Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 7, No.4, October 2025, pp. 02504022-01 ~ 02504022-011
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v7i4.2048

Effect of Natural Fiber Stacking Sequence on the Properties of Hybrid Composites for Drone Frame Applications

Janiviter Manalu[1*], Jefri Bale[2], Khristhoper Aris Arianto Manalu[3], Frans Augusthinus Asmuruf[3], Deni Fajar Fitriyana[4], Nizar Alamsyah[4], Januar Parlaungan Siregar[5,6], Al Ichlas Imran[6,7], Tezara Cionita[8], Natalino Fonseca Da Silva Guterres[9]

[1]Faculty of Engineering, Universitas Cenderawasih, Kota Jayapura 99358, Indonesia

[2]Mechanical Engineering Department, Universitas Nusa Cendana, Kupang, Nusa Tenggara Timur, Indonesia

[3]Faculty of Mathematics and Natural Sciences, Universitas Cenderawasih, Kota Jayapura 99358, Indonesia

[4]Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Semarang, Semarang 50229, Indonesia

[5]Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA), Pahang, Malaysia

[6]Automotive Engineering Center (AEC), Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA), Pahang, Malaysia

[7]Department of Mechanical Engineering, Universitas Halu Oleo, Kendari 93232, Indonesia

[8]Faculty of Engineering, Built Environment & Information Technology, SEGi University, 47810, Selangor, Malaysia

[9]Departement of Mechanical Engineering, Dili Institute of Technology, Timor Leste

*manalujanviter10@gmail.com

Abstract. The present study highlights the effective utilization of waste fibers in structural composites for drone frame applications, offering a sustainable pathway for developing high-performance materials while simultaneously addressing the issue of textile waste pollution. This study investigates the effect of ramie and cotton fiber waste fabric stacking sequences on the physical and mechanical properties of composites for quadcopter drone frames. Waste fabric was selected as an eco-friendly material to address textile pollution. The composites were fabricated using the hand lay-up technique with a 3:1 epoxy resin to hardener ratio, incorporating five layers of fabric in different configurations. The physical and mechanical properties, including density, water absorption, material hardness, flexural strength, and macro photography, were tested. The results showed that the composite made from fully cotton fabric (K-K-K-K-K) had the best density (1.182 g/cm^3), lowest water absorption (2.22%), highest hardness (85.6 HD), and flexural strength of 179.1 MPa. These findings indicate that cotton fabric waste is a promising, sustainable material for composite reinforcement in quadcopter drone frame applications.

Keywords: drone frame materials, hybrid composites, mechanical characterization, natural fiber reinforcement, textile waste recycling

(Received 2025-07-30, Revised 2025-09-05, Accepted 2025-09-16, Available Online by 2025-10-16)

1. Introduction

Drones, also known as unmanned aerial vehicles (UAVs), are remotely operated aircraft that are important for numerous purposes [1]. Their capacity to execute airborne surveys and deliveries depends on the drone frame's design [2]. The frame is the fundamental structural element, providing stability, agility, and strength to sustain delicate electronics and mechanical components [3]. The configuration, composition, and frame materials significantly influence flying performance and safety. Quadcopters are the most prevalent type, providing stability and control with their four arms equipped with engines and propellers [4,5]. Conventional materials like synthetic fibers (carbon fiber, glass fiber) and aluminum offer strength and durability; however, their elevated cost of production and environmental consequences present significant challenges [6–8]. Consequently, investigating alternative materials for drone frames is essential to decrease costs and improve sustainability.

Natural fiber composites (NFCs) are attracting attention because of their versatility and ecological advantages [9,10]. Additionally, they function as a sustainable substitute for polymer composites reinforced with glass or carbon fiber. Renewability, availability, high proficiency, lower abrasiveness, biodegradability, high specific strength, cost-effectiveness, safety, non-corrosive properties, and manufacturing flexibility are numerous benefits of NFCs compared to synthetic fiber composites [10,11]. Nevertheless, to operate efficiently in various applications and under extreme conditions, NFCs frequently require additional enhancements [12].

Improving composite material with textile waste helps mitigate the shortcomings of synthetic fibers. Textile waste possesses considerable potential for recycling in composites owing to its ductility, stiffness, flexibility, strength, and processability [13–15]. Priyahapsara et al. [16] showed that changing the configuration of the layers of cotton fabric waste (CF) and WR 600 glass fiber (GF) composites improved the mechanical performance for drone frames. The CF-GF-GF-CF specimen exhibited the highest tensile strength at 113.305 MPa, while the GF-CF-CF-GF specimen showed the best flexural strength at 229.996 MPa. Muslim et al. [17] found that bamboo fiber composites for drone shafts exhibited tensile strengths ranging from 220 to 547 MPa and lower densities than carbon fibers (0.9720–0.7790 g/cm^3). While the tensile strength required improvement, the reduced density improved maneuverability and extended flight duration.

