

Tensile and morphological properties of carbon-coir fiber reinforced epoxy hybrid composites

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Abstract

This study reports the tensile and morphological properties of carbon fiber-reinforced epoxy composites with the addition of coconut coir fiber. The composites were fabricated using the vacuum infusion method with coconut fiber weight fractions of 5%, 15%, and 25%. Tensile testing revealed that the highest tensile strength (70.92 MPa) was achieved at 15% fiber content, while 5% fiber content resulted in the lowest tensile strength (32.48 MPa). Scanning Electron Microscopy (SEM) and metallographic analyses showed variations in fiber-matrix bonding, with debonding and fiber pull-out observed at lower fiber content. The results suggest that optimal fiber-matrix bonding and fiber dispersion contribute to tensile strength enhancement, confirming the potential of coconut fiber-reinforced hybrid composites for structural applications.

Keywords:

SEM, metallography, tensile testing, coconut fiber, carbon fiber, vacuum infusion, composites

1 Introduction

Technological advancement is accelerating, particularly in the field of advanced materials [1]. More sophisticated materials with superior properties are needed to keep up with the rapid technological advancements [2]. There is a growing demand for high-performance materials across various industrial sectors, including transportation, automotive, aerospace, and housing [3]. Efforts are being made to develop materials with high strength but relatively low cost [4]. Advanced materials that are being widely developed for various applications are composites [5].

Composite materials consist of two or more different materials combined to enhance properties without compromising each other's properties [6]. A thought Composite material is carbon fiber reinforced Polymer (CFRP) [7]. CFRP composite materials consist of carbon fibers combined with thermoset, thermoplastic, and elastomeric matrices [8]. CFRP constituent material is carbon fiber with matrix selection that can use Epoxy, Polyester, Vinyl Ester, and others [9]. Epoxy resin has very high shape flexibility and has good mechanical, chemical, and thermal resistance, and is also compatible with various reinforcing fibers [10]. The combination of Epoxy and carbon fiber has advantages in good mechanical and physical properties [11]. However, the high cost is one of the drawbacks of making this composite [12]. To save the production cost of the materials, the addition of natural fiber is a solution [13]. Selection of natural fibers due to their advantages such as cost-effectiveness, reasonable mechanical strength, low density, and renewable [14].

One of the natural fibers that are abundant and have the potential to reinforce carbon fiber reinforced polymer is coconut coir fiber. Coconut coir fiber has a cellulose content of 50,5 % after alkali treatment [15]. Cellulose content affects the tensile strength of composites if incorporate natural fiber [16]. A previous study reported the use of coconut coir fiber reinforcement in combination with epoxy resin. This was reported in a previous study that made a hybrid composite of glass fiber and coconut coir fiber with an epoxy matrix [17]. The addition of coconut coir fiber resulted in an increase in tensile strength from 32.52 MPa to 40.7 MPa. This strength will be better if glass fiber is replaced with carbon fiber [18]. This is proven by previous research that combines woven carbon fiber and kenaf fiber using an epoxy matrix [19]. Hybrid composites consisting of 20% woven carbon fiber, 20% kenaf fiber, and 60% epoxy can achieve a tensile strength of up to 325.7 MPa. Good adhesion between matrix and fibers supports the high tensile strength. This phenomenon shows that carbon fiber-reinforced epoxy still has high strength when added to natural fibers like coconut coir fiber.

Based on these insights, this research examines hybrid composites with epoxy resin used as a matrix that will be combined with carbon fiber and coconut coir fiber. Coconut coir fiber is selected as reinforcement due to its high cellulose content and has been proven to increase tensile strength. This research aims to determine the tensile strength of an epoxy hybrid composite reinforced with carbon fiber and coconut coir fiber. Additionally, existing literature highlights that using natural fibers as reinforcement in composites is one way to reduce material costs and be environmentally friendly [20].

2 Material and methods

2.1 Material

Epoxy resin (density: 1,06 g/cm³) was obtained from Sigma-Aldrich (Merck. Ltd). Woven Carbon fiber (density: 1,2 g/cm³) was obtained from a local online store. Coconut coir fiber (density: 0,58 g/cm³) was obtained from local waste in Jember, Indonesia. Other chemical stuff, such as Sodium hydroxide (NaOH) was obtained from the local chemical market, CV. Aneka Kimia, Jember, Indonesia.

2.2 Coconut coir fiber preparation

Coconut coir fiber without alkalization treatment was prepared for control. Coconut coir fibers are dried using heat from sunlight to a constant weight. After that, an alkalization treatment was carried out for 30 minutes using 10% NaOH. The fibers were cleaned and dried again to constant weight.

