Pertanika J. Sci. & Technol. 25 (S): 259 - 264 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

An Overview of Bacterial Concrete on Concrete Durability in Aggressive Environment

JM. Irwan* and T. Teddy

Jamilus Research Centre for Susitainable Construction (JRC), Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

ABSTRACT

Concrete durability determines service life of structures. It can though, be weakened by aggressive environmental conditions. For instance, bio-corrosion process is due to the presence and activity of microorganisms which produce sulphuric acid to form sulphate deterioration of concrete materials. The problems related to durability and repair systems are due to lack of suitable concrete materials. The use bacteria for concrete repairing and plugging of pores and cracking in concrete has been recently explored. Previous studies had proved the possibility of using specific bacteria via bio concrete as a sustainable method for improving concrete properties. Thus, lack of information on the application of bio concrete exposed to extreme condition was the motivation for this research.

Keywords: Bacteria concrete, bio-concrete, concrete properties, durability, sea water

INTRODUCTION

Concrete is the material of choice for the construction of structures that are exposed to extreme conditions such as those located near the sea as well as exposed to sulphates and chlorides. Concrete durability affects the service life of concrete structures significantly. The presence of steel reinforced bars in any structure exerts pressure arising from corrosion.

A typical problem in many concrete constructions is crack formation. Most cracks hamper structural integrity of the structures and give rise to durability problems and increase matrix permeability (Jonkers, 2012). Bio-concrete can solve durability problems using technology bacteria in order to seal cracks (Irwan et al., 2016). However, not all bacteria are able to tolerate extreme conditions (Ramachandran et al., 2001). This

ARTICLE INFO

Article history:
Received: 29 September 2016
Accepted: 05 April 2017

E-mail addresses:
hf140033@siswa.uthm.edu.my (T. Teddy),
irwan@uthm.edu.my (JM. Irwan)
*Corresponding Author

ISSN: 0128-7680

development has witnessed the use of certain bacteria which has the capability to grow in environments that are alkaline and without oxygen (Irwan et al., 2014).

Durability Concrete on Aggressive Environment

Concrete durability is known as the ability of concrete to resist changes caused by environmental and chemical degradation. Factors affecting durability include material composition, proportioning, interactions, placing and curing procedures and the working environment. Therefore, different types of concrete require different degrees of durability.

According to Niyazi et al. (2016), cement paste which is too dense, low permeability and an environmental exposure like freeze-thaw-cycles are the major factors that influence durability of the concrete structure. Generally, fluctuations in concrete temperature and moisture do not affect the structure. However, alkali-aggregate reaction, sulphate attack, freeze-thaw cycles and reinforcement corrosion can adversely affect durability of structure. These factors may occur individually or simultaneously which lead to expansion and development of cracks in concrete.

The risk of corrosion is higher when concrete structures are exposed to an aggressive environment (seawater) or de-icing salts (as depicted in Figure 1). Corrosion is the single most prevalent factor causing deterioration of reinforced concrete structures. Findings of earlier studies indicate that corrosion is the main factor weakening steel bar in the reinforced concrete structure (Basheer, 1996). Environmental damages that lead to structural corrosion are caused by chemicals, sulphates, chlorides and coastal salts (Choi et al., 2015). The most significant corrosive constituents in coastal salts are sodium chloride, calcium chloride, and magnesium chloride, which are the same salts (chlorides) used for de-icing.

