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Selection of Automotive Brake Material Using Different MCDM Techniques and Their Comparisons

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Abstract

Brake pad is one of the crucial components of automobile to protect the vehicle against accidents. Natural fiber composites (NFCs) - Flax, Kenaf, Bamboo, Oil-Palm, Sisal, Coir, Hemp, Banana, Palf, and Jute - prepared by different reinforcing agent are used to manufacture brake pads. However, selection of suitable brake pad materials is critical, as there are many NFs, and each NF has some advantages, and limitations. MCDM (Multi-criteria decision-making) technique is widely adopted to select the most suitable alternative materials based on various criteria. In this research, ten alternative NFs have been ranked using seven MCDM methods. Criteria considered in this study are: density, hardness, coefficient of friction, wear rate, compressive strength, degradation temperature, and moisture gain; And weights of criteria are calculated using LGPMBWM (Linear Goal Programming Model for Best Worst-Method). And ranking of natural fibers have been done using CoCoSo (Combined Compromise Solution Method), WPM (Weighted Product Method), WSM (Weighted Sum Method), CoCoSo (Combined Compromise Solution), PIV (Proximity Indexed Value), TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution), and MABAC (Multi-Attributive Border Approximation Area Comparison methods). The final ranking of alternatives has been done by employing membership degree method. Further, the consistency, and reliability of applied MCDM methods is done by applying sensitivity analysis. As a result of this, Flax occupied the first rank, whereas bamboo proved to be the worst natural fiber for manufacturing of brake pads. This study uses different MCDM technique for the selection problem which makes it more reliable and performance of sensitivity analysis makes it consistent.

Keywords: Natural Fiber; Linear Goal Programming Model for Best Worst-Method; Natural Fiber Reinforced Composite; Combined compromise Solution method; Weighted Product Method; Weighted Sum Method; Proximity Indexed Value; The Technique for Order of Preference by Similarity to Ideal Solution; Multi-Attributive Border Approximation Area Comparison.

1. Introduction

The most critical parts of the braking mechanism are brake discs, brake pads, and linings. There are two types of brake pads: Asbestos, and Non- Asbestos. Asbestos brake pad is carcinogenic, whereas Non-Asbestos pads are environment-friendly. Various NFs are available, which can be used in the brake pads. Material selection for brake pad not only depends on material functions, but also on the cost, availability, and process-ability [1]. Various NFs are available, which can replace asbestos completely for the application in brake pads. Palm kernel fiber is used to develop the brake pads in which various tests have been carried out to find out moisture absorption, wear rate, coefficient of friction, porosity, hardness. It was found that palm kernel fiber made NFC exhibits high friction coefficient, and high wear rate, which reduce the life of the brake pad[2]. Bagasse fiber is taken for the production of brake pads, in which various samples are made by different sieve size, and different wt. percentage. Satisfactory results come out only at 100µm sieve grade of bagasse with a content of 70% Bagasse, 30% resin[3]. Banana peel fiber is employed for the formulation of NFC's brake pads, where they found that there is a rise in the coefficient of friction, as the percentage of weight of resin gets enhanced in the formulation[4].

Multi-criteria Decision-making (MCDM) techniques are applied for the material selection in various application: application of Taguchi's method for the calculation of various parameters for the manufacturing of Brake lining [5], application of AHP and VIKOR test for the material selection of Kevlar Lapinus for brake pads [6] and the result was: if the percentage of Lapinus and Wollastonite fiber increases, then flexural, and tensile strength of the friction composites decrease. On the other hand, addition of higher content of wollastonite, and Kevlar fiber resulted in improved wear, and recovery performance. All the MCDM methods have various advantages, and different limitations which are as follows in Table 1.

The aim of this research study is that it suggests a systematic technique to select the best material for brake pad. In this paper, various MCDM techniques like LGPBWM, WSM, WPM, CoCoSo, PIV, TOPSIS, and MABAC have been used to rank the different NFs; and the calculated ranks are, then, combined by Membership Degree Method. To the best of author's knowledge and understanding, such approach has not been used collectively on a single problem, which motivated us to carry out this study. LGPMBWM is employed

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to find out the optimal weights of different criteria; and the calculated weights are utilized to find out the rank. Further, sensitivity analysis is performed to verify the results. Industrial application, and future scope are also sketched in this research.

Table 1. Different MCDM methods used for materials, their advantages, and limitations.

