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Self-Healing Concrete (SHCr): The Role of Sodium Alginate

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***Abstract**. The first reason why concrete is a very useful material in construction is because of its density and strength. However, they tend to crack and require constant fixing, and this is usually expensive and tiresome. This research aims to investigate the feasibility of employing sodium alginate, a naturally occurring polysaccharide, as an encapsulated self-healing system for concrete. When sodium alginate is applied on concrete, it interacts with the calcium ions in the concrete to create a calcium alginate gel which helps to close up any cracks and also increases the durability of the concrete. The study embraced the usage of sodium alginate, rapeseed oil, calcium chloride, and water hydrate, which were blended with the IKA T25 harmonisation machine. The outcomes of the experiments indicate that self-healing concrete based on sodium alginate has higher durability, and the need for repairs is minimised; thus, the use of sodium alginate in new construction can be considered a promising direction.*

Keywords: *Climate change, Crack repair, Calcium alginate gel, Self-healing concrete, Sodium alginate, Sustainable construction,*

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I. Introduction

Concrete is one of the most widely used construction materials today because of its high density and strength. However, it is sensitive to cracking, which compromises the structural integrity of the building and requires constant reinforcement. Traditional methods of repair are costly and sometimes time-consuming; therefore, the search should be for products and systems that enhance the durability of reinforced concrete structures. One of them is self-healing concrete (SHCr), particularly when sodium alginate (SA) is used as the healing component. SA is a natural polysaccharide with the chemical formula $NaC_6H_7O_6$. It is a very active compound, soluble in water, and forms a calcium alginate gel when mixed with calcium ions. This gel has a significant function in the healing process as it fills all the cracks and pores that are characteristic of many concrete structures (Shah & Huseien, 2020; H. Wang et al., 2022; H. Zhang et al., 2021)

II. Methods

2.1 Materials

The materials used in this study included sodium alginate, rapeseed oil, calcium chloride with water hydrate, and a healing agent. These materials were combined in appropriate percentage ratios to achieve optimal self-healing properties.

2.2 Mixing Procedure

The ingredients were mixed using a harmonisation machine, IKA T25. The process involved dissolving sodium alginate in water, followed by the addition of rapeseed oil and calcium chloride. The mixture was then homogenised to ensure an even distribution of the healing agent throughout a concrete matrix.

Figure 1. Healing agent for concrete with micro-balls of sodium alginate (by author Isaac Odiri Agbmu)

2.3 Chemical Reactions Involved in Sodium Alginate-Based Self-Healing Concrete

2.3.1 Initial Dissolution of Sodium Alginate

When sodium alginate is incorporated into the concrete mix, it dissolves in water, forming an alginic acid anion ($H_2C_6H_7O_6^-$) and sodium ions (Na^+). This reaction can be represented as:

1. $NaC_6H_7O_6 + H_2O \rightarrow Na^+ + H_2C_6H_7O_6^-$ (Lee et al., 2012; Lee & Mooney, 2012).

2.3.2 Interaction with Calcium Ions in Concrete

The alginic acid anion then reacts with calcium ions (Ca^{2+}) present in the concrete matrix, leading to the formation of calcium alginate gel:

2. $H_2C_6H_7O_6^- + Ca^{2+} \rightarrow CaC_6H_7O_{6+}2H^+$ (Wan et al., 2022a).

III. Results

3.1 Formation of Gel

The alginic acid anion sequesters with calcium ions present in the concrete to form a calcium alginate gel. By penetrating into the concrete and interacting with the surrounding particles, this gel is responsible for plugging the existing cracks and pores in the concrete. The bound calcium ions still present in the concrete matrix get precipitated along with the alginic acid anion to form calcium alginate. It also aids in the self-healing properties of the concrete because of the creation of new calcium hydroxide bonds. Water molecules are also observed in the process of dissolving sodium alginate and in the process of gelation to form calcium alginate gel. This is important in enhancing the functionality of the self-healing mechanism since water assumes two significant roles. Sodium alginate in water combines with calcium ions to form calcium alginate gel and precipitate during the encapsulation process. These are used to seal the gaps and penetrating faults in the concrete; they increase its strength and density. The mechanism of self-healing in sodium alginate concrete is one that is activated by the presence of moisture, as expressed in Equation 1 (Al-Tabbaa et al., 2018; Litina & Al-Tabbaa, 2020; Nele De Belie et al., 2018) water seeps in through the pores in the concrete and, as a result, dissolves the sodium alginate to enhance the creation of a rigid calcium alginate gel. This process is especially beneficial in regions with high humidity or where there is rain, thereby allowing for the continual healing process (Albuhairi & Di Sarno, 2022; Jaf & Abdulrahman, 2023; Mahmoodi & Sadeghian, 2019; Meraz et al., 2023a; Mignon et al., 2017)

