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THE POTENTIAL OF BEMBAN FIBER AS RAW MATERIAL OF GEOPOLYMER

Ninis Hadi Haryanti[1], Nursiah Chairunnisa[2]*, Ratni Nurwidayati[2], Ade Yuniati Pratiwi[2], Yudhi Arnandha[3], Suryajaya[1], Tetti N Manik[1], Yoga Saputra[1], Nur Hazizah[1]

[1]Mathematics and Natural Sciences Faculty, Lambung Mangkurat University, Indonesia
[2]Faculty of Engineering, Lambung Mangkurat University, Indonesia
[3]Faculty of Engineering, Tidar University, Indonesia

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ABSTRACT: This study focuses on modifying Bemban fiber (Donax Canniformis) and assess its physical and mechanical properties as a material for concrete geopolymers. Bemban was cleaned and chopped into 20 cm pieces before being boiled for 60 minutes and dried at 75°C for 4 hours. Furthermore, the fiber was alkalized for 2 hours in a 3% NaOH solution. Three main aspects were investigated such as water content, cellulose content and the tensile strength of Bemban fiber. Moreover, the water absorption, porosity and compressive strength of mortar geopolymer using modified Bemban fiber were conducted in this research. The result research showed that the water content value of the Bemban fiber was 4% and met the requirements by SNI 06-3730-1995. Moreover, alkalization increased the cellulose content by 42.38% while decreasing the lignin content by 49.18% as well as shrinking the Bemban fiber diameter by 42%. The tensile strength of the Bemban fiber increases by 84.59%, and the fiber shape changes significantly. Carbon (C) and oxygen (O) are the most abundant elements in Bemban fiber. Using modified Bemban fiber in mortar geopolymers can reduce water absorption and porosity, especially the decrease in water absorption and porosity, together with the increased usage of Bemban fiber. Adding 1.5% modified Bemban fiber results in the lowest water absorption capacity and porosity, with physical parameters of 7.18% water absorption, 15.09% porosity, and the highest value of compressive strength is 5.93 MPa.

Keywords: Bemban fibers, Alkalization, Physical properties, Mechanical properties, Geopolymer

1. INTRODUCTION

Before using synthetic fiber reinforced composites, humans employed natural composites for a number of applications ages ago. The characteristics of several natural fibers (such as bamboo, flax, hemp, cotton, and wool) have been studied, and the results indicate that some of them could be used as an alternative to glass fibers in a variety of applications [1]. Kalimantan is home to a diverse range of plants, including Bemban. Bemban (Donax Canniformis) is a plant that grows naturally in swamp regions with acidic peat soil structure [2,3]. These regions are commonly found on the borders of bodies of water, in damp areas, bamboo woodlands, and even in the yards of houses, producing little islands [4]. Bemban is currently employed by the community to manufacture woven and roped handcraft products. Furthermore, it is used to tie bamboo to the roof of animal cages constructed from dried sagoleaves, which can endure animals for an extended length of time [5]. Bemban provides characteristics such as weather resistance, decay resistance, and durability. As a result, it has the potential to be utilized as a mixed material [6].

Saputra et al. [7] investigated the possible use of Bemban fiber as a mixed material in road construction as a porous asphalt mixture, resulting in the usage of 1% Bemban fiber, which can produce porous asphalt porosity of 18.86%. Furthermore, Idrus et al. [8] discovered that Bemban fiber composites had the best resistance compared to other fibers, namely 0.0449 Joules/mm^2 to the impact test. to the impact test. Basyir et al. [9] used Bemban fiber as a composite reinforcement in impact and bending tests at 0.0208 Joule/mm^2 and 114.16 MPa, respectively. Bemban fiber has the potential to be utilized as a mixture or reinforcement in a material according to this research. Bemban fiber and other natural fibers are hydrophilic, which may result in a poor adhesion force between the fiber and the binder, thus the Bemban fiber must be modified to enhance the binding between the fiber and the matrix, namely by the alkalization process [10].

The alkalization process can lower the lignin and hemicellulose content in the fiber, improving the bond between the fiber and the binder [4,11] Furthermore, alkalization attempts to break down cellulose crystals, enhance porosity, and reduce fiber size, all of which will promote contact between surfaces thereby improving mechanical characteristics [12]. Saputra et al. [13] found that applying 5% NaOH for 30 minutes reduced lignin content by 1.33% while raising cellulose levels by 22.52% in Bemban fiber. Syarief et al. [4] applied 4% NaOH to Bemban fiber for 30 and 60 minutes to get a bending value of 112.24 MPa and an impact value of 0.0208 Joules/mm^2.

