Applied Science and Engineering Progress, Vol. 20, No. 3, 2027, 8255

Research Article

Strategic Selection of Fiber-Reinforced Thermoplastics Via AHP-TRIZ for Aircraft Food Tray Application

Anahar Nurul Aina, Muhammad Asyraf Muhammad Rizal*, Shahril Hakimi Jusoh, Amer Iskandar Rae'is, Siti Khairunisah Ghazali, Rushdan Ahmad Ilyas, and Mohd Yazid Yahya
Centre for Advanced Composite Materials (CACM), Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, Malaysia

Noryani Muhammad
Fakulti Teknologi Dan Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

* Corresponding author. E-mail: muhammadasyraf.mr@utm.my DOI: 10.14416/j.asep.2026.07.004
Received: 18 May 2026; Revised: 11 June 2026; Accepted: 24 June 2026; Published online: 15 July 2026

Abstract
Thermoplastic polymers have attracted growing interest for aircraft interior applications due to their lightweight characteristics, recyclability, impact resistance, and compatibility with high-volume manufacturing processes. However, systematic approaches for selecting fiber-reinforced thermoplastic materials for aerospace interior components remain limited, largely due to the complexity of balancing mechanical performance, weight constraints, cost efficiency, and manufacturability requirements. This study proposes an integrated material selection framework combining Analytic Hierarchy Process (AHP) and Theory of Inventive Problem Solving (TRIZ) to support structured decision-making and resolve engineering trade-offs. Four evaluation criteria, namely density, tensile strength, Young's modulus, and availability, were considered within the AHP model, while TRIZ was applied to address contradictions between structural strength, weight reduction, and process feasibility. Among the evaluated alternatives, glass fiber-reinforced acrylonitrile butadiene styrene (ABS) achieved the highest overall ranking, demonstrating the most balanced combination of performance and practical suitability for aircraft food tray applications. The integrated AHP–TRIZ methodology provides a systematic and scalable decision-making tool for aerospace composite development. Future work will focus on hybrid fiber architecture optimization and long-term durability evaluation to enhance structural reliability in aviation interior systems.

Keywords: Analytic hierarchy process, Concurrent engineering, Flexural properties, Hybrid composite, Theory of inventive problem solving

1 Introduction

Lightweight material selection remains a critical requirement in aerospace engineering because even small reductions in cabin-component mass can contribute to lower fuel consumption, improved payload efficiency, and reduced environmental impact. In aircraft interiors, polymers and polymer composites are widely used for non-structural components such as seat backs, tray tables, galley items, partitions, panels, stowage-bin parts, and meal-service accessories because they offer low density, design flexibility, corrosion resistance, mouldability, and compatibility with high-volume manufacturing processes [1]. Aircraft meal trays and related tray-support components are commonly manufactured from thermoplastics such as acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polypropylene (PP), polyethylene terephthalate (PET), polyester, melamine, and other moldable plastics due to their low cost, ease of forming, cleanability, and lightweight characteristics [2], [3]. However, these conventional plastics may suffer from limited stiffness, surface damage, dimensional instability, thermal deformation, brittle cracking, creep under repeated loading, and reduced service life when exposed to repeated handling.

Although aircraft food trays are classified as non-structural cabin components, their performance is directly related to passenger safety, service reliability, hygiene, and maintenance cost. Tray and tray-table failures have been reported in several passenger injury cases, particularly where defective, unstable, or slanted tray-table surfaces caused hot food or beverages to slide and spill onto passengers. Therefore, the selection of material for aircraft tray applications must address not only weight reduction and cost, but also mechanical integrity, durability, manufacturability, regulatory compliance, and in-service safety.

Fiber-reinforced thermoplastics have emerged as promising materials for aircraft interior applications because fiber reinforcement can improve stiffness, tensile strength, impact resistance, dimensional stability, and damage tolerance while retaining the recyclability and processability advantages of thermoplastic matrices [4], [5]. Among the available reinforcements, glass fiber is particularly attractive for cabin-interior and tray applications because it provides a favorable balance between mechanical performance, density, availability, processability, and cost compared with more expensive reinforcements such as carbon fiber. Glass fiber-reinforced thermoplastics, especially glass fiber-reinforced polypropylene and other engineering thermoplastics, have been widely reported to improve tensile modulus, flexural performance, impact resistance, and dimensional stability compared with unreinforced polymers [6]–[8]. The incorporation of glass fiber can therefore overcome major limitations of neat thermoplastics, particularly insufficient rigidity, creep resistance, and load-bearing stability under repeated service loading.

Previous studies on fiber-reinforced thermoplastics have mainly focused on experimental characterization, including tensile strength, flexural strength, impact behavior, fiber loading, fiber orientation, interfacial bonding, and processing parameters [9]–[13]. These studies provide useful mechanical-property data, but they do not fully address how material candidates should be strategically ranked when multiple conflicting criteria must be considered simultaneously [14]–[17]. In the context of aircraft food tray applications, the material selection problem is more complex because a candidate with high stiffness may have higher density or cost, while a lightweight and low-cost polymer may lack sufficient mechanical stability or durability. Furthermore, limited studies have integrated experimental mechanical validation with structured multi-criteria decision-making methods specifically for aircraft tray or tray-table applications. The research gap is therefore not only the lack of mechanical data, but the absence of a systematic decision framework that can connect material performance, weight, availability, manufacturability, cost and government support for fiber-reinforced thermoplastic tray components.

The Analytic Hierarchy Process (AHP) is one of the most widely used multi-criteria decision-making methods for complex engineering selection problems. AHP decomposes a decision problem into a hierarchical structure consisting of a goal, criteria, sub-criteria, and alternatives, and then applies pairwise comparison to determine priority weights and ranking outcomes [18]. In composite material selection, AHP has been applied to evaluate polymer matrices, natural fiber reinforcements, hybrid composites, and sustainable materials by considering criteria such as density, strength, modulus, cost, availability, processability, and environmental performance [19]. For example, previous studies have used AHP to select suitable thermoplastic matrices for hybrid natural fiber/glass fiber polymer composites and to rank natural fibers for biopolymer composite applications [20], [21]. These works demonstrate that AHP is useful for translating material-performance data and expert judgement into a systematic ranking framework. However, AHP is primarily a prioritization tool; it identifies the most suitable alternative based on weighted criteria, but it does not directly resolve design contradictions between competing requirements.

The Theory of Inventive Problem Solving, commonly known as TRIZ, provides a complementary approach for resolving engineering contradictions. TRIZ is based on the principle that many technical problems involve conflicts, such as improving strength while reducing weight, increasing durability without increasing cost, or improving stiffness without compromising manufacturability. TRIZ tools, including the contradiction matrix, inventive principles, and ideality concept, have been applied in engineering design, product development, eco-design, and material substitution to generate innovative solutions beyond conventional compromise-based selection [22]. In the context of aircraft tray material selection, TRIZ is relevant because the design problem involves several contradictions: the tray must be lightweight but sufficiently stiff, low-cost but durable, manufacturable but mechanically reliable, and commercially available while meeting aerospace interior requirements.

Although AHP and TRIZ have both been used independently in engineering design and material selection, their integration remains limited for fiber-reinforced thermoplastic composites intended for aircraft interior tray applications. Existing studies on thermoplastic composites provide experimental property data, while AHP-based studies provide ranking methods for material alternatives. However, limited work has combined experimental mechanical validation, AHP-based material prioritization, and TRIZ-supported contradiction analysis in a single framework for aircraft food tray components. This creates a clear research gap: there is a lack of a systematic and innovation-driven material selection framework that can simultaneously rank hybrid fiber-reinforced thermoplastic alternatives and interpret the design contradictions associated with lightweight performance, stiffness, strength, availability, cost, manufacturability, and government support.

To address this gap, this study proposes a systematic material selection framework based on the AHP to evaluate fiber-reinforced thermoplastics for aircraft food tray applications. The AHP model enables quantitative comparison of multiple criteria, including density, tensile strength, Young's modulus, availability, cost, and practical suitability for aircraft interior use. In addition, the TRIZ is incorporated to resolve design contradictions between mechanical performance, structural weight, manufacturability, and economic constraints. The integration of AHP and TRIZ provides a structured decision-support approach that combines quantitative material ranking with contradiction-based design reasoning. This framework is expected to support more reliable material selection for lightweight aerospace interior components, where mechanical performance, weight efficiency, processability, and implementation feasibility must be considered simultaneously.

2 Materials and Methods

This study integrates the AHP and TRIZ methodology to establish a systematic material selection framework for aircraft food tray applications. The framework consists of two sequential phases. In the first phase, AHP is applied to rank selected fiber-reinforced thermoplastic alternatives based on measurable performance and feasibility criteria. In the second phase, TRIZ is used to interpret the material-selection conflicts and propose design-improvement strategies where contradictions exist between lightweight performance, stiffness, strength, availability, and cost. The overall research workflow is illustrated in Figure 1.

