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# Assessing Natural Fibers: A MCDM Methodological Approach to Sustainable Resource Evaluation

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ABSTRACT

Scientists are actively exploring eco-friendly options to synthetic fibers because of their persistent pollution problems. Natural fibers, derived from plants and animals like bamboo, hemp, jute, and oil palm, are emerging as viable replacements for synthetics in making biodegradable, lightweight composites with enhanced mechanical characteristics. Chemical modifications have the potential to improve these properties, and treatments can change the structure of fibers to enhance mechanical interlocking. This review explores the characteristics of these natural fibers and their possible uses to promote sustainability and economic viability. The environmentally friendly qualities, cost-effectiveness, superior life cycle, and lightweight attributes are propelling the adoption of natural fibers in cement-based composites. A research study utilizes experimental and finite element analysis to create a sustainable cementitious composite reinforced with natural fibers. The choice of materials is critical to avoid premature failures and associated losses. In this study, the WASPAS method is applied to choose the most suitable natural fiber for durable composites from a selection of eight options based on six criteria. The results indicate that Basalt is the preferred choice, followed by flax and cotton.

## 1. INTRODUCTION

Natural fibers have become a favorable choice for improving composite materials, largely due to sustainability considerations. They are renewable, cost-efficient, eco-friendly, and carbon-neutral. Fiber-reinforced composites, extensively utilized in industries such as construction, aerospace, and automotive, frequently utilize synthetic fibers like glass, carbon, and aramid, which are produced from fossil fuels using energy-intensive methods. Despite providing superior strength and durability, the production of these synthetic fibers is associated with environmental issues, including high energy consumption, costs, and pollution. Recycling petroleum-based products results in solid waste generation and carbon dioxide (CO2) emissions. Strict regulations regarding non-biodegradable composites in regions such as Europe and North America have accelerated the creation of sustainable alternatives using natural resources. Natural fibers, derived from plants, animals, or minerals, are categorized as biomass fibers. Plant fibers, in particular, are highly favored for their cost-efficiency and impressive mechanical characteristics. Examples of common natural fibers include wood fibers sourced from trees, non-wood plant fibers such as bamboo, jute, basalt, cotton, kenaf, flax, sisal, hemp, and chitin extracted from crustaceans, insects, and fungi. All these fibers are fully recyclable. They play a pivotal role in the advancement of eco-friendly materials. Using natural fiber-reinforced biocomposites can reduce the carbon footprint by nearly 50% compared to composites derived

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from petroleum. Wood and bamboo fibers, abundant and versatile, have been integral to engineering for centuries, notably in civil engineering. The key factors propelling the use of natural fibers in composite formation, which can compete with synthetic fiber-reinforced composites, are sustainability, respectable strength, low density, and cost-effectivenessIn recent years, there has been a focus on developing natural fiber composites that are both cost-effective and high-performing while minimizing environmental impact. These materials are being increasingly utilized in industries such as building and construction, aerospace, automotive, biomedical, electronics, and food packaging. The construction sector, which is a significant consumer of raw materials, contributes to 25-40% of global CO2 emissions and holds substantial importance in the global economy. Incorporating natural materials into construction is essential for moving towards a zero-carbon future. The use of lightweight materials can enhance fuel efficiency, while biodegradable materials can decrease pollution in production and recycling processes. Therefore, natural fiber composites with low density and biodegradability provide innovative solutions for the automotive and aerospace industries.

Natural plant fibers are mainly made up of cellulose, hemicellulose, lignin, and small quantities of pectin and waxes, which classify them as lignocellulosic composites. The high hydrophilicity of natural fibers, due to the presence of hydroxyl and acid groups in cellulose and hemicellulose, respectively, results in heightened water absorption and degradation. To improve composite performance, interfacial modifications are used to tackle compatibility problems between hydrophilic natural fibers and hydrophobic polymer matrices. Physical or chemical treatments can be applied to modify the structures, morphologies, and properties of both natural fibers and matrices, leading to enhanced interfacial compatibility, strength, and stability of natural fiber composites (NFCs) [9]. Nanoscale examination of natural fibers is essential for the advancement of NFCs, as factors like cellulose fibril orientation and the presence of lignin and hemicellulose greatly influence the mechanical, thermal, and physical properties of the fibers. Advancements in nanotechnology and computational modeling now allow for the microscopic and nanoscopic analysis of material systems, which is propelling the progress of NFCs. By understanding the interactions between fibers and matrices at the nanoscale in different chemical environments, composite processing can be optimized, leading to enhanced overall performance. The inclusion of nano-dimensional phases has been found to boost the mechanical properties, stability, and specific functionalities of composites. For instance, the hierarchical structure of natural fibers such as wood and bamboo fibers has inspired the integration of optical, electrical, and magnetic functionalities .

