International Journal of Civil and Structural Engineering– IJCSE
Volume 2 : Issue 2 *[ISSN : 2372-3971]*
Publication Date: 19 October, 2015

Bioconcrete Strength, Durability, Permeability, Recycling and Effects on Human Health: A Review

Mohanadoss Ponraj, Amirreza Talaiekhozani, Rosli Mohamad Zin, Mohammad Ismail, Muhd Zaimi Abd Majid*, Ali Keyvanfar, Hesam Kamyab

Abstract—**Concrete has become as one of the common material in the construction sector, which makes it of great interest to the researchers in pursuit for the production of concrete with better properties. This is mainly because the existing concrete has several limitations in terms of strength, ductility, durability and resistance to cracking. To overcome this problem with the use of bioconcrete, it can self-heal and also posses other value added features like high durability, increased strength and less water absorption capacity. Even though several studies to date have been focused on the development of bioconcrete but the aspects of advantage and disadvantages using bioconcrete has not been discussed so far. The objective of this study is to review the positive and negative impacts of bioconcrete application in the aspect of strength, durability, permeability, recycling and its effects on human health. A systematic review has been used to review some of the relevant and recently published works in this area. The diverse advantages has been mainly covered like; increasing the concrete durability, increasing the concrete strength, increasing of concrete permeability, and ability of biological concrete for recycling. The effect of biological concrete on human health as one of the main disadvantages using bioconcrete has also been covered. The findings of this paper can be considered significant for the stakeholders in the construction sector, as well as the engineers in gaining insight towards the potential use of biological concrete in the field of construction, considering both the merits and demerits of using biological concrete. As a conclusion, the research paper highlights several advantages and disadvantages of bioconcrete that helps to predict the future commercial application of bioconcrete in the construction industry.**

Keywords—**Biological concrete, Durability, Health hazard, Sustainability**

(Mohanadoss Ponraj, Rosli Mohamad Zin, Mohammad Ismail, Muhd Zaimi Abd Majid*, Ali Keyvanfar, Hesam Kamyab
Construction Research Center (CRC), Institute for Smart Infrastructure and Innovation Construction (ISIIC), Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, 81310 Johor Bahru, Malaysia
*Corresponding Author

(Amirreza Talaiekhozani)
Department of Civil Engineering, Jami Institute of Technology, Isfahan, Iran

I. Introduction

Cement is among one of the most commonly used materials for the construction of buildings worldwide and the demand for cement is increasing every year [1]. Therefore, a huge amount of concrete has been produced yearly to meet this demand. The production of concrete requires

The development of self-healing concrete technology has become one of the most important researcher's objectives in the field of civil engineering sciences and biotechnology in recent years [2-7]. In 1980s, only a few articles related to self-healing concrete can be found, and it wasn't until the late 1990's that some serious studies related to this area were established. The use of biological methods is the latest self-healing design methods.

The genus *Bacillus* has been mostly used for the biological development of calcium carbonate-based minerals as, which is considered to be as ureolytic bacteria. The formation of calcium carbonate using this type of bacteria is because of the hydrolysis of urea to carbon dioxide and ammonia. Although using microorganisms in concrete can usually increase its strength, durability and permeability, it may cause some negative impacts which have not been extensively studied such as the negative impact on psychological and physical condition of humanity. Therefore, the main challenge of this review paper is to find and compare the negative and positive impacts of biological concrete development in future. The main principle of this study is to review the possibilities of having the positive and negative impacts of bioconcrete application in the aspects of strength, durability, permeability, recycling and its effect on human health. This study can help researchers to conduct new research to find a solution for decreasing of negative impacts and increasing positive impacts of biological concrete to make it more trustworthy.

II. Positive impacts of biological concrete development

A. *Increasing the concrete durability*

Andalib et al., (2015) conducted a study for the assessment of durability improvement in several high strength bacterial structural concrete grades by using different type of acid [8]. The experimental results of Andalib et al., (2015) showed that biological concrete when compared to the ordinary Portland cement without microorganism has lost less weight and strength. It was also found that maximum weight loss and compressive strength occurred during the sulphuric acid immersion as compared to hydrochloric acid immersion. It was noticeable that lesser amount of chloride and sulphur were found in the bacterial concrete immersed in sulphuric acid and hydrochloric acid in comparison to Portland cement concrete because of the calcite deposition. The results of this study clearly show that using suitable bacteria in concrete can increase its durability and resistance even in the presence of strong acids such as sulphuric acid and hydrochloric acid [8].