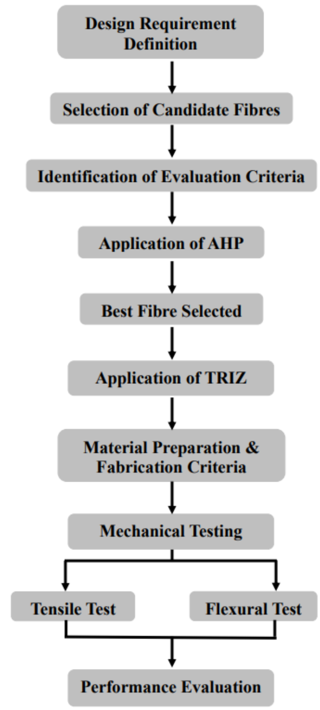


Figure 1: Integrated research framework combining AHP-based material selection and TRIZ-driven design optimization.

2.1 *Material alternatives and evaluation criteria*

The material alternatives considered in this study were selected through an initial screening process based on four requirements relevant to aircraft food tray applications: low density, adequate tensile performance, stiffness, and practical availability for composite manufacturing.

Four reinforcement candidates were shortlisted for evaluation with an ABS thermoplastic matrix, namely kenaf, glass, basalt fiber, and polystyrene fiber. These alternatives represent different material classes: natural fiber, conventional synthetic mineral fiber, advanced mineral fiber, and lightweight polymeric fiber. This classification enables the AHP model to compare materials with different performance–weight–availability properties rather than selecting candidates from only one fiber category. The selected fiber alternatives were chosen to represent both natural-origin and synthetic/manufactured reinforcement systems. Kenaf fiber was categorized as a lignocellulosic natural fiber due to its renewable origin, low density, and potential for sustainable lightweight composite applications. Basalt fiber was considered a natural-origin mineral fiber because it is derived from volcanic rock, although it undergoes industrial melting and fiber-forming processes before use as reinforcement. In contrast, glass fiber and polystyrene fiber were classified as synthetic/manufactured fibers, representing inorganic and polymeric reinforcement systems, respectively. Therefore, the study correlates natural and synthetic fiber systems by comparing their trade-offs in density, tensile strength, Young's modulus, availability, and government support using the same AHP framework.

The selection of these four fibers was justified using quantitative property ranges reported in the literature. Kenaf fiber was included because of its low density, typically around 1.2–1.5 g/cm³, and reported tensile strength values that may reach approximately 600–1000 MPa depending on fiber condition and treatment [23], [24]. Its renewable origin and low weight make it relevant for sustainable lightweight composite applications. Glass fiber was selected as the benchmark reinforcement because it is one of the most widely used fibers in polymer composites and offers high tensile strength of approximately 1950–2050 MPa and Young's modulus of approximately 72–85 GPa. Basalt fiber was considered because it offers mechanical and thermal performance comparable to or higher than glass fiber, with reported density around 2.6–2.8 g/cm³, tensile strength commonly above 3000 MPa, and modulus in the range of approximately 85–95 GPa. Polystyrene fiber was included as a lightweight and highly available polymeric alternative, with reported tensile strength of approximately 40–60 MPa and Young's modulus of approximately 3.0–3.6 GPa for polystyrene-based materials. Although its mechanical performance is lower than that of mineral fibers, its low processing complexity and commercial availability make it useful as a comparative lightweight polymer-based option. To provide a transparent basis for AHP input, the material alternatives were first screened according to the indicative property ranges shown in Table 1.

Four evaluation criteria were then defined for the AHP analysis: density, tensile strength, Young's modulus, and availability. Density was selected to represent the lightweight requirement of aircraft interior components. Tensile strength was used to evaluate resistance to failure under applied loading. Young's modulus was selected because tray components require sufficient stiffness to maintain dimensional stability and avoid excessive deformation during use. This is particularly important for aircraft tray-table and food-tray systems because service instability, slanted tray surfaces, or inadequate support may increase the risk of food or beverage sliding from the tray surface. Reported in-flight injury cases [25], [26] involving hot meals or beverages sliding from defective, slanted, or unstable aircraft tray

Table 1: Mechanical and physical properties.

Fiber type	Fiber classification	Density (g/cm³)	Tensile strength (MPa)	Young's modulus (GPa)	Availability	Government support	Refs.
Kenaf fiber	Natural lignocellulosic fiber	1.45	930	53	Widely available in tropical regions, such as Malaysia.	Supported by governments, especially in Malaysia, for sustainable development.	[27]
Glass fiber	Natural-origin mineral fiber / manufactured mineral fiber	2.5-2.55	1700-3400	71-72	Widely available; used across various industries.	Generally supported due to its extensive industrial applications.	[17]-[19]
Basalt fiber	Synthetic/manufactured inorganic fiber	2.6-2.7	2800-3100	80-90	Less common than glass fibers; availability depends on volcanic rock sources.	Limited government support; considered environmentally friendly	[30], [31]
Polystyrene	Synthetic polymer fiber	1.05-1.07	62	12	Widely available; commonly used in packaging and insulation.	Government support varies; environmental concerns due to non-biodegradability.	[32]

tables further demonstrate that tray stability is a relevant service and safety consideration. Availability was included to represent supply-chain readiness, commercial accessibility, and feasibility for larger-scale production.

As shown in the above table, the selected fiber reinforcements exhibit significant variations in density, tensile strength, Young's modulus, and availability. Glass and basalt fibers demonstrate superior mechanical strength and stiffness, while kenaf fiber offers lower density and renewable characteristics. Polystyrene fiber shows moderate mechanical performance but high commercial availability. These differences highlight the trade-offs between lightweight performance, structural capacity, and industrial feasibility. The data presented in the table serve as the foundational input parameters for the pairwise comparison process in the AHP evaluation.

The variations observed in the mechanical and physical properties of the selected fibers indicate inherent trade-offs between lightweight characteristics, structural performance, and industrial feasibility [28]-[29]. Therefore, a systematic multi-criteria decision-making approach is required to objectively evaluate and rank the alternatives. To address this complexity, the AHP was employed as the primary decision-making tool.

2.2 *Application of analytic hierarchy process (AHP) for material selection*

The AHP, developed by Thomas L. Saaty, was applied. AHP is a structured multi-criteria decision-making method that decomposes complex problems into a hierarchical framework consisting of a goal, evaluation criteria, and alternatives. The hierarchical structure developed for the AHP analysis is illustrated in Figure 2.

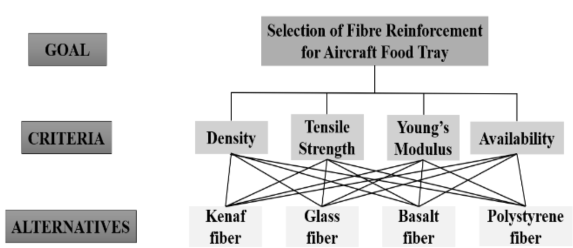


Figure 2: Hierarchical structure of the AHP model for fiber selection in aircraft food tray applications.

Following the development of the hierarchical model, pairwise comparisons among the evaluation criteria were conducted using Saaty's fundamental 1–9 scale to determine their relative importance. The fundamental scale used in this study is presented in Table 2.

Table 2: Fundamental scale for pairwise comparisons in AHP [23]-[25].

Relative intensity scale	Definition	Explanation
1	Equal importance	Two factors are equally important
3	Slightly more importance	Experience slightly favors one factor over the other
5	Strong importance	Experience strongly favors one factor over the other
7	Very strong importance	One factor is strongly favored, and its dominance is demonstrated in practice
9	Extreme importance	Evidence favoring one factor over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgements	Applied when a compromise or intermediate judgment is needed

The pairwise comparison matrix is expressed as:

$$A = [a_{ij}] \quad (1)$$

where a_{ij} represents the relative importance of criterion i compared to criterion j. To obtain the normalized matrix, each element was divided by the sum of its respective column:

$$a = \frac{a_{ij}}{\sum a_{ij}} \quad (2)$$

The priority weight for each criterion was then calculated by averaging the normalized values across each row:

$$w_i = \frac{\sum a_{ij}}{n} \quad (3)$$

where w_i represents the weight of criterion *i,* and n is the number of criteria. To verify the consistency of the judgments, the Consistency Index (CI) was calculated as:

$$CI = \frac{\lambda_{max}-n}{n-1} \quad (4)$$

The Consistency Ratio (CR) was determined using:

$$CR = \frac{CI}{RI} \quad (5)$$

where λ_{max} is the maximum eigenvalue of the comparison matrix and RI is the Random Index. A consistency ratio of CR≤0.10 was considered acceptable. To improve transparency and reproducibility, the criteria weighing process was demonstrated using the pairwise comparison matrix presented in Table 3.

