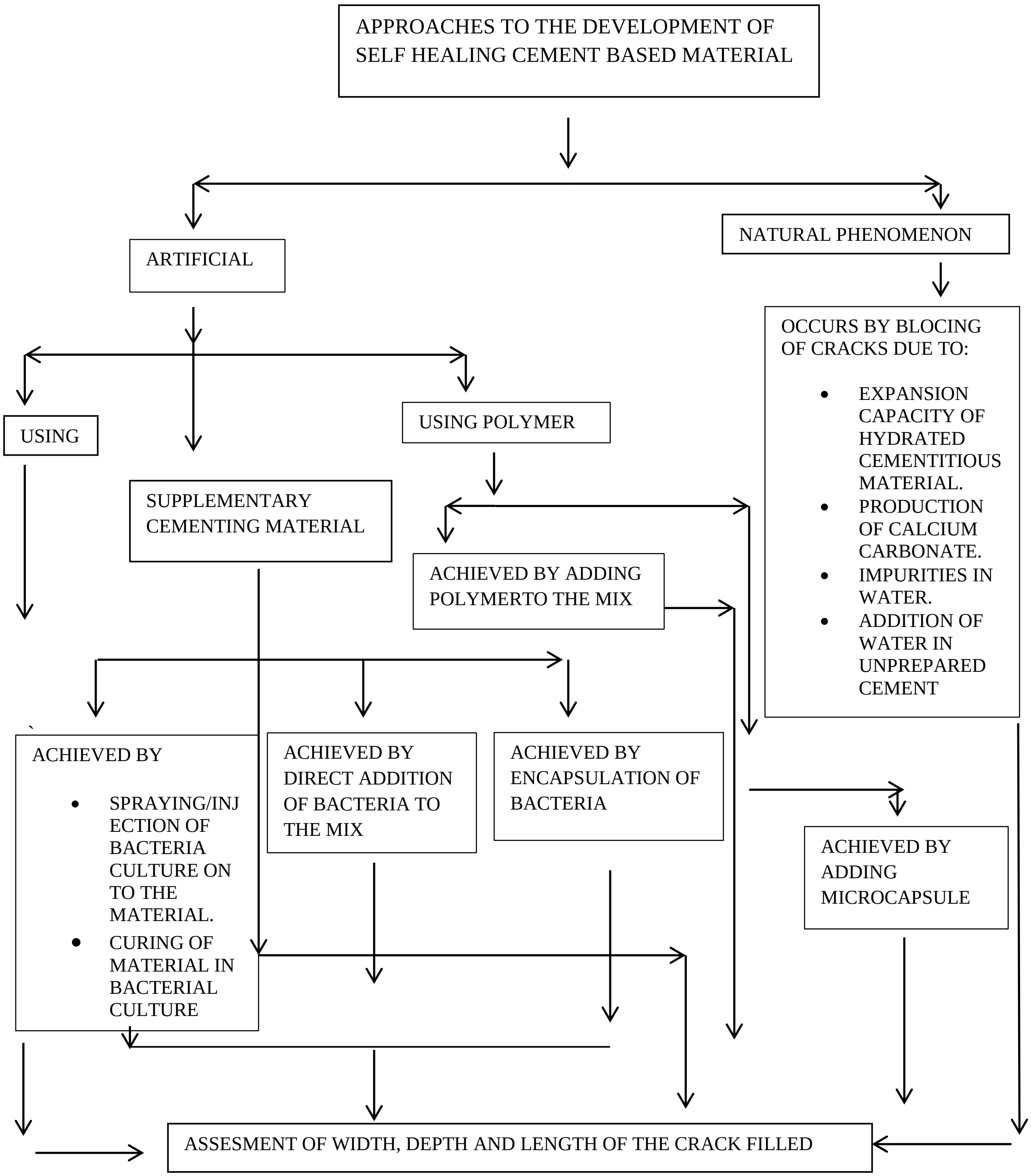

Fig. 1. Research based taxonomy of cement material (Muhammad *et al*., 2016).

In the end of reaction, we observed the production of calcium carbonate. Calcium carbonate is used as a suitable mineral which minimize the pores from deep formations by different reasons. In underground level of water, calcium is used as important cation where carbonate and bicarbonates are most important anions (Thomas, 2003). The calcium carbonate precipitation occurring by two ways

i. **Active Nucleation:**

In active nucleation bacterial cell's surface is used as an active site for nucleation. The clusters of cell have a net electronegative charge which results in the adsorption of calcium ions. The attraction of calcium ion with carbonate and bicarbonate results in the precipitation of calcium carbonate (Schultze-Lam *et al*., 1996; Hammes *et al*., 2003; Thomas H, 2003; Mitchell and Ferric, 2006).

ii. **Passive Nucleation:**

It occurs due to metabolically changes present in the bulk fluid environment surrounding the bacterial cells. This increases the mineral saturation and induces nucleation (Schultze-Lam *et al*., 1996). In the ureolysis, this process occurs from an increase in pH due to ammonification (Stocks-Fischer and Galinat, 1999).

Bio remediation is the process in which we use of either deliberating or naturally introduced bacteria to treat the contaminated media like subsurface material, soil and water. In many conditions, it is feasible, less expensive and renewable technique. In bio remediation process, we use bacteria which are highly efficient and minimize the need of adding costly reagents (Stocks-Fischer and Galinat, 1999).