Currently, there is limited exploration of sustainable composite materials for drone frames that utilize natural fibre waste, particularly from ramie and cotton fabrics. Composite materials reinforced by recycled fabric waste, mainly from ramie and cotton fibers, present a sustainable, economical, and readily accessible option [18,19]. Ramie offers superior tensile, compressive, and flexural strength, whilst cotton improves pliability, flexibility, and thermal stability [18–21]. Therefore, this study aims to design and evaluate a novel sustainable composite for quadcopter drone frames, employing ramie and cotton fiber fabric waste with different stacking sequence variations. The present study is distinguished from previous textile composite studies by its emphasis on recycling waste fabric and its application to

UAVs. It contributes to the materials' performance and sustainability in aerospace applications.

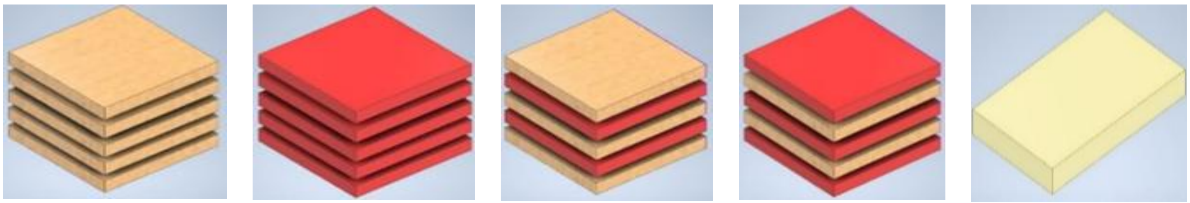
2. **Methods**.

2.1. Materials

The materials used in this research are ramie and cotton fabric waste obtained from the convection industry in Kudus Regency, Indonesia. As an initial stage, the fabrics were cut into sizes with dimensions of 20 cm x 15 cm. This cutting process is an important step before the fabrics are combined with resin to form a composite. To produce a strong and durable composite, this research uses Bisphenol A-Epichlorohydrin epoxy resin as the matrix, then mixed with Cycloaliphatic Amine type hardener obtained from Justus Semarang chemical store, Indonesia.

2.2. Fabrication Method

This study utilized the hand lay-up method to fabricate composites from fabric waste, a process selected for its straightforward application and versatility in producing components with diverse shapes [22]. The fabric waste was initially cut and organized according to the variations outlined in Figure 1. This study fabricated three kinds of laminate with distinct stacking sequences: specimens consisting of five layers of cotton fiber, five layers of ramie fiber, and hybrid specimens incorporating five layers of both fibers. In addition, a matrix specimen was added as a control. Das et al. [23] reported that the five-layer glass/pure polyester composite had superior flexural strength compared to the five-layer jute/pure polyester laminate. In the present study, the matrix and fiber volume fractions were calculated at 60% and 40% respectively. Barman et al. [24] and Lu et al. [25] concluded that composites with a 40% fiber volume fraction had the best tensile and flexural strengths. A mixture of epoxy resin and hardener (3:1 ratio) [26,27] was manually poured into a 20 x 25 cm mold. The mixture was smoothed using a brush with counterclockwise strokes for three minutes. To ensure uniform coating and effective bonding between layers, the mold surface was pre-coated with resin, and a heat gun was applied to each layer to remove air bubbles. Once all fabric and resin layers were arranged as specified, the specimens were left to cure at room temperature (20–25°C) for 24 hours, allowing the resin to achieve full hardness.



(a) (b) (c) (d) (e)

Figure 1. Specimens with different stacking sequences. (a) R-R-R-R-R (Ramie-Ramie-Ramie-Ramie-Ramie), (b) K-K-K-K-K (Cotton-Cotton-Cotton-Cotton), (c) R-K-R-K-R (Ramie-Cotton-Ramie-Cotton-Ramie), (d) K-R-K-R-K (Cotton-Ramie-Cotton-Ramie-Cotton), and (e) Epoxy Resin.

2.3. Testing

The density, hardness, flexural, and water absorption tests conducted in this study were repeated three times, with average values calculated to ensure result accuracy and reliability. Density testing in this study was conducted using an electronic density meter (DME 220 series) from Vibra Canada Inc. (Mississauga, ON, U.S.A.), following the ASTM D-570 standard. The specimens used for the density test measured 50 mm × 50 mm × 3.2 mm. Hardness testing was conducted using a Shore-D durometer (HT-6600D) manufactured by Jiancaicheng, Haidian District, Beijing, China. The test specimens, with a thickness of 6 mm, were prepared according to the ASTM D2240 standard. Flexural testing, carried out using the three-point bending method, adhered to the ASTM D790 standard. This test employed a universal testing machine from Hung Ta Instrument Co., Ltd., located in Samutprakarn, Thailand. The specimens used for flexural testing measured 127 mm in length, 12.7 mm in width, and 3.2 mm in thickness. Water absorption testing was also conducted in this study to evaluate the composite material's water uptake and its resistance to wet environments.