Researchers globally are prioritizing environmental and biodiversity conservation by improving the quality of eco-friendly and sustainable products. Natural fibers are gaining preference over harmful synthetic materials because of their advantageous macro and micro properties, as well as their environmentally friendly traits. Although natural fibers have drawbacks like hydrophilicity and biocompatibility, they can be effectively used with different chemical treatments and surface modifications. They have been successful in various applications, including composite materials (despite being less dense than glass fiber), biopolymers, textiles, biosensors, biomedical applications, and smart packaging [1]. Utilizing natural fibers can aid in decreasing pollutants such as waste, toxins, and greenhouse gas emissions from landfills. Natural fibers consist of plant, animal, and mineral fibers, with cellulose and protein being the main components of plant and animal fibers, respectively. These fibers are obtained from various plant parts, including stems, leaves, seeds, xylem, bark, and fruit, depending on the plant species. They are sourced from either primary or secondary meristematic tissue. We have developed and verified a new set of visual image features for application in the Multi-Criteria Decision-Making (MCDM) framework. Our study introduces a new MCDM problem concerning the adaptive selection of edge detection algorithms based on natural fibers. Using the WASPAS method, we ranked edge detection algorithms according to their appropriateness for various types of natural fibers. Guitouni et al. have provided guidelines for selecting the suitable MCDM algorithm. The WASPAS method merges the weighted sum model (WSM) and the weighted product model (WPM), providing a mathematically simple yet accurate approach compared to WSM and WPM. This makes the WASPAS method an effective tool for decision-making in algorithm selection. To handle uncertainty in initial information, a neutrosophic set environment was utilized.

## 2. MATERIAL AND RESEARCH METHODS

Bamboo, jute, basalt, cotton, kenaf, flax, sisal, and hemp are natural fibers with diverse industrial applications. Bamboo grows rapidly and is used in construction, furniture, and textiles. Jute, a strong and biodegradable fiber, is popular in packaging, textiles, and non-woven products. Basalt fibers, from basalt rock, are strong and fire-resistant, used in construction and automotive industries. Cotton is valued for its softness and breathability in textiles. Kenaf is used in paper and biodegradable plastics for its long, silky fibers. Flax fibers are strong and moisture-wicking, used in textiles and composites. Sisal fibers, from the agave plant, are durable and used in ropes, carpets, and geotextiles. Hemp fibers, from the cannabis plant, are strong, biodegradable, and used in textiles, paper, and as a sustainable alternative to synthetics. These fibers offer environmentally friendly alternatives to synthetic materials, each contributing uniquely to various industries.

Utilizing composite materials derived from sustainable and renewable sources is widely acknowledged as a critical component of future manufacturing processes. Biodegradable polymers, especially Poly lactic acid (PLA), are being investigated as potential matrix materials for sustainable composites. PLA, sourced from materials such as corn and potatoes, is highly preferred because of its biodegradability and renewability, while also offering mechanical properties similar to synthetic polymers. Achieving a crystalline structure and ensuring thermomechanical stability are crucial aspects that make PLA a promising structural material. There has been significant focus on reinforcing fibers with PLA, where the reinforcement fibers can be either synthetic, such as glass and carbon fibers, or natural, sourced from plants like hemp, jute, cotton, and flax, as well as animals. Given the importance of environmental protection, the biodegradable and recyclable nature of natural fibers makes them preferable to synthetic fibers. The thermal and mechanical characteristics of a product can be substantially influenced by the selection of materials, fiber treatment, and primary processing techniques. Hence, choosing the appropriate material is a crucial aspect of the design process, taking into account factors such as product specifications, cost, and environmental sustainability. This research seeks to determine the most suitable natural fiber for reinforcing bio-based polymers such as PLA, aiming to develop a functional material that is environmentally friendly and economically feasible. When there’s only one criterion to consider, selecting between options is simple. However, evaluating multiple criteria simultaneously, including their weighting, interdependencies, and other factors, can complicate the selection process. This complexity often necessitates more sophisticated approaches to identify a viable solution. Multi-criteria decision-making (MCDM) is a commonly employed methodology in complex decision-making scenarios. The analysis is carried out using a hybrid integrated framework that merges a primary alternative evaluation system, methods for weighting criteria, MCDM ranking techniques, and a mechanism for assessing final rankings and choosing the best material. This tool simplifies the selection process, assisting in the choice of input power for refrigeration systems, titanium alloy for biomedical applications, and the optimal natural fibers for functional composites in environmentally friendly solutions.