2.3 Composites fabrication

The hybrid composite uses the composition presented in Table 1. The method used was Vacuum Infusion by arranging the lamination between carbon fiber and coconut coir fiber as shown in the schematic in Fig. 1. The glass mold used was 150x80x3.2 mm. In the first layer, coconut fiber is spread over the glass mold.

Table 1. Hybrid Composites Composition

Hybrid Composite	Epoxy (wt%)	Carbon Fiber (wt%)	Coconut Coir Fiber (wt%)
5% Non-Alkalization	89,1	5,9	5
5%	89,1	5,9	5
15%	79,1	5,9	15
25%	69,1	5,9	25

After it is evenly distributed, the second or middle layer of carbon fiber is added. The last or topmost layer is coconut fiber. Prepare the vacuum infusion process by pulling the epoxy until it is spread on the mold. When the resin is spread, drying is carried out for up to 24 hours. When the sample is dry, cutting is done according to ASTM D638 Type 4.

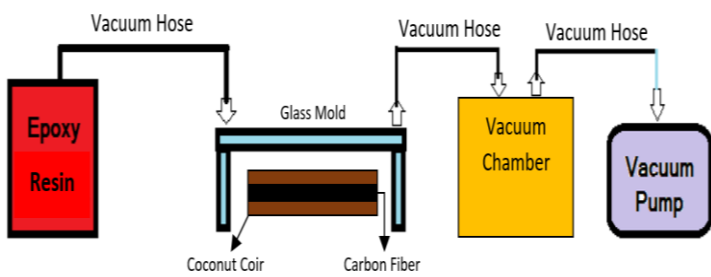


Fig. 1. Hybrid Composites Fabrication Scheme

2.4 Tensile Test

Tensile testing was carried out to determine the mechanical properties of the hybrid composites. Each variation has 3 replications. The test equipment used is the Universal Tensile Machine HT-2042 with 5 kN Capacity. Sample size according to ASTM D-638 Type 4.

2.5 Surface morphology test

The Digital Microscope (Olympus-CX43) observed the surface morphology of hybrid composites for all variations. Sample with lowest and highest tensile strength observed with Scanning Electron Microscopy (SEM) Hitachi TM 3030 Plus Brand.

3 Results and discussion

3.1 Tensile properties

Fig. 2 illustrates the results of the samples that fractured after tensile testing of the hybrid epoxy composites with carbon fiber and coconut coir fiber reinforcement. Tensile strength and elasticity modulus are used to determine the hybrid composites' mechanical properties. Tensile strength and elasticity modulus values of all samples tested are reported in Fig. 3 and Fig. 4.

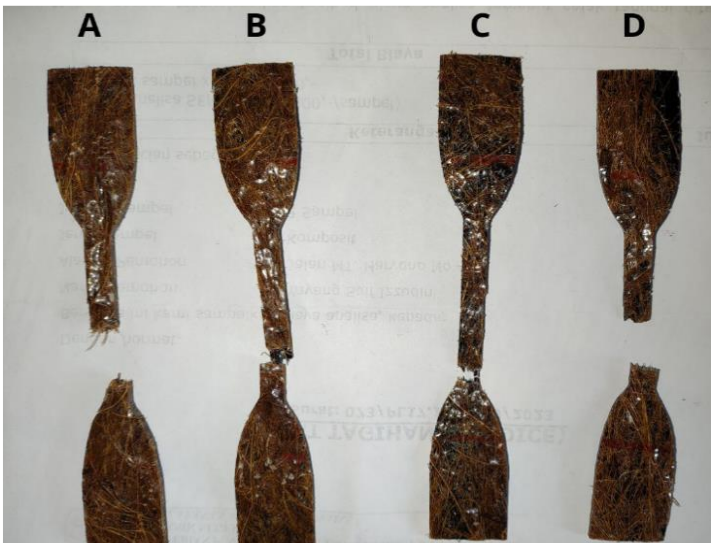


Fig. 2. Hybrid composites sample after tensile test; A) 5% Non Alkalization; B) 5%; C) 15%; D) 25%

Fig. 3 demonstrates that the tensile strength increases as the percentage of coconut coir fiber increases but decreases at the highest percentage. Alkali treatment of coconut fiber at 5% variation increases the tensile strength of the hybrid composite. Alkalization removes dirt, oil, and organic substances attached to the fibers, creating a clean fiber surface [21]. In addition, the alkaline solution can also remove the natural waxy coating on the coir fiber, making the fiber surface rougher [22]. This roughness of the fiber surface improves the adhesion between the fiber and the matrix [23]. This is supported by previous research where alkali treatment can increase the tensile strength of the hybrid composite [24]. The 25% variation increased tensile strength to 57 MPa and obtained the highest tensile strength at a 15% variation of 71 MPa.

