Prabha Materials Science Letters
Vol. 4, No. 1, 96-106, 2025
https://doi.org/10.33889/PMSL.2025.4.1.009

Ram Arti
Publishers

An MCDM-Based Approach for The Selection of Natural Fiber for Marine Applications

Durgeshwer Pratap Singh
Department of Mechanical Engineering,
Graphic Era (Deemed to be University), Dehradun, Uttarakhand, India.
E-mail: singh.durgeshwar@gmail.com

Shweta Saini
Department of Management Studies,
Graphic Era (Deemed to be University), Dehradun, Uttarakhand, India.
E-mail: sainishweta27@gmail.com

Shwetank Avikal
Department of Management Studies,
Graphic Era (Deemed to be University), Dehradun, Uttarakhand, India.
Corresponding author: shwetank.avikal@gmail.com

Brijesh Prasad
Department of Mechanical Engineering,
Graphic Era (Deemed to be University), Dehradun, Uttarakhand, India.
E-mail: Prasadbrijesh10@geu.ac.in

(Received on September 8, 2024; Revised on November 21, 2024; Accepted on December 10, 2024)

Abstract
Transportation is the driving force behind the modern age, and maritime transportation has significantly contributed to the development of the contemporary world. Researchers are working to produce natural fiber composites (NFC) for marine applications since NFC may be considered a sustainable or green material because it originates from renewable sources. While marine components need materials that are both lightweight and resistant to the marine environment, researchers are working to build these composites. The use of NFC is gaining popularity because of its advantageous mechanical properties, biodegradability, renewable energy, and cost-effectiveness. Our study is about selecting materials for manufacturing the marine engine compartment. Researchers employ Bamboo, Coir, Cotton, Flax, Hemp, Kapok, Pineapple, Ramie, Sisal, Wool, and other materials for the study. They use M-TOPSIS and the Fuzzy AHP technique to determine which materials are optimal.

Keywords- Natural fiber composites (NFC), Sustainable materials, Marine applications, Fuzzy AHP.

