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Weibull Integrated AHP for The Selection of Natural Fiber Composites Material

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Abstract

Natural Fibers are one of the important growing markets in the domain of bio-composites' processing, due to an unprecedented increase in environmental and economic challenges. As a result, proper selection of the natural fibers that meet the requirements for environment-friendly bio-composites is an important phase as it can heavily enhance the achievement of low-cost design for better sustainable societies. In general, Multi-Criteria Decision Making (MCDM) is considered as a powerful tool that helps designers and decision-makers to accomplish their intended goals. The current research paper extends a material selection model that incorporates Weibull distribution in the Analytical Hierarchical Process (AHP). The strength of this model lies in its ability to account the dispersion in material properties objectively and consider a pre-defined quality level at the time of the material selection process. A case study is presented in this study to illustrate the potential and applicability of the proposed method. The results show that the ranking is dynamic and is highly sensitive to the scenarios of six sigma levels. From the analytical outcomes, the study found that NENDRAN BANANA is the most appropriate fiber that can be used in the hybridization process to design a passenger-vehicle center-lever parking-brake component with a reasonable defect per million opportunities.

Keywords: Natural fibers, Material selection, composite, AHP, Weibull, Quality level.

1. Introduction

In the last five decades, the production of vehicles across the globe has tripled. The challenges that arise from both economic and environmental factors[1,2] are shaping a new era in the domain of automotive manufacturing. The automotive components need to conform to stringent quality and safety requirements. With the increasing level of stringent environmental legislations in recent years, the use of ecofriendly and lightweight materials has become the key process to enable the automotive industry to meet the next-generation emissions targets and the regulation of vehicles'end-of-life[3–6].

In recent years, the use of Natural Fibers (NFs) in composite materials, as an ecological alternative to synthetic composite materials, has gained much interest among the researchers in the automotive industry. The scientific articles published in line with this subject have increased significantly in the past years. This scenario proves the importance of this application in this domain of research [7–9]. In fact, when compared with synthetic fibers, the NFs derived from plant sources and their application in composite materials[10] are cost-effective, lightweight, biodegradable and non-abrasive [11,12].Therefore, it is crucial to study the performance of Natural Fibers Composites (NFCs) during a full life cycle of a composite part, intended for application in the automotive industry.

In reality, selection of the convenient materials is an important step in any sort of product development. In the study conducted earlier, screening and ranking have been mentioned as the two main approaches to be used in the selection of materials [13]. The screening methods constitute the first assortment intending to determine the alternative potential material by eliminating the rest of the materials which do not fulfill the requirements. Ashbey chart, questionnaire method and Cos per unit property are some of the main procedures used for this purpose [14]. After the identification and screening of the potential candidates, the ranking methods based on Multi-Criteria Decision Making (MCDM) are employed to identify the most suitable material amongst the potential alternatives[15].Indeed, MCDMs are powerful tools that assist engineers and decision-makers throughout a product's life cycle. To resolve the problems and choose the best solution, most designers deploy trade-offs [16]. The MCDM method can help the product designers in making proper, systematic and scientific decisions [17]. This is applicable especially in the field of composites and

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bio-composite materials since the designers frequently face challenges in satisfying multiple requirements listed by different stakeholders, prior to making the final decision. These adaptable methods have been used so far to accomplish the processes such as material selection, manufacturing, machining, and end-of-life product issues[18–22].

The researchers have investigated and combined severalMCDM tools to create the hybrid MCDM and find a suitable composite material for the given application. Patnaik et al [23] used Analytical Hierarchical Process (AHP) and Multi-Objective Optimization based on Ratio Analysis (MOORA) techniques to determine the appropriate composite material for the structural application. The weights of various mechanical properties were determined using the AHP technique whereas the MOORA approach was employed to rank the materials called in the name of alternatives. Singh et al [24]also showed the usefulness of fuzzy-AHP combined with the Technique Of ranking Preferences by Similarity of the Ideal Solution (TOPSIS) method for the selection of structural composite materials. In this study, the TOPSIS method was employed to select an appropriate and flexible composite configuration for cladding in the armor application that serves as a sacrificial structure[25]. Furthermore, Al-oqla et al [26] used the AHP process to find out the best refinement condition for date palm/epoxy composite in order to achieve the best tensile properties. A total of 11 possible reinforcement conditions were considered in this study with tensile properties. These alternatives included different levels of fiber diameters, lengths, and sodium hydroxide concentration treatments. According to the study findings, only about 60% of the initially considered bio-composites had the potential to be used based on their relative credentials. So, it was difficult to evaluate the entire desirable standpoints simultaneously since various bio-composites exhibited unclear trends about the entire desirable mechanical properties. Based on Grey Relational Analysis method (GRA), Maidin et al [27]found that pineapple is the best reinforcement for cyclist helmet application.

In the past two decades, NFCs have been widely used in the automotive industry [28,29] as a result of which numerous academicians have focused on finding the appropriate NFCs for a given automotive application. Sapuan et al [30] employed AHP technique to select the materials of NFCs for automotive dashboard panels. The researchers analyzed 29 potential materials based on two criteria such as their mechanical performance and physical properties. The authors found epoxy reinforced with 36% flax as the best alternative for the application under study. Likewise, Mansor et al [31] integrated AHP and TOPSIS techniques to determine the weight of the selection criteria. Their work focused on selecting the appropriate thermoset matrix of the hybrid bio-composite to be applied in bumper beams. Ahmed Ali et al [32] also used the AHP method for the selection of materials to be applied in NFCs for automated product development. In this study, Hemp NF and polypropylene matrix were found to be the most appropriate materials for the intended application. Other MCDM methods were also examined in the literature. Mastura et al [33] applied the integrated Environment Quality Function Deployment (QDFE) with AHP for the selection of materials in hybrid NFCs for the automotive anti-roll bar. The selection criteria were defined in terms of customers' requirement with consideration to cost, performance and environmental aspects. Additionally, the Vise Krierjiumska Optimizacija Kompromisno Resenje (VIKOR) method was also employed in the selection of NFC materials. A research paper authored by Ishak et al [34] applied this method to select the best natural fiber for the development of automotive front hoods using the NFC materials. The result found KENAF as the best NF for this application since it satisfied the compromises in the design of fiber metal laminate structures of car front hoods and also reduced the vehicle's weight and CO_2 gas emissions.

