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EVALUATION OF MECHANICAL AND MORPHOLOGICAL PROPERTIES COMPOSITE OF AGEL LEAF FIBER (ALF)-EPOXY MODIFIED WITH CARBON POWDER

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Abstract

This research focuses on the successful development of Agel Leaf Fiber (ALF)-Epoxy composites added with Carbon Active Powder (CAP) and printed using the Vacuum Pressure Infusion (VAPRI) method. Considering the importance of determining the mechanical properties of composites as raw materials for making fishing boats, this research aims to determine the use of Agel Leaf Fiber (ALF) in polymer matrix composites. The composite morphology was analyzed using Scanning Electron Microscopy (SEM) and ImageJ software. The mechanical properties evaluated included Tensile Strength, Flexural Strength, and Hardness. The composite was prepared by incorporating CAP in varying volumes of 0 %, 10 %, and 30 % with a fixed ALF percentage of 40 %. The results showed that the addition of CAP significantly increased the tensile strength to 128.51 MPa, with 0.068 % elongation, 1787.39 MPa modulus of elasticity, and a hardness value of 75.2 HD. Furthermore, the addition of 10 % carbon exhibited a remarkable improvement in flexural strength, reaching 238.51 MPa. This improvement could be attributed to reduced porosity, resulting in enhanced bonding between ALF-CAP-Epoxy components. The flexural strength of the composite with the highest CAP content experienced a significant increase of 238.51 MPa. Thus, Agel leaf fiber has the potential to be used as a reinforcing material in the manufacture of composites and is applied in the manufacture of environmentally friendly fishing boat bodies.

Keywords: natural fiber, agel leaf fiber, carbon powder, composite, mechanical properties.

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1. Introduction

Sea transportation serves as a crucial link and catalyst for national economic growth across Indonesia's diverse regions and territories [1]. In addition to serving as a vital connectivity node between islands, ships have a significant impact on the transportation of goods, fisheries, and agricultural products across different regions [2, 3]. Wooden ships are particularly used in Indonesia for cargo, fishing, and passenger purposes [4]. The utilization of wooden ships can be attributed to several factors, including abundant raw materials, ease of fabrication, affordability, and strong and straightforward construction [5]. Consequently, it is unsurprising that wooden ships continue to be prevalent and frequently observed as a fleet of choice among the local population for their shipping needs.

Although wood remains a potential raw material for shipbuilding, its utilization is considered inefficient due to the negative environmental impact caused by high demand, leading to deforestation and environmental damage. Additionally, wooden ships have various drawbacks, including flammability, susceptibility to weathering, and vulnerability to wood-destroying organisms. This means fishing boats constructed with wood often require frequent repairs (docking) at least every six months [6]. To address these limitations, there have been modifications and replacements of wood with composite materials in ship construction [7]. For instance, fishermen commonly use composite materials, particularly fiberglass composite, to construct 30 GT Type Purse Seine fishing boats [8, 9]. However, fiberglass composite materials are prone to leaks and fires during ship operations, necessitating further improvements to ensure the safety of fishing boats [4].

With technological advancements, composite materials have gained recognition for their various advantages, including lightweight, high strength, cost-effectiveness, and environmental friendliness [10, 11]. The use of composite, initially dominated by synthetic materials such as fiberglass, has shifted towards natural fiber composite (NFC) [12]. This does not imply that synthetic composite has been completely abandoned, but NFC hold immense potential for further development [13]. The abundance of natural fiber in tropical countries presents new opportunities for developing materials such as natural fiber-reinforced composites. These composites exhibit higher strength and lighter density than their counterparts [14]. NFC has been extensively explored using various natural fibers, including sea hibiscus tree fibers (HBF) [15, 16], banana stem fibers (BSF) [17] and Kenaf fiber [18].

Prior to delving into the development of natural fiber in polymer composite products for various applications, it is crucial to assess the mechanical properties of the composite [19]. The heterogeneous structure of natural fiber can lead to complex interactions with fiber constituents such as hemicellulose, lignin, cellulose, and extractive substances when combined with polymer matrices [20]. These interactions significantly influence the mechanical properties of the composite. Good mechanical properties will reduce the impact of structure failure. Therefore, analyzing and modifying the product to achieve superior mechanical properties is intriguing.