The test followed the ASTM D570 standard, where specimens were immersed in water for 14 days to measure weight changes resulting from water absorption. The surface of the flexural-tested composite specimens was analyzed fractographically using an Olympus CX41 microscope (Olympus Corporation, Tokyo, Japan). This examination offered critical insights into the internal structure of the composite, facilitating the identification of defects or imperfections that could potentially affect its performance and reliability.

3. Results and Discussion

3.1. Density Test

The present study demonstrates that the stacking sequence of waste fabric layers is crucial in influencing the density of composite specimens (Figure 2). Specimens with a higher proportion of cotton waste typically showed increased density values, whilst those primarily composed of ramie waste fabric had lower densities. The highest density of 1.182 g/cm³ was achieved in specimen K-K-K-K-K, while the lowest density of 1.112 g/cm³ was noted in specimen R-R-R-R-R. The density of the K-R-K-R-K and R-K-R-K-R specimens was 1.178 g/cm³ and 1.146 g/cm³, respectively. Additionally, the neat epoxy resin specimen demonstrated a density of 1.159 g/cm³.

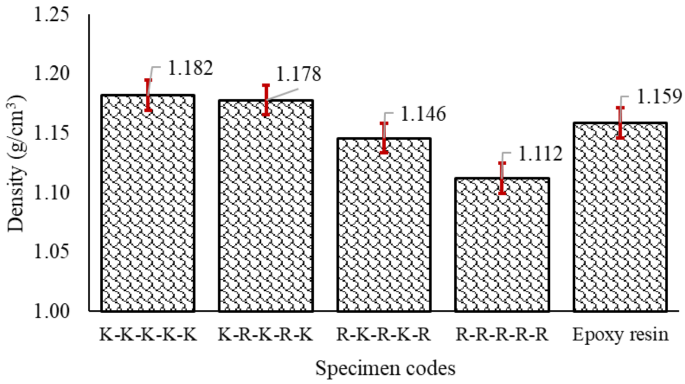


Figure 2. The effect of stacking sequences on the density of composite specimens

The density value of composite materials is strongly influenced by the type of reinforcing fiber and the layering sequence. The results show that specimens with layering sequences using cotton fabric have higher density compared to ramie fiber. This is due to the tighter structure of the cotton fabric, allowing better distribution of the polymer matrix. Specimens with a predominance of cotton layers (K-K-K-K-K and K-R-K-R-K) have a higher density compared to the ramie fiber dominant specimens (R-R-R-R-R and R-K-R-K-R). The density difference between cotton and ramie fabric composites depends upon the fibres' arrangement. Cotton fibers are more compact, resulting in reduced interstitial space. This compact structure renders cotton fabric denser and, when included in composites, yields a greater overall density. Conversely, ramie fiber possesses a more open and porous structure, featuring more excellent interstitial space among its constituent fibers. This generates 'voids' in the material, reducing density when included in composites. Zhang et al. [28] assert that ramie, a natural cellulosic fiber, possesses numerous advantages over cotton, such as its length, strength, moisture absorption, breathability, and lightweight characteristics. This finding is in line with the research of Gao et al. [29] which states that the distance between fibers affects the distribution of the matrix, thus having an impact on the density value of the composite. Thus, the selection of the right fiber type and layer arrangement can be used to optimize the density value of the composite material.

3.2. Hardness Test

The findings of this study indicate that variations in the stacking sequences of waste fabric layers significantly affect the hardness of the composite specimens, as illustrated in Figure 3.

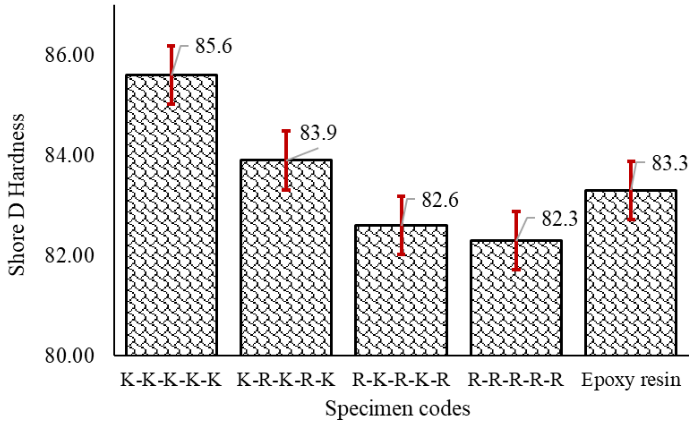


Figure 3. The effect of stacking sequences on the hardness of composite specimens

