MECHANICAL PROPERTIES OF ABACA FIBER REINFORCED POLYMER SHEET AS SUSTAINABLE GREEN STRENGTHENING MATERIAL

S Fahri[1*], Fakhruddin[3], R Djamaluddin[2], R Irmawaty[3], H Usman[4], and N A Mawaddah[4]

[1]Civil Engineering Department, Hasanuddin University, Indonesia.
[2]Civil Engineering Department, Hasanuddin University, Indonesia.
[3]Civil Engineering Department, Hasanuddin University, Indonesia.
[4]Civil Engineering Department, Hasanuddin University, Indonesia.

ABSTRACT

Today, FRP system is one of the most widely used methods of structural repair and strengthening but the price is relatively expensive. Therefore, it is necessary to develop FRP materials generated from natural fibers that have the potential for high tensile strength, environmentally friendly, and lower costs. In this study, Abaca fiber (Musa textilis) derived from Abaca banana is used as the constituent material of Abaca Fiber Reinforced Polymer Sheet (Abaca FRP Sheet), which will be used as strengthening materials of structural elements. Tensile strength testing was performed as the preliminary test to determine the mechanical properties of Abaca FRP Sheet. Abaca FRP Sheet with and without NaOH treatment was a test variation. The results of the tests were compared to commercial GFRP sheets. ASTM D3039/D3039M-14 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials is referenced in the test specimens. Alkali treatment changes the structure and visual observation of the abaca fiber. Immersion of abaca fibers in 0.5% NaOH solutions for 30 minutes increased the tensile strength, Young's modulus (GPa) and Strain at break as compared to the untreated abaca fibers.

Keywords: Abaca Fiber, Glass Fiber, Tensile Strength, Strengthening Material

1. INTRODUCTION

Reinforced concrete structures have a design life and will lose strength and even be damaged. Because of changes in building functions, changes in design standards, poor workmanship, natural disasters, and other factors. Repairing and strengthening the structure is one method of increasing the structure's capacity. Structure repair and strengthening methods currently available include cross-sectional enlargement, external strengthening, steel plate, and Fiber Reinforced Polymer (FRP). Today, FRP system is one of the most widely used methods of structural repair and reinforcement. FRP is a type of composite material that comes in sheets, rods, and fibers and is used to increase the flexural capacity of beams.

[1 1*] Corresponding author's email: syamsul.fahri1997@gmail.com

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Many previous researchers have conducted FRP research, including Wang, Zhang, and Liu (2021), Ajith and Nooh (2021), Al-Khafaji, Salim, and El-Sisi (2021), Huang et al. (2021), and Bhat (2021). FRP has several advantages, including light weight, high tensile strength, corrosion resistance, and ease of application, making it a viable option for strengthening reinforced concrete structural elements. Glass Fiber Reinforced Polymer is a one of the types of FRP (GFRP). The use of GFRP, on the other hand, has the disadvantage of being relatively expensive. As a result, it is necessary to create FRP materials from natural fibers that have the potential for high tensile strength, are environmentally friendly, and use lower costs.

According to Adeniyi et al. (2019), natural fibers such as coconut coir, palm oil, bananas, bamboo, rice husks, and friendly materials have the potential to be used as FRP materials. Abaca fiber is one of the most commonly used natural fibers (Musa textilis). According to Dedi Setiawan's (2015), abaca fiber can be used as an alternative composite strengthening material after being treated, including with alkali (NaOH). This treatment can change the mechanical properties of abaca fiber by increasing the strain by 50.89%, increasing the tensile strength by 26.52%, and decreasing the modulus of elasticity by 6.11%. Previously, research on abaca fiber is limited to its use as an additive to fiber concrete, as demonstrated by Rainer Tampi (2021). The results indicated that the addition of abaca fiber in the mixed process used as concrete reinforcement and evaluated through a flexural test demonstrated the flexural capacity of abaca fiber concrete for a 50 mm variation in length. The addition of 0.15% resulted in a 40.19% increase over normal concrete.

Abaca fiber also has a high tensile strength and is resistant to salt water, according to several studies. Abaca fiber is the strongest natural fiber, according to Vijayalakshmi (2014), when compared to other fibers. In this study, Abaca fiber (Musa textilis) from the Abaca banana's midrib will be used. This type of banana is common on the Indonesian island of Sulawesi.