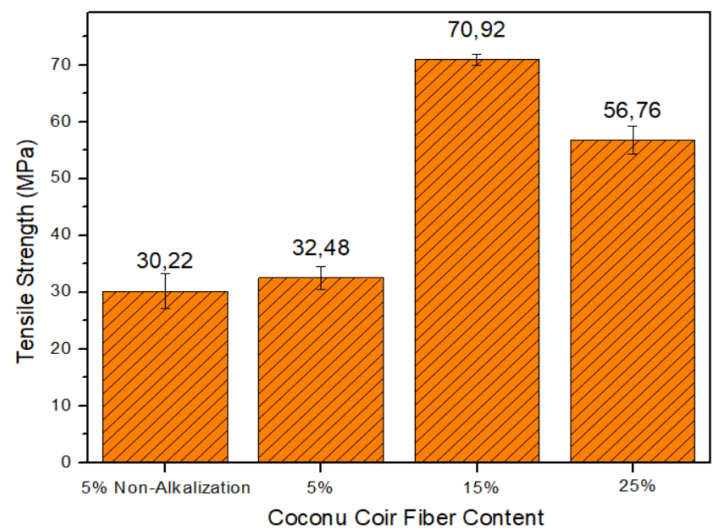


Fig. 3. Tensile Strength of Hybrid Composites

Compared to individual natural fiber composites, they consistently showed improved tensile strength due to the synergistic effects of combining different fibers [25]. This finding is supported by previous studies that reported optimum tensile strength not at the highest fiber variation [24]. In addition, the effective dispersion and good adhesion of the reinforcement material in the epoxy matrix cause increased tensile strength [26]. This result is supported by morphological observations on SEM in Fig. 7, which shows the presence of good fiber dispersion and interface bonding.

However, decreased tensile strength occurs at the highest variation of 20%. These findings are supported by similar research utilizing banana fiber at the highest fiber content to reduce tensile strength [27]. Tensile strength deteriorates due to inadequate fiber-matrix adhesion, which is particularly pronounced in composites with high coir fiber content [28]. Hybridization can be offset by the challenges posed by high natural fiber content, leading to structural abnormalities and reduced mechanical integrity [29].

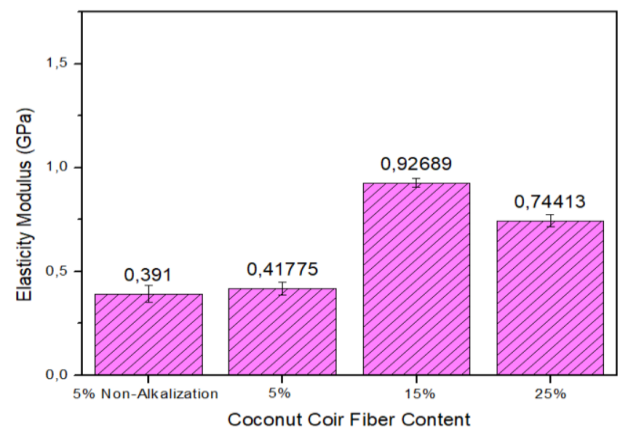


Fig. 4. Elasticity Modulus of Hybrid Composites

The elasticity modulus of the hybrid composites was illustrated in Fig. 4. Following the alkalization of the fiber, the modulus of elasticity is shown to have grown and increased further when the fiber content increased up to the 15% variation where the highest value was observed. The adhesion between fiber and matrix increases after alkali treatment because the fiber surface becomes smooth, thus increasing elasticity and stiffness [30]. In addition, the combination of high-strength carbon fibers with natural fibers improves the mechanical properties of the composite material, leading to increased stiffness and elasticity [31]. These findings are supported by another study that also utilizes natural fibers [32,33]. However, the highest variation decreased the elasticity modulus. This finding is related to the tensile strength results, where too high fiber content leads to structural abnormalities and reduced mechanical integrity [29].

3.2 Surface morphology by digital microscope

Surface morphology observation of the hybrid composite using an optical microscope is presented in Fig. 5. It is clear that improper soaking results in improper matrix distribution around the coir fibers resulting in poor bonding and bad adhesion [34]. This leads to the formation of voids, or empty spaces, between the fibers and the matrix, which can reduce the stiffness and strength of the composite [35]. Load transfer between the fibers and matrix is impaired by the voids [36]. The stresses in the composite material are concentrated around the voids when loaded, potentially leading to cracking and failure of the composite in that region [37].

