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Research Article
Green Material Selection Using an Integrated Fuzzy Multi-criteria Decision Making Model

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Abstract
Background and Objective: Material selection is one of the most important activities in the design process and development of products and it also critical to the success and competitiveness of the producers. The objective of this paper was to propose an integrated fuzzy multi-criteria decision making (MCDM) model to support the green material selection process. **Materials and Methods:** In the proposed integrated model, fuzzy analytical hierarchy process (AHP) is used to determine the criteria weights, whereas fuzzy technique for order preference by similarity to ideal solution (TOPSIS) is used to find the performance ranking of the alternative materials. The ratings of material alternatives and importance weights of criteria for material alternatives selection are represented by triangular fuzzy numbers. Then, the membership functions of the final fuzzy evaluation value in the proposed approach are developed based on the linguistic expressions. **Results:** This study applies the proposed integrated fuzzy MCDM approach to the material alternatives selection and evaluation in a company demonstrating its advantages and applicability. The results indicate that the proposed method is effective in the material alternatives selection for the producers. **Conclusion:** Evaluating a material alternative is a very important decision for many producers. This study has developed an integrated fuzzy MCDM method to solve the material selection and evaluation problem. The proposed method could be improved by employing the extension of fuzzy sets such as intuitionistic fuzzy sets and neutrosophic sets.

Key words: Green material selection, multi-criteria decision making, fuzzy TOPSIS method, fuzzy analytical hierarchy process, fuzzy numbers, integrated method

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INTRODUCTION

Green material selection plays an importance role in the design and development of products, which seeks to guarantee product performance and reduce the entire life-cycle impact to the environment and human health[1]. Improper selection of materials may significantly decrease the functionality and production cost of the product, thus negatively affecting productivity, profitability and reputation of an organization[2-4]. Each material has its own characteristics, advantages and disadvantages, it is difficult to choose the suitable material for particular application[2].

To select the suitable green material for design products, many criteria must be considered in decision process such as cost, physical property and environmental performance. Therefore, material selection can be viewed as a complex multi-criteria decision making (MCDM) problem[5]. The MCDM approach consists of generating alternatives, establishing criteria (attributes), evaluation of alternatives, assessment of criteria weights and application of a ranking system[6].

In the literature, many investigations and studies have been applied different fuzzy MCDM approaches for green material selection[3,7-13]. However, limited studies have taken into account the environment issues when evaluating the material alternatives. Additionally, most of these existing studies have ignored the physical properties which play a significant role in the assessment process for green material alternatives[1]. Mayyasa *et al.*[9] proposed an eco-material selection approach specific to the automobile body panels using a fuzzy TOPSIS, to incorporate both numerical and rating-based criteria into one holistic sustainability model. Kumar and Singal[10] presented a multiple attribute decision making method for solving the material selection problem for penstock in Small hydropower installations. The AHP and TOPSIS methods were used to select the best material. Four alternative materials such as polyvinyl chloride, high-density polyethylene, glass reinforced polymer and mild steel and five assessment attributes/criteria such as yield strength, life, thickness, cost of material and maintenance cost have been considered in the analysis. It has been found that TOPSIS and Modified TOPSIS methods are best suited for penstock material selection and mild steel is the suitable material as compared to other materials. Anojkumar *et al.*[11] proposed the hybrid MCDM techniques for material selection in sugar industry in order to reduce the corrosive wear. The hybrid techniques involves fuzzy analytical hierarchy process (FAHP), integrated with technique for order preference by similarity to ideal solution (TOPSIS) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) techniques. Seven criteria were used to select the appropriate material including yield strength, ultimate tensile strength, percentage of elongation, hardness, cost, corrosion rate and wear rate. Liu *et al.*[3] developed a MCDM method with interval 2-tuple linguistic information to solve the material selection problem under uncertain and incomplete information environment. The method was an extended VIKOR for group decision making with interval-valued intuitionistic variables. Huang *et al.*[13] presented a new MCDM model and uncertainty analysis method for the environmentally conscious material selection problem. TOPSIS method was employed and uncertainty analyses were performed for model flexibility and efficiency by addressing the materials selection challenge. Rao and Davim[12] presented an integreated MCDM method which is combination of TOPSIS and AHP method for material selection for a given engineering design.

