UDK 66.095.26:620.168
Original scientific article/Izvirni znanstveni članek

ISSN 1580-2949
Mater. Tehnol.

HYBRID POLYMER COMPOSITE OF ABACA-E-GLASS AND EPOXY-BAMBOO ACTIVATED CARBON NANOFILLER WITH VARIATIONS IN FIBER ORIENTATION

HIBRIDNI POLIMERNI KOMPOZIT OJAČAN S STEKLENIMI E-VLAKNI, VLAKNI MANILSKE KONOPLJE IN AKTIVIRANIM NANO POLNILOM IZ BAMBUSOVIH VLAKEN V EPOKSIDNI SMOLI S SPREMINJANJEM ORIENTACIJE VLAKEN

L. Banowati[1*], N. Chitraningrum[2]

[1]Department of Aeronautical Engineering, Nurtanio University, Bandung, Indonesia
[2]Department of Biomass and Bioproducts Research Center, Badan Riset dan Inovasi Nasional, Cibinong, Indonesia

Prejem rokopisa – received: 2024-09-23; sprejem za objavo – accepted for publication: 2025-05-18

doi:10.17222/mit.2024.1303

This research provides new composite materials utilizing treated abaca biomass fibers as reinforcement in composites, which are hybridized with E-glass synthetic fibers. This requires the employment of a bamboo-activated carbon-nanofiller composite polymer matrix. The mechanical characterization of the composites reinforced with abaca biomass fiber – treated with 5 % NaOH for 2 hours – and combined with an addition of a low percentage of bamboo-activated carbon nanofiller in the polymer matrix is conducted. Variants include abaca biomass fiber composites and abaca-E-glass hybrid composites, with fiber orientations in unidirectional (0°), bidirectional (0°/90°) and random configurations, providing potential solutions for improving the mechanical characteristics of the composites. The lamination of the composites is carried out using hand lay-up and vacuum bagging methods. Tensile tests are carried out according to ASTM D-3039. SEM analysis shows that the bamboo-activated carbon nanofiller and the matrix are properly combined. The matrix and the activated carbon nanofiller absorb the tensile test load simultaneously, distributing it to the fibers, acting as the composite reinforcement and thereby enhancing the composite's strength. In addition, the surface lamination of the composite is more uniform due to the hybridization of abaca fibers with E-glass fibers so that it has a higher tensile strength, exhibiting a more consistent arrangement in both fiber diameter and configuration. Therefore, the tensile strength of abaca-E-glass/epoxy-bamboo activated carbon nanofiller composites with bidirectional (0°/90°) and unidirectional (0°) fiber configurations is 62.5 MPa and 128.5 MPa, respectively, showing strong potential for further development and broader application in medical equipment and ballistic technology.

Keywords: hybrid, abaca, E-glass, nanofiller, epoxy, bamboo-activated carbon

V članku avtorji opisujejo raziskavo izdelave novega kompozitnega materiala z uporabo obdelanih vlaken (2 uri v 5 % NaOH) biomase iz abake (tudi manilska konoplja) kot ojačitev v hibridnih kompozitih v kombinaciji s sintetičnimi vlakni e-stekla (angl.: E-glass fibers). To je zahtevalo dodatno uporabo nanopolnila iz aktiviranih ogljikovih vlaken v kompozitni polimerni matrici. Pri izdelavi kompozitov so spreminjali medsebojni položaj oziroma smer (paralelna, pravokotna in naključna) vlaken abake, steklenih e-vlaken in aktiviranih ogljikovih vlaken iz bambusa v polimerni matrici. S tem so analizirali vpliv medsebojne lege vlaken na mehanske lastnosti kompozitov. Postopek laminacije (nanašanja plasti za plastjo) so izvajali ročno in z vakuumsko metodo. Natezno trdnost kompozitov so določili v skladu s standardom ASTM D-3039. Metalografske preiskave z vrstičnim elektronskim mikroskopom (SEM) so pokazale, da je kombinacija nanopolnila iz aktiviranih bambusovih vlaken in polimerne matrice ustrezna, ker istočasno oba absorbirata in enakomerno porazdelita natezno obremenitev po kompozitu. To ustrezno izboljša mehansko trdnost kompozita. Prav tako površinska laminacija plasti kompozita povzroči bolj enakomerno hibridizacijo vlaken abake, tako da imajo kompoziti večjo trdnost zaradi bolj ustrezne (konsistentne) ureditve tako glede premera vlaken, kot tudi njihove konfiguracije. Hibridni polimerni kompoziti sestavljeni iz vlaken abake, vlaken e-stekla in epoksidne matrice z nano polnilom iz aktiviranih ogljikovih vlaken iz bambusa imajo natezno trdnost 62,5 MPa (pravokotna lega vlaken; 0°/90°) in 128,5 MPa (vzporedna lega vlaken; 0°). Zato imajo te vrste kompozitov dobre možnosti za širšo uporabo v medicinskih in balističnih (zaščita pred izstrelki) aplikacijah.

