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Decision Support Strategy in Selecting Natural Fiber Materials for Automotive Side-Door Impact Beam Composites

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Abstract: The enforcement on sustainable design and environmental-friendly products has attracted the interest of researchers and engineers in the context of replacing metals and synthetic fibers with natural based fibers, especially in the automotive industry. However, studies on sustainable natural fiber material selection in the automotive industry are limited. Evaluation for the side-door impact beam was conducted by gathering product design specification from literature which amounted to seven criteria and it was forwarded to ten decision makers with automotive engineering and product design background for evaluation. The weightage required for decision-making was obtained using the Analytic Hierarchy Process (AHP) method based on six criteria. Following this, the best natural fiber materials to be used as reinforcement in polymer composites were selected using the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method. The results using both the AHP and VIKOR method showed that kenaf was the best natural fiber for the side-door impact beam composites. The result showed the lowest VIKOR value, $Q_{A1} = 0.0000$, which was determined to be within the acceptable advantage and acceptable stability conditions. It can be concluded that the application of integrated AHP-VIKOR method resulted in a systematic and justified solution towards the decision-making process.

Keywords: Materials selection; natural fiber; side-door impact beam; Analytic Hierarchy Process (AHP); VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

1 Introduction

Currently, natural fiber composites (NFC) are the subject of immense interest to researchers for its use in the automotive industry, due to attributes such as low cost, lightweight, environmentally friendly, their excellent specific strength and stiffness, recyclability, and their image as a natural product [1-3]. However, their mechanical properties are weak compared to the synthetic fibers and metal beam available in the market. Nevertheless, rapid changes in NFC research has greatly improved the existing properties such as by Sarker et al. whom produced high performance graphene based jute composites which resulted in higher tensile strength and young modulus [4,5]. NFC has been used as interior and exterior components to reduce the usage of expensive carbon, aramid, and glass fibers. For example, DaimlerChrysler has developed up to 50 car parts using bio-based materials [6,7]. The reasons why automotive industries are taking a big step on using NFC is because their lightweight properties can improve vehicle fuel consumption and are environmental friendly for recycling and safe disposal [8,9]. In the context of having plenty of natural fibers

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available sporting different mechanical and material properties, the selection of the material needs to be analyzed prior to product design and development. The flexibility afforded by changing materials at this stage is evident, as it would be more difficult to swap materials at later stages [10].

A thorough process is required in order to make the decision to select suitable materials of NFC for product design and development. Multiple criteria decision making (MCDM) method is implemented for selection in the conceptual design stage. Tools used for decision making include Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity (TOPSIS), ELimination Et Choice Translating REality (ELECTRE), Preference Ranking Organization Methods for Enrichment Evaluations (PROMETHEE), VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and others [11,12]. The MCDM method is used by some researchers in the materials selection process for the design of the automotive component. Sapuan et al. used AHP method to select the best NFC materials for the automotive dashboard panel [13]. The same method was used by Ahmed Ali et al. and Al-Oqla et al. to select the best natural fiber/polypropylene composites for automotive components while Mansor et al. selected the best hybrid natural/glass fiber material using the AHP method for hand brake lever [14-16]. Mastura et al. used an integrated strategy of AHP method and Quality Function Deployment (QFD) to select suitable natural fiber materials for automotive anti-roll bar, and Ishak et al. used VIKOR method for natural fiber materials selection for car front hood [17,18]. Besides natural fiber selection, there are studies in matrix materials selection where Ilangkumaran et al. used integrated fuzzy AHP and PROMETHEE, and Mansor et al. used TOPSIS to select the best matrix for bumper beam [19,20]. These studies verify that the MCDM method can be used for materials selection where there are multiple criteria with multiple alternatives of the natural fibers that can be chosen.

In this paper, the decision support strategy implemented was the integration of the AHP-VIKOR method to select the best natural fiber materials for the automotive side-door impact beam composites. The main objective of this paper was to find the best natural fiber for a bio-composites material for the automotive side-door impact beam, by determining the criteria, which include performance, weight, and product cost. The AHP method was utilized to determine the weight of the criteria, followed by the VIKOR method to rank and identify the best natural fiber candidates. By combining both methods, a more practical and systematic tool was presented and simultaneously met the objective of solving the MCDM problem of deciding on the best natural fiber materials for the automotive side-door impact beam composite.

2 Research Methodology

In a nutshell, this research was conducted in several main phases starting from identification of the selection criteria for the automotive side-door impact beam, the identification of the natural fiber materials and their properties, analyzing the weighting criteria (priority vector) of the criteria using AHP method, and finally the selection of the best material for side-door impact beam using the VIKOR method. The overall framework of this research is shown in Fig. 1.