Consistency:

$$\lambda_{max} = 5.00$$

$$CI = \frac{5.00-5}{5-1} = 0.00$$

For five criteria:

$$RI = 1.12$$

$$CI = \frac{0.000}{1.12} = 0.000$$

Since:

$$CR < 0.10$$

The pairwise comparison is consistent.

Based on the normalized priority weights and consistency verification, the relative importance of each evaluation criterion was determined. Subsequently, the same pairwise comparison procedure was applied to evaluate the fiber alternatives under each criterion [33]-[35]. The global priority score for each alternative was then calculated through weighted aggregation.

In the present study, AHP was employed to identify the most suitable fiber reinforcement for integration with the selected thermoplastic matrix, acrylonitrile butadiene styrene (ABS), which was previously determined through TRIZ-based conflict analysis. The decision hierarchy was structured with the primary objective of developing a high-strength, lightweight composite material for aircraft interior applications [19],[36]. Four fiber alternatives, kenaf, glass, basalt, and polystyrene, were evaluated using the AHP framework. The selection process was based on five critical criteria: density, tensile strength, Young's modulus, availability in Malaysia, and government support. These criteria were chosen to ensure that both mechanical performance and practical feasibility were considered. Pairwise comparisons were conducted to determine the relative importance of each criterion, followed by ranking of the fiber alternatives according to their weighted performance scores [37], [38]. This structured evaluation enabled objective identification of the fiber reinforcement most suitable for producing a high-performance thermoplastic composite system.

2.3 *First engineering contradiction: strength vs weight*

The primary design contradiction identified from the Product Design Specification (PDS) was the need to improve material strength without increasing product weight. In TRIZ terminology, this corresponds to:

- Improving parameter: #14 - Strength
- Preserving parameter: #2 - Weight of a stationary object

Table 3: Pairwise comparison matrix for the AHP evaluation criteria

Criteria	Density	Tensile strength	Young's modulus	Availability	Government support
Density	1	1/2	1/2	1/2	2
Tensile strength	2	1	1	1	4
Young's modulus	2	1	1	1	4
Availability	2	1	1	1	4
Government support	1/2	1/4	1/4	1/4	1

Strength refers to the ability of a material to withstand applied mechanical forces without failure, while the weight of a stationary object relates to the overall mass of the component that must remain minimized for aerospace efficiency. The contradiction matrix was consulted using these parameters (Table 4), which generated several inventive principles, including:

- Principle #40 - Composite Material
- Principle #1 - Segmentation
- Principle #26 - Copying
- Principle #27 - Cheap Short-Living Objects

Table 4: TRIZ contradiction and generic solution 1.

Feature to improve	Feature to preserve	Solution principle
Strength	Weight of stationary	#Composite material #Cheap short live object #C #Segmentation

Among these, Principle #40 (Composite material) was selected as the most suitable strategy [39], [40]. This principle suggests replacing uniform materials with composite systems to achieve enhanced mechanical properties without proportional weight increase. Accordingly, the design strategy involved integrating fiber reinforcement with a thermoplastic matrix (ABS) to develop a high strength yet lightweight composite system [41], [42].

2.3.2 Second engineering contradiction: environmental safety vs material quantity

The second contradiction concerned the selection of a material that is easily processable and environmentally safe while avoiding excessive material usage. This contradiction corresponds to:

- Improving parameter: #31 – Object-generated harmful factors
- Preserving parameter: #26 – Quantity of substances

Parameter #31 addresses environmental and health impacts during processing and service life, while parameter #26 represents the need to control material consumption. The TRIZ contradiction matrix suggested the following inventive principles (Table 5):

- Principle #3 -Local quality
- Principle #24 – Intermediary
- Principle #39 – Inert atmosphere
- Principle #1 – Segmentation

Table 5: TRIZ contradiction and generic.

Feature to improve	Feature to preserve	Solution principle
Object-generated harmful	Quantity of substance	#Local quality #Intermediary #Inert atmosphere #Segmentation

Among these, Principle #3 (Local Quality) was selected as the most appropriate for this study. This principle recommends modifying material structure locally rather than uniformly, allowing performance optimization without increasing overall material usage. Based on this principle, ABS was selected as the thermoplastic matrix due to its good moldability, mechanical robustness, controlled processing emissions, compatibility with fiber Reinforcement [43], [44].

Through the structured TRIZ analysis, two major engineering contradictions were resolved. The first contradiction justified the use of fiber-reinforced composite systems to enhance strength without increasing weight. The second contradiction supported the selection of ABS as a suitable thermoplastic matrix to ensure processability and environmental compliance. The TRIZ outcomes guided both material selection strategy and composite design optimization prior to fabrication and experimental validation.

As shown in Table 6, TRIZ was not used only to justify the general use of composite materials, but also to guide specific design decisions in the composite structure. Principle #40 supported the use of fiber-reinforced ABS to improve mechanical performance

Table 6: Relationship between TRIZ inventive principles and composite design decisions.

TRIZ principles	Design contradiction	Design decision
Composite material	Improve strength without increasing weight	Use fiber-reinforced ABS instead of neat ABS
Local quality	Improve local stiffness without increasing full material usage	Use fiberglass mesh reinforcement in selected laminate regions
Segmentation	Improve damage tolerance and structural stability	Use a layered laminate structure consisting of ABS sheets, woven glass fiber, and fiberglass mesh
Intermediary	Improve fiber–matrix interaction and load transfer	Use an ABS matrix as the bonding and load-transfer phase between reinforcement layers

while maintaining low weight (Table 7). Principle #3 supported localized reinforcement through fiberglass mesh to improve stiffness without excessive material addition (Table 8). Principle #1 supported the use of a layered laminate structure to improve damage tolerance, while the intermediary principle reflected the role of the ABS matrix in supporting fiber–matrix interaction and load transfer.

Table 7: TRIZ contradiction and generic solution 3.

TRIZ solution principles	Solution description	Design strategy description
#Composite material	Change from uniform to composite (multiple) materials	Applying the fiber with thermoplastic composite

Table 8: TRIZ contradiction and generic solution 4.

TRIZ solution principles	Solution description	Design strategy description
#Local quality	Change of the object's structure from uniform to non-uniform, change in the external environment (or external influence from uniform to non-uniform)	This is by using material such as thermoplastic like ABS (acrylonitrile butadiene styrene)

2.4 *Methodology*

2.4.1 Preparations and fabrication of materials

The composite laminates were fabricated using a hand lay-up technique followed by hot pressing. ABS thermoplastic sheets supplied by OPC Resources Sdn. Bhd. were used as matrix material, while woven glass fiber and fiberglass mesh were used as reinforcement layers supplied by TF Teraju Sdn. Bhd. The fiberglass mesh configurations were defined based on mesh opening size, namely, no fiberglass mesh, 1 × 1 mm² mesh opening, and 5 × 5 mm² mesh opening. The term "no fiberglass mesh" refers to the control laminate without mesh reinforcement, while the 1 × 1 mm² and 5 × 5 mm² configurations refer to the square opening size of the fiberglass mesh used in the laminate structure. Prior to lay-up, the steel mold surface was cleaned with acetone to remove dust, grease, and surface contaminants. The mold was then coated uniformly with TR-brand mold-release wax to facilitate laminate removal after consolidation. ABS sheets were used as the thermoplastic matrix, while glass fiber was incorporated in two reinforcement forms: woven glass fiber fabric and glass fiber mesh. The use of both reinforcement forms was intended to improve load transfer, tensile resistance, and dimensional stability of the thermoplastic laminate.

After lay-up, the stacked laminate was consolidated using a hot-pressing process at 180 °C under 4 MPa for 30 minutes. The laminate was then cooled to room temperature under pressure to reduce warpage and improve dimensional stability. The final laminate thickness was controlled within approximately 0-7-1.0 cm. For each configuration, the fabrication process was repeated using the same lay-up sequence, pressing condition, and specimen preparation method to minimize processing variability. This stacking sequence was selected to achieve a balanced distribution of thermoplastic matrix and fiber reinforcement through the laminate thickness. The outer ABS layers served as protective surface skins, while the internal glass fiber mesh and woven glass fiber layers provided mechanical reinforcement. The schematic arrangement of the laminate is shown in Figure 3. The laminate was arranged in a symmetrical sandwich-type configuration consisting of five ABS sheets, three layers of glass fiber mesh, which are 1, 3 and 5 mm^2, and four layers of woven glass fiber fabric with around 1 mm as shown in Figure 3.