1. Introduction

Marine engines require lightweight and corrosion-resistant materials for harsh environments. Natural Fiber Composites are a popular choice due to their strength-to-weight ratio and versatility. NFC offers benefits like improved fuel efficiency, resistance to corrosion, and design flexibility. However, challenges like cost, manufacturing complexity, long-term durability, and damage tolerance remain. Composite engine mounts, propeller shafts, hull structures, and exhaust systems offer benefits like vibration isolation, noise reduction, and reduced engine wear (Lowde et al., 2022). Research is also for exploring hybrid composites, nanotechnology, life-cycle assessment, and damage detection and repair. Combining various fiber types can create hybrid composites, while nanotechnology can improve mechanical properties and corrosion resistance (Mouritz et al., 2001). Life-cycle assessment is crucial for sustainable development, and advanced techniques are needed to identify and rectify potential damage. The use of fiber composites in marine engine design could revolutionize the industry, but challenges like cost, manufacturing complexity, and long-term durability must be addressed. With the introduction of glass-fiber-reinforced unsaturated polyester in the 1940s, FRP (Fiber reinforced plastic) composites became commodities (Kerni et al., 2020; Mohanty et al., 2005). Fibers were initially mixed with phenolic resins in the early 1900s. To accommodate the expanding and fluctuating demand from numerous industrial sectors, the composite materials industry has quickly risen since World War II, using solely synthetic fibers for reinforcement until recently (Bertagna et al., 2022; Gobikannan et al., 2021). Since environmental consciousness has grown, sustainability has become the key concern for industrial and academic sectors. Therefore, every industry must replace unsustainable goods with sustainable ones. By the end of 2024, the global market for natural fiber composites is predicted to have grown at a CAGR of 11.8%, reaching a value of $10.89 billion. Thus, using natural fibers in place of synthetic fibers is difficult; this is also evident by the substantial number of articles that compare synthetic fibers with natural fiber composites. There are articles published in various reputed journals and book chapters on natural fibers and composites, considering it as a key component. The number of articles, book chapters, and reviews increased annually, suggesting an increasing level of engrossment. Government efforts, and environmental and economic considerations have spurred biocomposite research. Based on the biodegradable behaviour of its component ingredients, biocomposite materials exhibit a variety of environmental sustainability stages (Boccarusso et al., 2016, 2018; Fowler et al., 2006). Petroleum polymers reinforced with natural fibers make up most industrial biocomposites. Natural fibers may come from the living world and minerals, however their review, like other research on natural fiber composites for industrial purposes, talks primarily about vegetable fibers from plants. Flax, hemp, and jute are the most sought-after natural fibers from seeds, stems, or roots due to their outstanding mechanical qualities like stiffness and strength (Boccarusso et al., 2021). Due to the ecological transformation in recent years, the maritime industry, where composites are frequently utilised, is well-suited to replacing synthetic fibers with vegetable fibers (Gangwar et al., 2021; Rubino et al., 2020). To choose the optimal ship body material among hybrid aluminum metal alloy composites based on physical, mechanical, and corrosion properties, the work done by Gangwar et al. (2021) suggest a hybrid fuzzy Preference Selection Method (f-PSI). Four stir cast hybrid aluminium alloy (AL7075) composites are reinforced with zirconium dioxide and SiC (Aravind et al., 2022). Physical characterisation shows that reinforcing wt.% increases voids and density. The mechanical properties show that hardness, ultimate tensile strength, flexural strength (or transverse rupture strength), and impact strength all go up by upto ten percent by wt. of reinforcement. At the same time, the corrosion rate goes down by upto ten percent by wt. of reinforcement and then goes up because carbide particles form along the grain boundary region. The suggested technique is validated and resilient by sensitivity analysis and compared fuzzy TOPSIS with fuzzy VIKOR methods. A-2 is the best ship body material replacement, according to the research (Naik et al., 2019). Marine constructions are prone to several types of damage caused by diverse stresses during their operational lifespan. Because of their flexibility, elastomers have higher failure strain and yield strength values and a low modulus of elasticity. Elastomers have become popular materials for applications that need elasticity due to their significant benefits over conventional materials. Nevertheless, the limited fire resistance of these elastomeric materials poses a risk to their suitability for some crucial applications. Therefore, elastomeric blends and composites that include flame retardant (FR) additives are often used. In contrast, elastomers have a high ratio of strength to weight, outstanding impact qualities, minimal infrared, magnetic, and radar signals, exceptional durability, and the ability to sustain severe loads. Therefore, this research specifically examines the viability of using elastomers/elastomeric composites in marine applications. It aims to evaluate the existing scientific and technical limitations of these materials and explore potential future developments to enhance their usage in the marine sector (Safarudin et al., 2023). Naik et al. (2019) takes into account the physical, mechanical, and corrosion properties of hybrid aluminum metal alloy composites. Four hybrid aluminum alloy composites of AL7075 have been developed using the stir casting technique, integrating varying quantities of zirconium dioxide and silicon carbide as reinforcements. Performing sensitivity analysis and comparing fuzzy TOPSIS with fuzzy VIKOR methods to verify and ensure the durability of the suggested approach (Singh et al., 2020a). According to the study, A-2 has been identified as the optimal alternative material for the ship body implementation (Singh et al., 2020b).

Selecting purveyors who can meet the material requirements of ship production is essential. In the process of choosing a supplier, qualitative and quantitative elements are multi-criteria issues. An integrative approach to supplier selection can be effectively determined using the AHP method. Their research is conducted on a laminated bamboo shipyard to assess various firms that could potentially serve as material suppliers (Peças et al., 2018). The analysis results revealed that the principal material provider in the Kediri region is the preferred source for bamboo utilized in the construction of ships, with a global weighting value of 0.363. An adhesive and Finishing supplier based in Surabaya is our top choice for a vendor of adhesive and completing material components whereas, another firm is situated in the Semarang region and is a key supplier of secondary material components, with a global weighting value. For ship mould components supplier was situated in the Surabaya region and is a leading supplier of ship mould components. Its global weighting value is 0.456, reflecting its significance on a global scale. Furthermore for clamp, cut and molding firm situated in the Surabaya region, is an outstanding vendor of material parts for clamps, sanding, and cutting blades, with an international weighing value of 0.496 and 0.351 (Peças et al., 2018). A variety of non-renewable fiber-reinforced composite materials are often used in modern transport structures. These materials include kevlar, carbon, spectra, glass fiber, aramid, carbon nanotube, zylon, and others. However, as a result of the diminishing supply of inorganic materials like petroleum and other minerals, the world is shifting, and environmentally friendly materials are taking center stage. Therefore, taking into account the needs of each kind of transportation vehicle, the transportation sector may meet the expectations for sustainability by transitioning to bio-composite materials, which are renewable, recyclable, and lightweight. Transportation weight reduction, fuel efficiency, and carbon dioxide (CO2) emissions may all be achieved by replacing a few heavier components with natural fiber composites that have strong performance characteristics (Singh et al., 2020c; Staiger & Tucker, 2008).

