MUNISI: Military Mathematics and Natural Sciences
e-ISSN: 3026-2968
Vol. 3, No. 2, December 2025, pp. 55-61
Available online at https://jurnal.idu.ac.id/index.php/munisi

Synthesize of Sodium Silicate from Coconut Fiber for The Manufacture of Anti-Corrosion

Muhammad Zuhairy Fahriansyah[1,*], Fajar Ismail Rhomadon[1], M. Sulthon Nurharmansyah Putra[1], Tedi Kurniadi[1]
[1] Chemistry Department, Faculty of Mathematics and Military Sciences, Republic of Indonesia Defense University

* Corresponding Author: fahri.zhr123@gmail.com

Abstract

Indonesia is second ranks after Brazil in terrestrial biodiversity globally. When combined with its rich marine biodiversity, Indonesia possesses the highest overall biodiversity in the world. This study aimed to synthesize sodium silicate (Na_2SiO_3) from coconut fiber and evaluate its characteristics as an anti-corrosion material. Coconut fiber, which has a high silica (SiO_2) content, was used as the primary raw material. The synthesis process involved two main stages: silica isolation from coconut fiber and the reaction of silica with sodium hydroxide (NaOH) to produce sodium silicate. The experimental results showed that the synthesized sodium silicate had a bluish-white color with a yield of 10.625%. The compound exhibited a pH of 13, was soluble in water, and insoluble in alcohol. The synthesized sodium silicate has potential applications as an anti-corrosion material in various industries, particularly for protecting metal structures in the defense sector.

Keywords: Coconut fiber; Sodium silicate; Anti-corrosion

Introduction

Indonesia is second ranks after Brazil in terrestrial biodiversity globally. When combined with its rich marine biodiversity, Indonesia possesses the highest overall biodiversity in the world [9]. As of 2017, Indonesia had identified 31,750 plant species, 25,000 of which are flowering plants based on LIPI information. The country hosts diverse ecosystems that support agricultural and plantation activities. Its vast territory allows each region to develop distinct agricultural commodities. One of the leading plantation crops is coconut [9].

According to the Central Statistics Agency (Plantation Company Survey), the coconut plantation area in Indonesia covers 3,331,600 hectares. Indonesia is one of the largest coconut producers in the world, with export potential reaching USD 25 billion in 2022. The extent of coconut plantation areas significantly influences their utilization, such as production capacity, processing types, as well as the economic and social impacts of the coconut industry. Based on previous studies, the utilization of coconut plants is categorized as food (95%), construction material (88%), crafts (80%), medicine (71%), fuel (60%), ritual ceremonies (20%), and cosmetics (6%) [4].

The coconut plant (*Cocos nucifera*) has vast potential for applications in various scientific fields. Different parts of the plant can be utilized based on their natural composition. According to Uliana et al. [2], the components of coconut husk consist of 30-33% fiber, 26.0% water, 14.25% pectin, 8.50% hemicellulose, 21.07% cellulose, 29.23% lignin, and 35% silica. These findings indicate that silica (SiO_2) is the most effective component for research and development. Silica utilization shows potential as a raw material for sodium silicate production by reacting silica with sodium hydroxide [10]. This compound offers significant advantages in defense-related applications, particularly as an anti-corrosion material.

Corrosion is a material degradation process primarily caused by chemical or electrochemical reactions. It occurs as a result of interactions with environmental elements such as water, oxygen, and other chemicals. In metals, corrosion happens when metal atoms lose electrons and dissolve into the surrounding solution as ions, gradually eroding the metal and forming rust. Corrosion prevention methods, or anticorrosion techniques, are essential for preventing, slowing down, or inhibiting the corrosion process, particularly in metals. The primary goal of corrosion protection is to safeguard materials from damage that could compromise their strength, durability, and service life. Anticorrosion materials refer to specially designed substances or coatings that protect metal surfaces from corrosion. Sodium silicate is a promising alternative for the development of anticorrosion materials due to its ability to create a thin protective film that isolates the metal surface from contaminants [3, 8]. This thin film consists of silicate ions that act as a protective barrier against corrosion (alkali ion attacks). Sodium silicate has the potential to serve as a critical anticorrosion material to support Indonesia's current military defense systems.

Therefore, based on the background of defense equipment in Indonesia, which generally uses steel as the primary material, protection is required to address the primary issue of corrosion. The use of coconut fiber as a base material in the production of sodium silicate is due to its high silica content, which enhances the effectiveness of sodium silicate. This experiment aims to determine the synthesis process of sodium silicate using coconut fiber as the base material and to analyze the fundamental outcomes of the sodium silicate synthesis.