Specimens with a greater number of cotton waste fabric layers generally exhibited higher hardness values. In contrast, those incorporating more ramie waste fabric displayed lower hardness. The highest hardness value, 85.6 HD, was observed in specimen K-K-K-K-K, while the lowest, 82.3 HD, was recorded in specimen R-R-R-R-R. These results highlight the considerable contribution of cotton waste layers to enhancing the hardness of composite materials. The hardness of composite materials is strongly influenced by the quality of adhesion between the matrix and the fibers [30–32]. Specimens with cotton fabric waste reinforcement have better adhesion, resulting in a more homogeneous matrix distribution and reduced pore formation. In addition, it increases the density of the material and its resistance to deformation. Meanwhile, in ramie fibers having weaker adhesion may result in uneven matrix distribution and pore formation, which decreases the hardness of the material. Thus, improving interfacial adhesion can result in composites with higher hardness and better mechanical performance. This study provides strong empirical evidence of the correlation between density and hardness of composite materials. This finding is in line with Abbass et al. [33] and supported by the research of Kerche et al. [34] which shows that an increase in density in a material correlates with an increase in hardness value. This suggests that the denser a material is, the higher its resistance to plastic deformation. This finding has important implications in material design, where increasing density can be one of the strategies to increase the hardness of composite materials.

3.3. Flexural Test

The results of this study demonstrate that the stacking sequences of waste fabric layers significantly influences the flexural strength of composite specimens, as depicted in Figure 4a. The composite entirely composed of cotton waste layers (K-K-K-K-K) achieved the highest flexural strength, measuring 179.11 MPa, which is more than twice that of pure epoxy resin (74.52 MPa).

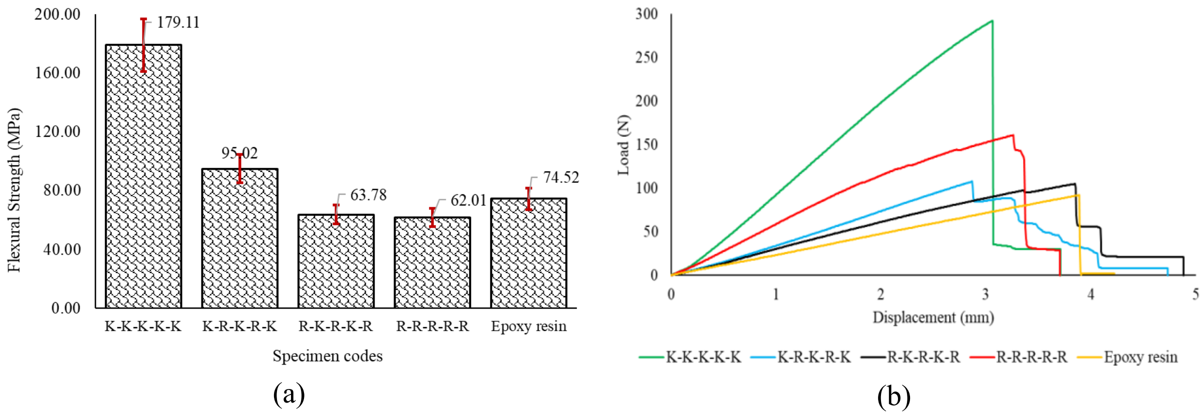


Figure 41. (a) Flexural Strength and (b) Load-Displacement Behavior of Specimens

This outcome underscores the superior reinforcing capabilities of cotton waste layers, likely attributed to their stronger bonding with the matrix and enhanced structural integrity. Conversely, the composite comprising only ramie waste layers (R-R-R-R-R) exhibited the lowest flexural strength at 62.01 MPa, falling slightly below that of epoxy resin. Mixed-layer composites, such as K-R-K-R-K and R-K-R-K-R, displayed intermediate strengths of 95.02 MPa and 63.78 MPa, respectively, suggesting that combining cotton and ramie layers compromises the flexural performance compared to composites with pure cotton layers. The findings underscore the substantial role of cotton waste layers in increasing the flexural strength of composites, rendering them exceptionally appropriate for applications requiring enhanced structural performance. In contrast, composites mostly made from ramie waste or mixed layering configurations may be more suitable for applications with reduced structural requirements, where a balance of moderate strength and cost effectiveness is essential.

Shivakumar et al. [35] revealed the complexity of the relationship between density and flexural strength in composite materials. Although in general higher density correlates with higher flexural strength, the results of this study show that the factor of interfacial adhesion also plays an important role. It was found that in specimens with a combination of fibers showing poor adhesion the flexural values were lower than those with a single fiber arrangement. This is due to uneven stress distribution and decreased bonding effectiveness between layers. This finding is in line with the research of Khalili et al. [36] which showed that composites with poor adhesion quality can cause a significant decrease in mechanical properties. Meanwhile, flexural strength is a critical parameter in composite performance evaluation. Composite layers that have high flexural strength are not only able to maintain their shape under load but can also withstand larger loads without being damaged. The load-displacement graph in Figure 4b provides a visual representation of the flexural behavior of each composite specimen. Analysis of this graph makes it possible to compare the flexural capabilities of different types of composites and select the most suitable material for a particular application.