In recent years, the TOPSIS method proposed by Hwang and Yoon[14] has been a popular technique to solve MCDM problems. The fundamental idea of TOPSIS is that the chosen alternative should have the shortest Euclidian distance from the positive-ideal solution and the farthest distance from the negative-ideal solution. The positive-ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely and crisp values are used in the evaluation process. Under many circumstances, however, crisp data are inadequate to simulate real-life decision problems. Consequently, a fuzzy TOPSIS method is proposed in which the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional TOPSIS. As a result, the fuzzy TOPSIS approach has been broadly applied to decision-making applications over the past few decades[15-22].

Several studies in the literature have mentioned the difficulty of weighting the criteria and keeping consistency of judgment when using fuzzy TOPSIS. Thus, the combination of the fuzzy TOPSIS with another method, such as fuzzy analytic hierarchy process (AHP), might be able to determine proper objective weightings under a vague environment. The AHP, a powerful tool in applying MCDA, was introduced and developed by Saaty[23]. The AHP helps identify the weights or priority vector of the alternatives or the criteria, using a hierarchical model that includes target, main criteria, sub-criteria and alternatives. Nevertheless, a major disadvantage of AHP is that it is unable to handle adequately the inherent uncertainty and imprecision of human thinking.

Fuzzy AHP has been developed to solve this problem[24]. In FAHP method, the application of the fuzzy comparison ratio tolerates vagueness in the model. Decision makers use natural linguistic emphasis as well as certain numbers to evaluate criteria and alternatives. Fuzzy AHP impressively resembles human thought and perception.

Therefore, the objective of this study was to present an integrated fuzzy MCDM which combines the fuzzy TOPSIS and the fuzzy AHP to select the green materials.

Fuzzy numbers: There are various ways to define fuzzy numbers. This study defines the concept of fuzzy numbers as follows[25-26].

Definition 1: A real fuzzy number A is described as any fuzzy subset of the real line R with membership function f_A, which has the following properties:

- f_A is a continuous mapping from R to the closed interval [0.1]
- $f_A(x) = 0$, for all $x \in (-\infty, a]$
- f_A is strictly increasing on [a, b]
- $f_A(x) = 1$, for all $x \in [b, c]$
- is strictly decreasing on [c, d]
- $f_A(x) = 0$, for all $x \in (d, \infty]$

Where, a, b, c and d are real numbers. Unless elsewhere specified, this research assumes that A is convex and bounded (that is, $-\infty < a, d < \infty$).

Definition 2: The fuzzy number A = (a, b, c and d) is a trapezoidal fuzzy number if its membership function is given by:

$$f_A(x) = \begin{cases} f_A^L(x) & a \le x \le b \\ 1 & b \le x \le c \\ f_A^R(x) & c \le x \le d \\ 0 & \text{otherwise} \end{cases}$$

Where, $f_A^L(x)$ and $f_A^R(x)$ are the left and right membership functions of A, respectively[26].

When b = c, the trapezoidal fuzzy number is reduced to a triangular fuzzy number and can be denoted by A = (a, b and d). Thus, triangular fuzzy numbers are special cases of trapezoidal fuzzy numbers.

Definition 3: The distance between fuzzy triangular numbers.

Let A = (a_1, b_1 and d_1) and B = (a_2, b_2 and d_2) be two triangular fuzzy numbers. The distance between them is given using the vertex method[9] by:

$$d(A,B) = \sqrt{\frac{1}{3}[(a_1-a_2)^2+(b_1-b_2)^2+(d_1-d_2)^2]} \quad (1)$$

Definition 4: α-cuts.

The α-cuts of fuzzy number A can be defined as $A^\alpha = \{x \mid f_A(x) \geq a\}$, $a \in [0,1]$, where A^α is a non-empty bounded closed interval contained in R and can be denoted by:

$$A^\alpha = \lfloor A_l^\alpha, A_u^\alpha \rfloor$$

where, A_l^α and A_u^α are its lower and upper bounds, respectively[26]. For example, if a triangular fuzzy number A = (a, b and d) then the α-cuts of A can be expressed as:

$$A^\alpha = [A_l^\alpha, A_u^\alpha] = [(b-a)\alpha + a, (b-d)\alpha + d] \quad (2)$$

Definition 5: Arithmetic Operations on Fuzzy Numbers.