Inspired by GFRP, abaca fiber has the potential to be developed as a natural fiber for reinforced concrete structures This study aims to produce a natural fiber reinforced polymer sheet that can be used as a shear strengthening material of reinforced concrete beams. Therefore, the tensile strength test was conducted to determine the mechanical properties of Abaca FRP sheet in terms of tensile strength, Young's Modulus and elongation at break. Abaca fiber with and without NaOH treatment was a test object variation. The results of the tests was also be compared to commercial GFRP products.

2. Research Methodology

2.1 Abaca Fiber

Abaca fiber is a natural fiber derived from the split midrib of the Abaca plant (Musa textilis). This type of banana is common on the Indonesian island of Sulawesi. Because abaca fiber is an unwanted material obtained after harvesting abaca bananas, it can be used as an industrial raw material without incurring additional costs. This strand has higher tensile properties, is not easily decomposed, and has the same flexural strength as glass fiber (Bledzki et al., 2006; Huang, 2009; Ramadevi et al., 2012, Agung et al., 2012, Mamun et al., 2015, Ming, et al., 2015, Agnivesh K et al., 2017). Abaca banana and Abaca fiber are depicted in Figures 1 a and b, respectively.

(c)

Figure 1. (a) Abaca banana, (b) Abaca fiber

2.2 Alkali Treatment

Figure 3 shows the alkali treatment process of abaca fiber. According to Cai et al. [4], alkali treatment aims to modify the morphology and chemical composition of the abaca fiber which can help in increasing the bond between the fiber and the epoxy. Abaca fibers with average length of 2-3 m were immersed in an aqueous NaOH solution (0.5%) for 30 minutes to ensure good penetration of the alkali solution into the bundle fibers. The fibers were then removed from the alkaline solutions and washed several times with acidic water (0.1% NHCl) to ensure that NaOH was completely removed from the fibers. Finally, the abaca fibers were dried in a vacuum oven at 60°C for 24 hours.

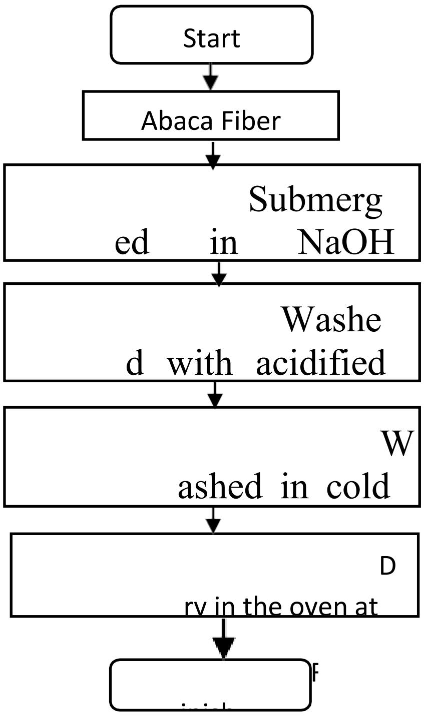


Figure 2. Alkali treatment of abaca fiber

a. Submerged in alkali solutions b. Washed with acidic water

Figure 3. Submerged and washed process of abaca fiber

After that, the abaca is formed into sheets by manual method as shown in Figure 4.

(c)

Figure 4. (a) Manual Fabrication, (b) Abaca FRP Sheet

2.3 Tensile Strength Test Specimens

The abaca fiber sheet will be tested for tensile strength to obtain its mechanical characteristics. The number and variation of test objects are shown in Table 1.

Table 1. Specimens

Specimens	NaOH Treatment of Abaca	Number of specimens
Abaca-Untreated	-	3
Abaca-Treated	Treated	3
GFRP	-	3

The testing method in this study follows the ASTM D3039/D3039M-14 Standard regarding the Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. The configuration of the test object in the Abaca FRP Sheet tensile test is shown in Figure 5.

