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# Effect of Incorporation of Various Chemicals in Self-Healing Property of Mortar

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***Abstract*—Concrete is one of the widely used building material in the world and chief agent which does the binding of all the compounds is cement. Deterioration of concrete structure takes place due to cracks in the concrete. In order to minimize the crack formation an attempt is made to incorporate self-healing compound. Few of the self-healing compounds that can be introduced are urea, calcium formate and calcium acetate. Various dosage of urea was added and its effect on three parameters consistency, setting time and compressive strength was evaluated. Optimum dosage of urea was found to be 2.5% beyond which incorporation in cement paste will lead to decrease in compressive strength. Similarly, when 2.5% of cement is replaced by calcium formate and calcium acetate it will lead to significant change in compressive strength.**

***Index Terms*— Urea; Calcium Formate; calcium acetate; consistency; compressive strength.**

## I. INTRODUCTION

Concrete the most widely used material after water. It has a characteristic of high compressive strength, good durability and very low cost of making comparatively. One of the major bottlenecks of the concrete is its brittle property which effects strength properties of concrete by the formation of cracks in the material. There are many reasons for such crack formation such as shrinkage, bleeding, expansion of concrete, settlement of concrete slab, overloading of slab etc. thus there are many mechanisms for the formation of cracks in concrete but due to the crack formation there is always reduction in strength of the concrete. The occurrence of cracks compromises the durability and integrity of concrete structures since formation of cracks provide a path for substance like sulphates, carbon dioxide, moisture to ingress into the concrete and start degrading the structure and making the structure more prone to sulphate attacks, alkali aggregate reactions etc. causing corrosion in reinforcement. The conventional repair of the cracks formed is to use epoxy injections where cracks are formed it can mitigate the risk associated with cracks but this method is impractical and costly as it is very hard to access areas or when cracks are not visible. To solve the problems of formation of cracks and to develop durable & sustainable infrastructure researchers have developed various self-healing technology it aims to improve the life span of structure and reduce its maintenance by various techniques which helps to repair the cracks formed in concrete by itself. This method includes the incorporation of various bacteria as biologically healing agents in concrete, incorporation of microcapsules as a healing agent in concrete and incorporation of various chemicals as a self-healing agent. In the present study the strength of mortar and concrete was examined by incorporation of various

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chemicals like urea, calcium acetate, calcium formate by replacing it with different percentage of cement material and identifying the best self-healing chemical and its percentage. Further using the best mix specimen, we will develop cracks in concrete specimen and the effect of these chemicals in self-healing of the specimen

## II. LITERATURE REVIEW

Literature review related to behavior of self-healing concrete, experimental studies carried out on mortar blocks and concrete blocks with combination of slag and fly ash are referred. Various literature has been referred to understand its past performance, advantages, limitations, analysis and design of self-healing Chunxiang Qian et al., 2021 focused on applied engineering solutions to repair concrete cracks using microbial induced Calcium Carbonate precipitation. By performing practical methods, it was found that the use of spray-dried fermented bacteria method contributed in preparing microbial healing agents of concrete in the form of powder as well as capsule. Spray-dried method was found to provide ease in preparation, handling and usage. To ensure proper self-healing adequate curing of concrete must be provided along with nutrients for bacteria. Instant results for self-healing concrete are difficult to examine but can be estimated by using various non-destructive test such as Ultrasonic wave test. Chris M. Vermeer et al., 2020 studied that Polyhydroxyalkanoates (PHAs) are produced by bacterial fermentation using bio-derived feed stocks and has potential to recover carbon from waste. This paper focuses on using PHA derived from waste as a bacterial substrate in self-healing concrete. Preparation of PHA is quite expensive due to purification steps and higher required quality which becomes a barrier in conducting detailed research on it. A proof of concept is provided in this paper that supports the theory of using PHA-based healing agent for self-healing concrete which also reduces the permeability of water in cracks. This paper relates two environment friendly methods that can be used to produce self-healing concrete which increases the efficiency and reduces the cost.

Hassan Amer et al., 2021 studied about using a bacteria named B. pseudomycoids for self-healing property of concrete. They studied about bacterial identification, ureolytic activity, DNA identification of the isolated bacteria, strength of concrete with bacteria as a healing agent. They used a technology named variable-pressure scanning electron microscope to observe the crack surface and EDX analysis was used to identify the filling product using VP-SEM-EDX. To identify the precipitation on the cracks after the healing was completed X-rays power diffraction (XRD) was used. As a result of this experiment, it was found that strength of bacterial concrete as compared to control concrete was 16% more and the bacterial concrete would also fill the concrete pores and micro cracks. The rate of healing mechanism as a comparison was high during early-stage w.r.t later stage. So, the introduction of B. pseudomycoides species to heal cracks in concrete helped in self-healing up to a certain level but the effectiveness and efficiency of the bacteria still needs to be improved.