Ključne besede: hibridni polimerni kompoziti, vlakna manilske konoplje, vlakna iz e-stekla, nanopolnilo, aktivirana ogljikova vlakna iz bambusa, epoksi

1 INTRODUCTION

Research on polymer composites has advanced rapidly due to their significant potential for use in advanced technological applications. Composite materials are widely employed as components within the structural industry. The urgency of this research lies in the utilization of abaca and bamboo biomass fibers, which are abundant and sustainable natural resources in Indonesia. However, these resources have not yet been fully optimized to enhance domestic supply levels and reduce dependence on imported products. The objective of this research is to present abaca and bamboo biomass fibers that enable good compatibility between them and the matrix. Therefore, it is essential to conduct a characterization of the abaca and bamboo biomass fibers through treatment with

*Corresponding author's e-mail:
liesbano@gmail.com (Banowati L.)

a sodium hydroxide solution (NaOH). The NaOH treatment effectively reduces the levels of pectin and lignin in abaca fibers, while the addition of bamboo-activated carbon nanofiller acts as an adsorbent for impurities within the fibers, which are integrated with an epoxy matrix.

This research presents new advanced materials by utilizing treated abaca biomass fibers as reinforcement in composites, which are hybridized with E-glass synthetic fibers. This involves the use of a bamboo-activated carbon nanofiller and a polymer matrix, specifically an epoxy polymer combined with a low-concentration bamboo-activated carbon nanofiller. Characterization is conducted to assess the mechanical properties of the resulting composites, which are expected to be strong, rigid, lightweight, and cost-effective, thereby serving as alternative materials to conventional materials.

The research focuses on the formulation of biocomposite and synthetic fiber configurations to create materials that can enhance the diversity of physical characteristics in composite structures.[1] The incorporation of natural fibers within the composition of synthetic fiber composites has demonstrated significant potential for scientific exploration. Natural fiber-reinforced biocomposites are utilized in various applications, including automobiles, unmanned aerial vehicles, the construction and building sector, consumer products, packaging, biomedical fields, and defense.[2–4] The use of natural fibers offers several advantages, such as being relatively inexpensive, renewable, partially or fully recyclable, biodegradable, and environmentally friendly. The hybridization of composites introduces a range of appealing characteristics derived from both natural and synthetic fibers, resulting in attractive properties at a cost-effective price for the final product.[5] Hybrid composites can be categorized into interlayer hybrids, where layers of two or more uniform reinforcements are arranged in a layered manner, and intralayer hybrids, where two or more types of constituent fibers are blended within the same layer. In this paper, we report on the results of the characterization of biomass fiber types and their applications.[6] Straw fibers with a high volume, low density, and viscosity higher than that of the resin used in hybrid composites indicate that a high volume of low-density fibers causes structural defects and reduces the wettability of the resin. Hybrid composites of silk, bamboo, and glass fibers with nanofillers can increase the strength of the composites developed for structural, interior, automotive, and aircraft industry applications.[7] Currently, investigations into hybrid applications of natural and synthetic fiber composites have been carried out using ramie fibers/epoxy composites for medical prosthesis socket devices,[8] as well as woven kenaf–kevlar[9] and abaca-E-glass/polyester,[10] used for ballistic applications.

Previous research included studies on various types of biomass fibers, treatments, and polymer matrices, specifically abaca and cement,[11] abaca-glass/epoxy hybrid,[12] abaca NaOH 5-*w*/%/epoxy,[13] bamboo bundle-wood veneer,[14] bamboo hydrogen peroxide,[15] bamboo/melamine,[16] bamboo bundles with one-time drying/phenolic resin,[17] abaca-E-glass/polyester,[10] bamboo-E-glass/epoxy[18] and purun tikus treated with NaOH/epoxy.[19] The research on biomass fiber composites and hybrid biomass-synthetic fibers combined with activated carbon nanofillers in polymer matrices includes the following materials: cotton, banana, hemp, kenaf, coir, sisal/polyester with nanoclay particles,[20] palm fiber-glass nanoparticle hybrid reinforced with palm kernel shell,[21] sisal-basalt/epoxy composite reinforced with multi-walled carbon nanotube,[22] and flax/PLA fiber-reinforced epoxy nanocomposite.[23] The literature review and prior research indicate that the treatment process significantly affects the strength of biomass fiber when used as a composite reinforcement. Numerous studies have previously employed the NaOH treatment as a method of enhancement.

In this research, the mechanical characterization of composites using abaca biomass fiber as a reinforcement that has been treated with 5-% NaOH for 2 hours and combined with a low percentage of bamboo-activated carbon nanofiller in the polymer matrix is conducted. Variations included an abaca fiber composite and abaca-E-glass hybrid, with fiber orientations in unidirectional (0°), bidirectional (0°/90°) and random configura-

Figure 1: a) Bamboo-activated carbon nanofiller powder; b) abaca fiber soaking; c) dried abaca fiber arranging; d) E-glass fiber arranging; e) hand lay-up composite lamination; f) vacuum bagging composite lamination

tions, offering potential solutions for improving the mechanical properties of the composites.