Recently, Yusof et al[35] incorporated a few techniques such as mind mapping, hierarchical frameworks, properties' tables, PUGH method and AHP technique into DMAIC (Define, Measure, Analyze, Improve, and Control) approach for the selection of NFC materials. They concluded that oil palm fiber is the best reinforcement for automotive crash box component. Moreover, statistical criteria such as the coefficient of determination, correlations, error analysis and analysis of variance (ANOVA) were conducted to rank and select the most suitable candidate. Noryani et al [36] used regression analysis to build a performance-scoring index and statistical error criteria to rank the NFs based on minimum error analysis for hand-brake lever application.

From the review of the literature and to the best of the author's knowledge, the dispersion of the NFCs and the NFs' mechanical properties are either subjectively quantified or ignored at the time of material selection. In reality, the natural origins of the NFs show an extreme number of variationsthrough different parameters compared to the synthetic fibers. The chemical composition, crystallinity, surface properties, diameter, cross-sectional shape, length, strength, and stiffness vary from fiber to fiber, even when collected from the same plant [37].

At the time of simple mechanical loading conditions, Weibull distribution provides a satisfactory description ofthe statistical distribution of the strength data for a wide range of materials (inclusive of bulk specimens and fibers)[38]. This distribution models the material as an n-link chain. The chain model was developed as a response to the observation i.e., the breaking load differswhen the identical rods are ruptured by external forces. The failure stress of the chain is determined by the strength of its weakest link. The material is divided into volume elements with each element having a single inhomogeneity. The volume elements compete for failure alike how the chain links do so. The volume element that causes the fracture ends up with success. This is the one element that has the highest critical severity inhomogeneity. In short, a chain link corresponds to a volume element. Furthermore, it is assumed that the link strengths are independent variants and that the link strength distribution is homogeneous in nature over material volume [39]. One of the advantages of Weibull distribution is its ability to include or approximate another set of distributions such as the exponential, Rayleigh, lognormal, and normal distributions [40].The explicit equation for this two-parameter Weibull cumulative distribution involves two parameters. Both the parameters can be easily estimated from the experimental failure data with a few numbers of samples (less than 20) [41]. In addition, the Weibull module is especially important and may interpret the physics of the failures and the failure rate [42]. In the aforementioned discussion, the academicians adopted the Weibull two-parameter distribution to fit the results of NFs and NFCs in terms of mechanical testing; tensile, bending, torsion, and pull-out tests [43–45] with an acceptable coefficient of determination (R^2).

The current research paper presents a novel method for material selection of the NFCs using AHP technique combined with Weibull two-parameter distribution. In this method, the dispersion of the NFC mechanical properties is integrated with Weibull two-parameter distribution to quantify the input value for AHP process for a given defect rate probability.The variationsin the defect probability rate allow to objectively guarantee a pre-defined quality level of the alternatives' performance. When the AHP process is used with constant inputs, it produces an unalterable ranking. The advantage of the proposed approach is that it may take into account a predetermined quality level at the time of selecting the materials and it can objectively accomplish the dispersion property of the material. By integrating the Weibull distribution, a dynamic ranking performance can be expected based on the predefined Six Sigma Levels (SSL) scenarios and unbiased decision-making. This is applicable, especially in the case of applications where quality and reliability are critical. The authors of this study have a verified assumption which is demonstrated through an application example for the best selection, leading to the finest NF and is to be hybridized for a passenger-vehicle center-lever parking-brake component.

2. Proposed Methodology

In 1970s, Thomas L. SAATY developed the Analytical Hierarchical Process (AHP)[46].This MCDM toolis highly helpful when dealing with complex interactions problems[47]. The overall reliability-integrated AHP methodology is presented in fig.1 and is described herewith.

2.1. Part I: Problem Statement:

AHP can be represented by a tree that is divided into several levels. The top level represents the goal whereas the second level defines the main criteria that influence the goal. If needed, the sub-criteria are also used to further evaluate the main criteria. The following level represents the alternatives. The latter corresponds to the identified solutions that can meet the given criteria and achieve the expected goal[48].

The last part in the problem statement phase is to determine the Six Sigma Level (SSL) and calculate the DefectPer Million Opportunities (DPMO).Sigma level is a statistical calculation that takes the short-term information about the DPMO of a process and the factors in process inclination to provide the level value score (SSL). This is done so to represent the modified DPMO with a shift in an attempt to determine the quality capability of a process in terms of meetingthe requirements.

DPMO is a mathematical calculation that helps in identifying the defects that may occur in per million opportunities during a process. DPMO calculation is given in Eq. (1) [49]and it indicates how frequently the process produces defects in terms of probability, P.DPMO helps in identifying the potential fail points in the material process that could result in the production of subpar products or material performance.

$$DPMO = \left[1 - P\left(X < (SSL - 1.5)\right)\right] \times 10^6 \tag{1}$$

Here, Xdenotes a normally-distributed random variable standard $(X \sim N(0,1))$

2.2. Part II: Evaluation phase

The first section in the evaluation process is to perform a pair-wise comparison among the defined goal, criteria and alternatives.The comparison can either be in an objective format or in a subjective manner based on the nature of attributes and criteria (Quantitative or Qualitative) and the availability of data.The criteria to assess the performance of the material can be divided into two categories such as beneficial and non-beneficial.The criterion is considered to be beneficial if the higher values of the alternatives are better for material performance. Otherwise, if a lower value is preferable, then the criterion is non-beneficial.The objective pair-wise comparison $(a^o_{i,j})$ is performed using equations, (2) and (3):