Wei Du et al, 2021 studied on one of the common causes of concrete degradation sulphate attack and to improve its self-healing property using microcapsules. The microcapsules were prepared from isophorone diisocyanate (IDPI) as a healing agent and using thermoplastic materials like nano silica, paraffin wax and polyethylene wax as the microcapsules shell. They prepared concrete specimen for different concentration of microcapsules and to evaluate its sulphate resistance and self-healing properties an NDT testing technique ultrasonic testing was used. As a result, it was seen that addition of microcapsule to concrete increases its sulphate resistance. SEM images of the experiment showed that concrete exposed to sulphate attack formed healing products with a mesh like structures in the pores if concrete containing microcapsules after self-healing.

Ramamohanrao Pannem et al., 2017 in the paper discusses about incorporation of a bacteria named Bacillus pasteurii also known as Sporosarcina pasteurii in normal as well as light weight concrete and comparing its compressive strength, split tensile strength and crack width analysis. Also, a chemical named calcium lactate was added in concrete mix as a replacement material by 6% weight of cement and its scanning electronic microscopy (SEM) and Energy-dispersive X-ray spectroscopic (EDS) analysis was done to find $CaCO_3$ precipitation and deposition of calcium in concrete specimen. Results showed that after healing process there was increase in tensile strength by 50%, Healing of cracks was observed and light weight bacterial concrete shows a better and effective healing compared to normal bacterial concrete. EDS analysis showed that calcium lactate helped in remediating of cracks and cracks were healed by $CaCO_3$ precipitation with bacteria and healing agent using SEM.

Xuejiao Zhu et al., 2020 studied in the paper on the direct and reliable bacteria survival measurements by incorporating it in mortar oxygen. The tests were conducted using optical oxygen sensing system. The test results depicted that a 90% sporulation of Bacillus sphaericus was achieved after 24-hour incubation. According to microcalorimeter measurements heat was generated from microbial activity on the third day of incubation which depicts those bacteria can be activated after encapsulating it inside the hydrogel. The $O_2$ sensing film was applied on the cracked mortar and the test results showed that the oxygen concentration near the crack opening was reduced to 66%. The test results confirmed that the activation of Bacillus sphaericus and use of oxygen as an electron acceptor for their metabolism after incorporation inside mortar specimens.

Jun Feng et al., 2020 in this paper focuses on developing bacteria based self-healing concrete by inducing microbial calcium carbonate precipitation mechanism. According to the test results of X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) alkali resistant Bacillus subtilis M9 was used for biomineralization test and calcium carbonate was used as precipitate mineral in calcite phase. Self-healing concrete beam specimens were prepared by incorporating polyvinyl alcohol fibres and Bacillus subtilis M9 is used as healing agent. 3-point bending test was conducted to form 0.3 mm width cracks on the bottom of beam. After 28 days of curing, it was found that the micro cracks were healed. According to the SEM tests it was found that calcite mineral is the main reason for the healing. There was enhancement in the flexural strength by 14% when compared to the residual flexural strength.

K.-S. Lauch used different admixtures like crystalline admixture CA, expansive agent CSA and superabsorbent polymer SAP to check the self-healing capacity of the concrete. Different exposure conditions were setup in the laboratory like water immersion, wet/dry cycles and ambient air for 3 months, water flow for 1 week as well as long term real outdoor exposure like 1 year in Montreal climate. A flexural macrocrack was formed and the self-healing was checked by water permeability measurements. The results presented the Healing Ratio and the crack width showing different kinetics and efficiency according to different composition. The average Healing ratios obtained were 84% in water, 93% in wet/dry cycles and 71% in water flow in the outdoor condition. There was no synergetic effect when combined with CA+CSA and CA+SAP. Additional microscopic analyses were done and it showed different healing products according to the composition.

Pedro Serna has designed the Ultra High-performance Fibre Reinforced Concrete (UHPFRC) to compare the conventional concrete types for the self-healing capacity. This work compares the healing efficiency of the conventional concrete with high-performance concrete and two types of UHPFRC with and without 0.8% of a crystalline admixture (CA) by the binder weight. The test results showed that the UHPFRC has excellent healing power when compared with the conventional concrete and showed that the self-healing properties depend on the size of the crack and the fibre content. UHPFRC had the least water permeability after the immersion with water for 1 month.