3.4. Water Absorption Test

The results of the study on the effect of water absorption on composite materials are presented in Figure 5. This test shows that layer arrangement has a significant influence on the ability of the composite to absorb water. Specimens with a combination of cotton fabric and ramie fiber, especially in the R-K-R-K-R variation, showed the highest percentage of water absorption, which was 4.91%. This indicates that the combination of certain fiber types can increase the water absorption potential of the composite. In contrast, specimens with a single fiber arrangement and pure epoxy resin showed lower water absorption values.

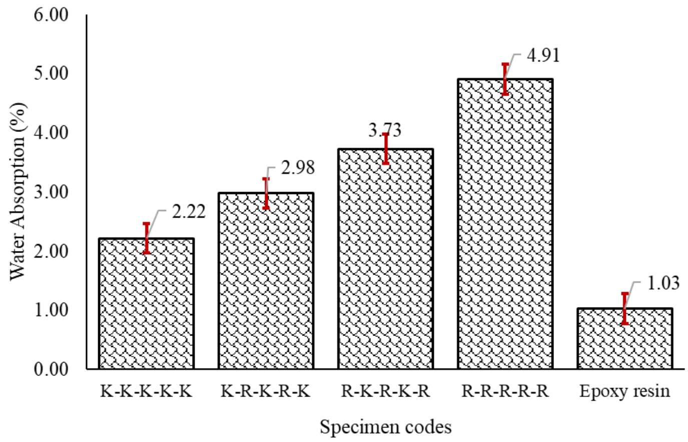


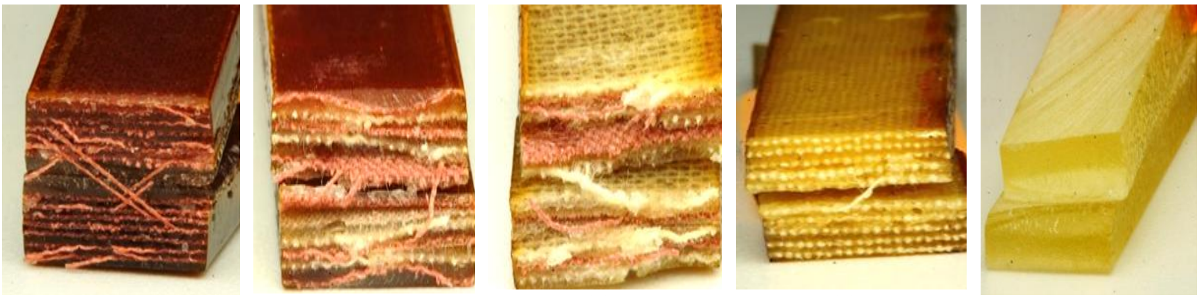
Figure 5. The effect of stacking sequences on the water absorption of composite specimens

These results indicate that both fiber type and layer arrangement contribute to the water absorption properties of the composite. The surface structure and adhesion properties between fibers play an important role in determining the level of water absorption in composites.

The porous cellulose fiber network in the fiber causes water to be easily absorbed [37]. The research findings show that ramie fibers have a more porous structure and weaker adhesion than cotton fibers which have a tighter structure. Thus, cotton fibers have better resistance to water absorption compared to ramie fibers. This is consistent with the natural hydrophilic nature of ramie fiber. As a result, composites with a higher percentage of ramie fibers also show higher moisture absorption values. Water absorption is one of the main factors that cause a decrease in the mechanical properties of composites. This finding is in line with the research of Hamdan et al. [38] which shows that water molecules entering the composite can interact with matrix components, triggering hydrolysis reactions that damage the fiber-matrix interface bond. In addition, the presence of water can also cause micro-cracks to form in the matrix, disrupt stress distribution, and reduce the ability of the composite to withstand loads. As a result, the strength and resistance of the composite to various types of loads will be significantly reduced.

3.5. Visual observations

A visual analysis using macro photographs captured with a digital camera and macro lens was conducted to examine the failure mechanism in the composite specimens after the flexural test (Figure 6). The analysis results showed the presence of several defects, such as porosity, voids, and fiber pull-out. Microscopic observation of the fracture area provides detailed information on the location and type of damage. Thus, it can be concluded that these defects play an important role in the failure process of composite materials. Observations showed that both specimens with a single fiber arrangement and a combination of cotton and ramie fibers experienced similar defects, namely voids and fiber pull-out. Voids are formed due to air trapping in the layers during the manufacturing process [39], which may be caused using a less-than-optimal heatgun. Meanwhile, fiber pull-out occurs due to weak fiber-matrix interface bonding and fiber damage. Monazami & Gupta explained that fiber pull-out occurs due to damage to the fiber, weak interfacial bonding, and uneven stress concentration [40]. These defects can reduce the strength and stiffness of the composite, so efforts need to be made to minimize the occurrence of voids and increase the strength of the fiber-matrix interface bond. Microscopic analysis of specimens with a combination of ramie fiber-cotton fabric (R-K-R-K-R) and cotton fabric-ramie fiber (K-R-K-R-K) showed delamination, debonding, and waviness. Delamination occurs due to uneven stress distribution [41], while debonding is caused by weak bonds between fibers and matrix, reducing the strength between layers. Meanwhile, waviness occurs when the composite manufacturing process is improper, causing a decrease in composite stiffness. The existence of these current defects results in a significant decrease in the mechanical characteristics of the specimens, highlighting the imperative to optimize the production process for the attainment of composites with improved performance.



