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A Hybrid AHP-MOORA Framework for Strategic Sustainable Selection Of High-Performance Biocomposites in Lightweight Automotive Strut Bar Applications for Electric Vehicles (EV)

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ABSTRACT

The transition to sustainable transportation has accelerated the search for alternative lightweight and environmentally friendly materials in the electric vehicle (EV) industry. This study introduces a hybrid Analytical Hierarchy Process-Multi-Objective Optimisation on the Basis of Ratio Analysis (AHP-MOORA) framework for strategic selection of high-performance natural fiber biocomposites in EV Strut Bar applications. The proposed methodology combines expert-based weighting of selection criteria using AHP with the computational ranking efficiency of MOORA, resulting in a balanced, objective material decision process. A detailed Product Design Specification (PDS) is developed, considering key attributes such as mechanical strength, stiffness, corrosion resistance, sustainability, weight, availability, and cost. The hybrid framework was used to evaluate fourteen natural fiber alternatives. The results revealed that coir fiber provides the best balance of performance, affordability, and sustainability, making it the top candidate. Kenaf, oil palm, and flax fibers followed closely, all with competitive profiles. In contrast, fibers such as sisal and ramie, while mechanically promising, were ranked lower due to cost and availability issues. The study confirms the AHP-MOORA method's robustness and applicability in complex material selection problems involving multiple, often conflicting criteria. This framework also provides a scalable, replicable model for long-term material innovation, primarily in automotive applications. The study supports the widespread use of biocomposites and demonstrates their viability in structural EV components, providing both environmental and engineering benefits.

Keywords: Biocomposites; AHP-MOORA; natural fiber; EV strut bar; sustainable materials

INTRODUCTION

The growing demand for sustainable materials in the automotive industry has led to the exploration of biocomposites as alternatives to traditional materials, especially for Electric Vehicles (EVs). Automotive strut bars, which play a crucial role in maintaining vehicle stability and structural integrity, are typically made from materials such as aluminum and steel (Mansor et al. 2024). However, the environmental impact and the high energy costs associated with these materials have prompted the need for more eco-friendly substitutes (Asmawa et al. 2020; Agarwal et al. 2020). Biocomposites, made from renewable natural fibers and biodegradable matrices, have emerged as a promising alternative due to their low environmental footprint, lightweight properties, and potential for high-performance applications (Girijappa et al. 2019).

Natural fibers (NF) are broadly divided into three types: plant-based, animal-based, and mineral-based fibers (Aaliya et al. 2021). Plant-derived fibers come from a wide variety of agricultural materials (Rowell, 2014; Li et al. 2010). Animal fibers include wool, hair, silk, and feathers,

whereas mineral fibers primarily include asbestos and glass fiber (Joshi et al. 2004). Among these categories, plant-based natural fibers have received the most research attention in recent years (Sathyamurthy et al. 2013). Natural Fiber Composites (NFCs) with plant-based reinforcements have been extensively studied for biodegradability, ecotoxicity, recyclability, and mechanical performance (Sari et al. 2020; Omkumar et al. 2017; Sanadi et al. 1995). Their applicability has been well documented in a variety of industries, including advanced manufacturing, sustainable food packaging, and lightweight automotive engineering.

The renewed scientific and industrial interest in plant-based NFCs is primarily motivated by their renewable nature, widespread availability, and favourable environmental profile (Turayev et al. 2021). Compared to traditional mineral and synthetic fiber-reinforced composites, NFCs have higher sustainability and lower environmental impact, making them promising candidates for next-generation green composite materials (Alves et al. 2010). In the context of EV, the need for lightweight, high-performance materials is even more critical, as reducing vehicle weight directly improves energy efficiency and range (Asmawa et al. 2020; Sanadi et al. 1995; Czerwinski, 2021). Selecting the most appropriate biocomposite material for automotive strut bars in EVs is a complex decision that involves multiple criteria, such as mechanical strength, cost, sustainability, and ease of manufacturing (Witik et al. 2011). Traditional decision-making methods often fall short in addressing the multi-criteria nature of material selection.

To address this challenge, this study proposes a hybrid decision-making framework that combines the Analytical Hierarchy Process (AHP) and Multi-Objective Optimization on basis of Ratio Analysis (MOORA). AHP is utilized to prioritize the selection criteria based on expert judgment, while MOORA is employed to rank the biocomposite alternatives based on their proximity ranking. This research aims to develop a systematic decision-support framework for the preliminary selection of suitable natural fiber reinforcements for biocomposites EV strut bar applications. The proposed hybrid AHP–MOORA approach focuses on evaluating candidate materials during the conceptual design stage, where multiple criteria such as mechanical performance, cost, weight, sustainability, and availability must be simultaneously considered. Focusing on the balance between Performance (Strength and Stiffness), Cost (availability and price), Weight, Corrosion and Sustainability obtained by Product Design Specification (PDS). The findings of this study are expected to contribute to the development of more sustainable automotive components and promote the adoption of biocomposites in the EV manufacturing industry.

PRODUCT DESIGN SPECIFICATIONS (PDS)

The composite strut bar is a critical structural reinforcement in automotive design, connecting strut towers to reduce chassis flex. It utilises advanced composite materials to provide superior stiffness-to-weight ratio, thereby improving vehicle handling dynamics, structural integrity, and overall performance, particularly in lightweight and high-efficiency automotive applications such as electric vehicles.

In this research, the Product Design Specification (PDS) framework was used as a foundational tool to systematically establish the necessary criteria for selecting appropriate natural fiber-reinforced composite materials for use in lightweight automotive strut bar applications (Czerwinski, 2021). The PDS outlines the functional, structural, environmental, and manufacturing requirements that the chosen material must meet to ensure alignment with the component's performance objectives. The PDS considers mechanical strength, stiffness, weight, environmental impact and cost-effectiveness with existing processing techniques (Idral et al, 2025). By clearly defining these parameters, the PDS makes material selection more focused, and purpose as shown in Figure 1.

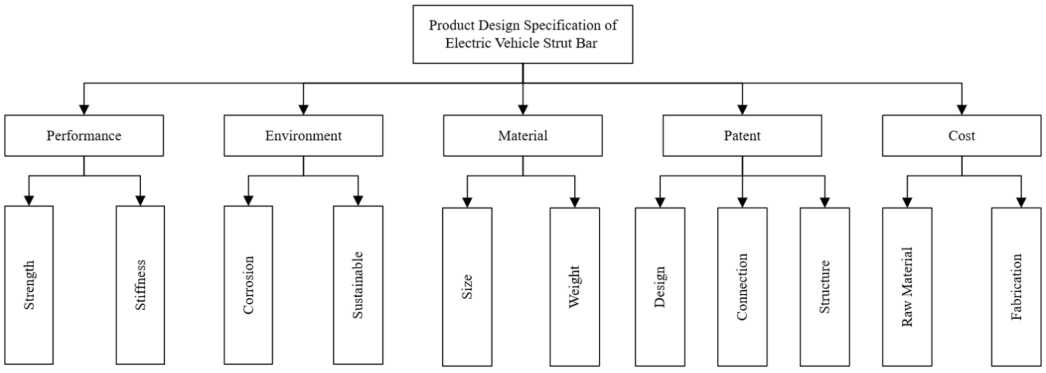


FIGURE 1. Product Design Specification of Electric Vehicle Strut Bar

By incorporating PDS in the early stages of material evaluation, this study ensures that all shortlisted natural fibers not only meet technical specifications but also support sustainable design goals, particularly in the context of Electric Vehicle (EV) applications. The systematic identification of material selection criteria using PDS provides a solid foundation for the subsequent use of Multi-Criteria Decision-Making (MCDM) methods, such as the AHP-MOORA hybrid approach, to rank and prioritise the best biocomposite alternatives. This structured methodology improves the reliability and traceability of the decision-making process, thereby contributing to the development of high-performance, environmentally responsible automotive components.

To make it easier to find a suitable natural fiber, a set of well-defined material selection criteria must be developed. These criteria, based on the PDS, provide a systematic framework for objectively evaluating candidate NF. By aligning the selection process with key functional and performance-driven attributes, the PDS ensures a structured and rational approach to determining the best natural fiber for the intended application. Table 1 descript decision criteria used in the AHP analysis based on EV strut bar Product Design Specifications.

