Review

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Review

Green Composites in Aviation: Optimizing Natural Fiber and Polymer Selection for Sustainable Aircraft Cabin Materials

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Abstract: The increasing demands on global resources due to technological development driven by consumer expectations and demands have resulted in significant problems with ecological sustainability and material availability. The creation of biocomposites has resulted in notable advancements in the green industry within the materials science area this century, owing to concerns regarding sustainability and the environment. Globally, there is a surge in the creation of highly efficient materials derived from natural resources. In aviation applications, plant-fiber-supported polymer composite materials are becoming increasingly popular. Aerospace materials are typically used in aircraft construction as structural materials to support loads throughout different flight phases. There are many diverse mechanical qualities of natural fibres; therefore, selecting one for the interior parts of an aircraft cabin based only on its attributes leads to a multiple-attribute decision-support issue. In this paper, the effective natural fibre and polymer choice for use as reinforcing materials in composite materials is represented for the composite materials' improvement to aircraft cabin luggage for aerospace implementations. This study can guide material designers in investigating different hybrid materials with the most effective natural fiber and polymer obtained by hierarchical strategy by elucidating the effective material choice to meet the criteria determined for the aircraft cabin luggage. For this purpose, the definitive rankings of the twelve polymers and sixteen natural fibers in terms of performance score were assessed using hierarchical strategy methodology.

Keywords: natural fibre; polymer; composite material; green material; aviation application

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1. Introduction

To protect nature from numerous challenges, worldwide consciousness has spurred humankind to action in recent years. These dangers include the depletion of natural resources, water contamination, and air pollution, which fuel global warming. Because of this, a lot of people are pushing for new kinds of development and behavior through regulations designed to make natural materials more effective. The idea of sustainable development has emerged as a result of this movement [1–3].

A renewed focus on creating completely biodegradable materials with acceptable qualities has resulted from public awareness of the rise in non-biodegradable solid waste and its effects on the environment. Biodegradable materials have garnered significant global attention in recent times. In relation to energy consumption, raw material costs, and manufacturing efficiency, the materials now in use are highly challenging. In consequence, endeavors are being made to locate appropriate substitute material sources, with regional, readily sustainable resources being the preferred option, provided that processing them later on uses little energy [4]. From the perspective of material resource sustainability, easily accessible renewable resources are crucial. Using naturally occurring fibre resources from agriculture is one of the solutions. Using recycled or industrial waste materials is another viable approach. Obtaining the requirements of structures primarily involves using high-quality structural materials, designing materials energy-friendly, and healthy existing structures.

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Additional benefits occur in these kinds of constructions when plant fibres are employed, including weather protection, heat regulation of the structure, and protection from direct sunlight, among other benefits that are corroborated by several research studies and findings. To fully utilize these systems' benefits, it is necessary to take into consideration the appropriateness of the structures, the kind of plants, and where they are located inside the plant, as well as issues related to plant maintenance [5–14]. Natural fibres have appeared as an important class of reinforcing materials lately [15–17]. It is anticipated that the global markets for material consumption will be dominated by biodegradable material consumption, which is predicted to increase at an average yearly ratio of around 0.13 [18]. Plant fibres are increasingly being utilized in plastic composite materials as reinforcers and fillers. However, the degradable materials' restricted qualities and high costs prevent them from being used in a variety of ways. Thus, various initiatives aimed at creating biodegradable materials have lately surfaced in an effort to address these issues and slow down the natural sources' depletion. It is widely anticipated that these materials will play a crucial role in overall sectors in the centuries to come. Polymer fiber-supported composite materials are materials of a particular kind that are typically made of a matrix consisting of biodegradable polymers and plant fibre. Because they have the potency to substitute conventional fibre-supported composite materials, particularly glass fiber-supported composite materials, polymer-fibre composites have garnered a lot of attention lately. According to forecasts, the plant-sourced fibres in reinforcement materials' market portion is expected to reach up to 38% by 2030 [19].

Through appropriate choices of additives, matrix, fibres, and production techniques, these composite materials' features can be customized for various implementations. The fibre's pretreatment procedure is crucial since it regulates all connections between surface characteristics and, consequently, the resulting composite materials' effective stress transfer. Because they are not biodegradable, garbage wastes such as containers, bottles, food packaging, plastic shopping bags, and so on are mostly to blame for environmental impurities in urban fields. It is imperative that we utilize less of these pollution-causing waste products in order to maintain a clean and safe environment [20]. That is why a lot of nations have outlawed plastic shopping bags, which are thought to be the cause of "white pollution." Because biodegradable plastics break down quickly in landfills, alternative uses for them and their plant-fibre biocomposites have grown in popularity. As a result, it could result in one of the fixes for the depletion of disposal grounds problem [21,22]. In order to meet this goal, current research is being used to combine plant fibre with biodegradable polymers to create a new class of entirely biodegradable composites [23]. Potency implementations of fibre-supported polymer composites are given in Table 1.

Table 1. Potential implementations of fibre-supported polymer composites.

Samples	Implementation
Storage silos, biogas containers, fuel containers, post boxes, etc.	Storage devices
Snowboards, frames, bicycle, ball, tennis racket,	leisure and sport goods
Laptops cases mobile cases,	Electronics appliances
Carpet, mats, sacking, hessians, bags, ropes, pipes, covers, units, bath, shower, helmets, paperweights, helmets, suitcases, lampshades, partitions, food trays,	Utility and household products
Profiles of door-frame, interior paneling, door panels,	
Fencing elements, chairs, and tables	
Panel for false and partition ceiling, door and window frames, floor, wall, partition boards, roof tiles, bridge, railing, transportable buildings that are resilient to natural disasters.	Construction and building sector

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Architectural moldings, interior paneling, boats, railway and automobile coach interior, spare-wheel pan, spare tyre covers, parcel shelves, decking, trunk liners, pallets, car door, dash boards, headliners, seat backs, door panels	Aviation, transportation and automobile sector