2 MATERIALS AND METHODS

Figure 1 shows the materials and manufacturing steps used to produce an abaca-E-glass hybrid polymer composite with a bamboo-activated carbon nanofiller. **Figure 1a** shows the bamboo-activated carbon nanofiller in the form of powder. Therefore, before carrying out the specimen manufacturing process, abaca fibers were soaked in 5-% NaOH solution for 2 hours (**Figure 1b**). **Figures 1c** and **1d** show the process of weaving abaca and E-glass fibers, respectively. The powders were then mixed with abaca and E-glass ramie fibers (**Figure 1e**) and the final mixture was placed into a mold. The fibers were carefully arranged; eventually, fiber specimens with unidirectional (0°), bidirectional (0°/90°) and random configurations were produced. The lamination of the composites was carried out using hand lay-up and vacuum bagging methods at a room temperature of 30 °C for 7 h. The pressure was 16 Psi. During the process of trial and error, it was found that the optimum fiber volume fraction is 50 %, with the bamboo-activated carbon nanofiller content being 3 % according to the research that was done previously on flax/PLA fiber-reinforced epoxy hybrid nanocomposites.[20] The resin mixed with bamboo-activated carbon nanofiller, used to laminate both abaca fiber and abaca-E-glass hybrids, was found to have a 50-% volume fraction of abaca and E-glass fibers. **Figure 2** shows the final specimens for the tensile tests.

3 RESULTS AND DISCUSSION

3.1 Mechanical characteristics

Tensile tests were carried out according to ASTM D-3039. The tests were done using a Tensilon universal testing machine with a maximum capacity of 10,000 N. **Figures 3** and **4** present typical load-displacement curves of the tensile tests for abaca/epoxy-bamboo activated carbon nanofiller and hybrid abaca-E-glass/epoxy-bamboo activated carbon nanofiller composite specimens, respectively, with unidirectional (0°), bidirectional (0°/90°), and random fiber orientations,.

The results for all fiber configurations and test types are given in **Table 1**.

Figure 2: Test specimens: a) abaca/epoxy-bamboo activated carbon nanofiller; b) abaca-E-glass/epoxy-bamboo activated carbon nanofiller

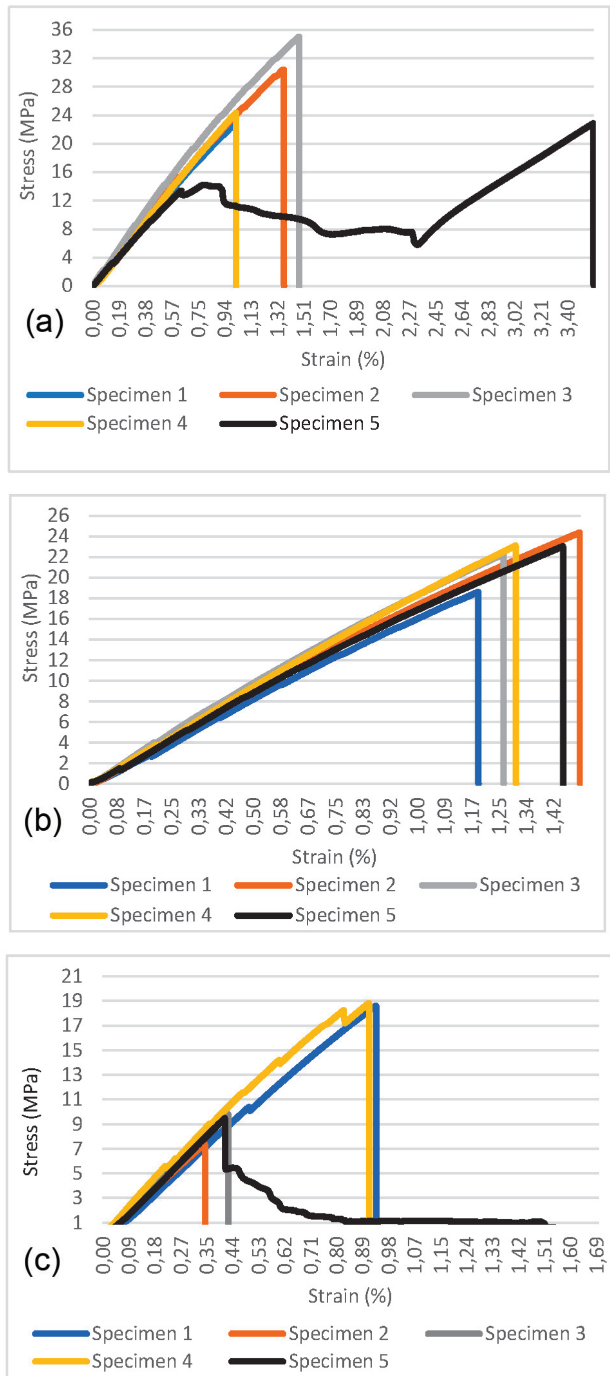

Figure 3: Typical stress-displacement curves for abaca/epoxy-bamboo activated carbon nanofiller composites: a) unidirectional (0°) fiber specimen; b) bidirectional (0°/90°) fiber specimen; c) random fiber specimen