2. Applied Approach

In decision-making science, the Fuzzy-AHP and Modified Technique for Order of Preference by Similarity to Ideal Solution (M-TOPSIS) are two methodologies that enable the annexation of subjective assessments and uncertainty of the system or study (Chen, 2020). The F-AHP is a decision-making method that decomposes complex judgments into hierarchical structures as well as evaluating items and guaranteeing coherence via consistency checks and weight computation. Whereas M-TOPSIS evaluates options by comparing their resemblance to an ideal solution (Mayyas et al., 2016). The combination of these methodologies may be used to enhance decision-making procedures by an individual or a firm, boost accuracy, and find extensive applications in material selection difficulties, including component design, process optimization, and sustainability evaluation (Chakladar & Chakraborty, 2008). By integrating the advantages of both methods, decision-makers may enhance their decision-making process in intricate and unpredictable decision contexts. Overall, the combination of Fuzzy AHP and M-TOPSIS offers a robust framework for material selection, making it a crucial tool for effectively handling intricate and unpredictable decision situations (Bhutia & Phipon, 2012). Bio-polymers, which are generated from biological sources, form alternatives that are more environmentally friendly when they link with natural fibers. The term “Uniform Load Design (ULD)” alludes to particular applications in the field of engineering or maritime engineering, whilst “NFC” materials are utilized in the production of Natural

Fiber Composites. This work employs Fuzzy AHP and M-TOPSIS to identify the optimal replacement natural fiber and biopolymer candidates that approximate the positive ideal solution, hence illustrating their efficacy in choosing the most appropriate NFC material for the Under-Piston Door (UPD).

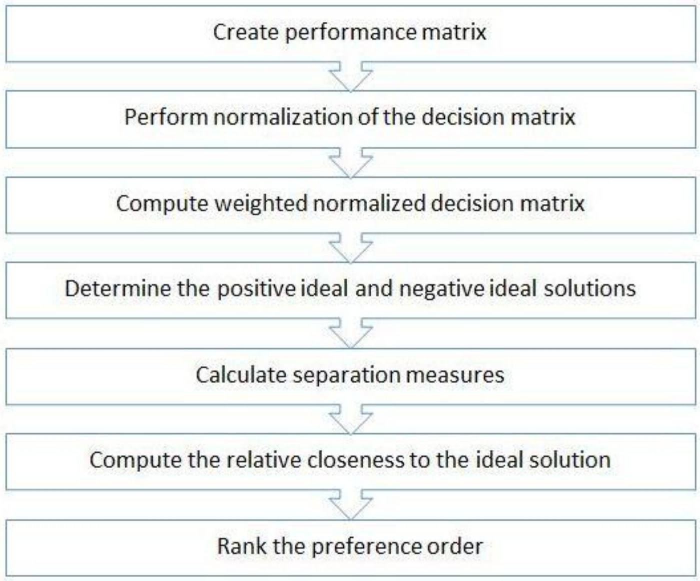

Figure 1. M-TOPSIS method algorithm.

The applied approaches were used to identify the ideal natural fiber and bio-polymer is the basis for selecting NFC material for UPD. Young's modulus, density, tensile strength, flammability, melting point, and cost are important attributes. Tensile strength and Young's modulus show how strong the UPD is overall and how resistant it is to deformation and fracture. Density, on the other hand, tells us how much the UPD weighs. Melting point and flammability give details on a substance's ability to withstand flames. Price enables examination from a financial standpoint. By using pairwise comparisons, the respondents assessed the significance of the selection criteria, supplying the information needed to create a pairwise comparisons matrix in the fuzzy AHP. The gathered survey data provided reasonable assessment and trust in the appraisal of the selected criteria.