Technique	Invention Year	Advantages	Limitations
WPM	1969	It's easy to use and it has the ability to convert qualitative data into quantitative information.	It does not provide optimal solution for all MCDM problems.
AHP	1970	Additional tool is not required for criteria weight determination.	As the number of criteria and alternatives increase, technique becomes complicated.
TOPSIS	1981	It's a simple technique and procedure doesn't change irrespective of number of alternatives and criteria.	If the problem is multi-dimensional, then vector normalisation may be required.
FAHP	1983	FAHP decision maker's personal judgement doesn't affect the final results.	Assumption made in FAHP is all the involved criteria are independent of each other but in reality interdependencies may occur.
VIKOR	1990	It is modified TOPSIS approach.	When conflicting criteria increases , technique becomes complicated
COPRAS	1994	It's a very simple technique and requires less calculations	It's little unstable as slight change in data can lead to change in overall ranking.
WSM	2009	It provides a basic and easy to use approach for multi objective optimisation problems.	It not capable of incorporating complex preference information.
ARAS	2010	It is easy to rank and evaluate the decision.	If alternatives are more, calculations become lengthy.
WASPAS	2012	It tries to achieve the highest degree of accuracy of optimisation.	If the dimension of the matrix increases, time required to solve the problem may be long.
BWM	2015	It provides pairwise comparison in a structured way.	It doesn't identify global optimal solution, calculation is complex.
MABAC	2015	It gives the consist solution to the MCDM problems.	To make the results more reliable sensitive analysis is performed, which makes this method little complex.
PIV	2018	It eliminates the rank reversal problem in most of the MCDM problems.	It doesn't eliminate the rank reversal problem occurred due to the normalisation process.
CoCoSo	2019	It's easy to implement as it provides ranking to available alternatives.	Calculations are complex and lengthy.

2. Methodology

The entire work methodology of the paper is shown in figure 1 for understanding the picture of the entire work of this paper.

For manufacturing of brake pads, various NFs are available, but each NF has its own specific properties, and limitations. The need is to find out the best alternative, depending on its properties, and availabilities. Various alternative materials considered in this study are: Hemp(H1), Flax(F1), Kenaf (K1), Palf (P1), Bamboo(B1), Oil palm(O1), sisal(S1), coir(C1), Banana(Ba1), Jute (J1); and they have been evaluated on the basis of the seven conflicting criteria: Density(Z1), Hardness(Z2), Wear Rate(Z3), Coefficient of friction(Z4), Compressive Strength(Z5), moisture gain(Z6), Thermal Degradation Temperature (Z7), as presented in Table 2.

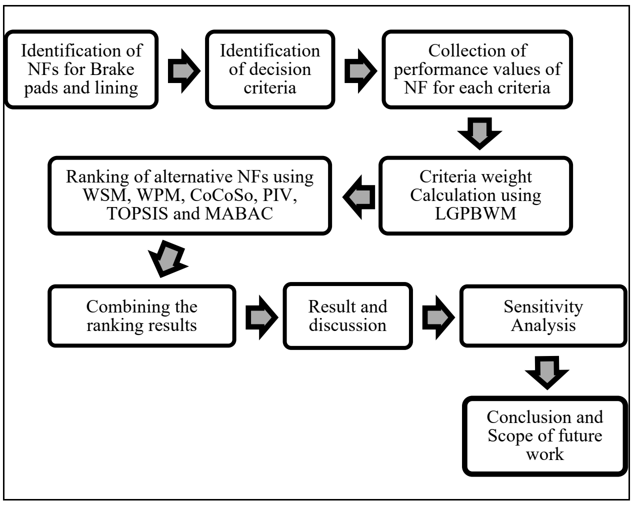

Fig. 1. Step wise work methodology of brake pad material selection problem.

2.1. LGPMBWM (Linear Goal Programming Model for Best Worst Method)

For this study, the weight calculation is done using a recently developed linear goal programming model for the best-worst method (LGPMBWM)[12], which involves selecting the best factor (the most important criterion) and the worst factor (the least important criterion), and then comparing them to other criteria using a comparison scale ranging from 1 to 9. As a result, two pairwise comparison vectors can be created: BO (Best to Others) and OW (Others to Worst). Furthermore, the optimal criteria weights and consistency ratio are computed using LGPMBWM. The BWM offers only a few advantages over the other techniques: (i) It provides minimum deviation, confirming closer weight ratios; (ii) It provides stable comparisons; and (iii) when compared to AHP, it provides minimum deviation, indicating superior ordinal consistency [13]. Based on various advantages of BWM, this method was used by many researchers to calculate criteria weight in various applications [14][15][16]. With these advantages, (2n-2) number of constraints are there in LGPMBWM, while in actual, BWM number of constraints are 4n-5 (n is the number of criteria). The LGPMBWM has lesser constraints as compared to BWM, due to which enhanced computational solution is found, and it also reduces the complexity in original BWM. Further, the details of this method can be studied from the research done by its developer[12]. However, to get the clear understanding of this method, following steps are explained here [12][17].