SELF-HEALING TECHNIQUES AND MEASURED VARIABLE

Van Tittelboom *et al* (2012) reported that supplementary material is used to improve the micro cracks in concrete by self-healing effect. This supplementary concrete material has two advantages, decreases the amount of cement material and increases the repairing efficiency of cracks. Parks *et al* (2010) found that if bulk quantity of water which has dissolved calcium, magnesium and sulphates are used to prepare concrete material so this has ability to heal the crack at micro level. Ahn *et al* (2012) reported that there was better self-healing effect than the last studied or it was observed that when sea water and oil are merged with concrete so, the cracks under 50µm were repaired successfully. Siad *et al* (2015) was observed when limestone (powdered) used in concrete, it recover or attain their functionality. Pang *et al* (2016) have reported that the steel slag (carbonated) act as a greatest self-healing effects and repaired the cracks of 5mm in length and 20µm in width.

Table 1. Measured variables (width of cracks) and Self-healing techniques (Muhammad *et al*., 2016).

Techniques	**Measured variables (width of cracks)**	**References**
Bacteria and encapsulation Immobilization	Healing of 0.970 mm	Qian *et al*., 2014; Dong *et al*., 2013
Natural	Healing of 60 µm	Yang *et al*., 2011; Parks *et al*., 2010
Polymer	138 µm was completely filled	Snoeck *et al*., 2014; Elmoaty and Elmoaty, 2011
Supplementary material	below 200 µm	Huang and Ye, 2014; Van Tittelboom *et al*., 2012
Other (biological & chemical)	Healing of 0.22 mm	Stuckrath *et al*., 2014

CALCIUM CARBONATE PRECIPITATION IN CONCRETE

Microorganisms which help in the production of biominerals like *Bacillus sphaericus* and *Bacillus peusturii* through metabolic pathway. These are urease positive bacteria which follows the nitrogen cycle. Precipitation of calcium carbonate crystals by *B. subtilis* and *B. sphaericus* are shown in Fig. 2. (Wiktor and Jonkers, 2011; Jonkers *et al*., 2010).

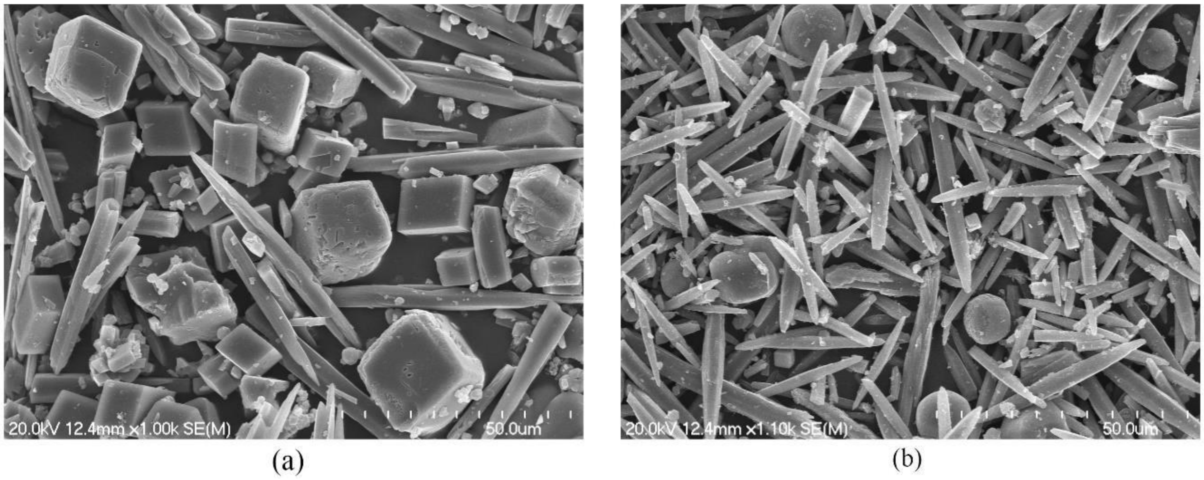

Fig. 2. (a) Scanning Electron Microscopy (SEM) image that shows the formation of calcite precipitate by *Bacillus sphaericus*. (b) SEM image that shows the formation of calcite precipitate by *Bacillus subtilis* . (Wiktor and Jonkers, 2011; Jonkers *et al*., 2010).

Table 2. Bacterial study for bio concrete (Muhammad *et al*., 2016).

	Bactreria	**Nutrient**	**Injected in concrete**	**References**
Metabolic conversion of organic acid	*Bacillus pseudofirmus*	Calcium lactate, calcium glutamate, yeast extract and peptone	Direct	Jonker and Schlagen, 2009
	Bacillus pseudofirmus B.cohnni	Calcium lactate, calcium glutamate,Yeast extract and peptone	Direct	Jonker *et al*., 2010.
	B.cohnni	Calcium lactate and yeast extract.	Immobilized	Sierra-Beltran,2014.
	Bacillus alkalinitrilicus	Calcium lactate and yeast extract	Immobilized	Wiktor and Jonker,2011
Ureolysis	*Bacillus spaericus*	Urea and calcium chloride	Direct	Achal et al., 2011
	Bacillus spaericus	Urea, calcium chloride, calcium nitrate and yeast extract	Immobilized	Van Tittelboom *et al.*, 2010
	Bacillus spaericus	Urea, Calcium acetate and calcium chloride	-	De Muynck *et al.*, 2008
	S. pasteurii, Pseudomonas aeruginosa	Urea and Calcium chloride	Direct	Ramachandan *et al*., 2001
	Bacillus sphaericus, S. pasteurii	Urea and calcium acetate	Direct	Kim *et al.*,2013
	S.pasteurii, pseudomonas aeruginosa	Urea and calcium chloride	Direct	Ramachandan *et al*., 2001
	S. pasteurii	Urea and calcium chloride	Immobilized	Bang *et al.* 2001
	S. pasteurii	Urea and calcium nitrate	-	Chungxiang et al., 2009
	Bacillus amyloliquedaciens	Urea, calcium acetate yeast extract and glucose		Lee, 2003
	Sporosarcina soli, Bacillus massiliensis, Arthrobacter crystallopoietes, Lysinibacillus fusiform	Urea and calcium chloride	Direct	Park *et al*., 2010
Denitrification	*Diaphorobacter nitroreducens, Bacillus sphaericus*	Urea, calcium acetate, calcium formate and yeast extract	Immobilized	Ersan *et al.*, 2015