TABLE 1. Decision Criteria Used in The AHP Analysis Based on EV Strut Bar Product Design Specifications

Main criteria	Sub-criteria	Description	Reference
Performance	Strength	The ability of the composite to withstand high loads without failure, ensuring safety under dynamic stress conditions	(Hu et al. 2011; Okubo et al. 2004)
	Stiffness	The resistance of the composite to deformation, maintaining structural shape and stability under applied force	(Okubo et al. 2004; Deka et. al 2013)
Environment	Corrosion	A moisture-sensitive component that increases water absorption and corrosion risk in biocomposites.	(Rowell, 2014)
	Sustainability	A hydrophobic, UV-resistant biopolymer that enhances durability and sustainability in natural fiber composites.	(Deka et. al 2013)
Material	Weight	A critical factor influencing vehicle efficiency, where lower composite weight contributes to improved fuel economy and extended EV range	(Ku et al. 2011)
Cost	Availability	Readily available raw materials support scalable production and supply chain stability	(Al-Oqla & Salit, 2017)
	Price	A cost-effective material ensures commercial viability without compromising performance.	(Alibaba.com, 2025)

DEVELOPMENT AHP HIERARCHICAL FRAMEWORK

The development of an AHP hierarchy framework is critical for organising the complex decision-making process involved in choosing natural fiber materials for EV strut bar applications. By systematically breaking down the selection problem into a multi-level hierarchy that includes the overall goal, evaluation criteria, and potential alternatives, AHP allows for objective prioritisation via pairwise comparisons and consistency checks (Al-Oqla & Salit, 2017). This method facilitates the integration of both qualitative and quantitative factors, allowing for precise weighting of each criterion. The resulting framework serves as a solid foundation for hybrid MCDM analysis, ensuring a clear, traceable, and rational path to determining the best natural fiber (Sapuan et al. 2011).

The first step in using the Analytic Hierarchy Process (AHP) method for this project is to create a hierarchical AHP framework. This structured framework clearly depicts the relationship between the overall project goal, its associated criteria, and alternatives (Mansor et al. 2013). The AHP hierarchy is typically represented as a tree-like diagram with multiple levels. Level 1 defines the project's primary objective. Level 2 outlines the main criteria that influence the achievement of this goal, while Level 3 identifies potential alternatives that align with the criteria to aid decision-making. Although the standard AHP hierarchy has three levels, it can be expanded—for example, by adding a sub-criteria level. However, such expansions may complicate the analysis and take longer to complete.

In this study, a four-level AHP framework was built using elements of the Product Design Specification (PDS) identified in earlier stages. At Level 1, the project's goal is to choose the best natural fiber to combine with glass fiber reinforced polymer composite for use in an electric vehicle strut bar. Level 2 includes four major criteria: performance, environment, material, and cost. Level 3 delves deeper into the sub-criteria that are relevant to these

main criteria, including strength, stiffness, corrosion resistance, sustainability, weight, availability, and price. Finally, Level 4 suggests fourteen natural fiber candidates for selection. The interconnections between these levels are represented by lines in the hierarchical diagram, which show the dependencies and relationships between the components. Figure 2 depicts the entire hierarchical framework for this decision-making problem, while Table 1 describes the criteria used in the AHP analysis, which were derived from the PDS for the electric vehicle strut bar.

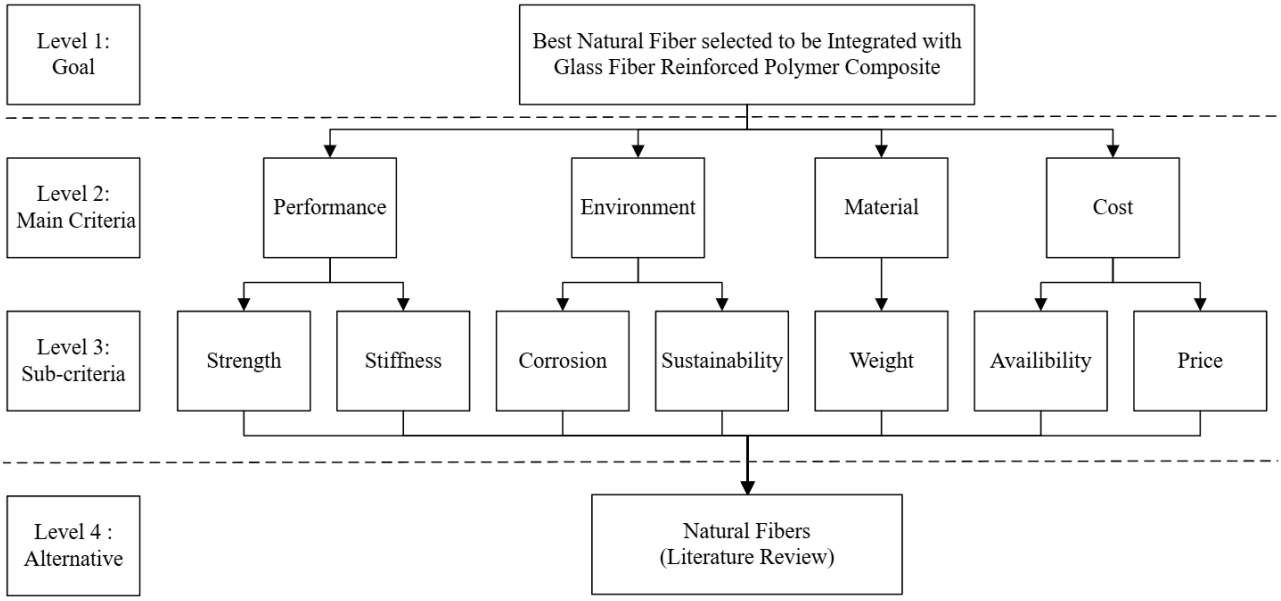


FIGURE 2. AHP Hierarchy Framework for Natural Fiber for Electric Vehicle Strut Bar

METHODOLOGY

A critical aspect of this research is the thorough examination of existing literature on the structural design and functional performance of automotive EV strut bars. The objective of this methodology is to support early-stage material screening in engineering design, where potential candidate materials are identified before detailed structural validation is conducted. Figure 3 show the EV strut bar as prior research, while valuable, has primarily focused on conventional metallic designs and standard geometric configurations, frequently overlooking the changing material paradigm driven by sustainability imperatives. For example, a 2023 study that used experimental and failure-mode simulation found that a traditional horizontal strut bar design failed under a peak load of 7500 N (Mansor et al. 2024; Mironenko et al. 2018). However, such research rarely examines the potential of advanced alternative materials. In this context, the transition from metallic constituents to bio-based composites particularly those reinforced with natural fibers stands out as a strategically significant frontier.



FIGURE 3. Electric Vehicle Strut Bar

Biocomposites provide superior specific strength, inherent damping capabilities, and significant weight reduction, all of which contribute to improved chassis efficiency and increased electric vehicle (EV) driving range (Calvalho et al. 2024; Kangishwar et al. 2023). Furthermore, the use of renewable, biodegradable resources is consistent with broader environmental and circular economy goals (Vieyra et al. 202). Integrating such materials into strut bar architecture not only meets structural requirements but also contributes to the next-generation design philosophy of lightweight, energy-efficient, and environmentally

responsible mobility (Zhang & Xu 2022, Salve & Mache 2023). Beyond material substitution, the literature emphasises the importance of comparative studies across various vehicle platforms and operational scenarios, reinforcing the significance of this research in closing current knowledge gaps and shaping future material innovation for EV structural systems (Hancock 2024).

OVERALL MATERIAL SELECTION METHODOLOGY USING AHP-MOORA

The selection process utilizing the AHP-MOORA method is thoroughly illustrated in FIGURE 4. This framework provides a clear and systematic overview of the sequential steps required to identify the most Suitable natural fiber, effectively demonstrating the operational flow of the hybrid decision-making approach.