Materials and Methods

Tools and Materials

The equipment used in this research includes a furnace, oven, hot plate, magnetic stirrer, analytical balance, porcelain crucible, mortar and pestle, glassware, filter paper, dropper pipette, and a 100-mesh sieve. The materials utilized consist of coconut husk, 1 M hydrochloric acid (HCl), 2 M and 3 M sodium hydroxide (NaOH), distilled water (H_2O), and a universal pH meter.

Preparation of the materials

Isolation of Silica from coconut Husk Waste

Sample preparation begins by reducing the size of coconut husk raw materials, thoroughly washing them, and then drying them. The dried husk is then ashed in a furnace at 600°C for 2 hours. The resulting coconut husk ash is washed with 1M HCl and left for 1 hour to allow for sedimentation. Afterward, the mixture is filtered using filter paper and dried at room temperature. The sediment is then mixed with 500 ml of 2M NaOH solution using a magnetic stirrer and heated on a hot plate at 150–

200°C for 1 hour. After heating, the solution is filtered, and the filtrate is neutralized by adding a sufficient amount of HCl until a neutral pH is reached. It is then left undisturbed for 18 hours to facilitate condensation, which allows the release of sodium salts from the gel volume. The resulting filtrate is filtered and washed gradually with distilled water until clean. The silica precipitate is placed in an oven and dried at 105°C for 12 hours. The dried silica is then ground using a mortar until it becomes a silica powder and sieved with a 100-mesh sieve.

Synthesis of Sodium Silicate

Silica was crushed and weighed to obtain 10 grams. The pulverized silica was placed in a beaker and mixed with 82.5 mL of 4 M NaOH. The sample was then boiled at 80°C for 4 hours under constant stirring. The mixture was transferred to a porcelain crucible and calcined at 500°C for 30 minutes. Subsequently, the sodium silicate was allowed to cool, ground, and further refined.

Results and Discussion

Sodium silicate, also known as water glass, is an inorganic compound composed of sodium ions (Na^+) and silicate ions (SiO_3^{2-}), where the silicate anions may vary depending on the molar ratio of Na^+ and SiO_2 in its formation. This compound forms a solid with highly useful properties due to its solubility in water [6]. Its pure composition is colorless or white with a molecular weight of 122.06. Sodium silicate exhibits high conductivity, significant ion mobility, and varying viscosities depending on its type [2]. Commercially available sodium silicate typically comes in solid form with a particle size of 120 mesh and is commonly used as a metal bleaching agent and as a detergent or soap to maintain an alkaline pH.

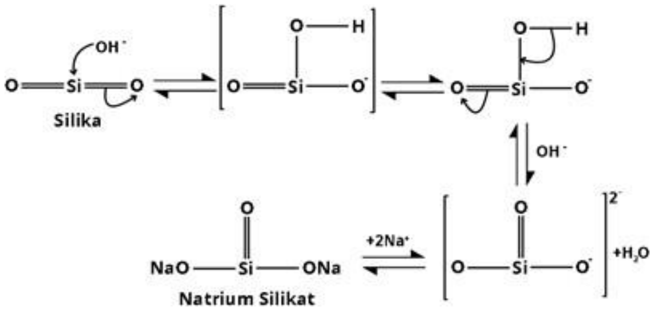


Figure 1. The Reaction Mechanism of Sodium Silicate Formation [11]

Sodium silicate exhibits ionic bonding, formed through the tendency of atoms to gain or lose electrons to achieve stability. The effective formation of sodium silicate significantly influences the recovery of silica, thereby maximizing its absorption. High temperatures can affect the synthesis process of sodium silicate. Under high temperatures, quartz heated in the presence of a base breaks the strong bonds within the silica mineral, transforming crystalline silica into an easily soluble ionic compound in the form of sodium silicate. This process enables the previously insoluble silica to become more accessible for various industrial applications.

(a) (b)

Figure 2. Coconut husk (a) coconut husk before being ashed; (b) coconut husk after being ashed

Figure 2 illustrates the first stage of silica isolation through the combustion of coconut husk at a temperature of 600°C. High-temperature combustion aims to oxidize the sample, allowing the complete removal of organic compounds and thereby increasing the silica (SiO_2) content in the sample. This process is followed by washing with HCl, which serves to dissolve other oxides apart from SiO_2, such as metal oxides like MgO, K_2O, and Ca_2O [11]. The use of HCl in the purification process is due to the chemical property of SiO2, which is insoluble or unreactive to all acids except HF, thereby preserving the yield of SiO_2 formed [1].

(a) (b)

Figure 3. Isolation results of silica (SiO2) with HCl (a) with aquades washing; (b) without aquades washing

Figure 3(a) shows the result of coconut husk ash purification using HCl. After the HCl washing process, the sample was rinsed with distilled water until a neutral pH was achieved. If the pH is below 7, the silica purity decreases due to impurities dissolved in HCl. Figure 3(b) illustrates the result of silica (SiO_2) isolation using HCl without a washing process.