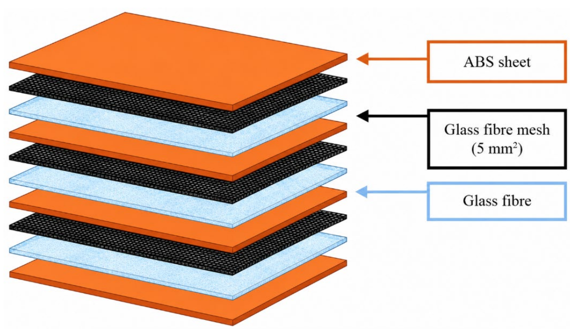


Figure 3: Schematic diagram of fiber arrangement in thermoplastic composites.

2.4.2 Tensile test

Tensile testing was performed in accordance with ASTM D3039 under room conditions of 23.1 °C and 50.5% relative humidity. The test was conducted using an INSTRON Universal Testing Machine equipped with a 100 kN load cell at a crosshead speed of 2 mm/min. The applied load was measured by the load cell positioned above the upper grip, while strain was recorded using an extensometer attached at the midsection of the specimen.

The base and crosshead ensured proper alignment and stability throughout the test. All tensile tests were carried out at the Mechanics of Materials and Structure Laboratory, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), Malaysia. Five specimens were prepared for each composite type. The tensile specimens had an average length of 250 mm, a width ranging from 15 to 16 mm, and a thickness ranging from 3 to 6 mm.

2.4.3 Flexural test

Flexural testing was conducted at the Centre for Advanced Composite Materials (CACM), Universiti Teknologi Malaysia (UTM), Malaysia, in accordance with ASTM D790 using a three-point bending configuration. The test was performed to evaluate the flexural strength, flexural modulus, and deformation behavior of the composite materials under bending loads, thereby providing insight into their stiffness and load-bearing performance. The composite laminates were cut into specimens with dimensions of 80 mm in length, 15 mm in width, and 5 mm in thickness using a bandsaw. Specimen preparation was carried out at the Manufacturing Laboratory, Faculty of Mechanical Engineering, UTM, Malaysia. The flexural tests were performed using a Shimadzu AG-10KN X-Plus Universal Testing Machine equipped with a 10 kN load cell, with a crosshead displacement rate of 2 mm/min applied throughout the test.

3 Results and Discussion

3.1 *AHP ranking results*

The global priority values derived from the AHP analysis indicate that glass fiber achieved the highest ranking among the evaluated alternatives. Based on the weighted aggregation of density, tensile strength, Young's modulus, and availability, glass fiber obtained the highest overall score, followed by polystyrene fiber, kenaf fiber, and basalt fiber.

The superior ranking of glass fiber can be attributed to its balanced combination of high tensile strength and stiffness while maintaining moderate density and strong industrial availability [45], [46]. Although basalt fiber exhibited competitive mechanical properties, its comparatively limited availability reduced its overall priority score. Kenaf fiber demonstrated favorable lightweight characteristics but had lower stiffness relative to glass fiber. Polystyrene fiber showed strong market availability; however, its mechanical performance was comparatively moderate.

These findings confirm that glass fiber offers the most suitable balance between structural performance and practical feasibility for aircraft food tray composite development [47]. The evaluation was conducted using mechanical and physical property data compiled from previous studies, as summarized in Table 1. The priority vector values obtained from the AHP analysis are illustrated in Figure 4, which indicates the relative influence of each criterion on fiber selection.

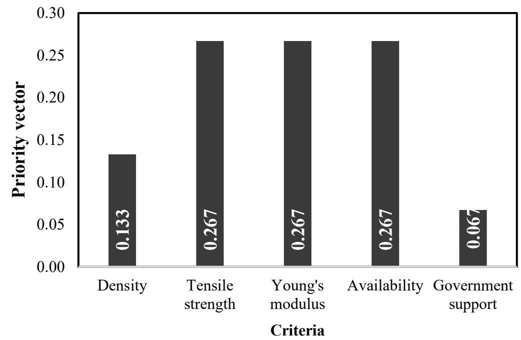


Figure 4: Priority vector values for criteria used in AHP analysis. Higher values indicate greater influence on fiber selection.

The priority vector distribution for kenaf fiber is presented in Figure 5. Among the evaluated criteria, Young's modulus recorded the highest priority value (0.275), followed by tensile strength (0.248), indicating that stiffness and load-bearing capacity are the dominant performance contributors for kenaf in this analysis. These values suggest that kenaf fiber provides reasonable structural rigidity and moderate tensile performance within the composite system [48].

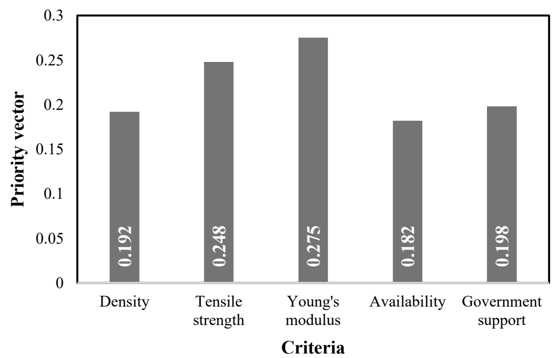


Figure 5: Priority values vs criteria of kenaf fiber.

Density obtained a priority value of 0.192, reflecting its lightweight characteristic, which is advantageous for aerospace interior applications where weight reduction is critical. However, availability recorded the lowest value (0.182), indicating relatively limited industrial accessibility compared to other fiber alternatives. Government support showed a moderate contribution (0.198), suggesting average institutional or policy backing. Overall, the results demonstrate that kenaf fiber offers a balanced but moderate performance profile, with stiffness being its strongest attribute. While it provides weight-saving benefits and acceptable mechanical properties, its comparatively lower availability may limit large-scale implementation in aircraft food tray composite applications.

The priority vector distribution for glass fiber is presented in Figure 6. The results indicate that glass fiber achieved the highest overall global priority score (0.365), confirming its superior ranking among the evaluated alternatives. In terms of individual criteria, tensile strength recorded the highest priority value (0.419), followed by Young's modulus (0.387), demonstrating that mechanical strength and stiffness are the dominant factors contributing to its selection. These high values reflect the material's strong load-bearing capacity and structural rigidity, which are critical for high-performance composite applications [32]-[34].

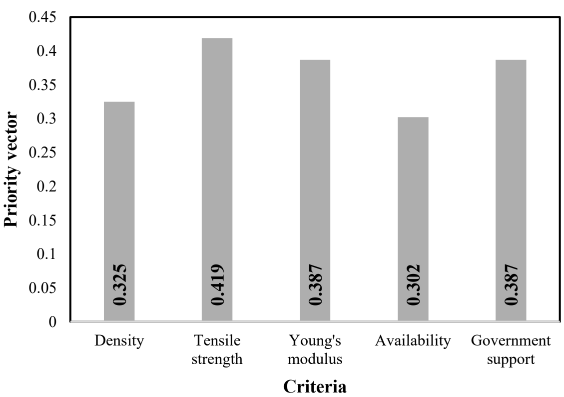


Figure 6: Priority vector vs. the criteria of glass fiber.

Density also showed a relatively strong contribution (0.325), indicating that glass fiber maintains an acceptable strength-to-weight balance suitable for lightweight structural components. Although availability recorded a comparatively lower value (0.302), it remains adequate for industrial-scale application. Government support exhibited a high priority value (0.387), suggesting strong institutional backing and established industry adoption. Overall, the results highlight that glass fiber provides a well-balanced combination of mechanical robustness, structural stiffness, and practical feasibility. Its superior tensile and stiffness characteristics, coupled with moderate density and strong institutional support, make it the most suitable reinforcement material for aircraft food tray composite development.

The priority vector distribution for basalt fiber is presented in Figure 7. The results indicate that basalt fiber achieved a comparatively low global priority score (0.152), reflecting its lower overall ranking among the evaluated alternatives. Among the assessed criteria, density recorded the highest contribution (0.242), suggesting that basalt fiber offers a moderate weight advantage within the composite system.

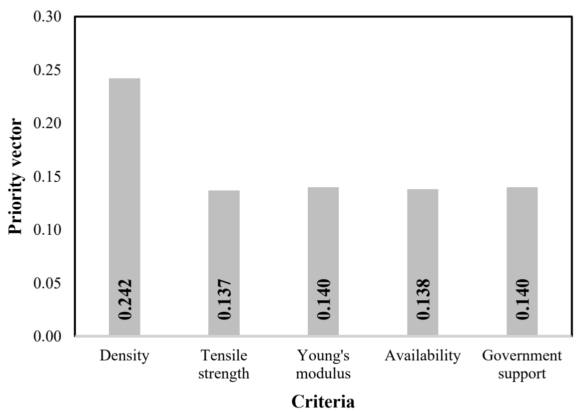


Figure 7: Priority vector vs criteria of basalt fiber.