For beneficial criteria

$$a^o_{i,j} = \frac{Pr_{i,l}}{Pr_{l,j}} \tag{2}$$

For non-beneficial criteria

$$a^o_{i,j} = \frac{Pr_{l,j}}{Pr_{i,l}} \tag{3}$$

In the proposed method, a subjective pair-wise comparison is conducted for both the main criteria as well as the sub-criteria to determine the weight (normalized eigenvectors for criteria).$Pr_{i,j}$corresponds*to* the performance of the alternative calculation using Weibull two-parameter cumulative distribution (F) function,as shown in equations, (4) and (5):

$$F = \frac{DPMO}{1000000} = (\, 1 \; - \; \exp(\left(-\frac{Pr_{i,j}}{\beta_{i,j}}\right)^{k_{i,j}}) \tag{4}$$

Here,

$$Pr_{i,j} \; = \beta_{i,j} \left[\ln\left(\frac{1}{1-F}\right)\right]^{1/k_{i,j}} \tag{5}$$

With $\beta_{i,j}$ denotes the scale parameter and $k_{i,j}$corresponds to the shape parameter.

(NB: $Pr_{i,j} = \beta_{i,j}$ $(k_{i,j} = 0)$ for constant performance value)

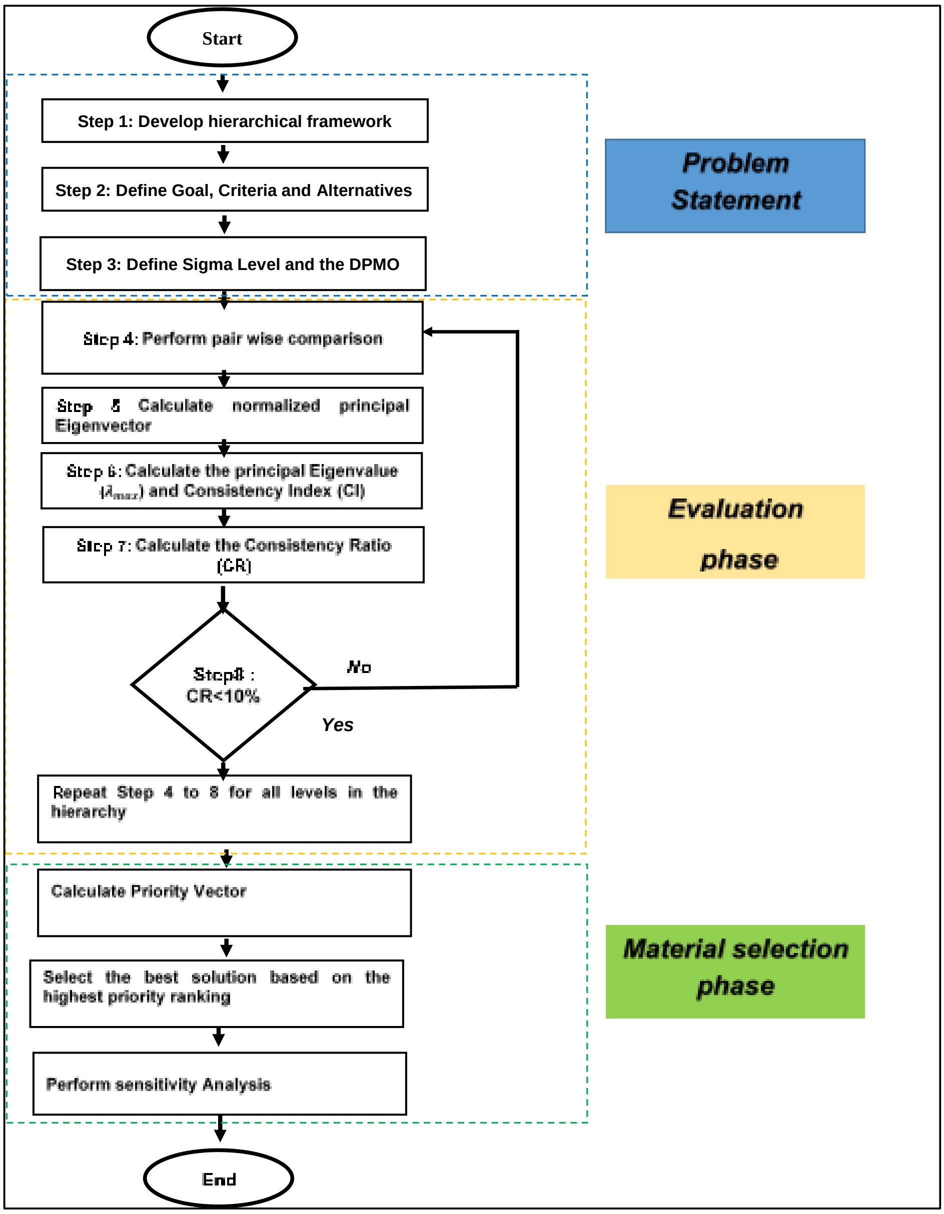


Figure 1. Methodology of the proposed MCDM

The subjective pair-wise comparison is conducted using the scale of importance as shown in (table 1).

Table 1. Subjective pair-wise comparison analysis: Scale of Importance

Relative Intensity	Definition
1	Equal importance
3	Slightly more importance
5	Essential or high importance
7	Very high importance
9	Extreme importance
2,4,6,8	Intermediate values between two adjacent judgements
Reciprocals	Reciprocals for inverse comparison

After the comparison process is executed, the normalised eigenvectors (W)are calculated using the Eq. (6):

$$W = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (6)$$

Consistency analysis is the last phase in the evaluation process. In order to determine whether the judgments made during pair-wise comparison are consistent ornot, especially for subjective judgement, the analysis is performed by calculating the Consistency Ratio (CR) using the following steps.

- A-Calculate the principal Eigenvalue λ_{max} using the Eq. (7):

$$\lambda_{max} = \sum_{i=1}^{n}\frac{\sum_{j=1}^{n} a_{i,j}\times W_j}{W_i} \qquad (7)$$

- B-Calculate the Consistency Index (CI) by following the Eq. (8)

$$CI = \frac{(\lambda_{max}-n)}{n-1} \qquad (8)$$

Here, n denotes the matrix size.