(a) (b) (c) (c) (e)

Figure 6. Photographs of surface fracture in (a) K-K-K-K-K, (b) K-R-K-R-K, (c) R-K-R-K-R, (d) R-R-R-R-R, and (e) epoxy resin Specimens

4. Conclusion

The present study emphasizes the potential of employing textile waste as a reinforcement in high-performance composites, enhancing sustainability in materials engineering. This study's findings demonstrate that variations in the layer arrangement of hybrid composites composed of ramie and cotton fiber waste substantially influence their physical and mechanical properties.

In comparison to other specimens, the specimens with the pure cotton fabric sequence (K-K-K-K-K) exhibit enhanced performance regarding density, water absorption, hardness, and flexural strength, rendering it highly appropriates for quadcopter drone frame applications. The density, water absorption, hardness, and flexural strength of the K-K-K-K-K specimen are 1.182 g/cm^3, 2.22%, 85.6 HD, and 179.1 MPa, respectively. Nevertheless, additional assessment is required to evaluate other critical performance criteria, including fire resistance, fatigue behavior under cyclic loading, and long-term environmental durability. These factors are crucial for guaranteeing the safety and dependability of drone operations in various environments. Future studies should investigate manufacturing ability and cost-effectiveness to facilitate industrial applications.

Acknowledgements

The author would like to express their gratitude to Universtias Cenderawasih, Jayapura, Indonesia for their support in this research.

References

[1] Mohsan SAH, Othman NQH, Li Y, Alsharif MH, Khan MA. Unmanned aerial vehicles (UAVs): practical aspects, applications, open challenges, security issues, and future trends. Intelligent Service Robotics 2023;16:109–37. https://doi.org/10.1007/s11370-022-00452-4.

[2] Raivi AM, Huda SMA, Alam MM, Moh S. Drone Routing for Drone-Based Delivery Systems: A Review of Trajectory Planning, Charging, and Security. Sensors 2023;23:1–26. https://doi.org/10.3390/s23031463.

[3] Andries V, Zaharia S-M. Generative Design, Simulation, and 3D Printing of the Quadcopter Drone Frame. Applied Sciences 2025;15:1–22. https://doi.org/10.3390/app15179647.

[4] Al-Haddad LA, Jaber AA, Giernacki W, Khan ZH, Ali KM, Tawafik MA, et al. Quadcopter Unmanned Aerial Vehicle Structural Design Using an Integrated Approach of Topology Optimization and Additive Manufacturing. Designs 2024;8:1–20. https://doi.org/10.3390/designs8030058.

[5] Peksa J, Mamchur D. A Review on the State of the Art in Copter Drones and Flight Control Systems. Sensors 2024;24:1–42. https://doi.org/10.3390/s24113349.

[6] Patti A, Cicala G, Acierno D. Eco-sustainability of the textile production: Waste recovery and current recycling in the composites world. Polymers 2021;13:1–22. https://doi.org/10.3390/polym13010134.