Aerospace materials are typically used in aircraft construction as structural materials to support loads throughout different flight phases. Many vital aircraft parts, including the landing gears, engine, elevator, airframes, rudder, fuselage, and wings, are vulnerable to structural harm as a consequence of the extreme strain. Strength in structure is the first consideration when choosing materials for an aircraft because of the safety risk. Any aerospace vehicle's design must prioritize weight reduction because it has a direct impact on fuel economy and cost. Research has demonstrated that a 1 kg weight reduction in a Boeing747 aircraft—which is commonly utilized for freight conveyance—reduces carbon emissions through 940 g and aeronautics energy source consumption through over 300 g [24]. For aeronautical applications, it is important to choose materials with maximum durability but less weightage. The need for developed composites that allow for important aircraft weightage degradation without sacrificing structural integrity is currently rising in the aerospace sector. These days, polymer matrix composites make up a sizable portion of aircraft materials. Because of their renewability, less cost, and high ratio of strength to weight, natural fibres have become an effective replacement for artificial fibres in the manufacturing of composite materials like carbon fibres and E-glass. However, because there are so many diverse kinds of plant fibres that can be hybridized with diverse matrix materials, choosing the best natural fibre for an aircraft implementation can be hard. The reinforced polymer material with fibre has drawn numerous considerations in aviation implementations because natural fibre has benefits over artificial fibres, like being relatively light, inexpensive, less likely to damage operational tools, having high notional mechanical features like flexural and tensile strengths, developing superficies finish of composite's molded areas, being abundant in sustainable sources, being flexible throughout treatment, being biodegradable, and posing few health risks. The addition of strong and lightweight plant fibre to polymers (thermoplastic and thermoset) can result in plant fibre polymer composite materials with maximum stiffness and strength [6]. Nonetheless, there are several issues with natural fibers, and they lack some important qualities. Some plants' structure allows the fiber to absorb moisture from its environment, which results in fragile bonds between the polymer and fiber. Moreover, couplings between natural fibers and the matrix and polymers are considered challenging due to their dissimilar chemical structures. These are the reasons behind the inefficient strength sent through the window between the composite materials. Plant fibre changes through particular processes are therefore unquestionably required. Utilizing functional groups as reagents, which can respond to fiber structures and alter their structure, is typically at the core of these alterations. Therefore, fiber changes result in a decrease in the natural fibers' ability to absorb moisture, which greatly improves the fiber's incompatibility with the polymer material [7]. Features of an aircraft structure are given in Table 2 [25].

Table 2. Features of an aircraft structure.

Applicability	Requirement	Effect
*Overall programs for aerospace	*Less weightage	* Use of low density materials * Stiffened structures or thin-walled box * Semi-monocoque construction * Composites * Al-alloys * Wood * High weight strain and weight/stiffness

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*Every space program	• Elevated dependability	* Certification: evidence of design * Ensure accurate data Tight quality control * Extensive testing to
* Vehicles for passengers	* Safety of passengers	* Comprehensive testing: Reliability * Using materials that are fire retardant
Reusable Spacecraft Aircraft	*Durability: Corrosion and fatigue Vacuum Radiation Thermal Degradation	* High-integrity thin materials * Thorough testing in the necessary setting * Damage and safe-life, life extension issues * Issues with damage, safe life, and life extension * There is no fatigue limit for al-alloys. * Thorough fatigue testing and analysis
Spaceships Reusable aircraft	Performance in aerodynamics	*Machinability: N/C Milling and Molding *Intricately curved shapes *Dynamics *Extremely intricate loading *Deformed shape-aeroelasticity *Control surfaces and flexible, thin, wings
*Every Aerospace initiative	*Multiple functions or roles	*Application: composites with useful characteristics *Effective design
Airplanes, primarily fighters but some passenger	*Fly-by-wire	*EMI protection *Prolonged usage of devices and computers
*Particular use in military aerospace	*Stealth	*Stealth coatin *Aircraft shape and Specific surface
*Aircraft	*Weather-Related Operations	*Erosion resistance, lightning protection

It must be acknowledged that materials having a unique property set are required to satisfy the requirements listed in Table 2. These kinds of factors have significantly driven the usage of composites. Several of these features are provided by the composites, as listed below [25]:

- Lightweight because of stiffness and high specific strength
- High degree of optimization capability, including directional strength and stiffness customization;
- Ability to mold big complicated shapes in short cycle times, minimizing part count and assembly times
- Good for construction with extensive curvature or thin walls
- Able to retain dimensions and alignment stability in space
- May have minimal dielectric loss in radar transparency
- The potential for a low radar cross-section
- There are certain intrinsic flaws in these composites as well.
- Weakly interfaced laminated structure: inadequate resistance to tensile pressures applied out of plane
- Absorption of moisture and ensuing deterioration of high temperature performance
- High potential for impact damage and a high likelihood of interior damage remaining undetected
- Variability in material properties and several manufacturing faults

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Frequently used polymeric matrices in the aerospace industry are given in Table 3 [25].

Table 3. Frequently used polymeric matrices in the aerospace industry.

Thermosets				Thermo-plastics
Creates cross-linked networks during heating-curing polimerization				No alteration in composition
Polyimides	Polyester	Phenolics	Epoxies	PPS, PEEK
* Brittle *Complicated to handle *300^0C high temperature application	* Recommended for general use at room temperature * Simple to employ *Low cost	* Difficult to obtain composites of high quality * Reduced viscosity *High temperature consumption * Simple to operate *Less expensive	*Comparatively expensive *Moderately high temperature* Most often used (80% of all composites)	*Process is challenging since a high temperature of 400–300^0C is needed. *High resilience to damage
	High shrinkage (about 7.5 percent)	Volatiles released while curing More shrinkage	*No volatiles are released when curing *Less shrinkage	
	*Low Temperature *Brittle *Broad spectrum of propetiles, albeit less so than epoxies *Natural stability in the face of oxidation * Strong resilience to chemicals	*More brittle than epoxy *Good resistance to fire and naming *Natural stability in the face of Oxidations	May be polymerized in a number of ways, yielding a wide range of structures, morphologies, and characteristics.	
	Challenging to prepare	*Less stable storage and challenging preparation	Sufficient storage stability for preparing	Endless existence in storage. But challenging to prepare
	Less moisture-sensitive than epoxy	• Absorbs moisture, but molasses has no discernible impact on its operational range.	Long-term ultra violet degradation. Complete wetness (5–6%), which causes temperature pastries to expand and degrade	Absence of moisture absorption

