Production of Self-healing Concrete using Gum Arabic for Immobilizing of Bacterial Spores on Sand

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Abstract

This paper studies the feasibility of producing self-healing concrete by immobilization of bacteria on the sand. In this study, the Gum Arabic (Acacia Senegal) was used to immobilize bacterial spores and its nutrient (Calcium lactate) on sand surface as a novel technique. Due to its availability and environment-friendly character, Bacillus subtilis bacteria have been selected and prepared. To achieve the aim of this study, three concrete mixes were made with 10%, 5%, and 2.5% of gum-capsulated sand with bacteria. The ability of self-healing of cracks was monitored using stereomicroscope and digital image camera. The experiments have shown that the proposed technique is efficient in healing of cracks without impairing the prisms' strength for mixes with 2.5% and 5% of gum-capsulated sand with bacteria. The results give a proof-of-concept to use Gum Arabic as an adhesion to immoblize the bacteria and its nutrient on sand to produce self-healing concrete.

Keywords: Self-healing concrete; Cracks; Gum Arabic; Immobilization; Bacteria; Capsulation

1 Introduction

Self-healing concrete is defined as the ability of concrerte to repair its cracks and recovery of the water-tightness throught bacterial consumption of calcium-based nutrient in concrete (Han et al., 2014; Pacheco-Torgal et al., 2017). It mimicks the healing of body wounds by production of a healing material without any manual intervention and relying only on the bacterial ones (De Belie et al., 2018). The most used type of bacteria and nutrient (i.e. healing agents) in the literature are "*Bacillus*" and Calcium Lactate ($CaC_6H_{10}O_6$), repectively (Khaliq & Ehsan, 2016). The self-healing of concrete activated once the cracks' mouths open and the water/mosture find its way through the surface cracks. Then bacteria starts to consume the nutrient and oxygen producing calcium carbonates ($CaCO_3$) that healed cracks ib concrete, Figure 1.

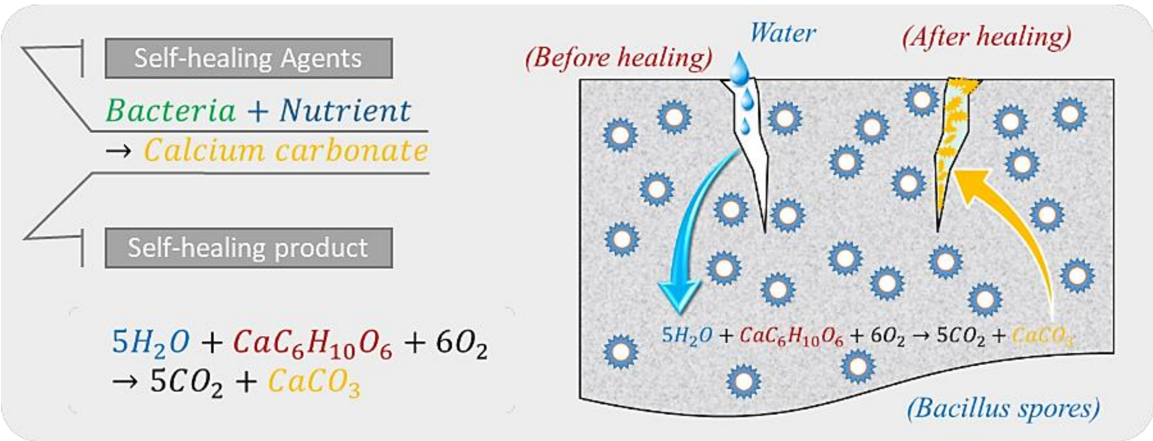


Fig. 1: Mechanism of Self-Healing Concrete

In general the production of self-healing concrete follows two techniques: direct method and immobilization/encapsulation method. In the direct method both bacteria and nutrient are mixed directly with the concrete. The main disadvantages of this method is that: 1) There is an early conversion of calcium source (Afiq et al., 2018); 2) Subjection of bacteria to mechanical stresses during concrete mixing; 3) Subjection of bacteria to chemical reactions of cement and the heat of hydration; and 4) Reaching the nutreitent by the bacteria is not granted (Alves et al., 2019; Jr et al., 2020). In the later method, many techniques and carriers are used to capsulate/immoblize bacteria and nutrient during the mixing and protect it from the harsh environment before releasing at the onset of the cracks (Talaiekhozan et al., 2014). Many carries and capsules are used in previous studies such as: light weight aggregate and graphite nano platelets (Khaliq & Ehsan, 2016); iron oxide and bentonite particles (Shaheen et al., 2019); diatomaceous earth (Wang et al., 2012); expanded clay particle (Jonkers, 2021); geo-polymer (Jadhav et al., 2018); and microcapsules (Al-Tabbaa et al., 2019). Use of organic and clay/earth based materials to concretize for immobilizing the bacteria can lead to ufavourable effects on properties of the produced concrete (Jonkers, 2021).