**WASPAS Methods:** This research focuses on selecting edge detection algorithms for natural fibers. The Weighted Aggregated Sum Product Assessment (WASPAS) approach, frequently employed in various Multi-Criteria Decision-Making (MCDM) problems, was reviewed. The method’s popularity stems from its simplicity and stability. Subjective criteria weights were established using a direct evaluation method, which involves assigning subjective values to assess alternative performance and make decisions [19]. The Weighted Aggregated Sum Product Assessment (WASPAS) method is utilized to evaluate alternatives using multiple decision criteria. WASPAS integrates the Weighted Product (WP) and Simple Adaptive Weighting (SAW) approaches [8]. This method is extensively applied in Multi-Criteria Decision Making (MCDM) to evaluate alternatives across numerous criteria [9]. WASPAS is recognized for its capacity to minimize errors and enhance assessment accuracy when determining the highest and lowest scores [10]. It is particularly effective in intricate decision-making contexts, producing highly precise models [12].

The Multi-Criteria Decision Making (MCDM) process involves several key steps. Initially, a decision matrix is formulated, outlining the problem with m alternatives and n criteria. The relative importance of each criterion is denoted by wj, while the performance value of each alternative concerning each criterion is recorded. Subsequently, the decision matrix is normalized using linear normalization for both beneficial and non-beneficial attributes. The relative importance of alternatives is then computed using the Weighted Sum Model (WSM), a popular Multiple Attribute Decision Making (MADM) approach valued for its practicality. Moreover, the Weighted Product Model (WPM) is employed to calculate relative importance, further enhancing ranking accuracy. The integration of additive and multiplicative forms of aggregation enhances the accuracy of alternative ranking. Ultimately, alternatives are ranked based on their overall performance across all criteria. The Weighted Aggregated Sum Product Assessment (WASPAS) method combines the strengths of the Weighted Sum Model (WSM) and the Weighted Product Model (WPM). WSM assumes additive utility, meaning the total utility of an alternative is the sum of products. However, combining dimensions with different units may violate this assumption. On the other hand, WPM is considered dimensionless as it eliminates units of measure. By integrating these two aggregation functions, the ranking accuracy of results is improved. The subsequent section provides a derivation of the ranking accuracy.

# 3. RESULT AND DISCUSSION

**TABLE 1.** Initial Decision Matrix for Natural Fiber

| | Strain at break (%) | Aspect Ratio ($\mu$m) | Specific Strength (MPa/g/cm$^3$) | Moisture Absorption (%) | Specific Modulus (GPa/g/cm$^3$) | Cost (US $/ton) |
|---|---|---|---|---|---|---|
| Bamboo | 1.73 | 48.67 | 383.1 | 14 | 22.1 | 500 |
| Jute | 1.8 | 226.67 | 411 | 12 | 14 | 950 |
| Basalt | 3.56 | 1760.56 | 787.5 | 0.1 | 24.18 | 1000 |
| Cotton | 6.5 | 1510.64 | 264.9 | 33.5 | 8 | 2850 |
| Kenaf | 1.6 | 258.33 | 641 | 9.1 | 36.55 | 400 |
| Flax | 1.4 | 1744.19 | 832.5 | 7 | 36 | 3150 |
| Sisal | 2.5 | 162.96 | 426.3 | 11 | 29 | 650 |
| Hemp | 1.6 | 983.61 | 360 | 8 | 47.3 | 1550 |

Table 1 shows the initial decision matrix for natural fibers, including bamboo, jute, basalt, cotton, kenaf, flax, sisal, and hemp. The matrix includes various criteria such as strain at break (%), aspect ratio ($\mu$m), specific strength (MPa/g/cm$^3$), moisture absorption (%), specific modulus (GPa/g/cm$^3$), and cost (US $/ton).

Bamboo has a strain at break of 1.73%, an aspect ratio of 48.67 $\mu$m, a specific strength of 383.1 MPa/g/cm$^3$, a moisture absorption of 14%, a specific modulus of 22.1 GPa/g/cm$^3$, and costs 500 US $/ton. Jute has a strain at break of 1.8%, an aspect ratio of 226.67 $\mu$m, a specific strength of 411 MPa/g/cm$^3$, a moisture absorption of 12%, a specific modulus of 14 GPa/g/cm$^3$, and costs 950 US $/ton.

Basalt has a strain at break of 3.56%, an aspect ratio of 1760.56 $\mu$m, a specific strength of 787.5 MPa/g/cm$^3$, a moisture absorption of 0.1%, a specific modulus of 24.18 GPa/g/cm$^3$, and costs 1000 US $/ton. Cotton has a strain at break of 6.5%, an aspect ratio of 1510.64 $\mu$m, a specific strength of 264.9 MPa/g/cm$^3$, a moisture absorption of 33.5%, a specific modulus of 8 GPa/g/cm$^3$, and costs 2850 US $/ton.

