

Research Paper

Ramie-PLA Composite Hollow Sections for EV Chassis: Development and Static Bending Test

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Abstract

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The increasing demand for sustainable and lightweight materials in the transportation sector, particularly in the context of electric vehicles (EVs), has accelerated the exploration of bio-based composites as viable alternatives to conventional structural materials. This study investigates the mechanical performance of hollow structural components fabricated from polylactic acid (PLA)-based composites reinforced with natural ramie fibers, targeting their application as chassis elements in urban electric vehicles. Emphasis is placed on replacing commercial steel hollow sections with environmentally benign alternatives that maintain mechanical integrity while offering additional functional benefits such as electrical non-conductivity. Three-point bending tests were conducted to evaluate the composite specimens' flexural strength, stiffness, and failure behavior to assess structural viability. This method was selected for its relevance to real-world bending stresses encountered in vehicular chassis components and suitability for consistent evaluation across beam-like geometries. Results demonstrate that the ramie-PLA bio-composite exhibits promising flexural performance, with sufficient bendability and stiffness for potential structural integration. Furthermore, the non-conductive nature of the composite presents a significant advantage for reducing electromagnetic interference with sensitive electronic systems common in EV platforms. The findings support the feasibility of deploying natural fiber-reinforced PLA composites as a sustainable, cost-effective solution for lightweight automotive structures, particularly in emerging markets where urban EV adoption is rapidly expanding.

Keywords: Ramie fiber; PLA Composite; Electric vehicle; Lightweight structure; Flexural strength; Three-point bending

1. Introduction

The escalating global climate crisis and rising environmental awareness have prompted a paradigm shift toward sustainable material development across multiple industries. In response, the scientific community has intensified

efforts to develop eco-friendly materials that can rival advanced synthetic alternatives in performance while maintaining environmental compatibility [1], [2]. Among these innovations, natural fiber-reinforced composites are gaining substantial attention as substitutes for conventional synthetic reinforcements. This trend



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is particularly evident in the automotive sector, where the demand for lightweight, high-performance materials has increased the use of bio-based polymers and fiber-reinforced composites. Natural fibers such as flax and sisal have successfully reduced the weight and production costs of composite components without compromising mechanical integrity [3], [4].

Simultaneously, the rapid global adoption of hybrid and electric vehicles (EVs)—especially low-cost models tailored to urban markets in regions such as Indonesia—has accentuated the need for sustainable, lightweight, and cost-effective vehicle components. However, most past research and industrial application focus on interior panels [5], trim components [6], and semi-structural parts [7] rather than primary load-bearing structural members such as chassis frames.

For natural-fiber composites with bio-based matrices, especially those combining high-strength fibers such as ramie with biodegradable polymers like polylactic acid (PLA) research remains limited. Although lab-scale studies have successfully fabricated ramie–PLA prepregs and characterized their static and flexural performance [8], systematic evaluation of these composites in hollow structural profiles (e.g., rectangular hollow sections) suitable for chassis applications is still scarce.

In this context, the present study addresses the critical demand for environmentally friendly structural materials by exploring the potential of bio-composite hollow sections for electric vehicle chassis applications. Specifically, the research investigates the replacement of conventional steel structural profiles with composite prepregs based on polylactic acid (PLA)—a biodegradable polymer derived from renewable plant sources—reinforced with ramie fibers, a high-strength natural fiber known for its mechanical performance [2], [4].

Beyond their mechanical benefits, these biocomposites offer a significant secondary advantage: their inherent electrical non-conductivity, which reduces the risk of electromagnetic interference with sensitive onboard electronics—a critical factor in the design of modern electric vehicles [9].