## III. METHODOLOGY

### *A. Normal Consistency of Water for Cement Paste*

IS 4031-4(1988), is used for the normal consistency of water for Cement Paste. Weight about 400 gm of Cement accurately and place it in the enamel trough. To start with, add about 25% of clean water and mix it by the means of a spatula. Care should be taken that the time of gauging is not less than 3 minutes and not more than 5 minutes. The gauging time shall be counted from the time of adding water to the dry cement until commencing to fill the mould. Fill the Vicat mould with the paste, the mould resting on non-porous plate. Make the surface of the cement paste in level with the top of the mould with a trowel weighing 210gm. The mould should be slightly shaken to expel the air. Place this mould together with the non-porous plate under the rod bearing the plunger. Adjust the indicator to show 0-0 reading when it touches the surface of test block. Release the plunger quickly, allowing it to sink into the paste. Prepare trial pastes with varying percentages of water and test as described above until the needle penetrates 5mm to 7mm above the bottom of the mould. Express the amount of water as a percentage by weight of the dry cement. Room temperature at the time of testing shall be 25°C to 29°C.

### *B. Determination of Setting Time*

Weigh about 400gm neat cement. Prepare a neat cement paste by adding 0.85 times the percentage of water required for standard consistency. Start the stop watch at the instant when water is added to the Cement. Fill the Vicat's mould with the Cement paste prepared with the mould resting on the non-porous plate. Gauging time should not be less than 3 minutes and not more than 5 minutes. Place the test block confined in the mould and resting on the non-porous plate, under the rod, bearing the needle. Lower the needle gently till it comes in contact with the surface of the test block and quickly release, allowing it to penetrate into the test block and note penetration, after every two minutes. Repeat this procedure until the needle fails to pierce the block for about 5mm measured from the bottom of the mould. Stop the stopwatch and note the time, which is the initial setting time. Replace the needle of the Vicat apparatus by the needle with an annular attachment. Lower the needle gently till it comes in contact with the surface of the test block and quickly release, allowing it to penetrate into the test block till the needle makes an impression only on the surface of the test block. The time that elapses between the moment the water is added to the cement and when the needle makes only an impression is considered as the final setting time for the cement under the test.

### *C. Casting of Cement Mortar*

Mixing of the mortar is done by mechanical mixer. Dry mix of cement, chemical and sand of required proportion was done to obtain the uniform color of the mix. The required proportion of water is added to the dry mix. The mixing of the mortar continued for at least three minutes after the addition of water.

## IV. MATERIALS USED

The materials used in this research are Cement of Ordinary Portland Cement of grade 53. The cement test was confirmed to IQS: 5/1984. Ennore Sand of Grade-I, II, III were used. The sand grading is within the limits specified by IQS: 5/1984. Ordinary Portable drinking water was used and Urea ($CO(NH_2)_2$), Calcium Formate (Ca (HCOO)2), Calcium Acetate (Ca(C□H□O□) □) were used as chemicals which have self-healing property.

## V. MIX DESIGN

Table 1 shows the effect of variation incorporation of different proportion of urea, calcium acetate and calcium Formate on consistency of cement paste.

TABLE I: VARIATION OF SELF-HEALING MATERIALS AND CONSISTENCY OF CEMENT PASTE

| Mix design for mortar cubes | | | | | | | |
|---|---|---|---|---|---|---|---|
| Materials | | | sand(gm) | | | | |
| | Cement(gm) | Replacing material (gm) | Type 1 | Type 2 | Type 3 | Water content(ml) | Consistency |
| Controlled mortar | 400 | 0 | 200 | 200 | 200 | 86 | 31 |
| Urea 1% | 396 | 4 | 200 | 200 | 200 | 89 | 32.5 |
| Urea 2% | 392 | 8 | 200 | 200 | 200 | 87 | 31.5 |
| Urea 2.5% | 390 | 10 | 200 | 200 | 200 | 85 | 30.5 |
| Urea 3% | 388 | 12 | 200 | 200 | 200 | 84 | 30 |
| Urea 3.5% | 386 | 14 | 200 | 200 | 200 | 84 | 30 |
| Urea 4% | 384 | 16 | 200 | 200 | 200 | 83 | 29.5 |
| Urea 5% | 380 | 20 | 200 | 200 | 200 | 83 | 29.5 |
| Calcium acetate 2.5% | 390 | 10 | 200 | 200 | 200 | 85 | 30.5 |
| Calcium formate 2.5% | 390 | 10 | 200 | 200 | 200 | 87 | 31.5 |

## VI. RESULTS AND DISCUSSION

The consistency (p%), initial setting time, final setting time, compressive strength at 3days 7 days and 28 days were measured and are shown in Table II.