Kenaf has a strain at break of 1.6%, an aspect ratio of 258.33 $\mu$m, a specific strength of 641 MPa/g/cm$^3$, a moisture absorption of 9.1%, a specific modulus of 36.55 GPa/g/cm$^3$, and costs 400 US $/ton. Flax has a strain at break of 1.4%, an aspect ratio of 1744.19 $\mu$m, a specific strength of 832.5 MPa/g/cm$^3$, a moisture absorption of 7%, a specific modulus of 36 GPa/g/cm$^3$, and costs 3150 US $/ton.

Sisal has a strain at break of 2.5%, an aspect ratio of 162.96 $\mu$m, a specific strength of 426.3 MPa/g/cm$^3$, a moisture absorption of 11%, a specific modulus of 29 GPa/g/cm$^3$, and costs 650 US $/ton. Hemp has a strain at break of 1.6%, an aspect ratio of 983.61 $\mu$m, a specific strength of 360 MPa/g/cm$^3$, a moisture absorption of 8%, a specific modulus of 47.3 GPa/g/cm$^3$, and costs 1550 US $/ton.

Table 2 presents the performance values of natural fibers based on strain at break, aspect ratio, specific strength, moisture absorption, specific modulus, and cost. Bamboo and jute show moderate overall values, while basalt exhibits high aspect ratio and strength but higher moisture absorption. Cotton demonstrates maximum strain at break and modulus, though with lower strength and higher cost. Kenaf provides a balanced profile with good strength and low cost. Flax achieves the highest specific strength and aspect ratio but is expensive. Sisal and hemp show moderate performance across most criteria,

**TABLE 2.** Performance Value

| | Strain at break | Aspect Ratio | Specific Strength | Moisture Absorption | Specific Modulus | Cost |
|---|---|---|---|---|---|---|
| Bamboo | 0.26615 | 0.02764 | 0.46018 | 0.00714 | 0.36199 | 0.80000 |
| Jute | 0.27692 | 0.12875 | 0.49369 | 0.00833 | 0.57143 | 0.42105 |
| Basalt | 0.54769 | 1.00000 | 0.94595 | 1.00000 | 0.33085 | 0.40000 |
| Cotton | 1.00000 | 0.85805 | 0.31820 | 0.00299 | 1.00000 | 0.14035 |
| Kenaf | 0.24615 | 0.14673 | 0.76997 | 0.01099 | 0.21888 | 1.00000 |
| Flax | 0.21538 | 0.99070 | 1.00000 | 0.01429 | 0.22222 | 0.12698 |
| Sisal | 0.38462 | 0.09256 | 0.51207 | 0.00909 | 0.27586 | 0.61538 |
| Hemp | 0.24615 | 0.55869 | 0.43243 | 0.01250 | 0.16913 | 0.25806 |

indicating their suitability for applications requiring balanced mechanical and economic properties.