For the selection of materials in marine applications M-TOPSIS and Fuzzy AHP methods are applied because they can handle complicated decision-making scenarios that involve many criteria that frequently clash with one another. M-TOPSIS is an extension of the TOPSIS method that has been optimised for situations in which criteria need to be evaluated with a "positive ideal" and "negative ideal" solution. In **Figure 1**, the M-TOPSIS flow diagram is displayed. Experts can describe their preferences in a manner that can capture ambiguity through the use of fuzzy AHP, which incorporates "fuzziness" to account for the inherent uncertainty that is present in expert judgments. Its hierarchical structure is well suited to the categorization of vital and particular qualities that are required for maritime applications. In our study, the selection of materials for marine purposes is determined by a bunch of criteria & sub-criteria that can be broken down into five categories: mechanical qualities, environmental resistance, cost efficiency, sustainability, and simplicity of maintenance. To provide a more nuanced weight distribution, experts assign weights to each criterion and sub-criterion depending on its value in a maritime setting. This is accomplished through the application of M-TOPSIS and F-AHP technology. This combination takes into account both objective technical criteria and subjective expert opinions, which ultimately results in a strong material selection process that is suitable for the difficult characteristics of the marine environment.

3. Problem Formulation

For the door of the marine engine compartment, the selection of natural fiber composite is important due to some crucial aspects like Young's modulus, density, flammability, melting point, tensile strength, etc. When it comes to safety, flammability is necessary in engine compartments because of the presence of high temperatures, sparks, or flames. There is a reduction in the danger of fire hazards when materials have a low flammability. The door's longevity and dependability are both improved by having a high melting point, which guarantees that the material will not destabilize. In our research, we're determining which criteria & alternatives should be considered to select natural fibers.

A survey should be carried out in order to carry out pair-wise comparisons of criteria. For the purpose of determining the weightage of the criterion, the fuzzy AHP is utilized. Determine which natural fiber is the most superior by ranking and selecting it using M-TOPSIS. **Figure 2** illustrates the proposed methodology.

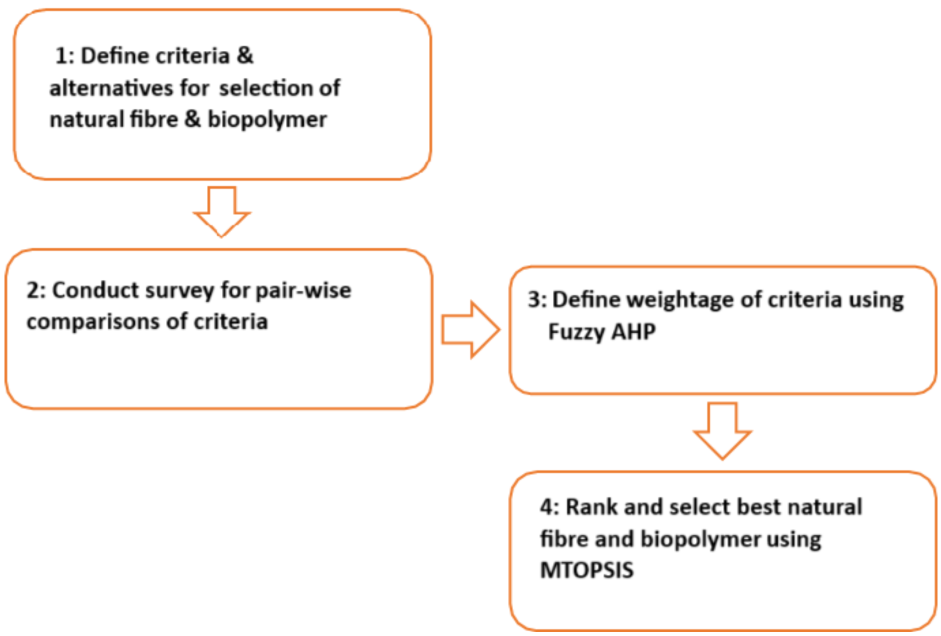

Figure 2. Material selection using the M-TOPSIS technique and fuzzy AHP.

4. Result and Discussion

The presented problem is characterised as a Multi Criteria Decision Making (MCDM) problem and a total of 4 criteria were selected for the study such as density (C1), tensile strength (C2), Young's modulus (C3), and price (C4). In these 4 selected criteria, the first 3 criteria are beneficiary criteria and the last criterion "Price" is the cost criteria. The weights of these criteria have been evaluated with the help of Fuzzy-AHP through pairwise comparisons.