Three-point bending was selected as the principal testing method to evaluate the mechanical viability of these bio-composites. This technique is highly relevant to chassis applications in urban environments, where components routinely encounter flexural stresses caused by road irregularities. The test provides critical insights into a material's bendability, defined as its capacity to undergo large deformations without structural failure—an essential property in developing lightweight vehicles [10]. Three-point bending is extensively employed in material testing owing to its experimental simplicity, high reproducibility, and broad applicability to various structural materials. At the same time, its straightforward specimen configuration facilitates efficient and cost-effective testing without sacrificing data accuracy [11]. Its compatibility with rectangular beam geometries, analogous to the hollow sections studied, enables uniform stress distribution and consistent measurement of key properties such as flexural strength and stiffness. It is recognized, however, that different bending test configurations may yield varied failure mechanisms. Therefore, the three-point bending test was deliberately chosen to ensure standardized and relevant comparisons for automotive structural applications [10].

Finally, a key challenge in adopting natural fiber composites for chassis use is meeting automotive structures' stringent mechanical performance requirements, including adequate multiaxial static strength and fatigue resistance under dynamic loading conditions. The primary objective of this study is to rigorously evaluate the structural viability of ramie-PLA bio-composite hollow sections as potential replacements for commercial steel profiles in lightweight chassis components for urban electric vehicles. Emphasis is placed on experimental assessment and comparative analysis of their bending performance.

2. Methods

Three-point bending is a widely adopted method for evaluating the mechanical performance of structural materials under bending loads due to its simplicity and consistency in results. Previous studies have shown that the selection of bending test methods

significantly affects the observed failure mechanisms and thus must be carefully considered when comparing different material systems [1].

This study used ramie fiber and polylactic acid (PLA) to fabricate unidirectional and bidirectional prepreg composites. The ramie fiber, sourced as woven fabric from Guangzhou Xinzhi Textile (China), was chemically treated with 5% NaOH for two hours, rinsed to neutral pH, and air-dried to improve fiber-matrix adhesion. PLA (Bio-poly 103, Shanghai Huiang Industrial Co., Ltd.) was dissolved in dichloromethane (1:10 w/v) and used to manually impregnate the fibers within a $254 \times 194 \text{ mm}^2$ glass mold. The prepregs were stored at -18°C for one week before being hot-pressed at 120°C and 132 bar for 90 minutes. No additional resin additives were used, focusing on fiber surface treatment and solvent-assisted matrix dispersion to achieve optimal composite bonding [12].

The rectangular ramie-PLA composite test specimen was designed with outer dimensions of 78 mm width and 44 mm height, a uniform wall thickness of 11 mm, and an overall span length of 268 mm. These geometries were selected to mimic the potential structural cross-sections utilized in EV chassis, in which high flexural stiffness and low weight are critical. The geometry of the specimen is shown in Figure 1.

The manufacturing process consists of prepreg preparation and forming techniques, as shown in Figure 2. The initial step in developing the composite material involved the fabrication of Ramie Fiber-Reinforced Polylactic Acid (RFRPLA) prepreg. Following the procedures outlined [8], the process consisted of three main stages:

PLA Solution Preparation: Polylactic Acid (PLA) was melted or dissolved using appropriate thermal or solvent-based methods until a uniform solution was achieved.

Ramie Fiber Immersion: Cleaned and dried ramie fibers were immersed in the PLA solution, allowing improved matrix impregnation of the fiber surfaces.

Prepreg Storage: The impregnated fibers, or prepregs, were stored in a freezer to maintain thermal stability and viscosity before molding and lamination processes.

The fiber-to-matrix volume fraction ratio was 47% ramie fiber and 53% PLA. This balance was

chosen to optimize tensile strength and flexural resistance and maintain PLA's biodegradable characteristics [12].

Two main fabrication techniques were employed: hand lay-up and hot pressing, and compression molding.

Hand Lay-up and Hot Pressing: In the hand lay-up method, layers of RFRPLA prepreg were manually arranged within a mold according to the designed laminate stacking sequence. This was followed by hot pressing, where the stacked layers were subjected to heat and pressure to consolidate the layers into a single cohesive composite structure. Each lamina was assigned a thickness of 0.5 mm, and the stacking orientation was optimized to produce a quasi-isotropic laminate structure.