- C-Calculate the Consistency Ratio (CR) by following the Eq.(9)

$$CR = CI/RI \quad (9)$$

Here, (RI) denotes the Random consistency Index of the same order matrix. The value of RI is taken from (table 2)[50]. The CR is acceptableif it is less than 10% or else, the subjective judgment should be improved.

2.3. Part III: material selection phase

The final choice is decided based on the highest Priority Vector (PV) in Eq. (10) for all the alternatives.

$$PV(A_i) = \sum_{j=1}^{n} W(C_j) \times W(A_j) \quad (10)$$

Here, $W(C_j)$denotes the criteria Eigenvector and $W(A_j)$corresponds to the Eigenvector Alternative performance for the j^{th}criteria.The sensitivity analysis aims to check the stability of the decision. In this process, the verification is conducted by varying the weightof the criteria, defined in the earlier analyses and by checking the outcomes[50].

3. Applications of the proposed methodology

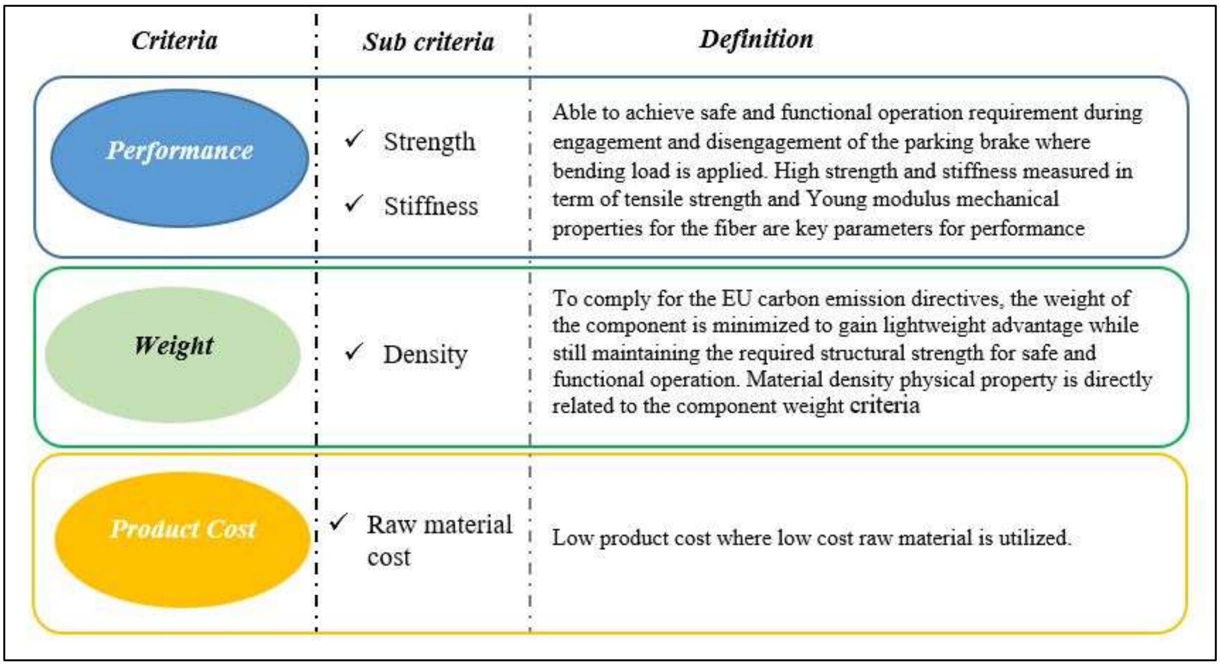
Mansor et al [51] proposed a material selection method with the help of AHP technique and sensitivity analysis. This research work aimed at selecting the best natural fiberamongst 13 candidates for the hybridation processto design a passenger-vehicle center-lever parking brake component.To demonstrate and validate the application of the proposed method, this example is studied in a step-by-step fashion using the methoddescribed in section 2.

3.1. Part I of the proposed methodology

The same hierarchy framework and the decision criteria, shown in figures 2 and 3 and considered by Mansor et al [33], were used in this analysis.The mechanical properties and Weibull two-parameter distribution of the 14 fibercandidates were collected from the literature and are summarized in table 3.Three scenarios of the Six Sigma Level (SSL) were simulated in the present study analysis (SSL= 1 , 3 and 6), whichcorrespond to DPMO 691 462, 66807 and 3.4 respectively.

Table 2. Random Index RI for n=14

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.48	1.49	1.51	1.56	1.57



Criteria	Sub criteria	Definition
Performance	✓ Strength ✓ Stiffness	Able to achieve safe and functional operation requirement during engagement and disengagement of the parking brake where bending load is applied. High strength and stiffness measured in term of tensile strength and Young modulus mechanical properties for the fiber are key parameters for performance
Weight	✓ Density	To comply for the EU carbon emission directives, the weight of the component is minimized to gain lightweight advantage while still maintaining the required structural strength for safe and functional operation. Material density physical property is directly related to the component weight criteria
Product Cost	✓ Raw material cost	Low product cost where low cost raw material is utilized.