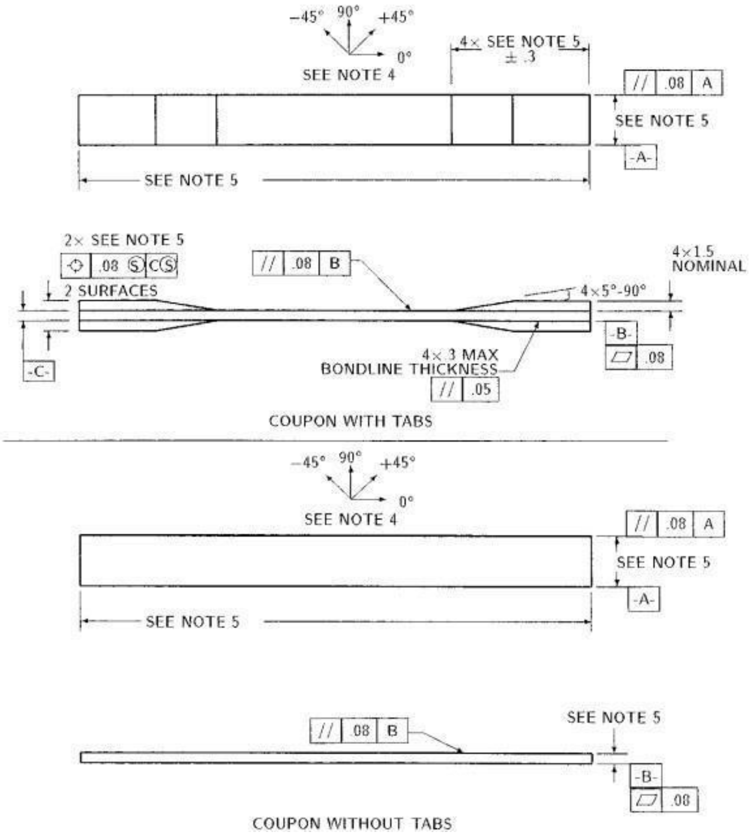


Figure 5. Specimens

2.4 Setup and Instrumentation

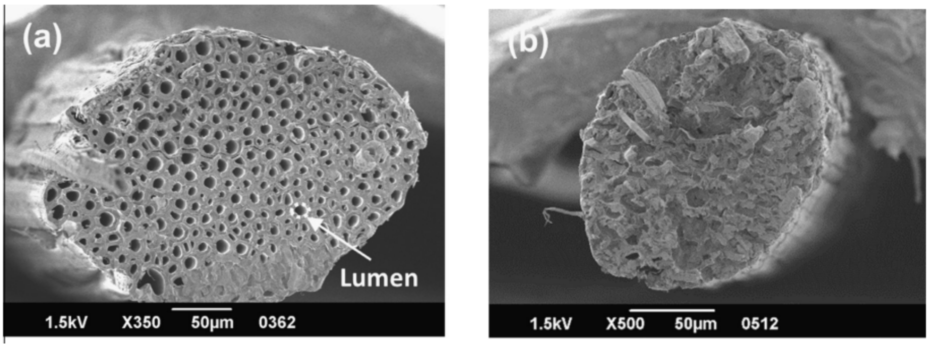
The specimens were tested by using Universal Testing Machine (UTM) as shown in Figure 6. A strain gauge was attached to each specimen to measure the strain development during the loading test. The displacement will also be measured by two LVDTs. The data logger was used to record all of the data.

Figure 6. Universal Testing Machine (UTM)

3. Results and Discussion

3.1. Surface and structures

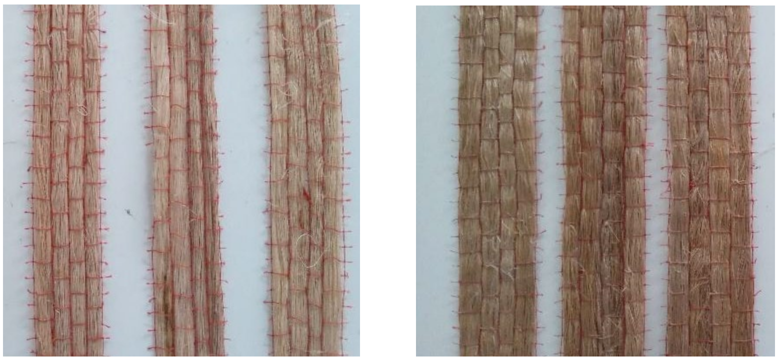
Alkali treated fibers had cleaner surface and smaller diameter than untreated fibers. This was due to the loss of materials such as hemicellulose, lignin and pectin contained in the fiber. In addition, Cai et al [4] reported that the lumen holes were clearly visible on untreated fibers according to SEM test results. While on treated fiber, the lumen hole was almost not visible which may be caused by the expansion of the fiber or lumen that dissolves during alkali treatment. This phenomenon is shown in Figures 6a and b.