Table 1 displays the pairwise comparison matrix. **Table 2** presents the weights of these selected criteria. The consistency check has also been performed for the pair-wise comparison matrix and it has been found that the used data passes the consistency check that is less than 0.1 (CR<0.1). The results of Fuzzy AHP show that the criteria "Tensile Strength of Material" has the highest weight followed by "Young's Modulus of Material", second highest weight, "Price of Material" and "Density of Material" shows the lowest weights.

Table 1. Pair-wise comparison matrix of selected criteria.

	Density of material (C1)	Tensile strength of material (C2)	Young's modulus of material (C3)	Price of material (C4)
Density of Material (C1)	1	$1/\tilde{3}$	$1/\tilde{2}$	$\tilde{1}$
Tensile Strength of Material (C2)	$\tilde{3}$	1	$\tilde{2}$	$\tilde{2}$
Young's Modulus of Material (C3)	$\tilde{2}$	$1/\tilde{2}$	1	$\tilde{2}$
Price of Material (C4)	$1/\tilde{1}$	$1/\tilde{2}$	$1/\tilde{2}$	1

Table 2. Criteria weight evaluated by Fuzzy-AHP.

Criteria	Weights	Consistency check
C1	0.111328	CI = 0.007397 RI = 0.008312
C2	0.338492	
C3	0.219009	
C4	0.131171	

Table 3. Available alternatives and their respective criteria's decision matrix.

Fiber alternate	C1 (g/cm^3)	C2 (MPa)	C3 (GPa)	C4 ($ per metric tonne)
Abaca A-1	1.505	981	20.02	2805
Angora A-2	1.406	1152	11.81	25008
Bagasse A-3	1.254	291.5	27.13	253
Bamboo A-4	0.605	800.2	32.04	1708
Banana A-5	1.353	500.1	12.07	5009
Coir A-6	1.151	230.6	6.03	152
Cotton A-7	1.502	800.4	12.62	503
Flax A-8	1.407	2000.2	103.06	1008
Hemp A-9	1.403	900.4	90.08	4802
Jute A-10	1.308	800.7	78.05	401
Kapok A-11	0.383	63.9	4.02	304
Kenaf A-12	1.201	930.3	53.01	535
Pineapple A-13	0.809	627	1.52	754
Ramie A-14	1.001	1000.6	128.0	20021
Sisal A-15	1.332	700.2	38.04	102
Wool A-16	1.321	239.8	17.05	608

A total of 16 natural fiber alternatives have been selected for the study and their data concerning the selected criteria has been shown in **Table 3**. As discussed in the earlier section, M-TOPSIS has been integrated with Fuzzy AHP and a hybrid approach has been used for ranking of the selected natural fibers alternatives. The data provided in **Table 3** has been normalized with the standard rules of the M-TOPSIS approach and the normalized data has been depicted in **Table 4**. The normalised decision matrix has been multiplied by the weights of the respective criteria determined by F-AHP, and the weighted normalised data is presented in **Table 5**. The Positive and Negative ideal solutions have also been evaluated for the decision matrix and have been displayed in **Table 6** and **Table 7** respectively. The final ranking of the decision alternatives was conducted with the help of distance from Positive ideal solutions and Negative ideal solutions of each alternative. Relative Closeness and Final Ranking of the materials have been computed and shown in **Table 8**.

Table 4. Normalized decision matrix.

Fiber alternate	C1 (g/cm^3)	C2 (MPa)	C3 (GPa)	C4 ($ per metric tonne)
A-1	1.0000	0.4736	0.1463	0.8915
A-2	0.9118	0.5619	0.0814	0.0000
A-3	0.7763	0.1175	0.2025	0.9939
A-4	0.1979	0.3803	0.2413	0.9355
A-5	0.8645	0.2253	0.0834	0.8030
A-6	0.6845	0.0861	0.0357	0.9980
A-7	0.9973	0.3804	0.0878	0.9839
A-8	0.9127	1.0000	0.8028	0.9636
A-9	0.9091	0.4320	0.7002	0.8113
A-10	0.8244	0.3805	0.6051	0.9880
A-11	0.0000	0.0000	0.0198	0.9919
A-12	0.7291	0.4475	0.4071	0.9826
A-13	0.3797	0.2908	0.0000	0.9738
A-14	0.5508	0.4838	1.0000	0.2002
A-15	0.8458	0.3286	0.2887	1.0000
A-16	0.8360	0.0908	0.1228	0.9797

Table 5. Weighted normalized decision matrix.

