Long term effect of strength and durability performance of concrete containing sulphate reduction bacteria under chloride condition

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Abstract. The chloride ingress in concrete cause deterioration in concrete due reinforcement corrosion. Adding bacteria in concrete can improve material properties and increase durability with mechanism resist chloride ingress in concrete. Chloride ingress in concrete by bacteria is particularly suited for applications in chloride ion penetration in concrete. The research is objective to determine the effect of adding bacteria to the concrete properties. The bacteria used is locally isolated and enriched to suite concrete environment. The type of the bacteria used is identified as Sulphate Reduction Bacteria (SRB). The SRB is added into concrete mix with concentrations of 3%, 5% and 7%. The compressive and water penetration tests at 28th, 56th, 90th, 180th and the 360th day of curing period were conducted. Cubes of size 150mm × 150mm × 150mm were prepared for compressive strength and water penetration tests. The result of compressive strength shows significant strength of 66.3 MPa on the 360 of day. The water depth penetration also shows a significant impact with addition of SRB with 80% reduction of penetrated water into concrete compared to the control specimen. The overall results of bacteria showed promising results and further study on chloride condition capability is encouraging. It can be concluded that SRB with 5% addition was the optimum percentage to obtain the optimum strength and durability performances.

1. Introduction
Corrosion of reinforcement steel bar due to chloride ingress processes by chloride penetration was the most well-known ecological assaults that lead to the decay of solid structures. Environment factors consist of chemicals in ground, ground water and relative humidity are the main concern degradation agents [1]. In fact, corrosion at reinforcement steel bars are responsible to failure due to the low durability performance [2], age of concrete structure and resistance from external factor.

The bacteria grows in dissolved zero oxygen levels and sufficient carbon with sulphate concentrations in the wastewater [3-4]. Sulfur ions was released with the sulfates and oxygen in the seawater [5]. When the bacteria derive their oxygen from dissolved oxygen, the sulfate was transform to sulfide in the wastewater [6]. The pH value plays an important role influencing the separation and solubility of molecules. This is an indirectly affect study methodologies of biological impact using microorganisms incorporate the on concrete [7]. Therefore, utilization of bacteria as bio-concrete is getting high attention from researcher to solve corrosion of steel bar in chloride condition.
The use of ureolytic and sulphate reduction bacteria isolated showed at pH 10.71 and 9.35 present an optimal growth respectively. The gram stain was positive for both types with the shape of coccus [8]. The bacteria incorporating with concrete was reduced the weight, volume variation (higher age) and water absorption [9-10]. Nosouhian et al. [9] studied concrete exposure to sulfate and enhancement of concrete containing bacteria subjected to sulfate, resulting in bacteria comprising concrete at a compressive strength of 28 days 20 percent higher than control samples. Darmawan [11] mentioned that flexural, compression strength and drying shrinkage behaviour of mortar contains bacteria are evaluated. The author claimed that the bonding behavior of mortar containing bacteria was increased compared to the control mortar.

Irwan et al. [12] indicated that both bacteria were enriched to fit the concrete environment during the enrichment period under alkaline and anaerobic conditions. The ureolytic and sulphate reduction bacteria need urea and sulphate salt, respectively to ensure only the desired strain growth. Therefore, at optimum pH 10.71 and 9.35 were optimal growth condition of ureolytic bacteria and sulphate reduction bacteria, respectively. It was claimed that concrete contains bacteria which isolated strains are able to sustain in concrete environment.

Jonker et al. [13] claimed that bacteria in concrete can be seen in microscopic after permeability test and found that complete healing of cracks occurred in bacterial concrete. This process called as crack-sealing mechanism. This process involves a metabolic conversion of calcium lactate to calcium carbonate. It found that sealing mechanism resulted in significant sealing of 0.15 mm width cracks. Further creation of this fresh form of self-healing concrete is anticipated to lead in a more sustainable concrete that is particularly suitable for implementations in wet environments where corrosion of strengthening continues to impede the durability of traditional concrete structures.

Suwito et al. [14] studied the addition of bio-chemical in Portland cement to study strength of concrete. It found that flexural strength of beam containing bio-chemical was increased 39.4% compared to normal beam. The author also claimed that bio-chemical in Portland cement have a resistance to environmental situation such as sulphate ions and water absorption. Gandhimathi et al. [15] studied bacterial concrete that can plugging minerals at crack area than control specimens. The author claimed that carbonate precipitation was decreases compared to control. Muynhck et al. [16] studied bacteria in concrete resulted in significant decrease of water intake compared to concrete without the presence of bacteria. The author claimed that process of calcium carbonate crystals at the surface presents decreased of water absorption by 85%, depending on the porosity of specimens.

Therefore, this research investigates the influence of Sulphate Reduction Bacteria (SRB) on concrete under chloride condition in terms of strength and durability with three different of SRB concentrations.