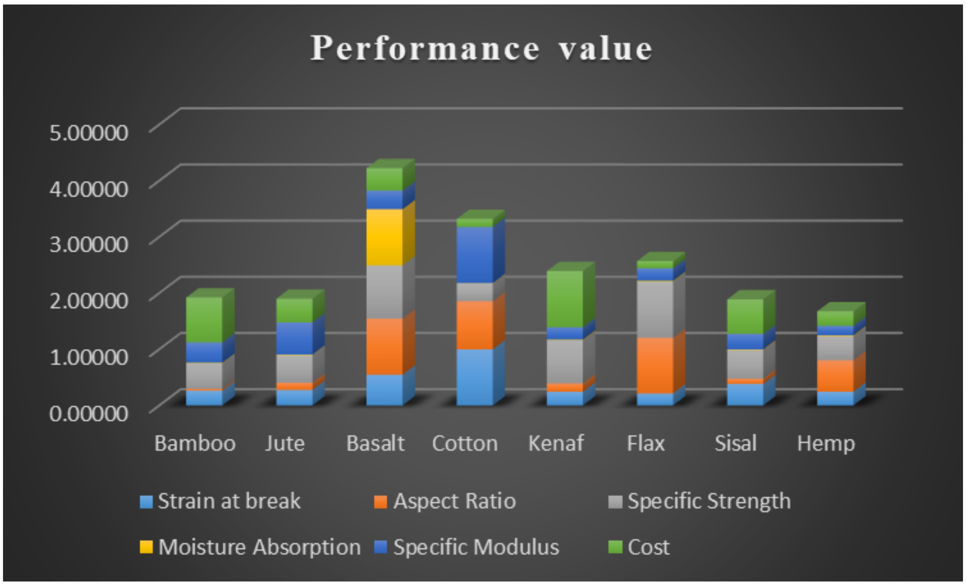


**FIGURE 1.** Performance value

Figure 1 presents the performance values of various natural fiber materials, including bamboo, jute, basalt, cotton, kenaf, flax, sisal, and hemp, across different criteria. The criteria include strain at break, aspect ratio, specific strength, moisture absorption, specific modulus, and cost. The values indicate the relative performance of each material in these categories. For instance, bamboo shows moderate values across most criteria, while cotton demonstrates high strain at break and specific modulus but low cost. Basalt stands out with high aspect ratio, specific strength, and moisture absorption values. These values can be crucial for selecting the appropriate material for different applications based on specific requirements and priorities.

**TABLE 3.** Weight

| | Strain at break | Aspect Ratio | Specific Strength | Moisture Absorption | Specific Modulus | Cost |
|---|---|---|---|---|---|---|
| Bamboo | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Jute | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Basalt | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Cotton | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Kenaf | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Flax | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Sisal | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Hemp | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |

Table 3 displays the weights assigned to each criterion for the evaluation of natural fibers. Each criterion, including strain at break, aspect ratio, specific strength, moisture absorption, specific modulus, and cost, is given equal weight of 0.17, totaling to 1. These weights indicate that each criterion is considered equally important in the evaluation process for all natural fibers, ensuring a balanced assessment across all criteria.

**TABLE 4.** WSM Weighted Normalized Decision Matrix

| | Strain at break | Aspect Ratio | Specific Strength | Moisture Absorption | Specific Modulus | Cost |
|---|---|---|---|---|---|---|
| Bamboo | 0.04418 | 0.00459 | 0.07639 | 0.00119 | 0.06009 | 0.13280 |
| Jute | 0.04597 | 0.02137 | 0.08195 | 0.00138 | 0.09486 | 0.06989 |
| Basalt | 0.09092 | 0.16600 | 0.15703 | 0.16600 | 0.05492 | 0.06640 |
| Cotton | 0.16600 | 0.14244 | 0.05282 | 0.00050 | 0.16600 | 0.02330 |
| Kenaf | 0.04086 | 0.02436 | 0.12782 | 0.00182 | 0.03633 | 0.16600 |
| Flax | 0.03575 | 0.16446 | 0.16600 | 0.00237 | 0.03689 | 0.02108 |
| Sisal | 0.06385 | 0.01537 | 0.08500 | 0.00151 | 0.04579 | 0.10215 |
| Hemp | 0.04086 | 0.09274 | 0.07178 | 0.00208 | 0.02808 | 0.04284 |

Table 4 presents the Weighted Sum Model (WSM) weighted normalized decision matrix for natural fibers based on multiple performance criteria. Bamboo and jute exhibit moderate contributions across most parameters, while basalt shows high values in aspect ratio and specific strength. Cotton demonstrates strong performance in strain at break and specific modulus but lower cost efficiency. Kenaf provides balanced strength with high cost contribution. Flax achieves the highest specific strength and aspect ratio but with lower cost effectiveness. Sisal and hemp display moderate overall contributions, indicating stable performance. Overall, the matrix highlights variations in fiber performance, supporting comparative evaluation and material selection decisions.

