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Effectiveness of tropical soil bacteria as self-healing agent in concrete

A R Mohd.Sam[1,5], H A A Al-Ghaifi[2], A M Ahmad Norain[2] , S Abu Bakar[2], M M Tahir[1], N H Abd Khalid[2], A Mohamed[3], and N Basar[4]

[1]UTM Construction Research Centre, Institute for Smart Infrastructure and Innovative Construction, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
[2]Department of Structure and Materials, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
[3]Department of Geotechnics and Transportation, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
[4]Department of Chemistry, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
[5]Corresponding email: abdrahman@utm.my

Abstract: Concrete is one of the most commonly used and popular materials in construction industry. It can be designed to have certain required strength and durability based on its application and surrounding environment. However, one of the setbacks for concrete is that it can suffer from internal micro-cracks during its service life due to various reasons. Thus, in ensuring the long-term performance of concrete, the micro-cracks problem need to be addressed. This paper discusses the possibility and potential use of local tropical soil bacteria as self-healing agent in concrete. The bacteria used in the concrete mix was obtained from UTM soil, *Lysinibacilluus sphaerius,* isolated and cultured for further testing in concrete to determine its suitability in enhancing the concrete performance. Slump test, compressive strength test and pulse velocity test were conducted to assess the effect of the selected bacteria on concrete properties. The initial results demonstrated the capability and possibility of the selected bacteria strain to be used as healing agent in concrete. The optimun percentage of bacteria found was 4%. The compressive strength and pulse velocity of concrete containing bacteria were found to be better than control concrete by 20% and 2%, respectively. The pores of bacteria concrete were also less than control concrete. These positive effects were most likely attributed to the precipitation of calcium carbonate from bacteria activity in filling the pores in the hardened concrete.

1.0 Introduction

Concrete is a material that easily cracks due to load or shrinkage. It is also naturally porous thus, it can allow aggressive agent such as sulphate and chloride ions to penetrate that can cause corrosion problem. In order to maintain the design strength and durability of building, the concept of self healing concrete can be used as it can seal the pores that presence in concrete. Thus, this will prevent the penetration of aggressive agent such as water, oxygen, sulphate, and chloride. One of the new technologies that have been introduced in modern concrete is the concept of self-healing. There are few methods that can be used in self-healing concrete such as secondary hydration and using bacteria spores. Secondary hydration is a process of re-precipitation of incomplete hydration process of cement and water during setting and hardening [1]. Once concrete cracked, water and air can penetrate into it thus, react with atmospheric carbon dioxide to produce calcium carbonate ($CaCO_3$) that eventually will seal the cracked concrete.

Bacteria spores as an agent to seal micro cracks in concrete is now widely studied as self-healing method. Bacillus type of strain normally can be found in soil, sand, and natural material and these bacteria will precipitate $CaCO_3$ [2]. A mixture of bacteria spores and calcium lactate will produce calcite precipitation once bacteria spores in contact with water and oxygen . Thus, it will feed organic compound to produce $CaCO_3$ and it affects the compressive strength of concrete. However, due to high alkalinity in concrete of pH 12 to 13, bacteria spores may crush and decrease the calcite formation at later age [3].

Usually concrete environment will have high pH value and high internal temperature due to hydration process. In relation to this microcapsules were proposed to act as bacteria carrier so that bacteria can resist the harsh condition inside concrete [4]. These capsules will break once there were micro cracks in concrete and exposed to atmosphere that will allow oxygen and water to react with bacteria. Other than microcapsules, silica gel or polyurethane (PU) immobilized bacteria also being used in self-healing concrete. This method will manually heal cracked concrete by penetrating into the cracked part of concrete. When silica gels with bacterial suspension activated, it will form $CaCO_3$ precipitation that will seal the cracks [5, 6]. The main purpose of this research is to study the optimum amount of bacteria to be used in concrete mix and effects of the local bacteria on fresh and hardened properties of self healing concrete.

2.0 Methodology

This research consisted of three key activities; concrete mix deign according to DoE method, preparation of bacteria in concrete mix and testing of fresh and hardened concrete. Tables 1, 2 and 3 show the concrete proportions, mix proportions with bacteria and identification of samples cast in the study, respectively.