Compression Molding: Post-lamination, compression molding was utilized to achieve the final form of the composite prosthetic component. In this process, the prepreg material was placed into a rigid mold and subjected to heat and compressive force to produce the final geometric shape of the prosthetic structure.

The three-point bending test's main purpose is determining a material's mechanical properties, particularly its resistance to bending loads. For natural composite materials such as Ramie-PLA, this test is particularly important because composite materials tend to exhibit different tensile and compressive behaviors and characteristic failure modes such as delamination, matrix cracking, or fiber breakage.

A three-point bending test was carried out to evaluate the specimen's flexural stiffness and strength properties. With some adjustments, the experimental setup was partially adapted from Zhang's methodology [13]. In this test, the specimen is placed on two supports and loaded from above at the midpoint. The configuration consisted of two cylinder supports, each with a

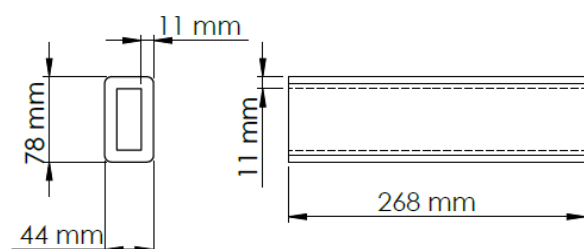


Figure 1. Test specimen geometry

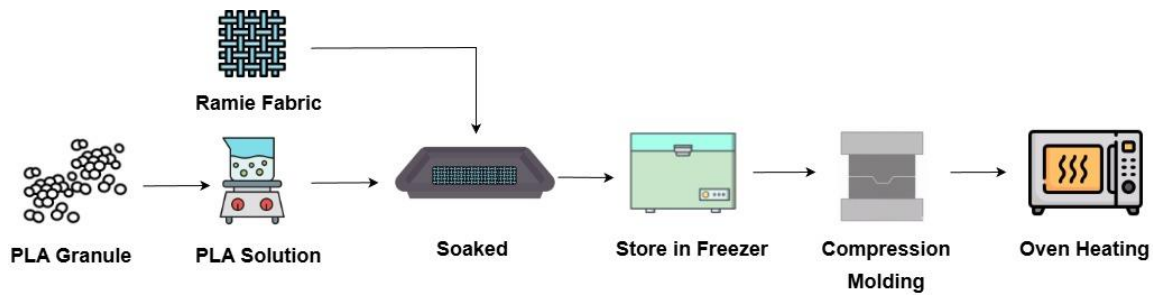


Figure 2. Manufacture process

diameter of 30 mm. These supports were located at a distance of 200 mm with symmetrical positioning below the specimen. The loads were applied through a cylindrical punch with a diameter of 25.4 mm placed at the specimen mid-span. The cylindrical punch directly applied a vertical downward load on the specimen's upper surface, as shown in Figure 3.

The testing was performed using an RME 100 Schenk Trebel machine with a maximum load capacity of 100 kN and equipped with a calibrated load cell and data acquisition system, as shown in Figure 4. A displacement-controlled loading rate of 0.3 mm/min was maintained throughout the tests to ensure quasi-static conditions and prevent inertial effects or sudden failure. The system provides precise loads applied and measurements of all parameters during the whole three-point bending test process.

Two composite-grade strain gauges with resistance of 120 ± 0.3 ohms, gauge factor of $2.06 \pm 1\%$, and transverse sensitivity of 0.4% were strategically installed to effectively record the mechanical response of the specimen subjected to bending loads. One strain gauge (SG-1) was placed at the exact center of the lower side of the specimen to monitor tensile strain. The other strain gauge (SG-2) was placed on the top (compressive) surface, near the contact point of the cylindrical punch. This configuration enabled comprehensive measurement of both tensile and compressive strain fields, facilitating analysis of strain distribution and neutral axis behavior during flexural loading. Figure 5 presents the placement of strain gauges.