Given fuzzy numbers A and B, where, A, B∈R^+, the α-cuts of A and B are $A^\alpha = \lfloor A_l^\alpha, A_u^\alpha \rfloor$ and $B^\alpha = \lfloor B_l^\alpha, B_u^\alpha \rfloor$, respectively. By the interval arithmetic, some main operations of A and B can be expressed as follows[26]:

$$(A \oplus B)^\alpha = [A_l^\alpha + B_l^\alpha, A_u^\alpha + B_u^\alpha] \quad (3)$$

$$(A \ominus B)^\alpha = [A_l^\alpha - B_u^\alpha, A_u^\alpha - B_l^\alpha] \quad (4)$$

$$(A \otimes B)^\alpha = [A_l^\alpha \cdot B_l^\alpha, A_u^\alpha \cdot B_u^\alpha] \quad (5)$$

$$(A \oslash B)^\alpha = [A_l^\alpha / B_u^\alpha, A_u^\alpha / B_l^\alpha] \quad (6)$$

$$(A \otimes B)^\alpha = [A_l^\alpha \cdot r, A_u^\alpha \cdot r], r \in R^+ \quad (7)$$

PROPOSED METHODOLOGY FOR GREEN MATERIAL SELECTION

In this section, an approach for green material selection by combining fuzzy TOPSIS and fuzzy AHP method is presented.

Data collection method: The main objective of this study was to propose the integrated fuzzy MCDM approach for green material selection. To achieve this, both primary and secondary information sources were used in order to triangulate the data. In-depth semi-structured interviews, surveys and conversations with company's managers were used as the primary sources of information. The secondary sources were collected from research papers and company documentation. These data collection methods are the best data collection techniques as they enable us to gather a larger amount of data and information from target respondents within a short period of time.

Proposed approach for green material selection: The procedure of the proposed approach is stated thus:

Step 1: Aggregate the ratings of materials versus the criteria
Step 2: Aggregate the importance weights of the criteria
Step 3: Normalize the fuzzy decision matrix
Step 4: Construct the weighted normalized fuzzy decision matrix
Step 5: Calculate normalized weighted rating
Step 6: Calculation of A^+, A^- d_i^+ and d_i^-
Step 7: Obtain the closeness coefficient

Assume that a committee of *l* decision makers (D_t, t = 1, ..., *l*) is responsible for evaluating m material alternatives (A_i, i = *l*, ..., m) under n selected criteria (C_j, j = 1, ..., n) where the suitability ratings of alternatives under each of the criteria, as well as the weights of the criteria, are assessed in linguistic terms[27-28] represented by triangular fuzzy numbers.

Aggregate the ratings of materials versus the criteria: Let $x_{ijt} = (e_{ijt}, f_{ijt}, g_{ijt})$, i = 1, ..., m, j = 1, ..., n, t = 1, ..., *l*, be the suitability rating assigned to green material A_i, by decision maker D_t, for criterion C_j. The averaged suitability rating, $x_{ij} = (e_{ij}, f_{ij}, g_{ij})$, can be evaluated as:

$$x_{ij} = \frac{1}{l} \otimes (x_{ij1} \oplus x_{ij2} \oplus \ldots \oplus x_{ijt} \oplus \ldots \oplus x_{ijl}) \quad (8)$$

Where,

$$eij = \frac{1}{l}\sum_{t=1}^{l} eijt, fij = \frac{1}{l}\sum_{t=1}^{l} fijt \text{ and } gij = \frac{1}{l}\sum_{t=1}^{l} gijt$$

Aggregate the importance weights of the criteria: In this section, a fuzzy AHP is applied to obtain more decisive judgments by prioritizing the economic and environmental criteria. Several fuzzy AHP methods have been proposed in literature to solve the MCDM problems. This study adopts the extent analysis method proposed by Chang[29] due to its popularity and computational simplicity. The Chang's[29] method is briefly discussed as follows.