This research aims to experimentally prove the concept of immobilization of bacteria and its nutrient on sand using Gum Arabic as an adhesive material to produce self-healing concrete. It is known that sand (as a crrier) is one of the main concrete constituent materials. On the other hand, the literature shows that Gum Arabic is used as concrete admixture that works in both retardation of the setting time and reduction of mixing water (Satti & Ahmed, 2018). Therefore, both carrier and immoblizer are expected to show minimal or no adverse effects on concrete strength.

2 Materials and Methods

The main aim of the experimental work is to examine the self-healing ability of the proposed concrete mixture. In the self-healing concrete mix, the Hashab Gum Arabic *Acacia Senegal gum* (as adhesive material) is utilize as immoblizer of bacteria together with calcium-based nutrient, on sand. In this study Bacillus subtilis spores and Calcium Lactate are used as bacteria and nutrient, respectively.

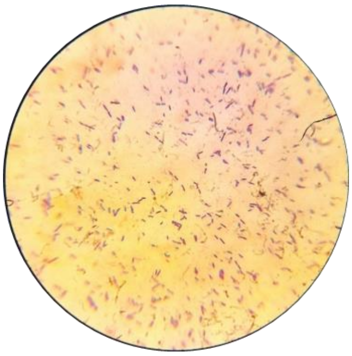
The following steps were taken to achieve the aim of the experiments:

1) Prepration of bacteria.
2) Immobilization of bacteria.

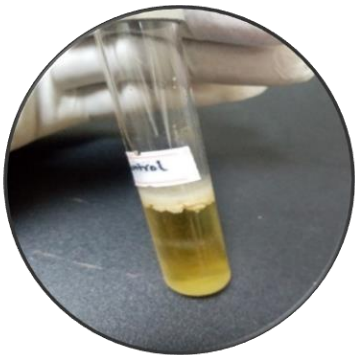
3) Preparation of the self-helaing concrete mixes.
4) Pre-cracking of the prisms.
5) Monitoring self-healing over the time.

2.1 Prepration of Bacteria

In this study, the *Bacillus subtilis* was isolated and provided as spores. The type of bacteria was identified and confirmed (**Fig. 2**a). To test its ability to produce calcium carbonat, *B. subtilis* spores were dissolved in peptone water supplemented with calcium lactate. Three days later, the $CaCO_3$ precipitated as shown in **Fig. 2**b. The X-ray diffraction (XRD) phase analysis showed that the calcium carbonate precipitation crystalline polymorphs structure is calcite (Abdelatif et al., 2022).



(a)



(b)

Fig. 2: (a) Growth of rod-shaped Gram-positive Bacillus on Nutrient Agar medium; (b) Precipitation of Calcium Carbonate

2.2 Immobilization of Bacteria

Simply, dried Bacillus Subtilis bacterial spores, Hashab Gum Arabic, Calcium Lactate, and sand were thoroughly mixed. Then, tap water was added gradually with continious mixing until spore-coated sand pellets (gum-camsulated sand) were formed and then left to dry, Figure 3.

Fig. 3: Immoblization of Bacillus Subtilis and Calcium Lactate on sand using Gum Arabic

2.3 Prepration of Self-healing Mixes

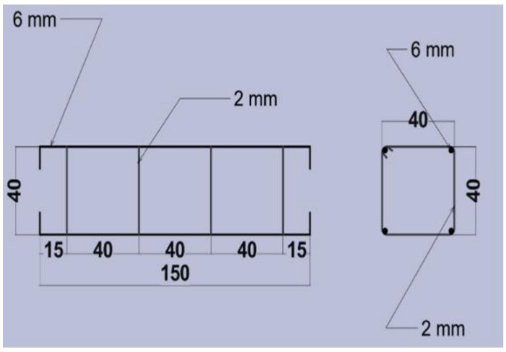
Four mixes were used with capsulated sands of percentages of 0% (the control mix), 2.5%, 5%, and 10%. Three prisms of each mix were prepared with the dimension of $40\ mm \times 4\ 0mm \times 160\ mm$. The test matrix is shown in **Table 1**.