2.1 Mix Design According to DoE Method

Based on the DoE method, the proportions of cement, water, aggregates, super plasticizer and bacteria were determined. Ordinary Portland cement, crushed granite of 10 mm, river sand, and superplasticizer were used in the concrete mix. The water-cemet ratio used was 0.45. Table 1, 2 and 3 show the details of the concrete mix used in the study.

Table 1. Concrete Mix Design Proportions.

Cement (kg/m^3)	Coarse aggregates (kg/m^3)	Fine aggregates (kg/m^3)	Water (kg/m^3)	Admixture
425	614	1094	240	1.5%

Table 2. Bio-Concrete Mix Design.

Cement (kg/m^3)	Coarse Aggregates (kg/m^3)	Fine Aggregates (kg/m^3)	Water (kg/m^3)	Admixture (kg/m^3)	Urea (2%)	Ca (4%)	Yeast extract (3g/L)	Bacteria broth (%)
425	614	1094	240	5.1	4.8	9.6	720 g	2,4,6,8

Table 3. Type of Specimen Classification and Details.

Type of specimen	Details
C1	control (0% bateria + 0% urea + 0% calcium
C2	(2% bateria + 2% urea + 4% calcium + yeast extract)
C3	(4% bateria + 2% urea + 4% calcium + yeast extract)
C4	(6% bateria + 2% urea + 4% calcium + yeast extract)

2.2 Preparation of Bacteria

Bacteria cultured and used in this study is basically based on local bacteria. Different bacteria act differently based on their surrounding condition. Based on other research work that has been done, it discovered local bacteria named *Lysinibacilluus sphaerius.* This bacteria is obtained from soil around UTM. The bacterial broth containing bacteria and media (LB) were prepared to be used in concrete mixture with 2% calcium nitrate and 2% urea. Briefly, the isolated bacterial species were inoculated into the required values of fresh broth (LB) in flask. Then, the growth condition (incubator) was preserved at 37 ^{0}C under shaking 150 rpm for one day. Noting that, the nutrient broth (LB media) and equipment must be autoclaved at 100 ^{0}C for 15 minutes before use.

Calcium and urea is an agent that help bacteria in the formation of calcium lactate inside concrete. These reacting agents will be added in powder form so that it will not take much place inside concrete and can bind perfectly in concrete mix. The amount of calcium and urea added into specimen also varies together with bacteria to obtain the optimum amount for effective self healing mechanism. Besides the control concrete mixture, a series of grown culture have been an integral part of the concrete mixture on the basis of that bacterial broth was diluted with the mixing water to obtain different cell concentration into concrete matrix. Urea (2%) and calcium nitrate (2%) were also added in the mixing water for the urease enzyme activity and its function in bacterial aggregate formation, respectively, accompanied by nutrient (yeast extract 0.3%) for bacterial growth.

2.3 Testing on Fresh and Hardened Concrete

The slump test was conducted to determine the fresh properties of concrete. For hardened concrete, compressive strength test and ultrasonic pulse velocity (UPV) test were conducted. For compressive strength test, 100 mm x 100 mm cube specimen was prepared with different amount of bacteria added in concrete mix. Each specimen is cured in water after 24 hours before being tested in compression and Ultrasonic Pulse Velocity (UPV) test at 7 and 28 days. In this study, the highest compressive strength result will indicate the optimum amount of bacteria to be used in self-healing concrete.

In addition, each specimen was tested for pulse velocity using UPV test in order to check the porosity of the concrete. After 7 and 28 days of curing, the UPV test was conducted to determine the velocity of the pulse through the specimen. The higher the velocity will indicates the concrete is denser and less porous.

3.0 Results And Discussion

All the results obtained from the experimental work were analysed and discussed in the following sections.

3.1 Workability

Figure 1 shows the slump test result and it can be said that that the workability of all concrete mixes is similar. With the average slump of 134 mm, the workability of this fresh concrete is good in which it is suitable for the concrete to be easily poured and flow into formwork and easy for the concrete to be compacted. The workability of concrete containing bacteria is quite similar to control specimen with differences in the range of 3 to 7%.

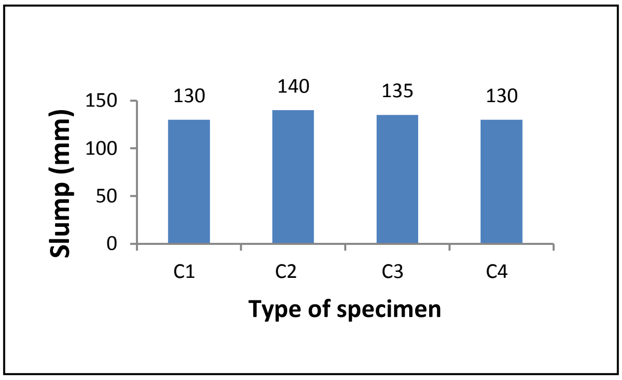

Figure 1. Slump Test Result.