Step 1: List n decision criteria {X_1, X_2, …, X_n} for the current problem. For the selection of NF, decision criteria are as follows: Density (Z1), Hardness (Z2), Wear Rate (Z3), Coefficient of friction (Z4), Compressive Strength (Z5), moisture gain (Z6), Thermal Degradation Temperature (Z7).

Step 2: Choose the best and the worst factors. On the advice of academic experts best and worst factors have been chosen in this study.

Step 3: In this step, comparison is performed pairwise between best criterion, and other criteria by assigning numbers from 1 to 9. Number 1 is assigned to the least important factor and number 9 is assigned to the most important factor. To find out the importance of the best criterion over others, that leads to the generation of best to others (BTO) vector as:

$$E_B = (e_{B1}, e_{B2}, e_{B3} \dots . e_{Bn}) \quad (1)$$

Table 2. Comparison of different properties of NFs[4], [7]–[11]

Alternative NFs	Z1 in gm/cm^3	Z2 in RHN	Z3 in mm^3/N-m	Z4	Z5 in (MPa)	Z6 in (%)	Z7 in °C
Goal	**Min**	**Max**	**Min**	**Max**	**Max**	**Min**	**Max**
H1	1.48	89	12	0.6	27	12	250
F1	1.52	75.6	6	0.6	1200	12	250
K1	1.4	73	1.2	0.4	34.2	17	219
P1	1.52	84	284	0.6	200	14	220
B1	1.4	94.9	8000	0.4	104.82	14	200
O1	1.65	89.5	1.9	0.76	1.4	20	250
S1	1.4	99	4	0.6	290.78	14	300
C1	1.25	60	26	0.6	31	13	190
Ba1	1.3	85	4	0.6	39.9	13.5	200
J1	1.37	48	8.42	0.4	44.4	17	205

Z1: Density; Z2: Hardness; Z3: Wear Rate; Z4: Coefficient of friction; Z5: Compressive Strength; Z6: moisture gain; Z7: Thermal Degradation Temperature; H1: Hemp; F1: Flax; K1: Kenaf; P1: Palf; B1: Bamboo; O1: Oil palm; S1: sisal; C1: sisal; Ba1: Banana, J1: Jute.

Where, E_B is the best to others (BTO) vector and e_{Bj} = Importance of best criterion over the jth criterion. It can be stated that$e_{BB} = 1$.

Step 4: Comparison of each and every criteria with the worst criterion is done in the same way as in previous step which provides the formulation of others-to-worst (OTW) vector as:

$$E_w = (e_{1w}, e_{2w}, e_{3w} \dots . e_{nw})^T \quad (2)$$

Where e_{jw} = importance of jth criterion w.r.t. the worst criterion. It is obvious, $e_{ww} = 1$.

Step 5: In the last step optimal weights (f_1, f_2, $f_{3,\dots\dots}$,f_n) are calculated. The amount of inconsistency is defined by $p_j^+ - p_j^-$ and $q_j^+ - q_j^-$ to show the priority of BTO, and OTW. The main objective of LGPMBWM is to minimize the total deviation. Eq. (3) represents the LGPMBWM model.

$$\min z = \sum_j \left(p_j^+ + p_j^-\right) + \sum_j \left(q_j^+ + q_j^-\right) \quad (3)$$

Subject to:

$$f_B - e_{Bj} f_j = p_j^+ - p_j^- \text{ , for all j,}$$

$$f_j - e_{jw} e_w = q_j^+ - q_j^- \text{ , for all j,}$$

$$\sum_j f_j = 1$$

$$f_j, p_j^+, p_j^-, q_j^+, q_j^- \geq 0, \qquad for\ all\ j$$

Step 6: Eq. (4), and (5) are used to calculate the consistency ratio. For the high degree of consistency, consistency ration must be close to zero and vice versa.

$$\xi = \max_j \left\{p_j^+ - p_j^-, q_j^+ + q_j^-\right\} \quad (4)$$

$$\text{consistency ratio} = \frac{\xi}{\text{consistency index}} \quad (5)$$

Table 3. Consistency table

E_{BW}	1	2	3	4	5	6	7	8	9
consistency index	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

