Performance of Sodium Silicate as Self-Healing Agent on Concrete Properties: A Review

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Abstract. Important materials in construction industry are concrete. Even though concrete is strong and durable, but it is still exposed to the crack. The most severe phenomenon of cracking happens in concrete without adequate and prompt care, and the framework of the crack continues to grow, which ultimately involves substantial potential maintenance costs increase. This study aims to review the effect of sodium silicate as self-healing agent on engineering properties and to observe the influence of sodium silicate inclusion in concrete on the microstructural characteristics. To obtain relevant paper for this research, a systematic literature review was used. The self-healing mechanism in a concrete help in reducing the cracking problem as it could delay the deterioration time and reduce the interaction of humans in managing the crack. Sodium silicate used in the concrete reacts with calcium hydroxide that already contains in the concrete to produce a new kind of binding material, namely calcium silicate hydrate (C-S-H). The outcome of this study has developed green and new technology to the concrete production in achieving sustainability which is the use of sodium silicate capable indicate healing properties in the cracking of concrete.

1.0 Introduction

Concrete is one of the widely popular building materials. Concrete is generally a mixture of coarse cement, sand, granular aggregate, and water. The general application in concrete is the mix of water and cement will form a paste or matrix that and next fill the voids of aggregates. For constructing structures such as bridges and buildings, the most preferred building material to be used is concrete. Because of the simplicity of casting in different shapes and sizes, the product has been successful and popular, and it also simple to obtain on the market and cheaper compared to other building materials. Another reason why concrete been selected as the best construction material is that concrete has high-strength qualities and high resistance to external effects. The difference of concrete from other construction materials such as stone and bricks are the compressive strength of concrete is higher than others [1]. Concrete technology has been developing rapidly for past years and prompted new kind of concrete with various grades and types. There is a lot of new kind of concrete that had been developed and investigated, including foam concrete, lightweight concrete, high strength concrete, and others. One of the concrete technologies that been demanded by the industry is an addition of chemical solvents such as sodium silicate as one of the materials to produce concrete, and the sodium silicate replaced a certain amount of water by percentage.

Concrete has become the most common building material, but the cracks in the concrete area major problem that has been encountered since time immemorial. A study conducted by [2] claimed that cracks are a common phenomenon. Larger cracks have the potential to undermine the integrity of
a structure, and repairing action is required, while smaller crack that has width 0.2 mm and can be considered as unproblematic [3]. Cracks occur due to various factors, and this crack can cause deterioration to the embedded reinforcement. This situation will induce rusting of steel reinforcement and thus decreases the quality of the structure [4]. Even though the concrete is believed to be strong and durable, but it is still having a major problem which is deterioration and cracks. Different processes, such as the tensile force, shrinkage, and hydraulic compressive, create cracks, which allow water and air to become further vulnerable to the embedded reinforcing. The enhance the deterioration as the ingestion rate of corrosive increased. To overcome this problem, a new technique has been developed by using a chemical in the production of concrete and introducing a self-healing mechanism to the concrete. Concrete deterioration is reduced by the application of different chemical admixtures, humidifying admixtures, concrete hardeners [5].

In recent years, concrete innovations have been strong, which is to meet the demand of the construction industry. Various forms of concrete have been built to conform to different buildings and climates. Among the concrete types which have been produced and tested are the geo-polymer concrete, self-compacting concrete, foam concrete, and bio concrete. Portland cement paste or cement filler mortar was used to create this foam concrete, and the application of this type of concrete is uniformly distributed pore structure produced by adding foaming agent [6]. A new type of concrete named bio concrete using microorganisms in the development of sustainable concrete that can improve the concrete properties naturally [7]. The primary goal of this research is to review the effect of sodium silicate as the self-healing agent on engineering properties.

2.0 Material and Methods

All the data and information collected in this study regarding the use of sodium silicate as the healing on the concrete was discussed in the experimental method. This phase of work important to indicate the method and effect of using the sodium silicate to the concrete. All data and information are from previous researchers.

2.1 Beglarigale et al., [8]

Sodium silicate solution was used and transport through the encapsulation method. The sodium silicate is encapsulated on aqueous sodium silicate droplets through interfacial polymerization of the shell-forming monomer. This study aims to determine the effectiveness of the microcapsules. Sodium silicate solution (Na2O, 10.6%, and SiO2, 26.5%) with deionized water used in the study were purchased from Sigma-Aldrich. Sigma-Aldrich also supplied the shell-forming monomer and also Dibutyltindilaurate that used as a catalyst. Four different mixtures, namely MDI 1 (7.5g), MDI 2 (10.0g), MDI 3 (12.5g), and MDI 4 (15.0g) prepared with a different portion of MDI. The ratio of the shell monomer to sodium silicate solution are 0.50, 0.67, 0.83, and 1.00. Microstructural observation was conducted by SEM, EDS, FTIR, TGA, and XRD.

