Assessment of climatic variation on bio cement mortar-based infrastructure

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Abstract. Over the last few decades, effects of climate change have been widely studied by researchers. This change alters environmental conditions, which in turn influence the activities of bacteria. Therefore, this study assesses the effect of climatic variation on bio cement mortar-based infrastructure. This is achieved by evaluating the effects of temperature and relative humidity on the compressive strength of bio cement mortar. The bacteria used in the bio cement mortar are bacillus subtilis. 30 ml of bacillus subtiliss pore solution was added to the mix to create bio cement mortar. Test sample cubes of bio cement mortar were prepared and cured at different temperatures and different relative humidity. In addition, control sample cubes of cement mortar without bacteria were water cured. The 7- and 28-days compressive strengths were obtained. The results showed that the compressive strength of the bio cement mortar increased as both temperature and relative humidity increased. The 7- and 28-days compressive strengths increased by as much as 83.3% and 110% respectively when temperature increased, and by as much as 106.1% and 73.5% respectively when relative humidity was increased.

1. Introduction
Infrastructure are the most important and valued asset of any society. Yearly, governments across the world allocate a large chunk of their annual budget on maintenance [1-2]. Despite these budgetary allocations, deterioration in civil infrastructures remains a critical issue. The appearance of crack in civil concrete structures due to shrinkage, settlement and contraction causes ingress of dangerous chemicals that may lead to severe damage [3].

Being the societal most valuable asset [4], researchers have come up with several concrete crack-sealing methods. These methods involve using epoxy systems [5], silicon-based polymer [5], chlorinated rubber [6] and acrylic resins [7]. However, the cost, compatibility and heat resistance has hindered the use of these crack-sealing methods. In view of this, self-healing concrete was developed to alleviate the problem of crack occurrence in concrete [8]. Self-healing method of concrete repair involves adding calcite-producing bacteria into the concrete [9]. The respiratory activities of the bacteria produce calcite which in turns fills in the cracks. In addition to filling-in cracks, the calcite produced also fill the micro pores in the concrete, thereby increasing strength, durability and density.

Several researchers have applied various bacteria to improve this property of concrete. Ramakrishnan [10] showed that \textit{Bacillus pasteurii} increased the 28 days compressive strength of concrete by 18%. Similarly, Ghosh et al. [11] increased the 28th-day compressive strength of cement mortar by 25% when calcite precipitating bacteria was added to it. They stated that bacteria activity
produced calcite within pores of the cement mortar. Achal et al. [12] improved the strength of cement mortar cubes by 17% when the cubes were treated with *Sporosarcina pasteurii*. The authors concluded that microbial calcite precipitated plugged the mortar pores, subsequently enhancing the compressive strength of the mortar cubes. Furthermore, Bundur et al. [13] increased the compressive strength of cement mortar by incorporating vegetative bacterial cells of *Sporosarcina pasteurii* into the cement mortar. A 23.5% increase in compressive strength was reported by Bensal et al. [14] by applying halophilic bacteria *Exiguobacterium mexicanum* isolated from sea water to concrete.

The incorporation of helpful bacteria has no doubt improved the self-healing and properties of concrete/cement mortar. It has also been shown by researchers that the environment influences the activities of bacteria [15]. Their calcite precipitation depends on factors like pH [16], nucleation site [17], dissolved inorganic carbon and calcium ions concentration [18]. The concentration of dissolved inorganic carbon depends on several environmental parameters such as temperature and the partial pressure of carbon dioxide [19]. Therefore, this study aims at investigating the effects of changing climatic conditions of bio cement mortar-based infrastructure. Cement mortar mixed with bacteria (bacillus substilis) are produced in cubes of 50 mm x 50 mm x 50 mm and cured at different temperature and in different relative humidity are examined. The 7 and 28 days compressive strengths of these bio cement mortar cubes are obtained and examined. In addition, control samples of cement mortar cubes are produced to serve as a baseline for comparison of the compressive strength.

2. Experimental materials

2.1. Fine aggregate and cement

Clean natural river sand obtained locally was used in this study. The sand was washed with water and sun-dried to remove the moisture content. The fineness modulus and density are 2.5 and 1750 Kg/m³. The sieve analysis performed showed that the fine aggregate is well-graded. The cement used was Ordinary Portland Cement (OPC) available in the market. The OPC has BS 12 1996 specifications and a product of Cement Industries of Malaysia Berhad (CIMA).

2.2. Microorganism

Spores of a bacteria isolate obtained from the upper layer of soil in Kuala Lumpur, Malaysia were used in this study. The bacteria was cultured in a liquid medium that contained 10 g tryptone, 5.0 g yeast extract and 10.0 g NaCl in 950 ml H2O. This was autoclaved at 120 °C for 30ins. Upon inoculation on laminar flow, the culture was incubated at 37 °C on a shaker operating at 150 rpm for 48 hrs. The microbial self-healing agent consisted of the 48 hr-grown bacteria cells and the substrate which were then suspended in the distilled water used in mixing the cement mortar.