3. Results and Discussion

Strain gauge sensors (SG-1 and SG-2) are used on both sides of the tube to monitor deformation due to bending. SG-1 represents the compression

side, SG-2 the tension side. Figure 6 shows that both strain gauges have a linear and small increase in strain, indicating elastic behavior during the initial elastic phase (0 – 0.80 kN). There were no indications of damage or structural abnormalities. Strain remained below $\pm 1000 \mu\epsilon$, indicating that the structure was still withstanding the load well.

At loads above 0.84 kN, strain increases significantly in SG-1 and SG-2. SG-1 experiences compression strain up to 1.40 kN. The specimen's deformation resulted in the strain gauge registering tensile strain despite being positioned on the compressive side. This anomaly is attributed to localized buckling at the sensor

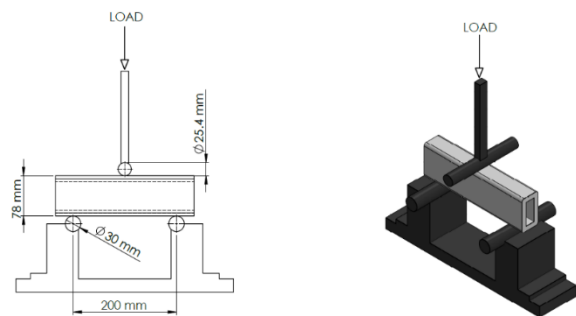


Figure 3. Experimental setup for the three-point bending test



Figure 4. RME 100 schenk trebel machine

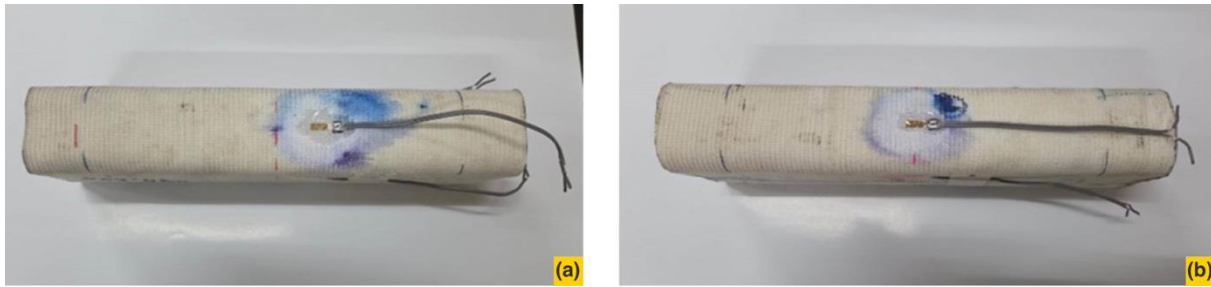


Figure 5. The placement of strain gauges: a. SG-1 on top (compression) side; b. SG-2 on the bottom (tension) side

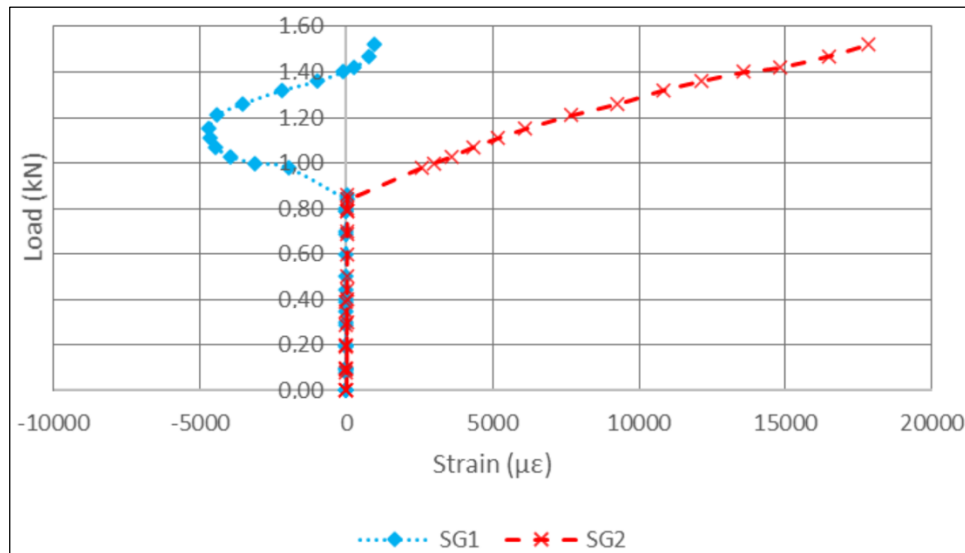


Figure 6. Graphic result of ramie composite test: strain gauge vs. three-point bending load