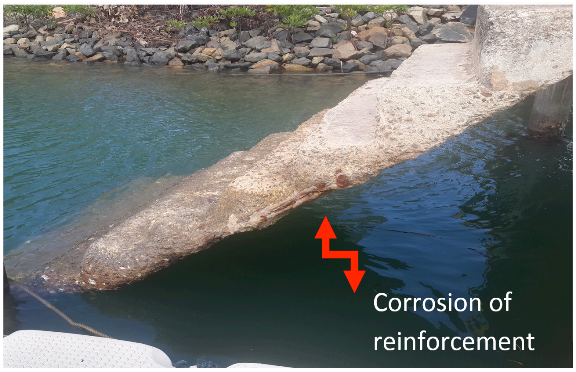

Figure 1. Failure of concrete due to structural corrosion as a result of aggressive environment (seawater) or de-icing salts (a case in one of the island)

Corrosion of reinforcement has been established as the principal factor causing widespread premature deterioration of concrete, especially structures located along the coast. The most important causes of corrosion initiation of reinforcing steel are chloride ions ingression and carbon dioxide exposure to steel surface. Corrosion initiation is triggered by iron oxides and hydroxides that are usually deposited in the restricted spaces in the concrete around the steel

(Song et al., 2007). Corrosion is an electro-chemical process with the basic mechanism at different areas of the same steel bar (anode and cathode). At the anode, steel releases ferrous ions (Kim & Ann, 2010). In contrast with the cathode, water in the presence of oxygen releases hydroxyl ions which increase alkalinity of the concrete (Broomfield, 1997).

The sulphate attack is a result of formation of gypsum (calcium sulphate) which in turn is due to specific reaction (Coppola et al., 1996). Sulphate ion from ground or seawater reacts with lime released during hydration process of portland cement and in the presence of calcium aluminate (Collepardi, 2003). This results in the formation of sulphate compounds that occupy greater volume than the original concrete components causing expansion and eventual concrete deterioration.

Bacterial Concrete

Bacteria is relatively simple, single-celled (unicellular) organisms. It can live and grow in organic matter and in plants and animals (Siddique, 2011).

The microbial precipitation of $CaCO_3$ is determined by several factors including: concentration of dissolved inorganic carbon, pH, concentration of calcium ions and presence of nucleation sites (Tittelboom et al., 2010). Certain groups of bacteria have ability to precipitate calcium carbonate. Studies on bio-concrete have examined *Bacillus cohnii* to precipitate $CaCO_3$ and *Bacillus sphaericus* to heal cracks in concrete (Wang et al., 2012). Meanwhile, Ramachandran et al. (2001) used different species of bacteria, *Bacillus pasteuri*, to precipitate calcium carbonate ($CaCO_3$).

Therefore, there are possibilities that other bacteria strain can survive in extreme conditions. Consequently, a sulphate reduction bacteria (SRB) that heal micro-cracks (Irwan et al., 2016) show a potential for use in aggressive environments.

Literature on Bio-Concrete

Concrete is mixtures of aggregate, cement, water and often chemical admixtures. Chemical and physical agents can attack the inert filler. The mineralogy of aggregate also plays a role in the chemical stability of hydrated cement paste, which ultimately leads to failure (Wiktor et al., 2011). The concrete structures have a certain capacity for autonomous healing of such micro cracks (Mindess et al., 2003; Reinhardt et al., 2003; Neville, 2004). The actual capacity of micro crack healing appears primarily related to the composition of the concrete mixtures. Mixtures based on a high binder content show remarkable crack-healing properties (Reinhardt et al., 2003). Autogenous self-healing of cracks traditionally occur in concrete with high-binder content mixtures and limited to cracks with a width smaller than 0.2 mm (Mindess et al., 2003; Reinhardt et al., 2003; Neville, 2004). The metabolic activity of bacteria is monitored by oxygen profile measurements, which reveal O_2 consumption by bacteria-based samples.

The bonding behaviour with the concrete substrate is evaluated based on pullout tests and restrained shrinkage (Li et al., 2007). Bacteria *S. pasteurii* improves the compressive strength better than *B. subtilis* for both in water and sulphate solution. *S. pasteurii* also showed the least compressive strength loss compared with 28-day compressive strength, and represented the most relative compressive strength compared with the sulphate environment. (Guadalupe et al., 2014). Nosouhian et al. (2015) had studied the durability of concrete in environments containing sulphate and found an improvement on concrete containing bacteria. The result at 28-days with 20% bacterial concrete was higher compared with the control. Isolated ureolytic and sulphate reduction bacteria strains are trained to survive in both alkaline and anaerobic condition to suit the concrete environment and have been proven to improve concrete properties (Irwan et al., 2014).