2.2 Methods for ranking alternatives

Multi-criteria decision-making is a process of decision-making, while considering various conflicting criteria. In MCDM method, a particular rank is given to each alternative, and the alternative, which gets the highest rank, is recommended as the best alternative. In most of the MCDM methods, initially, a decision matrix is formulated, which is obtained by arranging alternatives, and decision criteria in rows, and columns respectively. Considering *nA,* and *nC* as the total number of alternatives, and decision criteria and a_{ij} as the value for alternative *i* corresponding to criteria *j*, the decision matrix is represented by Eqn. (6)

$$DM = \begin{bmatrix} a_{11} & \dots & \dots & a_{1j} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ a_{i1} & \dots & \dots & a_{ij} \end{bmatrix}_{nA \times nC} \tag{6}$$

Since, it is expected that the criteria for evaluation are defined over different range, and may have different dimensions; they are normalized into a similar range. There are various methods to perform normalization: Linear, vector, and logarithm etc [18] and each method has a pre-defined normalization method associated with it. Further, a weight (w_j) to each criterion is defined, which signifies its importance for selection of the best alternative.

Table 4. Different MCDM methods, and their computational steps

Method	Step 1	Step 2	Step 3	Step 4	Step 5
WSM	$If\ j \in B, n_{ij} = \frac{\min_i a_{ij}}{a_{ij}}$ $If\ j \in C, n_{ij} = \frac{a_{ij}}{\max_i a_{ij}}$	$r_{ij} = n_{ij} \times w_j$	$P_i = \sum_j r_{ij}$		
WPM	$If\ j \in B, n_{ij} = \frac{\min_i a_{ij}}{a_{ij}}$ $If\ j \in C, n_{ij} = \frac{a_{ij}}{\max_i a_{ij}}$	$r_{ij} = (n_{ij})^{w_j}$	$P_i = \prod_j r_{ij}$		
TOPSIS	$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_i (a_{ij})^2}}$	$r_{ij} = n_{ij} \times w_j$	$v_j^+ = \begin{Bmatrix} \max_i r_{ij}\ ;\ if\ j \in B \\ \min_i r_{ij}\ ;\ if\ j \in C \end{Bmatrix}$ $v_j^- = \begin{Bmatrix} \min_i r_{ij}\ ;\ if\ j \in B \\ \max_i r_{ij}\ ;\ if\ j \in C \end{Bmatrix}$	$D_i^+ = \sqrt{\sum_j (v_j^+ - r_{ij})^2}$ $D_i^- = \sqrt{\sum_j (v_j^- - r_{ij})^2}$	$P_i = \frac{D_i^-}{D_i^+ + D_i^-}$
MABAC	$If\ j \in B, n_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}$ $If\ j \in C, n_{ij} = \frac{a_{ij} - \min_i a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}$	$r_{ij} = (n_{ij} + 1) \times w_j$	$v_j = \left(\prod_i r_{ij}\right)^{1/nA}$	$P_i = \sum_j (r_{ij} - v_j)$	
PIV	$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_i (a_{ij})^2}}$	$r_{ij} = n_{ij} \times w_j$	$If\ j \in B, v_{ij} = \max_i r_{ij} - r_{ij}$ $If\ j \in C, v_{ij} = r_{ij} - \min_i r_{ij}$	$P_i = \sum_j v_i$	
CoCoSo	$If\ j \in B, n_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}$ $If\ j \in C, n_{ij} = \frac{a_{ij} - \min_i a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}$	$WC_i = \sum_j (n_{ij} \times w_j)$ $PC_i = \sum_j (n_{ij})^{w_j}$	$A_i = \frac{WC_i + PC_i}{\sum_i (WC_i + PC_i)}$ $B_i = \frac{WC_i}{\min_i WC_i} + \frac{PC_i}{\min_i PC_i}$ $C_i = \frac{WC_i + PC_i}{\max_i WC_i + \max_i PC_i}$	$P_i = A_i \times B_i \times C_i$	

Various MCDM methods are presently available to solve material selection problem with different evaluation, and computational steps. WSM (Weighted sum model), and WPM(weighted product model) are the simplest, and the initial methods for ranking the alternatives[19] . In WPM, the weighted sum, and in WPM, weighted product of the criteria values are used as a performance score for ranking. An alternative with highest performance value is ranked one, and other alternatives are ranked in decreasing order [19][20]. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is the most commonly used MCDM method among researchers. This method was developed by[21], and is successfully employed to solve problems pertaining to different knowledge domain[22]. According to this method, an alternative with largest distance from the negative, and the smallest distance from positive ideal solution is ranked first. MABAC (Multi- Attribute Border Approximation area Comparison) introduced in 2015 ranks the alternatives on the basis of their distance from the border approximation area (BAO) [23]. It is suggested that an alternative with highest distance from the BAO is ranked first, and other alternatives are ranked as per descending values of the distance from BAO[23][24][25] . Proximity Index value (PIV) method identified in 2018 by Mufazzal and Muzakkir (2018), is a new method, which computes the ranks of the alternatives on the basis of proximity value[26]. An alternative with the least proximity value is ranked one, and the remaining alternatives are ranked in increasing order of the proximity value [17][26](12,21). Combined Compromise Solution Method (CoCoSo) method was developed by Yazdani (2019) [27] . This method depends on the relative distance of alternative from the ideal one, which gives compromised solution of alternatives ranking[27][28]. Fundamentally, computation of weight compatibility sequence, and power compatibility sequence are two noteworthy passages of ranking. Alternatives are ranked in such a way that an alternative, which has the highest performance value, will acquire first rank, followed by others with decreasing performance value.