These techniques are successful but still some drawbacks are present which needs to be studied. Ureolytic activity causes ammonium ions (NH_4^+) production which is the main drawback because it is directly emitted in atmosphere. The excess amount of ammonium ion in concrete enhances the salt damage property by convert into nitric acid. It is estimated that 4.7 g of nitrogen was produced by 10 g/L of urea which is required to remediate of one m^2 of concrete. This amount is about three times less that is produced by human every day Hence, it is necessary to optimize the beneficial amount of urea that is released (De Muynck *et al*., 2010).

For the production of bio minerals, another pathway is used which is also called as denitrification or dissimilatory nitrate reduction. Denitrification defines as a respiratory process that results in reduction of nitrate (NO_3^-) to nitric oxide (NO), nitrite (NO^{2-}), nitrogen gas (N_2). nitrous oxide (N_2O), and denitrifying bacteria precipitate minerals through oxidation of organic compounds by the reduction of nitrate (NO_3^-). The most important view of this method is its use in anaerobic conditions. Such bacteria (for example *Archomobacter*, *Alcaligenes,* Denitro *bacillus, Micrococcus* species *Spirillum, Thiobacillus, Pseuodomonas)* play a necessary role in denitrification process (Eq. 1). According to Eq. 2 which shows the production of carbonate and bicarbonate due to the increase in pH which is occurred by the consumption of H+ during the dentrification process. The final reaction of calcium source and carbonate results in precipitation of calcium carbonate (Eq. 3) (Erşan *et al*., 2015). Table 2 shows the use of various nutrients by different bacteria for healing of concrete.

$$Organic\ compound + a\ NO_3^- + b\ H + Denitrification \rightarrow c\ CO_2 + d\ H_2O + e\ N_2 \quad (1)$$
$$CO_2 + 2OH^- \rightarrow CO_3^{\ 2-} + H_2O \quad (2)$$
$$Ca^{2+} + CO_3^{\ 2-} \rightarrow CaCO_3 \quad (3)$$

STRUCTURE TESTS FOR EVALUATING SELF-HEALING EFFICIENCY AT MACRO, MICRO AND NANO SCALE

The three different tests are conducted to describe the quality criteria of concrete in hard state. These are macro-structure test, micro-structure test and Nano-structure tests. Literature review revealed that maximum test are conducted at macro level while the micro level test are presented to the reliability for the consequences and only few tests are conducted for Nano scale. Tables (3, 4, 5) are enlisted which describe the evaluating based self-healing efficiency on macro, micro and Nano structure tests (Muhammad *et al*., 2016):

ADVANTAGES DISADVANTAGES OF USING BIOCONCRETE

Table 6 describes the advantages and disadvantages of biologically prepared concrete with references (Mohanadoss *et al*., 2015).

HARMFULL EFFECTS OF BIOCONCRETE

There are many harmful effects of bio-concrete on human life. Studies also show that bio-concrete was caused negative effect on human phycology and also causes the diseases. Some microorganisms produce ureases which play a very necessary role in the discovery of pathogenesis of animals and human and causes diseases including Proteus mirabilis.

Table 3**.** Approach and measured variables.

Approach	Measured variable (crack,depth and length)	References
Microencapsulation	Maximum depth of 32 mm crack was successfully filled	Mostavi *et al.*, 2015.
Bacteria	Maximum depth of 27.2mm was successfully filled	Achal *et al*., 2011
Carbonated steel slag	Maximum depth of 5mm was successfully healed.	Pang *et al*., 2016.

Table 4**.** Scale of structural tests conducted using various approaches for evaluation of self-efficiency (Muhammad *et al*., 2016):

Test conducted	Scale of test	References
Ultrasonic pulse velocity, Stiffness,Flexual, compressive strength, Toughness,	Macrostructure test	Yildirm *et al*., 2015; Yang *et al*., 2011; Elmoaty and Elmoaty, 2011; Mostavi *et al*,.2015; Bang *et al*., 2001; Talaiekhozani *et al*., 2014; Cao *et al*. 2014; Xu and Yao 2014.
Water permeability, sulphate compressive strength, chloride permeability, ultrasonic pulse velocity, water absorption.	Macrostructure & Durability tests	Yildirm *et al*.; Soeck *et al* 2014; Aldea *et al*. 2000; Dong *et al*. 2013; Sangadji *et al*. 2013; Sarkar *et al*. 2014.
Rapid chloride penetration, Porosity, SEM, compressive strength, water absorption chloride permeability.	Macrostructure, Durability & Microstructure tests	Siad *et al*. 2015; Aldea *et al*. 2000; Achal *et al*. 2011.
Water absorption	Microscopic & Durability	Snoeck *et al*. 2014; Feiteira *et al*. 2014.
Esem, Xrd, SEM.	Microstructure & Microscopic tests	Ahn *et al*. 2012; Pang *et al*. 2015; Liu *et al*. 2015; Luo *et al*. 2015
Visual observation	Microscopic tests	Hosoda *et al*. 2009; Virginie and Junker 2011.
Flexual &Stiffness test	Macrostructure & Microscopic	Granger and Loukili, 2005
Flexural tensile splitting, ftir, Air permeability, eds, Xrd, fesem	Microstructure& Macrostructure tests	Struckrath *et al*. 2014; Huang and Ye, 2014; Rahman *et al*. 2015; Khaliq and Ehsan, 2016
Water absorption, capillary coefficient, Xrd, sorptivity, gas permeability, ftir, chloride diffusion, SEM	Microstructure & Durability	Li *et al*. 2013; Kanellopoulos *et al*. 2015.
Flexual, upv, Nanoscale mechanical measurement.	Macrostructure & Nanostructure tests	Xu and Yao 2014.
Water permeation coefficient, Thaw/Freezing, Coefficient of capillary suction.	Durability tests	Qian *et al*. 2014; Wikto and Jonkers 2015.