Pure silica was then dissolved in NaOH and subjected to fusion at 500°C. The fusion process at 500°C is based on the melting point of NaOH, which is 318°C, allowing NaOH to dissociate completely into Na^+ and OH^- ions [5]. The choice of NaOH is due to its lower melting point compared to Na_2CO_3, which is 851°C, facilitating the formation of sodium silicate at a relatively lower temperature. The dissolution followed by fusion aims to ensure a complete conversion of rice husk ash into sodium silicate. The resulting sodium silicate appears as a white solid.

The high-temperature melting process causes NaOH to melt and dissociate completely into Na^+ and OH^- ions. The high electronegativity of the oxygen atom in SiO_2 makes silicon more electropositive, leading to the formation of an unstable

$[SiO_2OH]^-$ intermediate, which undergoes dehydrogenation. The second OH^- ion bonds with hydrogen to form a water molecule, while two Na^+ ions balance the negative charge of the SiO_3^{2-} ion, forming sodium silicate [5].

Figure 4. The result of Na_2SiO_3 synthesis

Figure 4 presents the results of sodium silicate synthesis. In this experiment, the obtained sodium silicate appeared bluish-white. Pure sodium silicate is typically colorless or white. The bluish hue in the experimental result indicates the presence of impurities during the silica purification process. The yield of sodium silicate obtained was calculated using the following equation:

Mass SiO_2 experiment = 10 g

MW SiO_2 = 60 g/mol

Mol SiO_2 = g/MW = 0,1666 mol

V NaOH = 82,5 mL = 0,0825 L

[NaOH] = 4 M

Mol NaOH = [ ] x V = 4 x 0,0825 = 0,33

	SiO_2	+	2 NaOH	→	Na_2SiO_3	+	H_2O
S	0,1666		0,33		-		-
R	0,1666		2 (0,1666)		0,1666		0,1666
F	0		0		0,1666		0,1666

Mol theoretic Na_2SiO_3 = 0,1666

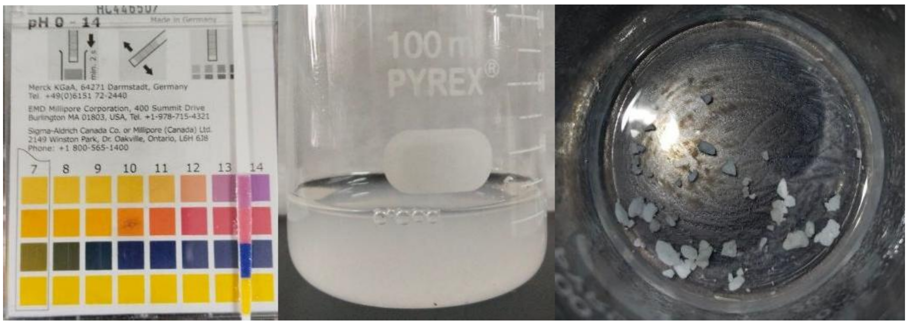
Mass experiment Na_2SiO_3 = 2,18 gram

Mol experiment = g/MW = 2,18/121,9412 = 0,017 mol

Yield = 100 %

= 100% = 10,625 %

In this experiment, a yield of 10.625% was obtained. The low yield of sodium silicate may be due to the suboptimal concentration of NaOH and the non-ideal gelation process. Silica cannot dissolve at pH below 11, necessitating a high pH for silica extraction. Silica levels increase as the pH approaches neutral, but decrease when acid is added. This is because during the gel formation process, acid addition forms sodium salts, which affect the purity of the resulting silica [7]. Sodium silicate was tested using distilled water, ethanol, and a pH indicator to determine the properties of the synthesized sodium silicate. Figure 5 shows the qualitative test results of sodium silicate.



(a) (b) (c)

Figure 5. Qualitative test results of sodium silicate. (a) pH test; (b) Water solubility test; (c) Alcohol solubility test.

In Figure 5(a), the results of the pH test for the sodium silicate obtained from the experiment are presented. The experiment showed a pH value of 13, which aligns with the literature stating that sodium silicate remains stable in a basic pH range of 11 to 13 (Madania et al., 2023). Additionally, sodium silicate was found to be soluble in water, as shown in Figure 5(b), but insoluble in alcohol (ethanol), as depicted in Figure 5(c). This insolubility in alcohol is attributed to the ionic nature of sodium silicate, composed of Na^+ and SiO_3^{2-} ions, which are polar. In contrast, alcohol typically dissolves non-polar compounds [7].

Conclusion

Sodium silicate can be synthesized through two stages: silica isolation from coconut husk and the addition of NaOH. The synthesis resulted in a bluish-white sodium silicate powder with a yield of 10.625%. It exhibits a pH of 13, is soluble in water, and is insoluble in alcohol.

Acknowledgements

This research was supported by the Republic of Indonesia Defense University for the facilities.

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