However, tensile strength (0.137) and Young's modulus (0.140) exhibited relatively low priority values compared to other fiber alternatives, indicating weaker contributions in terms of load-bearing capacity and stiffness. Availability (0.138) also remained limited, reflecting potential supply constraints and restricted industrial accessibility. Similarly, government support (0.140) showed a modest influence, suggesting comparatively lower institutional or market emphasis. Overall, although basalt fiber is often recognized for its durability and thermal resistance [37]-[39], the AHP evaluation demonstrates that its balanced but moderate performance across key mechanical and practical criteria results in a lower overall suitability for aircraft food tray composite development compared to glass fiber and other alternatives.

The priority vector distribution for polystyrene fiber is presented in Figure 8. The results indicate that

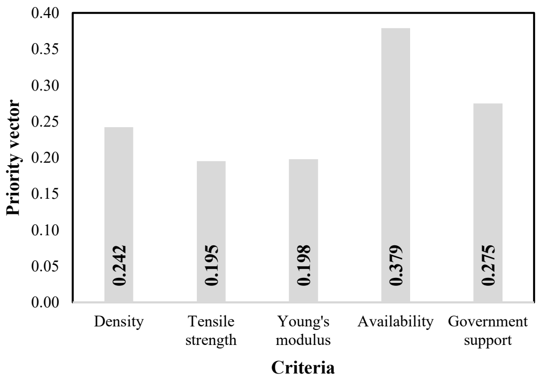


Figure 8: Priority vector vs criteria of polystyrene fiber.

polystyrene fiber achieved a moderate global priority score (0.257), ranking above basalt fiber but below glass fiber in the overall evaluation. Among the assessed criteria, availability recorded the highest priority value (0.379), highlighting its strong market accessibility and ease of procurement. Government support also showed a relatively significant contribution (0.275), reflecting stable institutional and industrial backing. These factors suggest that polystyrene fiber benefits from strong practical feasibility and supply stability.

In terms of mechanical performance, density recorded a moderate value (0.242), indicating acceptable lightweight characteristics. However, tensile strength (0.195) and Young's modulus (0.198) were comparatively lower than those of glass fiber, demonstrating reduced load-bearing capacity and stiffness. While polystyrene fiber may be suitable for applications with moderate structural requirements, its mechanical limitations reduce its competitiveness for high-performance composite systems. Overall, the AHP results suggest that polystyrene fiber offers strong availability advantages but does not provide the mechanical robustness required for demanding aerospace interior applications, thereby positioning it as a secondary alternative rather than the optimal reinforcement material.

The overall results of the AHP analysis indicate that glass fiber achieved the highest global priority value among the four evaluated alternatives. To improve the transparency of the AHP calculation, the global priority value for glass fiber is shown as an example. The global priority score was calculated by multiplying the local priority value of glass fiber under each criterion by the corresponding criterion weight, followed by the summation of all weighted values. The criterion weights used in this study were 0.133 for density, 0.267 for tensile strength, 0.267 for Young's modulus, 0.267 for availability, and 0.067 for government support. Meanwhile, the local priority values of glass fiber were 0.325, 0.419, 0.387, 0.302, and 0.387, respectively. Therefore, the global priority value for glass fiber was calculated as follows:

$$P_{glass} = (0.133 \times 0.325) + (0.267 \times 0.419) + (0.267 \times 0.387) + (0.267 \times 0.302) + (0.067 \times 0.387)$$

$$P_{glass} = 0.0432 + 0.1119 + 0.1033 + 0.0806 + 0.0259$$

$$P_{glass} = 0.365$$

This result indicates that glass fiber achieved the highest global priority value among the evaluated alternatives. The largest contributions came from tensile strength and Young's modulus, confirming that the selection of glass fiber was mainly governed by its superior load-bearing capacity and stiffness, while its acceptable density, availability, and government support further strengthened its overall suitability for aircraft food tray composite development.

As illustrated in Figure 9, glass fiber recorded a total priority score of approximately 0.365, clearly outperforming kenaf (0.226), polystyrene (0.257), and basalt fiber (0.152). The stacked weighted attribute chart demonstrates that tensile strength and Young's modulus contribute most significantly to the overall score of glass fiber. Specifically, glass fiber exhibits the highest tensile strength (0.419) and a strong Young's modulus value (0.387), indicating superior load-bearing capacity and structural stiffness. These attributes are critical for aircraft interior components where durability, resistance to deformation, and long-term mechanical stability are required.

Although its density contribution (0.325) is moderate relative to mechanical criteria, glass fiber maintains an effective strength-to-weight balance, which is essential for lightweight structural applications. The radar chart further highlights its consistently strong performance across all criteria, showing a well-balanced profile without significant weaknesses. In addition to mechanical performance, practical considerations further enhance its suitability. Glass fiber demonstrates adequate availability (0.302), ensuring reliable supply for industrial-scale production [51], [52]. Government support (0.387) also contributes significantly, reflecting strong institutional backing, established manufacturing

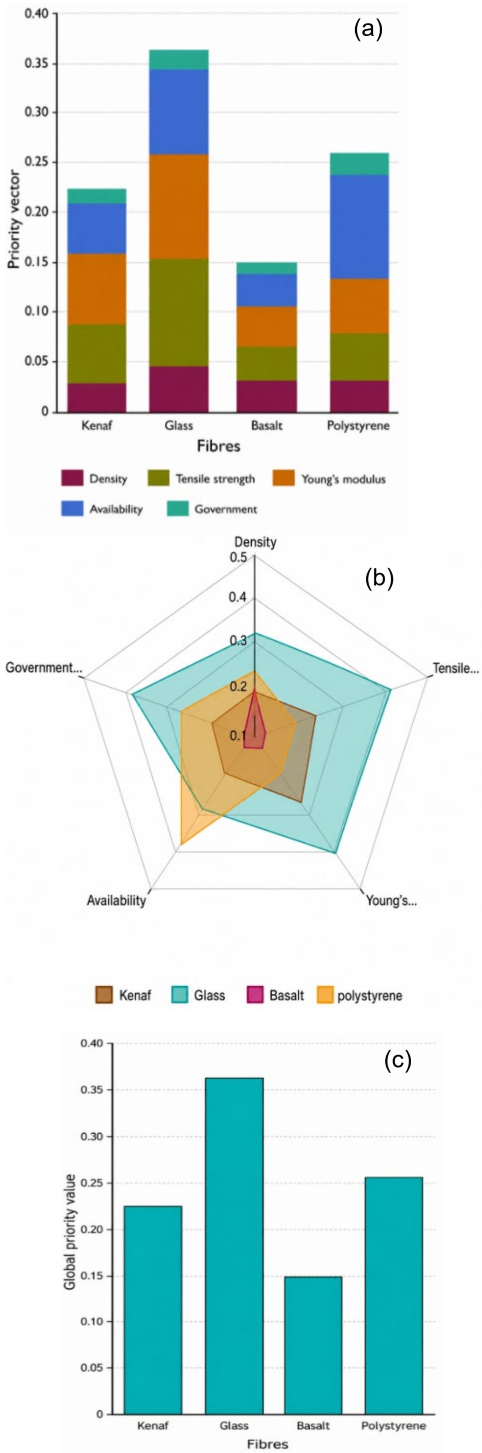


Figure 9: AHP evaluation results for fiber selection: (a) weighted attribute contributions of each fiber, (b) radar plot comparison of criteria performance, and (c) global priority ranking of alternatives.

infrastructure, and regulatory familiarity. These external factors reinforce its practicality and reduce implementation risks.

When comparing all materials holistically, kenaf fiber offers lightweight benefits but lower stiffness, basalt fiber shows moderate density but weaker overall mechanical contribution, and polystyrene fiber benefits from strong availability but limited structural robustness. In contrast, glass fiber consistently achieves high scores across both mechanical and feasibility criteria, resulting in the highest global priority.

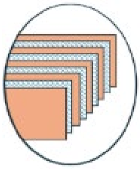
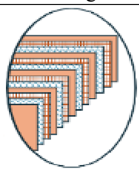
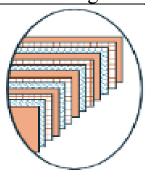
The AHP results also provide insight into the relationship between natural-origin and synthetic/manufactured fiber systems. The natural-origin fibers, namely kenaf and basalt, showed specific advantages but also clear limitations. Kenaf fiber contributed positively through its low density and renewable origin, making it attractive for lightweight and sustainable composite applications. However, its lower stiffness and relatively lower industrial readiness reduced its overall priority score. Basalt fiber showed good inherent mechanical potential, but its lower availability and weaker feasibility-related scores limited its ranking in this study. In comparison, the synthetic/manufactured fibers, particularly glass fiber, achieved stronger overall performance because they combined high tensile strength, high stiffness, acceptable density, commercial availability, and established industrial support.