2.3. Test cube specimens

The fine aggregate and cement were thoroughly mixed and water was added to it. The mix ratio was 1:2 and water-cement ratio was 0.45. 30 ml of the bacteria spore solution was added to the mixing water. The cubes were casted in 50 x 50 x 50 mm moulds and compacted with a vibration machine. The cubes were demoulded after 24 hrs and placed in their different curing conditions. Table 1 shows the curing conditions (temperature and relative humidity) applied to the bio cement mortar, while the control specimen was water-cured. These curing conditions were applied to simulate climatic variations we have around the world. The cubes were removed after 7 and 28 days and tested for their compressive strength according to ASTM C39 by using a Universal Testing Machine (UTM).

| Temperature (°C) | Relative humidity (%) |
|------------------|-----------------------|
| 10               | 50                    |
| 26               | 72                    |
| 40               | 95                    |
3. Results

3.1. Temperature effect on compressive strength

The results obtained from the compressive strength tests of bio cement mortar cubes that were cured under different temperatures are shown in Figure 1. These compressive strengths were taken on the 7th and 28th days. In addition, Figure 1 also includes the compressive strengths of water-cured cement mortar (WC). In Figure 1, it is observed that the compressive strengths of bio cement mortar cubes are higher than the cement mortar cubes (WC). The increased compressive strength is due to the activities of the calcite-producing bacteria in the bio cement mortar. These bacteria’s respiration produces calcites that fill up micro spores in the cement mortar, thereby increasing strength. In Figure 1(a), the results show that increased temperature increased the compressive strength at 7 days. For example, the 7 day compressive strength at 10 °C is 34.6 N/mm², and this value increased to 45.2 N/mm² when the curing temperature increased to 40 °C. This represents about 30.6% increment. The 7 day compressive strength of the bio cement mortar increased to 45.2 N/mm² showing an increase by as much as 110% compared to the water-cured cement mortar (WC). Similarly, the 28 day compressive strength shown in Figure 1(b) indicates that the bio cement mortar cubes exhibited higher compressive strength than water-cured cement mortar (WC). The 28 day compressive strength of the bio cement mortar increased by as much as 83% compared to the strength of water-cured cement mortar (WC). The 28 day compressive strength of the bio cement mortar attained a value of 50.1 N/mm². Furthermore, Figure 1(b) shows that increased curing temperature increased 28 day compressive strength bio cement mortar. The compressive strength increased from 42.6 N/mm² at 10 °C to 50.1 N/mm² at 40 °C. These increments in compressive strength due to temperature increase are because the optimum temperature for culturing the bacteria (*Bacillus subtilis*) is 37 °C [20].

![Figure 1. Compressive strengths using varying curing temperature (a) 7 days; (b) 28 days](image)

3.2. Relative humidity effect on compressive strength

This section reports the effect of relative humidity during curing on bacteria activities with respect to the compressive strength of bio cement mortar. The results explain the compressive strengths attained on the 7th and 28th days. In addition to the strength of bio cement mortar, the strengths attained by water-cured cement mortar (WC) at these times are also presented to serve as control. In Figure 2, the results of the strengths attained are shown graphically. Figure 2 shows that the compressive strength of the bio cement mortar cubes exceeded the control sample WC (water-cured cement mortar). For example, the strengths attained by WC were 21.4 N/mm² and 27.4 N/mm² on the 7th and 28th days respectively, while the minimum of the bio cement mortar were 40.1 N/mm² and 44.8 N/mm² respectively. From Figure 2(a), it is observed that increased relative humidity increased the early compressive strength. For instance, the early compressive strength increased from 40.1 N/mm² to 44.1
N/mm$^2$ when the relative humidity was increased from 50% to 95%. This indicates an increment of 10% at the early stage. Similarly, in Figure 2(b) that shows the 28 day results, the compressive strength increased as the relative humidity increased. At relative humidity of 50%, the compressive strength was 44.83 N/mm$^2$, and this value increased to 47.5 N/mm$^2$ at 95% relative humidity. This shows that relative humidity of bio cement mortar can be increased by as much as 6% when the suitable relative humidity is applied. The results in this section highlighting the effects of relative humidity on bio cement mortar show that relative humidity plays an important role in the compressive strength. The increased compressive strength experienced with increased humidity shows that the activities of the bacteria in the bio cement mortar was favored by this curing condition. This is similar to reports from several other studies that state that humidity positively affects microbial activities [21], thus more calcites were produced in the bio cement mortar. From the results presented in Figures 1 and 2, it can be seen that for the temperature and relative humidity considered in this study, both climatic factors have influence on the compressive strength of bio cement mortar at both stages. In addition, these two considered factors increased the strength at different manners.

![Figure 2. Compressive strengths using varying curing relative humidity (a) 7 days; (b) 28 days](image)

4. Conclusion
This study evaluates the effects of climate variation on bio cement mortar-based infrastructures. This was achieved by assessing the 7 and 28 days compressive strength of the bio cement mortar. 30 ml of bacteria (*bacillus substlis*) spore solution added to cement mortar and cured in different climatic conditions. The climatic variation factors that were considered were temperature and relative humidity. The study have shown that irrespective of the curing condition, all the bio cement mortar cubes exhibited higher compressive strength than the water-cure cement mortar cubes (control cubes). This is due to the presence of bacteria that produced calcites to fill up microspores in the bio cement mortar. The compressive strength of the bio cement mortar increased by as much as 110% of the control cubes. Furthermore, it was observed that increased temperature and relative humidity increased both the 7- and 28-days compressive strength of the bio cement mortar cubes.

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