The development of geopolymers began with the production of kaolin-based geopolymers [14]. Geopolymers composed of alumino-silicates (SiO_2 and Al_2O_3) derived from natural resources such as kaolin and fly ash waste, as well as other silica and alumina-containing minerals [15-17]. Geopolymers offer the benefits of being fire resistant, chemically corrosion resistant, and having high mechanical strength and durability [18–20]. In addition to their benefits, geopolymers have drawbacks, such as brittle characteristics, which need the use of a mixed material to boost tensile strength, such as fiber [21]. Natural fibers have the benefits of being cost-effective, lightweight, having a high maximum strength to weight ratio, being renewable, having a low density, and requiring little energy to process [22], and so have the potential to be employed as material admixtures in the production of geopolymers [23]. The experimental test of modified Bemban fiber for mortar geopolymer was investigated in this research in order to investigate the physical and mechanical performance of specimen.

2. RESEARCH SIGNIFICANCE

The use of Bemban fiber as a geopolymer material is novel in this study; additionally, Bemban fiber has beneficial properties such as resistance to the effects of hot sun and cold weather, resistance to weathering, resistance to rot, and durability, and the potential to be used as an added material to the geopolymer. Based on this description, additional investigation into the potential of Bemban fiber in the fabrication of geopolymers is an interesting topic. Bemban fiber was alkalinized for 2 hours in this research with 3% NaOH.

3. MATERIAL AND METHOD

3.1 Preparation of Material Sample

3.1.1 Bemban Fiber Preparation

The Bemban plant was taken from Kanamit Village in Pulang Pisau Regency. Stems are cleaned and cut into 20 cm lengths before being cooked for 60 minutes. Furthermore, to get Bemban fibers, stems that have been cut are combed. The Bemban fiber is dried for 4 hours at 75°C [4]. Bemban fiber is examined for physical, mechanical, and chemical characteristics, functional group identification, and morphological and elemental analysis before moving on to the next stage. The testing of Bemban fiber properties is consistent with the prior study by Saputra et al. [13]. Other researches that use plants as added geopolymer material are pineapple fiber [24-26] , banana tree fiber [27], coconut [28].

3.1.2 Bemban Fiber Alkalization

The Bemban plant as shown in Fig. 1(a) was cut into 20 cm long stems (Fig. 1(b)) and boiled for 60 minutes, then combed longitudinally to obtain Bemban fibers and then oven at 75°C for 4 hours. Bemban fibers before alkalinization can be seen in Fig. 1(c). The Bemban fiber alkalization process was carried out by drying it at 60°C for 1 hour, then soaking it in 3% NaOH solution for 2 hours. After soaking for 2 hours, the fibers were washed using water, then dried naturally at room temperature. Next, it is dried to a consistent humidity level of 60°C for 1 hour. The final bemban fiber that is ready for use can be seen in Fig. 1(d). Alkalization of Bemban fiber using 3% NaOH for 2 hours is different from previous studies such as those carried out by Saputra et al. [13] using 5% NaOH for 1 hour, Syarief et al. [4] using 4% NaOH for 30, 60, and 90 minutes. Furthermore, Wahyudi and Syarief [5] used 2, 4, and 6% NaOH for 1 hour.

Fig. 1 Mechanism Process of Bemban Fiber: (a) Bemban plant; (b) Bemban stem cut from Bemban plant; (c) Bemban fiber before alkalization; (d) Bemban after alkalization

3.1.3 Geopolymer Application

The geopolymer study design is based on the Mariamah et al. [29] and Nurwidayati et al. [30] with addition of 0.5, 1, 1.5, and 2 % Bemban fiber.

Geopolymer component materials are shown in Fig. 2. The alkaline solution used is a 2.5:1 combination of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). The NaOH solution has a molarity of 8M. Silica sand was used as a fine aggregate. The fine aggregate to binder ratio in the geopolymer paste is 65:35, and fly ash : alkaline solution is 60:40. The specimen is cylindrical, measuring 38 mm in diameter and 76 mm in height

[31]. Curing period of 28 days using the moist conditions process. The use of the addition of Bemban fiber with a variation of 0% - 2% refers to research by Khoirotun et al. [32]. The mix proportion for the experimental test was as stated in Table 1.