Therefore, the correlation between natural and synthetic fibers in this study is demonstrated through their multi-criteria trade-off: natural-origin fibers offer sustainability and lightweight benefits, whereas synthetic/manufactured fibers provide stronger mechanical reliability and implementation feasibility for aircraft food tray applications. Overall, the AHP evaluation confirms that glass fiber provides the most balanced combination of strength, stiffness, availability, and institutional support. Its superior multi-criteria performance makes it the most suitable reinforcement material for high-strength, lightweight aircraft food tray composite applications.

3.2 *Results of material selection using AHP and TRIZ*

To enhance the development of a high-performance thermoplastic composite, the TRIZ methodology was applied to resolve critical design contradictions identified after the AHP ranking [27]-[29]. While

Table 9: Mechanical properties of composite configurations with varying fiberglass mesh thickness.

Layer sequence	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)
 0 mm² of fiberglass mesh	107.40975	9.35728	98.4468	3.12276
 1 mm² of fiberglass mesh	126.87425	62.48774	91.6746	2.78036
 5 mm² of fiberglass mesh	148.33467	11.59862	89.4858	3.03127

AHP determined glass fiber as the most suitable reinforcement material based on multi-criteria evaluation, TRIZ was employed to validate and optimize the composite design strategy.

The primary contradiction involved improving structural strength without increasing component weight. This conflict corresponds to TRIZ parameters #14 (Strength) and #2 (Weight of a stationary object). The contradiction matrix analysis recommended several inventive principles, among which Principle #40 (Composite Material) was selected. This principle supports the integration of fiber reinforcement within a thermoplastic matrix to enhance mechanical performance without significantly increasing mass. The selection of glass fiber reinforced ABS, therefore, aligns with both AHP ranking and TRIZ optimization outcomes.

In addition to structural performance, manufacturability and environmental considerations were evaluated. The second contradiction addressed the need for improved processability and reduced environmental impact without increasing material consumption. This corresponds to TRIZ parameters #31 (Object-generated harmful factors) and #26 (Quantity of substance). The recommended inventive principles, particularly Principle #3 (Local Quality), supported the selection of ABS as the thermoplastic matrix due to its moldability, durability, and relatively controlled processing emissions [43]-[44].

By integrating AHP and TRIZ, the material selection process was strengthened through both quantitative evaluation and systematic innovation analysis [55]. The combined approach ensured that the final composite design not only satisfies mechanical performance requirements but also maintains lightweight characteristics, manufacturing feasibility, and environmental considerations [56]. This integrated framework enhances confidence in the selection of glass fiber-reinforced ABS as the optimal material system for aircraft food tray applications.

3.3 *Determination of the best specific solution*

Following the AHP-based material selection and TRIZ-guided design optimization, an experimental investigation was conducted to determine the most suitable fiber configuration for aircraft food tray applications. Three laminate configurations (0 mm, 1 mm², and 5 mm² fiberglass mesh) were fabricated and evaluated. Key mechanical properties, including tensile strength, tensile modulus, flexural strength, and flexural modulus, were measured. The results are summarized in Table 9.

Table 9 presents the tensile and flexural properties of composite laminates fabricated with varying fiberglass mesh thicknesses. The results clearly demonstrate that increasing fiber reinforcement enhances tensile performance. The 5 mm^2 fiberglass mesh configuration achieved the highest tensile strength (148.33 MPa), representing approximately a 38% improvement compared to the 0 mm configuration (107.41 MPa). This confirms the significant contribution of fiberglass mesh to load-bearing capacity. Although the 1 mm^2 configuration exhibited a lower tensile strength (126.87 MPa), it recorded the highest tensile modulus (62.49 GPa), indicating increased stiffness but potentially reduced ductility.

The values reported in Table 9 represent average mechanical properties obtained from five specimens for each configuration. However, only averaged values were available for the present analysis; therefore, standard deviation and statistical significance testing could not be calculated retrospectively. As a result, the results are interpreted based on the main observed trends, and small differences between configurations should be considered with caution.

In flexural testing, the 0 mm configuration showed the highest flexural modulus (3122.76 MPa), likely due to its homogeneous matrix structure providing initial resistance to bending deformation. The higher flexural modulus recorded for the 0 mm configuration may be related to its more uniform laminate structure, thickness consistency, or stronger initial bending response [57]. However, this configuration lacks tensile reinforcement, limiting its structural reliability under combined loading conditions. The 5 mm^2 configuration demonstrated a balanced mechanical profile, maintaining high tensile strength alongside stable flexural performance (3031.27 MPa). Overall, the 5 mm^2 fiberglass mesh configuration provides the most optimal combination of tensile strength, stiffness, and flexural integrity [58]. These characteristics are essential for aircraft food tray applications subjected to repeated mechanical loading, vibration, and stacking forces [49]-[50].

4 Conclusions

This study successfully established an integrated AHP–TRIZ material selection framework for identifying suitable hybrid fiber-reinforced thermoplastic composites for aircraft food tray applications. The proposed framework enabled a systematic transition from multi-criteria material prioritization to contradiction-driven design refinement, thereby overcoming the limitations of conventional property-based or experience-driven material selection. Based on the AHP evaluation, the AHP results identified glass fiber as the most suitable reinforcement material, achieving the highest global priority value (0.365) compared to other candidate fibers. Its superior contributions in tensile strength (0.419) and Young’s modulus (0.387) were the dominant factors influencing selection. The TRIZ analysis further supported the adoption of fiber-reinforced composite systems to enhance structural strength without increasing weight, reinforcing the suitability of glass fiber-reinforced ABS for aerospace interior applications. Experimental validation confirmed the effectiveness of this selection strategy, where the 5 mm^2 fiberglass mesh configuration achieved the highest tensile strength of 148.33 MPa, corresponding to approximately 38% improvement compared with the unreinforced 0 mm configuration. Although the unreinforced configuration showed a higher initial flexural modulus, the 5 mm^2 fiberglass mesh composite exhibited the most balanced mechanical profile by combining superior tensile performance with stable flexural integrity. Overall, the findings demonstrate that glass fiber-reinforced ABS, particularly with the 5 mm^2 mesh configuration, offers a technically viable and practically scalable material solution for lightweight aircraft food tray components. More importantly, the integrated AHP–TRIZ approach provides a robust decision-support methodology for aerospace composite development, where mechanical performance, weight efficiency, manufacturability, and service reliability must be considered simultaneously.

Future work should focus on advancing the proposed material system from laboratory-scale evaluation towards application-ready aircraft interior components. Further optimization of fiber architecture, mesh size, stacking sequence, and fiber–matrix interfacial bonding is required to enhance both tensile and flexural performance without increasing component weight. Long-term durability studies should also be conducted under aircraft-relevant service conditions, including cyclic loading, vibration, thermal ageing, humidity exposure, cleaning-agent resistance, impact loading, and creep deformation. Therefore, this study provides not only a candidate material solution for aircraft food trays, but also a transferable decision-making platform for strategic material selection in lightweight aerospace, transportation, and high-performance thermoplastic composite applications.

Acknowledgments

The authors would like to extend their appreciation to the Ministry of Higher Education, Malaysia, for financial support through the Funda mental Research Grant Scheme (FRGS) project under grant no. FRGS/1/ 2024/TK04/UTM/02/1. The authors would like to express their gratitude to Universiti Teknologi Malaysia, through the Centre for Advanced Composites Materials and the Faculty of Mechanical Engineering, for providing the facilities that enabled them to conduct this work. The authors also would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for their support via UTeM Research Fellowship.

Author Contributions

MAMR, ANA, SHJ, AIR and SKG contributed to prepare the draft of manuscript. RAI, MYY and NM contributed to edit the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors utilized the ChatGPT tool to enhance the language and readability of the manuscript.

References

[1] A. Al-Fatlawi, K. Jármai, and G. Kovács, “Optimal design of a fiber-reinforced plastic composite sandwich structure for the base plate of aircraft pallets in order to reduce weight,” *Polymers*, vol. 13, no. 5, pp. 834, Mar. 2021, doi: 10.3390/polym13050834.

[2] P. S. Khoo et al., “Sustainable chemically treated lignocellulosic pineapple leaf fibre-reinforced polymer composites: mechanical properties, environmental aspects and applications,” *Cellulose*, vol. 32, no. 7, pp. 4101–4142, 2025, doi: 10.1007/s10570-025-06519-6.

[3] P. S. Khoo et al., “ Chemical functionalisation-driven enhancement of mechanical and energy absorption performance in injection-moulded rubberwood/PLA composites,” *Fibers and Polymers*, Jun. 2026, doi: 10.1007/s12221-026-01462-0.

[4] N. I. N. Haris et al., “Dynamic mechanical properties of natural fiber reinforced hybrid polymer composites: a review,” *Journal of Material Research and Technology*, vol. 19, pp. 167–182, Jul. 2022, doi: 10.1016/j.jmrt.2022.04.155.