2.1 Design Criteria on Sustainable Natural Fibers Materials Selection for Side-Door Impact Beam

Fig. 2 shows the automotive side-door impact beam with tubular beam and panel type and the common material used for both is steel. In order to reduce the weight of the side-door impact beam, the materials can be replaced with lighter materials, provided that the side-door impact beam fulfilled the design criteria. The number of design criteria taken into consideration in the early stage for the side-door impact beam is seven which are standard specification, performance, size, weight, product cost, environment, and disposal. The criteria are formulated from literature on side-door impact beams, such as journals, books, standards, reports, and others. Apart from that, there are studies that have contributed to the material selection of natural fibers for automotive product components and are used as guidance to formulate the design criteria for side-door impact beam. The criteria shown in Fig. 3 was derived from literature [16-18].

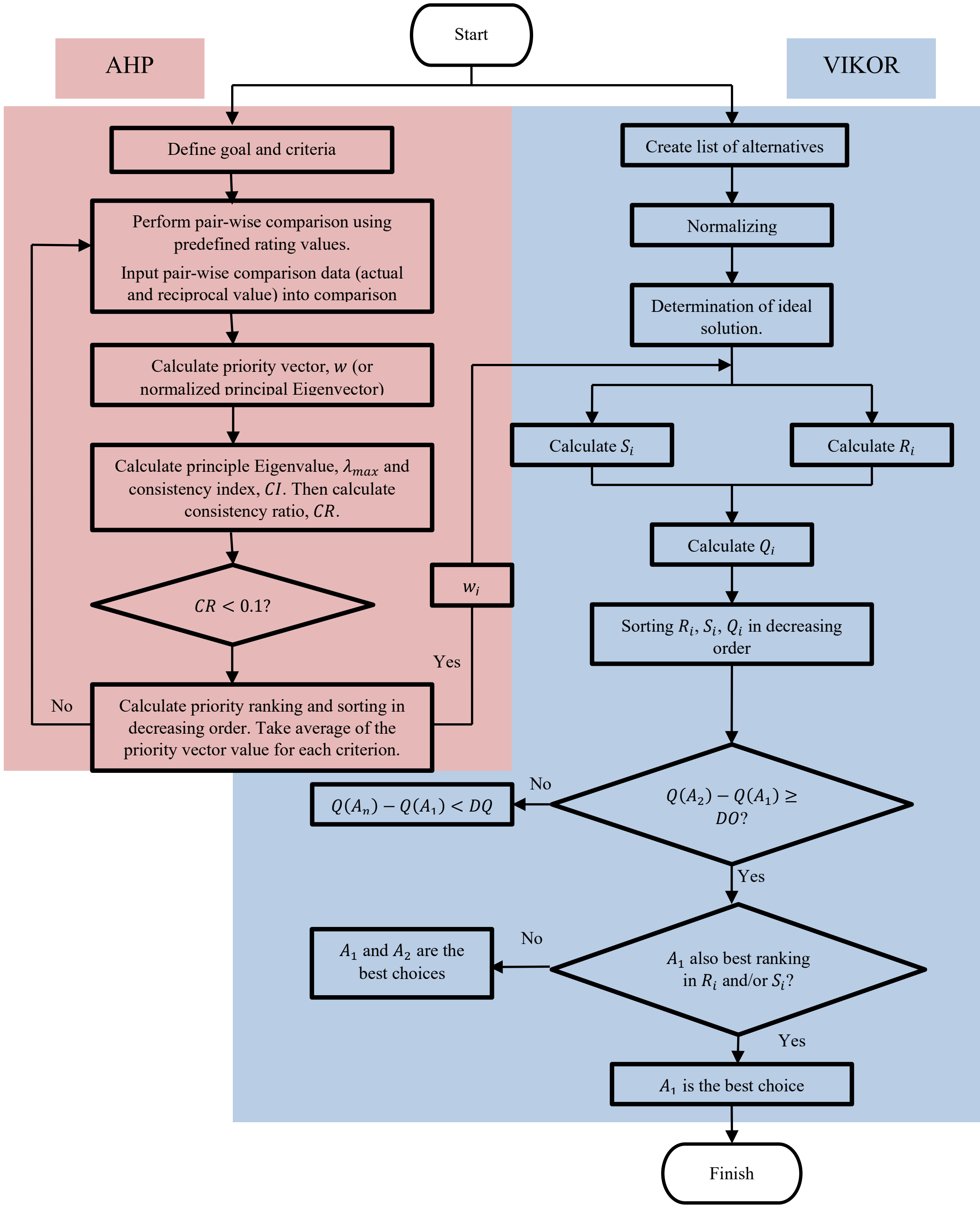

Figure 1: Overall research flowchart on natural fiber materials selection for side-door impact beam using integrated AHP-VIKOR

Figure 2: Automotive side-door impact beam of a passenger's car [21]