Figure 2. Decision criteria and Sub criteria[51]

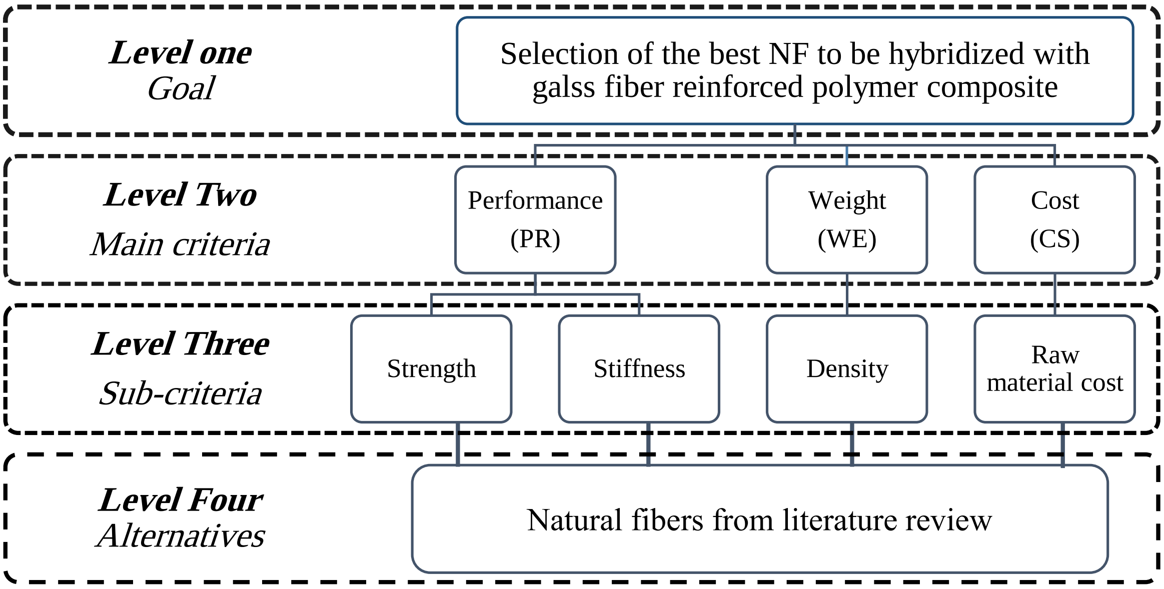


Figure 3: Hierarchical framework [33]

Table 3. Mechanical properties and Weibull two parameters of the NF candidates [52–59]

Fiber	Density	Mean σ (MPa)	Weibull 2P- σ		Mean E (GPa)	Weibull 2P-	
			Shape	Scale		Shape	Scale
AGAVE (RAW)	1336	142	2.35	133.4	2.14	2.00	3.3
COCCINIA GARANDIS L (RAW)	1243	237	13.07	284.6	10.17	9.10	10.7
COCCINIA GARANDIS L (TREATED)	1468	346	10.18	332.2	14.29	5.26	15.5
COIR (RAW)	1250	90	2.7	101.1	2.6	4.18	2.3
CURUA (RAW)	920	543	2.2	613.1	63.7	2,05	71.9
FLAX (RAW)	1290	432	2.39	846.1	31.4	3.3	63.7
JUTE (RAW)	1460	249	2.74	278.6	43.9	4	48.4
KENAF (RAW)	1360	184	1.98	207.6	13	2.38	14.8
NENDRAN BANANA PEDUNCLE (RAW)	972	65.51	22.73	65.7	49.5	62.13	47.9
PALM FRUIT BRANCHES (PHOENIX DACTYLIFERA L.) (RAW)	1009	117	4.45	128.2	4.3	3.73	4.8
PONGAMIA PINNATA L. BARK FIBER (RAW)	1345	322	22.4	329.5	9.67	20.47	9.9
PONGAMIA PINNATA L. BARK FIBER (TREATED)	1393	343	28.55	349.9	12.71	32.79	12.6
SAHARAN ALOE VERRA CACTUS (RAW)	1325	621	3.33	621.8	40.00	3.81	40.0
SAHARAN ALOE VERRA CACTUS (TREATED)	1623	805	3.22	805.5	42.30	3.72	42.3

(E): Young Modulus in GPa

(σ): Tensile strength in MPa

3.2. Part II of the proposed methodology

In this study, the researchers conducted the subjective pair-wise comparison using the scale of importance and the results are shown in table1. The analysis was conducted to determine the weight of each criterion and compare the alternativesconsidered, based on cost criterion. Relative pairwise comparison considered the cost of the raw material since the data cost was unavailable for the majority of the candidates.

The normalized eigenvector values for the criteria are as follows.

- W(Performance) = 33.33%
- W(Density) = 33.33%
- W(Product cost) = 33.33%

The subjective judgments were checked by calculating the CR using the Eqs. (7) (8) &(9). The calculated CR value was found to be less than 10%.The researchers conducted the objective pair-wise comparison for two beneficial sub-criteria i.e., tensile strength and young modulus and for the non-beneficial sub-criteria i.e., density. The alternative Eigenvector W_i was then calculated for all the fibers. Table 4 shows the tensile strength pair-wise comparison for 3-SSL.

Table 4. Pair-wise comparison among the fibers in terms of tensile strength – 3 SSL

fibers	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1)	1,00	0,20	0,18	0,21	0,17	0,25	0,23	0,21	0,83	1,37	0,32	0,56	1,56	1,09
(2)	5,00	1,00	0,92	1,05	0,83	1,26	1,14	1,06	4,16	6,83	1,61	2,78	7,78	5,43
(3)	5,45	1,09	1,00	1,14	0,91	1,37	1,25	1,15	4,53	7,44	1,75	3,03	8,48	5,92
(4)	4,77	0,95	0,87	1,00	0,79	1,20	1,09	1,01	3,96	6,51	1,53	2,65	7,42	5,18
(5)	6,01	1,20	1,10	1,26	1,00	1,51	1,38	1,27	4,99	8,21	1,93	3,34	9,35	6,52
(6)	3,97	0,79	0,73	0,83	0,66	1,00	0,91	0,84	3,30	5,42	1,27	2,21	6,17	4,31
(7)	4,37	0,87	0,80	0,92	0,73	1,10	1,00	0,92	3,63	5,97	1,40	2,43	6,80	4,74
(8)	4,73	0,95	0,87	0,99	0,79	1,19	1,08	1,00	3,93	6,46	1,52	2,63	7,36	5,14
(9)	1,20	0,24	0,22	0,25	0,20	0,30	0,28	0,25	1,00	1,64	0,39	0,67	1,87	1,31
(10)	0,73	0,15	0,13	0,15	0,12	0,18	0,17	0,15	0,61	1,00	0,24	0,41	1,14	0,79
(11)	3,11	0,62	0,57	0,65	0,52	0,78	0,71	0,66	2,59	4,25	1,00	1,73	4,84	3,38
(12)	1,80	0,36	0,33	0,38	0,30	0,45	0,41	0,38	1,49	2,45	0,58	1,00	2,80	1,95
(13)	0,64	0,13	0,12	0,13	0,11	0,16	0,15	0,14	0,53	0,88	0,21	0,36	1,00	0,70
(14)	0,92	0,18	0,17	0,19	0,15	0,23	0,21	0,19	0,77	1,26	0,30	0,51	1,43	1,00