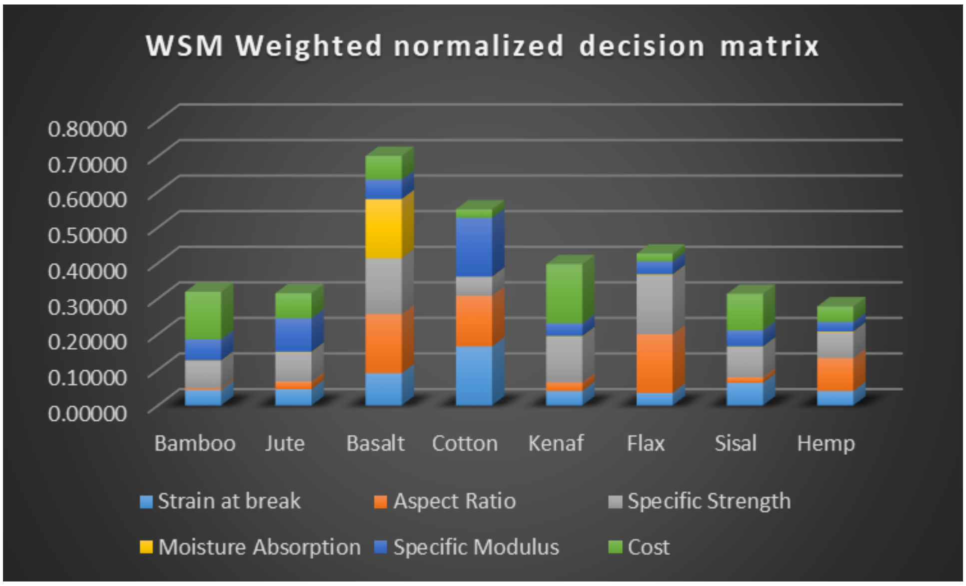


**FIGURE 2.** WSM Weighted normalized decision matrix

figure 2 displays the weighted normalized decision matrix for various natural fiber materials, including bamboo, jute, basalt, cotton, kenaf, flax, sisal, and hemp, based on the Analytic Hierarchy Process (AHP) method. The matrix provides a quantitative assessment of each material's performance across different criteria, which have been weighted to reflect their relative importance. For example, bamboo has a low score for strain at break and aspect ratio but higher scores for specific strength, specific modulus, and cost. Jute also scores relatively low in strain at break and aspect ratio but performs better in specific strength and specific modulus.

Table 5 displays the Weighted Product Model (WPM) weighted normalized decision matrix for natural fibers based on multiple evaluation criteria. Bamboo and jute exhibit moderate values across most parameters, indicating balanced

**TABLE 5.** WPM Weighted Normalized Decision Matrix

| | Strain at break | Aspect Ratio | Specific Strength | Moisture Absorption | Specific Modulus | Cost |
|---|---|---|---|---|---|---|
| Bamboo | 0.26615 | 0.02764 | 0.46018 | 0.00714 | 0.36199 | 0.80000 |
| Jute | 0.27692 | 0.12875 | 0.49369 | 0.00833 | 0.57143 | 0.42105 |
| Basalt | 0.54769 | 1.00000 | 0.94595 | 1.00000 | 0.33085 | 0.40000 |
| Cotton | 1.00000 | 0.85805 | 0.31820 | 0.00299 | 1.00000 | 0.14035 |
| Kenaf | 0.24615 | 0.14673 | 0.76997 | 0.01099 | 0.21888 | 1.00000 |
| Flax | 0.21538 | 0.99070 | 1.00000 | 0.01429 | 0.22222 | 0.12698 |
| Sisal | 0.38462 | 0.09256 | 0.51207 | 0.00909 | 0.27586 | 0.61538 |
| Hemp | 0.24615 | 0.55869 | 0.43243 | 0.01250 | 0.16913 | 0.25806 |

performance. Basalt shows high values in aspect ratio and specific strength, reflecting its superior mechanical characteristics. Cotton demonstrates strong strain at break and modulus but lower cost efficiency. Kenaf offers good strength with high cost contribution. Flax achieves the highest specific strength and aspect ratio but is less economical. Sisal and hemp present moderate overall values, highlighting their suitability for applications requiring balanced mechanical properties and cost considerations.