Jacobsen and Sellevold (1996) in their study determined the self-healing of high strength concrete after its deterioration by thaw/freeze [9]. It was found that concrete which has lost 50% of its initial relative dynamic module during thaw/freeze and storage in water could recover completely, only with a slight variation in the degree of deterioration and concrete composition. The reduction rate of 22–29% was due to deterioration, whereas the noticeable recovery rate of self-healing was found to be 4–5%. The test of thaw/freeze carried out on deteriorated and self-healed specimens contained in a partly sealed condition showed that the deterioration rate was due to the ability of water uptake that leaked through plastic foil during the process which contributed to the increasing of deterioration. Self-healing is considered to be the important factor providing concrete better frost durability in the field when compared to the specimens that are subjected to thaw/freeze cycles in presence of water [9]. Wiktor and Jonkers (2011) during their study determined the potential of crack-healing using a novel self-healing agent that is being embedded in a porous clay particle that acted as reservoir which can replace the minor portion of regular concrete aggregate [10]. The self-healing agent consisting of bacterial spores and calcium lactate were released through the crack ingress water, whenever crack formation occurred. The bacterial induced formation of calcium carbonate helped in sealing of the micro cracks up to 0.46 mm-wide. Therefore, it was concluded this novel bio-chemical self-healing agent has a true potential towards increasing the durability of concrete structures existing in the wet environment [10].

Muyncka et al. (2008) in their study on determining the effects of bacterial carbonate precipitation for the durability of mortar specimens with different porosity decreased the water absorption rate was found to be decreased from 65% to 90% due to the deposition of calcium carbonate on surface. In consequence the rate of chloride migration and carbonation decreased up to 10–40% and 25–30% along with the increased résistance shown towards thawing and freezing and thawing. The results obtained were similar to conventional surface treatments [11].

B. Increasing the concrete strength

The use of aerobic microorganisms (*Pseudomonas aeruginosa* and *Bacillus pasteurii*), as self-healing agents have shown 18% improvement in the compressive strength of cement mortar [12-13]. Jonkers (2007) in his study has investigated the use of bacteria for the healing of cracks occurring in the concrete as self-healing agent [14]. DeMuynck et al. (2008) have shown that durability of cementitious materials can be improved along with the deposition of carbonate by *Bacillus sphaericus* as surface treatment [15, 11]. Ramachandran et al. (2001) reported the use of bacteria for enhancing the durability of concrete as to show resistance towards the alkali, freeze-thaw attack, sulfate, drying and shrinkage [12]. Achal et al., (2011) investigated the effects of *Bacillus* sp. CT-5 isolated from cement for determining the water-absorption test and compressive strength. The result showed that the compressive strength of cement mortar increased to 36 % with the addition of microbes and the treated cubes were found to absorb water six times lesser when compared to the control cubes due to the deposition of microbial calcite. This indicates that by using *Bacillus* sp. For the production of "microbial concrete" it can enhance the durability of construction materials [16].

Ghosh et al. (2005) described a method for improving the strength of cement–sand mortar with microbial induced mineral precipitation [17]. The increase in the compressive strength of cement mortar (25 %) at 28th day was observed with the addition of thermophilic and anaerobic bacteria, in the range of 10^5 cells/ml to the mixing water. The strength improvement was due to the growth of filler material within the pores of cement–sand matrix. Ghosh et al. (2005) used the bacteria *E. coli* in cement mortar to enable a better comparison, but from the improvement in strength that was actually observed [17] it is clearly evident that mostly in the internal cracks, not much oxygen exists. As a result only the use of anaerobic microorganisms can solve this problem.

Bacillus megaterium which produces calcite can improve the properties of ash brick (Rice hush and Fly ash bricks) as investigated by Dhamia et al. (2012)**.** A significant reduction in water absorption was noticed in the treated bricks along with the increasing compressive strength due to the deposition of calcite on the voids and surface of bricks. The extracellular deposition of calcite crystals on the surface of bricks are due to the microbial activity as seen from the scanning electron micrographs. These findings show that this technology has a better potential towards the development of eco-friendly and durable building blocks [18].

The effects on compressive strength are reported to be between 10 to 30 % when different types of bacteria are used by researchers as shown in Table I.

TABLE I. EFFECT OF DIFFERENT BACTERIA DETERMINING THE COMPRESSIVE STRENGTH AND WATER ABSORPTION OF CONCRETE

Bacteria species	**Compressive strength**	**Water absorption**	**References**

	at 28 days (%)		
Bacillus pasteurii	2.67	50 – 70% less than normal concrete	[19,20, 21]
Sporosarcina pasteurii	18	85% less than normal concrete	[16, 20, 22,23, 24]
Shewanella sp.	25-30	-	[16, 20, 25, 26]
Bacillus sphaericus	36	It can decrease water absorption	[15, 16]
Bacillus pseudofirmus	-10	-	[27]
Comarca Laguna	21.92	-	[28]
Escherichia coli	22-26	-	[17, 29]
Marine bacterium	15	-	[30]
Sporosarcina coli	3.8	-	[20]
Arthrobacter crystallopoietes	8.9	-	[20]
Lynsinibacillus fasiformis	4.5	-	[20]
Bacillus subtilis	15	-	[20, 24, 31]
Bacillus megaterium	24.2	46% less than normal concrete	[18]
Pseudomonas aeruginosa	< 2	-	[32]
Bacillus mycoides	17	-	[33]
Bacillus cereus	-	83% less than normal concrete	[32]
Bacillus sphaericus	-	50% less than normal concrete	[32]
Pseudomonas putida	-	1% less than normal concrete	[32]