Table 1: Test Matrix

Mix	No. of prisms	Cement (g)	Water (g)	Sand (g)	Gum-capsulated Sand			
					Coated Sand (%)	Gum Arabic (g)	Calcium Lactate (g)	Bacterial Spores (g)
A (Reference)	3	450	250	1640	0.0	0.0	0.0	0.0
B				1584	2.50	5.60	5.60	3.30
C				1528	5.00	11.25	11.25	6.75
D				1512	10.00	22.5	22.50	13.50

2.4 Pre-cracking of Mortar Prisms

After 7 days of curing, the prisms were cracked using 3-point bending test under controlled loading rate. It is worth mentioning that the prisms are lightly reinforced to ease cracking of the prisms without complete splitting. The test setup and reinforcement of the prisms are shown in **Fig. 4**.



(a)

(b)

Fig. 4: Pre-cracking of Mortar Prism

2.5 Monitoring of Self-healing of Prism Cracking

Then, self-healing ability was monitored through the perception of the Calcite on the cracks. The healing and perception of Calcite were regularly monitored using stereomicroscopy and digital image photo.

3 Results and Discussions

Both the influence of gum-capsulated sand on the prism strength and self-healing-ability of the different mixes are discussed in this section.

3.1 Influence of Gum-Capsulated Sand on the Strength of the Mortar Prisms

As shown in **Fig. 5**, the strength of 2.5% and 5% of capsulated sand on mixes results in just 8% and 10%, respectively in comparison to the reference mix. In Mix D where 10% of capsulated sand is used, the strength is reduced by 36% in comparison to the reference prism's cracking load. This result is satisfactory (and far better for Mix A and Mix B) in comparison to 40 % reduction in mixes where expanded clay is used (Jonkers, 2011).

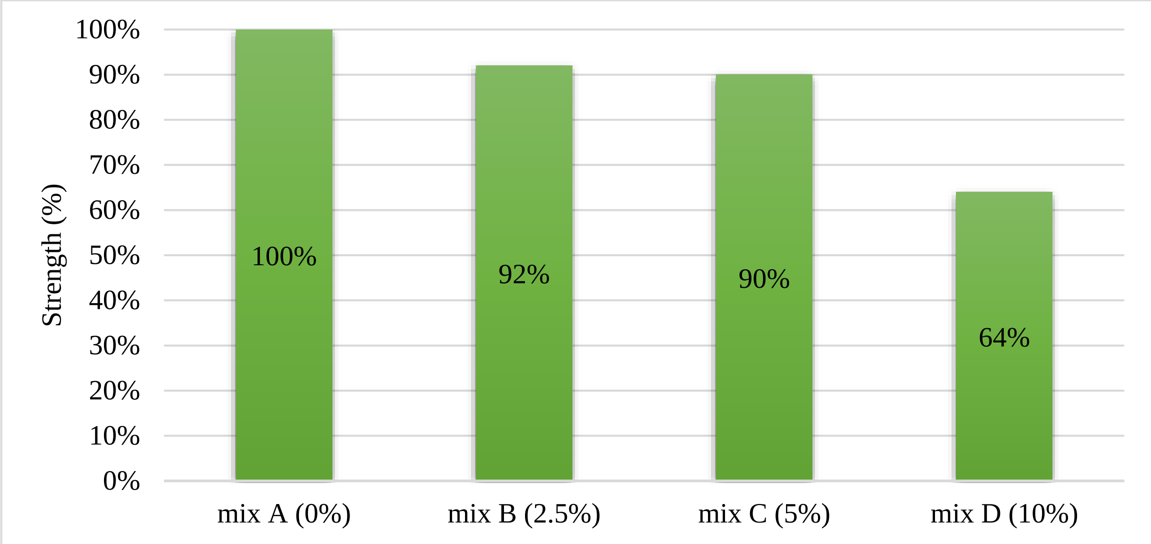


Fig. 5: Strength of Different Prisms in Comparison to the Cracking Load of the Reference Mix

3.2 Self-healing Ability of the Proposed Technique

Only the results of Mix C (5%) are presented in this paper, the rest of the results can be found elsewhere (Abdelatif et al., 2022). In Mix C, the progess of cracks healing was photographed in 3 days, 7 days and 14 days (Figure 6). The 25x stereomicroscope image clearly shows full healing of the crack by the bacterial product of Calite after 14 days.