attachment point, which altered the strain distribution in that region. SG-2 experiences a very large spike approaching $-3125 \mu\epsilon$ at loads above 1.0 kN and keeps getting higher as the load increases.

The maximum flexural strength of the Ramie–PLA tube profile was achieved at a load of 1.52 kN, as shown in [Figure 7](#). The profile demonstrated good elastic performance up to a load of 0.84 kN. The Ramie–PLA tubular specimen exhibited ductile behavior, as indicated by the substantial area under the force–displacement curve, corresponding to a high energy absorption capacity. This characteristic is particularly advantageous in automotive applications, where components are required to dissipate impact energy effectively. Such components include bumper beams [\[14\]](#) and crash boxes [\[15\]](#), which rely on ductile properties to enhance energy absorption and improve overall vehicle safety.

The Rectangular Ramie–PLA Composite Hollow Sections, intended for structural application in urban electric vehicle chassis, experienced permanent bending deformation at

the central loading point (No. 1) during the three-point bending test. Delamination was visibly observed at the mid-thickness region of the composite specimen, as illustrated in [Figure 8b](#). This phenomenon is likely attributed to insufficient resin impregnation [\[16\]](#), [\[17\]](#), [\[18\]](#) during the soaking process, which may compromise the interfacial bonding between the fiber and matrix. Consequently, the overall structural performance of the composite may be adversely affected due to the degradation in its structural integrity [\[19\]](#), [\[20\]](#). Several strategies can be implemented to mitigate delamination, including using alternative low-viscosity resins or applying controlled heating to reduce the resin's viscosity and enhance fiber impregnation [\[21\]](#), [\[22\]](#).

SEM testing was conducted to analyze the damage after bending testing. This was done in the transverse direction (perpendicular to the ramie yarn direction) and longitudinal direction (parallel to the ramie yarn direction) to determine the strength, failure, and quality of the fiber–matrix bond as a whole [\[23\]](#).

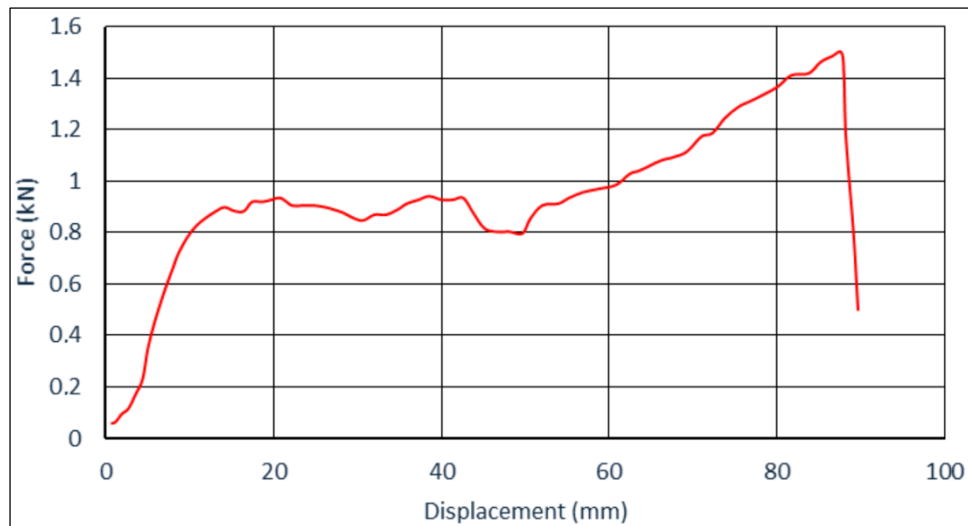


Figure 7. Graphic result of ramie composite test: displacement vs. three-point bending load