Table 1 Mix proportion of Geopolymer

Specimens	Fine Aggregate (%)	Geopolymer Paste (35%)		Additive
		Fly Ash (60%)	Activator Solution (40%)	Bemban Fiber (%)
GE1	65	21	14	0.0
GE2	65	21	14	0.5
GE3	65	21	14	1.0
GE4	65	21	14	1.5
GE5	65	21	14	2.0

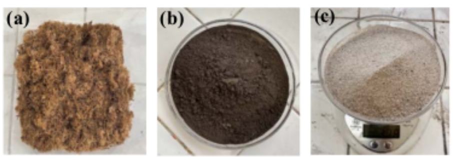


Fig. 2 Geopolymer component materials: (a) Bemban fiber; (b) fly ash; and (c) Silica sand

4. RESULT AND DISCUSSION

4.1 Bemban Fiber Characteristic

Characteristics of Bemban fiber without treatment and alkalization of 3% NaOH for 2 hours include physical, mechanical, and chemical properties, identification of functional groups, as well as analysis of morphology and elemental content.

4.1.1 Bemban Fiber Preparation

Measurement of physical properties including diameter, moisture content, mass, density, and porosity are shown in Table 2. Fiber size is critical for some applications, such as processing and matrix bonding [24]. The diameter of the Bemban fiber reduces by 42% following alkalization, as seen in Table 2. Alkalization treatment causes shrinkage of fiber diameter, which results in the decrease of certain amorphous materials (hemicellulose, lignin, and wax) and contaminants, as well as partial damage to the lumen or cellular structure on the fiber surface [29]. Alkalization treatment, according to Pratama et al. [10], can reduce fiber size, which enhances mechanical characteristics. The alkalization of natural fiber with 5% NaOH for 2 hours can reduce the fiber diameter [33]. When compared to other natural fibers, the Bemban fiber has a tiny diameter. According to Wang et al. [21], the smaller the fiber size, the stronger the fiber tensile strength since the fiber has fewer holes.

Table 2 Physical Properties of Bemban Fiber

Physical Properties	Bemban Fiber Preparation	
	Without Alkalization	With Alkalization
Dia. (mm)	0.050 ± 0.009	0.029 ± 0.007
Water content (%)	4.11 ± 0.00	4.00 ± 0.00
Massa (gr)	0.034 ± 0.001	0.048 ± 0.001
Density (gr/cm^3)	0.96 ± 0.03	1.44 ± 0.02
Porosity (%)	25 ± 0.10	0.24 ± 0.03

As demonstrated in Table 2, alkalization decreased the water content of Bemban fiber by 2.67%. Apart from eliminating dirt, the aim of fiber alkalization treatment is to protect the fiber from water [34]. When the fiber is alkalized with NaOH, hydroxide ions (OH-) from the NaOH react with it, forming OH- groups on the fiber's surface. This OH- group increases the fiber's hydrophobicity and decreases its ability to absorb water [35]. In general, increasing the moisture content of the fiber causes a reduction in elastic modulus and strength, as well as the production of significant voids in the geopolymer [36]. Alkaline treatment, according to Shahril et al. [37], breaks down the cellular structure of the fiber, resulting in decreased water content. The results of this water content are consistent with the findings of Saputra et al. [13], who utilized 5% NaOH alkalization on Bemban fiber for 1 hour. According to SNI 06-3730-1995, the resulting water content value fulfilled the standards of 14%.

In Table 2, the increased mass of Bemban fiber owing to alkalization is also connected with the release or breakdown of chemical bonds in lignin, resulting in an increase in cellulose content due to the fiber's interaction with NaOH [38]. The increase in fiber mass owing to alkalization occurred in palm frond fiber with an alkalization of 3% NaOH for 5 hours of 4.67% [39]. The increase of burdened fiber mass is also connected to its increasing density as a result of alkalization.

Table 2 displays the results of density measurements on Bemban fiber. The density value rose by 50% after the alkalization treatment, showing that the density of Bemban fiber increased as compared to no treatment. Bemban fiber has a low density when compared to ramie fiber, abaca fiber, and pineapple fiber, which all have a density of roughly 1.50 gr/cm^3 [40]. The increase in density of the Bemban fiber caused by alkalization is also related with a decrease in porosity.

Table **2** shows the porosity value of Bemban fiber. Bemban fiber has a porosity of 25% before alkalization and a shrinkage of 11.263%, or 0.24%, after alkalization. This demonstrates that alkalized Bemban fiber has low porosity due to closed holes or cavities in the fiber, resulting in higher fiber density as a result of the alkalization process [37]. Bemban fiber has a low porosity compared to water hyacinth and coconut coir fibers, which have porosities of 74.1% and 29.81%, respectively.