An appropriate candidate material choice for a given application has grown in importance in advanced materials research in order to achieve both eco-friendly design and consumer satisfaction. The process of multicriteria decision-making is commonly employed to determine which materials are best suited for a certain application [26,27]. AHP was the most often utilized multiple attribute decision support mechanism in a variety of material selection scenarios, along with TOPSIS, WPIM, and AHP, according to Mansor et al. [28]. Thomas invented it in the 1970s [29]. The commercially available "Expert Choice" software is an effective way to apply AHP Chang et al. used sensitivity analysis to assess their choice. Sensitivity analysis uses several criterion weights to validate the AHP results [30]. AHP is typically used to determine which alternative is best suited for a given project or application. Establishing objectives is the primary stage in the AHP strategy, followed by choosing criteria and options. The weighting of the attribute and the alternatives' respective notional significance determine the ultimate ranking of the options. By combining AHP and TOPSIS, Kumar et al. focused on a calculational framework for choosing the ideal aspirant cloud service [31]. The material selection of optimal matrix for aluminium integrated metal matrix composite materials via AHP was examined by Babu et al.. Their attention was on aluminium integrated metal matrix composite materials [32]. In order to overcome the specification problem of weighting components and gather various design criteria into a single composite, Sun suggested an improved multi-criteria decision analysis technique [33]. An index was proposed by Sun and Gollnick to assess a technique's effectiveness in the method selection process [34]. After doing a thorough analysis of MCDM approaches, Ogrodnik came to the conclusion that AHP is one of the most broadly utilized methodologies available today [35]. The novel AHP-sourceed method for choosing construction materials according to performance was presented by Lee et al. and used on a concrete formwork system case study [36]. Using AHP, Dinh et al. ranked 18 maintainability attributes' a list that apply to the choice of maintainable materials in Vietnam according to their level of significance for the nation's building industry [37]. Stainless steel and aluminum integrated panel were the two materials that Ruslan et al. determined to be the most sustainable for usage as façade materials using Value-based Analysis and AHP [38]. AHP was used by Mayhoub et al. to create a new evaluation framework for choosing sustainable façade materials that is depend on 4 green constructin rating mechanisms [39]. For post-tension bridges, a related approach was demonstrated through Renkas-Janowska et al., who chose the optimal high-efficiency concrete using FEAHP and Fuzzy-TOPSIS [40]. Singh and colleagues combined TOPSIS and FAHP while choosing composite materials for use in structural components [41]. AHP and gray-correlation TOPSIS were integrated by Tian et al. to choose eco-friendly décor materials [42]. Akadiri et al. used the Analytic Hierarchy Process (fuzzy extended) to select maintainable construction materials [43]. A framework for decision-making utilizing FAHP was presented by Figueiredo et al. to help with the selection of building materials [44]. In the automobile business, TOPSIS has been used to choose the most advantageous strategic fuel cell technology [45]. In order to choose the finest roofing materials for the UK property market, Rahman et al. used TOPSIS [46]. Lee used ANP to assess the competing types for airport development [47]. Materials were chosen by Liu et al. using the VIKOR method [48]. VIKOR was used by Khodabakhshi et al. to pick the best materials [49]. Using a hybrid MCRAT, LOPCOW, MEREC, and PSI modelling, Ulutas et al. determined the most performance bio-fiber for popular construction isolation materials. They then selected the insulation materials using the PSI-CRITIC based CoCoSo technique [50,51]. A novel hybrid MCDM model was presented by Aksakal [52] for the evaluation of insulation materials in a healthier environment. Balo was assessed for utilizing an AHP in the ecological insulation materials' manufacturing of [53]. Using AHP, Dweiri et al. suggested a decision-making modelling to find the automobile industry's most efficient supplier [54]. For Greek road transportation, the optimum alternative fuel was chosen using AHP by Tsita et al., taking into account both economic and policy considerations [55]. In order to select the most suitable ceramic waste to substitute ordinary concrete in terms of compressive strength and environmental effects, some research has combined AHP and TOPSIS by Rashid et al. [56]. During the selection process, they took the natural fiber's mechanical and physical qualities into account. AHP was applied in addition to material selection to determine which of the creative planning notions for the polymer composite materials intended for lever implatations of car brakes was the best design by Mansor et al. [57]. The 14 plant fibres and 7 attributes were considered. For the vehicle spall liner, they have selected kenaf as a feasible plant fibre to hybridize with Kevlar. AHP was utilized to choose the natural fiber for the dash board used in automobiles by Hani et al. [58]. Dalalah et al. were utilized to select the natural fibre for the car fracture liner using AHP [59]. Balo et al. analyzed energy-effective natural fibers for green building external walls [60–62]. AHP is used for wind turbine material choice by Sagbansua and Balo [63,64].

There are a number of characteristics to consider when selecting component materials for a combined material, but deciding which to select in order to get the greatest result out of the available options can be challenging [65]. Multiple-attribute decision-support strategies can be used to select the factors of combined materials since they provide decision-makers with a reasonable suggestion from a restricted number of options, too. Many multiple-attribute decision-making models evaluate the performance of options and provide the best possible resolution among a variety of options. Amarnath et al. investigated the best solution for flax components in composite materials using the TOPSIS methodology [66]. For the nutrient pack, AHP modeling was used to select the best fibre among 9 plant fibres. The authors also ran a sensitivity test on the modelling and found that the AHP model's system of priorities was stable, according to Salwa et al. [67]. Rocchi et al. identified economic and environmental criteria groups to evaluate the ecological and financial suitability of sustainable isolation [68]. Kumar et al. suggested an optimisation schema for comparing the features of different insulation materials, with a focus on lifecycle cost, comfort, operational energy, embodied energy, and carbon [69]. In Lithuania, Ruzgys et al. investigated modernized building planning resolutions. Utilizing the connected TODIM-SWARA method, the researchers ranked 6 external wall isolation options for consturiction modernization (mineral wool and fibercement panels; polystyrene foam; and thin plaster). A ventilated mechanism with fibro-cement panels and mineral wool insulating material with 0.13 m thickness was discovered to be the most effective option for residence modernization [70]. Bringezu and Sameer demonstrated the assessment of material resources and the importance of indicators, such as performance indicators, criteria, parameters, and inputs, in material choice to deal with maintainability [71]. TOPSIS Grey method utilized to arrange 5 modern isolating materials to support historically based constructions (hemp/flax fibre, thermo wool, eco wool, aerogel, and vacuum panel) by Zagorskas et al. The best insulating material was determined to be wool. Nonetheless, the findings of the other alternatives are very associated [72]. Through a comparative lifecycle analysis of defined insulating materials oriented toward maintainability in construction, Llantoy et al. demonstrated that insulating materials decrease building effects and energy usage [73]. For constructional implementations, Patnaik et al. utilized the analytical hierarchy methodology to define the attributes' weight values for choosing hybrid material [74]. Civic and Vucijak evaluated eight insulation materials using the VIKOR technique. The authors chose 7 attributes to display technical and environmental factors. Both the selection of attributes and their weightiness in this research depend on the choice of researchers. The results display that wood wool is the third alternative, glass wool is the second alternative, and styrofoam is the most favored option [75].