Given the importance of determining the mechanical properties of composite as development of raw materials for the manufacture of fishing boats, this study aims to investigate the use of Agel Leaf Fiber (ALF) in polymer matrix composite. Composite is made using vacuum infusion by varying the addition of carbon active powder (CAP). The purpose of adding CAP is to ensure the resulting composites have high mechanical properties to support better alternative raw materials for shipping. Furthermore, the mechanical properties of the composite evaluated include Tensile Strength, flexural strength, hardness, and morphology with Scanning Electron Microscopy (SEM) observation.

2. Material and Method

2. 1. Fiber Material

ALF was obtained from farmers in Sleman Regency, Yogyakarta, Indonesia. It was extracted from agel leaves that were approximately 5 years old. The process of obtaining the fiber involved separating the leaves from the stem and soaking them in water for 12–18 days. Subsequently, the fiber was cleaned with clean water and left to dry at room temperature for approximately ±12 days. The fiber is woven with a shape like a 1-1 net, as shown in **Fig. 1.**

a *b*

Fig. 1. Fiber material: *a* – Agel plant; *b* – Agel leaf fiber shape

CAP was derived from coconut shells sourced from PT Multi Chemical Indotrading, located in Tangerang, Indonesia, with a size of 1000 mesh. Meanwhile, Epoxy Matrix (EP) employed in the composite was supplied by PT Justus Kimia Raya, Surabaya, Indonesia.

2. 2. Composite making

The process of making composite specimens using the vacuum resin infusion (VARI) method is shown in **Fig. 2**. ALF fibers were arranged in a mold, forming a total of 5 layers in accordance with the testing standard. Additionally, carbon powder (CP) and EP were accurately weighed using an analytical balance, following the composition outlined in **Table 1**. The composite was left to dry in an open environment for 24 hours, followed by a 2-hour heating period in an oven at 40 °C. The specimens were coded NCAP (Non-Carbon Active Powder), LCAP (Low Carbon Active Powder), and HCAP (High Carbon Active Powder) [21]. The process of making composite specimens can be seen in the **Fig. 3**.

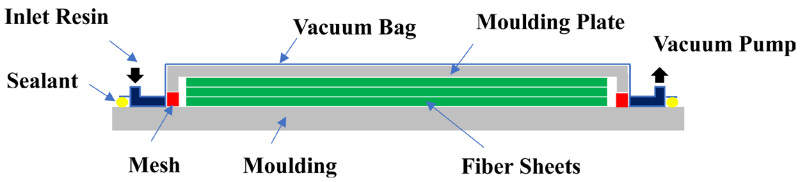


Fig. 2. Schematic diagram of vacuum resin infusion (VARI)

Table 1
Composite volume fraction

	Composite volume fraction (%)		
Code	**Composite layer**	**Carbon active powder (CAP)**	**Epoxy matrix (EP)**
NCAP	5	0	100
LCAP	5	10	90
HCAP	5	30	70

a *b* *c*

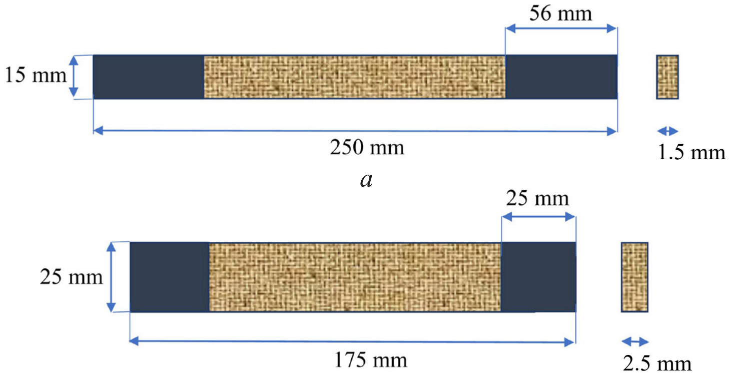
Fig. 3. Composite manufacturing process: *a* – fiber cutting; *b* – vacuum infusion process; *c* – removal of composite from molding

2. 3. Scanning electron microscopy testing and analysis

Scanning Electron Microscopy (SEM) analysis was employed to conduct morphological observations on the surface of the composite specimens for each variation. Observations were made with the FEI Type inspect S-50 SEM tool producing high-resolution results using thermal emission electron optics. The SEM images obtained were subsequently analyzed with the assistance of Image software, enabling further examination and evaluation of the results.