[5] M. F. Muhammad Fitri, M. R. Muhammad Asyraf, and S. Abu Hassan, “ Hybridizing kenaf and glass fibres as reinforcement in ABS composites: Current trends, properties and potential application in aircraft radome,” *Jurnal Kejuruteraan*, vol. 36, no. 5, pp. 2075–2096, Sep. 2024, doi: 10.17576/jkukm-2024-36(5)-25.

[6] M. R. M. Asyraf, M. R. Ishak, M. R. Razman, and M. Chandrasekar, “ Fundamentals of creep, testing methods and development of test rig for the full-scale crossarm: A review,” *Jurnal Teknologi,* vol. 81, no. 4, 2019, doi: 10.11113/jt.v81.13402.

[7] I. E. Tabrizi, A. Kefal, J. S. M. Zanjani, C. Akalin, and M. Yildiz, “Experimental and numerical investigation on fracture behavior of glass/carbon fiber hybrid composites using acoustic emission method and refined zigzag theory,” *Composite Structures*, vol. 223, p. 110971, Sep. 2019, doi: 10.1016/j.compstruct.2019.110971.

[8] A. I. Ra’eis, M. A. M. Rizal, A. P. Md Saad, M. S. R. M. Saufi, and A. Syamsir, “ Influence of stacking sequence on the structural performance and failure behaviour of pultruded glass fibre-reinforced polymer composites,” *Fibers and Polymers*, vol. 27, no. 4, pp. 1935–1954, Apr. 2026, doi: 10.1007/s12221-026-01333-8.

[9] R. Maier and A.-C. Mandoc, “ Investigation on layer hybridization of glass/carbon fibre woven reinforced composites subjected to low-speed impact,” *Journal of Composite Sciences*, vol. 7, no. 2, Art no. 83, Feb. 2023, doi: 10.3390/jcs7020083.

[10] M. N. F. Norrrahim et al., “ The frontiers of functionalized nanocellulose-based composites and their application as chemical sensors,” *Polymers*, vol. 14, no. 20, Art no. 4461, Oct. 2022, doi: 10.3390/polym14204461.

[11] R. Raju, G. Rajan, P. Farrar, and B. G. Prusty, “Dimensional stability of short fibre reinforced flowable dental composites,” *Scientific Reports*, vol. 11, no. 1, Art no. 4697, Feb. 2021, doi: 10.1038/s41598-021-83947-x.

[12] S. Gopinath, V. Arumugam, V. Dinesh Babu, and I. Elango, “Optimization of damage

parameters in glass fiber-reinforced composites: numerical and experimental insights into structural integrity enhancement," *Journal of Adhesive Science and Technology*, vol. 40, no. 1, pp. 94–118, Jan. 2026, doi: 10.1080/01694243.2025.2563904.

[13] N. K. Subramaniam, A. Subbaiyan, S. Velusamy, and M. Shanmugamoorthy, "Investigating the structural integrity of glass fiber reinforced polymer (GFRP) composite-striated reinforced concrete beams," *Matéria (Rio Janeiro)*, vol. 29, no. 4, Art no. e20240241, 2024, doi: 10.1590/1517-7076-rmat-2024-0241.

[14] L. Jiang, Y. Zhou, F. Jin, and Z. Hou, " Influence of polymer matrices on the tensile and impact properties of long fiber-reinforced thermoplastic composites," *Polymers*, vol. 15, no. 2, pp. 408, Jan. 2023, doi: 10.3390/polym15020408.

[15] D.-J. Kwon et al., "Impacts of thermoplastics content on mechanical properties of continuous fiber-reinforced thermoplastic composites," *Composites Part B: Engineering,* vol. 216, Art no. 108859, Jul. 2021, doi: 10.1016/j.compositesb.2021.108859.

[16] M. Overberg, M. M. Badrul Hasan, A. Abdkader, J. Rehra, S. Schmeer, and C. Cherif, " Investigations on the development of impact-resistant thermoplastic fibre hybrid composites from glass and steel fibre," *Journal of Composite Materials*, vol. 58, no. 14, pp. 1675–1687, Jun. 2024, doi: 10.1177/00219983241246128.

[17] M. R. M. Asyraf et al., " Evaluation of design and simulation of creep test rig for full-scale crossarm structure," *Advances in Civil Engineering*, vol. 2020, Article ID 6980918, pp. 1–12, 2020, doi: 10.1155/2020/6980918.

[18] M. R. Mansor, S. M. Sapuan, E. S. Zainudin, A. A. Nuraini, and A. Hambali, "Hybrid natural and glass fibers reinforced polymer composites material selection using Analytical Hierarchy Process for automotive brake lever design," *Materials and Design*, vol. 51, pp. 484–492, 2013, doi: 10.1016/j.matdes.2013.04.072.

[19] N. Bekraoui, Z. El Qoubaa, and E. Essadiqi, " Weibull integrated AHP for the selection of natural fiber composites material," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 17, no. 1, pp. 55–67, 2023, doi: 10.59038/jjmie/170105.

[20] N. S. B. Yusof, S. M. Sapuan, M. T. H. Sultan, and M. Jawaid, "Conceptual design of oil palm fibre reinforced polymer hybrid composite automotive crash box using integrated approach," *Journal of Central South University*, vol. 27, no. 1, pp. 64–75, 2020, doi: 10.1007/s11771-020-4278-1.

[21] N. S. B. Yusof, S. M. Sapuan, M. T. H. Sultan, and M. Jawaid, " Manufacturing process selection of 'green' oil palm natural fiber reinforced polyurethane composites using hybrid TEA criteria requirement and AHP method for automotive crash box," *Journal of Renewable Materials*, vol. 8, no. 6, pp. 647–660, 2020, doi: 10.32604/jrm.2020.08309.

[22] M. R. M. Asyraf et al., " Conceptual design of a sustainable bionanocomposite bracket for a transmission tower's cross arm using a hybrid concurrent engineering approach," *Sustainability*, vol. 15, no. 14, Art no. 10814, 2023, doi: 10.3390/su151410814.

[23] E. Rogha et al., "Flexural properties of additively manufactured continuous fibre reinforced thermoplastic polymers after exposure to elevated temperatures," *Composite Communications*, vol. 54, Art no. 102279, Feb. 2025, doi: 10.1016/j.coco.2025.102279.

[24] A. B. M. Supian et al., "Kenaf/glass fiber-reinforced polymer composites: Pioneering sustainable materials with enhanced mechanical and tribological properties," *Polymer Composites*, vol. 45, no. 16, pp. 14421–14447, 2024, doi: 10.1002/pc.28785.

[25] P. Juda, D. Pajor, Ł. Wójcik, A. Kaczmarska, M. Nowak, and T. Konopka, " Analysis of injuries in aircraft accident victims in 2002–2022 based on the resources of the Jagiellonian University Department of Forensic Medicine in Kraków," *Problems of Forensic Sciences*, vol. 136, pp. 295–305, 2023, doi: 10.4467/12307483PFS.23.017.19624.

[26] A. C. Shekhar and K. J. Ruskin, " Injuries due to in-flight turbulence during United States commercial airline flights (2008–2023)," *The American Journal of Surgery*, 2025, doi: 10.1177/00031348251397042.

[27] S. N. Z. Ahmad Nadzri, M. T. Hameed Sultan, A. U. M. Shah, S. N. A. Safri, and A. A. Basri, " A review on the kenaf/glass hybrid composites with limitations on mechanical and low velocity impact properties," *Polymers*, vol. 12, no. 6, Art no. 1285, 2020, doi: 10.3390/POLYM12061285.