Table 5. Macro, micro and nano structure tests (Muhammad *et al*., 2016):

Tests	DEPENDENT VARIABLE	STANDARD METHODS	BEST RESULTS	REFERENCES
Mechanical and Permeability properties	Sorptivity, Stiffness, Chloride penetration, Porosity, ultrasonic pulse velocity, Chloride permeability, flexural and compressive strength, Gas permeability, split tensile,	METHANOL LIQUID, RILEM25 PEM (11-6), ASTMC1585,MIP, ASTMC1202, JSCE-G571-2003, CEMBUREU, RILEM	Sorptivity (18% decreases), Gas permeability (69% decreases), Compressive strength (9.8% Increases), Water (60% recovery of compressive strength), Water permeability (68% decrease), Compressive strength (40% retrieve than the control speciman), Compressive strength (12% improvement & also the faster retrieval of global stiffness than control	Siad *et al*., 2015; Achal *et al*., 2011. Cao *et al*., 2014; Aldea *et al*., 2000; Sarkar *et al*., 2014; Khaliq and Ehsan, 2016; Li *et al*., 2013; Kanellopoulos *et al*., 2015; Luhar and Gourav, 2015; Dong *et al*., 2013; Granger and Loukili, 2005.

			sample).	
SEM,EDS,XRD.	Nanostructure concrete's Fabrics	Not specified	Significant betterment of some used method, mainly from optimum hydration rate.	Sarkar *et al.*, 2014; Huang and Ye, 2014; Dong *et al.*, 2013; Bekas *et al.*, 2015.
Nano structure measurement	Nano-mechanical value	Nano cavity	Nano mechanical values (20% increases) in transition zone, (intermix the concrete with deposited material) compared to the deposited layer.	Xu and Yao, 2014.

Table 6. Advantages disadvantages of using bioconcrete.

Advantages	References	Disadvantages	References
Significant increase in terms of compressive strength and concrete stiffness with effect of the bacterial concrete for the remediation of cracks.	Mikkola *et al.*, 2004; Bou *et al.*, 2008; Talaiekhozani *et al.*, 2014.	Cost of bacterial concrete is 7 to 28% more than the conventional one; however, it can help to reduce the cost of repairing afterwards, which normally cause more than installing the bacterial concrete.	Worlitzsch *et al.*, 2002
Good resistance is shown towards the freeze and thaw attack due to the bacterial chemical process.	Cappitelli *et al.*, 2007; Jonkers *et al.*, 2010.	Bacteria growing in concrete are not good for the human health and atmosphere. Its usage needs to be limited to the structure does not involve near to human life, such as houses or apartments.	Facklam and Elliot, 1995
The higher amount of carbonation in bacterial concrete can help decrease the porosity and permeability which are due to surface treatment resulting in increased resistance towards carbonation and chloride attack.	Mikkola *et al.*, 2004; Worlitzsch *et al.*, 2002	There are no standard designs in practice for the bacterial concrete design mix to obtain the optimum performance. The suitable amount of bacteria and its type is always changing depending on the applications.	Talaiekhozan *et al.*, 2013
The effect of bacterial usage in concrete can reduce the process of reinforcement bar corrosion,whereby the formation of calcite assists in terms of sealing the path of ingress at the same time providing longer lifespan to the bar.	Baumann *et al.*, 1991; Rowan *et al.*, 2003; Stevens *et al.*, 2009.	This method was used to investigate the studies related to calcite precipitation are always costly because it used in techniques like Scanning Electron Microscopy (SEM) which is costly and requires a skilled personnel to run the tests.	Buu-Hoi, *et al.*, 1985; Worlitzsch *et al.*, 2002.

Table 7. Diseases related to the microorganism (Mohanadoss *et al*., 2015)

Bacteria used in bio-concrete.	**Aerobic & Anaerobic**	**Diseases**	**References**
Bacillus sphaericus	Aerobic	Non-Pathogenic	Boumann *et al*., 1991
Bacillus amyloliquefaciens	Aerobic	Nervous diseases & Respiratory tract infections.	Mikkola *et al*., 2004
Bacillus lentus	Aerobic	Non-Pathogenic	Rowann *et al*., 2003
Bacillus pasteurii (Sporosarcina pasteurii)	Aerobic	Non-Pathogenic	Biswasa *et al*., 2010
Pseudomonas aeruginosa	Aerobic	Effect the damaged tissues or those which are immuno-deficient	Worlitzsch *et al*., 2002
Proteus mirabilis	Facultative Anaerobic	Stones formations and Urinary Tract Infections	Talaiekhozan *et al*., 2014
Proteus vulgaris	Facultative Anaerobic	Wounds & Urinary Tract Infections	Talaiekhozan *et al*., 2014
Acinetobacter species	Aerobic	Caused a large variety of diseases including pneumonia, blood infections & wound infections.	Health-care, 2014
Deleyahalophila	Anaerobic	In dialysis patients caused Bactremia	Stevens *et al*., 2009
Myxococcus xanthus	Aerobic	Non-Pathogenic	Jimenez *et al*., 2007
Escherichia coli	Aerobic	Urinary Tract Infections	Mohanadoss *et al*., 2015
Leuconostoc mesenteroides	Anaerobic	Affected the Immune-compromised peoples	Bou *et al*., 2008
Shewanella species	Facultative Anaerobic & Aerobic	Gastro-Intestinal diseases	Michael, 2014