Let $X = \{x_1, x_2, ..., x_n\}$ be an object set and $U = \{u_1, u_2, ..., u_m\}$ be a goal set. According to Chang[29] each object is taken and an extent analysis for each goal (g_i) is performed, respectively. Therefore, the m extent analysis values for each object are obtained as $M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^n, i = 1, 2, \ldots, n,$ where $M_{g_i}^1$, (j = 1, 2, ..., m) are triangular fuzzy numbers (TFNs).

Assume that $M_{g_i}^j$ are the values of extent analysis of the ith object for m goals. The value of fuzzy synthetic extent S_i is defined as[29]:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \quad (9)$$

Where,

$$\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right), \; j = 1, 2, \ldots, m, i = 1, 2, \ldots n$$

Let $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ be two TFNs, whereby the degree of possibility of $M_1 \geq M_2$ is defined as follows[29]:

$$V(M_1 \geq M_2) = \sup_{x \geq y} \left[\min(\mu_{M_1}(x), \mu_{M_2}(x))\right] \quad (10)$$

The membership degree of possibility is expressed as:

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & \text{if } m_1 \geq m_2 \\ 0 & \text{if } l_2 \geq u_1 \\ \dfrac{l_2 - u_1}{(l_2 - u_2) + (m_1 - m_2)} & \text{otherwise} \end{cases} \quad (11)$$

where, d is the ordinate of the highest intersection point of two membership functions μ_{M1} (x) and μ_{M2} (x).

The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers is defined as[29]:

$$V(M \geq M_1, M_2, ..., M_k) = \min V(M \geq M_i), i = 1, 2, ..., k \quad (12)$$

The weight vector is given by:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \quad (13)$$

Table 1: Linguistic variables describing weights of the "HOWs" criteria

Linguistic scale for importance	Triangular fuzzy scale M = (l, m, u)
Just equal	1.0, 1.0, 1.0
Equal importance	1.0, 1.0, 3.0
Weak importance	1.0, 3.0, 5.0
Strong importance	3.0, 5.0, 7.0
Very strong importance	5.0, 7.0, 9.0
Extremely importance	7.0, 9.0, 9.0
If factor i has one of the above numbers assigned to it when compared to factor j, then j has the reciprocal value when compared with i	Reciprocals of above $M_1^{-1} \approx (1/u_1, 1/m_1, 1/l_1)$

Where,

$$A_i(i = 1, 2, ..., n),\ d'(A_i) = \min V(S_i \geq S_k),\ k = 1, 2, ..., n,\ k \neq i \quad (14)$$

Via normalization, we obtain the weight vectors as:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \quad (15)$$

Where, W is a non-fuzzy number.

This study adopts a "Likert Scale" of fuzzy numbers starting from 1-9 to transform the linguistic values into triangular fuzzy numbers, as shown in Table 1.

Normalize performance of materials versus criteria: To ensure compatibility between average ratings and average weights, the average ratings are normalized into comparable scales. Suppose $r_{ij} = (a_{ij}, b_{ij}, c_{ij})$ is the performance of green material i on criteria j. The normalized value x_{ij} can then be denoted as:

$$x_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), j \in B \quad (16)$$

$$x_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), j \in C \quad (17)$$

Where,

$$a_j^- = \min_i a_{ij}, c_j^* = \max_i c_{ij}, i = 1,...,m, j = 1,...,n$$

Calculate normalized weighted rating: The normalized weighted ratings G_i are calculated by multiplying the normalized average rating x_{ij} with its associated weights w_{jt} as[15]:

$$G_i = x_{ij} \otimes w_j,\ i = 1, ..., m,\ j = 1, ..., h \quad (18)$$

Calculation of A^+, A^-, d_i^+ and d_i^-: The fuzzy positive-ideal solution (FPIS, A^+) and fuzzy negative-ideal solution (FNIS, A^-) are obtained as[15]:

$$A^+ = (1.0, 1.0, 1.0) \quad (19)$$

$$A^- = (0.0, 0.0, 0.0) \quad (20)$$

The distance of each green material alternative A_i, i = 1, ..., m from A^+ and A^- is calculated as:

$$d_i^+ = \sqrt{\sum_{i=1}^{n} (G_i - A^+)^2} \quad (21)$$

$$d_i^- = \sqrt{\sum_{i=1}^{n} (G_i - A^-)^2} \quad (22)$$

where, d_i^+ represents the shortest distance of alternative A_i and d_i^- represents the farthest distance of green material alternative A_i.