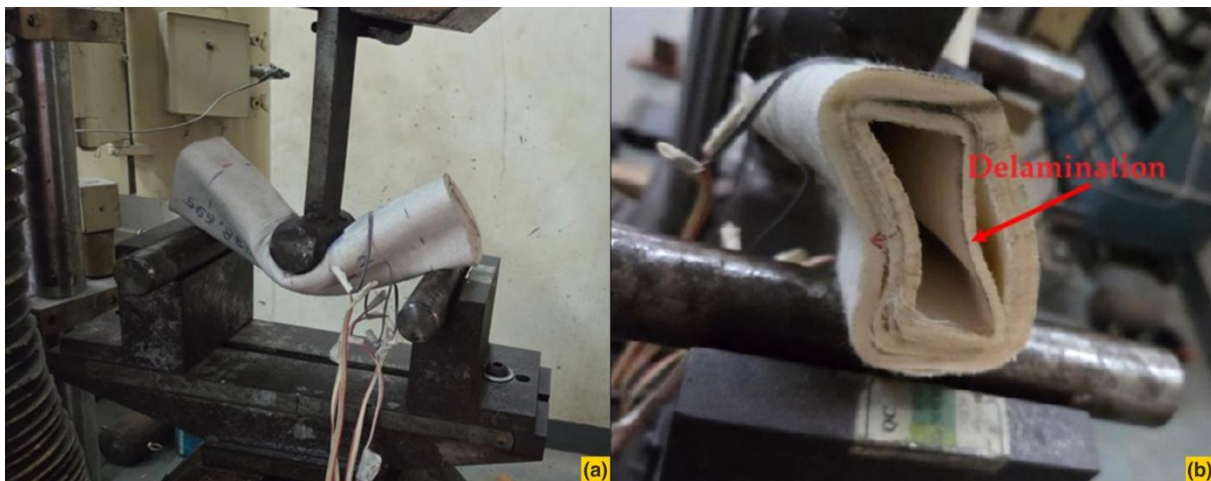


Figure 8. Specimen condition after reaching failure due to the ultimate load: (a) Front view; (b) Side view

Figure 9a shows distributed ramie fibers embedded in the PLA matrix, with small gaps observable between some fibers due to incomplete impregnation. **Figure 9b** highlights the fiber-matrix interface, where partial adhesion and microvoids at the interface are visible. **Figure 9c** indicates the presence of a large void surrounding a fiber, representing a manufacturing defect that may act as a crack initiation site under load. The SEM analysis reveals that although the fiber distribution in the central region appears relatively uniform, microvoids and large voids in the left area indicate imperfect matrix impregnation. These defects could significantly affect the mechanical integrity of the composite structure.

Figure 10a shows a high magnification view showing extensive fiber pull-out, microvoid coalescence, and a rough ductile fracture surface.

Figure 10b shows a lower magnification overview of the same zone, highlighting layered delamination and stepped tearing produced by combined tensile-shear loading. **Figure 10c** shows fracture morphology with non-uniform fiber orientation and complex crack paths, evidencing localized matrix deformation. This figure demonstrates that the material fails predominantly by a ductile mechanism involving interfacial debonding and fiber pull-out rather than catastrophic brittle cracking.

4. Conclusion

This study provides evidence that the Ramie-PLA composite exhibits meaningful potential as a sustainable structural material, particularly demonstrated by its elastic response up to 0.84 kN and its notable ductility and energy absorption capacity near failure. Such behavior aligns with