C. Increasing of concrete permeability

The common phenomenon observed in concrete structure is the formation of crack. The resulting micro crack formation hardly affects the structural properties of construction but in due course it may reduce the durability of concrete structure and may pose a threat due to the risk of ingress of aggressive substances particularly in a wet environment. Specific healing agents can be incorporated in the concrete matrix in order to increase the often observed autonomous crack-healing potential of concrete. *Bacillus sphaericus* are used for designing biological self-healing concrete according to the findings of Tittelboom et al. (2010). It is reported that pure bacterial cultures alone are not able to bridge the cracks but when they are present in silica gel, the cracks become fully cured [34]. The increase in permeability after treating the specimens with Bacillus *sphaericus* is due to the filling of unavoidable of air bubbles present in the specimen.

The removal of organic matter, nitrate and sulphate on the surface of artworks have been investigated using microbes [35, 36]. Heselmeyer et al. (1991) studied the removal of gypsum crusts from marble using *Desulfovibrio vulgaris* [37], further the procedure was optimized by Ranalli et al. (1997) using a carrier material known as sepiolite for *Desulfovibrio desulfuricans* and *D. vulgaris* [38]. Cappitelli et al. (2006) carried out further improvements using Carbogel as delivery system for bacteria, which allowed the retention of more viable bacteria and also decreased the time needed for the entrapment of microorganisms when compared to sepiolite [39, 40]. Cappitelli et al. (2006, 2007) being the members of Biobrush consortium, it allowed the use of Carbogel in the field of biodeposition [39- 41], as these delivery systems were used to control the harmful side effects of bacteria on stone. The application of this method resulted in a limited change of capillary water uptake by the Portland stone. The bacteria isolated from stream in Somerset (UK) and from culture collection was screened for its ability to deposit calcite in a modified liquid and solid B4 medium as a measure of biodeposition, among which *Pseudomonas putida* was selected for further study, which had a low risk to human health in addition to its ability to precipitate calcite at a wide range of temperature [42]. It was found that bacteria when applied to stone by brushing and covered with moistened Japanese paper along with 1–1.5 cm thick layer of Carbogel prepared with modified B4, resulted in decreasing of water absorption and open porosity about 1% to 5%. Therefore, water absorption is one of the important parameters to be considered during the investigation of permeability.

D. Ability of biological concrete for recycling

Waste concrete aggregates (WCA) are used to prevent erosion as a ground-filling material and protective barrier. However, for using it in large-scale projects like making runways and rebuilding roads, the expenditure required for the removal of debris can be reduced with the use of WCA. In addition by establishing the center for using WCA located nearer to the site of aforementioned project, the expenditure involved in the production can be substantially reduced [43, 44]. Topcu and Sengel (2004) studied the freeze–thaw durability of concrete made from WCAs [45]. During the conduction of experiment with the hardened and fresh concrete possessing recycled concrete aggregates (30%, 50%, 70%, 100%) under freeze–thaw cycles show that C16-quality concrete can be made requiring less than 30% of C14-quality WCA. Interestingly it was found that weight, workability and durability of concrete made out of WCA was found to decrease in inverse proportion according to the thaw-freeze cycles [45].

Different methods of producing WCAs to be used as concrete aggregates include crushing and grinding and the expert opinion of those working in this area is that WCAs can be used in the form of proper aggregates [46]. When compared to normal concrete, WCAs posses more percentage of water absorption ratio, including higher percentage of crushing value and Los Angeles abrasion, but lower specific gravity. The percentage of mortar used in WCA obtained from crushed concrete of destroyed structures were determined using a linear traverse method. As a conclusion WCA containing mortar (40%) would certainly affect the properties of WCAs like creep, shrinkage and elasticity [47]. In order to increase the efficiency of WCAs in concrete, more amount of water has to be added [48]. However, it is inevitable, based on the proportion of added water, not only the ration of cement will increase but at the same time it will be desirable to obtain finer aggregate particles for having a proper workability [49-50]. It was pointed out by Ravindrarajah and Tam (1985) have reported the existence of similarity between the workability of normal concrete and the concrete made out of WCA [51]. It was also found that newly produced concrete consisted of higher fresh unit weight, because of the presence of mortar with low density in the wasted concrete. It was also noticed that the mechanical properties of concrete with WCAs are lower, when compared to normal concrete aggregate. The flexural strength of concrete with WCAs was found to be F15%, when compared to normal concrete. It is also reported that the freeze–thaw cycles of concrete made up of WCAs in the presence of air content are less durable [52]. It was also found that thaw-freeze durability of concrete produced from fine materials of WCAs are higher when compared to concrete made up of normal sand. It is reported that by using 14% to 28% of fly ash the compressive strength of recycled concrete approaching the 28th day decreased from 38.85 to 35.5 MPa resulting in a 9% reduction and for the natural concrete it decreased from 38.08 to 34.14 MPa with a reduction of 11 % [15]. It was observed that the flexural strength of concrete produced from WCAs is directly proportional to the w/c ratio [53]. It was shown that depending on the type of mixture and curing period, the increase in the quantity of WCA will result in the decreasing of the durability of concrete that is made out of WCA [54] and there was a slight decrease in the fresh unit weight of concrete [55]. A similar type of result was obtained by Sagoe-Crentsil et al. (2001) [56] in terms of reduced fresh unit weight value as that of Hansen and Narud [57]. It was reported that the durability of concrete made out of WCAs is lower than normal concrete and it is also noted that along with the addition of WCAs into the new concrete, its durability was found to decrease identically.