In this study, WSM, WPM, TOPSIS, MABAC, PIV, and CoCoSo are used for the material selection of the brake pad. The computational steps involved in these methods are shown in table 4.

2.3 Method to combine the ranks obtained using different MCDM methods

Since the methods considered in this study have different computational steps, it is possible that the ranks obtained using these methods may vary. Therefore, a methodology given by [29] is used to calculate the final ranking of the NFs. The steps discussed are as follows [17][29]:

Step 1: Formulate rank frequency matrix (R) as given by Eqn. (7).

$$R = \begin{bmatrix} y_{11} & \cdots & y_{1r} \\ \cdots & \cdots & \cdots \\ y_{p1} & \cdots & y_{pr} \end{bmatrix} \quad (7)$$

Where, y_{pr} represents the sum of ranks of alternative p at rank r obtained using B different MCDM methods.

Step 2: Compute membership degree matrix using Eqn. (8).

$$\gamma_{pr} = \frac{y_{pr}}{B} \quad (8)$$

Where, γ_{pr}represents the membership degree of risk factor p at rank r.

Step 3: Compute rank index RI_p for alternatives using Eqn. (9).

$$RI_p = \sum_{q=1}^{N} \gamma_{pr} \quad (9)$$

Step 4: Alternatives are ranked depending on the rank index in ascending order.

3. Results and Discussion

Decision matrix of this issue is appeared in Table 2, which shows ten alternative NFs, and seven decision criteria. So as to utilize LGPMBWM to decide criteria weight, vital information is required, which were gathered from six automotive materials experts from different Universities and Industries in India. All the experts have more than 20 years of experience in the field of automotive materials. The specialists met, and it was requested to choose the best, and the worst criteria. The Best, and the worst criteria chosen by the specialists are shown in Table 5.

Table 5. Best and Worst Criteria Identified by Experts (1 to 6).

Factors	Identified as Best by Expert No.	Identified as Worst by Expert No.
Z1		3
Z2		4,5,2
Z3	5,2,1,6	
Z4		
Z5	3	
Z6	4	2,1
Z7		

Z1: Density; Z2: Hardness; Z3: Wear Rate; Z4: Coefficient of friction; Z5: Compressive Strength; Z6: moisture gain; Z7: Thermal Degradation Temperature

The experts were also requested to compare the best criterion with other criteria, and also other criteria with the worst criterion, and give their preference on a scale of 1 to 9. This comparison led to the formation of Best to Others (BTO), and Others to Worst (OTW) matrices, which are presented in Table 6, and Table 7 respectively.

On the basis of pairwise comparison, matrices appeared in Table 6 and 7, optimal criteria weights, and consistency ratio were determined using Eq. (5), as introduced in Table 8. Finally, a single value of the weight and consistency ratio was found out by the weight, averaging the weights of all six experts, which are shown in Table 8. It has to be stated here that the weights to the six experts are assigned as 0.1456, 0.1748, 0.1942, 0.1942, 0.1748, and 0.1165 on the basis of their experience.

It is clear from Table 8 that 0.0622 is the consistency ratio, which is much smaller than 1.0, which demonstrates that the determined criteria weights are both optimal, and reliable. After obtaining optimal criteria weights shown in Table 8, the steps of CoCoSo were implemented to obtain rank of the alternative natural fibers. The ranking results are given in Table 9.

Considering Table 2 as the decision matrix, and weights of the criteria shown in Table 8, WSM, WPM, TOPSIS, MABAC, PIV and CoCoSo, methods were employed. The steps shown in Table 5 are followed, and the performance values and ranks obtained for NFs are
Shown in table 9.

It has been observed from Table 9, that out of six methods, three suggests Flax (F1) to be the best alternative, while two suggests Sisal (S1), and one suggests (K1) as the best alternative, as they are ranked first. Further, Bamboo (B1) is ranked last i.e. 10 by all the six methods, which indicate it is the worst alternative among all. Since there is a variation in the ranks of the other alternatives, the final ranking is determined by combining the ranks of the alternatives, using membership degree method. As the first step of membership degree method is the formulation of rank frequency matrices, described in Eqn. (7). The rank frequency matrix is shown in Table 10.

