Sodium bicarbonate treatment of coir fiber on wettability and shear strength of coir fiber-epoxy composite

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Abstract. This research presented the influence of treated coir fiber with sodium bicarbonate on wettability and interfacial shear strength (IFSS) of coir fiber-epoxy composite. Coir fibers were immersed in the solution of sodium bicarbonate with three different densities (8wt%, 10wt%, and 12wt%) for 24 hours and 120 hours. Epoxy resin was utilized as a matrix of composite. Wettability and IFSS of coir fiber-matrix adhesion were evaluated. Fiber wettability to the matrix was performed by measuring the droplet contact angle. In addition, the IFSS of coir fiber–epoxy matrix was investigated by pull out method. The surface morphology of interfacial bonding between fiber and matrix after pull out testing was evaluated by scanning electron microscopy (SEM). The results show that fiber surface wettability was influenced by sodium bicarbonate where the contact angle decrease after treatment. It suggests that good wetting of fiber and matrix. While the density of 12 wt% sodium bicarbonate for 120 hours possessed the highest interfacial shear strength of fiber-epoxy adhesion compared with other densities.

1. Introduction
The performance of polymer matrix composite is influenced by interfacial fiber-matrix adhesion [1]. Relate to natural fibers as reinforcement of polymer composite, they are lack compatibility with matrix due to hydrophilic natural fiber and hydrophobic matrix [2]. Several researchers have investigated the chemical and physical treatments on natural fibers for improvement of the fiber-matrix bonding. The adhesion of fiber and matrix in the composite increase after the alkali, silane, and sodium bicarbonate treatments of natural fibers [3,4,5]. Chemical treatment can remove the lignin and some impurities on the natural fibers which may give better adhesion to the fiber-matrix due to mechanical interlocking and chemical bonding occurred [6]. In addition, physical treatment using plasma treatment altered the surface of coir fibers which display etching of fiber wall [7].

Fiber surface wettability can be defined by the contact angle which formed by the surface of fiber and the matrix [8]. Contact angle analysis can be used to obtain a notification for composite surface behavior like hydrophobicity or hydrophilicity [9]. Alkali treatment of coir fiber can improve the wettability between coir fiber and polyester [4].

Interfacial shear strength (IFSS) is a direct measurement of the adhesion of fiber and matrix. Alkali treatment of jute fibers improved the adhesion between fiber and matrix at the interface [10]. Khalil et al. [11] studied interfacial shear strength on coir fiber and oil palm empty fruit bunch composite using epoxy, polypropylene, and unsaturated polyester. Their results showed IFSS of fiber-matrix increases due to acetylation treatment of fiber which improve the hydrophobicity of fiber. Gu [12] studied coir
fiber with alkali treatment for reinforcing composite. Results showed that the improvement of the tensile strength and strain of fiber composite after coir fiber treatment. Furthermore, the fiber-matrix adhesion of composite improved after addition of compatibilizer and raised tensile strength [13].

In this paper, the influence of sodium bicarbonate treatment on wettability and interfacial adhesion of fiber-matrix was studied. Fiber surface wettability on the matrix was determined by measuring the contact angle. In addition, single fiber pull out testing was conducted to determine the strength of the interfacial adhesion of coir-epoxy. The morphology of the adhesion of coir-matrix at the interface was characterized by the scanning electron microscopy.

2. Methodology

2.1. Materials
Coir fibers were obtained from Tawaeli – Palu area, Central Sulawesi, Indonesia. Such fibers were separated from coconut husk by mechanical extraction and then cleaned. Surface treatment of coir fiber in this study used sodium bicarbonate (NaHCO₃) solution. Fibers were immersed in different densities of sodium bicarbonate solution (8wt%, 10wt%, and 12wt %) for 24 hours and 120 hours at room temperature. After soaking, fibers were rinsed with distilled water and dried at room temperature for 24 hours, then followed by drying in the oven at 110°C for 1 hour [14]. For interfacial shear strength testing, the epoxy resin was used as a matrix.

2.2. Wettability and pull out testing
Fiber surface wettability was determined by contact angle measurement. The epoxy droplet was injected by syringe perpendicular to coir fiber. The contact angle measurement of droplet samples was conducted after 24 hours at room temperature using an optical microscope. The measurement of contact angle (θ) can be seen in figure 1.

![Figure 1. Contact angle](image)

Interfacial shear strength was measured by using pull out testing. Samples of pull out testing were molded by using a metal mold with the end coir fiber bonded on the ruler. Samples then were released from mold and drilled on the samples through the fiber (figure 2). Coir fiber was embedded by epoxy resin with different embedded length (lₑ = 5 mm and 10 mm). The pull out testing was performed by Universal Testing Machine with Llyod L10K Plus series based on ASTM 3379 with 2.5 mm/min strain rate. The sample gauge length is 15 mm.

The IFSS is formulated as in equation (1) [9]:

$$\tau = \frac{F_{\text{max}}}{\pi d l_e}$$

where $F_{\text{max}}$ is the maximum force, $d$ is the coir diameter and $l_e$ is the length of embedded coir fiber in the matrix.
2.3. SEM characterization
The morphology of interfacial adhesion of coir-epoxy was characterized by SEM type JEOL JSM 6510 LA.