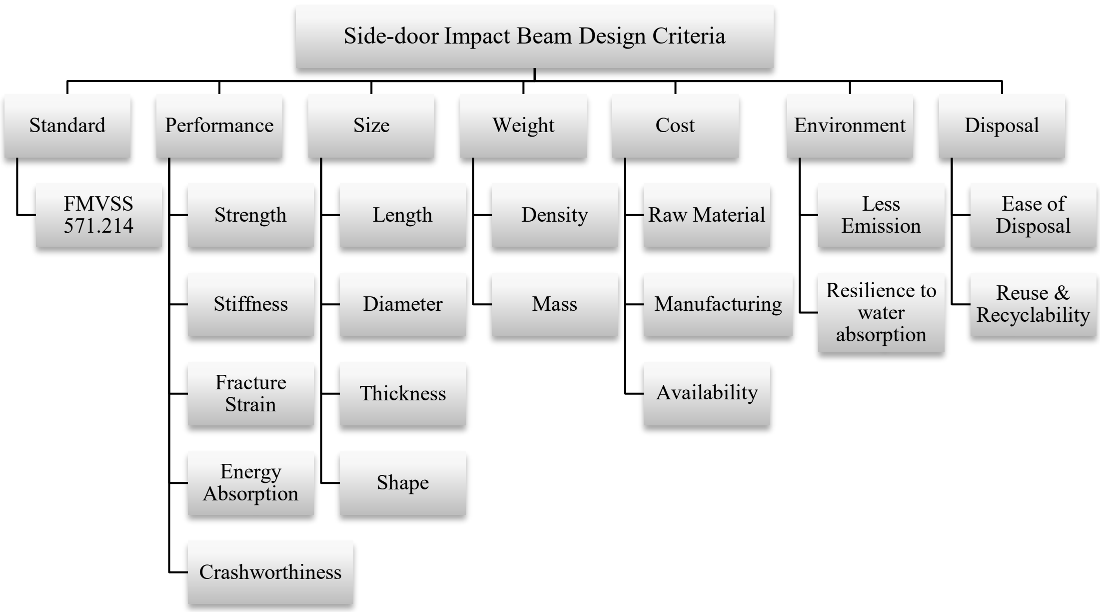

Figure 3: Design criteria for automotive side-door impact beam

For the material selection analysis using MCDM method, the standard specification was not included. This is because it is not comparable. The criteria on environment and disposal were also not included because alternative materials such as natural fibers are assumed to be resistant to corrosion, have equal sustainability performance and fair dimensional stability towards water absorption compared to synthetic fiber [16]. Tab. 1 shows the decision criteria used in the analysis on selecting the best natural fiber materials using VIKOR method for side-door impact beam while Tab. 2 summarized the mechanical properties, price and availability of the natural fibers used in the analysis.

Table 1: Decision criteria for the analysis using the VIKOR method

GOAL: To choose the best natural fiber materials for the automotive composites of side-door impact beam.		
Criteria	Subcriteria	Definition
Performance (PF)	i. Strength ii. Stiffness iii. Fracture Strain	Required of high strength and stiffness where it can be measured in terms of modulus Young and tensile strength. Fracture strain is the ratio of changed length and initial length to resist crack and can be measured in term of elongation at break. The component can achieve safe impact loads and secure position when involved in a collision.

Weight (WG)	i. Density ii. Specific energy absorption	The weight needs to be minimized so that the component can be lightweight. Highest specific energy absorption needed where the density is inversely proportional to the specific energy absorption.
Product Cost (PC)	i. Raw material cost ii. Availability	The raw material needs to be low cost where it can reduce the total product cost at an early stage. In the other hand, the availability (world production in 10^3 ton per year) of the natural fiber also considered in the sub-criteria.

Table 2: Mechanical properties and price of natural fibers [17,22-24]

	Criteria	Strength (MPa)	Stiffness (GPa)	Elongation at break (%)	Density (g/cm^3)	Cost (USD/kg)	Availability (10^3 ton)
Alternatives	Abaca	430-813	31.1-33.6	2.9	1.5	0.345	70
	Coir	175	6.0	15-25	1.20	0.20-0.40	100
	Flax	343-1035	50-70	1.2-3.0	1.38	3.11	830
	Hemp	580-1110	30-60	1.6-4.5	1.35	1.55	214
	Jute	187-773	20-55	1.5-3.1	1.23	0.926	2300
	Kenaf	295-930	22-60	2.7-6.9	1.20	0.378	970
	Pineapple	170-1627	60-82	1.0-3.0	1.50	0.40-0.55	74
	Oil Palm	248.0	3.2-6.7	25	0.7-1.55	0.30	40
	Ramie	400-938	61.4-128	2.0-4.0	1.44	2.00	100
	Sisal	507-855	9-22	1.9-3.0	1.20	0.65	378
	Sugar Palm	276.6	5.90	22.3	1.22-1.26	1.60-4.00	40

2.2 Evaluation of the Weightage Criteria Using the Analytic Hierarchy Process (AHP)

AHP method uses a pairwise comparison matrix to calculate the priority vector of the criteria. In this paper, ten decision makers were involved in assessing the criteria for the side-door impact beam. The five steps in this stage were developing the hierarchical structure, making a pairwise comparison, calculating the priority vector, calculating the consistency index (CI) and consistency ratio (CR) and finally calculating the average results for the weighting criteria of the side-door impact beam.