Azari discussed various methodologies for accountancy ecological matters, programs for life-cycle analyses, and energy analysis programs to raise user consciousness of the importance of energy-efficient buildings [76]. Robati et al. detailed the materials' environmental impacts of C-emissions embodied and prediction faults, which finally give rise to all energy usage [77]. TOPSIS methodology was used to assess and rank the maintainability of natural and artificial insulating construction materials by Streimikiene et al. The sensitivity analysis was executed by the authors using 4 diverse frameworks (balanced, equal, environmental, and technological) with diverse weightages for the chosen attributes. According to the evaluation, recycled glass is the most effective option among the 3 alternatives (balanced, technological, and equal). With reference to the evaluation, sheep wool is the most efficient alternative in terms of the environment [78].

In brief, biofiber composites have seen incredible metamorphosis in the past few decades. With the thorough investigation, development, and subsequent application of novel compositions and techniques, these materials have grown increasingly sufficient. Biocomposites gained considerable importance due to the petroleum crisis and are now widely used as engineering materials with a variety of characteristics. But like other materials, they are always under pressure from the worldwide market to compete, which means that ongoing research is required. Dealing with plant fiber-supported polymer composite materials presents a significant challenge owing to their wide-ranging qualities and characteristics. Many factors, such as the kind of fibre, the processing techniques, the location of the plant fibres' source, and any fiber alteration, affect a biocomposite's characteristics. Therefore, as new procedures and goods are developed, the growing utilization of natural resources becomes significant for these nations. This in turn contributes to higher living standards and the creation of jobs, especially in the rural sector, as well as preventing environmental degradation that will result from the improper disposal of these resources.

In this research, an overview is first given of the general attributes of the reinforcing fibers utilized in biocomposites, including their source, kind, structure, content, and mechanical properties. And then the analysis was made by following the steps below.

- To conduct an in-depth investigation of the mechanical properties of twelve polymers and sixteen natural fibers in terms of tensile strength, Young's modulus, density, and elongation at a break from existing literature.
- To examine and gather the chemical (micro-fibrillar angle, lignin, hemicellulose, cellulose, and moisture content) and physical (width of lumen, fiber length, thickness of single cell wall, and fiber diameter) characteristics of sixteen natural fibers
- To determine the influence of data variation on the obtained mechanical properties on the performance score of each polymer.
- To determine the influence of data variation on the obtained mechanical, physical, and chemical properties on the performance score of each natural fibre.
- To assign weights to the criteria using the hierarchical strategy methodology to indicate the relative importance of the criteria.
- To assess the performance scores of all the variants of the twelve polymers and sixteen natural fibers.

2. Materials and Methods

The methodology of hierarchical strategy is a methodical approach to material selection. The hierarchical approach methodology, as previously noted, can be utilized to identify appropriate natural fiber and polymer materials for aviation cabin luggage covers. Rather of dictating the "right decision," people deal with complex decisions; the hierarchical approach technique assists them in making one. Developed by Saaty (1980), it is based on human psychology and mathematics and has undergone substantial research and development since then. The hierarchical strategy approach is a way for the decision maker to organize complex problems into a hierarchy, or a series of integrated levels, and is useful for prioritizing alternatives when various factors need to be taken into account. The objective, the criteria, and the options are typically the first three tiers of the hierarchy. The objective of the material selection problem is to choose the best material overall. Physical, chemical, mechanical, and other criteria are all possible. This approach serves to streamline and expedite the natural process of decision-making and offers a framework for making wise choices in challenging circumstances (like material selection, for example).

In this study, we shall refer to the hierarchical strategy technique as previously discussed. It is credited to Saaty and is commonly referred to as the Saaty method.

The approach finds application across all hierarchical levels. Each component of the quantitative features is given a value based on its importance using Saaty's technique. These assessments are synthesized to determine the component with the highest priority. To find a solution to the choice dilemma, the decision maker concentrates on them. More experts are involved in the decision-making process. The degree of soundness of the objective and criteria is shown by the weights assigned to them by the assessors, who are experts in their field. Any expert who is familiar with his subordinates (e.g., job expertise, work experiences, and results) can be verified by the responsible supervisor. Expert soundness can be expressed as a weight vector:

$$v^{experts} = (v_1, v_2, \dots, v_r) \quad (1)$$

where: v1 is the first expert's weight; vr is the third expert's weight;

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$$\sum_{j=1}^{r} v_j = 1 \quad (2)$$

Saaty's approach has been selected to determine the weights of the criteria. This approach considers the varying preferences among the criteria and determines a broad point scale for assessment (Formula 3). As a result, even minute variations in the criteria's preferences can be found and taken into consideration when determining the weights:

$$(s_{ij}) = \begin{cases} 1 - i \text{ and } j \text{ are equivalent}; \\ 3 - i \text{ is mildly preferred to } j; \\ 5 - i \text{ is strongy preferred to } j; \\ 7 - i \text{ is very strongly preferred to } j; \\ 9 - i \text{ is absolutely preferred to } j. \end{cases} \quad (3)$$

The values 2, 4, 6, and 8 are meant to assess transitional phases. Every pair of criteria, i and j, is compared using this procedure. The following guidelines are followed when writing their evaluation in accordance with the Saaty's matrix:

$$s = \begin{pmatrix} 1 & s_{12} & \cdots & s_{1k} \\ \vdots & \ddots & \ddots & \vdots \\ {}^{1}/_{s_{ik}} & {}^{1}/_{s_{2k}} & \cdots & 1 \end{pmatrix} \quad (4)$$

The normalized geometric average of the lines in the Saaty matrix is used to calculate the weights vi in this five-step approach [79–84]. In order to determine if the ith criterion is preferred over the jth criterion, Saaty's matrix must first be filled in such a way that the diagonal values equal one (s_{ij}=1). Next, the proper value of Saaty's point scale (Formula 3) must be chosen. Inverse values must be expressed if the jth criterion is chosen above the ith criterion:

$$s_{ji} = {}^{1}/_{s_{ij}}; \quad (5)$$

For every i, the value $s_i = \prod_{j=1}^{k} s_{ij}$ was calculated; (6)

For every i, the value $R_i = \sqrt[k]{s_i}$ was calculated; (7)

where: R is geometric average; k is total number of criteria;

In the next step, the value $\sum_{i=1}^{k} R_i$ was calculated; (8)

The criteria weights are determined during the last step according to the following formula:

$$v_i = \frac{R_i}{\sum_{i=1}^{k} R_i} \quad (9)$$

Weights of criteria are determined if we multiply all elements for each row and determine the nth root of this product, when n is the number of elements. Then we standardize resulting geometric averages of each Saaty'smatrix row (we divide geometric averages of each row by the sum of all geometric averages).

