

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.

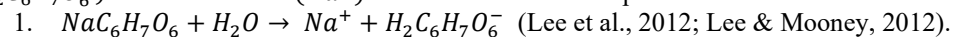


Figure 1. Healing agent for concrete with micro-balls of sodium alginate (by author Isaac Odiri Agbmu)

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

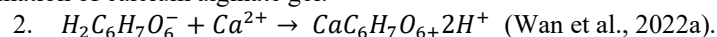
2.3.1 Initial Dissolution of Sodium Alginate

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:



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:



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 & Sema, 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.

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