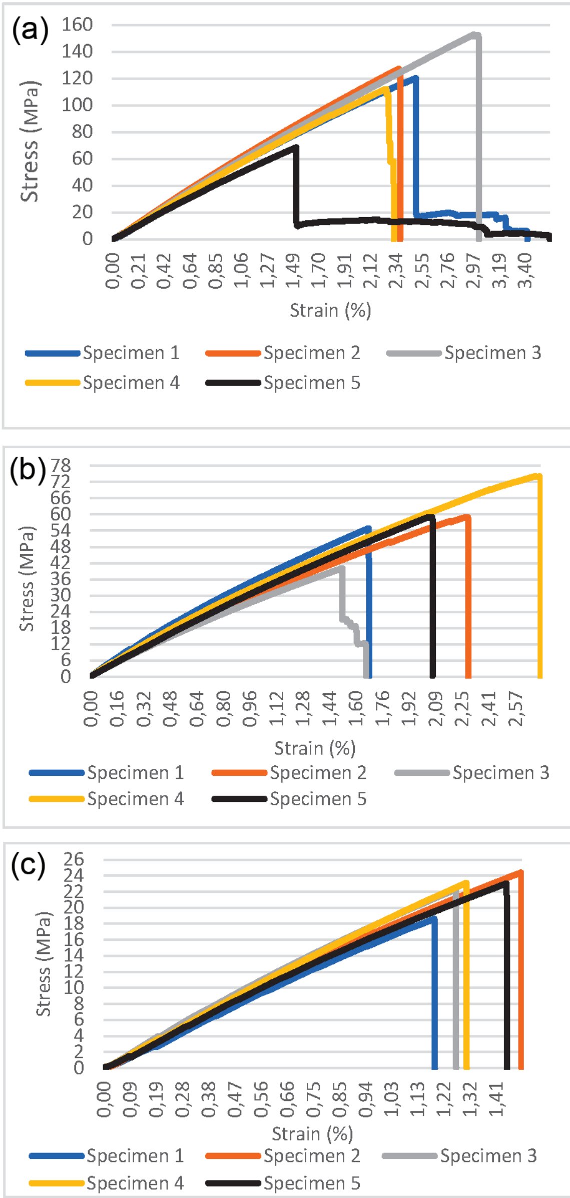

Figure 4: Typical stress-displacement curves for hybrid abaca-E-glass/epoxy-bamboo activated carbon nanofiller composites: a) unidirectional (0°) fiber specimen; b) bidirectional (0°/90°) fiber specimen; c) random fiber specimen

Table 1: Results for the tensile strengths of the composites

Composites	Unidirectional (0°) specimens	Bidirectional (0°/90°) specimens	Random-fiber specimens
Abaca/epoxy-bamboo activated carbon nanofiller, AB (MPa)	30	24.5	16
Strain, AB (%)	2.6	2.3	1.4
Density, AB (gr/cm^3)	1.1	1.1	1.1
Hybrid abaca-E-glass/epoxy-bamboo activated carbon nanofiller, AEB (MPa)	128.5	62.5	24
Strain, AEB (%)	1.9	1.4	0.7
Density, AEB (gr/cm^3)	1.5	1.5	1.5

The results for all fiber configurations and test types are given in **Table 1** while **Figure 5** shows that the tensile strength of the unidirectional (0°) specimen is higher than that of the bidirectional (0°/90°) and random-configuration specimens. This is typical of composite materials since unidirectional composite materials usually have higher tensile strengths and strains than those with bidirectional and random directions. Unidirectional composites show that the tensile test load received is entirely distributed in the direction of loading, perpendicularly to the direction of the 0° fiber arrangement in a composite specimen. On the other hand, in bidirectional composite specimens, the load received by the fibers is only partially distributed perpendicularly to the 0° direction, and some of the load is distributed in the 90° direction so that the bidirectional tensile test value is smaller compared to the unidirectional value; the same applies to random-fiber-arrangement composite specimens.

3.2 SEM Analysis

Figure 6 shows results of the SEM (scanning electron microscopy) test conducted to observe the surface morphological structure of the abaca/epoxy-bamboo activated carbon nanofiller composites.

Figure 6 demonstrates that the nearly equal distribution of black carbon granules within the matrix indicates that the bamboo-activated carbon nanofiller and the matrix are properly combined. The matrix and activated carbon nanofiller absorb the tensile test load simultaneously, distributing the load to the fibers acting as the composite reinforcement, thereby enhancing the composite's strength. Besides, the SEM findings show that

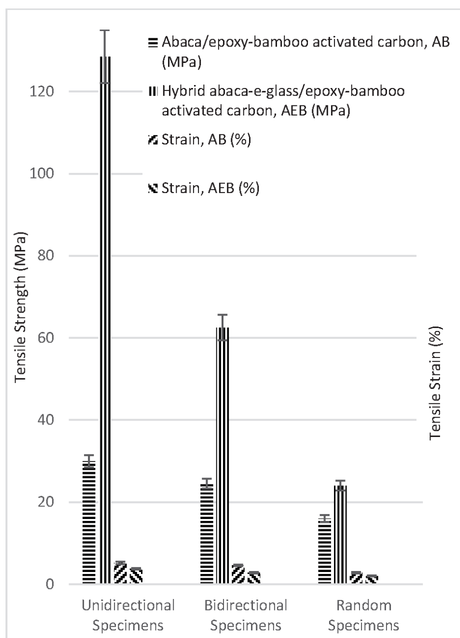

Figure 5: Tensile strength of abaca/epoxy-bamboo activated carbon nanofiller and hybrid abaca-E-glass/epoxy-bamboo activated carbon nanofiller