CONCLUSION

All the bacteria have ability to produce carbonate mineral precipitates as a result of its metabolic activity specially *Bacillus specie*. Sometime, the metabolic activity of specific bacteria helps to the improvement in the behavior of concrete material. Whenever we use the bio-concrete (which is prepared by mixing the bacteria or its spores to the concrete) using for construction sector helps in the self-healing mechanism which have greatest effects on compressive strength, permeability workability etc. The tests which discussed in this review have been conducted at macro, micro and Nano levels which increase the reliability of results. These tests are either for characterizing or identifying the deposited layer present within the concrete after self-healing mechanism including X-ray diffraction (XRD), scanning electron microscope (SEM), and field emission scanning electron microscope (FESEM). This review also shows that “the coin has two sides” means bio-concrete has advantages and disadvantages as well. Bio self-healing mechanism is more long-standing and sustainable technique. While it has produced several negative effects on human health and causes many diseases so, some people assuming that to live in environment of bio-concrete is not safe in term of physiology. Further research is needed. Advantages overcome the disadvantages and researcher takes keen interest in using bio concrete.

REFERENCES

Achal, V., A. Mukherjee and M.S. Reddy (2011). Effect of calcifying bacteria on permeation properties of concrete structures, *J. Ind. Microbiol. Biotechnol*., 38 (9) 1229–1234.

Ahn, T.H., D.J. Kim and S.H. Kang (2012). Crack self-healing behavior of high performance fiber reinforced cement composites under various environmental conditions. *Earth Space*, (2012): 635–640.

Ahn, T.H. and T. Kishi (2009). The effect of geo-materials on the autogenous healing behavior of cracked concrete. in Concrete Repair, Rehabilitation and Retrofitting II - Proceedings of the 2nd International Conference on Concrete Repair, Rehabilitation and Retrofitting, ICCRRR.

Aldea, C.M., W.J. Song and J.S. Popovics (2000). S.P. Shah, Extent of healing of cracked normal strength concrete, *J. Mater. Civ. Eng*., 12 (1): 92–96.

Balazs, A.C. (2007). Modeling self-healing materials, *Mater. Today.*, 10: 18–23.

Bang, S.S., J.K. Galinat and V. Ramakrishnan (2001), Calcite precipitation induced by polyurethane- immobilized Bacillus pasteurii. *Enzyme and Microbial Technology*, 28(4-5): 404-409.

Barton, L.L. and D.E. Northup (2011). Microbes at Work in Nature: Biomineralization and Microbial Weathering, in Microbial Ecology. *John Wiley & Sons, Inc.: Hoboken, NJ, USA*. p. 299-326.

Baumann, P., M. A. Clark, L. Baumann and A. H. Broadwell (1991). *Bacillus sphaericus* as a Mosquito Pathogen:Properties of the Organism and Its Toxins. *Microbiological Reviews*, 55: 425-436.

Bekas, D.G., K. Tsirka, D. Baltzis and A.S. Paipetis (2015), Self-healing materials: a review of advances in materials, evaluation, characterization and monitoring techniques, *Compos. B Eng*., 87: 92–119.

Belie, N.D. and W. Muynck (2008). Crack repair in concrete using biodeposition, in Concrete Repair, *Rehabilitation and Retrofitting II*., Cape Town, South Africa.

Biswasa, M., S.Majumdar, T.Chowdhury, B.Chattopadhyay, S.Mandal, U. Halder and S. Yamasaki (2010). Bioremediase a unique protein from a novel bacterium BKH1, ushering a new hope in concrete technology, *Enzyme and Microbial Technology*, 46: 581–587.

Boquet, E., A. Boronat and C.A. Ramos (1973). Production of calcite (calcium carbonate) crystals by soil bacteria is a general phenomenon. *Nature*, 246: 527–9.

Bou, G., J. L.Saleta, J. A.Sáez Nieto, M.Tomás, S. Valdezate, D. Sousa, F. Lueiro, R. Villanueva, M. J. Pereira and P. Llinares (2008). Nosocomial Outbreaks Caused by Leuconostocmesenteroidessubsp. mesenteroides, *Emerging Infectiouse Diseases*, 14(6): 968-971.

Buu-Hoi, A., C. Branger and F. J. Acar (1985). Vancomycin resistant Streptococci or *Leuconostoc* sp. *Antimicrob Agents Chemother*., 28: 458–60.

Cao, Q.Y., T.Y. Hao and B. Su (April 2014). Crack self-healing properties of concrete with adhesive. *Adv. Mater*., *Res*. 1880–1884, 919–921.

Cappitelli, F., L. Toniolo, A. Sansonetti, D. Gulotta, G. Ranalli, E. Zanardini and C. Sorlini (2007). Advantages of using microbial technology over traditional chemical technology in removal of black crusts from stone surfaces of historical monuments, *Appl. Environ. Microbiol*., 73(17): 5671–5675.

Clear, C.A. (1985). *Effects of autogenou healing upon the leakage of water through cracks in concrete in Technical Report*. Cement and Concrete Association.

Chunxiang, Q., Jianyun Wang and Ruixing Wang (2009), Corrosion protection of cement-based building materials by surface deposition of CaCO3 by *Bacillus pasteurii*. *Materials Science and Engineering C*, 29(4): 1273-1280.