This procedure gives estimate weights of each criterion, which can be written in the form of weight vector:

$$v = v_1, v_2, \dots, v_k \quad (10)$$

Saaty's method can be used not only to determine preferences between criteria but also between variants, using the Hierarchical Strategy Methodology [85–89].

3. Results and Discussion

3.1. Data

This section provides information about the data used as part of our methodology. The world's largest producers of natural fibers for commerce are given in Table 4. The chemical features,

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mechanical features and physical features of natural fibers are presented in Table 5, Table 6, and Table 7, respectively.

Table 4. The world's largest producers of natural fibers for commerce.

Fibers	Global	Country	Reference
Rice	16000000	China, India, Indonesia, Malaysia,	[90,91]
Corn	122080	USA, China, brazil, Argentina, India,	[92]
Cotton	21400000	Asia, USA	[93]
Ramie	10000	India, China, Brazil, Philippines	[94–104]
Kenaf	97000	India, Bangladesh, United States	[94–102,105]
Bamboo	3000	India, China, Indonesia, Malaysia,	[94–102]
Oil palm	4000	Malaysia, Indonesia	[94,95,98,99,106,107]
Flax	83000	Canada, France, Belgium	[94–103]
Abaca	7000	Philippines, Ecuador, Costa Rica	[94–99,108]
Banana	1920	Latin America and the Caribbean Asia	[109]
Jute	230000	India, China, Bangladesh	[94–102,110]
Pineapple	7400	Philippines, Thailand, Indonesia	[94,95,98–102,104]
Sisal	37800	Tanzania, Brazil, Kenya	[94–102,104,108,110,111]
Coir	10000	India, Sri Lanka, Philippines, Malaysia	[94–102,112–117]
Coconut	7700	Indonesia, Philippines, India, Sri Lanka	[118]
Sugar can	7500000	India, Brazil, China	[94–102]

Table 5. The chemical features of natural fibers.

Fibre Code	Fibres	Micro-fibrillar angle [°]	Lignin (wt%)	Hemicellulose (wt%)	Cellulose (wt%)	Moisture content (%)	Reference
NF 1	Rice		20	19–28	35–45	7,9	[94–96,98–102,108,119,120]
NF 2	Corn	-	7,4	46	41,7	8,5	[121,122]
NF 3	Cotton				82,7–92	9,8	[121,123]
NF 4	Ramie	61,85–85	3–7,58	0,5–9,06	69–83	9	[94–96,100,101,119–121,124–126]
NF 5	Kenaf	2 2–6,2	9 8–21	20–33	31–72	9,2	[94–96,98–102,108,114,119–121,124,125,127,129,130]
NF 6	Bamboo	-	21–31	17,2–43,8	22,8–56,7	8,9	[94–96,100–102,119–121,130]
NF 7	Oil palm		24,45–29	19,06	47,91–65	11	[94–96,119–121,138]
NF 8	Flax	5–10	2–5	10,37–20,6	64,1–75	7	[94–96,98–102,108,114,121,122,124,127–129,133–137]
NF 9	Abaca	20–25	7–12,4	20–25	56–63	15	[94–96,98–102,108,119–121,123,124,128,129,138,139]
NF 10	Banana	11–12	5–10	10–24	60–65	12,1	[100,101,121,124,140,141]
NF 11	Jute	8	5–13	13–20,4	61–71	12	[94–96,98–102,108,114,119–121,124,127–129,133,136,142,143]
NF 12	Pineapple	5-12,7		18	70–82	13	[94–96,101,102,112,119–121]
NF 13	Sisal	10–25	8–14	10–38,2	60–78	11	[94–96,98–102,108,114,119–121,127–129,133,143–146]
NF 14	Coir	30,45	40–45	0,15–0,25	32–43	10	[94–96,98–102,108,114,119–121,124,125,127–129,143,147]
NF 15	Coconut		8–13,1	4–20	70–77,6	8,2	[121,123,148]
NF 16	Sugar can bagasse		22,3–25,3	16,8–31,8	41,1–55,2	8,8	[94–96,119–121,149,150]

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Table 6. The mechanical features of the plant fibres.

Fibre Code	Fiber source	Elongation at break (%)	Young's modulus (GPa)	Tensile strength	Density (g/cm^3)	References
NF 1	Rice	2,2	0,3–2,6	19–135	1,4	[100–102,116,151]
NF 2	Corn	3–4,7	10,1–16,3	355–580	1,2–1,4	[95,96,105,115,121,152–158]
NF 3	Cotton	3–10	5,5–12,6	45,5–1000	1,5–1,6	[95,96,105,114,121,152–157]
NF 4	Ramie	1,2–8	24,5–128	348–938	1,45–1,5	[94,96,105,114,121,152–158]
NF 5	Kenaf	1,6–6,9	2,86–60	215,4–1191	0,6–1,5	[94–96,98–103,114,121,128,129,152–161,165,166]
NF 6	Bamboo	1,5-11	11–17	140–230	0,6–11	[121,159]
NF 7	Oil palm	8–25	1–9	92-1200	0,7–1,55	[121]
NF 8	Flax	1,2–10	24–80	88–1600	0,6–1,5	[94–96,105,110,114,128,129,134,143,152–164,166–168]
NF 9	Abaca	3–10	3–12	220–980	1,5	[96,99,105,107,112–114,121,152–157,160,169,170]
NF 10	Banana	3–53	12–33,8	350–980	1,35	[96,105,114,121,152–158,169]
NF 11	Jute	1,16–8	10–55	385–850	1,3–1,5	[96,105,114,121,152–158,169]
NF 12	Pineapple	1–14,5	60–82	170–1672	0,8–1,6	[95,96,105,114,121,152–158]
NF 13	Sisal	2–25	9–38	80–840	1,3–1,5	[94–96,99–102,105,110,114,115,121,127–129,143,144,152,166–168,171,172]
NF 14	Coir	14,21–59,9	1,27–6	106–593	1,1–1,6	[94,96,105,110,114,115,121,127–129,143,144,152,166–168,172]
NF 15	Coconut	10-23	21,1	150	0,43	
NF 16	Sugar can bagasse	1,1	17–27,1	20–290	1,2–1,5	[95,96,105,114,121,152–159]

Table 7. The physical features of natural fibers [110,124,125,135,139,140,142,166,173,174].