2. 4. Evaluation of tensile test, bending test, and hardness of composite

The composite strength was evaluated using a universal testing machine model JTM-UTS510 at a speed of 0.5 mm/s at room temperature ±32 °C. The specimens were fabricated in accordance with the international standards ASTM D 3039 for the tensile test and ASTM D 790 for the bending test. Each composite specimen underwent 5 repetitions of testing. The dimensions and shape of the specimen are shown in **Fig. 4**. Meanwhile, the hardness test was conducted using Shore-type D testing in accordance with ASTM D 2240.



a

b

Fig. 4. Standard test specimen: *a* – ASTM D 3039; *b* – ASTM D 790

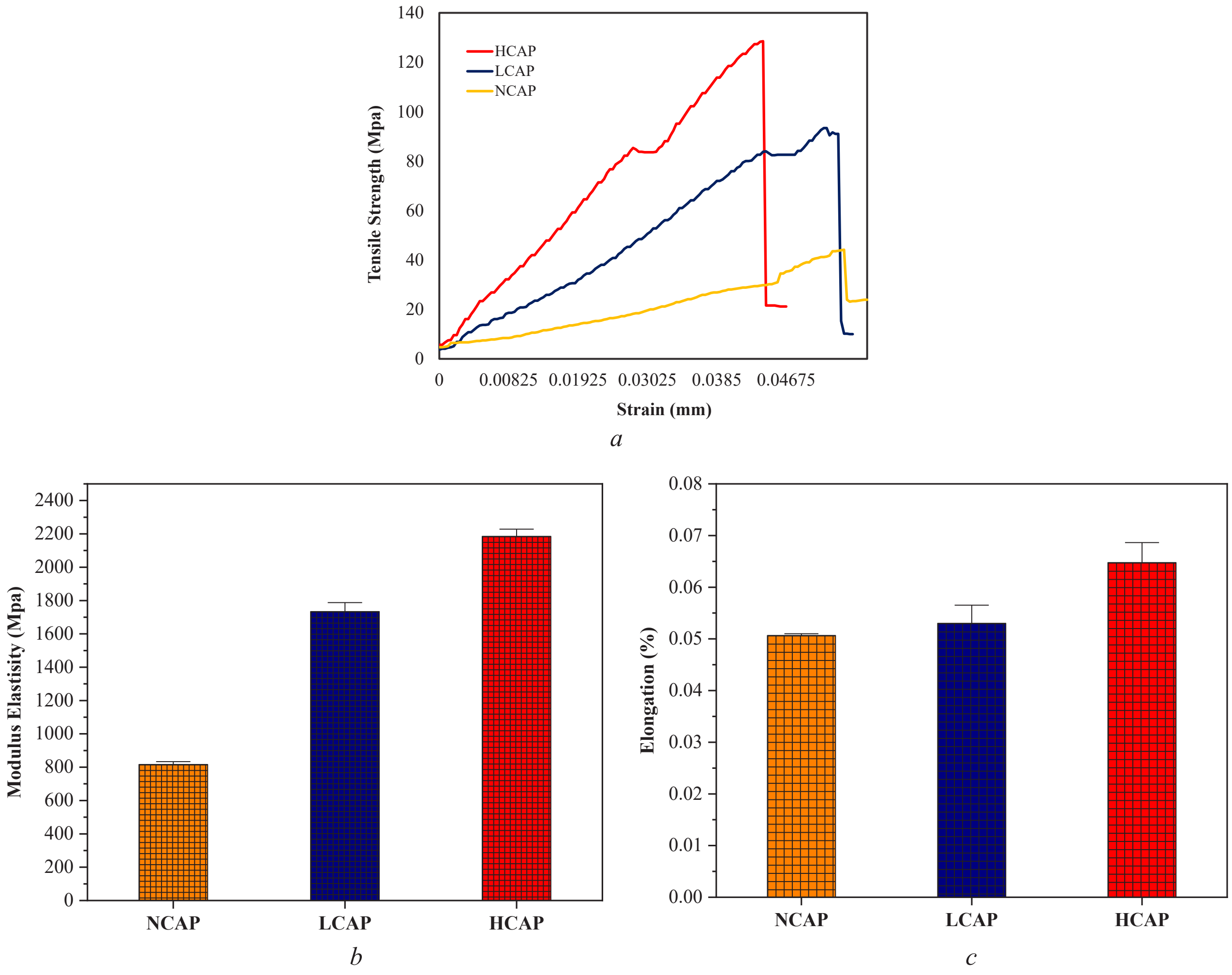
3. Result and Discussion

3. 1. Tensile strength

After completing the tensile testing using a universal machine, calculations were performed, and various test parameters were determined. A typical graph of the stress-strain relationship generated in the tensile testing of composite is shown in **Fig. 5**. It can be seen that the addition of CAP can provide an opportunity to increase the strength value of the ALF-Epoxy produced. The NCAP exhibits an average strength value of 44.15 MPa, while the LCAP and HCAP are 91.04 MPa and 128.51 MPa, respectively. When compared to composites using E-glass-Epoxy synthetic fibres with the hand layup technique, these findings still have an advantage in tensile properties. The tensile strength of GFRP composites with 20 % fibre loading is 59.3 MPa [22]. This can prove that the addition of carbon powder in natural fibre composites is better than synthetic fibres. Therefore, it has great potential in development such as ship raw materials. The increase in strength can be attributed to the strong adhesion bond between ALF-CAP-Epoxy, facilitating the uniform distribution of tensile stress, which is evident in SEM observations. Furthermore, adding CAP offers the advantage of filling