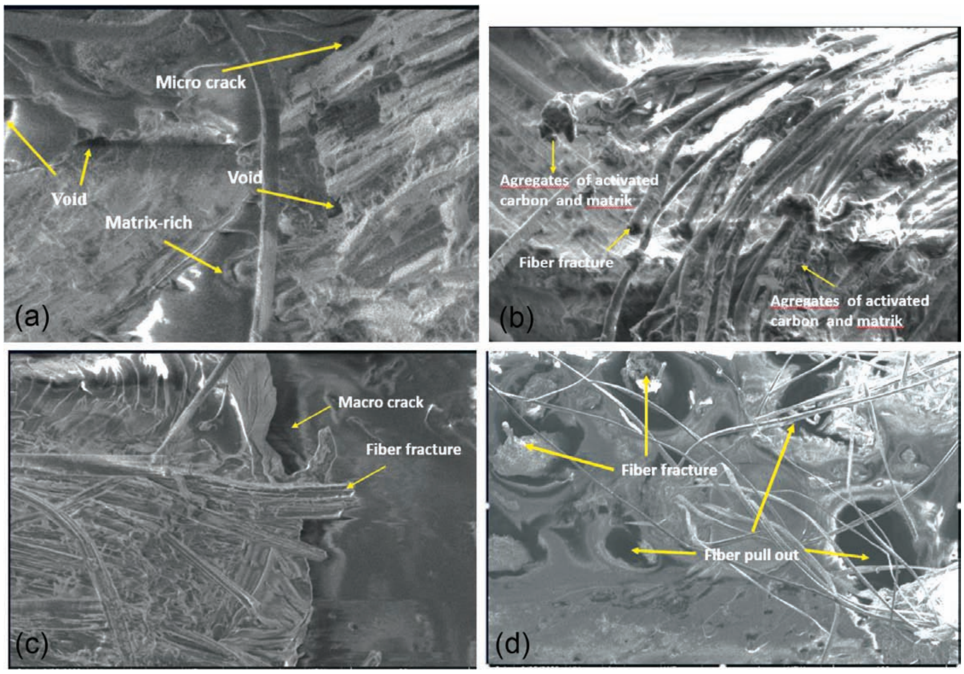

Figure 6: SEM morphology of abaca/epoxy-bamboo activated carbon nanofiller composites

adding bamboo-activated carbon nanofiller can eliminate voids and absorb dirt from the composite. In **Figure 6a**, a matrix-rich area is found in the composite, also showing that voids are visible in multiple locations. The computation of the void volume fraction in the composite is presented in **Table 1**. As a result, the strength of the composite is less than optimal. The observed damage consists of fractured fibers accompanied by aggregates of activated carbon and matrix that remain connected to the abaca fibers, suggesting that the matrix and bamboo-activated carbon nanofiller exhibit strong adhesion to the fibers, as shown in **Figure 6b.** Fiber fracture and long macrocracks are also found to contribute to fractures in composite specimens as shown in **Figure 6c. Figure 6d** illustrates the impact of tensile loading, revealing that the predominant failure mode observed is fiber fracture. Nevertheless, instances of fiber pull-out failure mode are also identified, suggesting inadequate bonding between the fiber and the matrix. This issue arises from an insufficient lamination process, where an entire fiber surface has not been thoroughly wetted by the matrix. This leads to a reduced interfacial bond within the composite, resulting in the fiber being pulled from the matrix.

Figure 7 shows the morphological structures of the surface abaca-E-glass/epoxy-bamboo activated carbon nanofiller composites.

Figure 7a reveals the presence of microcracks in several locations. However, it is evident that the nearly equal distribution of black carbon granules within the matrix indicates that the bamboo-activated carbon nanofiller and the matrix have properly combined. In addition, the surface lamination of the composite appears to be more uni-

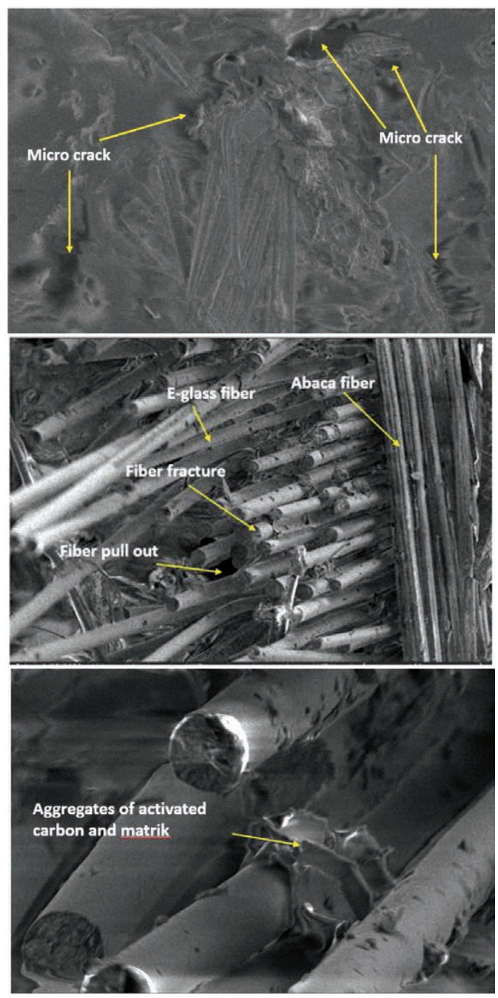

Figure 7: SEM morphologies of abaca-E-glass/epoxy-bamboo activated carbon nanofiller composites