Fiber alternate	C1 (g/cm^3)	C2 (MPa)	C3 (GPa)	C4 ($ per metric tonne)
A-1	0.1113	0.1603	0.0320	0.1169
A-2	0.1015	0.1902	0.0178	0.0000
A-3	0.0864	0.0398	0.0443	0.1304
A-4	0.0220	0.1287	0.0528	0.1227
A-5	0.0962	0.0763	0.0183	0.1053
A-6	0.0762	0.0291	0.0078	0.1309
A-7	0.1110	0.1288	0.0192	0.1291
A-8	0.1016	0.3385	0.1758	0.1264
A-9	0.1012	0.1462	0.1533	0.1064
A-10	0.0918	0.1288	0.1325	0.1296
A-11	0.0000	0.0000	0.0043	0.1301
A-12	0.0812	0.1515	0.0892	0.1289
A-13	0.0423	0.0984	0.0000	0.1277
A-14	0.0613	0.1637	0.2190	0.0263
A-15	0.0942	0.1112	0.0632	0.1312
A-16	0.0931	0.0307	0.0269	0.1285

Table 6. Positive ideal solution.

Fiber alternate	C1 (g/cm^3)	C2 (MPa)	C3 (GPa)	C4 ($ per metric tonne)	S++
A-1	0.0000	0.0317	0.0350	0.0002	0.0000
A-2	0.0001	0.0220	0.0405	0.0172	0.0001
A-3	0.0006	0.0892	0.0305	0.0000	0.0006
A-4	0.0080	0.0440	0.0276	0.0001	0.0080
A-5	0.0002	0.0688	0.0403	0.0007	0.0002
A-6	0.0012	0.0957	0.0446	0.0000	0.0012
A-7	0.0000	0.0440	0.0399	0.0000	0.0000
A-8	0.0001	0.0000	0.0019	0.0000	0.0001
A-9	0.0001	0.0370	0.0043	0.0006	0.0001

Table 6 continued…

A-10	0.0004	0.0440	0.0075	0.0000	0.0004
A-11	0.0124	0.1146	0.0461	0.0000	0.0124
A-12	0.0009	0.0350	0.0169	0.0000	0.0009
A-13	0.0048	0.0576	0.0480	0.0000	0.0048
A-14	0.0025	0.0305	0.0000	0.0110	0.0025
A-15	0.0003	0.0516	0.0243	0.0000	0.0003
A-16	0.0003	0.0947	0.0369	0.0000	0.0003

Table 7. Negative ideal solution.

Fiber alternate	C1 (g/cm^3)	C2 (MPa)	C3 (GPa)	C4 ($ per metric tonne)	S--
A-1	0.0124	0.0257	0.0010	0.0137	0.0124
A-2	0.0103	0.0362	0.0003	0.0000	0.0103
A-3	0.0075	0.0016	0.0020	0.0170	0.0075
A-4	0.0005	0.0094	0.0003	0.0150	0.0005
A-5	0.0092	0.0029	0.0005	0.0078	0.0092
A-6	0.0057	0.0036	0.0005	0.0171	0.0057
A-7	0.0106	0.0072	0.0001	0.0166	0.0106
A-8	0.0103	0.0728	0.0184	0.0158	0.0103
A-9	0.0100	0.0026	0.0118	0.0113	0.0100
A-10	0.0084	0.0072	0.0086	0.0168	0.0084
A-11	0.0000	0.0000	0.0000	0.0169	0.0000
A-12	0.0066	0.0131	0.0072	0.0165	0.0066
A-13	0.0018	0.0030	0.0001	0.0163	0.0018
A-14	0.0024	0.0024	0.0299	0.0007	0.0024
A-15	0.0087	0.0058	0.0022	0.0172	0.0087
A-16	0.0078	0.0007	0.0004	0.0165	0.0078

Table 8. Relative closeness and final ranking.