III. Negative impacts of biological concrete development

The advantages and disadvantages as reviewed in this study are summarized in Table II. Also, the negative impacts on the physical and psychological condition of humans are being considered. In this paper, the pros and cons of bacterial concrete are shown in order to make it easier for the reader to make a decision whether or not to use bio-concrete since it consists of microorganisms. However, in a general point of view, bacterial concrete can provide a more positive effect when compared to the negative ones.

.

TABLE II. COMPARISON OF THE MERITS AND DEMERITS OF USING BIOLOGICAL CONCRETE

Advantages	References	Disadvantages	References
Significant increase in terms of compressive strength and concrete stiffness with effect of the bacterial concrete for the remediation of crack	[28, 30, 58, 59, 60, 61, 62].	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.	[28, 59, 63, 64, 65]
Good resistance is shown towards the freeze and thaw attack due to the bacterial chemical process.	[27, 41]	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.	[59, 67, 68]
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.	[30, 61, 63, 64, 65]	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.	[1, 59, 67]
The effect of bacterial usage in concrete can reduce the process of	[59, 64, 66, 70, 71]	The methods to investigate involving the studies related to calcite precipitation are always costly	[30, 59, 63, 64, 67, 69].

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	because it involves techniques like Scanning Electron Microscopy (SEM) which is costly and requires a skilled personnel to run the tests.

The reporting frequency obtained for the reviewed articles pertaining to the advantages and disadvantages of using bioconcrete is shown in Table III, whereas Table IV. shows the advantages and disadvantages mediated with the direct addition of bacteria or its spore into the bioconcrete.

A. Effect of biological concrete on human health

1) Negative impact on the psychological condition of humans

Our survey shows that there is little information about the tendency of people to stay in a house or office made up of biological concrete which has self-healing property. The only study in this area is in related to the study carried out by Talaiekhozani and Ponraj (2015). They have provided a questionnaire and it was distributed among the students and lecturers of Universiti Teknologi Malaysia as to understand the viewpoint of people in terms of staying in a house or office made of biological concrete. Analysis of the filled questionnaire showed that 81% of people would like to stay in a house or office made up biological concrete and 19% would not.

TABLE III. REPORTING FREQUENCY OF REVIEWED ARTICLES PERTAINING TO THE ADVANTAGES AND DISADVANTAGES OF USING BIO-CONCRETE

Ref.	Advantages of using bioconcrete				Disadvantages of using bioconcrete		
	A1	A2	A3	A4	D1	D2	D3
58	√						
30	√		√		√		
60	√						
28	√						
61	√		√				
62	√						
41		√					
27		√					
63			√	√	√	√	
64			√		√	√	
65			√				
59	√			√	√	√	√
66				√			
70				√			
71				√			
65					√	√	
28					√	√	
67					√		√
69					√		
68						√	√
RF	7	2	5	5	8	6	3

√ refers to the aspect of advantage or disadvantage
RF: Reporting frequency
A1: Compressive strength improvement
A2: Resistance against freeze and thaw
A3: Permeability improvement
A4: Reducing of corrosion
D1: High cost of biological concrete
D2: Negative effect on human health
D3: Lack of standard method for preparation of biological concrete

TABLE VI. ADVANTAGES AND DISADVANTAGES OF DIRECT ADDITION OF MICROORGANISMS OR ITS SPORE TO BIOLOGICAL CONCRETE

Methods	Disadvantages	Advantages	References
Addition of encapsulated microorganisms or its spore directly to the concrete	(1) Expensive method (2) complex procedure to prepare encapsulated microorganisms (3) cannot heal the crack that is propagated frequently at the same place	(1) High life time of microorganisms or their spores (2) Less effect on durability (3) strength and permeability (4) high biological concrete workability	[1]
Addition of attached microorganisms or their spores to the activated carbon or silica gel	(1) Decreasing of concrete strength (2) durability and permeability (3) Lesser protection for the microorganisms or their spores	(1) Inexpensive (2) not complex (3) higher biological concrete workability (4) partially can heal a crack that is frequently occurring at the same place	[1, 72]
Circulation of microorganisms in the micro vessels throughout the concrete	(1) Very complex (2) Very expensive (3) Low biological concrete workability (4) No information about its effect on concrete strength.	(1) Able to repair a crack occurring at the same place (2) Highly durable (3) can heal a crack that is frequently occurring in the same place	[1, 58]
Addition of microorganisms or their spores into the hollow pipettes	(1) Complete information about its effects on concrete strength is not available (2) expensive (3) complex (4) cannot heal a	(1) Higher lifetime of microorganisms or their spores (2) high biological concrete	[1, 58, 72]

	crack that is occurring frequently at the same place	workability	
Addition of microorganisms or their spores directly to the concrete	(1) Presence of low microorganisms or reduces the lifetime of spores (2) cannot heal a crack that is propagated frequently at the same place	(1) Not effective on strength (2) not expensive (3) Noncomplex (4) high biological concrete workability	[1]