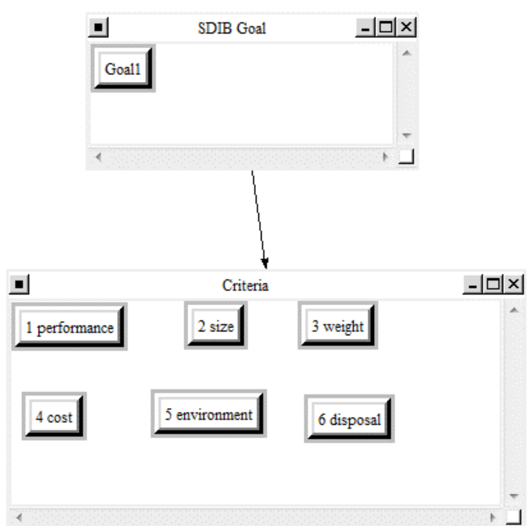

Figure 4: Two-level of hierarchical structure for side-door impact beam

Step 1: Two-level hierarchical structure was formed where the main objective was given top-level priority while the design criteria of the side-door impact beam was at the second level. A Super Decisions software with two-level hierarchy setup was used to conduct the AHP method as shown in Fig. 4.

Step 2: The pairwise comparisons of the criteria was done by ten decision makers with expertise in automotive engineering and product design. The relative importance of each requirement in level 2 was determined by decision makers using a predefined rating value shown in Tab. 3. The rule *n(n-1)* rule, where *n* is the number of criteria was used to calculate the number of pairwise comparison evaluations which is dependent on the number of criteria in level 2. Eq. (1) shows the pairwise comparison matrix while the decision by the decision-makers is shown in Fig. 5 [25].

Table 3: Judgement scale for pairwise comparison

Numerical Value	Preference Level
1	equally preferred
2	equally to moderately preferred
3	moderately preferred
4	moderately to strongly preferred
5	strongly preferred
6	strongly to very strongly preferred
7	very strongly preferred
8	very strongly to extremely preferred
9	extremely preferred

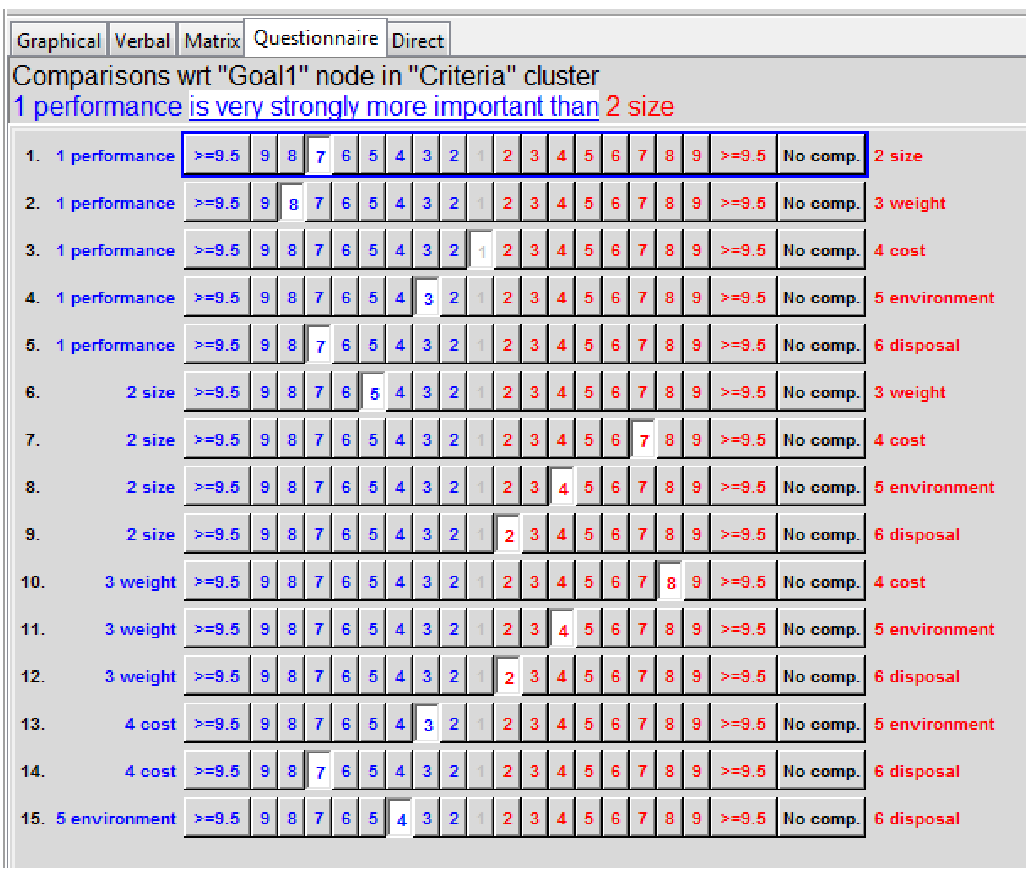

Figure 5: User interface (UI) of Super Decisions software in pairwise comparison judgement