It can be observed that addition of urea in different percentage i.e., 1% to 5% will lead to decrease in water content with increase in urea content. Compared to control concrete when 1% and 2% urea are incorporated in paste it has more water requirement compared to cement paste without urea. Similarly with incorporation of 2.5 % Calcium Acetate in cement paste there is very small decrease in consistency limit while 2.5% Calcium Formate will have very small increase in consistency limit. Figure 2 shows consistency graph for self-healing material incorporated in cement paste.

As observed in figure 2, incorporation of self-healing material like urea in different percentage will have increase in initial and final setting time as compared control cement paste. With addition of 2.5% of calcium acetate or calcium formate in cement both initial and final setting time decreases.

TABLE II: SETTING TIME AND COMPRESSIVE STRENGTH AT VARIOUS AGE

| Materials | Consistency (p%) | Initial setting time | Final setting time | Compressive strength (Mpa) | | |
|---|---|---|---|---|---|---|
| | | | | 3days | 7days | 28 days |
| Controlled mortar | 31 | 90 min | 6 hours | 19.53 | 30.8 | 44.03 |
| Urea 1% | 32.5 | 2hrs 13min | 8hrs 30 min | 23.5 | 30.8 | 32.96 |
| Urea 2% | 31.5 | 1hrs 40min | 7hrs 50 min | 16.05 | 24.75 | 30.05 |
| Urea 2.5% | 30.5 | 3hrs 30 min | 6 hours 10 min | 41.85 | 49.4 | 55.52 |
| Urea 3% | 30 | 3hrs 25min | 6 hours | 19.8 | 28.5 | 32.3 |
| Urea 3.5% | 30 | 3hrs 23min | 6 hours 05 min | 38.27 | 46.73 | 53 |
| Urea 4% | 29.5 | 3hrs 20min | 6 hours | 20.85 | 25.0 | 46.1 |
| Urea 5% | 29.5 | 3hrs 15min | 6 hours 05 min | 19.9 | 24.0 | 47.84 |
| Calcium acetate 2.5% | 30.5 | 30min | 5 hours | 22.5 | 34.09 | 53.76 |
| Calcium formate 2.5% | 31.5 | 40min | 5 hours | 19.9 | 31.0 | 49.88 |