However, 38% of participants in this part of the study believe that staying in a house or office made of biological concrete can cause illness. Approximately 76% of people would like to recommend others to stay in this kind of house or office and 24% would not. Opposition against the recommendation of biological concrete to others can be due to lack of clear information about safety issues of using biological concrete. The life time of humans is shorter than concrete structures. Therefore, people hesitate to pay more money for using biological concrete in their office or house. Although biological concrete is not of significant importance to people, it can be very important for those who are thinking about huge construction projects such as dams, bridges, tunnels, etc. As children are more sensitive than adults 67% of participants in this study believe that biological concrete in houses will affect their children's health. It should be noted that 25% of participants in this study were expert in biological concrete technology and 75% had no information about that.

2) Negative impact on physical health

Many of the applied bacteria in designing of self-healing concrete are important in medical sciences; therefore, having knowledge about them is very important. In some bacteria the release of ureases play an important role in the determination of pathogenesis of human and animals in causing diseases like the *Proteus mirabilis*. *Bacillus pasteurii* is an ureolytic, non-pathogenic bacteria which is widely being used for designing biological concrete [59]. As this microorganism is harmless to humans, it can be the best choice for designing biological concrete. In Table V. all the types of bacteria that are involved in designing biological concrete and the related illnesses that can be produced are mentioned.

TABLE V. TYPES OF BACTERIA INVOLVED IN THE DESIGNING OF BIOLOGICAL CONCRETE AND ITS RELATED DISEASE TO HUMANS

Application of bacteria in biological concrete	Disease caused by the bacteria	Aerobic or anaerobic organism	References
Sporosarcina pasteurii (or *Bacillus pasteurii*)	non-pathogenic	Aerobic	[73]
Leuconostoc mesenteroides	It can affect the immuno compromised patients	Anaerobic	[60]
Bacillus amyloliquefaciens	Respiratory tract infection and nervous illness	Aerobic	[61]
Shewanella species	Gastro intestinal infections	Aerobic and Facultative Anaerobic	[62]
Pseudomonas aeruginosa	It can infect the damaged tissues or those with reduced immunity	Aerobic	[63]
Escherichia coli	Urinary tract infections	Aerobic	[64]
Acinetobacter species	It can cause a wide range of diseases, ranging from pneumonia to blood or wound infections.	Aerobic	[65]
Bacillus lentus	Non-pathogenic	Aerobic	[66]
Bacillus sphaericus	Non-pathogenic	Aerobic	[70]
Deleyahalophila	Bactremia in dailysis patient	Anaerobic	[71]
Myxococcus xanthus	Non-pathogenic	Aerobic	[67]
Bacillus megaterium	It is not generally associated with infection, although immuno-suppressed persons are easily susceptible to any type of infection	Aerobic	[74]
Proteus vulgaris	Causes wound and urinary tract infections	Facultative anaerobic	[58]
Proteus mirabilis	Urinary tract infections and the formation of stones.	Facultative anaerobic	[58, 64]

B. *Other disadvantages*

As it is predicted that the lifespan of biological concrete is longer than conventional concrete [1, 58, 72], it may cause a decrease in the demand for cement in the near future and will decrease the manpower requirement or job opportunities related to cement industries. On the other hand, using biological cement can create new job opportunities for experts in this area. Unfortunately, until now there have been no related articles which are concerned with this subject, or articles which highlight these issues and this creates a gap for new researchers working in this field to explore.

As biological concrete is relatively a much younger field of study there is no conclusive idea related to the lifetime of biological concrete. Based on the opinion of many researchers, lifetime of biological concrete for actual use should be longer than conventional concrete [1, 58,72]. Based on the case study report, the cost of concrete (80 €/m^3) with self-healing property would increase by up to 7–28%, depending on the type and amount of healing agents that are being added to the concrete. However, in the cost required for the later repair works and maintenance can be largely reduced [75].