(1)NENDRAN BANANA PEDUNCLE (RAW)
(2) PONGAMIA PINNATA L. BARK FIBER (RAW)
(3) PONGAMIA PINNATA L. BARK FIBER (TREATED)
(4) SAHARAN ALOE VERRA CACTUS (RAW)
(5) SAHARAN ALOE VERRA CACTUS (TREATED)
(6) COCCINIA GARANDIS L (RAW)
(7) COCCINIA GARANDIS L (TREATED)
(8) FALX (RAW)
(9) PALM FRUIT (RAW)
(10) AGAVE (RAW)
(11) CURUA (RAW)
(12) JUTE (RAW)
(13) COIR (RAW)
14 KENAF (RAW)

3.3. Part III of the proposed methodology

Table 5 shows the priority vector values for the proposed AHP analysis for three different predefined SSL measures. The ranking of the NFs, investigated in this study, was determined based on the PV Eq. (10) that was calculated for each SSL scenario. The ranking was provided to the candidates heavily based on the SSL values. The final AHP ranking (figure 4) suggests that for 1,5 SSL, CURUA (RAW) scored the highest PV (0.1204) followed by FLAX (RAW) (0.0991) and COCCINIA GARANDIS L (RAW)(0.084). The ranking got changed, when the SSLwas increased from 1.5 to 3. For instance, at 3 SSL, NENDRAN BANANA PEDUNCLE (RAW) was found to be the best alternative with a PV of 0.094 followed by COCCINIA GARANDIS L (RAW) (0.091) and COCCINIA GARANDIS L (TREATED) (0.089). At 6SSL, the NENDRAN BANANA PEDUNCLE (RAW) remained the most suitable with an increased PV of 0,1642, followed by PONGAMIA PINNATA L. BARK FIBER (TREATED) (0.119) and PONGAMIA PINNATA L. BARK FIBER (RAW) (0.103).In table 3, NENDRAN BANANA PEDUNCLE (RAW) fiber exhibits the highest strength and young modulus shape parameters[60].This explains the fact that the PV values increase with an increase in the sigma values (from 0.123 for 1 sigma level to 0.332 for 6-sigma level).

Table 5. Eigenvectors, Priority Vectors (PV) and ranking for 1SSL, 3 SSL and 6 SSL

SSL	Fibers	Performance (33.33%)		Weight (33.33%)	Product Cost (33.33%)	PV	Ranking
		Strength Eigenvector	Stiffness Eigenvector	Density Eigenvector	Raw material cost Eigenvector		
1 SSL	(1)	0,012	0,119	0,092	0,068	0,075	5
	(2)	0,062	0,025	0,067	0,068	0,059	10
	(3)	0,066	0,031	0,064	0,068	0,060	9
	(4)	0,122	0,103	0,068	0,023	0,068	8
	(5)	0,158	0,109	0,055	0,023	0,071	7
	(6)	0,054	0,027	0,072	0,136	0,083	3
	(7)	0,063	0,039	0,061	0,136	0,083	4
	(8)	0,169	0,165	0,069	0,068	0,102	2
	(9)	0,025	0,012	0,089	0,068	0,059	11
	(10)	0,027	0,009	0,067	0,068	0,051	13
	(11)	0,123	0,192	0,097	0,068	0,108	1
	(12)	0,055	0,124	0,061	0,068	0,073	6
	(13)	0,020	0,006	0,072	0,068	0,051	14
	(14)	0,042	0,039	0,066	0,068	0,058	12
3 SSL	(1)	0,023	0,223	0,092	0,068	0,094	1
	(2)	0,114	0,042	0,067	0,068	0,071	7
	(3)	0,125	0,056	0,064	0,068	0,074	6
	(4)	0,109	0,096	0,068	0,023	0,064	10
	(5)	0,137	0,100	0,055	0,023	0,066	9
	(6)	0,091	0,039	0,072	0,136	0,091	2
	(7)	0,100	0,045	0,061	0,136	0,090	3
	(8)	0,108	0,138	0,069	0,068	0,087	4
	(9)	0,028	0,011	0,089	0,068	0,059	11
	(10)	0,017	0,004	0,067	0,068	0,049	14
	(11)	0,071	0,095	0,097	0,068	0,083	5
	(12)	0,041	0,121	0,061	0,068	0,070	8
	(13)	0,015	0,006	0,072	0,068	0,050	13
	(14)	0,021	0,023	0,066	0,068	0,052	12
6 SSL	(1)	0,054	0,611	0,092	0,068	0,164	1
	(2)	0,267	0,083	0,067	0,068	0,103	3
	(3)	0,319	0,134	0,064	0,068	0,120	2
	(4)	0,020	0,023	0,068	0,023	0,037	13
	(5)	0,023	0,022	0,055	0,023	0,034	14
	(6)	0,154	0,042	0,072	0,136	0,102	4
	(7)	0,137	0,022	0,061	0,136	0,092	5
	(8)	0,006	0,022	0,069	0,068	0,051	8
	(9)	0,011	0,003	0,089	0,068	0,055	7
	(10)	0,001	0,000	0,067	0,068	0,045	11
	(11)	0,003	0,002	0,097	0,068	0,056	6
	(12)	0,004	0,032	0,061	0,068	0,049	9
	(13)	0,001	0,002	0,072	0,068	0,047	10
	(14)	0,001	0,001	0,066	0,068	0,045	12