2. Experimental program

2.1. Isolation of Sulphate Reduction Bacteria
Sulfate reduction bacteria (SRB) were collected from domestic acidic at Sungai Pelepah Kota Tinggi, Johor, Malaysia. Sodium chloride (NaCl) was added to imitate the chloride environment [17-18]. The penetration of 3% sodium chloride was used as reduction of water permeation. The compound of the media in the culture SRB process is prepared as Table 1.

| Sample | Nutrient Broth, ml | NaCl, ml | SRB | Total composition, ml |
|--------|-------------------|----------|-----|----------------------|
| Control | 25                | 10 (3%)  | -   | 35                   |
| SRB    | 25                | 10 (3%)  | 1 bead | 35               |

2.2. Materials
Concrete mix proportion was using a different percentage of SRB concentration which are 3%, 5% and 7% as shown in Table 2.
Table 2. Mix proportion of bio-concrete with different percentages of SRB prepared for fabrication

| Percentage (%) of bacteria | Cement (kg/m$^3$) | Water (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Coarse aggregate (kg/m$^3$) |
|---------------------------|-------------------|------------------|---------------------------|---------------------------|
| 0%                        | 420               | 210.00           | 685                       | 1115                      |
| 3%                        | 420               | 207.90           | 685                       | 1115                      |
| 5%                        | 420               | 203.70           | 685                       | 1115                      |
| 7%                        | 420               | 199.50           | 685                       | 1115                      |

2.3. Test procedure
Compressive strength and water absorption tests were conducted in this study using 150mm x 150mm x150mm mould. In order to simulate chloride condition, concrete specimens were cured in 3% NaCl for 28, 56, 90, 180 and 360 days of age curing. The compressive strength test was performed using a universal testing machine. Meanwhile, water permeability test was conducted to determine water depth penetration into concrete. Mechanism of cyclic wetting and drying cycles for deeper penetration of chloride condition cause at a rate 20 times by continuous immersion [19]. Specimen was transferred to sodium chloride solution tank with 15 hours of wetting and 9 hours of drying after 28 days of age curing [19].

3. Results and discussion

3.1 Compressive strength test
The compressive strength of concrete containing SRB at 3%, 5% and 7% are presented in Figure 1. The specimens had been tested after achieving the maturity of concrete on the day 28, 56, 90, 180 and 360 days. Specimens containing SRB shows slightly increase in compressive strength compared to the control specimen for 28 and 56 days. Meanwhile, the highest compressive strength occurred at 180 days was specimen containing 3% of SRB which is 63.9 MPa, followed by 5% of SRB which is 58.6 MPa and 7% of SRB which is 58.7 MPa. The specimen of concrete containing 5% and 7% SRB were increasing gradually after 180 days of curing at 63.9 MPa at 360 days.

![Figure 1. Compressive strength with different percentage of SRB at different curing times](image)

This study presented concrete containing SRB increased up to 15.7%, 10.4% and 11.8% for 3%, 5% and 7% of SRB, respectively compared to control in terms of strength (28 days) as shown in Figure 2. Meanwhile, the compressive strength of SRB concrete on the day of 360 was increased up to 11.7%,
61% and 30% for 3%, 5% and 7% of SRB, respectively. It was a clear trend of increase in compressive strength of 5% of SRB specimens increased up to 61% compared to the control specimens.

![Figure 2](image-url)

**Figure 2.** The comparison of concrete strength at the age of 28 and 360 days with different of SRB percentages

The density and strength of concrete was increased due to pores in concrete is partially filled up by material growth of bacteria. It similar trend result by Kalhori and Bagherpour [17] which is applied *Bacillus subtilis* into concrete and indicates 30% of increment strength compared to control. This situation occurred because of the bacteria precipitation of calcium carbonate inside the pores of the concrete [20].

### 3.2. Water penetration

This study conducted 24 hours water absorption test for 28, 56, 90, 180 and 360 days age of curing a shows in Figure 3.

![Figure 3](image-url)

**Figure 3.** Water penetration with different percentage of SRB at different curing times

The specimen containing SRB shows a reduction of water depth penetration as compared to the control specimen. The control specimen shows a slight decrease from 28 days curing until 360 days curing at
ranges of 6% to 10%. On the day of 180, the optimum reduction of water penetration occurred in 7% of SRB (2.8 cm) followed by 3% of SRB (3.3 cm) and 5% of SRB (4 cm). The pattern of reduction of concrete containing SRB was 75% to 80% compared to control specimen. Lastly, for the 365 of day curing shows concrete containing 7% SRB was the optimum reduction of water penetration with a reduction of 80.1% compared to control specimen as shown in Figure 4.

![Figure 4](image_url)  
*Figure 4. The comparison of water depth penetration concrete at the age of 28 and 360 days with different of SRB percentages*

### 4. Conclusion
The study was designed to investigate the effect of sulphate reducing bacteria (SRB) on compressive strength and water depth penetrations influenced by the percentage of SRB under chloride condition. These findings were obtained according to the highest strength and water depth penetration observed based on the curing period. It can be concluded that SRB with 5% addition with concrete was the optimum percentage to obtain the optimum strength and durability performances. Further study should be implemented in rapid chloride penetration test (RCPT) to determine behaviour of concrete containing SRB under chloride conditions such as chloride attack.

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Acknowledgements
This study has been granted by the Ministry of Education Malaysia and supported by Universiti Tun Hussien Onn Malaysia (GPPS Vot. U445).