2.2 Shaikh et al., [9]

The main objective of this experiment is to develop a new kind of concrete that able to heal the crack by itself. The main material used in this study is sodium silicate solution that capable as crack healing agent. Glass tube with 16mm diameter was used in this study to store sodium silicate solution before being added into the concrete mix. The concrete specimen created in this experiment is M35 grade, with a dimension of 150 x 150 x 150mm. The idea in this project is the 28 days age concrete specimen will be applied with mechanical stress using a compressive machine, and it caused the rupture of the glass tube. The sodium silicate solution stored in the tube will be released into the fair crack.

2.3 Devi et al., (2016) [10]

Sodium silicate was used as the healing agent and replaced directly to the water. Concrete grade 30 was constructed and the portion of the sodium silicate solution used is 2% of the water. Polyethylene Glycol also being added into the concrete mix to increase the compressive strength of the concrete. After the concrete mixture, it cured into two different curing methods which self-curing and water
curing. On self-healing and water curing materials, a compressive strength check was carried out to assess the quality of the concrete after sodium silicate had been applied.

2.4. Irico et al., [11]
The use of sodium silicate solution and hydrated Portland cement was investigated. The reactivity of the sodium silicate solution as the healing agent for cement-based products was studied between the two materials. The mineralogy investigation was conducted by using XRPD, and the mechanical recovery was tested on the hydrated cement.

2.5. Giannaros et al., [12]
There are two different microcapsules used which is namely L500 and T130. The L500 microcapsules were stored with 42% liquid sodium silicate solution dispersed in mineral oil and emulsifier. On the other hand, in situ polymerization was used to manufacture the T130. CEM I 52.5N cement was created in this experiment, and both microcapsules were added into the specimen during the mixing process. Table 1 shows the properties of the microcapsules.

| Name  | Shell Material | Cargo Material   | Mean size (µm) |
|-------|----------------|------------------|----------------|
| L500  | Gelatin-gum Arable | Na₂SiO₃ (liquid) | 500            |
| T130  | Poly-urea      | Na₂SiO₃ (solid)  | 130            |

2.6. Manoj Prabahar et al., [13]
The experiment conducted with fifteen concrete beams that contain different amounts of sodium silicate percentage (0, 1.5, 3, 4.5, and 6%). The sodium silicate was capsulated and introduced to the concrete during the mixing process. The casted specimen was next being cured for 28 days before testing. Artificial crack was created on the concrete by using the three-point bending system as shown in figure 1.

![Figure 1: Crack induced by three-point bending test [13]](image)

2.7. Amir Sidiq et al., [14]
Sodium silicate was stored in microcapsules with polyurethane as the shell material. The microcapsules containing sodium silicate will be presented to the concrete during the mixing process. The evaluation of the mechanical and non-destructive tests was conducted to observe the strength recovery. Microstructural investigation using X-ray tomography and XRD analysis to determine the chemical composition and also to observe the production of healing material.
3.0 Results and Discussion
This chapter discussed the results of using sodium silicate as a self-healing agent in the concrete. The engineering properties of the concrete and the microstructural characteristics of the product has been identified and discussed after adding the sodium silicate into the concrete mix.

3.1 Compressive Strength
Compressive strength testing for construction material is a relatively common and effective test. So, to improve the compressive strength of the concrete, a lot of additional materials have been used by previous researchers include bacteria and chemical composition. The strength of that concrete largely represents the concrete quality. In concrete technology, various types of additional materials used to improve the strength of the concrete and to reduce pozzolanic materials [15]. Bacteria were used in producing bioconcrete to improve the strength of the concrete [16].

The engineering properties of the concrete mostly obtained and observe based on the compressive strength of the concrete. Concrete with higher compressive strength shows that the concrete is much more durable and stronger. This study indicates the introduction of sodium silicate into concrete production as the healing agent does giving impact on the concrete engineering properties. Based on a study by [11] shows that the specimen that containing sodium silicate as the admixture does giving positive impact on the compressive strength compared to the concrete that does not contain sodium silicate. However, based on the experiment conducted by [12] and [14] shows a significant decrease in compressive strength as the concrete was ageing more than 28days. In the other hand, the experiment conducted by [17] shows that the curing method does not give much difference on the compressive strength of the concrete than containing sodium silicate.