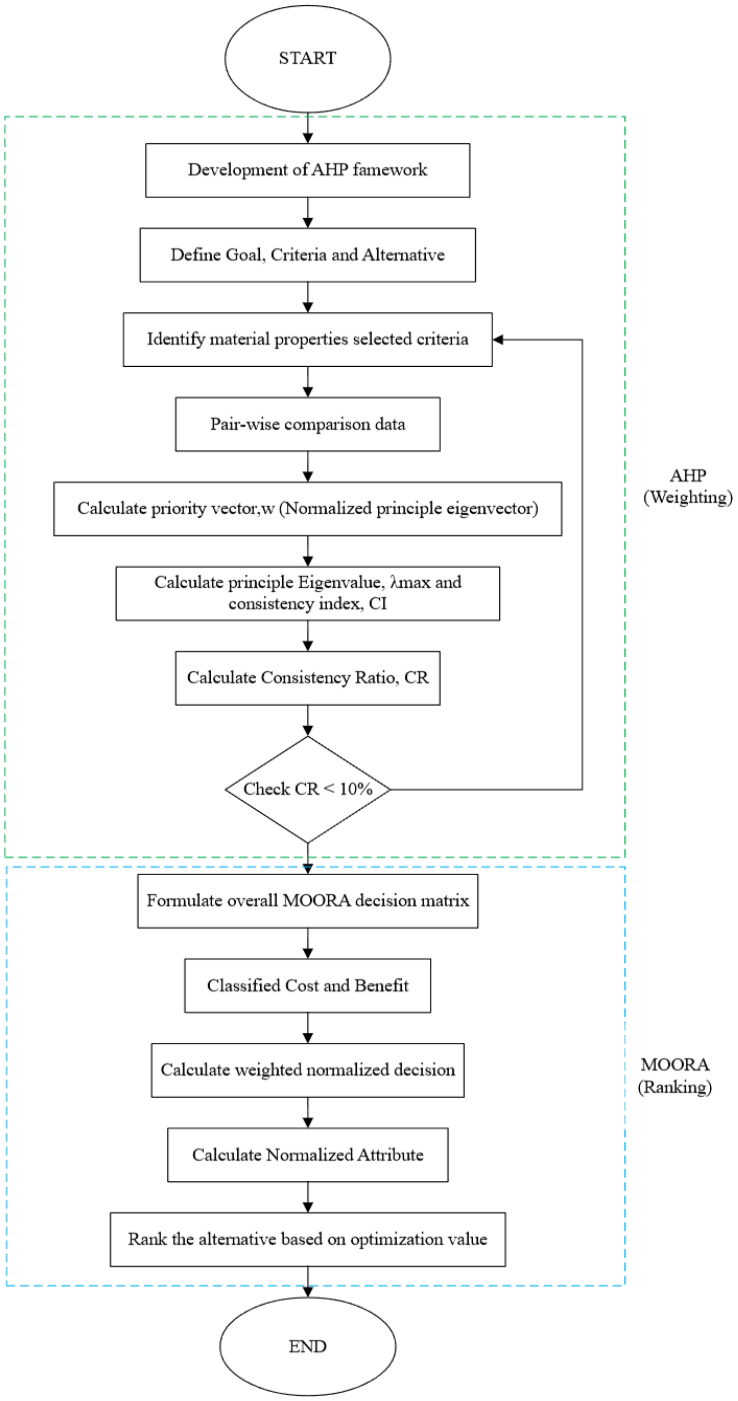


FIGURE 4. AHP-MOORA Methodology for Material Selection

AHP-MOORA METHOD

The comparison of AHP-MOORA with other hybrid MCDM methods reveals several advantages that justify its use in this study. By using AHP for weight derivation, the framework benefits from a structured pairwise comparison approach, allowing for consistent and rational prioritisation of evaluation criteria based on expert feedback. Unlike more complex hybrid models like Analytic Hierarchy Process (AHP) – VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) or Fuzzy Analytic Hierarchy Process (FAHP) – Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), AHP-MOORA is computationally simple yet produces reliable results. MOORA's simple ratio-based ranking mechanism also enables efficient decision-making without the use of iterative or fuzzy calculations, making it more transparent and interpretable (Brauers et al. 2008). Although fuzzy logic approaches handle uncertainty better, they frequently require more complex formulations, which may limit their usefulness in engineering-based material selection (Karande & Chakroborty 2012). AHP-MOORA provides a balanced methodology for selecting the best natural fiber for biocomposite EV strut bars, which must address multiple criteria such as mechanical performance, weight, cost, and sustainability. It ensures computational efficiency, clear ranking, and suitability for multi-attribute engineering problems, particularly those involving sustainable material innovation (Patnaik et al. 2020; Mitra 2021).

The Table 2. below compares the AHP-MOORA method with other commonly used hybrid MCDM techniques in the context of selecting natural fiber materials for EV strut bar applications. Key criteria include computational complexity, ease of use, transparency, and overall suitability for sustainability-driven design decisions.

TABLE 2. Comparison AHP-MOORA with Other Hybrid Multi Criteria Decision Making.

Criteria	AHP-MOORA (Patnaik et al. 2020)	AHP-TOPSIS (Mansor et al. 2014; Vern et al. 2025)	AHP-VIKOR (Shaharuzaman et al. 2018; Rao, 2008)	FAHP-TOPSIS (Gupta et al. 2025)
Computational Complexity	Low – simple normalization and ratio-based evaluation	Moderate – requires distance from ideal solutions	High – involves interdependencies and compromise	High – uses fuzzy logic and ideal distance calculations
Ease of Use	High – easy to implement and understand	Moderate – requires understanding of distances	Low – complex network structure	Low – fuzzy logic adds complexity
Transparency & Traceability	High – clear and traceable steps	Moderate – closeness coefficient interpretation needed	Low – complex matrix operations	Low – fuzzy computations reduce clarity
Weighting Method	AHP – pairwise comparison-based	AHP – same as MOORA	ANP – handles interdependence	Fuzzy AHP – manages uncertainty
Suitability for Natural Fiber Selection	Very suitable – balances sustainability and performance	Suitable – but harder to communicate	Less suitable – overly complex	Suitable – only with high uncertainty
Computation Time	Fast	Moderate	Slow	Slow
Preferred for Sustainability-focused Studies	Yes	Possible	Not ideal	Possible – if uncertainty is high

MATERIAL CONSTRAINS FOR NATURAL FIBER

The material property data presented in Table 3 were compiled from multiple peer-reviewed literature sources reporting the mechanical, chemical, and economic characteristics of natural fibers. Due to the inherent variability of natural fibers, these properties may differ depending on factors such as plant origin, extraction method, fiber treatment, and testing standards. To enable meaningful comparison across different datasets, the study applied vector normalisation within the MOORA method, which standardises the magnitude of each parameter prior to evaluation. This approach reduces the influence of differences in units, scales, and experimental conditions reported in the literature, allowing the materials to be compared within a unified decision-making framework. Nevertheless, it should be acknowledged that variability in natural fiber properties remains an inherent limitation of literature-based material selection studies, and further experimental verification is recommended for future work.

The comprehensive Table 3 compares 14 different natural fibers based on a variety of mechanical, chemical,

and economic parameters, providing useful information for selecting the best candidate for biocomposite strut bar applications in electric vehicles (EVs). Mechanically, flax, hemp, and kenaf have exceptional tensile strength (up to 1500 MPa for flax and kenaf) and high Young's modulus values, indicating excellent strength and stiffness properties essential for structural automotive components. In contrast, fibers such as coir and oil palm have significantly lower tensile properties, implying that they are only Suitable for high-stress applications if hybridised (Bawono et al. 2025).

Most fibers have a lightweight density of 0.7-1.6 g/cm³, supporting weight reduction goals in electric vehicle design. Ramie and pineapple leaf fiber (PALF) exhibit superior stiffness (up to 128 GPa) and moderate elongation, making them promise for achieving a balance of rigidity and flexibility. Chemically, fibers with high cellulose content, such as cotton, ramie, and PALF, are expected to have greater mechanical integrity and compatibility with polymer matrices. Meanwhile, hemicellulose and lignin content influence biodegradability and moisture sensitivity; for example, coir and kenaf, which contain more lignin, may have better resistance to microbial degradation and dimensional stability (Bettini et al. 2010).