4.1.2 Bemban Fiber Mechanical Properties

The tensile strength of a single fiber reveals the mechanical qualities of Bemban fiber. Table 3 displays the results of the Bemban fiber tensile strength test.

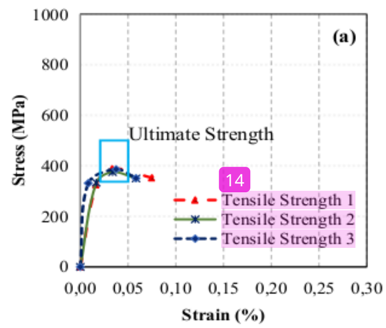
Table 3 Tensile Strength of Bemban Fiber

Mechanical Properties	Bemban Fiber Preparation	
	Without Alkalization	With Alkalization
Max load (N)	0.38 ± 0.02	0.44 ± 0.01
Tensile strength (MPa)	353.258 ± 0.096	732.640 ± 0.091
Strain (%)	0.047 ± 0.028	0.051 ± 0.008

The maximum load of the non-alkalized fiber differs from that of the alkalized fiber, whereas the maximum load of the alkalized fiber rises, which is also connected to its tensile strength. The tensile strength of Bemban fiber without alkalization is 353.258 MPa, whereas the tensile strength of fiber after alkalization is 732.640 MPa. Bemban fiber's tensile strength may be increased by 107.4% after a 2-hour alkalization treatment with 3% NaOH. This demonstrates that the goal of alkalization is to enhance the tensile strength of the fiber. Fig. 3 depicts the stress-strain relationship. There were three specimens of Bemban fiber for each characteristic, namely tensile strength 1, 2 dan 3.

When compared to fiber without alkalization treatment (a), the specimen of with alkalization treatment increases the tensile strength of fiber (b). According to Wang et al. [21], the presence of cavities in the fiber will reduce the tensile strength. The Alkalization of NaOH process can cover the pores, making the fiber dense, which is connected to the density and porosity of the fiber, as confirmed by the physical test findings in Table 2. The reduced lignin in the alkalized fiber resulted in more brittle fibers with a strain value of 5%. Furthermore, the alkalization process increases the fiber's cellulose content, which leads to an increase in tensile strength. This is owing to the cellulose molecule's long and dense structure, which offers natural fibers with significant strength [24].

Bemban fiber has a greater tensile strength than galangal fiber, which has a tensile strength of around 497.336 MPa after being alkalized with 5% NaOH for 2 hours [41]. As a consequence, Bemban fiber treated with 3% NaOH alkalization for 2 hours can improve the tensile strength used in geopolymer manufacture. In addition, the tensile strength of the modified Bemban fiber is almost close to the tensile strength value of steel fibers that commonly used as additives in concrete namely between 1000-1200 MPa [42].



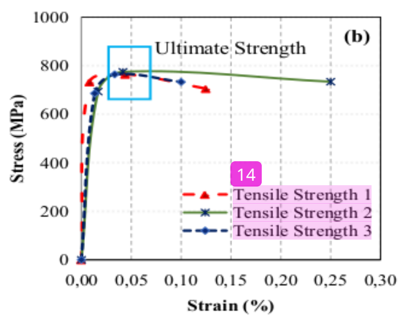


Fig. 3 Stress and strain of Bemban fiber (a) Without alkalization, (b) With alkalization

Kamaruddin et.al [34] found that the NaOH alkalization treatment of natural fibers increased cellulose levels while reduced lignin levels, affecting the tensile strength of the fibers. The increase in cellulose and decrease in lignin in Bemban fiber is seen in Table 4.

4.1.3 Bemban Fiber Chemical Properties

Tests for chemical components of Bemban fiber, such as lignin content according to SNI 0492-1989-A and cellulose content according to SNI 14-0444-1989, are shown in Table 4. The results of the lignin content test showed that there had been a 32.96% reduction in lignin due to the alkalization treatment. The NaOH alkalization process can reduce the lignin content in the fiber because NaOH can release the bonds that bind lignin to the cell wall. Lignin is a component that reduces fiber flexibility and strength [34]. The reduction in lignin in the fiber is due to its reaction with OH- ions which are oxidized from NaOH and bind to H in lignin, and H_2O is formed, which dissolves when rinsed so that the lignin content in the fiber decreases [10]. This process causes lignin to separate from the cell wall and reduces the lignin content in the Bemban fiber. SNI 0492-1989-A requires that the lignin content after alkalization is a maximum of 6%; the value obtained for alkalization of Bemban fiber is appropriate, namely 4.29%. The result is similar to Hikmah et al. [39], which discovered that adding 3% NaOH to palm frond fiber for 5 hours decreased lignin levels by 3.63%. Previous research by Saputra et al. [13] used 5% NaOH for 1 hour on Bemban fiber and found that the lignin percentage was 9.24%. In addition to lowering lignin levels in Bemban fiber, alkalization treatment can increase cellulose levels.