Obtain the closeness coefficient: The closeness coefficient of each green material alternative, which is usually defined to determine the ranking order of all green materials, is calculated as[15]:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (23)$$

A higher value of the closeness coefficient indicates that an alternative is simultaneously closer to PIS and further from NIS. The closeness coefficient of each alternative is used to determine the ranking order of all green material alternatives and indicates the best one among a set of given feasible green materials.

Table 2: Linguistic ratings evaluated by decision makers

Criterias	Green material alternatives	Company managers D_1	D_2	D_3	D_4	r_{ij}
C_1	A_1	H	H	H	VH	0.575, 0.750, 0.925
	A_2	M	H	H	M	0.400, 0.600, 0.800
	A_3	H	H	VH	H	0.575, 0.750, 0.925
	A_4	H	M	H	H	0.450, 0.650, 0.850
C_2	A_1	L	M	M	L	0.200, 0.400, 0.600
	A_2	M	H	H	M	0.400, 0.600, 0.800
	A_3	VH	H	VH	H	0.650, 0.800, 0.950
	A_4	H	H	VH	H	0.575, 0.750, 0.925
C_3	A_1	M	L	L	M	0.400, 0.600, 0.800
	A_2	H	VH	H	H	0.300, 0.500, 0.700
	A_3	H	VH	VH	H	0.650, 0.800, 0.950
	A_4	L	L	L	L	0.350, 0.550, 0.750
C_4	A_1	H	H	H	M	0.200, 0.400, 0.600
	A_2	VH	H	H	VH	0.575, 0.750, 0.925
	A_3	H	H	H	VH	0.650, 0.800, 0.950
	A_4	VH	H	H	VH	0.100, 0.300, 0.500
C_5	A_1	H	M	H	H	0.450, 0.650, 0.850
	A_2	L	M	M	M	0.650, 0.800, 0.950
	A_3	H	H	H	M	0.575, 0.750, 0.925
	A_4	M	H	H	M	0.650, 0.800, 0.950

Table 3: Fuzzy pairwise comparison of criteria

Criterias	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1.0, 1.0, 1.0	1.0, 3.0, 5.0	5.0, 7.0, 9.0	1.0, 3.0, 5.0	1.0, 1.0, 3.0	1.0, 3.0, 5.0
C_2	1/5, 1/3, 1/1	1.0, 1.0, 1.0	1/9, 1/7, 1/5	1/5, 1/3, 1/1	3.0, 5.0, 7.0	5.0, 7.0, 9.0
C_3	1/9, 1/7, 1/5	5.0, 7.0, 9.0	1.0, 1.0, 1.0	1/9, 1/7, 1/5	1/7, 1/5, 1/3	1/5, 1/3, 1/1
C_4	1/5, 1/3, 1/1	1.0, 3.0, 5.0	5.0, 7.0, 9.0	1.0, 1.0, 1.0	1/3, 1/1, 1/1	1/7, 1/5, 1/3
C_5	1/3, 1/1, 1/1	1/7, 1/5, 1/3	3.0, 5.0, 7.0	1.0, 1.0, 3.0	1.0, 1.0, 1.0	3.0, 5.0, 7.0
C_6	1/5, 1/3, 1/1	1/9, 1/7, 1/5	1.0, 3.0, 5.0	3.0, 5.0, 7.0	1/7, 1/5, 1/3	1.0, 1.0, 1.0

APPLICATION FOR GREEN MATERIAL ALTERNATIVES SELECTION PROBLEM

In this section, the proposed approach is applied to solve the green building materials selection problem in Vietnam. In order to help the company to select the most suitable green building material alternative and test the efficacy of the proposed method, the proposed approach was applied to the process of evaluating the green building material for this company. The data used as input to implement the proposed method were collected by means of semi-structured interviews with the top managers and head of departments. Four company managers were required to make their evaluation separately, according to their preferences for the importance weights of criteria and the ratings of alternative based on each criterion.