Table 1 shows majority of the researcher confirmed that bio-concrete resulted in an increase in concrete properties. However, there is limited information on the application of bio-concrete in other aggressive environments namely, chloride attack or other chemicals. Thus, future research should look examine optimum bio-concrete on aggressive environment. Adding the bacteria further confirms the mechanism or reactions by the bacteria inside the concrete. Microstructure and elemental analysis using Scanning Electron Microscope (SEM) show the appearance of distinct calcite crystals in concrete while X-ray defraction confirms the formation of complex calcium in the treated concrete (bio-concrete).

Table 1
Previous studies on bio-concrete

Researchers	Findings	Type of Bacteria	Concentration of bacteria added
Nosouhian et al. (2015)	Carbonate producing bacteria to improve concrete characteristics	*S.pasteurii* (SP) and *Bacillus subtilis* (BS)	BS: 6 x 10^9 cells/mL SP: 9 x 10^7 cells/mL
Guadalupe et al. (2014)	Bio-based via bacteria-mediated calcium carbonate production improved mechanical properties and bonding strength of concrete	*Bacillus cohni*	1.2 x 10^7 bacterial spores/gr +15% calcium lactate
Irwan et al. (2014)	Survive in the alkaline environment with anaerobic conditions. Improve concrete properties	The Ureolytic bacteria (UB) and Sulphate Reduction Bacteria (SRB)	3% UB 0.1-0.5 mol/L & 5% SRB 0.1-0.5 mol/L
Wang et al. (2011)	Polyurethane has potential to be used as bacterial carrier for self-healing of concrete cracks	*Bacillus sphaericus*	10^9 cells/mL
Jonkers et al. (2011)	Self-healing capacity of concrete to seal the crack	*Bacillus cohni*	2.4 x 10^8 spores/cm^3 cement stone
Tittelboom et al. (2009)	Repair crack in concrete	*Bacillus sphaericus* (BS)	20 g/L BS+20 g/L urea
Ghosh et al. (2009)	Strength of bacteria modified mortar increases	*Bacillus hewanella* (BS)	10^4-10^6 BS cells/ml
Muynck et al. (2008)	Improves the durability of cement materials	*Bacillus sphaericus*	10^3 spores/g mortar
Ramakrishnan et al. (2005)	Improvement of concrete durability	*Bacillus pasteruii*	1 x 10^8 cells/ml

CONCLUSION

This study examined the use of bacteria in concrete technology. Bio-concrete has better durability as it improves the properties of concrete. However, an extensive study on bio-concrete should be undertaken with the aim of adopting bio-concrete technology.

ACKNOWLEDGEMENTS

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) and The Ministry of Higher Education Malaysia through GPPS, Vot U 445and FRGS Vot 1577.

REFERENCES

ACI Committee 201. (2001). Quid to durable concrete. A*merican Concrete Institute, Report of ACI Committee*, ACI 201.2R-7

Bajza, A., & Zivica, V. (2001). Acidic attack of cement based materials - a review: Part 1 Principle of acidic attack. *Construction and Building Materials, 15*(8), 331-340.

Basheer, P. A. M. (1996). Predictive models for deterioration of concrete structures. *Construction and Building Materials, 10*(1), 27-37.

Basheer, P. A. M., Nanukuttan S. V., McCarter, W. J, Tang, L., Holmes. N., Chrisp, T. M., Starrs, G., & Magee, B. (2015). The performance of concrete exposed to marine environments: Predictive modelling and use of laboratory/on site test methods. *Construction and Building Materials, 93*, 831-840.

Broomfield, J. P. (1997). Corrosion of steel in concrete, E & F.N. Spon. 7, DETER, Detroit, 1982, pp. 37.