Fiber alternate	S++	S--	Score	Rank
Abaca A-1	0.0459	0.0385	0.29051	6
Angora A-2	0.0566	0.0431	0.315816	9
Bagasse A-3	0.0914	0.0599	0.389029	13
Bamboo A-4	0.0565	0.0628	0.345471	8
Banana A-5	0.0824	0.0682	0.388154	11
Coir A-6	0.1100	0.0610	0.413516	15
Cotton A-7	0.0601	0.0536	0.337202	10
Flax A-8	0.0000	0.0000	0	1
Hemp A-9	0.0257	0.0525	0.279725	2
Jute A-10	0.0335	0.0479	0.285375	4
Kapok A-11	0.1380	0.0727	0.458977	16
Kenaf A-12	0.0343	0.0459	0.283238	5
Pineapple A-13	0.0828	0.0675	0.387625	12
Ramie A-14	0.0273	0.0528	0.283063	3
Sisal A-15	0.0536	0.0542	0.328343	7
Wool A-16	0.1016	0.0626	0.405158	14

The results presented in **Table 8** indicate that alternative “Flax (A-8)” got the highest importance and rank over all other alternatives.

The findings in **Table 8** indicate that, out of all the options, "Flax (A-8)" received the greatest priority and ranking.

The alternative "Hemp (A-9)" got the second highest rank over other selected alternatives. The alternatives "Kapok (A-11)" got the lowest importance and last rank among all selected decision alternatives.

5. Conclusion

This research addresses a MCDM problem, emphasising four criteria: density (C1), tensile strength (C2), Young's modulus (C3), and price (C4). The first three criteria are beneficiary criteria, and the last one is cost. The weights of these criteria are evaluated using F-AHP through pairwise comparison. The data passes a consistency check, with the highest weights for tensile strength of material, followed by Young's modulus, price, and density. A total of 16 natural fiber alternatives are selected, and their data is shown in **Table 3**. M-TOPSIS is combined with Fuzzy AHP, employing a hybrid method for the ranking of selected alternatives. The data has been normalised using the M-TOPSIS method, and the weighted normalised data is presented in **Table 4**. The weighted normalized decision matrix is multiplied by weights of the respected criteria determined through Fuzzy-AHP, and the final ranking is done using distance from Positive ideal solutions and Negative ideal solutions of each alternative. The results show that the alternative "Flax (A-8)" has the highest importance and rank, followed by "Hemp (A-9)" and "Kapok (A-11)". The study concludes that the chosen alternatives have different weights and importance. This approach not only highlights the potential of NFCs in marine engineering but also reinforces their role in driving sustainable innovation in the transportation sector. In future studies, many other MCDM techniques could also be used to get better solutions. Many other factors could also be considered to define the problem better and achieve more accurate and practical solutions.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors would like to thank the editor and anonymous reviewers for their comments that help improve the quality of this work.

References

Aravind, D., Senthilkumar, K., Rajini, N., Kumar, T S.M., Chandrasekar, M., Ismail, S.O., & Devi, M.P.I. (2022). Feasibility of elastomeric composites as alternative materials for marine applications: A compendious review on their properties and opportunities. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *236*(4), 839-855.

Bertagna, S., Braidotti, L., Laurini, E., Marinò, A., Pricl, S., & Bucci, V. (2022). Thermoplastic materials for the metal replacement of non-structural components in marine engines. *Applied Sciences*, *12*(17), 8766. https://doi.org/10.3390/app12178766.

Bhutia, P.W., & Phipon, R. (2012). Application of AHP and TOPSIS method for supplier selection problem. *IOSR Journal of Engineering*, *2*(10), 43-50.

Boccarusso, L., Carrino, L., Durante, M., Formisano, A., Langella, A., & Minutolo, F.M.C. (2016). Hemp fabric/epoxy composites manufactured by infusion process: Improvement of fire properties promoted by ammonium polyphosphate. *Composites Part B: Engineering*, *89*, 117-126. https://doi.org/10.1016/j.compositesb.2015.10.045.

Boccarusso, L., De Fazio, D., & Durante, M. (2021). Production of PP composites reinforced with flax and hemp woven mesh fabrics via compression molding. *Inventions*, *7*(1), 5. https://doi.org/10.3390/inventions7010005.

Boccarusso, L., Durante, M., & Langella, A. (2018). Lightweight hemp/bio-epoxy grid structure manufactured by a new continuous process. *Composites Part B: Engineering*, *146*, 165-175. https://doi.org/10.1016/j.compositesb.2018.04.009.