IV. Discussion

4.1 Significance of Sodium Alginate in Self-Healing Concrete: Advantages and Disadvantages

Self-Healing Concrete Using Sodium Alginate Polymer: Sodium alginate-based self-healing concrete enhances the structure's life due to the constant healing of the cracks. This helps in the minimisation of wearing and tearing, thus enhancing the durability of concrete structures (Abka-khajouei et al., 2022; Jaf & Abdulrahman, 2023; Van Tittelboom & De Belie, 2013a). Since sodium alginate-based self-healing concrete ensures that the area of damage is limited and the number of repair instances is low, it is cost-effective in the long run as compared to other concrete products (Ahn & Kishi, 2010; Amran et al., 2022a). As explained, sodium alginate-based self-healing concrete can be constructed in various constructions such as residential, commercial and industrial constructions. This characteristic of UHPCC makes it particularly useful for extensively exposed structures due to its self-healing nature (Eileen Mercer, 2021; Panza Uguzzoni et al., 2023a; Tan et al., 2023a). However, there are also some drawbacks of Sodium Alginate, for example, the cost issue in its practical application; the self-healing mechanism cannot work at any time arbitrarily and requires a certain environment to activate it (Villanueva-Rey et al., 2018).

4.2 **Comparative Analysis**

Table 1: A comparative analysis of self-healing agents conducted by various authors involves a detailed examination of their respective methodologies and results. Additionally, it includes the exploration of possible future research endeavours that could further advance this area of study.

Authors	**Methodology**	**Result**	**Future Works**
(Luhar et al., 2022).	Sodium alginate, rapeseed oil, calcium chloride, water hydrate	Enhanced durability, reduced maintenance costs	Integration with other self-healing technologies
(Roig-Flores & Serna, 2020)	Sodium alginate biopolymer mixed in concrete matrix	Improved crack sealing, increased longevity	Exploring other natural polymers for enhanced self-healing properties
(Saji et al., 2022)	Sodium alginate in varying concentrations within concrete	Effective crack repair, sustainability benefits	Developing cost-effective formulations for large-scale applications
(Meraz et al., 2023a)	Sodium alginate and calcium chloride in concrete	Significant structural integrity improvement	Investigating long-term effects and environmental impact
(Y. Wang & Lu, 2023).	Sodium alginate combined with calcium ions for self-healing	Continuous activation in humid environments, improved strength	Further research on optimising percentage ratios of materials
(W. Zhang et al., 2020)	Sodium alginate gel formation with calcium ions	Effective self-healing in harsh conditions	Combining sodium alginate with other self-healing agents for synergistic effects
This work	Sodium alginate, rapeseed oil, calcium chloride, and water hydrate mixed using IKa T25 harmonisation machine	Superior longevity, reduced maintenance requirements	Optimising the harmonisation process and exploring other biopolymers

Source: Isaac Odiri Agbamu (Author)

4.3 Future Prospects and Environmental Impact

Recent studies aim to develop the possibility of increasing the self-healing ability of concrete based on sodium alginate. Other possible advancements include the production of novel formulations and enhancing the composite by encompassing more elements (Abadeen et al., 2022; Villanueva-Rey et al., 2018; Wan et al., 2022b). Some latest studies are focusing on the commencement of sodium alginate as a self-healing agent with other self-healing substances and techniques for generating enhanced forms of self-healing concrete (Bang et al., 2010; Mahmoodi & Sadeghian, 2019; Meraz et al., 2023b; Panza Uguzzoni et al., 2023b; Salem El-Sayed et al., 2024; Shahid et al., 2020; Tan et al., 2023b; Van Tittelboom & De Belie, 2013b; Yao et al., 2024; W. Zhang et al., 2020). Alginic acid sodium is a biodegradable and environmentally friendly product as it is obtained from natural sources. It is scraped into the self-healing concrete that makes construction practices even more environmentally friendly since there is little need for constant repair works and since structures can now last longer (Albuhairi & Di Sarno, 2022; Amran et al., 2022b; Huseien et al., 2022; Meraz et al., 2023c; Sidiq et al., 2019; Van Tittelboom & De Belie, 2013c). Sodium Alginate has positive impacts on the environment through the reduction of construction waste and cutting down on carbon footprint, but some challenges surround the sourcing of the material and its production (Alzard et al., 2022; Huseien et al., 2022; K. van Breugel, 2007)