Dhami, N., S. M. Reddy and A. Mukherjee (2012). Biofilm and microbial applications in biomineralized concrete. In: *Advanced Topics in Biomineralization,* (Ed. Jong Seto). InTech. Publisher, China. pp.137-164.

De Muynck, W., N. De Belie and W. Verstraete (2010). Microbial carbonate precipitation in construction materials: *A review. Ecological Engineering.*, 36(2): 118-136.

De Muynck, W., Dieter Debrouwer, Nele De Belie UGent and Willy Verstate (2008). Bacterial carbonate precipitation improves the durability of cementitious materials. *Cement and Concrete Research*, 38(7): 1005-1014.

Dong, B., N. Han, M. Zhang, X. Wang, H. Cui and F. Xing (2013). A microcapsule technology based self-healing system for concrete structures, *J. Earthquake Tsunami*., 07 (03).

Edvardsen, C. (1999). Water permeability and autogenous healing of cracks in concrete. *ACI Materials Journal*, 96(4): 448-454.

Elmoaty, A. and M.A. Elmoaty (2011). Self-healing of polymer modified concrete, *Alexandria Eng. J*., 50 (2): 171–178,

Erşan, Y.Ç., N.d. Belie and N. Boon (2015). Microbially induced $CaCO_3$ precipitation through denitrification: An optimization study in minimal nutrient environment. *Biochemical Engineering Journal*, 101: 108-118 .

Facklam, R. and J. A. Elliott (1995). Identification, classification, and clinical relevance of catalase-negative, gram-positive cocci, excluding Streptococci and Enterococci, *ClinMicrobiol Rev.,* 8: 479–95.

Feiteira, J., E. Gruyaert and N. De Belie (2014). Self-healing of dynamic concrete cracks using polymer precursors as encapsulated healing agents, *Concr. Solutions*, 65–69.

Granger, S. and A. Loukili (22-24 August 2005). Mechanical behavior of self-healed ultrahigh performance concrete: from experimental evidence to modeling, in: 3rd International Conference on Construction Materials: Performance, *Innovations and Structural Implications (ConMat'05), Vancouver, Canada*.

Hammes, F. and W. Verstraete (2002). Key roles of pH and calcium metabolism in microbial carbonate precipitation *Advanced Materials*, 22(47): 5424-5430.

Hammes F., N. Boon, J. de Villiers, W. Verstraete and S.D. Siciliano (2003). Strain-specific ureolytic microbial calcium carbonate precipitation. *Appl Environ Microbiol*., 69(7): 4901–9.

Hosoda, A., S. Komatsu, T. Ahn, T. Kishi, S. Ikeno and K. Kobayashi (2009). Self healing properties with various crack widths under continuous water leakage, Concrete Repair, *Rehabilitation & Retrofitting II.*, vol. 2, Taylor & Francis Group, pp. 221–228.

Huang, H., G. Ye and D. Damidot (2014). Effect of blast furnace slag on self-healing of microcracks in cementitious materials, *Cem. Concr. Res*., 60: 68–82.

Huang, H and G. Ye (2014). Self-healing of cracks in cement paste affected by additional Ca2+ ions in the healing agent, *J. Intell. Mater. Syst. Struct*., 26 (3): 309–320.

In, C-W., R.B. Holland, J.-Y. Kim, K.E. Kurtis, L.F. Kahn and L.J. Jacobs (2013). Monitoring and evaluation of self-healing in concrete using diffuse ultrasound, *NDT E Int*., 57: 36–44.

Jonkers, H.M., A. Thijssen, G. Muyzer, O. Copuroglu, and E. Schlangen (2010), Application of bacteria as self-healing agent for the development of sustainable concrete, *Ecol.Eng*., 36(2): 230–235.

Jonkers, H.M. and E. Schlangen (2009). A two component bacteria-based self-healing concrete. in Concrete Repair, *Rehabilitation and Retrofitting II* - Proceedings of the 2nd International Conference on Concrete Repair, Rehabilitation and Retrofitting, ICCRRR.

Jugnia, L.B., A.R. Cabral and C.W. Greer (2008). Biothic methane oxidation within an instrumented experimental landfill cover. *Ecol Eng*., 33: 102–9.

Kanellopoulos, A., T.S. Qureshi and A. Al-Tabbaa (2015). Glass encapsulated minerals for self-healing in cement based composites, *Constr. Build. Mater*., 98: 780–791.

Khaliq, W and M.B. Ehsan (2016). Crack healing in concrete using various bio influenced self-healing techniques, *Constr. Build. Mater*., 102: 349–357.

Kim, H.K., S.J. Park, J.I. Han and H. K. Lee (2013). Microbially mediated calcium carbonate precipitation on normal and lightweight concrete. *Construction and Building Materials*, 38: 1073-1082.

Le Métayer-Levrel, G., S. Castanier. G. Orial, J.-F. Loubière and J.-P. Perthuisot (1999). Applications of bacterial carbonatogenesis to the protection and regeneration of limestones in buildings and historic patrimony. *Sedimentary Geology*., 126(1-4): 25-34.

Lee, Y.N. (2003). Calcite Production by Bacillus amyloliquefaciens CMB01. *Journal of Microbiology*, 41(4): 345-348.

Li, W., Z. Jiang, Z. Yang, N. Zhao and W. Yuan (2013). Self-healing efficiency of cementitious materials containing microcapsules filled with healing adhesive: mechanical restoration and healing process monitored by water absorption, *PLoS One* 8(11): e81616.

Liu, B., J.L. Zhang, J.L. Ke, X. Deng, B.Q. Dong, N.X. Han and F. Xing (22-24 June, 2015). Trigger of self-healing process induced by EC encapsulated mineralization bacterium and healing efficiency in cement paste specimens, in: *5th International Conference on Self-Healing Materials*., pp. 1–4. Durham North Carolina's Bull City.