Table 4 Chemical Components of Bemban Fiber

Bemban Fiber	Lignin Content (%)	Cellulose Content (%)
Without Alkalization	6.37 ± 0.40	26.23 ± 0,51
With Alkalization	4.27 ± 0.31	47.33 ± 0,67

The cellulose content shown in Table 4 increased by 80.44% due to alkalization. The high cellulose content in fiber positively affects fiber strength and can increase the adhesive properties between fibers and the matrix [43]. Modification of fibers with NaOH treatment will give rise to alkoxide functional groups (NaO+) in cellulose fibers which initially only have hydroxyl groups (OH) [38]. The cellulose content refers to SNI 14-0444-1989, which requires a minimum of 40% after alkalization. The value of cellulose content obtained in the alkalization of Bemban fiber is appropriate, namely, 47.33%, which is used as an additive in the manufacture of geopolymers.

The alkalization process also reduces the content of hemicellulose and other extractive substances by destroying the bonds that bind extractive substances to the cell wall, as shown in Fig. **4**. Extractive substances are components found in fibers such as waxes, pectins, oils, fatty acids, and pigments which can reduce fiber quality. The reaction that occurs when the alkalization of the fiber is the hydrolysis of the bond that binds the extractive substance to the cell wall. NaOH reacts with this bond and causes the extractive substance to separate from the cell wall [44]. The decrease in lignin and increase in cellulose, as well as the decrease in extractive substances in Bemban fiber, are also confirmed by the FTIR results in Fig. **4**.

4.1.4. Chemical Bonds and Functional Groups of Bemban Fiber

Identification of functional groups in Bemban fiber was carried out by Fourier-Transform Infrared Spectroscopy (FTIR) with a wave number range of 4000 cm^{-1} - 500 cm^{-1} which is a reference for viewing the molecular vibrations of organic compounds [45]. Figure 4 shows the FTIR spectra of Bemban fiber without and alkalization of NaOH 3% 2 hours. There is a difference in absorption intensity with the wave number obtained, indicating the functional groups and bonds formed.

The absorption region of non-alkalized and alkalized untreated fiber with a wavelength of 3324 cm^{-1}, 2892 cm^{-1} is related to the O-H and C-H stretching bands on cellulose [46]; 1732 cm^{-1} related C=O ester group on hemicellulose [47]; 1637 cm^{-1}, 1602 cm^{-1} related to C=C stretching bands in lignin and pectin [48] ; 1419 cm^{-1}, 1370 cm^{-1} showing cellulose associated C-H stretching bands; 1247 cm^{-1}, 1200 cm^{-1} related to C-H bending vibrations in hemicellulose [49]; 1030 cm^{-1} associated C-O ether stretching bands on cellulose [37]; 895 cm^{-1} indicates a C-H aromatic ring linked to cellulose [38].

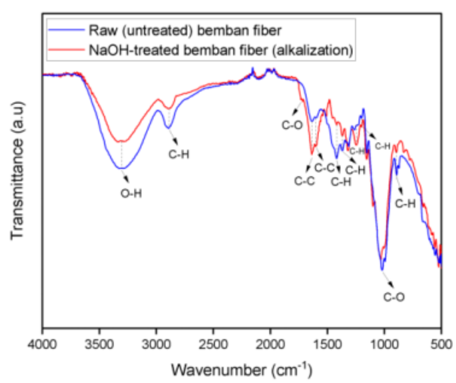


Fig. 4 FTIR spectra of Bemban fiber without alkalization and alkalization of NaOH 3%

The strong and wide absorption is in the 3324 cm^{-1} area, indicating that O-H stretching has occurred as a result of alkalization. Alkalization weakens hydrogen bonds by causing hydroxyl groups to react with sodium hydroxide, resulting in an increase in -OH concentration relative to untreated fiber [35]. The relatively significant intensity at 2892 cm^{-1} suggests a rise in cellulose in the alkalization fiber as a result of the alkalization process, as well as increase in cellulose in the absorption areas of 1419 cm^{-1}, 1370 cm^{-1}, 1030 cm^{-1}, and 895 cm^{-1}. At wave number 895 cm^{-1} related to the C-H aromatic ring area or what is known as the fingerprint area, which shows an increase in intensity in cellulose, this indicates that the treatment with NaOH is quite suitable for Bemban fibers because there is no damage to the cellulose, as well as with an increase in the intensity of the number the wave on cellulose indicate that NaOH can strengthen the presence of cellulose [38].