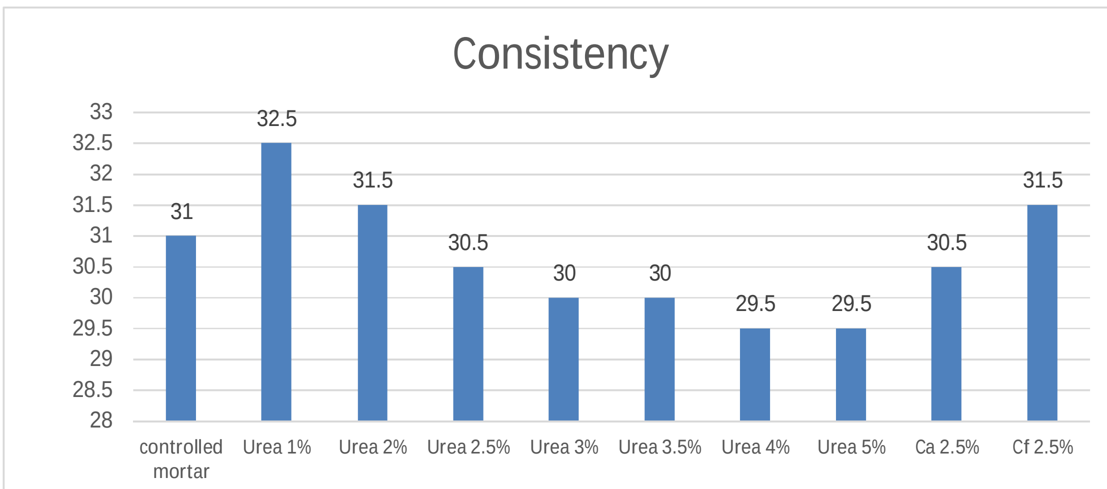
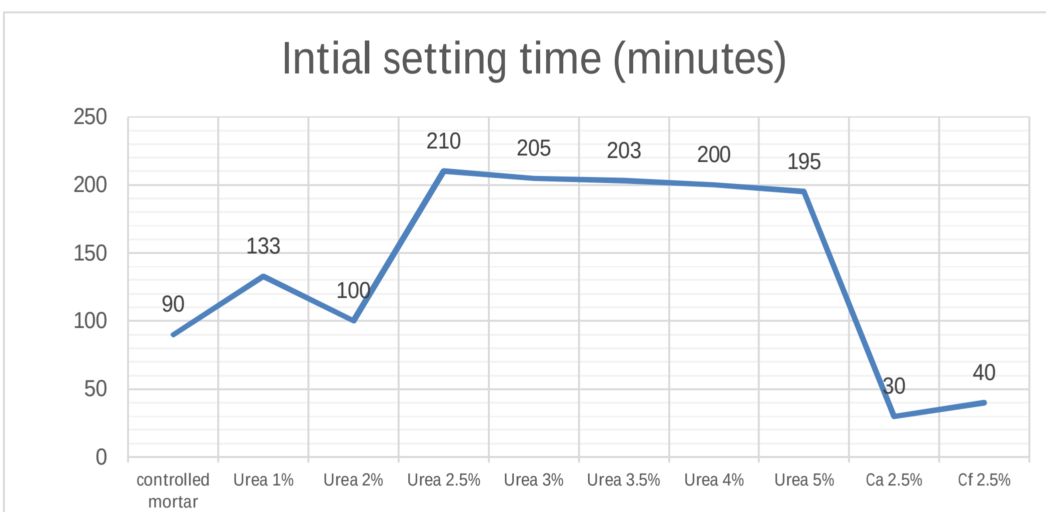



Figure 1: Consistency limits for various dosage of self-healing materials



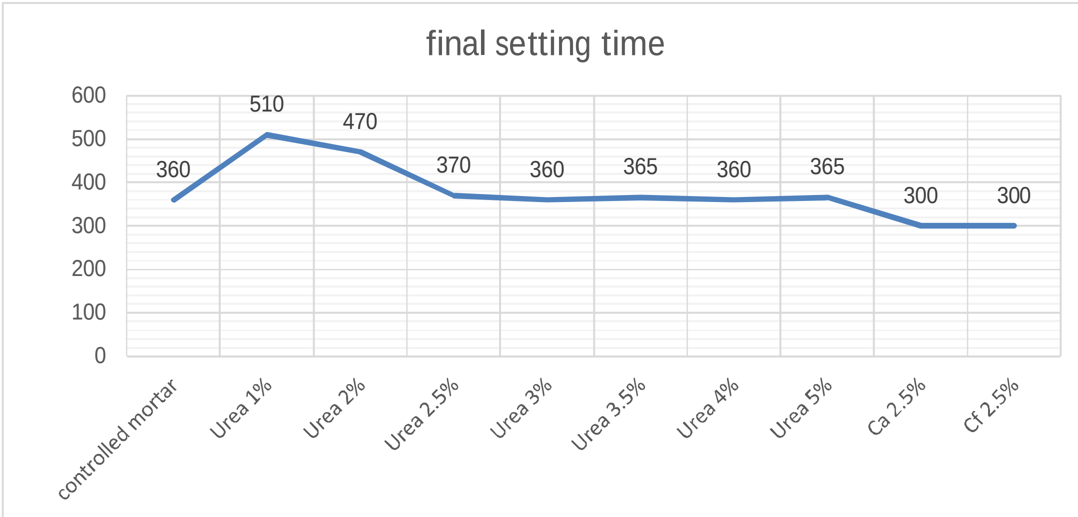



Figure 2: Setting Time of Cement Paste with various self-healing compounds

As shown in figure 3, it can be observed that there is increase in compressive strength when dosage of urea is 2.5 or 3.5% as replacement of cement. Therefore, optimum dosage of replacement of cement is 2.5% beyond which it will not lead to increase in compressive strength. Similarly, addition of 2.5% of calcium formate and calcium acetate will also lead to increase in compressive strength.

