

## **The Effect of Fungus on Concrete as Self-Healing Agent: A Systematic Review**

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**Abstract:** Concrete is made from a combination of three basic materials which are fine aggregate, cement and water. Concrete is widely used around the world because it is economical and easy to cast into shape. However, due to its moisture expansion, concrete has a high tendency to crack easily. The effect of crack on concrete leads to a reduction in the lifespan of the concrete. In this study, self-healing concrete is introduced to fill up the cracks. Fungi are a new biological approach added into concrete to produce calcium carbonate. Although fungi can be a self-healing agent and promote precipitate of  $\text{CaCO}_3$  but the study about this topic is still in the early stage. The main objective of this study is to investigate the effect of fungus on bio-concrete self-healing in terms of ability to survive in alkalinity condition and identify the most factors that affecting fungus in bio-concrete self-healing through a case study. In this study, the systematic review used to evaluate the effect of fungus in concrete structure as a self-healing agent. It undergoes a few process to get the suitable articles and Scopus is one of the platforms that used for this research that offers precise insights whether searching for specific information or browsing themes, authors, journals or books. The total article used for this research is four. From previous study, the method used is X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) to confirmed that fungi have ability to precipitate calcium carbonate. Types of fungi, duration of incubation on the growth medium and type of nutrient used in test is discussed in the analysis. As the result from this study, only few fungi have tendency to survive in alkalinity condition and able to promote calcium carbonate. The fungus that able to withstand high pH tend to grow and survive on concrete.

**Keywords:** Concrete, Self-Healing, Fungus

## 1. Introduction

Concrete has been generally used in construction materials over the past few decades ago around the world because of its durability, versatility, increase in compressive strength, lower cost of manufacture, and availability. It is made of a combination of coarse aggregates, fine aggregates, water, and cement [1]. Concrete is used for most infrastructure in past and present, and it can hold up against weather conditions and easy to handle. Concrete is necessary for the construction industry, and it was applied in bridges, dams, buildings, and roads [2]. In the construction industry, concrete is typically utilised because it is simply a reasonably decent building material for basic road construction and a big project.

However, Talaiekhazan et al., 2014[3] state that regular concrete is not environmentally friendly because it can reduce the natural resource, high energy depletion, and disposal issues. Concrete is prone to crack by itself due to moisture and temperature movements. The strength will decrease due to cracks on concrete. Shrinkage is the leading cause that allows the crack to occur due to the evaporation of excess water [4]. To minimize this problem and reduce the cost, self-healing could be the best alternative to solve the problem.

In recent years, researchers have developed a new approach to improving concrete properties. A new system is a biological approach by using fungus to be added into the concrete. Luo et al., 2014[5] stated that fungi are used to repair cracks in concrete construction utilising precipitation of calcium minerals. The vital role of fungi had been explored in organic matter degradation. However, their inorganic material connection focuses primarily on the intake of minerals via mycorrhizal symbiosis, production of lichen bio-weathering. In short, adding some amount of fungus into the mix design of concrete yields better results [6].

### 1.1 Crack on Concrete

Based on Martuscelli et al., 2011[7] cracks in concrete lower their resistance capability and allow hazardous substances to enter the structure, causing damage to both the microstructure of the concrete and the reinforcement placed within the building's interior. The freshly produced calcium-based compound mineral precipitates, calcium carbonate, may serve as a kind of biocement, successfully sealing newly generated cracks. The calcium carbonate fills the gap between the cement particles and increases concrete quality.

### 1.2 CaCO<sub>3</sub> precipitate due to fungi

Microbial calcium carbonate has been extensively researched for its ability to repair cracks in concrete. However, the issue of the efficiency of crack self-healing remains critical [8]. According to Seifan et al., 2019[9], calcium carbonates could be produced through a biological process towards the concrete constituents. The addition of calcium precipitates fungus during the mixing process is the basic principle of self-healing. Self-healing of fungi needs to be in alkaline environment to induce calcium precipitation, equation 1 shows the fundamental mechanisms of calcium carbonate and calcium hydroxide.



Based on Prima et al., 2020[10] calcium carbonate is the main reaction result of the microbial metabolic process produced by hydration products, and its characteristics are not harmful to concrete. Aside from the material properties, the mixture's viscosity is lower than that of the conventional materials used for crack repair, such as epoxy resin. This has the potential to overcome the drawbacks associated with traditional repair materials. Due to the ability of mixes to enter deeper zones and fill gaps between concrete components, the water tightness of damaged concrete is effectively increased, which is advantageous for concrete repair in wet areas due to the difficulties of injection repair.