Reduction of lignin and pectin in alkalized fiber was shown at 1637 cm^{-1} and 1602 cm^{-1} with quite strong intensity. The presence of hemicellulose at 1732 cm^{-1} on the fiber without alkalization has disappeared due to the alkalization process, then absorption at 1247 cm^{-1} and 1200 cm^{-1} with reduced intensity due to the alkalization process. The alkalization process occurs when the NaOH solution dissociates into Na+ and OH- reacts with lignin. OH- ions react with H groups on lignin to form H_2O. This causes the O group to become a free radical and reactive with C to form C-O-C. A series of C groups unbond the O groups. The reaction produces two separate benzene rings, each of which has a reactive O group. This reactive O group reacts with Na+ and dissolves in alkaline solutions so that the lignin is lost when rinsed. In addition, this reaction also produces H_2O. Cellulose is hydrophilic, so H_2O is bound by cellulose which causes the concentration of O-H bonds to increase [35]. The presence of cellulose and reduced lignin is shown in the SEM results in Fig.5.

4.1.5. Morphology and Bemban fiber

The surface morphology of Bemban fiber with SEM results is shown in Fig. 5. Fiber morphology with and without alkalization treatment differs from one another. The results of the SEM analysis in Fig. 5(b and d) show that the NaOH alkalization treatment leads to changes in fiber morphology which were also reported in other research [25,42,40]. The untreated fiber surface in Fig. 5 (a and c) is covered with a protective layer of non-cellulose components (such as lignin, wax, oil, pectin, and hemicellulose) which was also confirmed by Kathirselvam et al. [50].

The 3% NaOH treatment for 2 hours resulted in a cleaner surface which was associated with the removal of some non-cellulose components by NaOH shown in Fig.5 (b) but still left some lignin and hemicellulose which was also confirmed by the results of the chemical component tests in Table 4 and FTIR in Fig. 4. The rough surface morphology is characteristic of alkalization-treated fibers [40]. This is caused by a change in the orientation of the very dense crystalline cellulose arrangement to form amorphous regions that allow the O-H groups from the alkaline solution to decompose to react with water molecules and then leave the fiber structure [51]. Surface roughness is required if the material is used as a composite reinforcement because it will increase the adhesion between the fiber and the matrix [12]. The same thing if it is used for the manufacture of geopolymers.

The EDX results in Fig. 6 also evidence the increase in cellulose and the reduction in other ineffective components by analyzing its elemental content.

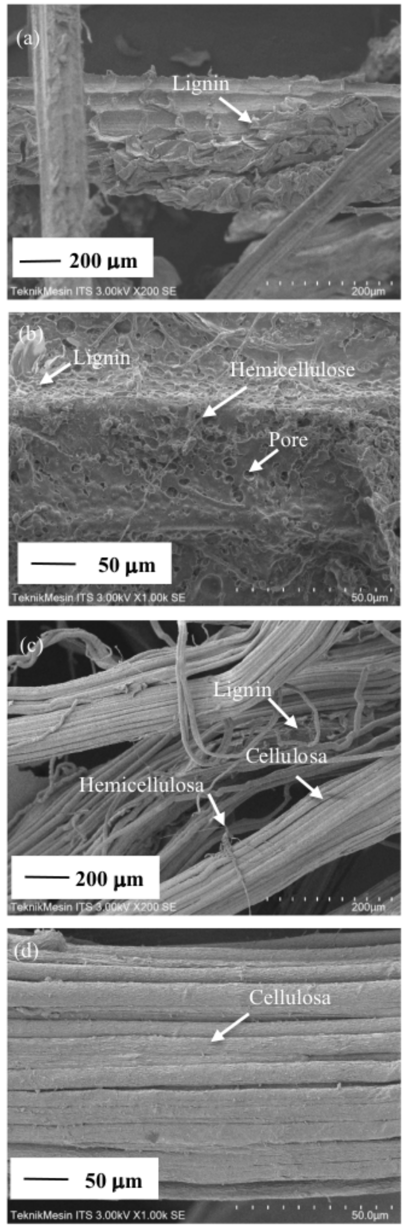


Fig. 5 Morphology of fiber without alkalization with magnification of 200 times (a) and 1000 times (c); morphology of alkalized fibers with magnification of 200 times (b) and 1000 times (d) using SEM.