[7] Săftoiu GV, Constantin C, Nicoară AI, Pelin G, Ficai D, Ficai A. Glass Fibre-Reinforced Composite Materials Used in the Aeronautical Transport Sector: A Critical Circular Economy Point of View. Sustainability (Switzerland) 2024;16:1–23. https://doi.org/10.3390/su16114632.
[8] Kapil Dev P, Balaji C, Gurusideswar S. Material characterization of sugarcane bagasse/epoxy composites for drone frame material. Materials Today: Proceedings 2022;68:2586–90. https://doi.org/https://doi.org/10.1016/j.matpr.2022.10.114.
[9] Khan F, Hossain N, Hasan F, Rahman SMM, Khan S, Saifullah AZA, et al. Advances of natural fiber composites in diverse engineering applications—A review. Applications in Engineering Science 2024;18:1–26. https://doi.org/https://doi.org/10.1016/j.apples.2024.100184.
[10] Saha S, Das S, Rahman MZ. Hybridization in Natural Fiber Composites: Enhanced Performance and Sustainability. Composites Part B: Engineering 2025:1–97. https://doi.org/https://doi.org/10.1016/j.compositesb.2025.112986.
[11] Kamarudin SH, Mohd Basri MS, Rayung M, Abu F, Ahmad S, Norizan MN, et al. A Review on Natural Fiber Reinforced Polymer Composites (NFRPC) for Sustainable Industrial Applications. Polymers 2022;14:1–36. https://doi.org/10.3390/polym14173698.
[12] Balakrishnan TS, Sultan MTH, Shahar FS, Ahmad KA, Dol SS, Naning FH. Bio-inspired coatings for natural fibre composites. Journal of Science: Advanced Materials and Devices 2025;10:1–17. https://doi.org/https://doi.org/10.1016/j.jsamd.2024.100841.
[13] Kamble Z, Behera BK. Mechanical properties and water absorption characteristics of composites reinforced with cotton fibres recovered from textile waste. Journal of Engineered Fibers and Fabrics 2020;15:0–7. https://doi.org/10.1177/1558925020901530.
[14] Arif M, Nawab Y, Umair M, Shaker K. Performance Assessment of Composites from Post-consumer and Post-industrial Denim Waste. Journal of Textile and Apparel, Technology and Management 2022;2022:1–14.
[15] Sathasivam T, Sugiarto S, Yew MPY, Oh XY, Chan SY, Chan BQY, et al. Transforming textile waste into nanocellulose for a circular future. Nanoscale 2024;16:14168–94. https://doi.org/10.1039/d4nr01839g.
[16] Priyahapsara I, Mulyani S, Prattiwi EA, Rasyid R. Green Material Characterization Of Recycled Fabric Waste Composite For Unmanned Aerial Vehicle (UAV) Structure. Proceedings of the 5th Annual Advanced Technology, Applied Science, and Engineering Conference (ATASEC) 2023, Atlantis Press International BV; 2023, p. 162–8. https://doi.org/10.2991/978-94-6463-358-0_16.
[17] Muslim N, Md Ariffin L, Rahim MZ. Application of Bamboo Composite for Unmanned Aerial Vehicle Rod Structure. Progress in Aerospace and Aviation Technology 2023;3:48–54. https://doi.org/10.30880/paat.2023.03.02.007.
[18] Shakir MH, Singh AK. Ramie fiber and its composites: A review. Polymer Composites 2025;46:6813–41. https://doi.org/https://doi.org/10.1002/pc.29417.
[19] Cho H, Li G, Zhu J. Chapter 16 - Ramie fibers, their composites and applications. In: Mavinkere Rangappa S, Parameswaranpillai J, Siengchin S, Ozbakkaloglu T, Wang their Composites, and Applications HBT-PF, editors. The Textile Institute Book Series, Woodhead Publishing; 2022, p. 363–78. https://doi.org/https://doi.org/10.1016/B978-0-12-824528-6.00010-2.
[20] Lakshmaiya N, Udhayakumar G, Sathiyamurthy S, Nadh VS, Maranan R, Mammo WD. Multi-functional natural fiber composites using flaxseed and cotton: tailoring acoustic, mechanical, and thermal properties for eco-friendly applications. Discover Applied Sciences 2025;7:1–19. https://doi.org/10.1007/s42452-025-07345-y.
[21] Li M, Huang G-W, Li N, Liu Y, Qu C-B, Huang Y. Flexible Cotton Fiber-Based Composite Films with Excellent Bending Stability and Conductivity at Cryogenic Temperature. ACS Applied Materials & Interfaces 2022;14:21486–96. https://doi.org/10.1021/acsami.2c03199.
[22] Jamir MRM, Majid MSA, Khasri A. 8 - Natural lightweight hybrid composites for aircraft structural applications. In: Jawaid M, Thariq MBT-SC for AA, editors. Woodhead Publishing Series in Composites Science and Engineering, Woodhead Publishing; 2018, p. 155–70. https://doi.org/https://doi.org/10.1016/B978-0-08-102131-6.00008-6.