$$\boldsymbol{A} = (\boldsymbol{a_{ij}})_{n\times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ \vdots & 1 & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

where $a_{ji} = 1/k$, which implies the reciprocal value of $a_{ij} = k$ and $i, j = 1, \ldots, n$ and $i \neq j$

Step 3: The normalized principle Eigenvectors was used to determine the weighting of the criteria, in order to calculate the priority vectors by synthesizing the pairwise judgments from Step 2. Eq. (2) was used to calculate the priority vector, or Eigenvectors, w.

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

where w is the eigenvector or priority vector, a_{ij} is the importance scale as per Tab. 3, and n is the number of criteria.

Step 4: To calculate the consistency index (CI) and consistency ratio (CR) of the judgments in pairwise comparison, the principal eigenvalue, λ_{max} was used, as computed in Eq. (3) to Eq. (5), respectively. CR was used to calculate the consistency judgment, where the judgment is acceptable when CR value obtained is less than 10% (or 0.1) [26]. Otherwise, Step 2 and Step 3 were repeated until the CR value was under 10%. The Random Index (RI) shown in Tab. 4 were used to calculate the CR in Eq. (5):

$$\lambda_{max} = \sum_{i=1}^{n}\frac{\sum_{j=1}^{n} a_{ij}\times w_j}{w_i}, \qquad i, j = 1, 2, \ldots, n \quad (3)$$

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

$$CR = \left(\frac{CI}{RI(n)}\right) \times 100\% \quad (5)$$

Table 4: Random Index (RI) of random matrix [27]

n	2	3	4	5	6
RI(*n*)	0.00	0.58	0.90	1.12	1.24

Step 5: Step 2 to Step 4 were repeated for each decision makers, and all the results were recorded. The average value was calculated to get the final weight of the criteria based on the arithmetic mean.

2.3 Ranking Sustainable Natural Fiber Candidates Using VIKOR Method

The VIKOR method is a MCDM method where it compares, analyzes and ranks multiple criteria based on established criteria to reach the solution that is a compromise closest to the ideal [28,29]. Opricovic and Tzeng further developed the method starting from the L_p-metric used in a compromise programming method as per Eq. (6) for the calculation of Eq. (9) and Eq. (10) [30,31].

$$L_{pi} = \left\{\sum_{j=1}^{n}\left[w_j\frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)}\right]^p\right\}^{1/p}, 1 \leq p \leq +\infty; i = 1, 2, \ldots I \quad (6)$$

where L_{pi} is the L_p-metric use to formulate ranking measure for alternatives i, w_j is the weight of importance for the jth criterion, f_j^* is the best values and f_j^- is the worst values for all criterion functions.

Step 6: The normalized value for the matrix of the i alternatives and j criteria were calculated, namely natural fibers and criteria, respectively. Eq. (7) shows the normalized matrix value where Eq. (8) was used for the normalized calculation.

$$\begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \dots & C_j \end{array} \\ \boldsymbol{D} = \begin{array}{c} \boldsymbol{A_1} \\ \boldsymbol{A_2} \\ \vdots \\ \boldsymbol{A_i} \end{array} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ x_{i1} & x_{i2} & \dots & x_{ij} \end{bmatrix} \end{array} \quad (7)$$

where matrix D shows Alternatives of $A_1, A_2,\dots,A_i$ and Criteria of $C_1, C_2,\dots,C_j$.

$$\boldsymbol{f_{ij}} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \quad (8)$$

where x_{ij} denotes the value of ith alternative and jth criterion.

Step 7: The best f_j^* and worst f_j^- values of all criterion functions were determined in this step. Users need to be aware if the criterion needed was either of benefit or a cost. Benefit meant that the user needs the criterion to be maximum whereas for a cost the criteria need to be minimum. If the benefit was selected for the criterion, then the user needed to use $f_j^* = \max f_{ij}$ and $f_j^- = \min f_{ij}$ while for the cost criterion, $f_j^* = \min f_{ij}$ and $f_j^- = \max f_{ij}$. The f_j^* is the positive and f_j^- is the negative ideal solution for the jth in this step. A positive ideal solution is the best alternative while the negative ideal solution consists of the worst alternatives with respect to each evaluation criterion.