a. Untreated abaca fibers b. Treated abaca fiber

Figure 7. SEM images of cross-sectional surfaces of abaca fibers [4]

Based on visual observation, alkali treated fiber had a darker color and a stiffer surface than untreated (Figure 8). Rigid fiber is helpful during the fabrication process of abaca fiber sheet from the bundled fibers.



a. Untreated fiber sheet b. Treated fiber sheet

Figure 8. Visual appearance of untreated and alkali-treated abaca fiber sheet

3.2. Mechanical properties

The tensile properties of untreated and alkali-treated abaca fibers reinforced polymer (Abaca FRP) are summarized in Figure 9 and Table 2. As comparison, the tensile strength test of commercial GFRP sheet was also presented.

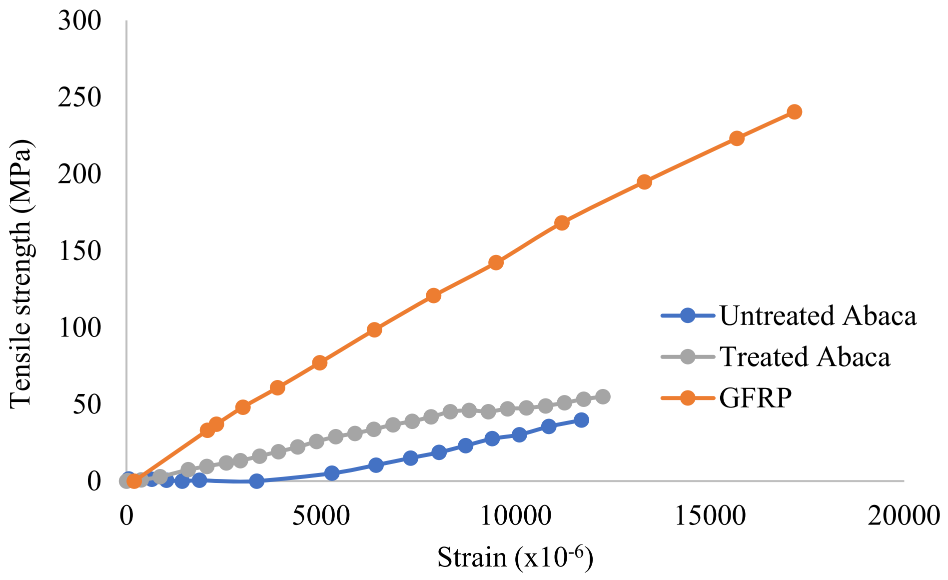


Figure 9. Tensile stress-strain curves of abaca fiber reinforced polymer and GFRP

Table 2. Mechanical properties of abaca fiber reinforced polymer and GFRP

Fiber	Tensile Strength (MPa)	Young's modulus (GPa)	Strain at break ($x10^{-6}$)
Untreated Abaca	39.7	3.39	11706
Treated Abaca	54.9	4.48	12252
GFRP	240.4	13.99	17180

The untreated abaca FRP had a tensile strength of 39.7 MPa and Young's modulus 3.39 MPa. After NaOH treatment, the tensile strength of abaca FRP increased by 38.3% and Young's modulus by 32.1% with respect to the untreated abaca FRP. The strain at break of treated abaca FRP increased slightly compared to the untreated abaca FRP. The improvement in tensile strength and Young's modulus reflect the improved crystallinity of the fibers following the 5 wt.% NaOH treatment [4].

The mechanical properties of abaca FRP sheet was still smaller than GFRP. The tensile of abaca FRP was about 0.17 to 0.23 times of GFRP sheet. Young's modulus of abaca FRP was about 0.24-0.32 times of GFRP sheet. However, stain at break of abaca FRP was 0.68-0.75 of GFRP. The tensile properties of abaca FRP sheet might be increased by providing more layers of abaca FRP sheet.

4. Conclusion

Based on the literature study and test results, the following conclusions are obtained:

1. Alkali treatment changes the structure and visual observation of the abaca fiber. Immersion of abaca fibers in 0.5% NaOH solutions for 30 minutes increased the tensile strength, Young's modulus (GPa) and Strain at break as compared to the untreated abaca fibers.

2. The mechanical properties of GFRP were still superior than abaca fiber reinforced polymer.

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