the voids between the fiber and the matrix. This configuration allows for improved infiltration and wetting of the composite gaps by the epoxy resin, resulting in enhanced mechanical bonding [21]. This mechanical bounding provides an opportunity to increase the tensile strength of LCAP and HCAP. An illustration of this mechanical bounding is shown in **Fig. 6.**

NCAP has the lowest strength due to the presence of voids between the reinforcement and the resulting matrix. Voids within the matrix pose a significant risk since the reinforcement relies on the matrix for support, while the reinforcement consistently transfers stress to the matrix. This causes cracks to appear, leading to brittleness and premature failure of the composite [15]. Voids can adversely affect the bond between the fiber and the matrix, which causes the matrix to be unable to fill the space in the mold. When the composite is subjected to a load, stress concentration occurs in the void regions, reducing the strength of NCAP.

The stress-strain relationship graph shows a drawback of the composite, wherein the addition of high CAP results in lower strain values despite increased strength. This shows that the addition of high CAP also impacts the brittleness of the composite. Notably, the highest elongation value is observed in HCAP with a 30 % addition of CP by volume. High CAP helps fill the void between the fiber layer and the matrix, leading to a greater elongation value. However, a larger elongation value also implies increased fragility in the composite. The calculation results of the composite's Elasticity Modulus also show that a significant increase in value is at NCAP 802.63 MPa, LCAP 1787.39 MPa, and HCAP 2128.54 MPa. These values indicate that the composite becomes stiffer with the addition of CP [23].



a

b *c*

Fig. 5. Tensile strength analysis: *a* – graph of the stress-strain; *b* – modulus of elasticity; *c* – elongation