[28] H. Hojo, H. Yaguchi, T. Onodera, and E. G. Kim, " Simulation of compression molding with matrix-fibre separation and fibre orientation for long fibre-

reinforced thermoplastics," *International Polymer Processing*, vol. 3, no. 1, pp. 54–61, Mar. 2022, doi: 10.1515/ipp-1988-0005.
[29] I. Papa, A. T. Silvestri, M. R. Ricciardi, V. Lopresto, and A. Squillace, " Effect of fibre orientation on novel continuous 3D-printed fibre-reinforced composites," *Polymers*, vol. 13, no. 15, Art no. 2524, Jul. 2021, doi: 10.3390/polym13152524.
[30] M. R. M. Asyraf, M. Rafidah, A. Azrina, and M. R. Razman, "Dynamic mechanical behaviour of kenaf cellulosic fibre biocomposites: a comprehensive review on chemical treatments," *Cellulose*, vol. 28, no. 5, pp. 2675–2695, Mar. 2021, doi: 10.1007/s10570-021-03710-3.
[31] C. C. Austin, C. N. Mondell, D. G. Clark, and A. C. Wilkie, " Kenaf: Opportunities for an ancient fiber crop," *Agronomy*, vol. 14, no. 7, Art no. 1542, Jul. 2024, doi: 10.3390/agronomy14071542.
[32] C. Li, Y. Liu, and Z. Chen, " Study of mechanical properties of micron polystyrene-toughened epoxy resin," *Applied Sciences*, vol. 13, no. 6, Art no. 3981, Mar. 2023, doi: 10.3390/app13063981.
[33] T. L. Saaty, "How to make a decision: The analytic hierarchy process," *European Journal of Operational Research*, vol. 48, no. 1, pp. 9–26, Sep. 1990, doi: 10.1016/0377-2217(90)900 57-I.
[34] S. M. Sapuan, J. Y. Kho, E. S. Zainudin, Z. Leman, B. A. Ahmed Ali, and A. Hambali, " Materials selection for natural fiber reinforced polymer composites using Analytical Hierarchy Process," *Indian Journal of Engineering & Materials Sciences*, vol. 18, no. 4, pp. 255–267, 2011.
[35] Y. Huang, M. Sultan, A. Łukaszewicz, F. Shahar, and Z. Oksiuta, " AHP-based evaluation of hybrid kenaf/flax/glass fiber-reinforced biocomposites for unmanned maritime vehicle applications," *Materials*, vol. 18, no. 16, Art no. 3731, Aug. 2025, doi: 10.3390/ma18163731.
[36] M. AlMuhanna and B. AlMangour, "Effect of building orientation and fibre type on the mechanical behaviour of additively manufactured ABS matrix composites," *Materials Research Innovations*, vol. 27, no. 7, pp. 482–489, Nov. 2023, doi: 10.1080/14328917 .2023.2196480.
[37] K. Bajaj and R. V. Rao, "Correlating weight assignment and ranking approaches: the versatility of the best holistic adaptable ranking of attributes technique," *International Journal of Mechatronics and Manufacturing Systems*, vol. 18, no. 2, pp. 134–159, 2025, doi: 10.1504/ IJMMS.2025.150080.
[38] N. T. Mai, "Implementation of an enhanced criterion weighting method based on standard deviation in multi -criteria decision-making," *EUREKA: Physics and Engineering*, no. 2, pp. 129–139, Feb. 2026, doi: 10.21303/2461-4262.2026.003983.
[39] H. Hassanijajini, Z. Hassanimohebi, and M. Gardoni, " Preparation of archi-TRIZ matrix for accelerating innovation in building design process," *International Journal of Design Management and Professional Practice.*, vol. 19, no. 1, pp. 35–53, 2024, doi: 10.18848/2325-162X/CGP/v19i01/35-53.
[40] S. N. H. Mazlan, A. Z. Abdul Kadir, M. Deja, D. Zieliński, and M. R. Alkahari, " Development of technical creativity featuring modified TRIZ-AM inventive principle to support additive manufacturing," *Journal of Mechanical Design*, vol. 144, no. 5, May 2022, doi: 10.1115/1.405 2758.
[41] A. Verma, P. Singh, H. Fatina, and H. Sharma, " Fundamentals of composite materials," in *Hybrid Materials and Advanced Manufacturing*, Boca Raton, FL, USA: CRC Press, 2025, pp. 1–22. doi: 10.1201/9781003607359-1.
[42] U. Maurya, J. S. Chordiya, and V. Saini, " Atomic-scale interface of matrix and reinforcement for tribological applications," in *Micro- and Nanocomposites*, Boca Raton, FL, USA: CRC Press, 2025, pp. 17–40. doi: 10.1201/ 9781003530909-3.
[43] M. M. Owen et al., " Improved thermal and mechanical properties of kenaf fiber/ABS polymer composites via resin coating treatment," *Pertanika Journal of Science and Technology*, vol. 31, no. S1, pp. 39–57, 2023, doi: 10.47836/pjst.31.S1.03.
[44] S. Mashelmie, M. Rabiatul Manisah, N. Bahiyah Baba, and A. Mohd, "The effect of kenaf loading on kenaf/ABS composites structure and thermal properties," *Journal of Achievements in Materials and Manufacturing Engineering*, vol. 111, no. 2, pp. 49–56, 2022, doi: 10.5604/01. 3001.0015.9994.
[45] Z. Ali, Y. Yan, H. Mei, L. Cheng, and L. Zhang, "Impact of fiber-type and autoclave-treatment at different temperatures on the mechanical properties and interface performance of various fiber-reinforced-printed composites," *Polymer*

Composites, vol. 44, no. 6, pp. 3232–3244, Jun. 2023, doi: 10.1002/pc.27314.

[46] I. Milosan, T. Bedo, C. Gabor, and M. A. Pop, " Mechanical characteristics of glass-fiber-reinforced polyester composite materials," *Materials*, vol. 18, no. 15, Art no. 3595, Jul. 2025, doi: 10.3390/ma18153595.

[47] A. F. M. Nor, M. T. H. Sultan, A. Hamdan, A. M. R. Azmi, and K. Jayakrisna, " Hybrid composites based on kenaf, jute, fiberglass woven fabrics: Tensile and impact properties," *Materials Today: Proceedings*, vol. 5, no. 5, pp. 11198–11207, 2018, doi: 10.1016/j.matpr.2018.01.144.

[48] N. A. Mohd Radzuan et al., " Kenaf composites for automotive components: Enhancement in machinability and moldability," *Polymers*, vol. 11, no. 10, Art no. 1707, Oct. 2019, doi: 10.3390/polym11101707.

[49] P. Domone and J. Illston, "Analysis of the behaviour of polymer composites," in *Construction Materials*, 5th ed. London, UK: CRC Press, 2018, pp. 328–337. doi: 10.1201/9781315272436-48.

[50] V. N. Sukumaar, S. M. Rangappa, Y. Liu, and S. Siengchin, "A comprehensive review on the influence of fused deposition modelling process parameters upon thermoplastic composite materials," *Advanced Industrial and Engineering Polymer Research*, vol. 9, no. 2, pp. 281–303, Apr. 2026, doi: 10.1016/j.aiepr.2025.11.006.

[51] Q. Zu, M. Solvang, and H. Li, " Commercial glass fibers," in *Fiberglass Science and Technology*, Cham, Switzerland: Springer, 2021, pp. 1–87. doi: 10.1007/978-3-030-72200-51.

[52] J. T. Orasugh, S. Roy, S. S. Ray, and D. Chattopadhyay, "Glass fibres – Production, structure, and applications," in *Technical Organic and Inorganic Fibres from Natural Resources*, Amsterdam, Netherlands: Elsevier, 2025, pp. 491–525. doi: 10.1016/B978-0-443-15459-1.00027-9.

[53] P. Jagadeesh, S. M. Rangappa, and S. Siengchin, "Basalt fibers: An environmentally acceptable and sustainable green material for polymer composites," *Construction Building Materials*, vol. 436, Art no. 136834, Jul. 2024, doi: 10.1016/j.conbuildmat.2024.136834.

[54] B. Chidambaranathan, S. Raghavan, G. Soundararajan, S. Arunkumar, R. Ashok Kumar, and K. Rajesh, " Review of mechanical properties of basalt fibre-reinforced polymer composites for automotive applications," *Society of Automotive Engineers Technical Paper Series*, Art no. 2024-01-5246, Jan. 2025. doi: 10.4271/2024-01-5246.

[55] N. Kretzschmar and S. Chekurov, " The applicability of the 40 TRIZ principles in design for additive manufacturing," in *Proceedings of the 29th DAAAM International Symposium*, 2018, pp. 0888–0893. doi: 10.2507/29th.daaam.proceedings.128.

[56] R. Murugan, R. Ramesh, and K. Padmanabhan, " Influence of stacking sequence on mechanical properties and vibration characteristics of glass/carbon hybrid plates with different fabric areal densities," in *Lecture Notes in Mechanical Engineering*, Cham, Switzerland: Springer, 2020, pp. 87–97. doi: 10.1007/978-981-13-8767-87.

[57] J. Sayyed, A. Ramprasad, and Y. Pai, "Effect of mesh sizes on the mechanical properties of stainless-steel wire mesh/glass fiber reinforced hybrid composite laminates for aerospace applications," *Scientific Reports*, vol. 15, no. 1, Art no. 36080, Oct. 2025, doi: 10.1038/s41598-025-20038-1.

[58] S. Cai, S. Yan, L. Jiang, Z. Meng, and Y. Niu, " Compressive failure mechanisms of NCF laminates with double-hole defects," *Materials*, vol. 19, no. 3, Art no. 495, Jan. 2026, doi: 10.3390/ma19030495.

[59] M. R. M. Asyraf, M. R. Ishak, S. M. Sapuan, and N. Yidris, "Influence of additional bracing arms as reinforcement members in wooden timber cross-arms on their long-term creep responses and properties," *Applied Sciences*, vol. 11, no. 5, Art no. 2061, Feb. 2021, doi: 10.3390/app1105 2061.