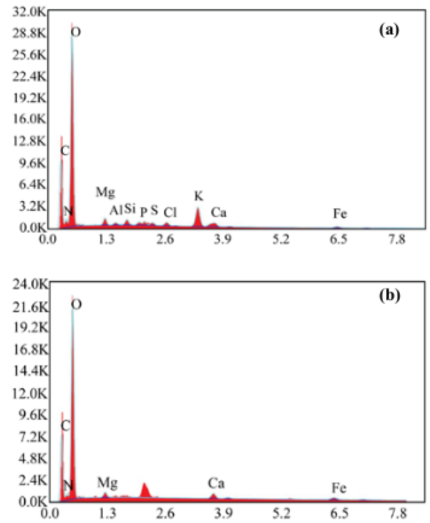


Fig. 6 Elemental spectra of fiber: (a) without alkalization; (b) with alkalization

4.2 Geopolymer Characteristic

4.2.1. Physical properties of Geopolymer

Geopolymers' physical characteristics, such as their capacity to absorb water and porosity of specimens are shown in Table 5. Test for water absorption is based on SNI 03-0349-1989. This physical property test was carried out to determine the percentage of water absorbed by each sample. The water absorption values obtained ranged from 7.18% to 10.00%. The sample with the highest water absorption (10%) in the geopolymer without Bemban fiber (0%), it is evident that the examined samples varied in their ability to absorb water. Razak et.al [52] state that the higher compressive strength and the least amount of porosity and water absorption which is shown in Table 5.

Table 5 Physical Properties of Geopolymer

Specimens	Water Absorption (%)	Porosity (%)
GE1	10.00	20.89
GE2	8.89	18.57
GE3	8.29	17.41
GE4	7.18	15.09
GE5	8.24	16.66

Water absorption can be decreased by the inclusion of Bemban fibers. It is evident that as the utilization of fiber increases, the capacity to absorb water decreases. The lowest water absorption capacity (7.18%) was the addition of 1.5% Bemban fiber which was the optimum level. Then raised once more after a composition that contains 2% fiber, this is due to the possibility of cavities being caused by an excess of fibers. The water absorption increased further, because fiber has been alkalized to become hydrophobic, density has increased, and porosity is minimal, using fiber in geopolymers helps reduce water absorption, as shown in Table 5. All values comply with SNI 03-0691-1996's specifications for concrete quality, with a water absorption value maximum of 10%.

The value of water absorption at the optimum composition of this study is of lower value than [48] which uses 1% coconut fiber to obtain a water absorption of 11.20%. Yanou et.al [53] using 1.5% bagasse fiber obtained a water absorption of 19.9%

Porosity testing aims to determine the percentage of pores in the sample to the sample volume. The porosity value will rise as the pore volume rises. The geopolymer porosity of specimens are shown in Table 5. The geopolymer porosity is visible to be between 15.09% to 20.89%. Similar to how water absorbs, the addition of 1.5% Bemban fiber results in the lowest porosity of (15.09%), which subsequently increases again in the composition with 2% Bemban fiber. Based on the previous research, the low value of the geopolymer porosity can increase the compressive strength properties [52]. In contrast to Setiani [54], who discovered a geopolymer porosity of 25.5%, this study's geopolymer porosity is lower. Additionally, Ariska [55] found that the geopolymer porosity was 17.03 percent. The addition of Bemban fiber to the geopolymer affects the decrease in porosity along with the increase in the percentage of its use.

Geopolymer porosity decreases with the increasing use of Bemban fiber, reaching the lowest point of 1.5% and becoming the optimum composition according to the relationship between the two variables. As indicated in Table 5, the alkalization treatment was able to lower the porosity of the fiber, which resulted in the low porosity value with the addition of Bemban fiber, as well as the increased adhesive properties between the fiber and the matrix. The highest porosity was found in the GE1 sample which was 20.89%.

4.2.2 Mechanical Properties of Geopolymer

Testing the mechanical properties of cylindrical geopolymer based on the ASTM C39 [31] test method for compressive strength. There are differences in compressive strength based on each composition and with the addition of Bemban fiber which can be seen in Table 6. Fig. 7(a) displays before compressive strength test meanwhile Fig. 7(b) is after compressive strength test. The collapse that occurs as a result of compressive testing forms a cone pattern.