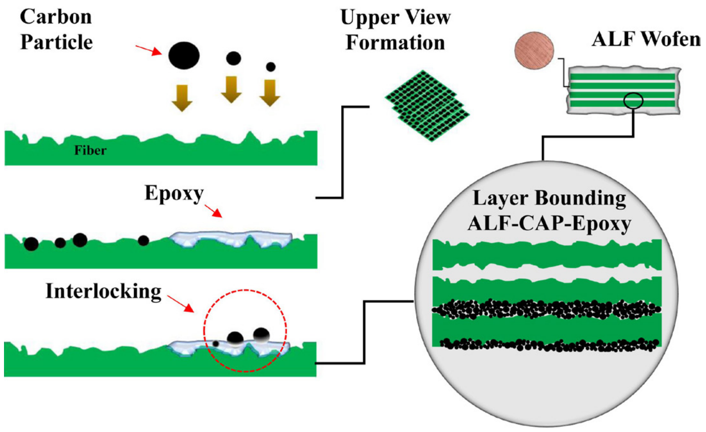
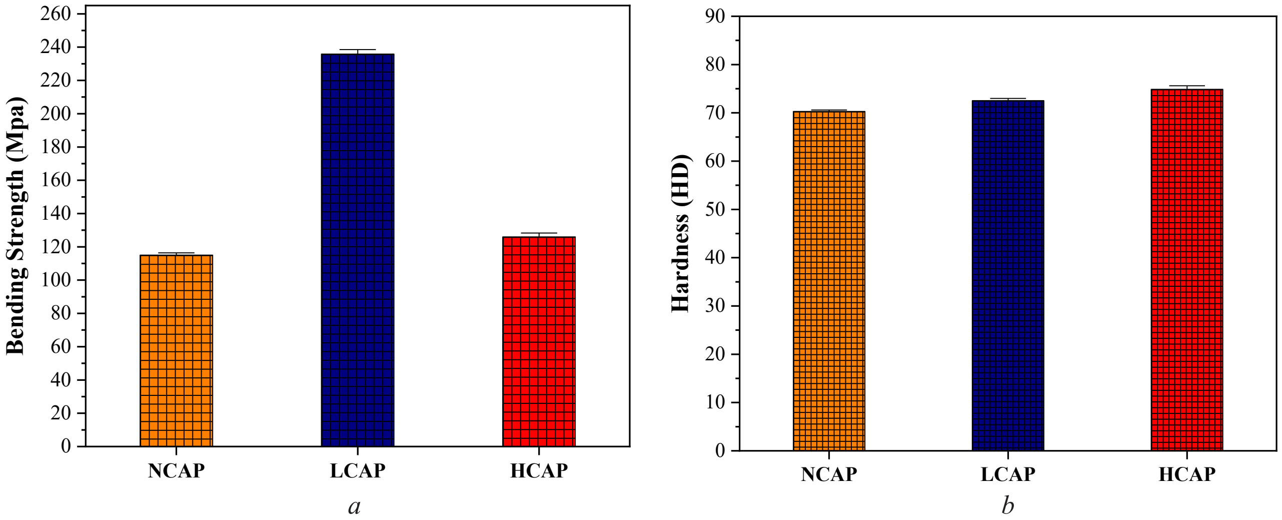


Fig. 6. Illustration of mechanical bounding arrangement of Agel leaf fiber, carbon powder, and epoxy matrix

The interaction between the constituent elements of fiber composite and matrices plays a significant role in determining its properties. The interfacial strength between the composite components, such as fibers and matrices, is crucial for load transfer from the matrix to the fiber [6]. **Fig. 6** illustrates the interface contact between ALF, CAP, and EP. The addition of CP leads to improved mechanical bonding, thereby enhancing the tensile strength. CAP adheres to the fiber surface and fills the voids between the fiber and the matrix. It becomes trapped upon drying, resulting in an interlocking mechanism [11]. The strength of this interface bond contributes to the higher longitudinal tensile strength of the composite [24].

3. 2. Flexural strength and hardness

The flexural strength results of the analyzed composite developments are shown in **Fig. 7, *a***. The average flexural strength values of NCAP, LCAP, and HCAP were 116.29 MPa, 238.51 MPa, and 126.33 MPa, respectively. The highest flexural strength value occurred in LCAP with 20 % CAP addition composition. However, it is important to note that HCAP with a higher CAP addition of 30 % exhibited a decrease in flexural strength. This decrease could be attributed to the non-uniformity of the size and shape of CP used. Different shapes and sizes of CP can lead to stress concentration, resulting in reduced flexural strength of HCAP. Another factor to consider is the compatibility issue between the hydrophilic ALF and the hydrophobic EP [2]. The addition of 30 % CAP can increase the hydrophilic properties, thereby preventing the epoxy resin from effectively enveloping the fibers and CP. This observation is consistent with the findings from SEM analysis.