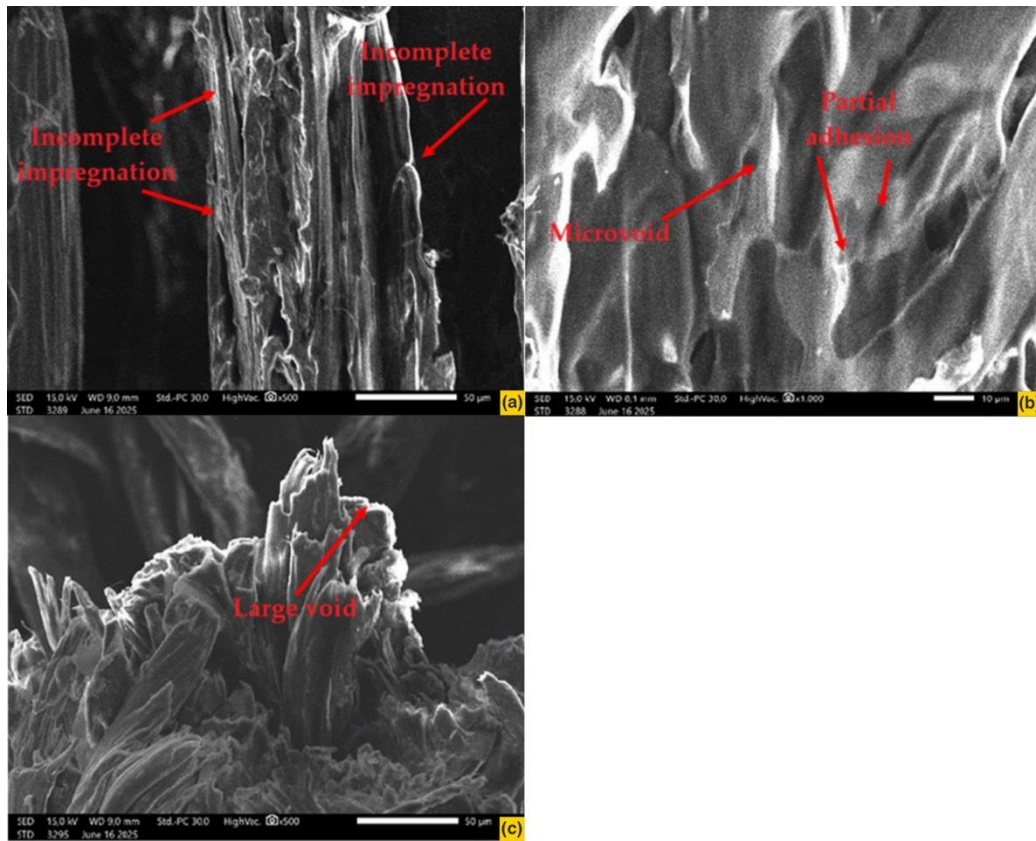


Figure 9. SEM results of Ramie-PLA composite in the longitudinal position: (a) Central area 500x; (b) Central area 1000x; (c) Left area 500x