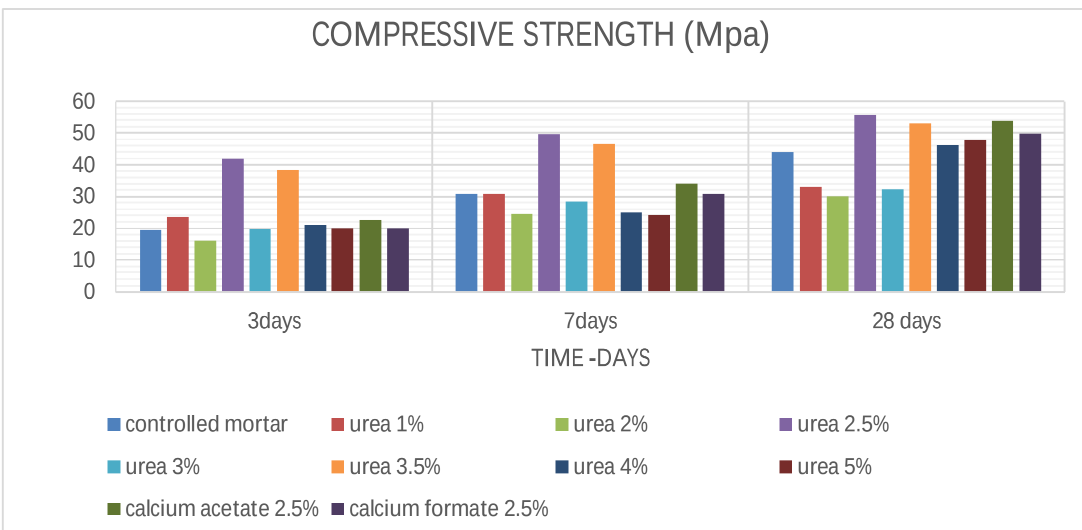



Figure-3 compressive strength of mortar cubes

## VII. Conclusion

Addition of appropriate dosage of self-healing compounds has effect on all the properties of cement. 2.5% dosage of Urea as replacement of cement will lead to decrease in final setting time and increase in initial setting time while it will lead to increase in compressive strength. Similarly, addition of calcium formate and calcium acetate 2.5% by weight of cement will lead to increase in compressive strength and reduction of initial and final setting time.

## REFERENCES


[1] Algaifi, Hassan Amer, et al. "Bio-Inspired Self-Healing of Concrete Cracks Using New B. Pseudomycoides Species." *Journal of Materials Research and Technology*, Elsevier BV, May 2021, pp. 967–81. *Crossref*, doi: 10.1016/j.jmrt.2021.03.037.

[2] Du, Wei, et al. "Investigation of Isophorone Diisocyanate Microcapsules to Improve Self-Healing Properties and Sulfate Resistance of Concrete." *Construction and Building Materials*, Elsevier BV, Sept. 2021, p. 124438. *Crossref*, doi: 10.1016/j.conbuildmat.2021.124438.

[3] "Experimental Study of Behavior of Self-Healing Concrete." *International Journal of Modern Trends in Engineering & Research*, no. 8, International Journal of Modern Trends in Engineering and Research, Sept. 2017, pp. 164–70. *Crossref*, doi: 10.21884/ijmter.2017.4265.mcoz5.

[4] Feng, Jun, et al. "Microbial Induced Calcium Carbonate Precipitation Study Using Bacillus Subtilis with Application to Self-Healing Concrete Preparation and Characterization." *Construction and Building Materials*, Elsevier BV, Apr. 2021, p. 122460. *Crossref*, doi: 10.1016/j.conbuildmat.2021.122460.

[5] Qian, Chunxiang, et al. "Application of Microbial Self-Healing Concrete: Case Study." *Construction and Building Materials*, Elsevier BV, July 2021, p. 123226. *Crossref*, doi: 10.1016/j.conbuildmat.2021.123226.

[6] SAITO, Hisashi, and Toshiharu KISHI. "PROPERTIES AND EVALUATION OF SELF-HEALING EFFECT OF MORTAR WITH SELF-HEALING MATERIAL COATED WITH ORGANIC MATERIALS." *Cement Science and Concrete Technology*, no. 1, Japan Cement Association, Mar. 2021, pp. 185–92. *Crossref*, doi:10.14250/cement.74.185.

[7] Zhu, Xuejiao, et al. "Viability Determination of Bacillus Sphaericus after Encapsulation in Hydrogel for Self-Healing Concrete via Microcalorimetry and in Situ Oxygen Concentration Measurements." *Cement and Concrete Composites*, Elsevier BV, May 2021, p. 104006. *Crossref*, doi: 10.1016/j.cemconcomp.2021.104006.