## 2. Methodology

A systematic review requires a comprehensive and logical overview of the results and available publications on a specific subject or clinical issue. Due to the rapid growth in published research, the

review articles are currently key-value knowledge. This paper aims to form an opinion based on the available scientific evidence to improve clinical decision-making. The importance of systematic reviews is to provide a consistent, comprehensive, and systematic technique to searching, selecting, and sequencing literature [11].

This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines. It is systematically explored articles and grey literature from international databases. Several databases, including Scopus, Google Scholar and ScienceDirect, were systematically investigated. The method used in this research was basically from Scopus. Scopus is one of the platforms that provide research information. Scopus offers precise insights into peer-reviewed literature in science and technology, whether searching for specific information or browsing themes, authors, journals, or books.

The keywords were selected based on the topic which is the effect of fungus on concrete as self-healing agent. A systematic review consists of a few steps shown in Figure 2. The first step included identification based on the database using a Boolean operator to combine the terms which are “concrete” AND “self-healing” AND “fungus”. The result shows that concrete (n=419,090), self-healing (n=3123) and fungus (n=49), the total articles obtained based on these keywords were 49. In the next step, the article was chosen based on the year and published type (2016-2020); this limiting factor has excluded nine articles leads to 40 articles remaining. Next, the extracted articles were screened again based on the related title, which is 34 in total. The full article chosen is 14 and finally, a number of case studies used in this review article was four.

Based on the analysis data from the four case studies, it stated that there are only certain fungi can be a self-healing agent on concrete; fungi that could survive in the harsh environment have more tendency to be crack repair agents. First case studies showed from six fungi examined that was only one fungus manages to survive. The development of the mycelium of fungi depends on pH value; only a few fungi could survive in high alkalinity. Then, the duration of incubation time could affect the efficiency of the self-healing process. A longer time is needed to activate the self-healing process and sealing the crack. The third case study shows that fungi' incubation duration in the growth medium was 21 days, and only one fungus manages to survive. The test used to obtain the existing fungus data on the concrete is XRD test, SEM test, and urea hydrolysis test. XRD and SEM tests were conducted to confirm the crystal precipitate on fungi can precipitate calcium carbonate. XRD was used to observe the precipitated calcium carbonate due to the involvement of fungus in mineral production and to verify the function of the fungus-based concrete repair system. SEM analysis was conducted from a previous study to observe the crystalline morphology located on the fungi specimen of concrete.

### 3.0 Comparison of the effect of fungus on bio-concrete for all articles

Comparison is made from the previous results of different researchers due to fungi's effect on concrete as a self-healing agent; each article shows a particular result. Table 1 shows the difference of elements used for experiment with all papers.

**Table 1: Element used for each article**

Author	Species of fungi	Growth medium	Self-healing incubation temperature (°C)	Duration (days)
Luo et al., 2017[13]	Trichoderma reesei Aspergillus nidulans Cadophora interclivum Umbeliopsis dimorpha Acidomelania panicicola Pseudophialophora magnispora	Potato Dextrose Agar (PDA)	25°C & 30°C	21
Menon et al., 2019	Aspergillus nidulans (ATCC38163)	Potato Dextrose	22°C & 30°C	21

[12]	Aspergillus nidulans (MAD1445) Aspergillus nidulans (MAD0305) Aspergillus nidulans (MAD0306) Aspergillus oryzae (ATCC1011) Aspergillus terreus (ATCC1012) Rhizopus oryzae (ATCC22961) Phanerochaete chrysosporium (ATCC24725) Saccharomyces cerevisiae (Yeast)	Agar (PDA)		
Martuscelli et al., 2020[7]	Phoma glomerata Cladosporium cladosporioides Valsa nivea Fusarium lateritium Phoma herbarum Fusarium lateritium Coniochaetaceae sp. Cladosporium herbarum Phoma aliena Phoma saxea Phoma saxea Phoma saxea Alternaria alternate Penicillium brevicompactum Phoma herbarum Cladosporium angustihherbarum Phoma saxea Penicillium brevicompactum Cladosporium cladosporioides	Potato Dextrose Agar (PDA)	25°C	7
Xijin et al., 2020[14]	Fusarium oxysporum	Potato Dextrose Broth (PDB)	29 ± 1.2°C	21

**Table 2: Comparison of each fungi survival in each article**

Author	Luo et al., 2017 [13]	Menon et al., 2019[12]	Xijin et al., 2020 [14]	Martuscelli et al., 2020[7]
Fungi survive	-Trichoderma reesei	-Aspergillus nidulans (MAD1445)	-Fusarium oxysporum	-Cladosporium herbarum -Cladosporium angustihherbarum -Penicillium brevicompactum

Table 1 and Table 2 clearly stated species of fungi that manages to survive on the growth medium in every experiment run by the researcher in every article. Research by Luo et al., 2017[13] shows that only one type of fungi, Trichoderma reesei, at 30°C manage to survive because of the ability to survive in the worst concrete condition compared to other species of fungi. Menon et al., 2019[12] show

*Aspergillus nidulans* (MAD1445) at 22°C, and 30°C could survive. Xijin et al., 2020[14] show *Fusarium oxysporum* in 29°C manage to grow on concrete and Martuscelli et al., 2020[7] state from 19 fungal strain there was only three fungal manage to survive in 25°C which is *Cladosporium herbarum*, *Cladosporium angustihbarum* and *Penicillium brevicompactum*.