(1)NENDRAN BANANA PEDUNCLE (RAW)
(2) PONGAMIA PINNATA L. BARK FIBER (RAW)
(3) PONGAMIA PINNATA L. BARK FIBER (TREATED)
(4) SAHARAN ALOE VERRA CACTUS (RAW)
(5) SAHARAN ALOE VERRA CACTUS (TREATED)
(6) COCCINIA GARANDIS L (RAW)
(7) COCCINIA GARANDIS L (TREATED)
(8) FALX (RAW)
(9) PALM FRUIT (RAW)
(10) AGAVE (RAW)
(11) CURUA (RAW)
(12) JUTE (RAW)
(13) COIR (RAW)
14 KENAF (RAW)

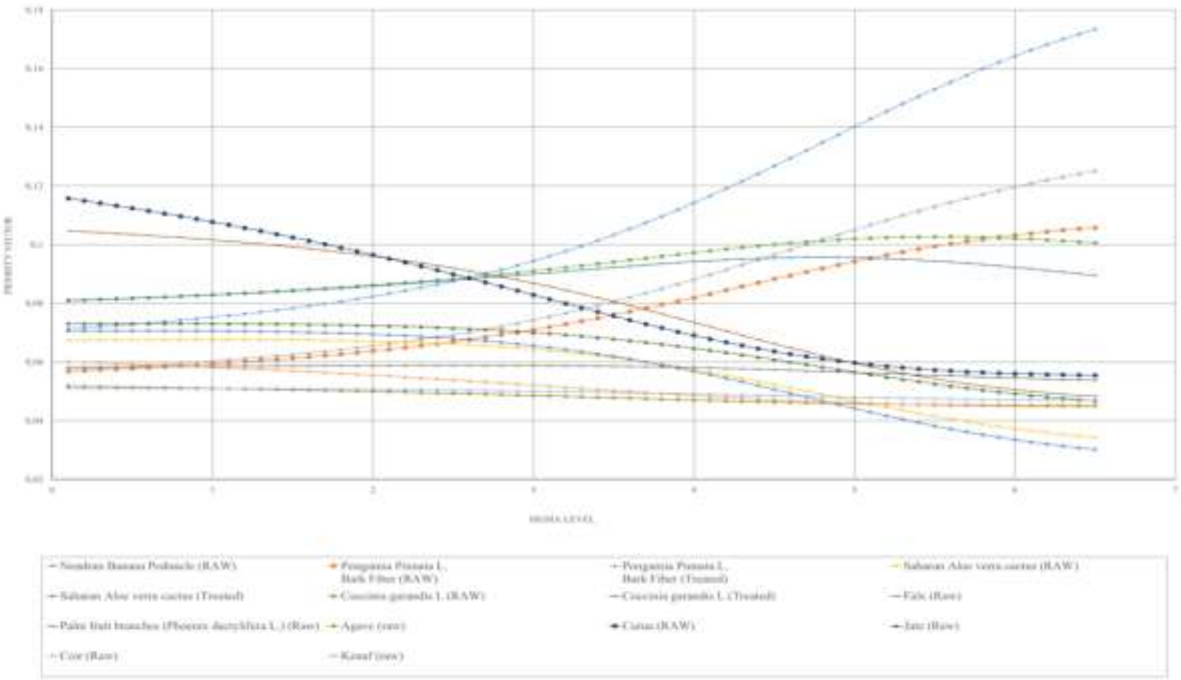


Table 6. Ranking: obtained by simulating three situations of sensitivity analysis

SSL	Fibers	*Performance Increased by 20%*		*Weight Increased by 20%*		*Cost Increased by 20%*	
		PV	Rank	PV	Rank	PV	Rank
1 SSL	*(1)*	0.041	13	0.055	14	0.056	12
	(2)	0.070	8	0.079	4	0.098	1
	(3)	0.073	6	0.076	5	0.098	2
	(4)	0.039	14	0.057	13	0.056	13
	(5)	0.122	1	0.104	1	0.095	3
	(6)	0.121	2	0.091	2	0.091	4
	(7)	0.078	5	0.069	6	0.071	6
	(8)	0.052	11	0.060	12	0.061	10
	(9)	0.07	7	0.080	3	0.073	5
	(10)	0.046	12	0.067	8	0.061	9
	(11)	0.054	10	0.061	10	0.062	8
	(12)	0.056	9	0.061	11	0.062	7
	(13)	0.081	4	0.067	7	0.054	14
	(14)	0.089	3	0.065	9	0.056	11
3 SSL	*(1)*	0.037	14	0.054	14	0.054	12
	(2)	0.083	4	0.085	3	0.104	1
	(3)	0.084	3	0.081	5	0.103	2
	(4)	0.038	13	0.056	12	0.055	11
	(5)	0.082	5	0.087	2	0.078	5
	(6)	0.097	2	0.081	4	0.081	4
	(7)	0.073	9	0.067	9	0.069	8
	(8)	0.043	12	0.056	13	0.056	10
	(9)	0.103	1	0.093	1	0.086	3
	(10)	0.047	11	0.067	8	0.061	9
	(11)	0.073	10	0.069	7	0.070	7

	(12)	0.079	7	0.071	6	0.072	6
	(13)	0.075	8	0.065	10	0.051	14
	(14)	0.081	6	0.062	11	0.052	13
6 SSL	*(1)*	0.031	12	0.051	11	0.052	11
	(2)	0.100	4	0.091	3	0.112	2
	(3)	0.088	5	0.082	5	0.105	3
	(4)	0.033	10	0.054	9	0.053	10
	(5)	0.040	7	0.068	6	0.059	6
	(6)	0.039	9	0.056	8	0.055	8
	(7)	0.039	8	0.052	10	0.054	9
	(8)	0.031	13	0.051	12	0.051	12
	(9)	0.214	1	0.142	1	0.135	1
	(10)	0.040	6	0.064	7	0.058	7
	(11)	0.124	3	0.092	4	0.092	5
	(12)	0.151	2	0.103	2	0.104	4
	(13)	0.032	11	0.046	13	0.032	13
	(14)	0.030	14	0.040	14	0.030	14