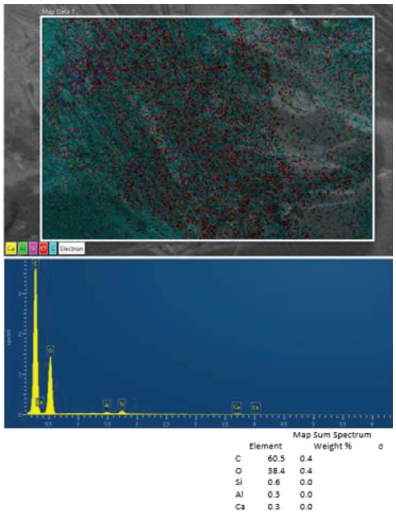

Figure 8: EDS of abaca/epoxy-bamboo activated carbon nanofiller composite

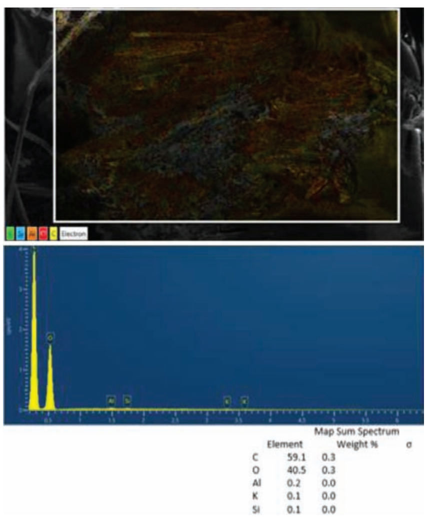

Figure 9: EDS of abaca/epoxy-bamboo activated carbon nanofiller composite

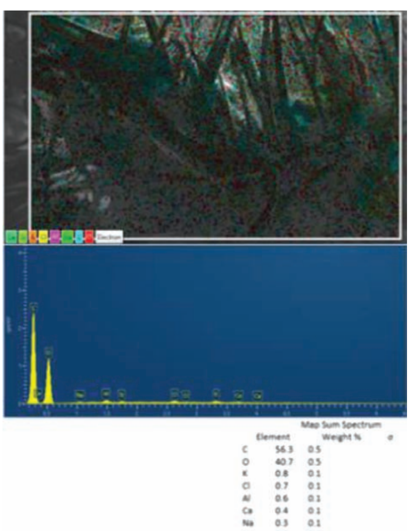

Figure 10: EDS of abaca/epoxy-bamboo activated carbon nanofiller composite

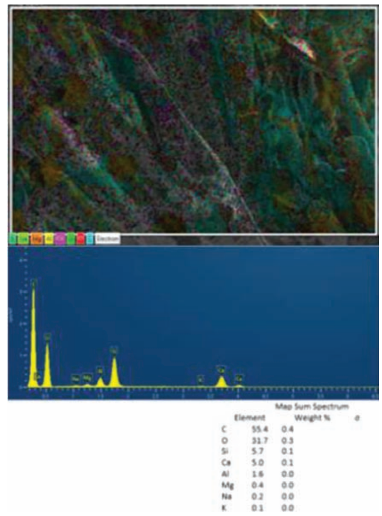

Figure 11: EDS of abaca-E-glass/epoxy-bamboo activated carbon nanofiller composite

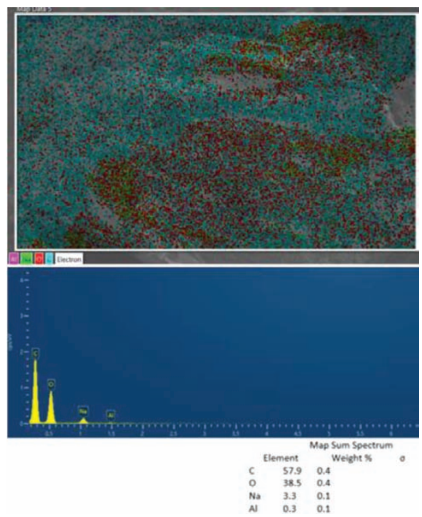

Figure 12: EDS of abaca-E-glass/epoxy-bamboo activated carbon nanofiller composite

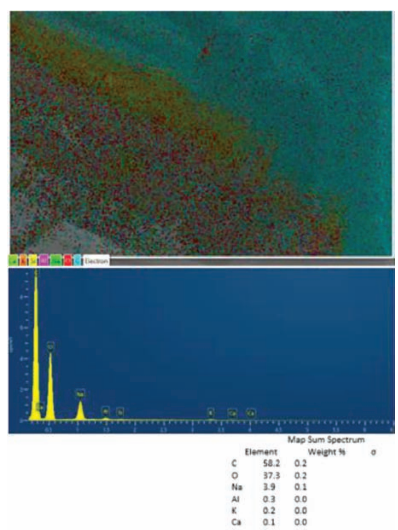

Figure 13: EDS of abaca-E-glass/epoxy-bamboo activated carbon nanofiller composite

form due to the hybridization of abaca fibers with E-glass fibers, which exhibit a more consistent arrangement in both fiber diameter and configuration. This is one of the parameters that enhances the strength of composites. In addition to the higher strength parameters of synthetic fibers compared to biomass fibers, the advantages of biomass fibers include their abundant and sustainable availability. To achieve this, a hybridization of synthetic fibers and biomass fibers is conducted to enhance the strength of the composite.