Banana, sisal, and jute rank high in terms of availability and cost because of their abundance and low material costs. However, despite their excellent properties, flax and hemp may have higher processing costs or regulatory limitations in certain regions. Overall, this table serves as a critical screening tool, allowing for a multi-criteria evaluation that considers mechanical performance, sustainability (via chemical composition), and practical considerations like economic viability and supply chain accessibility as shown in Table 3.

TABLE 3. Natural Fibers Selection Material Properties

Fiber	Density (g/cm³)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Availability (n/a)	Material Cost (n/a)	Ref
Abaca	0.83-1.3	650-780	29-32	2-4	56-63	15-25	7-9	8	2	(Munawar et al. 2007; Kumar et al. 2018)
Banana	1.3-1.35	355-754	7.7-33.8	5.3	60-65	19	5-10	9	1	(Zhang et al. 2018; Subagyo & Chafidz, 2018)
Bamboo	0.91	262	9.8	2.7	26-74	12-31	10-37	8	3	(Okubo et al.; Zhang et al. 2018)
Coir	0.87-1.2	95-593	4-6	4-47	32-43	0.12-0.25	40-45	8	3	(Munawar et al. 2007; Goyat et al. 2022)
Cotton	1.5-1.54	200-800	5.5-13	3-10	82.7-90	5.7	6-21	8	2	(Marcel et al. 2019; Westmen et al. 2012; Asim et al. 2015)
Flax	1.5	1500	27.6	3.2	71	18.6-20.6	2.2	4	6	(Ku et al. 2022)
Hemp	1.47	690	70	4	57-77	14-22.4	3.7-13	3	7	(Ku et al. 2022)
Jute	1.3-1.46	393-900	10-55	1.5-1.8	45-71.6	13.6-21	21-26	4	6	(Munawar et al. 2007)
Kenaf	1.31-1.5	930-1500	23-53	1.6-7.3	31-57	20-34	21.2	6	4	(Bharat et al. 2015)
Oil Palm	0.7-1.55	248	3.2	25	65	14.94	29	8	4	(Mastura et al. 2017; Khalil et al. 2008
Pineapple	1.32-1.54	400-627	34-82	0.8-27	81	9.45-18.8	12.7	7	3	(Asim et al. 2015)
Ramie	1.38-1.6	400-1000	44-128	2-3.8	68.6-91	5-16.7	0.6-0.7	7	4	(Zhang et al. 2018; Marcel et al. 2019)
Sisal	0.76-1.58	274-855	9-38	2-7	47-78	10-24	7-11	1	9	(Munawar et al. 2007)
Sugar Palm	1.22-1.26	276.6	5.9	22.3	52.3	13.3	31.5	7	3	(Noryani et al. 2018)

RESULT AND DISCUSSION

The quantitative values for each natural fiber will be transformed into pair-wise comparisons based on the TABLE 3 data. This transformation allows for a systematic evaluation of each fiber's relative performance across multiple criteria. The evaluation process employs a priority-based scale within the pairwise comparison analysis in Table 4, allowing for the consistent derivation of weights that reflect the importance of each attribute in material selection.

TABLE 4. Pair-wise Comparison Evaluation Value

Relative Intensity/Score	Definition	Explanation
1	Equal value	Those two requirements are same value
3	Slightly more value	Difference slightly favors one requirement over another
5	Essential or strong value	Different strongly favor one requirement over another
7	Very strong value	A requirement is strongly favored, and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another of the highest possible order affirmation
2,4,6,8	Intermediate value between two adjacent judgements	When compromise is needed
Reciprocal	Reciprocal for inverse comparison	

These pairwise comparisons are then organised into a judgement matrix using the Analytic Hierarchy Process (AHP) as shown in TABLE 5. Each criterion such as tensile strength, density, cellulose content, and material cost compared to others on a fundamental scale to determine its significance in the context of biocomposite application for EV strut bars.

The pairwise comparison matrix used in the AHP analysis was developed based on literature-supported engineering judgement rather than direct expert surveys. The relative importance of the selection criteria was established by synthesising findings from previous studies on natural fiber composites and automotive material selection, where mechanical performance, weight reduction, sustainability, availability, and cost are commonly identified as critical design considerations.

This literature-driven approach allows the decision framework to reflect widely accepted engineering priorities reported in the existing body of research. To verify the reliability of the constructed judgement matrix, a consistency analysis was conducted using the Consistency Ratio (CR). The calculated CR value of 0.0249 is significantly below the acceptable threshold of 0.1, indicating that the pairwise comparisons are consistent and suitable for the material selection process (Sapuan et al. 2011; Al-Oqla & Salit 2017).

TABLE 5. AHP ANALYSIS (Pair-wise Comparison Matrix for Natural Fiber Selection)

Factor	Strength	Stiffness	Corrosion	Sustainability	Weight	Availability	Price
Strength	1.00	2.00	6.00	4.00	3.00	7.00	5.00
Stiffness	0.50	1.00	5.00	3.00	2.00	6.00	4.00
Corrosion	0.17	0.20	1.00	0.33	0.25	2.00	0.50
Sustainability	0.25	0.33	3.00	1.00	0.50	4.00	2.00
Weight	0.33	0.50	4.00	2.00	1.00	5.00	3.00
Availability	0.14	0.17	0.50	0.25	0.20	1.00	0.33
Price	0.20	0.25	2.00	0.50	0.33	3.00	1.00

The AHP analysis begins by converting all pairwise comparison data into a structured matrix format, which is then normalised and computed to yield the priority vector, denoted as w. To begin, pairwise comparison matrices created for each element at the lower levels of the hierarchy. Each matrix corresponds to a specific criterion from the level directly above it. Reciprocal values are assigned automatically to ensure consistency in comparisons as shown in TABLE 6. It is derived using Equation (1) as shown below:

$$A=(a_{ij})_{n\times n}=\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 1 \end{bmatrix} \quad (1)$$

where a_{ij} = 1/k is the reciprocal value of the scale of importance, $a_{ij} = k$ and $i;j = 1, 2, \ldots, n$.

TABLE 6. Priority Vector AHP Analysis (Normalize Matrix for Natural Fiber Criteria Selection)

Criteria	Strength	Stiffness	Corrosion	Sustainability	Weight	Availability	Price
Strength	0.385675	0.4494	0.2791	0.3609	0.4119	0.2500	0.3158
Stiffness	0.192837	0.2247	0.2326	0.2707	0.2746	0.2143	0.2526
Corrosion	0.064279	0.0449	0.0465	0.0301	0.0343	0.0714	0.0316
Sustainability	0.096419	0.0749	0.1395	0.0902	0.0686	0.1429	0.1263
Weight	0.128558	0.1124	0.1860	0.1805	0.1373	0.1786	0.1895
Availability	0.055096	0.0375	0.0233	0.0226	0.0275	0.0357	0.0211
Price	0.077135	0.0562	0.0930	0.0451	0.0458	0.1071	0.0632

Once these matrices are established, hierarchical synthesis is carried out, with the eigenvectors weighted based on the relative importance of their respective criteria. The final priority vector is calculated by adding the weighted eigenvector components from across the hierarchy. The resulting priority vector, w in Table 7 reflects the relative significance of each alternative and can be obtained using the eigenvalue method defined by the following equation:

$$w = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{i=1}^{a} a}, i,j = 1,2,\ldots,n \quad (2)$$

where w is the priority vector (or eigenvector), a_{ij} is the importance scale, i.e. 1,2, …, and n is the number of criteria.

TABLE 7. AHP Weightage (Priority Vector) for Natural Fiber Selection

Criteria	Strength	Stiffness	Corrosion	Sustainability	Weight	Availability	Price
Weightage	0.3504	0.2375	0.0462	0.1056	0.1590	0.0318	0.0696

According to the pairwise comparison and normalisation process, the most influential factors were Strength (0.3504) and Stiffness (0.2375). In contrast, Availability (0.0318) and Corrosion (0.0462) were the least significant. These weightages reflect the importance of mechanical performance when selecting the best natural fiber for EV strut bar applications. Figure 5 illustrates the outcome for quick understanding.