Fibre Code	Fibers	Width of	Thickness of	Fiber	Fiber length
NF 1	Rice	8.7	1.2	15.5	8.7
NF 2	Corn	20,1	1,4	26,7	20,1
NF 3	Cotton	16,4	56,0	45,0	16,4
NF 4	Ramie	13,0	60,4	80,0	13,0
NF 5	Kenaf (core)	22,7	1,1	37,0	22,7
NF 6	Bamboo	8,6	9,0	17,8	3,0
NF 7	Oil palm	9,8	11	25,0	1,4
NF 8	Flax	6,42	20,0	38,0	65,0
NF 9	Areca	18,1	1,2	476	60
NF 10	Banana	22,4	1,5	30,0	4,2
NF 11	Jute	7,6	11,3	30,0	6,0
NF 12	Pineapple	3	18,3	80,0	9,0
NF 13	Sisal	12,0	25,0	47,0	8,0
NF 14	Coir	21	0,06	12,0	0,3
NF 15	Coconut	3,2	8,0	14,0	1,0
NF 16	Sugar can	19,1	9,4	40,0	2,8

3.1. Results

This article discusses the most widely used matrices in biofiber-reinforced composites that are derived from renewable and petrochemical resources. The first step involves developing the decision hierarchy involving mechanical, physical, and chemical features as the main criteria. The features listed in Tables 5, 6, and 7 are added to the hierarchy as the sub-criteria. Figure 1 in the Appendix illustrates the final hierarchy composed of main and sub-criteria. Application of Eq. 1-10 results in the weights provided in Table 8 for the main criteria.

Table 8. Main Criteria Weights.

Criteria	%
Physical	16.98
Mechanical	44,29
Chemical	38,73

The next step involves pairwise comparison of sub-criteria under each main criteria. Table 9 presents the decision matrices using Saaty's comparison scheme and the resulting weights.

Table 9. Decision Matrices.

	Micro-fibrillar angle	Lignin	Hemicellulose	Cellulose	Moisture content	**Normalized Principal Eigenvector**
Chemical Features	1	2	3	4	5	
Micro-fibrillar angle	1	1/3	1/3	1/4	1/2	7,92%
Lignin	3	1	1	1/2	1/2	16,02%
Hemicellulose	3	1	1	1/2	1/2	16,02%
Cellulose	4	2	2	1	1/3	24,69%
Moisture content	2	2	2	3	1	35,34%
Mechanical Features	Elongation at break	Young's modulus	Tensile strength	Density		**Normalized Principal Eigenvector**
Elongation at break	1	2	3	1		36,32%
Young's modulus	1/2	1	1/2	1/2		13,82%
Tensile strength	1/3	2	1	1/2		17,88%
Density	1	2	2	1		31,98%
Physical Features	Width of lumen	Thickness of single cell wall	Fiber diameter	Fiber length		**Normalized Principal Eigenvector**
Width of lumen	1	1/3	1/2	1/4		9,97%
Thickness of single cell	3	1	2	1		34,52%
Fiber diameter	2	1/2	1	1/2		18,50%
Fiber length	4	1	2	1		37,01%

Figure 2 illustrates the weights of the selected sub-criteria.

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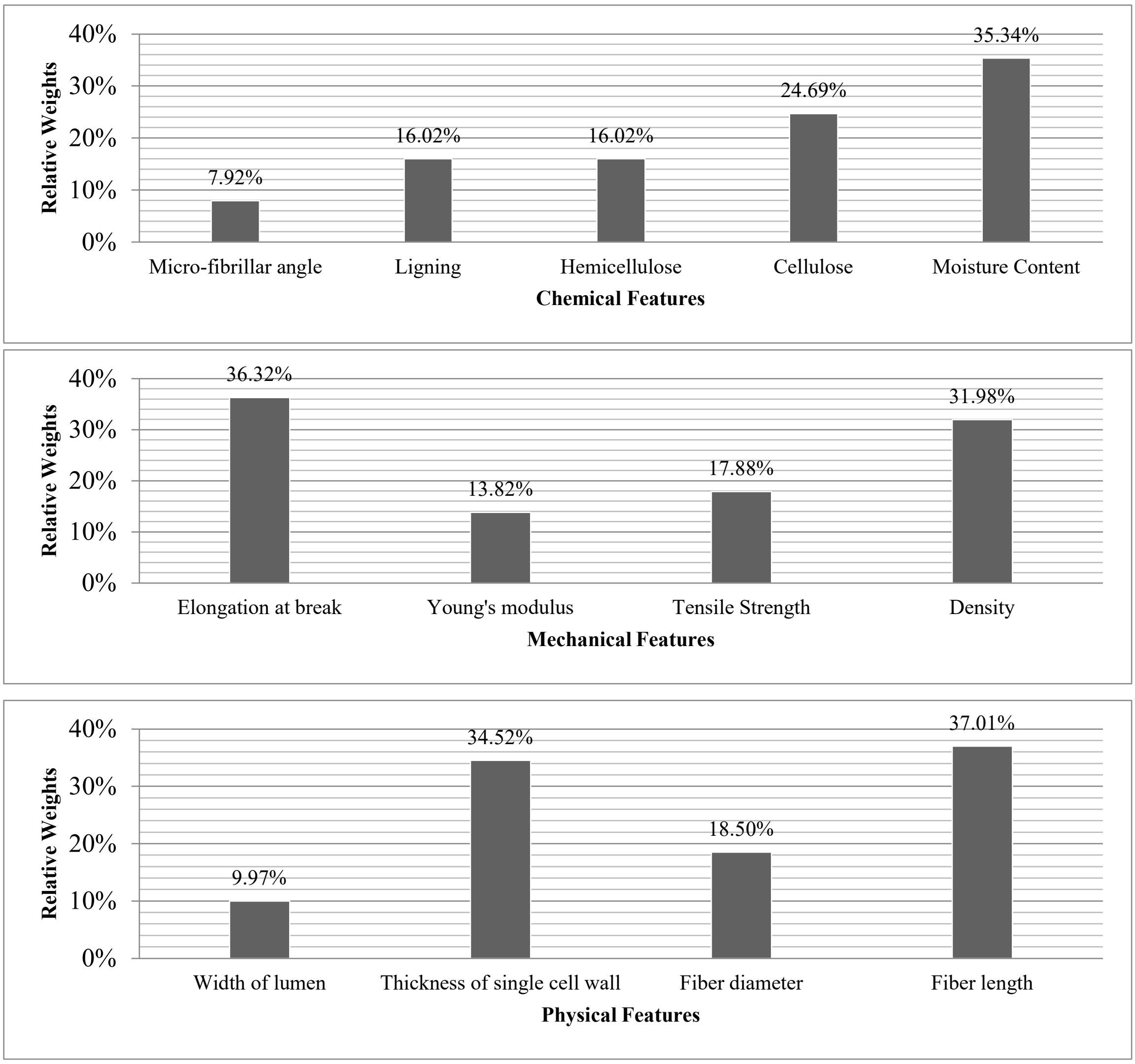