Luo, M., C. Qian and R. Li (2015). Factors affecting crack repairing capacity of bacteria based self-healing concrete, *Constr. Build. Mater*., 87: 1–7.

Luhar, S and S. Gourav (2015). A review paper on self healing concrete. *J. Civ. Eng. Res*., 5(3): 53–58.

Mann, S. (2001). Biomineralization, *Principles and concepts in bioinorganic materials chemistry*. 6th ed, New York: Oxford University Press.

Michael, J.J. (2014). Shewanella: a Marine Pathogen as an Emerging Cause of Human Disease. *Clinical Microbiology Newsletter*, 36(4): 25-29.

Mikkola, R., M. A. Andersson, P. Grigoriev, V. Teplova, N. E. L. Saris, F. A. Rainey and M. S. Salkinoja-Salonen (2004). *Bacillus amyloliquefaciens* strains isolated from moisture damaged buildings contained surfactin and a substance toxic to mammalian cells, *Archives of Microbiology*, 181: 314- 323.

Mitchell, A.C and F.G. Ferric (2006). The influence of Bacillus pasteurii on the nucleation and growth of calcium carbonate. *Geomicrobiol J*., 23(3&4): 213–26.

Mohanadoss, Ponraj, Amirreza Talaiekhozani, Rosli Mohamad Zin, Mohammad Ismail, Muhd Zaimi Abd Majid, Ali Keyvanfar and Hesam Kamyab (January 2015). Bioconcrete: Strength, Durability, Permeability, Recycling and Effects on Human Health: A Review; *Institute of Research Engineers and Doctors*., USA.

Mostavi, E., S. Asadi, M. Asce, M.M. Hassan and M. Alansari (2015), Evaluation of selfhealing mechanisms in concrete with double-walled sodium silicate microcapsules, *J. Mater. Civ. Eng*., 27 (12): 1–8.

Muhammad, N. Z., A. Shafaghat, A. Keyvanfar, M.Z.A. Majid, S. K. Ghoshal, S. E.M. Yasouj, ... and M.R. Shirdar (2016). Tests and methods of evaluating the self-healing efficiency of concrete: A review. *Construction and Building Materials*, 112: 1123-1132.

Narayanasamy, R., A. Alvarado, J.S. Medrano, J.B. Hernandez and N. Balagurusamy (2013)> Potential of Soil Bacteria From The Comarco Lagunera, North-East Mexico for Bioconcrete, *in Proceedings of the 4th International Conference on Self-Healing Materials*, Ghent, Belgium, p. 601–605.

Nosonovsky, M. and B. Bhushan (2008). Multiscale Dissipative Mechanisms and Hierarchical Surfaces: Friction, Super hydrophobicity and Biomimetics. *Springer-Verlag*., Heidelberg Germany.

Pacheco-Torgal, F. and J.A. Labrincha (2013). Biotech cementitious materials: Some aspects of an innovative approach for concrete with enhanced durability. *Construction and Building Materials*, 40: 1136-1141.

Park, S.J., Y.M. Parks, W.Y. Chun, W.Y. Kim and S.Y. Ghim (2010)> Calcite-forming bacteria for compressive strength improvement in mortar. *Journal of Microbiology and Biotechnology*, 20(4): 782-788.

Pang, B., Z. Zhogui, H. Pengkun, D. Peng, Z. Lina and X. Hongxin (2016). Autogenous and engineered healing mechanisms of carbonated steel slag aggregate in concrete, *Constr. Build. Mater*., 107: 191–202.

Qian, S.Z., J. Zhou and E. Schlangen (2010). Influence of curing condition and precracking time on the self-healing behavior of Engineered Cementitious Composites. *Cement and Concrete Composites*., 32(9): 686-693.

Qian, C.X., M. Luo, L.F. Ren, R.X. Wang, R.Y. Li, Q.F. Pan and H.C. Chen (October 2014). Self-healing and repairing concrete cracks based on bio-mineralization, *Key Eng. Mater*., 629–630, 494–503.

Rahman, A., M. Sam, N.F. Ariffin, M. Warid, H.S. Lee, M.A. Ismail and M. Samadi (2015). Performance of epoxy resin as self-healing agent, *Jurnal Teknologi*., 16: 9–13.

Ramm, W. and M. Biscoping (1998). Autogenous healing and reinforcement corrosion of water-penetrated separation cracks in reinforced concrete. *Nuclear Engineering and Design*., 179(2): 191-200.

Reinhardt, H.W. and M. Jooss (2003). Permeability and self-healing of cracked concrete as a function of temperature and crack width. *Cement and Concrete Research*, 33(7): 981-985.

Rivadeneyra, M.A., Rafael Delgado, Ana del Moral, Maria Rita Ferrer and Alberto Ramos-Cormenzana (1994). Precipatation of calcium carbonate by Vibrio spp. from an inland saltern. *FEMS Microbiology Ecology*., 13(3): 197-204.

Ramachandran, S.K., V. Ramakrishnan and S.S. Bang (2001). Remediation of concrete using micro-organisms. *ACI Materials Journal*, 98(1): 3-9.

Rowan, N. J., G. Caldow, C. G.Gemmell and I. S. Hunter (2003). Production of Diarrheal Enterotoxins and Other Potential Virulence Factors by Veterinary Isolates of *Bacillus* sp. associated with Nongastrointestinal Infections,"*Appl Environ Microbiol*., 69(4): 2372–2376.

Şahmaran, M. and B. Suleyman. Keskin (2008). Self-healing of mechanically-loaded self consolidating concretes with high volumes of fly ash. *Cement and Concrete Composites.*, 30(10): 872-879.