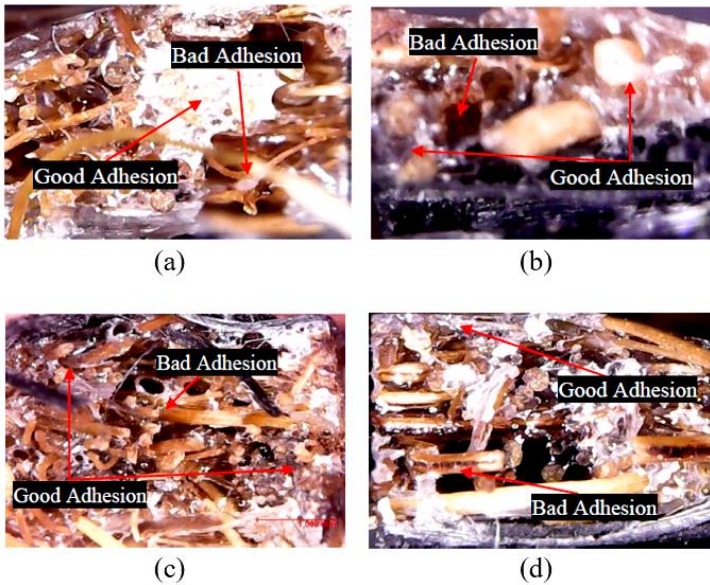


Fig. 5. Surface morphology by optical microscope (a); 5% Non-Alkalinization (b) 5%; (c) 15%; (d) 25%

3.3 Surface morphology by SEM

Fig. 6 shows the distribution of coir fibers in the hybrid composite at 5% addition. The distribution of these fibers within the composite matrix is uneven. This occurs as a result of the fibers congregating in places of higher concentration due to their limited number and creating areas of low fiber concentration that have minimal contact with the epoxy resin matrix [38]. As a result, the composite has unequal stresses as load transfer from the matrix to the fibers is hindered. This phenomenon is one of the reasons why the 5% variation has a lower tensile strength. Fiber fracture can result from higher tensile loads applied to areas with lower fiber concentration compared to areas with higher fiber concentration [24]. To maintain efficient load transfer and improve the composite's overall strength and dimensional stability, it is crucial to monitor and improve the even distribution of coir fibers in epoxy resin composites [39].

However, the SEM results in Fig. 7 show the distribution of coir fibers in the variation with the highest tensile strength of 15%. The tensile properties and overall performance of the composite are greatly affected by the even distribution of coconut fibers throughout the material. The coconut fiber and epoxy resin matrix effectively transfer the load, increasing the total strength and stiffness of the composite [30]. The even distribution of fibers can minimize the danger of breaking the fibers. Uniform distribution reduces the strain caused by dimensional variation, reduces contraction variation, and improves the dimensional stability of the composite [40]. Achieving uniform fiber distribution requires careful consideration of composition. The mechanical characteristics and general performance of epoxy resin composites are greatly improved by uniform coir fiber distribution [41]. Similar things were found in previous studies [19].