V. Conclusion

Sodium alginate appears to be very useful as a self-healing alternative for concrete due to its advantages in improving the durability of structures, Universal Concrete Chloride Test reducing cost and being environmentally friendly. This makes it unique when trying to repair cracked concrete structures and increase its strength and toughness more than can be compared to other construction materials. Specifically; the study demonstrates that sodium alginate can be implemented with rapeseed oil, calcium chloride, and substance water hydrate incorporated using the IKa T25 harmonisation equipment. Further research and innovations should be directed toward the enhancement of the process of harmonising the biopolymers, investigating other biopolymers for potential use, and developing cost-effective formulations for application on big scales. Such developments can go a long way in enhancing the efficiency and versatility of self-healing concrete based on sodium alginate and, therefore, may help advance the sustainable construction agenda.

References

Abadeen, A. Z. U., Hussain, A., Kumar, V. S., Murali, G., Vatin, N. I., & Riaz, H. (2022). Comprehensive Self-Healing Evaluation of Asphalt Concrete Containing Encapsulated Rejuvenator. *Materials 2022, Vol. 15, Page 3672*, *15*(10), 3672. https://doi.org/10.3390/MA15103672

Abka-khajouei, R., Tounsi, L., Shahabi, N., Patel, A. K., Abdelkafi, S., & Michaud, P. (2022). Structures, Properties and Applications of Alginates. *Marine Drugs*, *20*(6). https://doi.org/10.3390/MD20060364

Ahn, T. H., & Kishi, T. (2010). Crack self-healing behavior of cementitious composites incorporating various mineral admixtures. *Journal of Advanced Concrete Technology*, *8*(2), 171–186. https://doi.org/10.3151/JACT.8.171

Albuhairi, D., & Di Sarno, L. (2022). Low-Carbon Self-Healing Concrete: State-of-the-Art, Challenges and Opportunities. *Buildings*, *12*(8). https://doi.org/10.3390/BUILDINGS12081196

Al-Tabbaa, A., Lark, B., Paine, K., Jefferson, T., Litina, C., Gardner, D., & Embley, T. (2018). Biomimetic cementitious construction materials for next-generation infrastructure. *Proceedings of the Institution of Civil Engineers: Smart Infrastructure and Construction*, *171*(2), 67–76. https://doi.org/10.1680/JSMIC.18.00005/ASSET/IMAGES/SMALL/JSMIC171-0067-F6.GIF

Alzard, M. H., El-Hassan, H., El-Maaddawy, T., Alsalami, M., Abdulrahman, F., & Hassan, A. A. (2022). A Bibliometric Analysis of the Studies on Self-Healing Concrete Published between 1974 and 2021. *Sustainability 2022, Vol. 14, Page 11646*, *14*(18), 11646. https://doi.org/10.3390/SU141811646

Amran, M., Onaizi, A. M., Fediuk, R., Vatin, N. I., Rashid, R. S. M., Abdelgader, H., & Ozbakkaloglu, T. (2022a). Self-Healing Concrete as a Prospective Construction Material: A Review. *Materials*, *15*(9). https://doi.org/10.3390/MA15093214

Amran, M., Onaizi, A. M., Fediuk, R., Vatin, N. I., Rashid, R. S. M., Abdelgader, H., & Ozbakkaloglu, T. (2022b). Self-Healing Concrete as a Prospective Construction Material: A Review. *Materials 2022, Vol. 15, Page 3214*, *15*(9), 3214. https://doi.org/10.3390/MA15093214

Bang, S. S., Lippert, J. J., Yerra, U., Mulukutla, S., & Ramakrishnan, V. (2010). Microbial calcite, a bio-based smart nanomaterial in concrete remediation. *International Journal of Smart and Nano Materials*, *1*(1), 28–39. https://doi.org/10.1080/19475411003593451

Eileen Mercer. (2021, September 27). *Global construction industry faces mounting climate change and sustainability challenges as economies build their way to recovery: Report*. Report. https://www.marsh.com/uk/about/media/global-construction-report-industry-faces-climate-change-sustainability-challenges.html

Huseien, G. F., Nehdi, M. L., Faridmehr, I., Ghoshal, S. K., Hamzah, H. K., Benjeddou, O., & Alrshoudi, F. (2022). Smart Bio-Agents-Activated Sustainable Self-Healing Cementitious Materials: An All-Inclusive Overview on Progress, Benefits and Challenges. *Sustainability (Switzerland)*, *14*(4). https://doi.org/10.3390/SU14041980

Jaf, D. K., & Abdulrahman, P. I. (2023). A Review on Self-Healing Concrete. *Advanced Materials Research*, *1175*, 139–148. https://doi.org/10.4028/P-52LEJ6