IV. Conclusion

Currently, biological methods have gained the attention of most researchers in designing self-healing concrete. It is found that the use of biological methods to design self-healing concrete can have a positive effect on the durability, strengthening and permeability of concrete. Some of the bacterial strains that are used in developing self-healing concrete such as *Pseudomonas aeruginosa* are undoubtedly pathogen and cannot be directly applied in building structures like houses and offices because of health concerns. On the other hand, strains like *Bacillus pasteurii*, *Bacillus sphaericus* and *Bacillus lentus* have higher ability for the precipitation of calcium carbonate and have been categorized as saprophytes, which makes them as ideal strains for the designing of self-healing concrete. However, many people believe that staying in an environment made of biological concrete may not be safe in terms of physiological. To overcome these problems it can be predicted that in the near future by obtaining more valuable information about biological concretes and its benefits, opinions of people will be changed to overcome the disadvantages and to move towards using bioconcrete by taking into consideration its several advantages.

Acknowledgment

The authors would like to thank for the financial support received from Malaysian Ministry of Science, Technology and Innovation (MOSTI), University Teknologi Malaysia (UTM) under Vote No. 4S042 to carry out this work successfully.

References

[1] A. Talaiekhozan, A.Keyvanfar, A.Shafaghat, R. Andalib, M.Z. Majid, M. A.Fulazzaky, M. Z. Rosli, C. T. Lee, M. W. Hussin, N. Hamzah, N. F. Marwar, H. I. Haidar,"A Review of Self-healing Concrete Research Development," Journal of Environmental Treatment Techniques, 2(1), 1-11,2014.

[2] A. C. Balazs,"Modeling self-healing materials," Mater. Today., 10, 18–23, 2007.

[3] S. Vander-Zwaag (Ed.),Self Healing Materials–an Alternative Approach to 20 Centuries of Materials Science. Springer, Dordrecht, The Netherlands, 2007.

[4] R. P. Wool, "Self-healing, Materials: a review," Soft Matter., 4, 400–418, 2008.

[5] M. Nosonovsky, B. Bhushan,Multiscale Dissipative Mechanisms and Hierarchical Surfaces: Friction, Super hydrophobicity and Biomimetics. Springer-Verlag, Heidelberg, Germany, 2008.

[6] M. Nosonovsky, B. Bhushan,"Thermodynamics of surface degradation, self-organization, and self-healing for biomimetic surfaces," Phil. Trans. R. Soc. A., 367, 1607–1627, 2009.

[7] Koch K., Bhushan B., Ensikat H. J., Barthlott W.,"Self-healing of voids in the wax coating on plant surfaces," Phil. Transact. A Math. Phys. Eng. Sci., 367, 1673-1688, 2009.

[8] R. Andalib, M. Z. Majid, A. Keyvanfar, A. Talaiekhozan,"Durability improvement assessment in different high strength bacterial structural concrete grades against different types of acids," Sadhana,1-14, 2015.

[9] S. Jacobsen, E. J. Sellevold,"Self-healing of high strength concrete after deterioration by freeze/thaw," J. CementConcrete Res., 26:55–62, 1996.

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

[11] De MuynckW., DebrouwerD., De BelieN., VerstraeteW., "Bacterial carbonate precipitation improves the durability of cementitious materials," Cement Concrete Res., 38:1005–1014, 2008.

[12] S. K. Ramachandran, V. Ramakrishnan, S. S. Bang,"Remediation of concrete using micro-organisms," ACI Mater. J., 98, 3–9, 2001.

[13] V. Ramakrishnan, S. S. Bang, K. S. Deo,"A novel technique for repairing cracks" in "high performance concrete using bacteria, Proc. Int. Conf. on High Performance High Strength Concrete." Perth, Australia, p.p597–618, 1998.

[14] H. Jonkers,"Self-healing concrete: A biological approach."Self-healing materials: An alternative approach to 20 centuries of materials science," S. van der Zwaag, ed., Springer, Netherlands, p.p195–204, 2007.

[15] W. De Muynck, K. Cox, N. De Belie, W. Verstraete,"Bacterial carbonate precipitation as an alternative surface treatment for concrete," Constr. Build. Mater.,22, 875–885, 2008.

[16] V. Achal, A. Mukherjee, M. S. Reddy,"Microbial Concrete: Way to Enhance the Durability of Building Structures," Journal of Materials in Civil Engineering. 23:730-734, 2011.

[17] P. Ghosh, S. Mandal, B. D. Chattopadhyay, S. Pal,"Use of microorganism to improve the strength of cement mortar," Cement and Concrete Research. 35:1980–1983, 2005.

[18] Dhamia N. K., Reddy M. S., Mukherjee A., Improvement in strength properties of ash bricks by bacterial calcite, Ecological Engineering. 39, 31–35, 2012.

[19] S. S. Bang, J. K. Galinat, V. Ramakrishnan,"Calcite precipitation induced by polyurethane-immobilized *Bacillus pasteurii*," Enzyme Microb. Technol., 28: 404–409, 2001.

[20] Y. Park, W. Chun, W. Kim, and S. Ghim,"Calcite-Forming Bacteria for Compressive Strength Improvement in Mortar," J. Microbiol. Biotechnol., 20, 782–788, 2010.

[21] C. Qian, J. Wang, R. Wang, L. Cheng,"Corrosion protection of cement-based building materials by surface deposition of $CaCO_3$ by *Bacillus pasteurii*," Mater.Sci.Eng. C., 29(4), 1273–80, 2009.