3.2 Density of Concrete

Figure 2 shows the density of all concrete mixes. It can be seen that the density of all concrete mixes is relatively similar. This indicates that the inclusion of bacteria will not affect the density of the hardened concrete. The lowest density recorded was for specimen C3 which has 4% of bacteria added into the concrete mix.

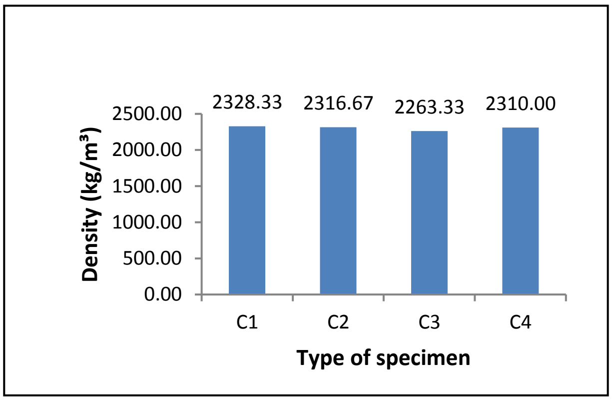

Figure 2. Density of Concrete.

3.3 Compressive Strength of Concrete

The results of compressive strength of all concrete mixes are shown in Figure 3. It can be seen that the compressive strength of concrete increases as the amount of bacteria increases. But after 4% of bacteria added, the compressive strength started to decrease. The trend of the graph of 7 days and 28 days is similar to each other so it is certain that the maximum compressive strength of the concrete can be achieved when 4% of bacteria are added into the concrete.

The ratio of compressive strength between 7 to 28 day for control concrete was 0.83. On the other hand for concrete containing bacteria the ratio was in the range of 0.83 to 0.92. This indicates that the early strength development of concrete containing bacteria is higher than control concrete. The higher strength development may be due to the formation of calcium carbonate inside the concrete in addition of the C-S-H gel generated during cement hydration process. In addition, at 7 days, the amount of water and oxygen inside of concrete is relatively high. So the reaction of bacteria to form calcium carbonate is very high during 7 days. However, after 7 days, when most of the water and oxygen has been used up, bacteria inside the concrete probably cannot react more to form limestone as the source of water and oxygen has been depleted.

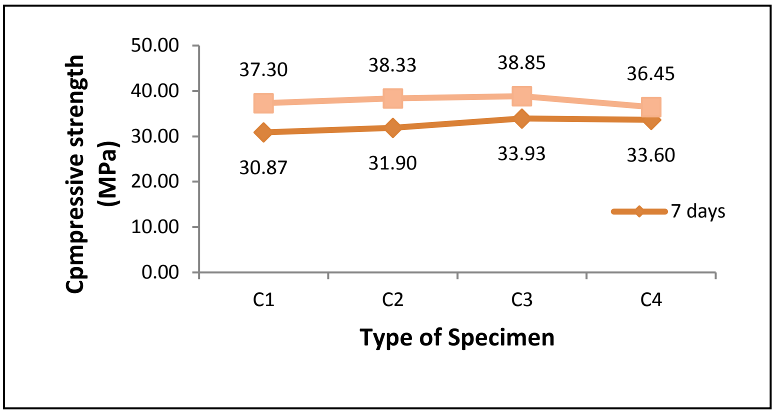

Figure 3. Compressive Strength of Specimens at 7 and 28 days.

3.4 Optimum Amount of Bacteria in Concrete

Based on the comparison graph shown in Figure 4, the trend of the result gradually increase when bacteria is added, but when the percentage of bacteria added is more than 4%, the results started to drop. This condition occur may be due to the amount of bacteria added affecting the strength of the concrete. Therefore, a 4% of bacteria added into concrete can be said as the optimum amount because the compressive strength of the concrete increase by 10% at 7 days and 4% at 28 days from control specimen which give the higest increament compared to other specimens.