3. Results and Discussions

3.1. Wettability
Wettability of coir fiber-epoxy matrix can be determined by measurement of droplet contact angle of coir fiber-matrix adhesion. Coir fiber-epoxy contact angle is displayed in figure 3 where the contact angle decrease with increasing densities of sodium bicarbonate solution for both soaking time 24 hours and 120 hours. The decrease of contact angle takes place due to the surface of coir fiber becomes cleaner and formed micropores after sodium bicarbonate treatment consequently the matrix can be easily absorbed to the fiber. The surface morphology of coir fiber by SEM has been reported by authors [14]. The more absorption of matrix in the fiber may cause the contact angle between fiber and matrix decrease. This result is similar to reported by Musanif et al.[16]. The lowest contact angle between fiber and matrix is attributed as the highest adhesion ability by means of favorable wettability. Yuan and Lee [15] state that small contact angles (<<90°) correlate with high wettability, while large contact angles (>>90°) correlate with low wettability.

![Figure 3. Fiber-matrix contact angle after sodium bicarbonate treatment of fiber](image)

3.2. Interfacial Shear Strength
The IFSS of coir fiber-epoxy adhesion is shown in figure 4 and figure 5. The IFSS of single coir fiber-epoxy matrix composite was influenced by sodium bicarbonate treatment of coir fiber. The IFSS of raw
coir fiber-epoxy matrix for 0.5 mm and 1.0 mm embedded fibers are 7.95 MPa and 2.82 MPa respectively. These value are relatively lower than IFSS with treated coir fiber. For both 0.5 mm and 1.0 mm embedded fibers, the IFSS of coir fiber-matrix enhances after sodium bicarbonate treatment. The highest IFSS for 0.5 mm and 1.0 mm embedded fibers is 12%NaHCO₃ for 120 hours. These values of IFSS are 11.53 MPa, 5.43 MPa respectively (table 1). Meanwhile, the lowest IFSS of coir fiber-epoxy matrix after treatment of coir fibers is 10%NaHCO₃ for 120 hours. The increase of interfacial shear strength (IFSS) after sodium bicarbonate treatment is caused by removal of impurities at the coir fiber surface so that it improves the interaction between fiber and matrix, and also micropores at the surface of coir fiber which facilitate to matrix penetration in the fiber leading to interfacial locking between fiber and matrix. Similar results have been studied by Fiore et al. [5] in sisal fiber treatment with sodium bicarbonate solution corresponded to interfacial shear strength. Then, table 1 showed correlation between IFSS and the embedded length of coir fiber in the epoxy matrix. It can be seen that 0.5 mm embedded fiber in the matrix has higher IFSS than 1 mm embedded fiber length. This indicates that the embedded length of fiber in the matrix influences the IFSS value. This influence has been reported by Tran et al. [17] for IFSS of coir fiber-matrix adhesion.

Figure 4. IFSS of coir fiber-epoxy matrix adhesion with 0.5 mm embedded fiber length after treatment of sodium bicarbonate of coir fiber

Figure 5. IFSS of coir fiber-epoxy matrix adhesion with 1 mm embedded fiber length after treatment of sodium bicarbonate treatment of coir fiber
Table 1. IFSS of coir fiber-epoxy adhesion for raw and after sodium bicarbonate treatment

| Samples         | IFSS (MPa) | 24 hours | 120 hours |
|-----------------|-----------|----------|-----------|
|                 | 0.5 mm    | 1.0 mm   | 0.5 mm    | 1.0 mm    |
| Raw             | 7.95      | 2.82     | 7.95      | 2.82      |
| 8%NaHCO₃        | 9.02      | 4.16     | 9.22      | 3.57      |
| 10%NaHCO₃       | 11.17     | 4.54     | 8.01      | 3.47      |
| 12%NaHCO₃       | 9.23      | 5.17     | 11.53     | 5.43      |

3.3. SEM characterization

The SEM micrographs of coir fiber-matrix adhesion are displayed in figure 6. Epoxy matrix penetrates to fiber through micropores which may cause adhesion fiber-matrix occurs. This adhesive in the surface of coir fiber appear after pull out test as can been in figure 6(b), 6(d), 6(f) and 6(h). This indicates that adhesion between fiber and matrix takes place. All epoxy matrices appear the hole after pull out test and seem no cracking (figure 6(a), 6(c), 6(e) and 6(g) which attributes that all fibers in the matrix are pulled out.

Figure 6. SEM micrographs of coir fiber-epoxy adhesion with 1 mm embedded fiber length after sodium bicarbonate treatment for 120 hours (a)-(b) epoxy-raw, (c)-(d) epoxy-8%NaHCO₃, (e)-(f) epoxy-10%NaHCO₃, (g)-(h) epoxy-12%NaHCO₃.
4. Conclusion
From results and discussion, the following conclusions are drawn: sodium bicarbonate treatment influenced the fiber surface wettability measured by droplet contact angle. Then, the density of 12wt% sodium bicarbonate for 120 hours has the highest IFSS of fiber-epoxy adhesion compared with other densities.

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