[22] B. Topc,“Properties of concretes produced with waste concrete aggregate,” Cem. Concr. Compos., 34, 1307–1312, 2004.

[23] R. Chidara, R. Nagulagama, S. Yadav, “Achievement of Early Compressive Strength in Concrete Using *Sporosarcina pasteurii* Bacteria as an Admixture,” Adv. Civ. Eng., 2014, 1-7, 2014.

[24] R. Pei, J. Liu, S. Wang, and M. Yang,“Use of bacterial cell walls to improve the mechanical performance of concrete,”Cem. Concr. Compos., 39, 122–130, 2013.

[25] S.Ghosh, M.Biswas, B. D.Chattopadhyay, andS. Mandal, “Microbial activity on the microstructure of bacteria modified mortar,” Cem. Concr. Compos., 31 (2), 93–98, 2009.

[26] N. R. Iyer,“An overview of techniques based on biomimetics for sustainable development of concrete,” Curr. Sci., 101, 741-741, 2011.

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

[28] Narayanasamy R., Alvarado A., Medrano J. S., Hernandez J. B., and Balagurusamy N.,“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, pp. 601–605, 2013.

[29] P. Ghosh,S. Mandal, “Development of bioconcrete material using an enrichment culture of novel thermophilic anaerobic bacteria,” Indian J. Exp. Biol., 44: 336–339, 2006.

[30] K. P.Kota,R. K. Kota, J. B. Dulla, and A. P. Karlapudi,“Bioconcrete Enhancement from Biofilm Producing Marine Bacterium,” Int. J. Pharm. Sci. Rev. Res., 25(52), 276–279, 2014.

[31] I. I. Muhammad, H. Afifudin, S. H. Mohd, “*Bacillus Subtilis* and *Thermus Thermophilus* Derived Bioconcrete in Enhancing Concrete Compressive,” Int. Sustain. Civ. Eng. J., 1(1), 48–56, 2012.

[32] W. De Muynck, N. De Belie, W. Verstraete, “Microbial carbonate precipitation in construction materials: A review,”Ecol. Eng., 36(2),118–136, 2010.

[33] N. K. Dhami, A. Mukherjee, M. S. Reddy,“Biofilm and Microbial Applications in Biomineralized Concrete, in Advanced Topics in Biomineralization,”ed Jong Seto, editor (New York, NY: In Tech;), p.p 137–164, 2012.

[34] K. V. Tittelboom,N. De Belie, W. De Muynck, W. Verstraete,“Use of bacteria to repair cracks in concrete,” Cement and Concrete Research. 40, 157–166, 2010.

[35] K. L. Gauri, L. Parks,J. Jaynes, R. Atlas,“Removal of sulphated crust from marble using sulphate-reducing bacteria.”in Robin, G.M. (Ed.), Stone Cleaning and the Nature, Soiling and Decay Mechanisms of Stone. Proceedings of the International conference.” Donhead Publishing Ltd., Edinburgh, United Kingdom, p.p 160–165, 1992.

[36] G.Ranalli, M.Matteini, I. Tosini, E. Zanardini, C. Sorlini,“Bioremediation of cultural heritage: removal of sulphates, nitrates and organic substances.” In: Ciferri O, Tiano P, Mastromei G (Eds.), Proc. of International Conference on Microbiology and Conservation Of Microbes and Art: The Role of Microbial Communities on the Degradation and Protection of Cultural Heritage, Florence, Italy, pp. 231–245, 1999.

[37] K. Heselmeyer, U. Fisher, K. E. Krumbein, T. Warscheid,“Application of *Desulfovibrio vulgaris* for the bioconversion of rock gypsum crusts into calcite,” Bioforum, 1/2, 89, 1991.

[38] G. Ranalli, M. Chiavarini,V.Guidetti, F. Marsala, M. Matteini, E. Zanardini, C. Sorlini,“The use of micro-organisms for the removal of sulphates on artistic stoneworks,” Int. Biodeterior. Biodegrad., 40(2–4), 255–261, 1997.

[39] F. Cappitelli, E. Zanardini, G. Ranalli,E.Mello, D. Daffonchio, C. Sorlini, “Improved methodology for bioremoval of black crusts on historical stone art-works by use of sulfate-reducing bacteria,” Appl. Environ. Microbiol., 72 (5), 3733–3737, 2006.

[40] M. I. Carretero, J. M. Bernabé, E. Galan,“Application of sepiolite-cellulose pastes for the removal of salts from building stones,” Appl. Clay Sci., 33, 43–51, 2006.

[41] F. Cappitelli, L. Toniolo, A. Sansonetti, D. Gulotta, G. Ranalli, E. Zanardini, C. Sorlini,“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, 2007.

[42] E. May, “Biobrush research monograph: novel approaches to conserve our European heritage,” EVK4-CT-2001-00055, 2005.

[43] A. D. Buck,“Recycled concrete,” Highw. Res. Rec. 430, Highway Re-search Board, pp. 1–8, 1973.