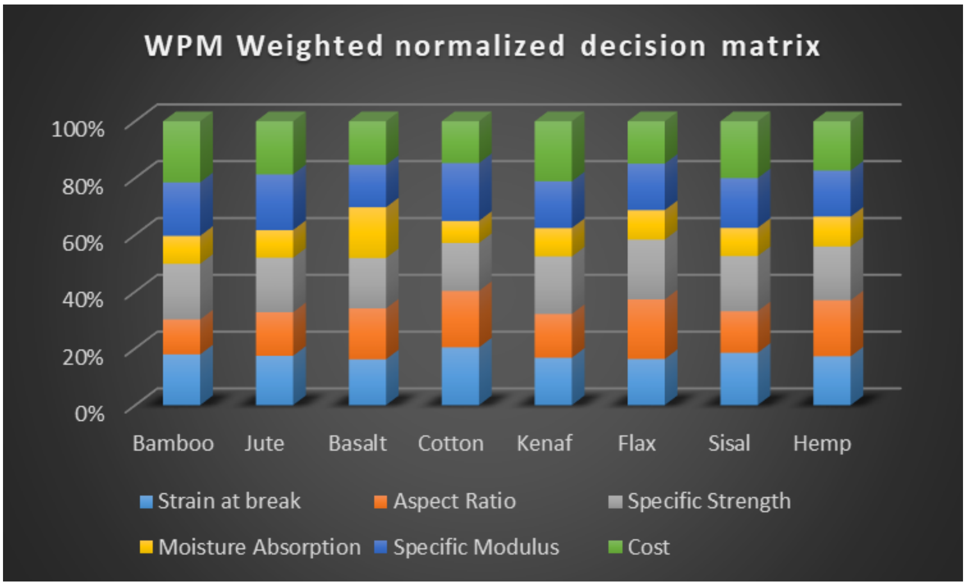


**FIGURE 3.** WPM Weighted normalized decision matrix

**TABLE 6.** WSM and WPM Preference Score

| | WSM Preference Score | WPM Preference Score |
|---|---|---|
| Bamboo | 0.31924 | 0.13942 |
| Jute | 0.31543 | 0.182354 |
| Basalt | 0.701265 | 0.640903 |
| Cotton | 0.55105 | 0.221662 |
| Kenaf | 0.397192 | 0.202773 |
| Flax | 0.42655 | 0.211419 |
| Sisal | 0.313671 | 0.17562 |
| Hemp | 0.278378 | 0.179826 |

Table 6 presents the preference scores for natural fibers calculated using the Weighted Sum Model (WSM) and Weighted Product Model (WPM). Basalt achieves the highest scores in both methods, followed by cotton and flax, indicating superior overall performance. Kenaf shows moderate performance, while bamboo, jute, sisal, and hemp exhibit relatively lower scores. These values reflect the comparative ranking of fibers based on multiple criteria, where higher scores indicate better suitability. Furthermore, the Weighted Aggregated Sum Product Assessment (WASPAS) with $\lambda = 0.5$ provides a balanced evaluation by equally considering both additive and multiplicative approaches in decision-making.

**TABLE 7.** WASPAS Coefficient

| | WASPAS Coefficient |
|---|---|
| Bamboo | 0.229328 |
| Jute | 0.248892 |
| Basalt | 0.671084 |
| Cotton | 0.386356 |
| Kenaf | 0.299983 |
| Flax | 0.318984 |
| Sisal | 0.244645 |
| Hemp | 0.229102 |

The Table 7 WASPAS coefficients for various bio-degradable reinforced epoxy composite materials are as follows: Bamboo (0.229328), Jute (0.248892), Basalt (0.671084), Cotton (0.386356), Kenaf (0.299983), Flax (0.318984), Sisal (0.244645), and Hemp (0.229102). These coefficients represent the weights assigned to each material based on their performance across selected criteria in the analysis. Basalt has the highest coefficient, indicating it is considered most favorable according to the criteria evaluated, while Bamboo and Hemp have the lowest coefficients, suggesting they are less favorable in comparison.

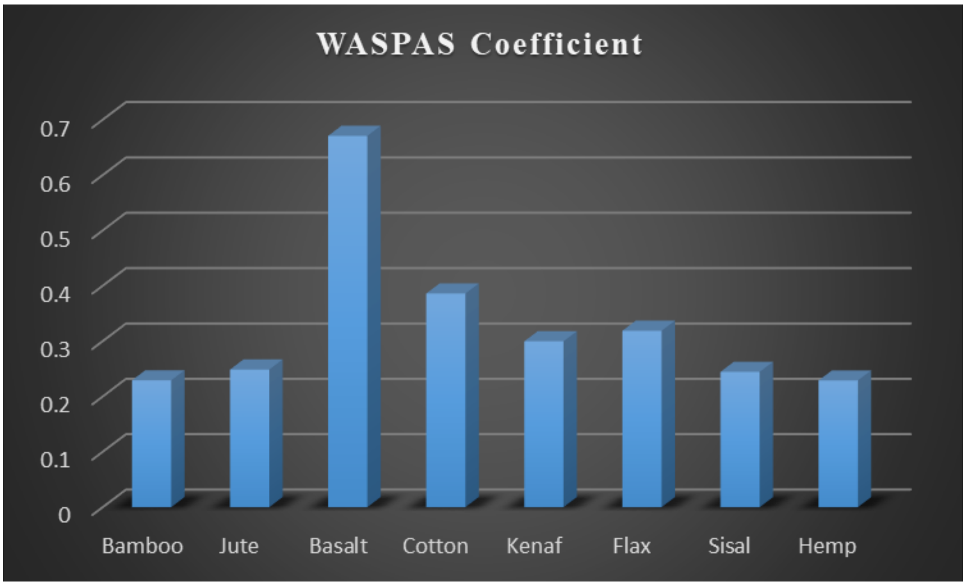


**FIGURE 4.** WASPAS Coefficient

Figure 4 presents the Weighted Aggregated Sum Product Assessment (WASPAS) coefficients for various natural fiber materials, including bamboo, jute, basalt, cotton, kenaf, flax, sisal, and hemp. These coefficients are indicative of the overall performance and suitability of each material based on the criteria considered in the analysis. Among the materials, basalt demonstrates the highest coefficient, indicating its favorable performance across the evaluated criteria.