Figure 2. Sub-criteria weights.

Sub-criteria weights are multiplied with their associated values given in Tables 5, 6, and 7, followed by a normalization of the resulting values due to the various scales. The top half of Table 10 provides the resulting normalized values. The final step of the methodology involves multiplying the weights of the main criteria with the associated normalized values under each sub-criteria. The bottom half of Table 10 provides the weighted score of each sub-criteria. Calculating the total scores for each natural fiber alternative shows the contribution of each alternative toward the overall goal of choosing the best natural fiber.

Table 10. Weighted Scores of Natural Fibers.

								Normalized								
Micro-	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Ligning	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0
Hemicel.	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Cellulose	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Moisture	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Elong.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,2	0,0	0,0
Young's	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0
Tensile	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0
Density	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Width of	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
Thicknes	0,0	0,0	0,2	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0
Fiber D.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Fiber	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Priorities																
Micro-	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Ligning	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Hemicel.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Cellulose	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Moisture	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Elong.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Young's	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Tensile	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Density	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Width of	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Thicknes	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Fiber D.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Fiber	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Weighted	**0,1**	**0,1**	**0,2**	**0,2**	**0,1**	**0,1**	**0,1**	**0,2**	**0,3**	**0,1**	**0,1**	**0,2**	**0,1**	**0,1**	**0,1**	**0,1**

Total weighted scores presented in the last row of Table 10 and Figure 3 show that Areca is the optimum fiber type with a total weight score of wt = 0.313.

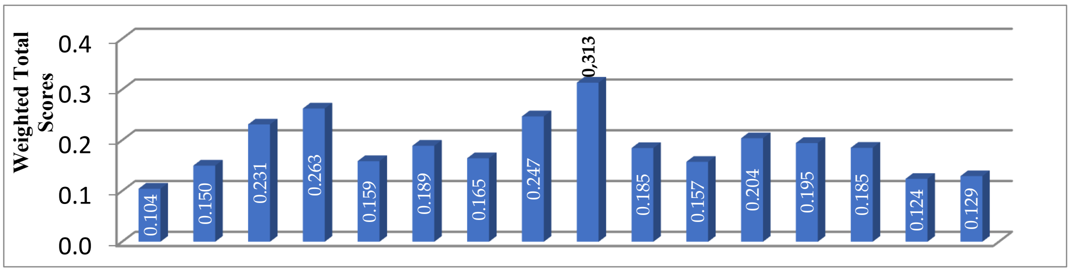

Figure 3. Weighted Scores.

Table 11 presents the characteristics of polymers commonly utilized for producing composite materials with natural fibers.

Table 11. The technical characteristics of polymers.

Polymer code	Polymer material	Elongation at break (%)	Modulus of elasticity(GPa)	Tensile strength (MPa)	Density (g/cm³)	References
P 1	Vinyl ester	2	2–4.5	40–90	1,2–1,5	[175–177]
P 2	Polystyrene	1–3,6	1,2–2,6	35,9–56,6	1,04–	[100–
P 3	Epoxy	1–6	3–6	35–100	1,1–1,4	[175–177]
P 4	Polybutylene terephthalate	250	1,93–3	50–60	1,30–1,38	[139]
P 5	Polyethylene terephthalate	30–300	2,76–4,14	48,3–72,4	1,29–1,40	[100–102,142]
P 6	Polycarbonate	70–150	2–2,44	60–72,4	1,14–	[100–
P 7	Nylon 6	20–150	2,9	43–79	1,12–	[175–177]
P 8	Polyamide	30–100	1,2–3,2	90–165	1,12–	[100–

P 9	High density polyethylene (HDPE)	2,0–130	0,4–1,5	14,5–38	0,94–0,96	[175–177]
P 10	Low-density polyethylene (LDPE)	90–800	0,055–0,38	40–78	0,910–0,925	[175–177]
P 11	Acrylonitrile b utadiene styrene	1,5–100	1,1–2,9	27,6–55,2	1–1,2	[100–102,142]
P 12	PP	15–700	0,95–1,77	26–41,4	0,899–0,920	[175–177]

Applying the same steps in comparing the polymer alternatives result in the values provided in Table 12.

Table 12. Normalized and weighted scores of polymer alternatives.

	Normalized											
Elongation at break	0,00	0,00	0,00	0,14	0,09	0,06	0,04	0,09	0,06	0,25	0,02	0,20
Young's modulus	0,11	0,06	0,15	0,08	0,12	0,07	0,10	0,07	0,03	0,00	0,06	0,08
Tensile Strength	0,09	0,06	0,09	0,07	0,08	0,09	0,08	0,18	0,03	0,08	0,05	0,04
Density	0,09	0,07	0,09	0,09	0,09	0,08	0,08	0,08	0,07	0,06	0,08	0,06
	Priorities											
Elongation at break	0,00	0,00	0,00	0,05	0,03	0,02	0,01	0,03	0,02	0,09	0,01	0,07
Young's modulus	0,01	0,00	0,02	0,01	0,01	0,01	0,01	0,01	0,00	0,00	0,00	0,01
Tensile Strength	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,03	0,00	0,01	0,01	0,00
Density	0,03	0,02	0,02	0,03	0,03	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Total Weighted	**0,06**	**0,04**	**0,06**	**0,10**	**0,09**	**0,07**	**0,07**	**0,10**	**0,05**	**0,13**	**0,05**	**0,11**

Total weighted scores presented in the last row of Table 12 and Figure 4 shows that Low-density polyethylene (LDPE) is the optimum polymer type with a total weight score of wt = 0.130.