3.3 EDS Analysis

The figures below show the EDS analysis of different phases of the composite (particle, interface, and matrix). The EDS analysis indicates the presence of C, Si, O, AI, Ca, K, Na, and Mg in the particle and at the interface.

The results of SEM-EDS analyses of grain fractions of both abaca/epoxy-bamboo activated carbon nanofiller (AE) and abaca-E-glass/epoxy-bamboo activated carbon nanofiller (AEB) composites are presented in **Table 2**.

Table 2: SEM-EDS results of abaca/epoxy-bamboo activated carbon nanofiller (AE) and abaca-E-glass/epoxy-bamboo activated carbon nanofiller (AEB) composites

Element (*w*/%)	AE1	AE2	AE3	AEB1	AEB2	AEB3
C	60.5	59.1	56.3	55.4	57.9	58.2
O	38.4	40.5	40.7	31.7	38.5	37.3
Si	0.6	0.1	–	5.7	–	0.1
Al	0.3	0.2	0.6	1.6	0.3	0.3
Ca	0.3	–	0.4	5.0	–	0.1
K	–	0.1	0.8	0.1	–	0.2
Cl	–	–	0.7	–	–	–
Na	–	–	0.5	0.2	3.3	3.9
Mg	–	–	0.3	0.4	–	–

The results of SEM-EDS analyses of grain fractions of both AE and AEB composites are listed in **Table 2**. A large content of activated carbon nanofiller in the matrix increases its tensile strength because the load applied to the composite is received by the matrix and activated carbon nanofiller simultaneously and then distributed throughout the fiber surface. A high matrix-filler interfacial area is the result of a uniform and homogeneous dispersion of the nanofiller. This allows the nanofiller to improve the fracture and mechanical properties of a brittle matrix.

4 CONCLUSION

The aim of developing a hybrid polymer composite of abaca and E-glass with bamboo-activated carbon nanofiller was achieved in this investigation, using abaca biomass fibers as the composite reinforcement and bamboo fibers as active carbon nanofillers within an epoxy matrix. Both types of biomass fibers are abundantly available, but their potential as raw materials in biomass fiber-based composites had not been fully explored. Subsequently, abaka was hybridized with E-glass synthetic fibers to enhance the mechanical properties of the composite. The tensile test shows that the tensile-strength value of the unidirectional (0°) specimen is higher than those of the bidirectional (0°/90°) and random-direction specimens. Since unidirectional composite materials usually have a higher tensile strength than bidirectional and random-direction materials, the hybrid abaca-E-glass/epoxy-bamboo activated carbon composites have a higher tensile strength than abaca/epoxy-bamboo activated carbon nanofiller composites. The bamboo-activated carbon nanofiller and the matrix are properly combined. The matrix and activated carbon nanofiller absorb the tensile-test load simultaneously, distributing it to the fibers acting as the composite reinforcement, thereby enhancing the composite's strength. Besides, SEM examination findings show that the addition of bamboo-activated carbon nanofiller can eliminate voids and absorb the dirt from the composite. Even with simple manufacturing processes, specimens of good quality and with moderate tensile strengths can be produced. Therefore, the abaca-E-glass/epoxy-bamboo activated carbon nanofiller composite has good potential to be developed further for wider applications in medical and ballistic equipment.

5 REFERENCES

[1] M. Yaakob, M. Saion, M. Husin, Potency of Natural and Synthetic Composites for Ballistic Resistance: A Review, Appl. Res. Smart Technol., 1 (**2020**) 2, 43–55

[2] K. M. F. Hasan, P. G. Horváth, M. Bak, T. Alpár, A state-of-the-art review on coir fiber-reinforced biocomposites, RSC Adv., 11 (**2021**) 18, 10548–71

[3] A. G. Adeniyi, D. V. Onifade, J. O. Ighalo, A. S. Adeoye, A review of coir fiber reinforced polymer composites, Compos. Part B: Eng., 176 (**2019**), 107305

[4] B. Gangil, L. Ranakoti, S. Verma, T. Singh, S. Kumar, Natural and Synthetic Fibers for Hybrid Composites, in: Hybrid Fiber Composites, Wiley Online Library, 2020, 1–15

[5] O. Ozbek, O. Y. Bozkurt, A. Erklig, An experimental study on intraply fiber hybridization of filament wound composite pipes subjected to quasi-static compression loading, Polym. Test, 79 (**2019**), 106082

[6] A. Alkandary, A. Netravali, Hybrid green composites using rice straw and jute fabric as reinforcement for soy protein-based resin, Compos. Part B: Eng., 256 (**2023**), doi:101016/j.compositesb2023110626.2023;256

[7] S. Subash, B. Stanly Jones Retnam, J. Jerin Happy, J. Edwin Raja Dhas, K. Anton Savio Lewise, M. Ganesh, Preparation and characterization of Silk/Bamboo/Glass nano polymer composites, Mater. Today Proc., 64 (**2022**), 298–301, doi:10.1016/j.matpr.2022.04.570