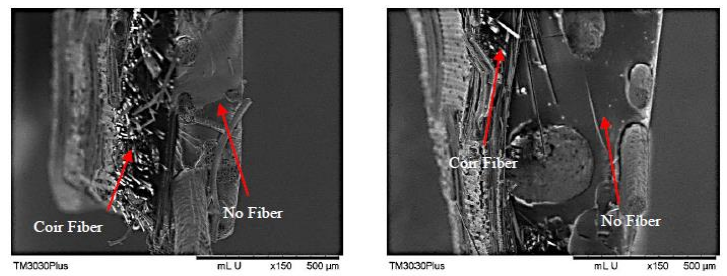


Fig. 6. Fiber distribution of 5% coconut coir fiber on hybrid composites

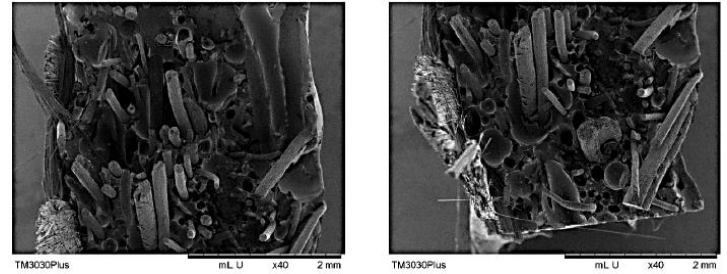
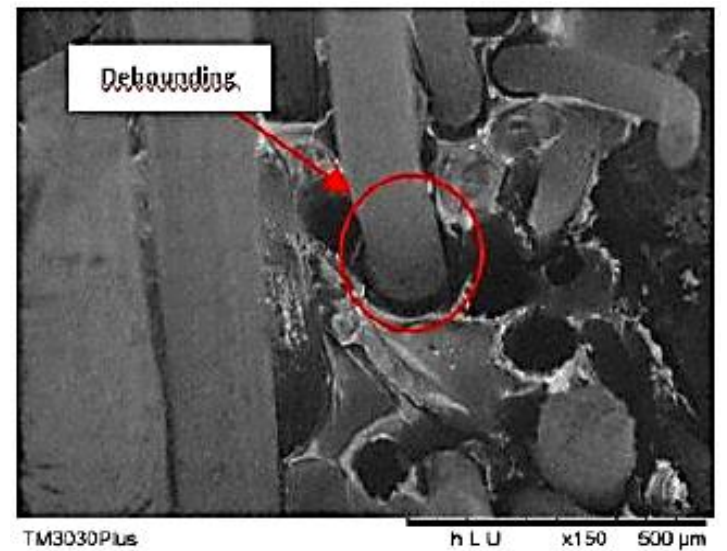
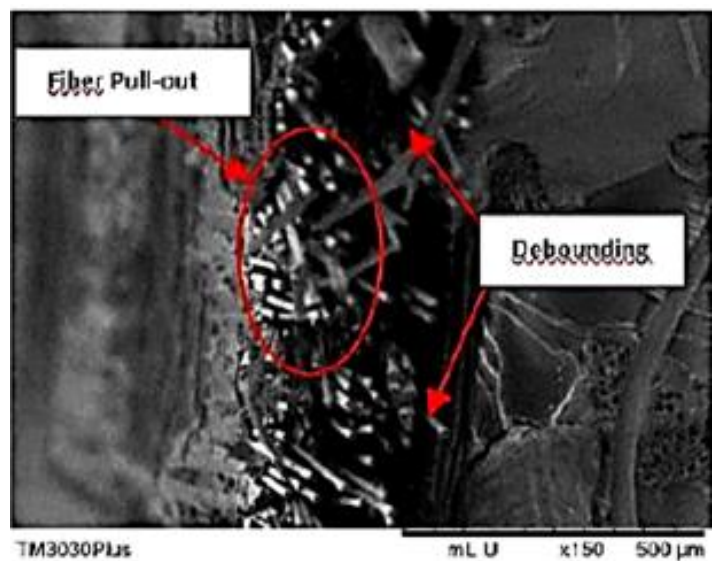


Fig. 7. Fiber distribution of 15% coconut coir fiber on hybrid composites



(a)



(b)

Fig. 8. Coconut Coir fiber hybrid composite observation results; (a) 15% (b) 5% Non Alkalinization

A comparison of the SEM results between the variation with the highest tensile strength value at 15% and the lowest tensile strength at 5% non-alkali treatment is presented in Fig. 8. In the 15% variation shown in Fig. 8a, there is still a slight debonding despite having the highest tensile strength. Due to the debonding, it is clear that the matrix and fiber interaction is still not perfect [42]. Adhesion and debonding in composite materials are significantly affected by alkalization treatment. As a result, the fiber surface becomes cleaner, improving the ability of the fiber to adhere and connect with the matrix [23]. In coconut fiber epoxy resin composites, increasing adhesion and decreasing the possibility of debonding is highly dependent on a proper and ideal alkalization process [41]. Similar findings were found in a previous study [24].

4 Conclusion

This research fabricated and tested carbon-coconut fiber-reinforced epoxy hybrid composites using the vacuum infusion method. The results showed that 15% coconut fiber content yielded the highest tensile strength (70.92 MPa), while 5% non-alkalized fiber content had the lowest (32.48 MPa). The addition of coconut fiber enhanced tensile strength, with fiber dispersion and interfacial bonding playing a crucial role in mechanical performance. SEM analysis confirmed variations in fiber-matrix interaction, with debonding and fiber pull-out observed in lower fiber content composites. These findings demonstrate the potential of coconut coir fiber as a sustainable reinforcement material for hybrid composites, particularly in lightweight structural applications. Future research should explore fiber treatment methods and long-term durability for improved performance.

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