Step 8: The distance of the alternatives to the ideal solution was computed and summed to obtain the final value using Eq. (9) and Eq. (10).

$$\boldsymbol{S_i} = \sum_{j=1}^{n} \boldsymbol{w_j} \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \quad (9)$$

$$\boldsymbol{R_i} = \boldsymbol{max} \;\; \boldsymbol{w_j} \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \quad (10)$$

where S_i is the weighted summation of the distance to the best evaluation value for *ith* alternative with respect to all criteria and R_i is the maximum weighted distance to the best evaluation value for the ith alternative with respect to the jth criterion. The best ranking for a positive ideal solution was based on S_i values, while the worst ranking for a negative ideal solution was based on R_i values. In other words, S_i, R_i indicate L_{1i} and $L_{\infty i}$ respectively from L_p-metric in Eq. (6).

Step 9: The VIKOR values, Q_i for i=1, 2,…, m were calculated, using Eq. (11)

$$\boldsymbol{Q_i} = \boldsymbol{v}\left[\frac{S_i - S^+}{S^- - S^+}\right] + (\boldsymbol{1} - \boldsymbol{v})\left[\frac{R_i - R^+}{R^- - R^+}\right] \quad (11)$$

where $S^- = \max S_i$, $S^+ = \min S_i$, $R^- = \max R_i$, $R^+ = \min R_i$ and v is the weight of the strategy of the majority criteria or the maximum group utility. Overall benefits for the ith alternatives refer to S_i where smaller values mean larger benefits, so $S^+ = \min S_i$ and $S^- = \max S_i$ and individual regret for the ith alternative refers to R_i where smaller value means smaller individual regret of the opponent, so $R^+ = \min$, R_i and $R^- = \max R_i$. The distance rate from the positive ideal solution of the ith alternative is represented by $(S_i - S^+ / S^- - S^+)$ which means that the majority agree to use the rate of the ith. While the distance rate of the negative ideal solution of the ith alternative is represented by $(R_i - R^+ / R^- - R^+)$ meaning that the majority disagree with the rate of the ith alternative. Generally, $v = 0.5$ to show that the compromising attitude of evaluation experts where v is the weight of maximum group utility and $1-v$ is the weight of individual regret [32,33].

Step 10: The alternatives were ranked by the values S_i, R_i and Q_i in descending order. According to the Q_i values calculated in Step 9, the alternatives were ranked to make a decision. The compromise solution was then proposed by the measurement of Q value with the minimum remarks as an alternative $A^{(1)}$, was the best ranked if the following two conditions were satisfied:

Condition 1: Acceptable advantage. $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$, where $DQ = 1/(J-1)$, J is the number of alternatives, and $A^{(2)}$ is the alternative with the second position on the ranking list by Q.

Condition 2: Acceptable stability in decision-making. The alternative $A^{(1)}$ must also be the best ranked by S or/and R. This compromise solution was stable within a decision-making process where the value of v lies in the range of 0-1. The strategy of voting could be by consensus when $v \approx 0.5$, by majority rule when $v > 0.5$, or with a veto when $v < 0.5$. In this paper, these strategies were compromised by $v = 0.5$

If one of the conditions above is not satisfied, then a set of compromise solutions were proposed, which consisted of:

Condition 3: Alternative $A^{(1)}$ and $A^{(2)}$ if only condition 2 is not satisfied, or

Condition 4: Alternatives $A^{(1)}, A^{(2)},\ldots,A^{(M)}$ if condition 1 is not satisfied. $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum m which means that the positions of these alternatives are close to the ideal solution.

3 Results and Discussion

The criteria of the automotive side-door impact beam were decided by ten decision makers (DM) experts in automotive engineering and product design. The DM made a judgment of each criterion to determine the relative importance among them with respect to the project goal using the AHP method. Step 1 until Step 4 was analyzed using Super Decisions software while in Step 5, the data was recorded, and the results were determined based on the arithmetic mean as shown in Tab. 5. The results indicated excellent consistency subjective judgments of each DM performance and the average value of CR less than 0.1. The results of the priority vector, w, had then been summed and the average taken as the weight of importance for the criteria of the automotive side-door impact beam. Fig. 6 shows the average value of the priority vector for the criteria.