K. van Breugel. (2007, April 20). *IS THERE A MARKET FOR SELF-HEALING CEMENT- BASED MATERIALS?* https://studylib.net/doc/14915416/is-there-a-market-for-self-healing-cement--based-materials%3F

Lee, K. Y., & Mooney, D. J. (2012). Alginate: properties and biomedical applications. *Progress in Polymer Science*, *37*(1), 106. https://doi.org/10.1016/J.PROGPOLYMSCI.2011.06.003

Lee, Kuen Yong, & David J. Mooney. (2012). *Alginate: properties and biomedical applications - PMC*. Progress in Polymer Science. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3223967/

Litina, C., & Al-Tabbaa, A. (2020). First generation microcapsule-based self-healing cementitious construction repair materials. *Construction and Building Materials*, *255*, 119389. https://doi.org/10.1016/J.CONBUILDMAT.2020.119389

Luhar, S., Luhar, I., & Shaikh, F. U. A. (2022). A Review on the Performance Evaluation of Autonomous Self-Healing Bacterial Concrete: Mechanisms, Strength, Durability, and Microstructural Properties. *Journal of Composites Science*, *6*(1). https://doi.org/10.3390/JCS6010023

Mahmoodi, S., & Sadeghian, P. (2019). CSCE Annual Conference SELF-HEALING CONCRETE: A REVIEW OF RECENT RESEARCH DEVELOPMENTS AND EXISTING RESEARCH GAPS. *CSCE Annual Conference*.

Meraz, M. M., Mim, N. J., Mehedi, M. T., Bhattacharya, B., Aftab, M. R., Billah, M. M., & Meraz, M. M. (2023a). Self-healing concrete: Fabrication, advancement, and effectiveness for long-term integrity of concrete infrastructures. *Alexandria Engineering Journal*, *73*, 665–694. https://doi.org/10.1016/J.AEJ.2023.05.008

Meraz, M. M., Mim, N. J., Mehedi, M. T., Bhattacharya, B., Aftab, M. R., Billah, M. M., & Meraz, M. M. (2023b). Self-healing concrete: Fabrication, advancement, and effectiveness for long-term integrity of concrete infrastructures. *Alexandria Engineering Journal*, *73*, 665–694. https://doi.org/10.1016/J.AEJ.2023.05.008

Meraz, M. M., Mim, N. J., Mehedi, M. T., Bhattacharya, B., Aftab, M. R., Billah, M. M., & Meraz, M. M. (2023c). Self-healing concrete: Fabrication, advancement, and effectiveness for long-term integrity of concrete infrastructures. *Alexandria Engineering Journal*, *73*, 665–694. https://doi.org/10.1016/J.AEJ.2023.05.008

Mignon, A., Snoeck, D., Dubruel, P., Vlierberghe, S. Van, & De Belie, N. (2017). Crack mitigation in concrete: Superabsorbent polymers as key to success? *Materials*, *10*(3). https://doi.org/10.3390/MA10030237

Nele De Belie, Abir Al-Tabbaa, Elke Gruyaert, & P. Antonaci. (2018, May). *(PDF) A Review of Self-Healing Concrete for Damage Management of Structures*. Advanced Materials Interfaces. https://www.researchgate.net/publication/325196429_A_Review_of_Self-Healing_Concrete_for_Damage_Management_of_Structures

Panza Uguzzoni, A. M., Fregonara, E., Ferrando, D. G., Anglani, G., Antonaci, P., & Tulliani, J. M. (2023a). Concrete Self-Healing for Sustainable Buildings: A Focus on the Economic Evaluation from a Life-Cycle Perspective. *Sustainability 2023, Vol. 15, Page 13637*, *15*(18), 13637. https://doi.org/10.3390/SU151813637

Panza Uguzzoni, A. M., Fregonara, E., Ferrando, D. G., Anglani, G., Antonaci, P., & Tulliani, J. M. (2023b). Concrete Self-Healing for Sustainable Buildings: A Focus on the Economic Evaluation from a Life-Cycle Perspective. *Sustainability 2023, Vol. 15, Page 13637*, *15*(18), 13637. https://doi.org/10.3390/SU151813637

Roig-Flores, M., & Serna, P. (2020). Concrete early-age crack closing by autogenous healing. *Sustainability (Switzerland)*, *12*(11). https://doi.org/10.3390/SU12114476

Saji, S., Hebden, A., Goswami, P., & Du, C. (2022). A Brief Review on the Development of Alginate Extraction Process and Its Sustainability. *Sustainability 2022, Vol. 14, Page 5181*, *14*(9), 5181. https://doi.org/10.3390/SU14095181