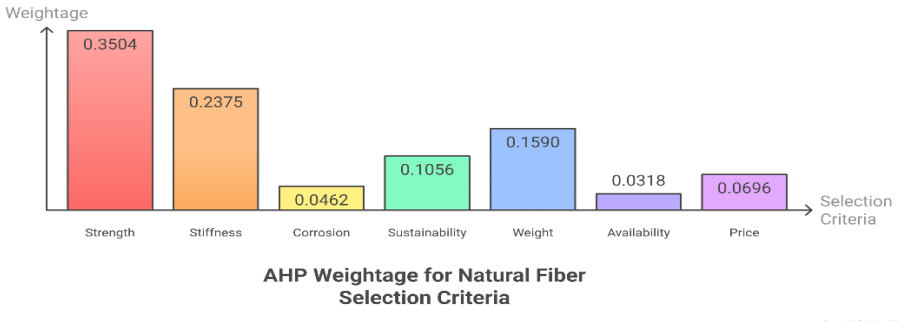


FIGURE 5. Weightage Created by AHP

To ensure the reliability and consistency of the AHP results, a Consistency Index (CI) and Consistency Ratio (CR) were calculated to evaluate the coherence of the pairwise comparisons, as shown in Table 8. The comparison matrix's principal eigenvalue (λ_{max}) has been determined.

$$\lambda_{max} = \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} \times w_j}{w_i} \quad (3)$$

where $i, j = 1, 2, \ldots, n$.

The formula for Consistency Index is:

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

This is a ratio of the Consistency Index (CI) to the Random Consistency Index (RI). The formula for CR is:

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

TABLE 8. Principle Eigenvalue, λ_{max}, Consistency Index, *CI*, and Consistency Ratio, *CR* for Natural Fiber

Principle Eigenvalue, λ_{max}	7.197278
Consistency Index, *CI*	0.03288
Consistency Ration, *CR*	0.024909

Based on the criteria Table 9, the optimisation direction differentiates between benefit and cost attributes to guide the material selection process. Strength, stiffness, corrosion resistance, sustainability, and availability are classified as benefit criteria, with higher values indicating a direct positive impact on the structural integrity, environmental performance, and supply consistency of the EV strut bar. Weight and price, on the other hand, are treated as cost criteria, with lower values preferred to improve vehicle energy efficiency and reduce production costs. This clear separation is required for accurate normalisation and ranking within MOORA, ensuring that each criterion makes an appropriate contribution to the final decision result.

The normalized response of *i*th alternative with respect to *j*th objective *(x*ij)* is calculated according to equation (5), as shown below:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} X_y^2}} \quad (6)$$

TABLE 9. Clasification of The Benefit Criteria and Cost Criteria

Criteria	Strength	Stiffness	Corrosion	Sustainability	Weight	Availability	Price
Optimize	Max	Max	Max	Max	Min	Max	Min

TABLE 10. Vector Normalization Matrix for Natural Fiber

Fibers	Strength	Stiffness	Corrosion	Sustainability	Weight	Availability	Price
Abaca	0.26860	0.06501	0.29474	0.10575	0.21754	0.31974	0.11644
Banana	0.20831	0.11484	0.28001	0.09914	0.27065	0.35971	0.05822
Bamboo	0.09843	0.05851	0.31685	0.28420	0.18588	0.31974	0.17467
Coir	0.12923	0.55255	0.00273	0.56178	0.21142	0.31974	0.17467
Cotton	0.18783	0.14085	0.08400	0.17845	0.31049	0.31974	0.11644
Flax	0.56350	0.06934	0.28885	0.02908	0.30640	0.15987	0.34933
Hemp	0.25921	0.08667	0.26822	0.11037	0.30027	0.11990	0.40756
Jute	0.24287	0.03575	0.25495	0.31063	0.28699	0.15987	0.34933
Kenaf	0.45644	0.09643	0.39791	0.28023	0.29210	0.23981	0.23289
Oil Palm	0.09317	0.54171	0.22017	0.38333	0.22980	0.31974	0.23289
Pineapple	0.19272	0.30119	0.41633	0.16787	0.29210	0.27978	0.17467
Ramie	0.26297	0.06284	0.15990	0.00859	0.30436	0.27978	0.23289
Sisal	0.21207	0.09751	0.25053	0.11897	0.23899	0.03997	0.52400
Sugar Palm	0.10391	0.48321	0.19601	0.41638	0.25329	0.27978	0.17467

The 14 natural fibers normalised performance ratings in relation to the seven material sub-criteria are displayed in the vector normalisation matrix. Vector normalisation is used to obtain each value, standardising the data to allow for Equitable comparison across all criteria. For instance, coir and oil palm do well under Stiffness, although Kenaf and Flax have good, normalized values under Strength. For ease of comprehension, Figure 7 presents the outcome.

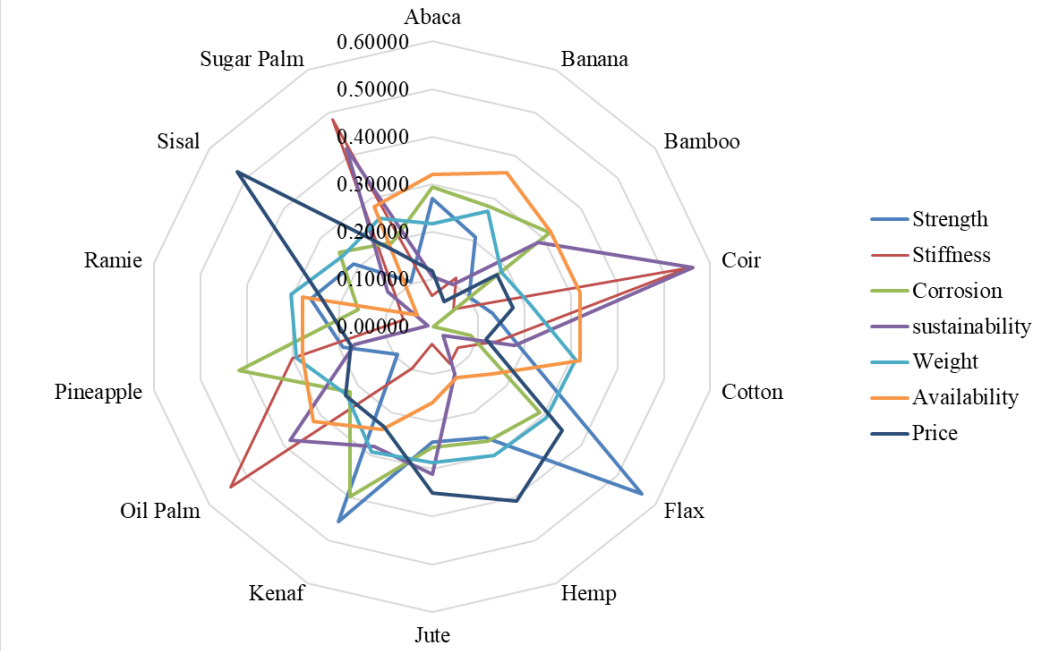


FIGURE 6. Vector Normalization Matrix for Natural Radar Chart

To estimate the assessment value of a candidate alternative, compare its normalised attribute optimisation performance to the corresponding weightage obtained from AHP. Due to decision-making, this situation will result in a more precise outcome using equation 7.

$$X_{ij}^{*}=w_j \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} X_y^2}} \tag{7}$$

TABLE 11. Normalized Attribute Optimization (Decision Matrix)

Fibers	Strength	Stiffness	Corrosion	Sustainability	Weight	Availability	Price
Abaca	0.09412	0.01544	0.01362	0.01117	0.03459	0.01017	0.00810
Banana	0.07299	0.02728	0.01294	0.01047	0.04303	0.01144	0.00405
Bamboo	0.03449	0.01389	0.01464	0.03001	0.02956	0.01017	0.01216
Coir	0.04528	0.13123	0.00013	0.05932	0.03362	0.01017	0.01216
Cotton	0.06582	0.03345	0.00388	0.01884	0.04937	0.01017	0.00810
Flax	0.19745	0.01647	0.01334	0.00307	0.04872	0.00508	0.02431
Hemp	0.09083	0.02059	0.01239	0.01166	0.04774	0.00381	0.02837
Jute	0.08510	0.00849	0.01178	0.03280	0.04563	0.00508	0.02431
Kenaf	0.15994	0.02290	0.01838	0.02959	0.04644	0.00763	0.01621
Oil Palm	0.03265	0.12866	0.01017	0.04048	0.03654	0.01017	0.01621
Pineapple	0.06753	0.07153	0.01923	0.01773	0.04644	0.00890	0.01216
Ramie	0.09214	0.01492	0.00739	0.00091	0.04839	0.00890	0.01621
Sisal	0.07431	0.02316	0.01157	0.01256	0.03800	0.00127	0.03647
Sugar Palm	0.03641	0.11476	0.00906	0.04397	0.04027	0.00890	0.01216