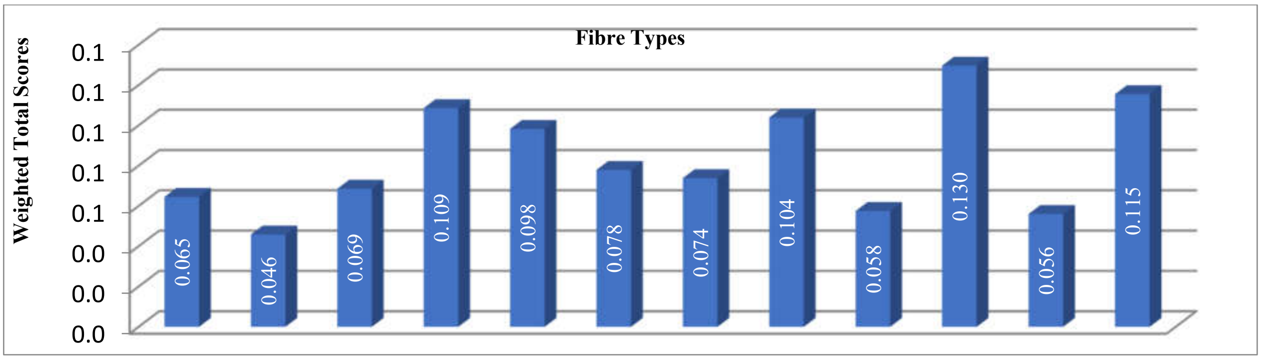

Figure 4. Polymer scores

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5. Conclusions

The sectoral use of composite materials supported with polymer materials and containing biofibers has garnered significant attention in recent times. The usage of polymer materials as bindings for composites supported by biofibers has increased significantly. In this study, a methodical process was followed in the most efficient natural fibre and polymer selection for use in aerospace implementations. First, this research presents a thorough investigation of the literature on the natural fibres and polymers that are most commonly used. To improve comprehension, information on the natural fibres' chemical (micro-fibrillar angle, lignin, hemicellulose, cellulose, and moisture content), mechanical (elongation at break, Young's modulus, tensile strength, and density), physical (width of lümen, fiber length, thickness of single cell wall, and fiber diameter) characteristics, and polymer's technical characteristics (elongation at break, modulus of elasticity, tensile strength, and density) were gathered and examined prior to the selection process starting. For the purpose of this study, criteria and sub-criteria were assessed by experts. A hierarchical strategy methodology was performed to identify the weightages assigned to the attributes based on the notional significance of each of the criteria. Using the process, the best variation of each fiber and polymer was chosen for use in applications. Based on the ranking and performance scores of these chosen polymers and fibers, the optimal substitute was evaluated. This analysis can help researchers, designers, and decision-makers in future research endeavors for aviation material applications.

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Appendix A

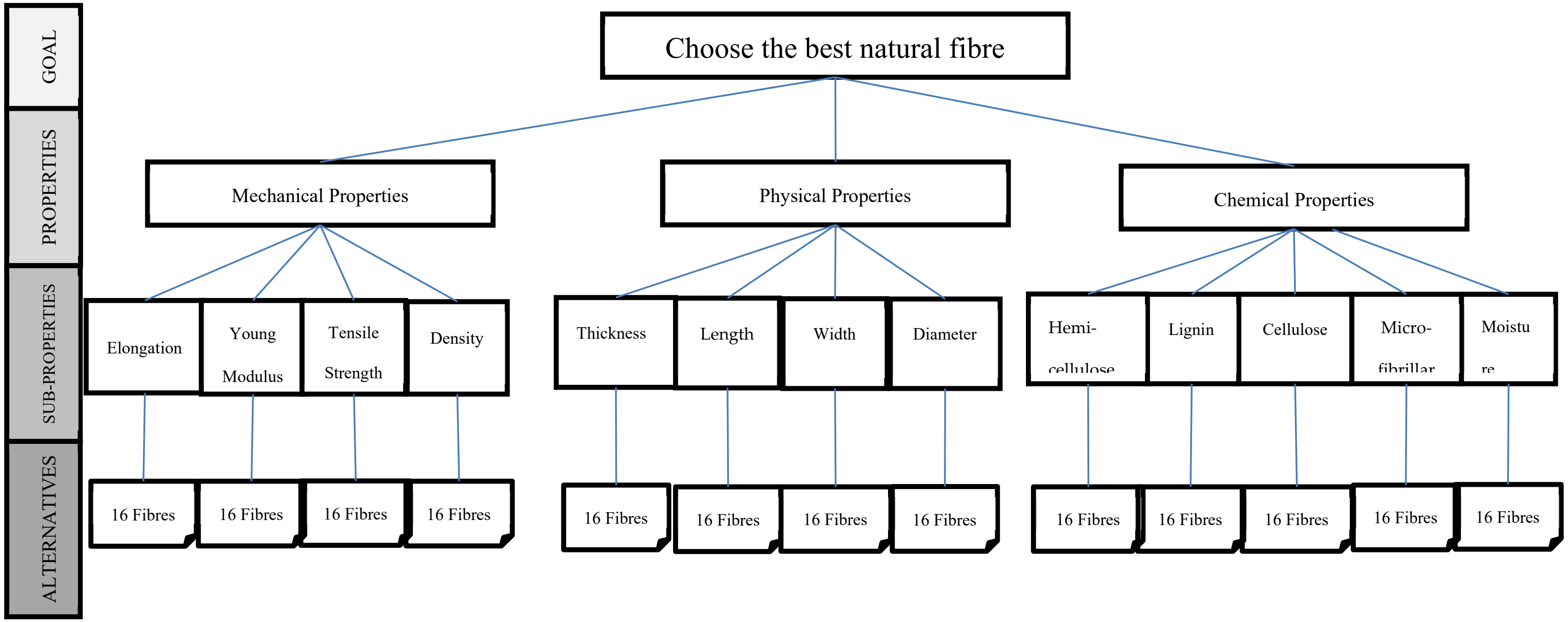

Figure 1. Decision Hierarchy.

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