[44] Buck A. D.,“Recycled concrete as a source of aggregate,” ACI J. Proc., 74(5), 212–219, 1977.

[45] I. B. Topcu, S. Sengel,“Properties of concretes produced with waste concrete aggregate,” Cement and Concrete Research, 34, 1307–1312, 2004.

[46] S. Sengel,“Using waste concrete as aggregate,” BS thesis, Anadolu University, Faculty of Engineering and Architectural, Department of Civil Engineering. In Turkish, 1992.

[47] S. Sengel,“Strength and freezing durability of concretes using in waste concrete as aggregate,” X. Engineering Symposium, Civil Engineering ,Su¨leymanDemirel University, Isparta, Turkey, pp. 343–350. In Turkish, 1999.

[48] D. J. Witcher,“Recycling concrete pavement: Out with the old-in with the old,”Concr. Int. Des. Constr., 6 (7) 32–33, 1984.

[49] S. W. Forster,“Recycled concrete as aggregate,”Concr. Int. Des. Constr., 8(1),34–40, 1986.

[50] S. Frondistou-Yannas,“Waste concrete as aggregate for new concrete,” ACI J. Proc., 74(8), 373–376, 1977.

[51] R. S. Ravindrarajah, C. T. Tam,“Properties of concrete made with crushed concrete as coarse aggregate,” Mag. Concr. Res., 37(130), 29–38, 1985.

[52] N. Chahal, R. Siddique, A. Rajor,“Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete,” Constr. Build. Mater., 28(1), 351–356, 2012.

[53] M. Tavakoli, P. Soroushian,“Strengths of recycled aggregate concrete made using field-demolished concrete as aggregate,” J. ACI Mater., 93(2), 182–190, 1996.

[54] F. T. Olorunsogo, N. Padayachee, “Performance of recycled aggregate concrete monitored by durability indexes,”Cem. Concr. Res., 32 (2): 179–185, 2002.

[55] J. M. V. Gomez-Soberon,“Porosity of recycled concrete with substitution of recycled concrete aggregate,”Cem. Concr. Res., 32(8), 1301–1311, 2002.

[56] K. K. Sagoe-Crentsil, T. Brown, A. H. Taylor,“Performance of concrete made with commercially produced coarse recycled concrete aggregate,”Cem. Concr. Res., 31(5), 707–712, 2001.

[57] T. C. Hansen, H. Narud,“Strength of recycled concrete made from crushed concrete coarse aggregate,” Concr. Int. Des. Constr., 5(1),79–83, 1983.

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

[59] N.Ranganathan, A.Macherone, B.Patel, R. Mehta, J. Marczely, J. Dickstein,Urea Hydrolysis And Ammonia Uptake by *Bacillus Pasteurii*, Kibow Biotech, Inc. Philadelphia, USA., 10th International Congress on Nutrition and Metabolism in Renal Disease - poster #P-19, 2012.

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

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

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

[63] D.Worlitzsch, 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, "Effects of reduced mucus oxygen concentration in airway *Pseudomonas* infections of cystic fibrosis patients," J Clin Invest., 109(3):317–325, 2002.

[64] *Proteus mirabilis*, online resource, last accessed on 12/31/2014, http://web.uconn.edu/mcbstaff/graf/Student%20presentations/Proteus/Proteus.html, 2014.

[65] Healthcare-associated Infections (HAIs), *Acinetobacter* in Healthcare Settings, last accessed on 12/31/2014, http://www.cdc.gov/HAI/organisms/acinetobacter.html,2014.

[66] N. J. Rowan, G. Caldow, C. G.Gemmell, I. S. Hunter,"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, 2003.

[67] C.Jimenez-Lopez, F.Jroundi, M.Rodríguez-Gallego, J. M. Arias, and M. T.Gonzalez- Muñoz,"Biomineralization induced by Myxobacteria, Communicating Current Research and Educational Topics and Trends in Applied Microbiology." A. Mendez-Vilas(Ed),pp. 143-154, 2007.

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

[69] A. Buu-Hoi, C. Branger, F. J. Acar,"Vancomycin-resistant Streptococci or *Leuconostoc* sp.," Antimicrob Agents Chemother., 28:458–60, 1985.

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

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

[72] A. Talaiekhozan, M. A.Fulazzaky,A.Keyvanfar, R.Andalib, M.Z.Majid, M. Ponraj, M. Z. Rosli, C. T. Lee, ShafaghatA., M. W. Hussin,"Identification of Gaps to Conduct a Study on Biological Self-healing Concrete," Journal of Environmental Treatment Techniques, 1(2), 62-68, 2013.

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

[74] HealthTap, https://www.healthtap.com/user_questions/357551 - lastaccessed on 12/31/2014.

[75] J.Wang, K. V.Tittelboom, N.De Belie, W.Verstraete,"Use of silica gel or polyurethane immobilized bacteria for self-healing concrete," Construction and Building Materials. 26, 532–540, 2012.