Table 8 presents the ranking of natural fibers based on their performance in the evaluation criteria. Basalt is ranked first, indicating its superior performance across the criteria compared to other fibers. Cotton is ranked second, followed closely by Flax in third place. Kenaf is ranked fourth, while Jute is ranked fifth. Sisal is ranked sixth, Bamboo is ranked seventh, and Hemp is ranked eighth.These rankings provide a clear hierarchy of the natural fibers, with Basalt, Cotton, and Flax being among the top-performing fibers and Hemp being the least preferred in this evaluation.

**TABLE 8.** Ranking

| | Rank |
|---|---|
| Bamboo | 7 |
| Jute | 5 |
| Basalt | 1 |
| Cotton | 2 |
| Kenaf | 4 |
| Flax | 3 |
| Sisal | 6 |
| Hemp | 8 |

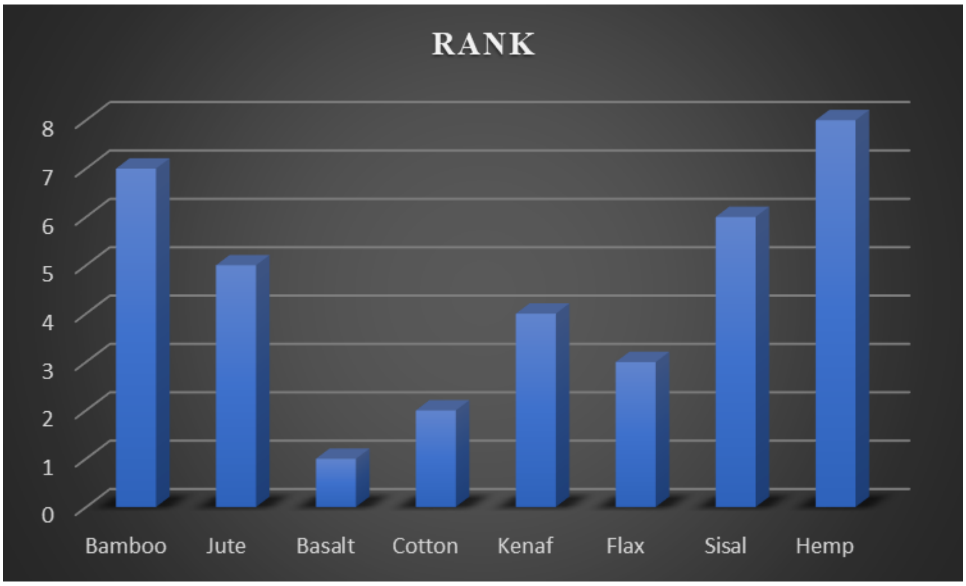


**FIGURE 5.** Ranking

Figure 5 shows the rankings of various natural fiber materials, including bamboo, jute, basalt, cotton, kenaf, flax, sisal, and hemp, based on their overall performance in the analysis. The rankings provide a clear hierarchy of the materials, with basalt securing the top position, indicating its superior performance across the evaluated criteria. Cotton follows closely behind in the second position, indicating its strong performance as well. Flax, jute, and kenaf are ranked next, highlighting their competitive positions in the analysis. Sisal and bamboo are ranked lower in the sixth and seventh positions, respectively, suggesting areas where these materials may have limitations compared to others. Hemp secures the last position in the ranking, indicating its relatively weaker performance in this analysis. These rankings can be valuable in decision-making processes, helping stakeholders identify the most suitable material for their specific applications.

## 4. CONCLUSION

In conclusion, throughout human history, natural fibers have played a crucial role as a sustainable and environmentally friendly source of raw materials, contributing to the development of civilization. The evaluation of natural fibers including bamboo, jute, basalt, cotton, kenaf, flax, sisal, and hemp using the Weighted Sum Model (WSM) and Weighted Product Model (WPM) in the context of strain at break, aspect ratio, specific strength, moisture absorption, specific modulus, and cost, has provided valuable insights. Basalt emerged as the top-ranked fiber, demonstrating superior performance across the criteria, followed by cotton and flax. These findings indicate that natural fibers can offer sustainable and environmentally friendly alternatives to synthetic materials in various industries. However, the selection of the most suitable natural fiber should be based on the specific requirements of each application, considering factors such as strength, cost, and environmental impact. Further research and development in this area can lead to the widespread adoption of natural fibers, contributing to a more sustainable future.

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