Samani, A.K. and M.M. Attard (2014). Lateral strain model for concrete under compression. *ACI Structural Journal*, 111(2): 441-451.

Sangadji, S., V. Wiktor, H. Jonkers and E. Schlangen (16-20 June,2013). Injecting a liquid bacteria based repair system to make porous network concrete healed, in: *4th International Conference on Self-Healing Materials*., pp.118–122.

Sarkar, M., T. Chowdhury, B. Chattopadhyay, R. Gachhui and S. Mandal (2014). Autonomous bioremediation of a microbial protein (bioremediase) in Pozzolana cementitious composite, *J. Mater. Sci*., 49 (13): 4461–4468.

Schultze-Lam S, D. Fortin, B.S. Davis and T.J. Beveridge (1996). Mineralization of bacterial surfaces. *Chem Geol*.,132: 171–81.

Siad, H., A. Alyousif, O.K. Keskin, S.B. Keskin, M. Lachemi, M. Sahmaran and K.M.A. Hossain (2015). Influence of limestone powder on mechanical, physical and selfhealing behavior of engineered cementitious composites, *Constr. Build. Mater*., 99: 1–10.

Siddique, R. and N.K. Chahal (2011). Effect of ureolytic bacteria on concrete properties, *Construction and Building Materials*, 25: 3791–3801.

Sierra-Beltran, M.G., H.M. Jonkers and E. Schlangen (2014). Characterization of sustainable bio-based mortar for concrete repair. *Construction and Building Materials.*, 2014. 67(PART C): 344-352.

Snoeck, D., K. Van Tittelboom, S. Steuperaert, P. Dubruel and N. De Belie (2014). Selfhealing cementitious materials by the combination of microfibres and superabsorbent polymers, *J. Intell. Mater. Syst. Struct*., 25 (1): 13–24.

Stevens, D.A., J. R.Hamilton, N.Johnson, K. K. Kim and J. S. Lee (2009). Halomonas, a newly recognized human pathogen causing infections and contamination in a dialysis center: three new species, *Medicine (Baltimore)*, 88(4): 244-249.

Stocks-Fischer, S. and J. K. Galinat (1999). Bang SS. Microbiological precipitation of $CaCO_3$.*Soil Biol Biochem*., 31(11): 1563–71.

Stuckrath, C., R. Serpell, L.M. Valenzuela and M. Lopez (2014). Quantification of chemical and biological calcium carbonate precipitation: performance of self-healing in reinforced mortar containing chemical admixtures. *Cement Concr. Compos*., 50: 10–15.

Suji, D. and A. Gandhimathi (2015). Studies on the development of eco-friendly selfhealing concrete a green building concept, *Nat. Environ. Pollut. Technol*., 14 (3): 639–644.

Talaiekhozan, A., A keyvanfar, A Shafaghat, R Andalib, M.Z.Majid, M.A Fulazzaky, M.Z Roshi, C.T Lee, M.W Hussin, N. Hamzah, N.F Marwar and H.I Haider (2013). A Review Of Self- Healing Concrete Reseach Development. *Jounal Of Environmental Treatment Techniques*, 2(1): 1-11.

Thomas, H. (2003). Groundwater quality and groundwater pollution. University of California Department of Agriculture and Natural Resources, *Publication 8084, FWQP reference sheet* 11: 2.

Talaiekhozani, A., A. Keyvanfar, R. Andalib, M. Samadi, A. Shafaghat, H. Kamya, M. Z. Majid, M. Z.Rosli, M. A.Fulazzaky, C. T. Lee and M. W. Hussin (2014). Application of Proteus mirabilis and Proteus vulgaris mixture to design self-healing concrete, *Desalination and Water Treatment*, 52: 3623–3630.

Van Tittelboom, K., *et al*., (2010).Use of bacteria to repair cracks in concrete. Cement and Concrete Research, 40(1): 157-166.

Warscheid, T. and J. Braams (2000). Biodeterioration of stone: a review. *International Biodeterioration & Biodegradation*, 46(4): 343-368.

Wiktor, V. and H.M. Jonkers (2011). Quantification of crack-healing in novel bacteria-based self-healing concrete. *Cement and Concrete Composites*, 33(7): 763-770.

Wiktor, V. and H.M. Jonkers (2015). Field performance of bacteria-based repair system:pilot study in a parking garage, *Case Stud. Constr. Mater*., 2: 11–17.

Worlitzsch, D.R.Tarran, M.Ulrich, U. Schwab, A. Cekici,K. C. Meyer, P. Birrer, G. Bellon, J. Berger, T.Weiss, K. Botzenhart, J. R. Yankaskas,S.Randell, R. C.Boucher and G. Döring (2002). Effects of reduced mucus oxygen concentration in airway Pseudomonas infections of cystic fibrosis patients, *J Clin Invest*., 109(3): 317–325.

Wu, M., B. Johannesson and M. Geiker (2012). A review: Self-healing in cementitious materials and engineered cementitious composite as a self-healing material. *Construction and Building Materials*, 28(1): 571-583.

Xu, J. and W. Yao (2014). Multiscale mechanical quantification of self-healing concrete incorporating non-ureolytic bacteria-based healing agent, *Cem. Concr. Res*., 64: 1–10.

Yıldırm, G., Ö.K. Keskin, S.B. Keskin, M. S ahmaran and M. Lachemi (2015). A review of intrinsic self-healing capability of engineered cementitious composites: recovery of transport and mechanical properties, *Constr. Build. Mater*., 101:10–21.

Yang, Y., E-H. Yang and V.C. Li (2011). Autogenous healing of engineered cementitious composites at early age, *Cem. Concr. Res*., 41 (2): 176–183.

(*Accepted for publication August 2018*)