a *b*

Fig. 7. Flexural strength analysis: *a* – bending Strength; *b* – hardness

Fig. 7, *b* illustrates the hardness values of the developed composite. As the volume fraction of CAP rises, the composite hardness also increases. NCAP has an average hardness value of 70.3 HD, while LCAP and HCAP are 72.5 HD and 75.2 HD, respectively. This increase in hardness can be attributed to CP ability to fill the gaps between the fiber and the matrix, resulting in a denser composite structure, as shown in **Fig. 6**. Furthermore, the hollow nature of CP allows EP to fill the voids, contributing to the increased density. The high density achieved helps reduce the presence of voids, leading to higher hardness values in the composite. Another factor is the high volume fraction of CP, which contributes to good homogeneity within the composite, resulting in uniform hardness across the specimens [3].

3. 3. Scanning electron microscopy analysis

SEM observations were conducted to examine each composite's morphology after adding CAP. The SEM images of NCAP, LCAP, and HCAP are shown in **Fig. 8**.

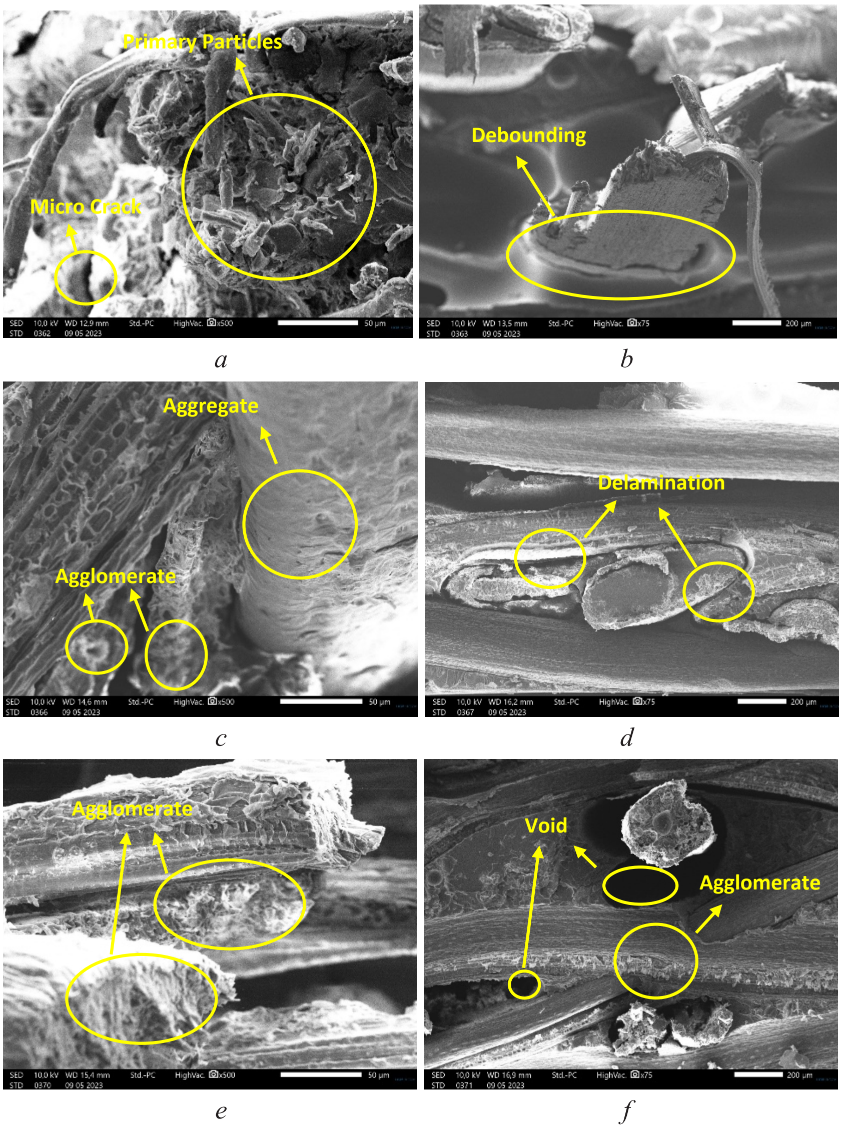


Fig. 8. SEM images observation results: *a* – longitudinal cross-section NCAP; *b* – cross-section NCAP; *c* – longitudinal cross-section LCAP; *d* – cross-section LCAP; *e* – longitudinal cross-section HCAP; *f* – cross-section HCAP