Further, membership degree is computed by dividing the rank frequency matrix by 6, as given by Eqn. (8). Finally, rank index is computed using Eqn. (9), and the alternatives are ranked in ascending values of rank index. Table 11 exhibits the membership degree, rank index, and final rank of the NFs obtained.

Table 6. Best to Others (BTO) pairwise comparison matrix.

Expert No.	Best criteria	Z1	Z2	Z3	Z4	Z5	Z6	Z7
1	Z3	3	4	1	2	5	9	7
2	Z3	2	4	1	2	5	8	5
3	Z5	9	3	3	2	1	7	7
4	Z6	7	9	8	8	7	1	8
5	Z3	6	9	1	7	5	7	8
6	Z3	2	9	1	3	7	8	8

Z1: Density; Z2: Hardness; Z3: Wear Rate; Z4: Coefficient of friction; Z5: Compressive Strength; Z6: moisture gain; Z7: Thermal Degradation Temperature.

Table 7. Others to Worst (OTW) pairwise comparison matrix.

Expert No. Worst Factors	1 Z6	2 Z6	3 Z1	4 Z2	5 Z5	6 Z2
Z1	7	7	1	8	3	6
Z2	6	3	7	1	1	9
Z3	9	9	8	2	9	1
Z4	8	9	7	3	3	7
Z5	4	6	9	7	3	3
Z6	1	1	3	9	3	2
Z7	2	7	2	4	2	2

Z1: Density; Z2: Hardness; Z3: Wear Rate; Z4: Coefficient of friction; Z5: Compressive Strength; Z6: moisture gain; Z7: Thermal Degradation Temperature.

Table 8. Calculation of consistency ratio

Expert No	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Consistency Ratio
1	0.1351	0.1013	0.4052	0.2026	0.081	0.0169	0.0579	0.0484
2	0.1867	0.0933	0.3733	0.1867	0.0747	0.0107	0.0747	0.0644
3	0.0167	0.1337	0.1337	0.2005	0.401	0.0573	0.0573	0.0479
4	0.0851	0.0106	0.0745	0.0745	0.0851	0.5957	0.0745	0.0956
5	0.0913	0.0261	0.5479	0.0783	0.1096	0.0783	0.0685	0.0599
6	0.2199	0.0209	0.4398	0.1466	0.0628	0.055	0.055	0.0481
Weighted Average	0.1136	0.0661	0.3117	0.1463	0.1457	0.1512	0.0655	0.0622

Z1: Density; Z2: Hardness; Z3: Wear Rate; Z4: Coefficient of friction; Z5: Compressive Strength; Z6: moisture gain; Z7: Thermal Degradation Temperature.

Table 9. Performance value, and Ranks of NFs using different MCDM methods

Alternative	WSM		WPM		TOPSIS		MABAC		PIV		CoCoSo	
NFs	Pi	Rank	Pi	Rank	Pi	Rank	Pi	Rank	Pi	Rank	Pi	Rank
H1	0.49679	6	0.25695	7	0.69486	5	0.10926	3	0.16935	4	2.71967	3
F1	0.65892	2	0.54673	1	0.9474	1	0.22337	2	0.03639	1	3.03354	2
K1	0.69959	1	0.48885	3	0.69062	9	-0.0522	8	0.19863	8	2.15883	7
P1	0.45761	7	0.12375	9	0.71814	3	0.04425	7	0.16862	3	2.5986	5
B1	0.41149	10	0.03762	10	0.05601	10	-0.3285	10	0.49599	10	1.38717	10
O1	0.65442	3	0.29332	5	0.69098	7	0.05845	5	0.17287	5	2.07174	8
S1	0.61917	4	0.52765	2	0.74768	2	0.22969	1	0.12504	2	3.04381	1
C1	0.44352	8	0.19528	8	0.6923	6	0.04631	6	0.18367	7	2.39087	6
Ba1	0.53884	5	0.37183	4	0.69549	4	0.07609	4	0.17523	6	2.62505	4
J1	0.41207	9	0.26711	6	0.69087	8	-0.0944	9	0.20631	9	1.84893	9

Z1: Density; Z2: Hardness; Z3: Wear Rate; Z4: Coefficient of friction; Z5: Compressive Strength; Z6: moisture gain; Z7: Thermal Degradation Temperature, H1: Hemp; F1: Flax; K1: Kenaf; P1: Palf; B1: Bamboo; O1: Oil palm; S1: sisal; C1: sisal; Ba1: Banana, J1: Jute