[23] Das SC, Paul D, Grammatikos SA, Siddiquee MdAB, Papatzani S, Koralli P, et al. Effect of stacking sequence on the performance of hybrid natural/synthetic fiber reinforced polymer composite laminates. Composite Structures 2021;276:1–8. https://doi.org/https://doi.org/10.1016/j.compstruct.2021.114525.
[24] Barman Parthapratim, Dutta Polash P, Bardalai Monoj, Dutta Partha P. Experimental investigation on bamboo fiber reinforced epoxy polymer composite materials developed through two different techniques. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science 2023;238:2185–204. https://doi.org/10.1177/09544062231195474.
[25] Lu N, Oza S. A comparative study of the mechanical properties of hemp fiber with virgin and recycled high density polyethylene matrix. Composites Part B: Engineering 2013;45:1651–6. https://doi.org/https://doi.org/10.1016/j.compositesb.2012.09.076.
[26] Khafidh M, Putera FP, Yotenka R, Fitriyana DF, Widodo RD, Ismail R, et al. A Study on Characteristics of Brake Pad Composite Materials by Varying the Composition of Epoxy, Rice Husk, Al2O3 and Fe2O3. Automotive Experiences 2023;6:303–19.
[27] Irawan AP, Fitriyana DF, Siregar JP, Cionita T, Anggarina PT, Utama DW, et al. Influence of Varying Concentrations of Epoxy, Rice Husk, Al2O3, and Fe2O3 on the Properties of Brake Friction Materials Prepared Using Hand Layup Method. Polymers 2023;15:1–19. https://doi.org/https://doi.org/10.3390/polym15122597.
[28] Zhang X, Yang J, Wang Y, Duan C, Liu Y, Lu M. Study on the Ramie Fabric Treated with Copper Ammonia to Slenderize Fiber for Eliminating Prickle. Journal of Natural Fibers 2023;20:1–12. https://doi.org/10.1080/15440478.2022.2120150.
[29] Gao M, Gao P, Wang Y, Lei T, Ouyang C. Study on Metallurgically Prepared Copper-Coated Carbon Fibers Reinforced Aluminum Matrix Composites. Metals and Materials International 2021;27:5425–35. https://doi.org/10.1007/s12540-020-00897-1.
[30] Kore S, Theodore M, Vaidya U. Effect of the Segmental Structure of Thermoplastic Polyurethane (Hardness) on the Interfacial Adhesion of Textile-Grade Carbon Fiber Composites. ACS Applied Polymer Materials 2021;3:6138–46. https://doi.org/10.1021/acsapm.1c01001.
[31] Imran AI, Siregar JP, Cionita T, Fajar D. Mechanical Performance of Epoxy Composite Reinforced with Wood Dust and Crumb Rubber Waste. Advance Sustainable Science, Engineering and Technology 2025;7:0250408-01–8. https://doi.org/https://doi.org/10.26877/kkjzs792.
[32] Kalatharan SN, Imran AI, Irawan AP, Siregar JP, Cionita T, Fitriyana DF, et al. Mechanical Performance of Alkali-Treated Rattan Strips with Epoxy Coating for Sustainable Composite Applications. Advance Sustainable Science Engineering and Technology 2025;7:02503018-01–9. https://doi.org/10.26877/fm53nd79.
[33] Abbass OA, Salih AI, Al Hurmuzy OM. Study of the mechanical and physical properties of bio-composite material based on wheat starch and wheat straw fibers. IOP Conference Series: Materials Science and Engineering 2020;745:1–12. https://doi.org/10.1088/1757-899X/745/1/012075.
[34] Fischer Kerche E, Aparecido da Cruz J, Campos Amico S. The Influence of Density on the Mechanical Response of Reinforced High-Density Polyurethane Foams: A Statistical Approach. Journal of Research Updates in Polymer Science 2022;11:31–5.
[35] Shivakumar H, Renukappa NM, Shivakumar KN, Suresha B. The Reinforcing Effect of Graphene on the Mechanical Properties of Carbon-Epoxy Composites. Open Journal of Composite Materials 2020;10:27–44. https://doi.org/10.4236/ojcm.2020.102003.
[36] Khalili H, Jabor Tlemcani SE, Moumou M, Kassab Z, Sehaqui H, Ablouh EH, et al. Effect of Fabric Layering Sequence and Architecture on Mechanical Properties of Clay, Jute, and Glass Fibers Reinforced Polyester Laminated Hybrid Composites. Journal of Natural Fibers 2022;19:15531–40. https://doi.org/10.1080/15440478.2022.2128966.

[37] Tezara C, Hadi AE, Siregar JP, Muhamad Z, Hazim M, Hamdan M, et al. The Effect of Hybridisation on Mechanical Properties and Water Absorption Behaviour of Woven Jute / Ramie Reinforced Epoxy Composites. Polymers 2021:1–17.
[38] Hamdan MHM, Siregar JP, Cionita T, Jaafar J, Efriyohadi A, Junid R, et al. Water absorption behaviour on the mechanical properties of woven hybrid reinforced polyester composites. International Journal of Advanced Manufacturing Technology 2019;104:1075–86. https://doi.org/10.1007/s00170-019-03976-9.
[39] Dhimole VK, Serrao P, Cho C. Review and suggestion of failure theories in voids scenario for VARTM processed composite materials. Polymers 2021;13:1–25. https://doi.org/10.3390/polym13060969.
[40] Maryam M, Rishi G. Effect of Curing Age on Pull-Out Response of Carbon, Steel, and Synthetic Fiber Embedded in Cementitious Mortar Matrix. Journal of Materials in Civil Engineering 2022;34:4022275. https://doi.org/10.1061/(ASCE)MT.1943-5533.0004426.
[41] Yang Y, Chen J, Huang Z. Damage evolution in fibrous composites caused by interfacial debonding. International Journal of Damage Mechanics 2020;29:67–85. https://doi.org/10.1177/1056789519854488.