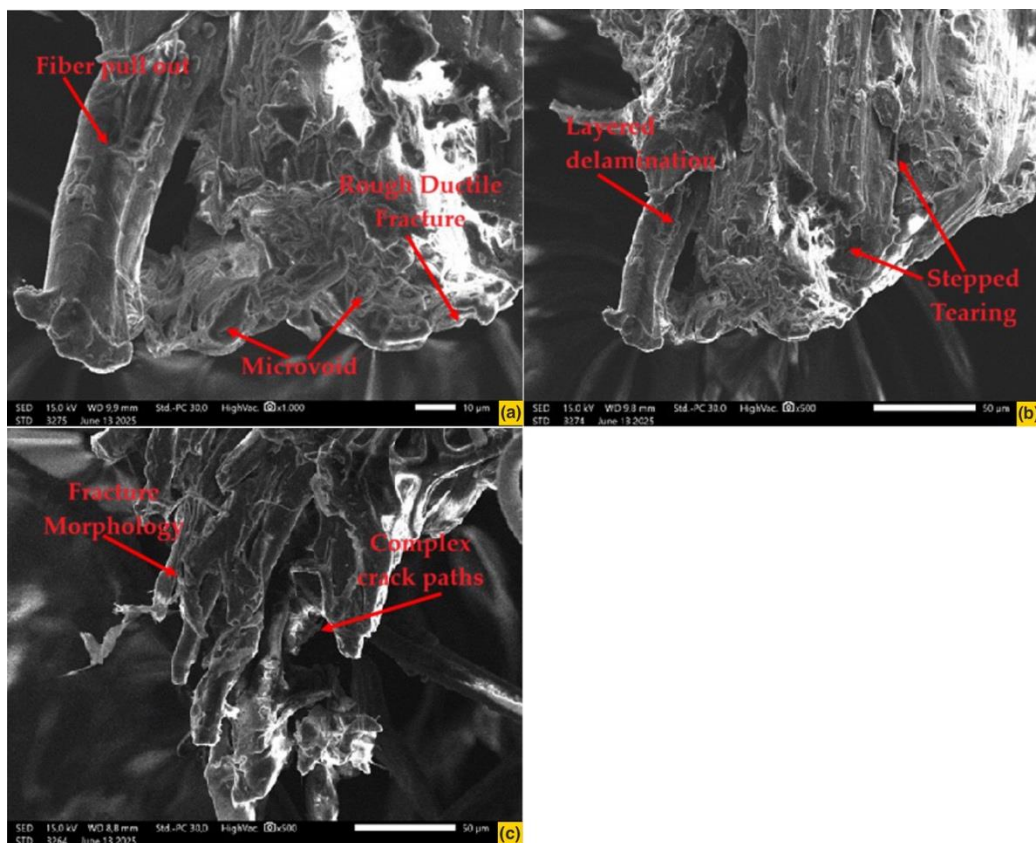


Figure 10. Composite SEM results of Ramie-PLA in the transverse position: (a) Left area 1000x; (b) Left area 500x; (c) Central area 500x

the performance requirements of crashworthy components in lightweight electric mobility systems, indicating a relevant pathway for future engineering application.

However, while the mechanical response is promising, the results must be interpreted within the context of processing-induced limitations that emerged throughout the investigation. Macroscopic failure observations revealed permanent deformation and delamination at the mid-thickness region, while SEM analysis confirmed critical microstructural deficiencies, including incomplete impregnation, microvoid formation, partial interfacial bonding, and pronounced fiber pull-out. These findings underscore that the observed mechanical performance is currently constrained by non-uniform matrix–fiber integration rather than intrinsic material limitations.

Collectively, these outcomes suggest that the material is technologically viable but not yet application-ready. Before this composite can transition toward industrial deployment, processing optimization must become a primary research priority. Improvements such as matrix rheology modification, controlled heating environments, or pressure-assisted consolidation may be necessary to eliminate voids and enhance fiber wetting consistency. Furthermore, the present work should be expanded with broader mechanical characterization—including fatigue, impact, and environmental durability testing—to establish a comprehensive validation framework aligned with real-world operational demands.

In conclusion, the Ramie–PLA composite demonstrates strong potential as an environmentally responsible alternative to synthetic fiber–reinforced materials. Yet, its future depends on resolving the microstructural challenges identified in this study and substantiating its performance through deeper, multi-scale, and application-driven research.

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Author's Declaration

Authors' contributions and responsibilities

Mustasyar Perkasa: Conceptualization, Methodology, Funding Acquisition. Tresna Priyana Soemardi: Methodology, Validation, Writing – review & editing. Djoko Wahyu Karmiadji: Methodology, Validation, Writing – review & editing. Yudan Whulanza: Supervision, Methodology, Validation. Arief Setyawan: Data Curation, Data Analysis, Interpretation. Rizky Pratama Mulyana: Investigation, Data Curation, Data Analysis. Arga Agung Nugroho: Investigation, Data Curation, Writing – Original Draft. Wahyu Sulistiyo: Resources, Investigation, Software. Masriyah: Investigation, Data Analysis, Visualization. Ridho Dwimansyah: Writing – Original Draft, Interpretation, Visualization. Makmuri: Supervision, Project Administration, Validation. Wely Pasadena: Supervision, Resources, Investigation. Olivier Polit: Supervision, Methodology, Validation..

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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