In NCAP, numerous delaminations and pullout failures are evident. This can be attributed to the abundance of voids between the fiber and the matrix, resulting in weak bonding [6, 25]. Weak bonds contribute to crack initiation, leading to a decrease in the tensile strength of the fiber [15]. On the other hand, the SEM images of LCAP show that the voids between ALF and Epoxy are filled with CP. The composite exhibits a dense and uniform structure, with the resin penetrating and wetting the gaps, resulting in improved mechanical bonding. CP adheres well to the fiber walls, reducing the occurrence of delamination and pullout mechanisms in LCAP. In HCAP, the cavity between the fiber and the matrix is almost indiscernible in the cross-section. The composite appears highly dense and uniform, contributing to the high hardness and tensile strength values [23, 26–28]. It also appears from the longitudinal cross-section that the resin and CAP can stick to the fiber well to form thin layers. The cross-section of HCAP reveals a longitudinal groove layer, reduced fiber and matrix porosity, and overall uniformity. These findings indicate a strong bond between ALF-CAP and Epoxy. However, behind the good bonding, the provision of 30 % large CP seems to have a negative impact on HCAP. This is because the nature of carbon active has large pores that can initiate early failure, therefore, HCAP has a lower bending resistance.

This is also the case with the iron sand composite to which carbon powder is added. It can be seen that the composite material has a dense and uniform structure, and the carbon powder is effectively dispersed throughout the epoxy matrix, resulting in significant structural reinforcement. The surface shows good bonding between iron sand, carbon powder, and epoxy matrix, and no cracks are visible in SEM images. The results indicate that the composite material can be well bonded, thus contributing to the flexural strength. The distribution of carbon powder in the epoxy matrix is high, non-uniform and tends to form agglomerates [17, 21, 29].

From this study, the use of ALF natural fibres as reinforcement in composite materials offers several advantages, including lower weight and cost compared to synthetic fibres, as well as being environmentally friendly and sustainable. However, the hydrophilic nature of natural fibres poses challenges in terms of water absorption and reduced mechanical properties in composite materials. To overcome these challenges, modification techniques with the addition of CP carbon powder have been applied to reduce the hydrophilic nature of natural fibres and improve their compatibility with hydrophobic polymer matrices. Given the limitations of the study, it is necessary to evaluate other properties such as physical, thermal and chemical properties for wider applications. In addition, effective processing of natural fibres is essential to achieve the desired properties in composite materials. By considering these factors, the results of the mechanical properties evaluation on ALF-Epoxy composites can be applied in the development of high strength structures and thermal insulation.

4. Conclusions

The investigation of ALF-Epoxy composite modified with CP yielded positive results. The addition of CAP significantly increased the tensile strength to 128.51 MPa, with 0.068 % elongation, 1787.39 MPa modulus of elasticity, and a hardness value of 75.2 HD. Furthermore, LCAP exhibited a remarkable improvement in flexural strength, reaching 238.51 MPa. The addition of CAP effectively reduced the presence of pores between the fiber and the matrix, leading to enhanced bonding between ALF, CAP, and Epoxy. The results of SEM observations confirmation on the longitudinal cross-section showed that the resin and CAP can stick to cover the fiber well to form thin layers. In the case of HCAP, the cross-section showed the formation of a longitudinal groove layer with reduced fiber and matrix pores, indicating uniformity. However, a high concentration of CP, such as 30 %, negatively impacts HCAP. This is because the presence of large pores in CP can initiate early failure, resulting in lower bending resistance for HCAP.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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