Based on Luo et al., 2017[13], the characteristic of *T.reesei* that allows it to become self-healing agents is it non-pathogenic, which is it not cause any harm to another organism. In addition, the fungus also needs to withstand the high alkalinity of the concrete. Therefore, *T.reesei* have safe to use in industrial-scale production. Xijin et al., 2020[14] stated that *Fusarium oxysporum*, which has the capability to grow in concrete compares to other fungi, as it has the following characteristics: fast growth, the capability to precipitate calcium minerals, and water repellency, which enables self-healing concrete.

### 3.1 Factor affecting fungus on bio-concrete

Table 3, Table 4 and Table 5 below show the factor affecting fungus on bio-concrete.

**Table 3: Result of pH measurement**

Fungi survive	pH value	Finding	Researcher
<i>Trichoderma reesei</i>	13	<i>T.reesei</i> are drastic pH increasing from 6.5 to 13 and proved it could germinate into hyphal mycelium and growth consistently.	Luo et al., 2017[13]
<i>Aspergillus nidulans</i> (MAD1445)	13	pH value of <i>A. nidulans</i> ,(MAD1445) increased from 6.5 to 13 due to the leaching of calcium hydroxide from concrete.	Menon et al., 2019[12]
<i>Fusarium oxysporum</i>	9.2	<i>Fusarium oxysporum</i> able to develop mycelium and covered the surface of the mortar sample. The pH might affect the formation of CaCO <sub>3</sub> .	Xijin et al., 2020[14]

**Table 4: Ratio of the mixture in concrete**

Water to cement ratio	Sand to cement ratio	Finding	Researcher
0.5	3	<i>Trichoderma reesei</i> could react with concrete based on the cement ratio stated.	Luo et al., 2017[13]
0.5	2.46	<i>Fusarium oxysporum</i> could react with concrete based on the cement ratio stated.	Xijin et al., 2020[14]

**Table 5: Self-healing with different properties.**

Growth medium	Incubation duration (days)	Finding	Researcher
Potato Dextrose Agar (PDA)	21	Only one fungi could survive which is <i>Trichoderma reesei</i>	Luo et al., 2017[13]

Potato Dextrose Broth (PDB)	21	Fusarium oxysporum manage to survive.	Xijin et al., 2020[14]
Potato Dextrose Agar (PDA)	7	The total number of fungi that manage to growth is three out of nineteen.	Martuscelli et al., 2020[7]

Table 3 show the result of pH measurement based on previous research. The finding could be concluded that the development of the mycelium of fungi depends on pH value; only a few fungi could survive in high alkalinity. *Fusarium oxysporum* manages to survive in pH 9.2. *Trichoderma reesei* and *Aspergillus nidulans* (MAD1445) could grow at a pH value of 13. Based on Table 4, the findings conclude that both fungi could react to the concrete water to cement ratio and sand to cement ratio. Table 5 show the different properties used based on previous research. The incubation duration give an impact on the number of fungi growth. The number of days is 21 days in research of Luo et al., 2017[13] and Xijin et al., 2020[14]. Both of study manage to have one survival fungi which are *Trichoderma reesei* and *Fusarium oxysporum*. However, the survival of fungi in research Martuscelli et al., 2020[7] is three out of nineteen; this shows that the duration of incubation influences the growth of fungi on the concrete structure.

### 3.2 Effect of fungus in bio-concrete as self-healing agent

Based on the analysis data on the effect of fungus on concrete creates by the previous researcher, it could be concluded that the role of fungus has a positive impact on the construction industry. The self-healing of concrete happened when the fungi with nutrients were added together with the concrete mix. The water and oxygen will find their way in when a crack occurs. The dormant fungal spore will germinate with enough water and oxygen, and the precipitated calcium carbonate will heal the crack on concrete [14]. From the previous researcher, there are only certain fungi that could be a self-healing agent on concrete; fungi that could survive in the harsh environment have more tendency to be a crack repair agent. Luo et al., 2017[13] showed from six fungi examined, only *T.reesei* manages to survive. Most of the microorganisms cannot endure high alkalinity and die. The development of the mycelium of fungi depends on pH value; only a few fungi could survive in high alkalinity. The high alkalinity environment in cement-based composites reduces the amount of fungus that may survive. The duration of incubation time could affect the efficiency of the self-healing process. Menon et al., 2019[12] show that the incubation duration of fungi in the growth medium was 21 days, and only one fungus manages to survive, which is *Aspergillus nidulans* (MAD1445). Martuscelli et al., 2020[7] state that the duration for incubation of fungi on the growth medium is seven days, and only three out of nineteen strains of fungus manage to survive; the duration allocates less compared to other research, which is 21 days. The more duration of time, the fewer number of fungi could survive.