Choi, Y. K., Yi, Seong-Tae., Kim, M. Y., Jung, W. Y., & Yang, E. I. (2015). The performance of concrete exposed to marine environments: Predictive modelling and use of laboratory/on site test methods', in *Construction and Building Materials, 93*, pp 831-840.

Collepardi, M. A. (2003). State-of-the-art review on delayed ettringite attack on concrete. *Cement Concrete Composite, 25*(4), 401-407.

Coppola, L., Fratesi, R., Monosi, S., Zaffaroni, P., & Collepardi, M. (1996). Corrosion of reinforced concrete in sea water submerged structures", in *Proceedings of the Third International Conference on Performances of Concrete in Marine Environment*, pp 127-160. New Brunswick, Canada.

Kim, S. H. K., & Ann, K. Y. (2010). Modeling steel corrosion in concrete structures-part 1: A new inverse relation between current density and potential for the cathodic reaction. *International Journal of Electrochemical Science, 5*(3), 302-313.

Guadalupe Sierra-Beltran, M., Jonkers., H. M., & Schlangen, E. (2014). "Characterization of sustainable bio-based mortar for concrete repair". In *International Conference Delft University, of Technology, Faculty of Civil Engineering & Geosciences, Department of Materials and Environment, Stevinweg 1, 2628 CN Delft, The Netherlands*.

Irwan, J. M., Faisal Alshalif, A., Othman, N., & Asyraf. R. M. (2014). Isolation of uratolytic and sulphate reduction bacteria: Acclimatize to concrete environment", in *International conference on civil, Biological and Environmental Engineering (CBEE), Istanbul, Turkey*.

Irwan, J. M., Faisal, A., Othman, N., & Anezza, L. H. (2016). "Isolation of sulphate reduction bacteria (srb) to improve compress strength and water penetration of bio-concrete", in *International Conference on Civil and Environmental Engineering for Sustainability (IConCEES 2015), Melaka, December 1 – 2, 2015, MATEC Web of Conferences*, 47:01016.

Jonkers, H. M. (2012). Bacteria-based self-healing concrete. In Department of Materials and Environment – Microlab, Delft, the Netherlands.

Li, V. C., & Yang, E. (2007). Self-healing in concrete materials". In *self-healing materials – An alternative approach to 20 centuries of materials science* (ed. S. van der Zwaag), pp. 161–194. Springer, the Netherlands.

Mindess, S., Young, J. Francis., & Darwin, D. (2003). Concrete, Upper saddle River Prentice Hall: NJ, pp. 644.

Muynck, W. D., Cox, K., Belie, N. D., & Verstraete, W. (2008). Bacterial carbonate precipitation as an alternative surface treatment for concrete. *Construction and Building Materials, 22*, 875–885.

Neville, A. (2004). The confused world of sulfate attack on concrete. *Cement Concrete Research, 34*(8), 1275-1296.

Kockal, N. U., & Turker, F. (2007). Effect of environmental conditions on the properties of concretes with different cement types. *Construction and Building Materials, 21*, 634–645.

Nosouhian, F., Mostofinejad, D., & Hasheminejad, H. (2015). Concrete durability improvement in a sulfate environment using bacteria. J*ournal of Materials in Civil Engineering, © ASCE, ISSN 0899-1561/04015064*.

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

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

Siddique, R., & Chahal, N. K. (2011). Effect of ureolytic bacteria on concrete properties. *Construction and Building Materials, 2*5, 3791-3801.

Song, H. -W., & Saraswathy, V. (2007). Corrosion Monitoring of Reinforced Concrete Structures; A Review", in *International Journal Electrochemical. Sci*., 1- 28.

Tittelboom, K. V., Belie, N. D., Muynck, W. D., & Verstraete, W. (2010). Use of bacteria to repair cracks in concrete. *Cement and Concrete Research, 40*,157–166.

Wang, J., Tittelboom, K. V., Belie, N. D., & Verstraete, W. (2012). Use of silica gel or polyurethane immobilized bacteria for self-healing concrete, *Construction and Building Materials, 26*, 532–540.

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