Table 10. Rank frequency matrix

Alternative NFs	**Rank**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
H1	0	0	2	1	1	1	1	0	0	0
F1	3	3	0	0	0	0	0	0	0	0
K1	1	0	1	0	0	0	1	2	1	0
P1	0	0	2	0	1	0	2	0	1	0
B1	0	0	0	0	0	0	0	0	0	6
O1	0	0	1	0	3	0	1	1	0	0
S1	2	3	0	1	0	0	0	0	0	0
C1	0	0	0	0	0	3	1	2	0	0
Ba1	0	0	0	4	1	1	0	0	0	0
J1	0	0	0	0	0	1	0	1	4	0

H1: Hemp; F1: Flax; K1: Kenaf; P1: Palf; B1: Bamboo; O1: Oil palm; S1: sisal; C1: sisal; Ba1: Banana, J1: Jute.

Table 11. Membership degree, rank index, and final ranks of the NFs

	Rank										Rank	
NFs	1	2	3	4	5	6	7	8	9	10	Index	Rank
H1	0	0	0.333	0.167	0.167	0.167	0.167	0	0	0	4.667	4
F1	0.5	0.5	0	0	0	0	0	0	0	0	1.5	1
K1	0.167	0	0.167	0	0	0	0.167	0.333	0.167	0	6	7
P1	0	0	0.333	0.000	0.167	0	0.333	0	0.167	0	5.667	6
B1	0	0	0	0	0	0	0	0	0	1	10	10
O1	0	0	0.167	0	0.5	0	0.167	0.167	0	0	5.5	5
S1	0.333	0.5	0	0.167	0	0	0	0	0	0	2	2
C1	0	0	0	0	0	0.5	0.167	0.333	0	0	6.833	8
Ba1	0	0	0	0.667	0.167	0.167	0	0	0	0	4.5	3
J1	0	0	0	0	0	0.167	0	0.167	0.667	0	8.333	9

H1:Hemp;F1:Flax;K1:Kenaf;P1:Palf;B1: Bamboo; O1: Oil palm; S1: sisal; C1: sisal; Ba1: Banana, J1: Jute

Table 11 clearly shows that the best available alternative natural fiber for fabrication of NFCs used for manufacturing of brake pad is Flax (F1), as its rank is 1st, Whereas the worst choice among all the NFs is Bamboo (B1) having rank 10. Flax is the best choice due to the following reasons: (i) Its wear rate is very low in comparison to other NFs which increase their life under variable loads, (ii) Its coefficient of friction is high due to which sufficient frictional forces will be produced for the braking, (iii) Its compressive strength (1200MPa) is high, which makes it enable to bear high compressive loads during braking, (iv) its thermal degradation temperature is moderately high (250°C)which allows it to sustain heat, produced due to frictional forces. It can be concluded from Table 11, that the natural fibers in decreasing order of their preference for fabrication of brake pads are Flax>Sisal> Banana >Hemp>> Oil Palm >Palf>Kenaf> Coir> Jute> Bamboo.

3.1 Sensitivity Analysis

Sensitivity analysis is carried out to guarantee that the found results do not reveal any biasness, and furthermore, to analyze the consequence of the highest weight criterion on other criteria considered in the current research work. From the literature, a methodology is found out to perform sensitivity analysis [30][31], where the weight of each criteria is changed in proportion to the weight of highest weight criteria, and the same method is also used in the current study. Since, the highest ranked criterion is Z3 as its weight is highest i.e. 0.312. Therefore, the value of the weight has been altered from 0.1 to 1.0; and all the other criteria weights have been determined, which are shown in Table 12.

In sensitivity analysis, the effect of changing weight on the ranking of alternative materials is observed. For each of the new weight, the ranking of the alternatives is done using all the six methods which are combined to determine the final ranking. The ranks of the NFs for all the sensitivity runs are shown in Table 13.

Table 12. Weights of Criteria in sensitivity analysis

Criteria	Normal	r-0.1	r-0.2	r-0.3	r-0.4	r-0.5	r-0.6	r-0.7	r-0.8	r-0.9
Z1	0.114	0.149	0.132	0.116	0.099	0.083	0.066	0.050	0.033	0.017
Z2	0.066	0.086	0.077	0.067	0.058	0.048	0.038	0.029	0.019	0.010
Z3	0.312	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900
Z4	0.146	0.191	0.170	0.149	0.128	0.106	0.085	0.064	0.043	0.021
Z5	0.146	0.191	0.169	0.148	0.127	0.106	0.085	0.064	0.042	0.021
Z6	0.151	0.198	0.176	0.154	0.132	0.110	0.088	0.066	0.044	0.022
Z7	0.065	0.086	0.076	0.067	0.057	0.048	0.038	0.029	0.019	0.010