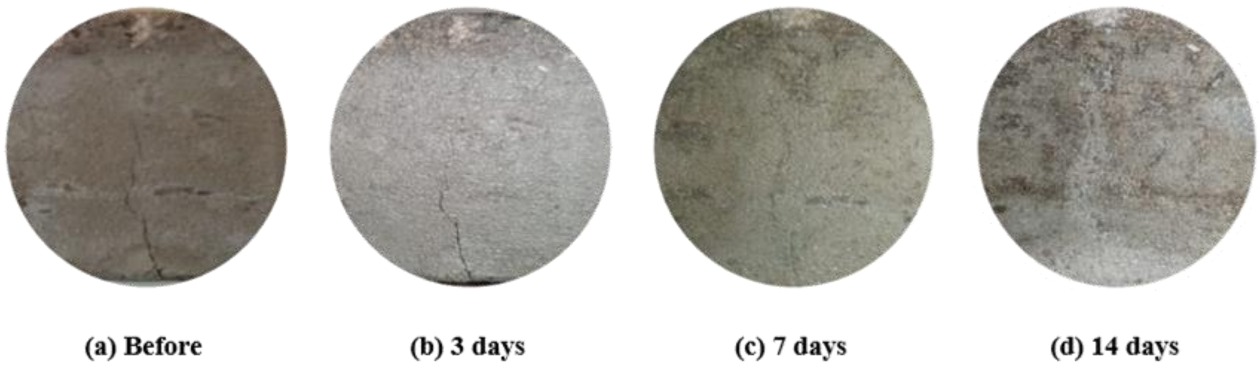


Figure 6: Self healing of a Crack Mix C over the Time

Fig. 7: 25x Stereomicroscope Image Showing the Formation of Calcite on a Crack

4 Conclusion

This study gives a proof-of-concept to use this novel, simple, and sustainable immobilization technique of bacteria for self-healing concrete. The Bacillus Subtilis (bacteria) was immobilized on sand (carrier) and capsulated with its Calcium Lactate (nutrient) by using Hashab Gum Arabic (adhesion) in the production of self-healing concrete. Three different percentages of capsulated sand was used to proof and examine the self-healing-abilty of the proposed technique. The results show the novelty of the proposed technique and how it is easy and simple to apply for self-healing of cracks without impairing the strength.

References

Abdelatif, A.O. et al. (2022). Production of Self-Healing Concrete by Bacillus Subtilis Spores Immobilized on Sand Using Gum Arabic as an Adhesion Material: Proof of Concept. J. Mater. Civ. Eng. 34, 4022310.

Afiq, M. et al, (2018). Development and Performance of Bacterial Self-healing Concrete - A Review Development and Performance of Bacterial Self-healing Concrete.

Al-Tabbaa et al. (2019). First UK field application and performance of microcapsule-based self-healing concrete. *Constr. Build. Mater*. 208, 669–685.

Alves et al. (2019). Characterization of Bioconcrete and the Properties for Self-Healing. Proceedings 38, 4.

De Belie, N. et al. (2018). A review of self ‐ healing concrete for damage management of structures. Adv. Mater. Interfaces 5, 1800074.

Han, B., Yu, X. & Ou, J. (2014). Self-sensing concrete in smart structures. Butterworth-Heinemann.

Jadhav, U. U. (2018). Viability of bacterial spores and crack healing in bacteria-containing geopolymer. *Constr. Build. Mater. 169*, 716–723.

Jonkers, H. M., 2011. Bacteria-based self-healing concrete 56, 1–12.

Jonkers, H. M., 2021. Bacteria-based self-healing concrete. In-Genium 56, 1–12.

Jr, A. A. G., Daly, M. K. M., Ongpeng, J. M. C. (2020). Applied sciences Bio-Influenced Self-Healing Mechanism in Concrete and Its Testing : A Review.

Khaliq, W. & Ehsan, M.B. (2016). Crack healing in concrete using various bio influenced self-healing techniques 102, 349–357.

Pacheco-Torgal, F. et al. (2017). *Eco-efficient repair and rehabilitation of concrete infrastructures*. Woodhead Publishing.

Satti, S. A. A. & Ahmed, Y. H. (2018). Use of Gum Arabic (Acacia Seyal) as Concrete Admixture. In: Conference Proceedings Civil Engineering 2018. pp. 198–202.

Shaheen, N. (2019). Synthesis and characterization of bio-immobilized nano / micro inert and reactive additives for feasibility investigation in self-healing concrete. *Constr. Build. Mater. 226*, 492–506.

Talaiekhozan, A. (2014). A Review of Self-healing Concrete Research Development 2, 1–11.

Wang, J. Y., De Belie, N. & Verstraete, W. (2012). Diatomaceous earth as a protective vehicle for bacteria applied for self-healing concrete. J. Ind. Microbiol. Biotechnol. 39, 567–577.

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