When the objectives or attributes are of varying importance (weights), the assessment value is computed by multiplying the attributes by the corresponding weight or significance coefficient. Normalised performances with respect to beneficial objectives are all added, while normalised performances with respect to cost (non-beneficial) objectives are all subtracted. The weighted normalised assessment value (Y_i) is calculated using equation (8) as follows.

$$Y_i = \sum_{j=1}^{g} X_{ij}^{*} - \sum_{j=g+1}^{n} X_{ij}^{*} \quad (8)$$

The number of beneficial attributes, or objectives to be maximised, is denoted by g, while the number of cost attributes, or objectives to be minimised, is represented by (n-g). The algebraic sum of the maxima (beneficial objectives) and minima (cost objectives) determines whether the value of Y_i is positive or negative provide an ordinal ranking of candidate alternatives. Where Y_i is the weighted normalised assessment value (dimensionless) of *i*th alternative in relation to all the objectives.

TABLE 12. Final Ranking and Selection for Natural Fiber

Fibers	Maximum	Minimum	*Yi* (Max-Min)	Ranking
Abaca	0.1445	0.0427	0.1018	7
Banana	0.1351	0.0471	0.0880	8
Bamboo	0.1032	0.0417	0.0615	12
Coir	0.2461	0.0458	0.2004	1
Cotton	0.1322	0.0575	0.0747	9
Flax	0.2354	0.0730	0.1624	4
Hemp	0.1393	0.0761	0.0632	11
Jute	0.1433	0.0699	0.0733	10
Kenaf	0.2384	0.0627	0.1758	2
Oil Palm	0.2221	0.0527	0.1694	3
Pineapple	0.1849	0.0586	0.1263	6
Ramie	0.1243	0.0646	0.0597	13
Sisal	0.1229	0.0745	0.0484	14
Sugar Palm	0.2131	0.0524	0.1607	5

The Y_i values, which are obtained by deducting the sum of the cost criteria (Minimum) from the sum of the advantageous criteria (Maximum) for each fiber, are displayed in the final decision matrix for the MOORA approach. Better overall performance across all weighted sub-criteria is indicated by a higher Y_i score. According to the results, coir is the best appropriate natural fiber based on the assessed criteria, having the greatest Y_i value (0.2004) and ranking first. Kenaf (0.1758) and Oil Palm (0.1694) come next, in second and third place, respectively. Sisal, on the other hand, performed the worst, ranking 14th with a Y_i value of 0.0484. The diagram of the natural fiber arrangement in sequence is displayed in the Figure 7.

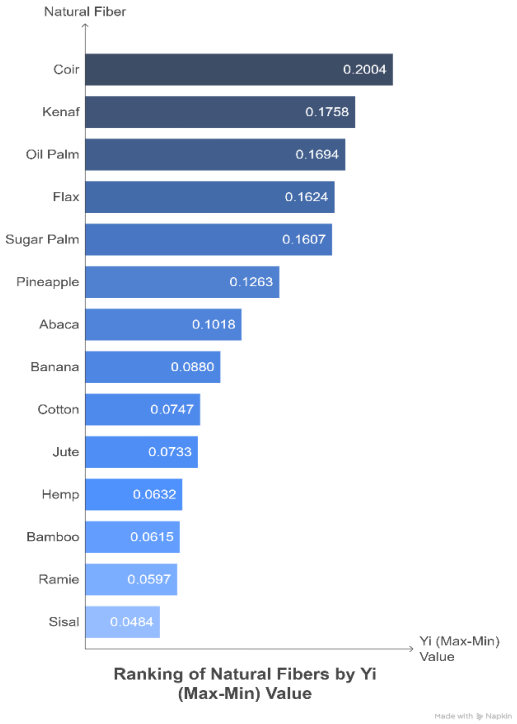


FIGURE 7. Final Ranking of Natural Fiber by Y_i (Max-Min) Value.

The final evaluation results obtained using the hybrid AHP-MOORA approach demonstrate the method's comprehensive ability to deal with complex multi-criteria material selection problems, particularly in the context of sustainable engineering. By systematically combining expert judgement with quantitative performance indicators, the analysis produced a well-defined ranking of 14 natural fiber candidates based on key mechanical, environmental, and economic criteria. The highest-ranked alternative, coir, had a *Yi* value of 0.2004, indicating superior performance across the decision matrix. The review study by Goyat et al. also corroborated the findings. They discussed the benefits of coir, which is widely utilised in the construction and automotive industries and has been employed as reinforcement for polymer composites. Coir is a possible option, item, or material for reinforcing of medium-strength composites due to its easy availability and inexpensive cost. The next ranking was closely followed by kenaf, oil palm, and flax, which all demonstrated a balanced combination of tensile strength, stiffness, sustainability, availability, and cost-effectiveness factors that are critical to the functionality and viability of biocomposites applications in electric vehicle structural components.

Although coir fiber generally exhibits lower tensile strength and stiffness compared with fibers such as flax or kenaf, its high ranking in the AHP–MOORA analysis reflects the multi-criteria nature of the decision-making framework, which simultaneously evaluates mechanical, environmental, and economic factors. In practical automotive applications, natural fibers are often used within hybrid composite systems, where they are combined with synthetic reinforcements such as glass fiber to achieve the required structural performance. In such configurations, coir fibers can contribute to sustainability, cost reduction, and improved impact energy absorption while the primary load-bearing function is supported by higher-strength reinforcement materials. Furthermore, coir fibers contain relatively high lignin content, which enhances moisture resistance and durability compared with several other natural fibers. These characteristics make coir a promising candidate for further investigation in sustainable hybrid biocomposite structures for automotive applications.

Fibers such as Sisal, Ramie, and Hemp, on the other hand, ranked lower due to weaker trade-offs, particularly in terms of economic and availability, despite demonstrating potential in isolated mechanical properties. This clear distinction emphasises the AHP-MOORA methodology's ability to handle both benefit-type (e.g., strength, corrosion resistance, sustainability) and cost-type (e.g., price, weight) criteria using a systematic normalisation and ranking process. The integration of AHP enables hierarchical weighting based on expert consensus, while MOORA's computational efficiency allows for transparent comparison of alternatives, yielding analytically sound and decision-relevant results. Such structured decision-making is invaluable in materials research, where competing goals frequently render intuitive selection impossible.

In this study, the use of AHP-MOORA not only resulted in a more defensible and rational material selection outcome, but it was also consistent with the larger goals of sustainable product design. The findings suggest that coir fiber represents a promising candidate for further investigation in biocomposites EV strut bar applications, particularly when considering sustainability, cost-effectiveness, and material availability. However, additional validation through mechanical testing, structural analysis, and numerical simulation is required to fully assess its suitability for structural automotive components. The results support the viability of natural fiber-reinforced biocomposites as next-generation alternatives to traditional synthetic materials. A plentiful agricultural byproduct, coconut coir fiber is a viable substitute because of its high lignin concentration, mechanical strength, and environmental advantages (Bawono et al. 2025; Bettini et al. 2010). More importantly, the methodological approach presented here can be used to create a replicable framework for future material selection challenges in other engineering domains, particularly those where sustainability, performance, and economic feasibility must all be optimised simultaneously.