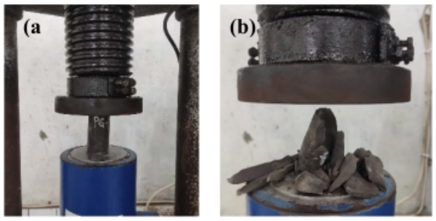


Fig. 7 Compressive strength test of geopolymer specimens: (a) Before test and (b) After test

Table 6 Mechanical properties of Geopolymer

Specimens	Max Load (N)	Compressive Strength (MPa)	Deviation Standard
GE1	32680.66	3.98	0.23
GE2	22471.94	4.14	0.10
GE3	27792.05	5.13	0.13
GE4	32460.01	5.93	0.02
GE5	36215.96	4.61	0.13

Geopolymer specimens without Bemban fiber (GE1) obtained the lowest compressive strength of 3.97 MPa to the all specimens. The addition of 0.5-2% Bemban fiber can enhance the compressive strength of the geopolymer. The result showed that increasing the fiber content used, can intensify the compressive strength of geopolymer and the optimum is the addition of 1.5% Bemban fiber. Furthermore, Wang et.al [21] studied that the compressive strength of geopolymer concrete is improved by the use of fiber-reinforced components. However, after the fibers have reached their optimum limit, a drop will take effect. The addition of fibers can amplify the compressive strength of geopolymer but when the amount has exceeded the optimum condition, the compressive strength will decrease because the fiber will cause more space between the geopolymer matrix.

Porosity has a significant effect on the mechanical properties of geopolymers. The relationship between compressive strength and porosity of specimens can be seen in the Fig. 7. It can be clearly that, the density and strength of the material decrease as its porosity increases. Increasing porosity can reduce the strength and resistance of a material to degradation. The porosity value in this study is lower if compared to research by Walbrück et al. [56] that utilizing natural fibers to obtain a porosity of 49-76%.

Moreover, Yanou et.al [53] using 1.5% bagasse fiber to obtain a geopolymer porosity of 12%. Finally, it can be argued that the use of Bemban fiber as much as 1.5% can reduce porosity up to a value of 5.80%. Porosity has a direct impact on compressive strength, even though a small amount of porosity can improve compressive strength [57].

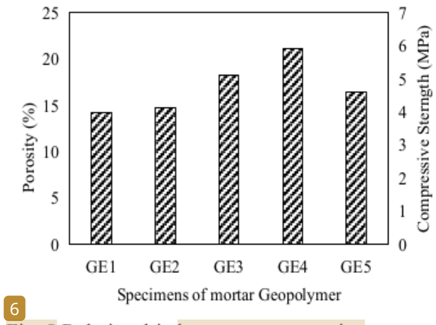


Fig. 8 Relationship between compressive strength and porosity

The alkalization treatment of Bemban fibers makes it easier for the fibers to bond with the matrix and it can escalate the adhesive properties between the fibers and the matrix [51]. The alkalization process on Bemban fiber reveals that the contaminants that were thought to cover the surface and prevent the matrix from attaching to the fiber have diminished till they completely vanished or can be said to have dissolved in 3% NaOH solution [10]. Fibers and NaOH solutions might interact during the alkalization process, where the OH- ions in NaOH react with H groups in lignin, then form water molecules (H_2O). Finally, the lignin material diminishes and dissolves in water. Better interlocking is achieved by lowering lignin and other contaminants like wax, hemicellulose, and oil in fiber.

5. CONCLUSION

This article focused on the potential of Bemban fiber in the application of geopolymers. The following conclusion were drawn:

1. The properties of Bemban fiber with alkalization treatment of 3% NaOH for 2 hours as a candidate for geopolymer materials obtained a moisture content value of 4% that fulfills the requirements of 14% based on SNI 06-3730-1995.
2. The alkalization treatment leads to significant changes in fiber morphology, resulting in a cleaner surface which is associated with the removal of some non-cellulosic components.
3. Alkalization treatment can increase the tensile strength of Bemban fiber by 84.59%.
4. Water absorption and porosity can be decreased by adding Bemban fiber to geopolymer mixes, specifically by reducing water absorption and porosity while using more fiber.

5. By utilizing 0.5-2% Bemban fiber as an addition in the mixtures, the compressive strength of the geopolymer can be increased by up to 49% when compared to the specimen without Bemban fiber.

6. ACKNOWLEDGMENTS

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