[8] Tresna P. Soemardi, Widjajalaksmi Kusumaningsih, Agustinus Purna Irawan, Mechanical properties of ramie fiber reinforced epoxy lamina composite for socket prosthesis, Makara Journal of Technology, 13 (**2009**) 2, 96–101

[9] R. Yahaya, S. M. Sapuan, M. Jawaid, Z. Leman, E. S. Zainudin, Measurement of ballistic impact properties of woven kenaf–aramid hybrid composites, Measurement, 77 (**2016**), 335–343, doi:10.1016/j.measurement.2015.09.016

[10] L. Banowati, P. Sari, B. K. Hadi, Comparison analysis of abaca fiber/polyester and abaca-e-glass/polyester hybrid composites to im-

pact strength and its application to ballistic, IOP Conf. Ser.: Mater. Sci. Eng., 1173 (**2021**) 1, 012068

[11] G. W. Lee, Y. C. Choi, Effect of abaca natural fiber on the setting behavior and autogenous shrinkage of cement composite, J. Build. Eng., 56 (**2022**), https://www.sciencedirect.com/science/article/abs/pii/S235271022200732X

[12] V. Prakash, S. Majhi, S. K. Acharya, Effect of stacking sequence on abrasive wear behavior of abaca natural fiber reinforced polymer composites hybridized with glass fiber, Mater. Today Proc., 78 (**2023**) 4, doi:10.1016/j.matpr.2023.02.414

[13] A. K. Sinha, H. K. Narang, S. Bhattacharya, Tensile Strength of Abaca Epoxy Laminated Composites, Mater. Today Proc., 5 (**2018**) 14, 27861–4, doi:10.1016/j.matpr.2018.10.024

[14] X. Wang, Z. Yuan, X. Zhan, Y. Li, M. Li, L. Shen, et al, Multi-scale characterization of the thermal – mechanically isolated bamboo fiber bundles and its potential application on engineered composites, Constr. Build. Mater., 262 (**2020**), 120866, doi:10.1016/j.conbuildmat.2020.120866

[15] T. P. S. Reynolds, B. Sharma, E. Serrano, P. J. Gustafsson, M. H. Ramage, Fracture of laminated bamboo and the influence of preservative treatments, Compos. Part B: Eng., 174 (**2019**), 107017, doi:10.1016/j.compositesb.2019.107017

[16] S. R. Shukla, B. Kelkar, A. Bijila, Studies on laminated and scrimber composites produced from thermally modified *D. strictus* bamboo bonded with melamine-based adhesive, Ind. Crops Prod., 188, Part A (**2022**), doi:10.1016/j.indcrop.2022.115649

[17] E. Liang, Q. Zhou, L. Xiuyi, W. Xianju, Feasibility of one-time drying for manufacturing bamboo scrimber: fresh bamboo bundle at high initial moisture content impregnated by PF, Ind. Crops Prod., 194 (**2023**) 2, doi:10.1016/j.indcrop.2023.116302

[18] L. Banowati, K. A. Putra, R. A. Ghani, Analisis Kekuatan Tarik Komposit Termoseting Hibrid Serat Bambu-E-Glass/ Epoxy Unidirectional 0° Vs Hibrid Serat Bambu E-Glass WR/ Epoxy dan Aplikasinya Pada Struktur Frame Quadkopter, Conf Senat STT Adisutjipto Yogyakarta, 7 (**2022**), 79–84, doi:10.28989/senatik.v7i0.470

[19] N. H. Haryanti, S. Suryajaya, L. Banowati, M. Rahmah, A. Safi'i, Modification of Purun Tikus (Eleocharis Dulcis) as a Natural Fiber Composite Using KMnO4 and NaOH, Spektra J. Fis. dan Apl., 6 (**2021**) 1, 37–48

[20] M. Y. M. Zaghloul, M. M. Y. Zaghloul, M. M. Y. Zaghloul, Developments in polyester composite materials – An in-depth review on natural fibres and nano fillers, Compos. Struct., 278 (**2021**), doi:10.1016/j.compstruct.2021.114698

[21] J. E. Raja Dhas, K. A. Savio Lewise, K. N. Kumar, V. Raja, H. A. Z. AL-bonsrulah, H. Ahmad, et al., Effect of coconut shell nanopowder reinforcement in the development of palm fiber composites, Front. Mater., 9 (**2022**), 1–16

[22] J. Lakshmi, Eluri Kalyana Chakravarthi, Sarath Kumar, K. Jayanarayanan, K. M. Mini, Nano filler incorporated epoxy based natural hybrid fiber confinement of concrete systems: Effect of fiber layers and nano filler addition, Structures, 51 (**2023**), doi:10.1016/j.istruc.2023.03.050

[23] Adnan Amjad, M. Shukur Zainol Abidin, Hassan Alshahrani, Aslina Anjang Ab Rahman, Effect of Fibre Surface Treatment and Nanofiller Addition on the Mechanical Properties of Flax/PLA Fibre Reinforced Epoxy Hybrid Nanocomposite, Polymers MDPI, 13 (**2021**), 3842, doi:10.3390/polym13213842