In practical composite applications, several additional factors may influence the performance of natural fiber reinforced composites, including fiber–matrix interfacial bonding, moisture absorption behaviour, processing techniques, and long-term durability. Natural fibers generally exhibit hydrophilic characteristics due to their cellulose content, which may lead to increased moisture absorption and potential degradation of fiber–matrix bonding over time. To mitigate these issues, various surface treatment methods such as alkaline treatment, silane treatment, and acetylation have been widely used to improve fiber–matrix interfacial adhesion and reduce moisture sensitivity. Furthermore, suitable composite manufacturing processes such as compression moulding, resin transfer moulding, and injection moulding can significantly influence the final mechanical performance of natural fiber composites. Although these factors were not directly incorporated into the decision-making framework of the present study, they represent important considerations for subsequent material development and structural validation stages following the initial material screening process.

The robustness of the ranking results is supported by the high consistency of the AHP judgement matrix, as indicated by the Consistency Ratio (CR) value of 0.0249, which is significantly lower than the acceptable threshold of 0.1, confirming that the weighting structure used in the decision-making framework is logically consistent. In addition, the MOORA method is recognised for its stable and transparent ranking mechanism in multi-criteria decision-making problems, as it evaluates alternatives using direct ratio-based normalisation, thereby reducing the influence of scale differences among criteria. Nevertheless, further robustness evaluation through sensitivity analysis or comparison with other MCDM techniques such as AHP–TOPSIS or AHP–VIKOR could provide additional insights into the stability of the ranking results and may be considered in future studies to further enhance the reliability of the proposed framework.

CONCLUSION

In line with the automobile industry's drive for sustainable innovation, this study offers a thorough hybrid AHP-MOORA framework for the strategic selection of high-performance biocomposites for lightweight strut bar applications in EVs. The system efficiently strikes a

compromise between mechanical performance, sustainability, cost, and manufacturability by combining expert-driven AHP weighting with MOORA's strong multi-criteria ranking. Among the fourteen natural fibers evaluated, coir emerged as the most promising candidate based on the multi-criteria decision-making analysis, demonstrating a favourable balance between mechanical performance, sustainability, cost, and availability. It should be noted that the proposed framework primarily serves as a preliminary material screening tool, and further validation through experimental testing, structural modelling, and durability analysis is necessary before practical implementation in EV structural components. It should be noted that the proposed framework serves primarily as a preliminary material screening tool during the conceptual design stage, and further validation through structural analysis, experimental testing, and life cycle assessment is necessary before practical implementation in EV structural components. The results confirm that the hybrid approach may produce data-driven, transparent, and traceable judgements for intricate engineering applications. Additionally, this research offers a reproducible and scalable paradigm for future material selection in design settings driven by sustainability, making a significant contribution to the development of environmentally friendly transportation solutions.

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DECLARATION OF COMPETING INTEREST

None.

REFERENCE

Aaliya, B., Sunooj, K.V. & Lackner, M. 2021. Biopolymer composites: A review. *International Journal of Biobased Plastics* 3(1): 40–84. https://doi.org/10.1080/24759651.2021.1881214

Agarwal, J., Sahoo, S., Mohanty, S. & Nayak, S.K. 2020. Progress of novel techniques for lightweight automobile applications through innovative eco-friendly composite materials: A review. *Journal of Thermoplastic Composite Materials* 33(7): 978–1013. https://doi.org/10.1177/0892705718815530

Alibaba. n.d. Natural fiber. *Alibaba.com*.

Al-Oqla, F.M. & Salit, M.S. 2017. Material selection of natural fiber composites using the analytical hierarchy process. In *Materials Selection for Natural Fiber Composites*, edited by F.M. Al-Oqla & M.S. Salit, 169–234. Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100958-1.00006-2

Alves, C., Ferrão, P.M.C., Silva, A.J., Reis, L.G., Freitas, M., Rodrigues, L.B. & Alves, D.E. 2010. Ecodesign of automotive components making use of natural jute fiber composites. *Journal of Cleaner Production* 18: 313–327. https://doi.org/10.1016/j.jclepro.2009.10.022

Amasawa, E., Hasegawa, M., Yokokawa, N., Sugiyama, H. & Hirao, M. 2020. Environmental performance of an electric vehicle composed of 47% polymers and polymer composites. *Sustainable Materials and Technologies* 25: e00189. https://doi.org/10.1016/j.susmat.2020.e00189

Asim, M., Abdan, K., Jawaid, M., Nasir, M., Dashtizadeh, Z., Ishak, M.R. & Hoque, M.E. 2015. A review on pineapple leaves fibre and its composites. *International Journal of Polymer Science* 2015: 950567. https://doi.org/10.1155/2015/950567

Bawono, N.M.H., Bawono, B., Anggoro, P.W. & Jamari, J. 2025. Study of application of coconut coir fiber-based wood-based panels: A literature review. *Composites Part C: Open Access* 17: 100588. https://doi.org/10.1016/j.jcomc.2025.100588

Bettini, S., Bicudo, A., Augusto, I., Antunes, L., Morassi, P., Condotta, R. & Bonse, B. 2010. Investigation on the use of coir fiber as alternative reinforcement in polypropylene. *Journal of Applied Polymer Science* 118(5): 2841–2848. https://doi.org/10.1002/app.32418

Bharath, V.R.R., Ramnath, B.V. & Manoharan, N. 2015. Kenaf fiber reinforced composites: A review. *ARPN Journal of Engineering and Applied Sciences* 10: 5483–5485.

Brauers, W.K.M., Zavadskas, E.K., Turskis, Z. & Vilutienė, T. 2008. Multi-objective contractor's ranking by applying the MOORA method. *Journal of Business Economics and Management* 9(4): 245–255. https://doi.org/10.3846/1611-1699.2008.9.245-255

Carvalho, D., Ferreira, N., França, B., Marques, R., Silva, M., Silva, S., Silva, E. et al. 2024. Advancing sustainability in the automotive industry: Biopreprегs and fully bio-based composites. *Composites Part C: Open Access* 14: 100459. https://doi.org/10.1016/j.jcomc.2024.100459

Czerwinski, F. 2021. Current trends in automotive lightweighting strategies and materials. *Materials* 14(21): 6631. https://doi.org/10.3390/ma14216631

Deka, H., Misra, M. & Mohanty, A. 2013. Renewable resource based "all green composites" from kenaf

biofiber and poly(furfuryl alcohol) bioresin. *Industrial Crops and Products* 41: 94–101. https://doi.org/10.1016/j.indcrop.2012.03.037

Thyavihalli Girijappa, Y.G., Mavinkere Rangappa, S., Parameswaranpillai, J. & Siengchin, S. 2019. Natural fibers as sustainable and renewable resource for development of eco-friendly composites: A comprehensive review. *Frontiers in Materials* 6: 226. https://doi.org/10.3389/fmats.2019.00226

Goyat, V., Ghangas, G., Sirohi, S., Kumar, A. & Nain, J. 2022. A review on mechanical properties of coir based composites. *Materials Today: Proceedings* 62(4): 1738–1745. https://doi.org/10.1016/j.matpr.2021.12.252

Gupta, I., Raeisi, S.T., Correa, S. & Wicaksono, H. 2025. Evaluating risk factors in automotive supply chains: A hybrid fuzzy AHP-TOPSIS approach with extended PESTLE framework. *Journal of Open Innovation: Technology, Market, and Complexity* 11(1): 100489. https://doi.org/10.1016/j.joitmc.2025.100489

Hancock, K. 2024. Driving toward sustainability: Green technologies reshaping the automotive composite landscape. *Hypetex*.