Chakladar, N.D., & Chakraborty, S. (2008). A combined TOPSIS-AHP-method-based approach for non-traditional machining processes selection. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *222*(12), 1613-1623.

Chen, C.H. (2020). A novel multi-criteria decision-making model for building material supplier selection based on entropy-AHP weighted TOPSIS. *Entropy*, *22*(2), 259.

Fowler, P.A., Hughes, J.M., & Elias, R.M. (2006). Biocomposites: technology, environmental credentials and market forces. *Journal of the Science of Food and Agriculture*, *86*(12), 1781-1789.

Gangwar, S., Arya, P., & Pathak, V.K. (2021). Optimal material selection for ship body based on fabricated zirconium dioxide/silicon carbide filled aluminium hybrid metal alloy composites using novel fuzzy based preference selection index. *Silicon*, *13*(8), 2545-2562.

Gobikannan, T., Portela, A., Haldar, A.K., Nash, N.H., Bachour, C., Manolakis, I., & Comer, A.J. (2021). Flexural properties and failure mechanisms of infusible thermoplastic-and thermosetting based composite materials for marine applications. *Composite Structures*, *273*, 114276. https://doi.org/10.1016/j.compstruct.2021.114276.

Kerni, L., Singh, S., Patnaik, A., & Kumar, N. (2020). A review on natural fiber reinforced composites. *Materials Today: Proceedings*, *28*, 1616-1621.

Lowde, M.J., Peters, H.G.A., Geraghty, R., Jones, J.G., Pemberton, R., & Summerscales, J. (2022). The 100 m composite ship?. *Journal of Marine Science and Engineering*, *10*(3), 408. https://doi.org/10.3390/jmse10030408.

Mayyas, A., Omar, M.A., & Hayajneh, M.T. (2016). Eco-material selection using fuzzy TOPSIS method. *International Journal of Sustainable Engineering*, *9*(5), 292-304.

Mohanty, A.K., Misra, M., & Drzal, L.T. (2005). Natural fibers, biopolymers, and biocomposites. *CRC Press eBooks.* https://doi.org/10.1201/9780203508206.

Mouritz, A.P., Gellert, E., Burchill, P., & Challis, K. (2001). Review of advanced composite structures for naval ships and submarines. *Composite Structures*, *53*(1), 21-42.

Naik, B., Paul, S., Barua, A., Jeet, S., & Bagal, D.K. (2019). Fabrication and strength analysis of hybrid jute-glass-silk fiber polymer composites based on hybrid Taguchi-WASPAS method. *International Journal of Management, Technology Engineering Economics*, *9*, 3472-3479.

Peças, P., Carvalho, H., Salman, H., & Leite, M. (2018). Natural fiber composites and their applications: a review. *Journal of Composites Science*, *2*(4), 66. https://doi.org/10.3390/jcs2040066.

Rubino, F., Nisticò, A., Tucci, F., & Carlone, P. (2020). Marine application of fiber reinforced composites: a review. *Journal of Marine Science and Engineering*, *8*(1), 26. https://doi.org/10.3390/jmse8010026.

Safarudin, A.R., Supomo, H., & Supomo, W.S. (2023). Analysis of material supplier selection in laminated bamboo shipyards using the analytical hierarchy process method. *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, *20*(1), 92-102.

Singh, A.K., Avikal, S., Kumar, K.N., Kumar, M., & Thakura, P. (2020a). A fuzzy-AHP and M− TOPSIS based approach for selection of composite materials used in structural applications. *Materials Today: Proceedings*, *26*, 3119-3123.

Singh, M., Pant, M., Godiyal, R.D., & Sharma, A.K. (2020b). MCDM approach for selection of raw material in pulp and papermaking industry. *Materials and Manufacturing Processes*, *35*(3), 241-249. https://doi.org/10.1080/10426914.2020.1711917.

Singh, R., Avikal, S., Rashmi, R., & Ram, M. (2020c). A Kano model, AHP and TOPSIS based approach for selecting the best mobile phone under a fuzzy environment. *International Journal of Quality & Reliability Management*, *37*(6/7), 837-851.

Staiger, M.P., & Tucker, N. (2008). Natural-fiber composites in structural applications. In Pickering, K.L. (ed) *Properties and performance of natural-fiber composites* (pp. 269-300). Woodhead Publishing. https://doi.org/10.1533/9781845694593.2.269.