Table 13. Ranking of NFs in Sensitivity Analysis

Alternative NFs	Normal	r-0.1	r-0.2	r-0.3	r-0.4	r-0.5	r-0.6	r-0.7	r-0.8	r-0.9
H1	4	3	3	4	4	4	4	4	4	5
F1	1	1	1	1	1	1	2	2	2	2
K1	7	7	7	7	5	6	6	6	6	5
P1	6	5	5	6	7	7	7	8	9	9
B1	10	10	10	10	10	10	10	10	10	10
O1	5	6	6	5	5	5	5	5	5	4
S1	2	2	2	2	2	2	1	1	1	1
C1	8	8	8	8	8	8	7	7	7	7
Ba1	3	4	4	3	3	3	3	3	3	3
J1	9	9	9	9	9	9	9	9	8	7

It can clearly be observed from Table 13 that on changing weight of criterion Z3 from 0.1 to 0.9, alternative F1 acquired first rank in six out of ten sensitivity runs, and alternative B1 is placed at last in all the sensitivity runs, which show the reliability of the combined method used in this work. Thus, it is proved that F1 is best alternative NF for composite fabrication for brake pads, whereas B1 is the worst choice for the same. Further, ranking of alternatives on varying the weight of criterion during sensitivity analysis is shown in the form of radar chart in Figure 2.

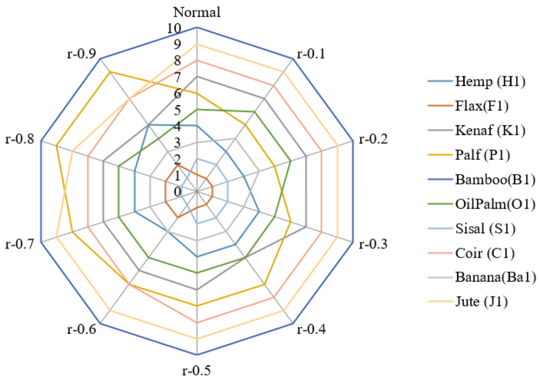

Fig. 2. Ranking of alternatives in Sensitivity Analysis.

4. Conclusions and Scope for Future Work

In this research study, selection of appropriate natural fiber for fabrication of NFCs for manufacturing of brake pad was successfully made by employing a hybrid MCDM method i.e. BWM- CoCoSo method. As per the findings of this study, major conclusions are as follows:

- Ranks calculated by the above mention MCDM techniques are combined by the Membership degree method. This method suggests that Flax is the best material for the Brake pads, as it gets first rank; and Bamboo is the worst material, as it gets the tenth rank.
- The order of preference of natural fibers obtained in the present study is Flax>Sisal> Banana >Hemp> Oil Palm > Palf> Kenaf> Coir>Jute> Bamboo.
- While doing sensitivity analysis it was found that flax acquired first rank in six out of ten sensitivity runs, and Bamboo gets the tenth rank in all the sensitivity runs.
- Sensitivity coefficient of wear rate is maximum, which indicates that it is the most sensitive criterion in the selection of the alternative NF for the brake pads.

In future, similar study may be carried out by including more alternative natural fibers, and more evaluation criteria in the selection problem, and the problem may be solved by using other MCDM methods; and the results may be compared with those presented in this paper.

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Abbreviation

AHP	Analytic Hierarchy Process	NFCs	Natural fiber composites
ARAS	Additive Ratio Assessment *method*	NFC	Natural fiber composite
B1	Bamboo	NFs	Natural fibers
Ba1	Banana	O1	Oil palm
BTO	Best to Others	OTW	Others to Worst
BWM	Best Worst Method	P1	Palf
BAO	The Border Approximation area	PIV	Proximity Indexed Value
C1	coir	S1	Sisal
CoCoSo	Combined Compromise Solution	TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
COPRAS	Complex Proportional Assessment	VIKOR	Vise Kriterijumska Optimizacija I Kompromisno Resenje
F1	Flax	WASPAS	The weighted aggregated sum product assessment

FAHP	Fuzzy Analytic Hierarchy *Process*	WPM	Weighted Product Method
H1	Hemp	WSM	Weighted Sum Method
J1	Jute	Z1	Density
K1	Kenaf	Z3	Wear Rate
LGPMBWM	Linear Goal Programming Model for Best Worst-Method	Z4	Coefficient of friction
MABAC	Multi-Attributive Border Approximation Area Comparison methods	Z5	Compressive Strength
MCDM	Multi-criteria decision-making	Z6	Moisture Gain
NF	Natural fiber	Z7	Thermal Degradation Temperature