## 4.0 Conclusion

Based on past research, it can conclude that *Trichoderma reesei*, *Aspergillus nidulans* (MAD1445), *Fusarium oxysporum*, *Cladosporium herbarum*, *Cladosporium angustitherbarum* and *Penicillium brevicompactum* managed to promote calcium mineral to fill the crack on concrete and be a self-repairing agent on concrete. Self-healing efficiently depends on the species of fungi. The fungus that able to withstand high pH tend to grow and survive on concrete. Due to its high pH levels, concrete is classified as a harsh environment for fungi. The first and most important stage in using fungus to repair concrete cracks is to select fungal strains that can tolerate the severe concrete conditions and stimulate calcium carbonate precipitation. Then, during incubation on the growth medium, the duration of time could also affect the efficiency of the self-healing process. The more incubation duration on the growth medium, the fewer fungi could survive because the longer period of time needed to activate the self-healing process and sealing the crack which is shown based on the research.

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## References

- [1] Chen, H.-J., Chen, M.-C., & Tang, C.-W. (2020). Research on improving concrete durability by biomineralization technology. *Sustainability (Switzerland)*, 12(3).
- [2] Colin, R. G., (2014). Cement and concrete as an engineering material: An historic appraisal and case study analysis, 114-140.
- [3] Talaiekhozan, A., Keyvanfar, A., Shafaghat, A., Andalib, R., Majid, M. Z. A., & Fulazzaky, M. A. (2014). A Review of Self-healing Concrete Research Development . *Journal of Environmental Treatment Techniques* , October 2018.
- [4] Durga, C. S. S., Ruben, N., Chand, M. S. R., & Venkatesh, C. (2020). Performance studies on rate of self healing in bio concrete. *Materials Today: Proceedings*, 27, 158–162.
- [5] Luo, J., Chen, X., Crump, J., Zhou, H., Davies, D. G., Zhou, G., Zhang, N., & Jin, C. (2017). Interactions of fungi with concrete: Significant importance for bio-based self-healing concrete. *ArXiv*, 1–23.
- [6] Wiktor, V., & Jonkers, H. M. (2011). Quantification of crack-healing in novel bacteria-based self-healing concrete. *Cement and Concrete Composites*, 33(7), 763–770.
- [7] Martuscelli, C., Soares, C., Camões, A., & Lima, N. (2020). Potential of fungi for concrete repair. *Procedia Manufacturing*, 46, 180–185.
- [8] Hassan, A., Suhaimi, A. B., Abdul, R. M., Mohammad, I., Ahmad, R. Z., Shafinaz, S., & Wahid, A. H. A.,(2020). Insight into the role of microbial calcium carbonate and the factors involved in self-healing concrete.
- [9] Seifan, M., & Berenjian, A. (2019). Microbially induced calcium carbonate precipitation: a widespread phenomenon in the biological world. *Applied Microbiology and Biotechnology*, 103(12), 4693–4708.
- [10] Prima, Y. P., Isao U., Nevy S., Fitra R., & Totoh A., (2020). Calcium Carbonate in Bio-Based Material and Factor Affecting Its Precipitation Rate for Repairing Concrete, 132-140.
- [11] Bearman, M., Smith, C. D., Carbone, A., Slade, S., Baik, C., Hughes-Warrington, M., & Neumann, D. L. (2012). Systematic review methodology in higher education. *Higher Education Research and Development*, 31(5), 625–640.
- [12] Menon, R. R., Luo, J., Chen, X., Zhou, H., Liu, Z., Zhou, G., Zhang, N., & Jin, C. (2019). Screening of Fungi for Potential Application of Self-Healing Concrete. *Scientific Reports*, 9(1), 1–13.
- [13] Luo, J., Chen, X., Crump, J., Zhou, H., Davies, D. G., Zhou, G., Zhang, N., & Jin, C. (2017). Interactions of fungi with concrete: Significant importance for bio-based self-healing concrete. *Construction and Building Materials*, 164, 275-285.
- [14] Xijin Zhang , Xudong Fan , Min Li , Anna Samia , Xiong Yu (2020). Study on the behaviors of fungi-concrete surface interactions and theoretical assessment of its potentials for durable concrete with fungal-mediated self-healing.