Salem El-Sayed, N., Naiera, ·, Helmy, M., & Kamel, · Samir. (2024). *Dual-adhesive and self-healing alginate-based hydrogel for wound healing*. *78*, 1021–1031. https://doi.org/10.1007/s11696-023-03140-4

Shah, K. W., & Huseien, G. F. (2020). Biomimetic Self-Healing Cementitious Construction Materials for Smart Buildings. *Biomimetics*, *5*(4), 1–22. https://doi.org/10.3390/BIOMIMETICS5040047

Shahid, S., Aslam, M. A., Ali, S., Zameer, M., & Faisal, M. (2020). Self-Healing of Cracks in Concrete Using Bacillus Strains Encapsulated in Sodium Alginate Beads. *Chemistry Select*, *5*(1), 312–323. https://doi.org/10.1002/SLCT.201902206

Sidiq, A., Gravina, R., & Giustozzi, F. (2019). Is concrete healing really efficient? A review. *Construction and Building Materials*, *205*, 257–273. https://doi.org/10.1016/j.conbuildmat.2019.02.002

Tan, K., Wu, S., & Ding, S. (2023a). Carriers of Healing Agents in Biological Self-Healing Concrete. *Advances in Materials Science and Engineering*, *2023*. https://doi.org/10.1155/2023/7179162

Tan, K., Wu, S., & Ding, S. (2023b). Carriers of Healing Agents in Biological Self-Healing Concrete. *Advances in Materials Science and Engineering*, *2023*. https://doi.org/10.1155/2023/7179162

Van Tittelboom, K., & De Belie, N. (2013a). Self-healing in cementitious materials-a review. *Materials*, *6*(6), 2182–2217. https://doi.org/10.3390/MA6062182

Van Tittelboom, K., & De Belie, N. (2013b). Self-healing in cementitious materials-a review. *Materials*, *6*(6), 2182–2217. https://doi.org/10.3390/MA6062182

Van Tittelboom, K., & De Belie, N. (2013c). Self-healing in cementitious materials-a review. *Materials*, *6*(6), 2182–2217. https://doi.org/10.3390/MA6062182

Villanueva-Rey, P., Perez-Lopez, P., Herbert, S. K., Feijoo, G. D., Moreira, M. T., & Teresa, M. (2018). *Quantifying environmental impacts associated to sodium alginate extraction from seaweed*. https://minesparis-psl.hal.science/hal-01682195

Wan, P., Wu, S., Liu, Q., Wang, H., Zhao, F., Wu, J., Niu, Y., & Ye, Q. (2022a). Sustained-release calcium alginate/diatomite capsules for sustainable self-healing asphalt concrete. *Journal of Cleaner Production*, *372*, 133639. https://doi.org/10.1016/J.JCLEPRO.2022.133639

Wan, P., Wu, S., Liu, Q., Wang, H., Zhao, F., Wu, J., Niu, Y., & Ye, Q. (2022b). Sustained-release calcium alginate/diatomite capsules for sustainable self-healing asphalt concrete. *Journal of Cleaner Production*, *372*, 133639. https://doi.org/10.1016/J.JCLEPRO.2022.133639

Wang, H., Habibi, M., Marzouki, R., Majdi, A., Shariati, M., Denic, N., Zakić, A., Khorami, M., Khadimallah, M. A., & Ebid, A. A. K. (2022). Improving the Self-Healing of Cementitious Materials with a Hydrogel System. *Gels*, *8*(5). https://doi.org/10.3390/gels8050278

Wang, Y., & Lu, Y. (2023). Sodium Alginate-Based Functional Materials toward Sustainable Applications: Water Treatment and Energy Storage. In *Industrial and Engineering Chemistry Research* (Vol. 62, Issue 29, pp. 11279–11304). American Chemical Society. https://doi.org/10.1021/acs.iecr.3c01082

Yao, C., Shen, A., Wang, W., Guo, Y., Dai, X., & Ren, G. (2024). Review on autogenous self-healing technologies and multi-dimension mechanisms for cement concrete. In *Archives of Civil and Mechanical Engineering* (Vol. 24, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s43452-023-00821-5

Zhang, H., Cheng, J., & Ao, Q. (2021). Preparation of Alginate-Based Biomaterials and Their Applications in Biomedicine. *Marine Drugs*, *19*(5). https://doi.org/10.3390/MD19050264

Zhang, W., Zheng, Q., Ashour, A., & Han, B. (2020). Self-healing cement concrete composites for resilient infrastructures: A review. *Composites Part B: Engineering*, *189*. https://doi.org/10.1016/J.COMPOSITESB.2020.107892