Different with specimen with 6% of bacteria added into the concrete at 7 days, the strength increase by 9% compared to control specimen. However, at 28 days, the compressive strength drop by 2%. The decrease of strength may occur due to the reaction of bacteria is lagging. As the amount of bacteria increases, the bacteria need to compete with each other in getting food and nutrient. Thus, the nutrient needed for the bacteria to develop the formation of calcium carbonate is not enough. Other than that, the reaction of bacteria will use up all oxygen and water for the reaction to be completed.

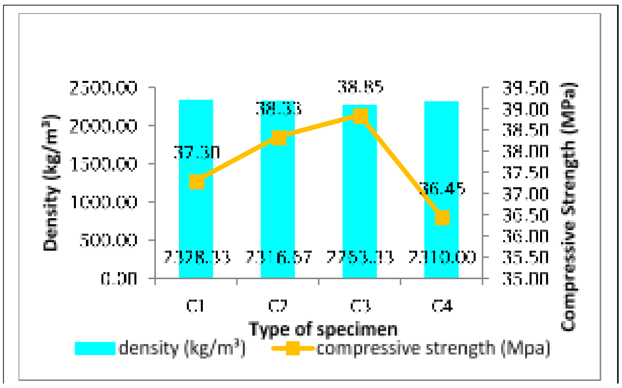

Figure 4. Comparison of Density and Compressive Strength.

3.5 Ultrasonic Pulse Velocity

Figure 5 shows the results of pulse velocity for all concrete mixes. The difference of pulse velocity values between 7 and 28 days indicated that the concrete cube at 28 days is denser than 7 days. Figure 5 indicates that as the amount of bacteria increase, the velocity of concrete also increases. This may indicates that concrete containing bacteria has develop the formation of limestone inside it. Calcium carbonate is expected to form in the pores inside the concrete and fill up the gap between pores inside concrete.

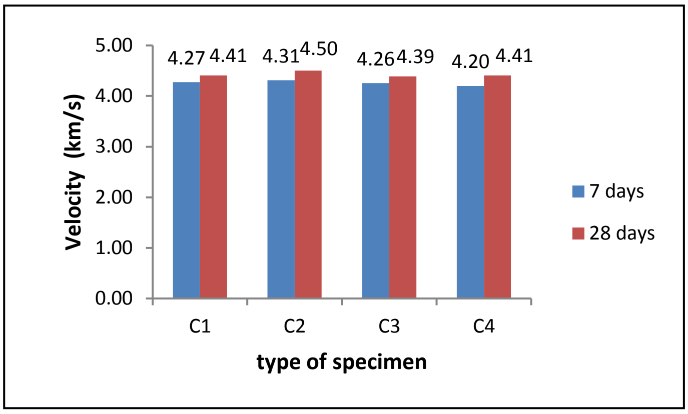

Figure 5. UPV Test Result at 7 days and 28 days.

3.6 Mode of Failure

The type of failure of specimen containing bacteria is the same as control specimen. After the surface of specimen failed, the condition inside the concrete can be visually evaluated. Based on photos shown in Figure 6, it can be seen that the control specimen is relatively more porous compared to specimen containg bacteria. Specimen C3 did not have much pores as the bacteria might have reacted with the reacting agent to form calcium carbonate inside the concrete thus, filling the gap and pores inside the concrete. However, the formation of limestone cannot be seen clearly by using naked eyes as may be the size of calcium carbonate formed is too small and will only be seen under microscope.

(a) C1 (control) (b) C3 (4% bacteria)

Figure 6. (a) Visual evaluation of specimen C1. (b) Visual evaluation of specimen C3.

4.0 Conclusion

In this paper, the effects of local bacteria on fresh and hardened properties of self-healing concrete have been investigated. The conclusions that can be drawn from the study are as follows:

i. The workability and density of concrete containing bacteria are relatively similar to the control concrete.
ii. The optimum amount of bacteria to be added into concrete is 4% as the result show the highest increament in compressive strength and pulse velocity.

iii. The compressive strength and ultrasonic pulse velocity of concrete increases as the amount of bacteria increases indicating the formation of calcium carbonate inside concrete.
iv. The mode of failure of specimen containing bacteria is similar to the control specimen and visual evaluation showed that the specimen containing bacteria has lower porosity compared to control specimen.
v. It can be concluded that local bacteria, named *Lysinibacilluus sphaerius***,** can be used as self-healing agent in concrete.

5.0 References

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