Table 5: Results of pairwise comparison judgment by decision makers using Super Decisions software

*	PF	SZ	WG	PC	EV	DP	Consistency Ratio (CR)
DM1	0.5766	0.0727	0.0710	0.1341	0.0727	0.0727	0.0049
DM2	0.5565	0.1103	0.1103	0.1416	0.0407	0.0407	0.0346
DM3	0.3486	0.0595	0.0309	0.3486	0.1534	0.0589	0.0651
DM4	0.3126	0.0345	0.0436	0.3392	0.1041	0.1661	0.0855
DM5	0.5246	0.0226	0.1846	0.0750	0.0966	0.0966	0.0800
DM6	0.3853	0.0437	0.3853	0.0933	0.0462	0.0462	0.0059
DM7	0.2923	0.2923	0.0308	0.2923	0.0461	0.0461	0.0084
DM8	0.2353	0.0588	0.2353	0.2353	0.1176	0.1176	0.0000
DM9	0.1791	0.0315	0.5561	0.1718	0.0308	0.0308	0.0891
DM10	0.1806	0.0463	0.0783	0.1102	0.4145	0.1701	0.0891
TOTAL	3.5916	0.7722	1.7262	1.9415	1.1227	0.8459	0.4626
AVERAGE	0.3592	0.0772	0.1726	0.1941	0.1123	0.0846	0.0463
Ranking	1	6	3	2	4	5	

*Performance (PF), Size (SZ), Weight (WG), Product Cost (PC), Environment (EV), Disposal (DP)

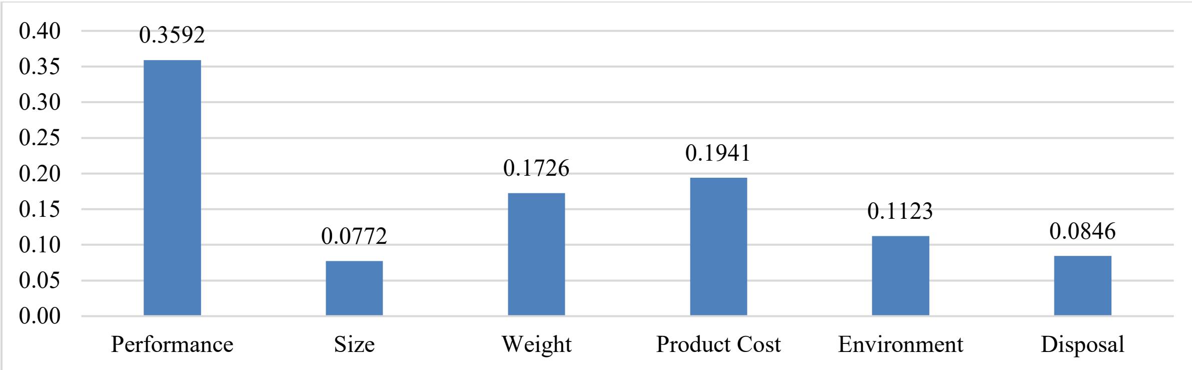

Figure 6: Average value for weight of importance between the selection criteria

Natural fiber materials in Tab. 1 are considered to perform similarly to synthetic fibers, thus making reuse, recycling, renewing, and disposal safe easy. As for the environmental criteria, has a fair dimension and stability due to water absorption. To be fair, for the criteria on size, the automotive side-door impact beam was assumed to be the same in this research. Thus, the criteria that were analyzed in this research was performance, weight, and product cost. The sub-criteria for performance are strength, stiffness, elongation at break. The energy absorption considered the specific energy absorption, where the density was determined using Eq. (12) [9,34], which was combined with the weight criteria. The product cost took into account the raw material price in USD/kg and also the world production (availability) in 10^3 tonnes of the natural fibers. Before proceeding, the weightage of the criteria was recalculated, because three criteria with six sub-criteria were considered. The summation for the weightage for performance, weight, and product cost was 0.7259. Then, the weightage of the criterion was divided by the summation value, where the weightage to performance, weight, and product cost were 0.4947, 0.2379 and 0.2674 respectively [35].

$$\boldsymbol{E_s} = \frac{\int_0^{\delta} \boldsymbol{F \cdot d\delta}}{\boldsymbol{\rho A \delta}} \tag{12}$$

where E_s is the specific energy absorption, F is the crush force, δ is total crush displacement, ρ is density and A is the cross-section area.

Table 6: Normalized matrix and best and worst values for fij (Step 7)

	Criteria	Strength	Stiffness	Elongation	Density	Cost	Availability
	Weights	0.1649	0.1649	0.1649	0.2378	0.1337	0.1337
Alternatives	Abaca	0.3081	0.2084	0.0727	0.3447	0.0678	0.0262
	Coir	0.0868	0.0386	0.5013	0.2758	0.0590	0.0374
	Flax	0.3416	0.3865	0.0526	0.3171	0.6115	0.3106
	Hemp	0.4190	0.2898	0.0764	0.3102	0.3048	0.0801
	Jute	0.2380	0.2415	0.0576	0.2827	0.1821	0.8606
	Kenaf	0.3037	0.2641	0.1203	0.2758	0.0743	0.3630
	Pineapple	0.4455	0.4573	0.0501	0.3447	0.0934	0.0277
	Oil Palm	0.1230	0.0319	0.6266	0.2585	0.0590	0.0150
	Ramie	0.3317	0.6100	0.0752	0.3309	0.3933	0.0374
	Sisal	0.3376	0.0998	0.0614	0.2758	0.1278	0.1414
	Sugar Palm	0.1371	0.0380	0.5589	0.2850	0.5506	0.0150
	f_j^*	0.4455	0.6100	0.6266	0.2585	0.0590	0.8606
	f_j^-	0.0868	0.0319	0.0501	0.3447	0.6115	0.0150

