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The Influence of *Sulphate Reduction Bacteria* on the Durability of Concrete in Seawater Condition

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ABSTRACT

Strength and durability are important characteristics of concrete and desired engineering properties. Exposure to aggressive environment threatens durability of concrete. Previous studies on bio-concrete using several types of bacteria, including sulphate reduction bacteria (SRB), had to increase durability of concrete have shown promising results. This study used mixtures designed according to concrete requirement for sea water condition with SRB composition of 3%, 5% and 7% respectively. The curing time were 28, 56 and 90 days respectively. The mechanical properties, namely compressive strength and water permeability, were tested using cube samples. The results showed compressive strength had higher increase than the control at 53.9 Mpa. The SRB with 3%composition had maximum water permeability. Thus, adding SRB in concrete specimens improves compressive strength and water permeability. This is particularly suitable for applications using chloride ion penetration (sea water condition) where corrosion tends to affect durability of concrete constructions.

Keywords: Compressive strength, durability, permeability, sea water, sulphate reduction bacteria

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INTRODUCTION

An archipelago is an area with a long coastline surrounded by sea. This creates challenges to civil engineers to choose appropriate and robust construction material to withstand sea water corrosion. The materials of choice for concrete should be able to resist extreme weather conditions or exposure to environment-related chemicals such as sulphates, chlorides and salt; for example, sulphate is present in both soil and groundwater originating from fossil fuel and biomass combustion. This increases acidity of the area, threatening the concrete structure around the area. Interactions of concrete with other external influences also decrease its durability. Other factors such as freezing and thawing, abrasion, corrosion of steel, chemicals may deteriorate quality of concrete (Bajza et al., 2001).

In general, chemical corrosion refers to acid attack, alkali attack, carbonation, chloride attack, leaching or sulphate attack (ACI 201). Thus, concrete durability influences the selection of appropriate material. Crack formation is a typical example of concrete durability. Large cracks hamper structural integrity and smaller sub-millimetre sized cracks may result in durability problems as connected cracks increase matrix permeability (Jonkers, 2012). Concrete in general can lead to fluctuations in temperature and moisture without deterioration, and under adverse exposure conditions, most concrete will fail by following causes: alkali-aggregate reaction, sulphate attack, freeze-thaw cycles and reinforcement corrosion. These three factors may occur individually or simultaneously, leading to expansion and development of cracks in concrete. Alkali-silica reaction, sulphate attack (Aguiar et al., 2008) and freeze-thaw cycle (Muynck et al., 2008) are common culprits. Deterioration can also occur due to corrosion of reinforcement. Corrosion risk is higher for structures exposed to aggressive environment (seawater) or de-icing salts. In short, corrosion has emerged as the most important factor affecting reinforced concrete structures.

Basheer (1996) had pointed out that the deterioration of concrete due to sulphates, chlorides, salts can damage its structure (Choi et al., 2015). Thus, bio-concrete has been introduced as an alternative material to overcome these problems. The application of microorganisms in concrete decreases pores in concrete as well as seals cracks (Aguiar et al., 2008). The bacteria also reduces mass variation, volume variation (higher age) and water absorption (Basheer, 1996). Earlier studies have shown that application of bioconcrete results in higher durability of concrete structures (Jonkers, 2012; Muynck et al., 2008). Therefore, an attempt to explore bioconcrete at aggressive environment is timely. In this research, sulphate reducing bacteria, previously isolated with specific behaviour to tolerate with alkaline and anaerobic condition, are tested (Alshalif et al., 2015). This research, hence, was aimed at examining the influence of Sulphate Reduction Bacteria (SRB) on concrete in aggressive condition (high salt/sodium) by testing on its compressive strength and water permeability.

MATERIALS AND METHODS

SRB Preparation

The SRB that was previously isolated (Alshalif et al., 2015) was acclimatised in 3% NaCl condition. Prior to acclimatisation, the growth curve of the SRB was monitored to determine the optimum enrichment condition. This process was to ensure survival of the SRB added in aggressive condition concrete. The amount of SRB prepared was based on the amount of water calculated in casting process. The SRB would be as partial replacement of water by 3%, 5% and 7%. respectively.

Material

The concrete mix design was calculated using DOE and is shown in Table 1. The samples were prepared based on G35 using DOE method. The fabrication of concrete was done according to BS 1881-125:2013 (British Standard, 2013). In simulating aggressive environment, the samples were removed after 24 hours and kept air dry until tests were conducted.

Test Procedure

Two tests were conducted, namely compressive strength and water penetration. The compressive strength and water penetration test were performed according to BS EN 12390-3:2009 (British Standard, 2009) and BS EN 12390-8:2009 (British Standard, 2009) respectively. In this study, cubes 150 mm × 150 mm × 150 mm, were used. The tests were conducted using three samples that were immersed for 28 days in a solution containing 3% NaCl.

Table 1
Amount of materials prepared for fabrication

Material	Cement (kg)	Sand (kg)	Aggregate (kg)	Water (kg)	Sulphate reduction bacteria (kg)
Control	65.10	149.0	91.3	29.3	-
3% *SRB	65.10	149.0	91.3	27.8	1.5
5% *SRB	65.10	149.0	91.3	27.3	2.0
7% *SRB	65.10	149.0	91.3	26.37	2.93

RESULTS AND DISCUSSION

The SRB Bacteria

The volume of SRB was stirred and kept aside for 14 days before being used in the casting process. In this study, only SRB strain that was acclimatised in 3% of sodium chloride was used to ensure good survival in an aggressive environment.