The increment in the compressive strength is caused by the reaction between sodium silicate and calcium hydroxide and producing a healing material into the pores and cracks of the concrete, namely calcium silicate hydrate (C-S-H). Calcium silicate hydrate (C-S-H) acts as a binding material to the concrete. The calcium silicate hydrate (C-S-H) precipitation will fill the crack and allows some recovery of strength. The production of calcium silicate hydrate (C-S-H) can be proven from the microstructural characteristic of the concrete specimen based on the previous study.

![Figure 2. Compressive Strength of specimen [11]](image-url)
3.2. Determination of healing material on the concrete

Determination of healing material produced from the use of sodium silicate is important to prove that the use of sodium silicate in the concrete production can give impact on the engineering properties of the concrete. The determination of the healing material based on the previous research was conducted on the microstructural characteristic of the concrete. This is important in order to identify the type and characteristic of the healing material produced in the concrete. A scanning electron microscope (SEM) was used to support the first visual inspection done by using a light microscope [18].

Utilization of sodium silicate as a healing agent in the concrete is able to produce a material that able to coverup the pores and crack of the concrete. The sodium silicate used will be reacting with calcium hydroxide and producing healing material that acts as a binder to the cracks, namely calcium silicate hydrate (C-S-H). Based on the observation on the microstructural characteristic of the concrete or specimen containing sodium silicate as the healing agent, the material produced has been identified as calcium silicate hydrate (C-S-H). Calcium silicate hydrate (C-S-H) has been identified by [12] and [11].
**Figure 5.** X-ray diffractogram of hardened cement paste [12]

**Figure 6.** XRPD diffraction patterns (Sample S) [11]

**Figure 7.** XRPD diffraction patterns (Sample W) [11]
3.3. Concluding remarks
Based on the observation from the methodology used by the previous shows that sodium silicate had been used in various ways. One of the best ways to transport the sodium silicate into the concrete is by the encapsulation method which is shown in [8,10,12,13] and [14]. The encapsulated sodium silicate will be introduced to the concrete during the mixing process. The advantage of this encapsulated method is self-healing agent sodium silicate that is added into the specimen having a higher probability of undergoing the chemical reaction as the shell or microcapsules ruptured the sodium silicate with better composition will be released.

The sodium silicate also being used by directly mix into the concrete mixture by replacing the amount of water in the mix, as shown in [17] and [11]. This method is less effective compare to the encapsulated method as the composition of the self-healing agent sodium silicate might be changed during the mixing process. The healing mechanism started if the chemical reaction occurred between sodium silicate and other chemicals and believed it would be able to produce a material that can cover the crack and pores.

4.0 Conclusion
Main goals of this study are to review the effect of sodium silicate as the self-healing agent on engineering properties based on previous research. The compressive strength of the concrete containing sodium silicate as the self-healing agent is better than the conventional concrete that does not contain sodium silicate. There is an improvement in the compressive strength of concrete containing sodium silicate as the healing agent sodium silicate helps in strengthening the concrete composition. The sodium silicate used in the concrete will react with the calcium hydroxide that already contains in the concrete to produce a new kind of binding material, namely calcium silicate hydrate (C-S-H). This calcium silicate hydrate (C-S-H) will be helping in improving the strength and durability of the concrete by healing and covering the cracks and pores that occurred on concrete. This condition helps in improving the lifetime of a concrete structure and also would be able to minimise and reduce the repair and maintenance cost. The calcium silicate hydrate (C-S-H) was proven from the microstructural analysis conducted. Calcium silicate hydrate (C-S-H) has been identified by [12] and [11].

Besides that, to observe the influence of the sodium silicate inclusion in concrete on the microstructural characteristics. Calcium silicate hydrate (C-S-H) produced by the chemical reaction between healing agent sodium silicate and calcium hydroxide was observe based on the microstructural of the concrete. The importance of this microstructural analysis is to confirm the production of healing material in the concrete, and for this case, the used of sodium silicate as the self-healing agent are able to produce a binding kind of material that could cover up the cracks and pores in the concrete, and it was namely Calcium silicate hydrate (C-S-H).

In can be concluded that both of objectives of this study were accomplished, and sodium silicate is proved and capable to improve the characteristics and composition of concrete. The self-healing method by using sodium silicate can be further commercialized in construction industries. The durability and strength of the concrete structure will be improved, and the interaction of human on the crack repairing and maintenance could be reduced. This condition created much better environment in the future.

5.0 References
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