Idral, F., Mansor, M.R., Mohamad, E. & Basori. 2025. Synergizing TRIZ and Design Thinking: A novel approach for enhanced design in product development. *Jurnal Kejuruteraan* 37(8): 3795–3808. https://doi.org/10.17576/jkukm-2025-37(8)-12

Joshi, S.V., Drzal, L.T., Mohanty, A.K. & Arora, S. 2004. Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied Science and Manufacturing* 35: 371–376. https://doi.org/10.1016/j.compositesa.2003.09.016

Kangishwar, S., Radhika, N., Sheik, A.A., Chavali, A. & Hariharan, S. 2023. A comprehensive review on polymer matrix composites: Material selection, fabrication, and application. *Polymer Bulletin* 80: 47–87. https://doi.org/10.1007/s00289-022-04087-4

Karande, P. & Chakraborty, S. 2012. Application of MOORA for materials selection. *Materials & Design* 37: 317–324. https://doi.org/10.1016/j.matdes.2012.01.013

Khalil, H.P.S.A., Alwani, M.S., Ridzuan, R., Kamarudin, H. & Khairul, A. 2008. Chemical composition, morphological characteristics, and cell wall structure of Malaysian oil palm fibers. *Polymer-Plastics Technology and Engineering* 47: 273–280. https://doi.org/10.1080/03602550701866840

Kumar, R., Jesudoss Hynes, N.R., Senthamaraikannan, P., Saravanakumar, S. & Rangappa, S.M. 2018. Physicochemical and thermal properties of *Ceiba pentandra* bark fiber. *Journal of Natural Fibers* 15(8): 822–829. https://doi.org/10.1080/15440478.2017.1369208

Li, K., Fu, S., Zhan, H., Zhan, Y. & Lucia, L. 2010. Analysis of the chemical composition and morphological structure of banana pseudo-stem. *BioResources* 5: 576–585. https://doi.org/10.15376/biores.5.2.576-585

Mansor, M.R., Idral, F., Mohamad, E., Ito, T., Rahman, A.A. & Oktavianty, O. 2024. Structural performance analysis of electric vehicle strut bar with end constraints using HyperMesh-OptiStruct. In *Proceedings of Manufacturing System Design Conference*.

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

Mastura, M.T., Sapuan, S.M., Mansor, M.R. & Nuraini, A.A. 2017. Environmentally conscious hybrid bio-composite material selection for automotive anti-roll bar. *The International Journal of Advanced Manufacturing Technology* 89: 2203–2219. https://doi.org/10.1007/s00170-016-9217-9

Mironenko, R.Y., Balaev, E.Y. & Blednova, Z.M. 2018. Engineering design of safe automobile front strut tower brace with CAD/CAE system. *IOP Conference Series: Materials Science and Engineering* 327(3): 032039. https://doi.org/10.1088/1757-899X/327/3/032039

Mitra, A. 2021. Materials selection for thermal comfort properties of cotton fabrics—A MOORA approach. *Research Journal of Textile and Apparel*. https://doi.org/10.1108/RJTA-02-2021-0021

Moshi, A.A.M., Ravindran, D., Bharathi, S.R.S., Suganthan, V. & Singh, G.K.S. 2019. Characterization of new natural cellulosic fibers from *Barringtonia asiatica* (L.) fruit pericarp. *IOP Conference Series: Materials Science and Engineering* 574(1): 012013. https://doi.org/10.1088/1757-899X/574/1/012013

Munawar, S., Umemura, K. & Kawai, S. 2007. Characterization of the morphological properties of seven nonwood plant fiber bundles. *Journal of Wood Science* 53: 108–113. https://doi.org/10.1007/s10086-006-0836-x

Noryani, M., Sapuan, S.M. & Mastura, M.T. 2018. Multi-criteria decision-making tools for material selection of natural fibre composites: A review. *Journal of Mechanical Engineering and Sciences* 12(1): 3330–3353. https://doi.org/10.15282/jmes.12.1.2018.5.0299

Okubo, K., Fujii, T. & Yamamoto, Y. 2004. Development of bamboo-based polymer composites and their mechanical properties. *Composites Part A: Applied Science and Manufacturing* 35: 377–383. https://doi.org/10.1016/j.compositesa.2003.09.017

Omkumar, M., Vignesh, V.P. & Kumar, S.A. 2017. Scope of *Sterculia foetida* in composites. In *Proceedings of the International Conference on Recent Innovations in Production Engineering (RIIPE)*, 85–86.

Patnaik, P.K., Swain, P.T.R., Mishra, S.K., Purohit, A. & Biswas, S. 2020. Composite material selection for structural applications based on AHP-MOORA approach. *Materials Today: Proceedings* 33(8): 5659–5663. https://doi.org/10.1016/j.matpr.2020.04.063

Rao, R.V. 2008. A decision-making methodology for material selection using an improved compromise ranking method. *Materials & Design* 29(10): 1949–1954. https://doi.org/10.1016/j.matdes.2008.04.019

Rowell, R.M. 2014. The use of biomass to produce bio-based composites and building materials. In *Advances in Biorefineries: Biomass and Waste Supply Chain Exploitation*, 803–818. Woodhead Publishing. https://doi.org/10.1533/9780857097385.2.803

Salve, A.V. & Mache, A. 2023. Friction and wear studies on jute fiber particulate and LBL composites under dry conditions. *SAE Technical Paper* 2023-01-0727. https://doi.org/10.4271/2023-01-0727

Sari, N.H., Fajrin, J., Suteja & Fudholi, A. 2020. Swellability and mechanical properties of corn husk fiber composites. *Composites Communications* 18: 49–54. https://doi.org/10.1016/j.coco.2020.01.009

Sapuan, S.M., Kho, J.Y., Zainudin, E.S., Leman, Z., Ali, B.A.A. & Hambali, A. 2011. Materials selection for natural fiber reinforced polymer composites using Analytical Hierarchy Process. *Indian Journal of Engineering and Materials Sciences* 18(4): 255–267.

Sathiyamurthy, S., Thaheer, A.S.A. & Jayabal, S. 2013. Prediction and optimization of mechanical properties of coir–polyester composites using full factorial design. *Indian Journal of Fibre & Textile Research* 38: 81–86.

Shaharuzaman, M.A., Sapuan, S.M., Mansor, M.R. & Zuhri, M.Y.M. 2018. Material selection for side door impact beam using AHP-VIKOR. In *6th Postgraduate Seminar on Natural Fiber Composites*, 8–11.

Subagyo, A. & Chafidz, A. 2018. Banana pseudo-stem fiber: Preparation, characteristics, and applications. In *Banana Nutrition – Function and Processing Kinetics*, edited by Afam I.O. Jideani & Tonna A. Anyasi, 47–65. IntechOpen. https://doi.org/10.5772/intechopen.82204

Turayev, S., Tuychiyev, X., Sardor, T., Yuldashev, X. & Maxsudov, M. 2021. The importance of modern composite materials for the automotive industry. *Asian Journal of Multidimensional Research* 10: 398–401. https://doi.org/10.5958/2278-4853.2021.00144.0

Vern Yiow, R., Mansor, M.R. & Shaharuzaman, M.A. 2025. Natural fiber composite selection for two-stroke marine engine under-piston door using hybrid MCDM approach. *International Journal of Lightweight Materials and Manufacture* 8(1): 66–73. https://doi.org/10.1016/j.ijlmm.2024.07.006

Vieyra, H., Molina-Romero, J.M., Calderón-Nájera, J. de D. & Santana-Díaz, A. 2022. Engineering, recyclable, and biodegradable plastics in the automotive industry: A review. *Polymers* 14(16): 3412. https://doi.org/10.3390/polym14163412

Wasti, S., Kamath, D., Armstrong, K., Clarkson, C., Tekinalp, H., Ozcan, S. & Vaidya, U. 2024. Life cycle assessment of coir fiber-reinforced composites for automotive applications. *Journal of Cleaner Production* 485: 144368. https://doi.org/10.1016/j.jclepro.2024.144368

Westman, M.P., Laddha, S.G., Fifield, L.S., Kafentzis, T.A. & Simmons, K.L. 2010. *Natural Fiber Composites: A Review*. PNNL-19220. Richland, WA: Pacific Northwest National Laboratory. https://doi.org/10.2172/989448

Witik, R.A., Payet, J., Michaud, V., Ludwig, C. & Månson, J.-A.E. 2011. Life cycle costs and environmental performance of lightweight materials in automobile applications. *Composites Part A: Applied Science and Manufacturing* 42: 1694–1709. https://doi.org/10.1016/j.compositesa.2011.07.024

Zhang, K., Wang, F., Liang, W., Wang, Z., Duan, Z. & Yang, B. 2018. Thermal and mechanical properties of bamboo fiber reinforced epoxy composites. *Polymers* 10(6): 608. https://doi.org/10.3390/polym10060608

Zhang, W. & Xu, J. 2022. Advanced lightweight materials for automobiles: A review. *Materials & Design* 221: 110994. https://doi.org/10.1016/j.matdes.2022.110994