Tab. 6 shows the normalized values for f_{ij} and the calculation using Eq. (8) with the determination of best values of f_j^* and worst values f_j^- for each criterion. Tab. 7 shows the values of a positive ideal solution, negative ideal solution and VIKOR values (*S, R, Q*) for the alternatives involved in selection. It can be seen that from the eleven alternatives, kenaf fiber showed the lowest VIKOR value, *Q*, where it is closest to an ideal solution suggest by VIKOR method. The second and third lowest value was obtained for pineapple and jute fiber respectively. Kenaf ranks first for a positive ideal solution, *S* and also a negative ideal solution, *R*.

Table 7: The positive ideal solution, S negative ideal solution, R and VIKOR values, Q

Rank	*S*	*S* value	*R*	*R* value	*Q* (v = 0.5)	*Q* value
1	Kenaf	0.4387	Kenaf	0.1449	Kenaf	0.0000
2	Pineapple	0.4469	Hemp	0.1574	Pineapple	0.1233
3	Jute	0.4597	Sisal	0.1617	Jute	0.1354
4	Sisal	0.5347	Jute	0.1628	Sisal	0.2689
5	Coir	0.5415	Sugar Palm	0.1632	Coir	0.2988
6	Oil Palm	0.5863	Flax	0.1642	Oil Palm	0.7740
7	Hemp	0.5865	Pineapple	0.1649	Hemp	0.3418
8	Ramie	0.6209	Coir	0.1649	Ramie	0.6335
9	Sugar Palm	0.6499	Ramie	0.1998	Sugar Palm	0.4906
10	Flax	0.6581	Oil Palm	0.2378	Flax	0.5114
11	Abaca	0.7081	Abaca	0.2378	Abaca	1.0000

In the VIKOR method, two conditions were needed to be satisfied a material can be concluded as the best natural fiber suggestion in this paper. The first condition was the acceptable advantage, where the difference of *Q* for the second-best alternative minus the first best alternative must be less than the *DQ* value as in step 10. There were eleven alternatives, so the *DQ* value was 0.1. The first and second-best alternatives were kenaf and pineapple fiber, with 0.0000 and 0.1233 *Q* value, respectively, resulting in 0.1233 - 0.0000 = 0.1233, which is larger than the *DQ* value, which means that kenaf fiber satisfied the first condition. The second condition, as per step 10 was acceptable stability, where the best alternative must be ranked in S and/or R. From Tab. 7, kenaf fiber satisfied the best rank in both *S* and *R*, with a value of 0.4387 and 0.1449 respectively. Thus, it can be concluded that kenaf is the best natural fiber that fulfilled the required design specification for automotive side-door impact beam using integrated AHP-VIKOR method.

To support the results, there are many reports on suitability and application of kenaf fiber as the reinforcement of polymer composites material in producing automotive components, such as spare tire cover, door trims, pillars, instrument panels, door panels, and others to replace plastic and synthetic fibers [24,36,37]. The results showed similar findings on the selection of kenaf fiber as a natural fiber polymer composites for producing automotive parts such as dashboard panels [13,38], bumper beam [39], hand brake levers [40], automotive spoiler [41], automotive brake pad [42], and for car front hood [18]. This shows the suitability of kenaf as the reinforcement material in natural fiber composites fabrication for automotive applications compared to other types of natural fiber materials.

4 Conclusions

Six product criteria were taken into consideration in determining the weightage of criteria for the natural fiber polymer composites, for the side-door impact beam. The weightage of the criteria was calculated using AHP method by Super Decisions software and determined by ten experts in automotive engineering and product design. The highest weightage of the criteria is given to performance with the value of 0.3592 followed by product cost (0.1941), weight (0.1726), environment (0.1123), disposal (0.0846), and finally size (0.0772). The VIKOR method then used the weightage criteria to determine the best natural fiber materials based on three criteria and six sub-criteria. The kenaf fiber reported the least VIKOR value, *Q* = 0.0000 followed by pineapple fiber and jute fiber with the value of 0.1233 and 0.1354 respectively. Kenaf fiber satisfied two conditions in the VIKOR method which are acceptable advantage and stability conditions. Kenaf fiber was selected as the best natural fiber material to be used as the reinforcement material in polymer composites of side-door impact beam. Apart from that, the application of integrated AHP-VIKOR method in this paper resulted in a systematic and justified solution towards the decision-making process when there are multiple requirements and different attributes that needed consideration.

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