(1)AGAVE (RAW)
(2) COCCINIA GARANDIS L (RAW)
(3) COCCINIA GARANDIS L (TREATED)
(4) COIR (RAW)
(5) CURUA (RAW)
(6) FLAX (RAW)
(7) JUTE (RAW)
(8) KENAF (RAW)
(9) NENDRAN BANANA PEDUNCLE (RAW)
(10) PALM FRUIT BRANCHES (PHOENIX DACTYLIFERA L.) (RAW)
(11) PONGAMIA PINNATA L.
(12) PONGAMIA PINNATA L.(TREATED)
(13) SAHARAN ALOE VERRA CACTUS (RAW
(14)- SAHARAN ALOE VERRA CACTUS (TREATED)

Moreover, the sensitivity analysis was conducted on several SSL scenarios to check the stability of the ranking outcomes regarding the subjectivity weight of the criteria. In this study, three situations were simulated and each criterion of the eigenvector increased by about 20%. The change in the priority vector and ranking are shown in table 6.At 1-SSL, when the performance eigenvalue was increased with an additional weight of 20%, the CURUA (RAW) fiber remained the most suitable for both situations. However,when the cost was increased up to 20%, the COCCINIA GARANDIS L (RAW) was found to be the most suitable material. For 3-SSL and more, NENDRAN BANANA PEDUNCLE (RAW) fiber dominated at least two out of the three simulated situations.

4. Discussion

Quality costs determine the costs that are specifically associated with the achievement or non-achievement of the product quality including the whole set of product or service requirements[61]. The MCDM method, developed in this research work, combines both AHP tool and the Weibull two parameters distribution. This hybrid method allows one to consider the quality level, when it comes to material selection. Such a process allows the designer to avoid the issue of poor quality during early stages of product development itself.

In fact, when only the mean value is considered and the alternatives' dispersion is ignored in the selection of NFC materials, it engenders an unacceptable DPMO. The ranking of the NFs, based on the mean of tensile strength, is presented in table 3. The table shows that the SAHARAN ALOE VERRA CACTUS (TREATED) fiber accomplished the best performance with a mean tensile strength of 805 MPa. On the other hand, the NENDRAN BANANA PEDUNCLE (RAW) was ranked at the last position, in terms of mean tensile strength, since it secured a value of 65.51 MPa. By calculating the probability of failure using Weibull distribution, more than 90.3% of the SAHARAN ALOE VERRA CACTUS (TREATED) fiber failed under 800 MPa tensilestress. By integrating the quality level factor, the decision-making process gets altered. For instance, in the case of a high-quality application with 6 SSL, it is acceptable only for 3.4 fibers to fail per million. In this situation, the applied tensile stress should not exceed 16,13 MPa for SAHARAN ALOE VERRA CACTUS (TREATED) fiber and 37.78 MPa for NENDRAN BANANA PEDUNCLE (RAW) fiber. This outcome denotes that the latter fiber displayed a better performance.

The results infer that in case of high-quality levels' application, the ranking is highly sensitive to the measure of performance uniformity than the value of the performance attribute itself. In fact, the mean only provides the central value around which all the values spread along. However, it fails to provide an accurate picture of the data variability. Therefore, it is not reliable to solely consider the mean of the mechanical properties for NFC material selection.

Most of the AHP studies on material selection [26,30,32,62] used only the Consistency Ratio (CR) and sensitivity analysis to assess the decision-making reliability. The existing methods only checked the sensitivity of the ranking and subjectivity of the decision, without considering the uniformity of the alternative performance itself. As demonstrated above, for applicationsin which a high-quality level of output is required, the material selection process is biased from the outset.

Elsewhere, the proposed method has a few limitations. In fact,the criteria are assumed to be independent of the properties of the alternatives. It is a well-known fact that there exist several relationships among the material properties that need to be acknowledged in the material selection process [37,63]. The method described in this paper also considers the properties as random variables that follow Weibull distribution. But, it ignores the physics that governs these properties. When using the AHP models, it is highly advantageous in terms of heavy time consumption when the number of levels in the hierarchy increases[64].The proposed method is implemented based on the assumption that the fiber properties, obtained as experimental data, will remain the same as in composite manufacturing as well.

5. Conclusion

The AHP method provides a flexible tool to address the problems encountered in the material selection process. The proposed method ranks the alternatives from the best to the worst. It can deal with both quantitative and qualitative data, independent of measurement scales. The sensitivity analysis outcomes allow the decision makers to check the elasticity of the final decision.

The current study used Weibull distribution to calculate the value of quantitative properties, scattered in the interval, to ensure that the defects remain under the desired DPMO. The simulation outcomes of several SSL scenarios in the AHP technique allow the decision maker to consider the quality and reliability system during the design process and build a dynamic ranking accordingly. This is especially interesting in the case of NFCsgiven the fact that it presents a large variability in their mechanical properties.The said scenario is illustrated through a case study in which the ranking process was demonstrated to be dynamic and it changed totally with variations in the SSL. The results showed that CURUA (RAW) fiber is the best suitable material for the hybridization process to design a passenger vehicle center lever parking brake component with low SSL whereas the NENDRAN BANANA PEDUNCLE (RAW) fiber is the optimal material for moderate and high SSL.

In order to ensure that the NFC material is successfully selected, various mechanical properties, processing techniques and cost analysis should be taken into consideration. To achieve this aim in the future, a novel material selection method is planned to be developed by integrating Weibull distribution and Hashin failure criterion with TOPSIS. This method will allow the researchers to identify the weaknesses of each biocomposite compared to the others. Thus, the mechanism can be understood in a targeted way along with its weaknesses and the possible improvements that can be undertaken.

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