Compressive Strength

The compressive strength results are shown in Table 2 and Figure 1. In general, compressive strength of bio-concrete is higher compared with control. The highest compressive strength after 28 days of curing were for samples added with 7% of SRB. After 90 days, maximum compressive strength of 24.4% was achieved compared with control s for specimens with 5% of SRB addition. The results revealed that adding significant amount of SRB improved compressive strength. The findings are consistent with those of earlier studies on bio-concrete on the enhancement of concrete properties (Jonkers, 2012), (Muynck et al, 2008). The addition of specific bacteria group with specific enzyme functions to precipitate calcium carbonate at the pore of the concrete (Muynck et al., 2008). The process of plugging in the pores at the binder matrix improves compressive strength.

Table 2
Results related to compressive strength

Days	0% SRB		3% SRB		5% SRB		7% SRB	
	Samples (MPa)	Average (Mpa)	Samples (Mpa)	Average (Mpa)	Samples (Mpa)	Average (Mpa)	Samples (Mpa)	Average (Mpa)
	44.7		47.3		49.0		48.5	
	40.0	42.2	46.3	46.4	45.2	46.6	46.8	47.2
28	42.0		45.7		45.6		46.3	
	42.2		50.7		51.2		48.0	
	40.8	41.0	49.2	49.5	49.0	49.9	47.7	47.6
56	40.1		48.5		49.4		47.0	
	44.2		44.8		56.4		48.5	
	44.9	43.3	46.4	47.0	55.1	53.9	48	48.5
90	40.8		49.7		50.1		49	

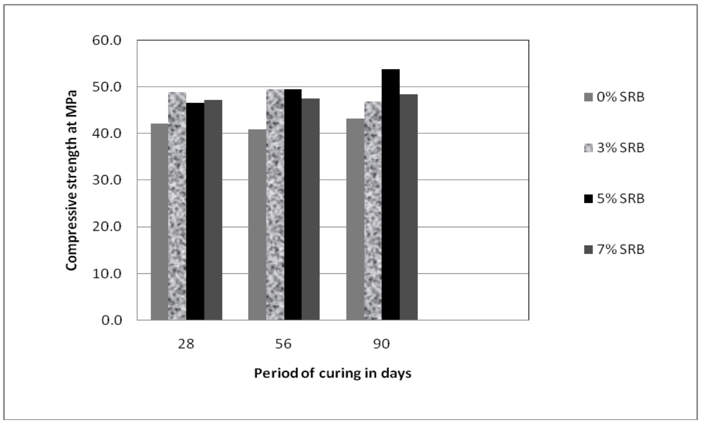

Figure 1. Influence of different concentrations of bioconcrete containing SRB

Permeability Concrete Test

The test results showed reduction in water permeability when bioconcrete sis used by adding SRB at 3%, 5% and 7% concentration respectively compared with control as seen in Figure 2. Maximum reduction of water permeability after 28 days was seen for samples with 7% SRB concentration. After 90 days, the results for maximum reduction of water permeability were for specimens with 5% SRB. The presents of bacteria in concrete with capability to deposit calcium salt at concrete pores allow less water to penetrate it. Therefore, it increases the durability of concrete as it would prevent water seeping and causing carbonation of steel to affect the structure of the entire building (BS, 2014). In this study, reduction of water seeping also minimise penetration of sodium chloride that is already dissolved in curing water. This reduces the possibility of chloride attack leading to an aggressive environment. Nilsson et al. (2014) had pointed out that chloride corrodes any steel material in concrete structure, thus reducing its durability (Nosouhian et al., 2015).

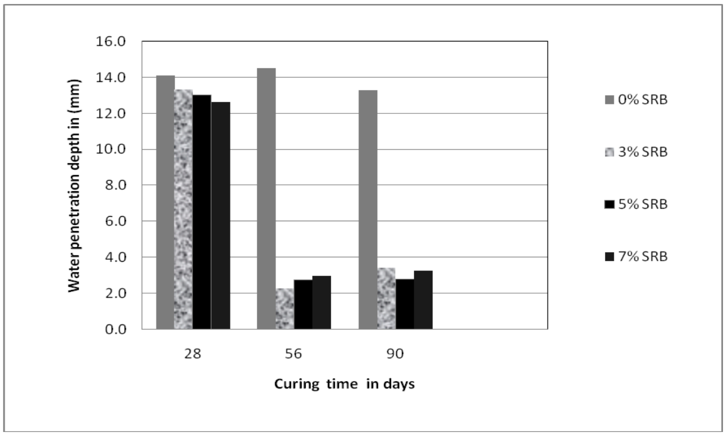

Figure 2. Permeability concrete of different concentrations of bioconcrete containing SRB

CONCLUSION

The concrete added with 3%, 5% and 7% SRB respectively showed positive results in increasing compressive strengths and decreasing water penetration. The results proved that bacteria improve the durability of concrete also in addition to minimising chloride ingress when exposed to an aggressive environment (sea water condition).

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