Following a survey of the literature and discussions with company's top managers, six criteria were chosen to select the green material alternatives including initial cost (C_1), maintenance cost (C_2), disposal cost (C_3), potential for recycling and reuse (C_4), density (C_5) and tensile modulus (C_6).

Step 1: Aggregate ratings of alternatives versus criteria: Four managers use the linguistic rating set S = {VP, P, F, G and VG} where, VP = Very Poor = (0.0, 0.0, 0.2; 0.6), P = Poor = (0.1, 0.3, 0.5; 0.7), F = Fair = (0.3, 0.5, 0.7; 0.8), G = Good = (0.6, 0.8, 0.9; 0.9) and VG = Very Good = (0.8, 0.9, 1.0; 1.0), to evaluate the suitability of the green building material alternatives under each criteria. Using the arithmetic operations, the aggregated suitability ratings of four green building material alternatives, i.e., A_1, ..., A_4 versus six criteria, i.e., C_1, ..., C_6 from four managers can be obtained as shown in Table 2.

Step 2. Aggregate the importance weights of the criteria: After the determination of the material criteria, each of four company managers is asked to conduct a pairwise comparison with regard to the different criteria using the fuzzy linguistic assessment variables. The completed matrices for the required cell are shown in Table 3. Applying Equations (9-15), the final weights of the economic and environmental criteria are obtained as shown in Table 4.

Table 4: Fuzzy weights of the criteria

Criterias	Fuzzy weight
C_1	0.1, 0.244, 0.663
C_2	0.095, 0.287, 0.455
C_3	0.066, 0.126, 0.373
C_4	0.077, 0.152, 0.41
C_5	0.085, 0.191, 0.458
C_6	0.055, 0.122, 0.344

Table 5: Normalized weighted ratings of each material alternative

Green material alternatives	G_i
A_1	0.030, 0.106, 0.352
A_2	0.035, 0.117, 0.366
A_3	0.048, 0.143, 0.418
A_4	0.035, 0.119, 0.363

Table 6: Distance of each green material alternatives from A^+ and A^-

Green material alternatives	d^+	d^-
A_1	1.469	0.369
A_2	1.453	0.386
A_3	1.407	0.444
A_4	1.454	0.384

Table 7: Closeness coefficients of alternatives

Alternatives	Closeness coefficient	Ranking
A_1	0.201	4
A_2	0.210	2
A_3	0.240	1
A_4	0.209	3

Step 3. Normalized performance of material alternatives versus criteria: For simplicity and practicality, all of the fuzzy numbers in this study are defined in the closed interval [0, 1]. Consequently, the normalization procedure is no longer needed.

Step 4. Calculate normalized weighted rating: Using Eq. 18, the normalized weighted ratings G_i can be obtained as shown in Table 5.

Step 5. Calculation of A^+, A^-, d_i^+ and d_i^-: The distance of each green material alternatives from A^+ and A^- can be calculated by Equations (19~22) as shown in Table 6.

Step 6. Obtain the closeness coefficient: The closeness coefficients of green material alternatives can be calculated by Eq. 23, as shown in Table 7. Therefore, the ranking order of the four green material alternatives is $A_3 \succ A_2 \succ A_4 \succ A_1$. Consequently, the best green material alternatives is A_3.

DISCUSSION

Green material selection plays the importance role in the design process and development of products for many companies. To select the most suitable green material, several economics, environmental and physical properties should be considered in the decision process under vague environment[2,5]. Therefore, green material selection can be viewed as the fuzzy MCDM problem[9]. Although, many studies have employed different fuzzy MCDM approaches for green material selection, few of them have taken into account the environment issues when evaluating the material alternatives[1,9]. Additionally, most of these existing studies have ignored the physical properties in the assessment process for green material alternatives[1].

The proposed method which combines fuzzy TOPSIS and fuzzy AHP could overcome the shortcomings of the existing fuzzy TOPSIS method[9,15,18]. The application of the proposed method indicates that the proposed method is effective in green material selection for the companies. The proposed method could be extended by using intuitionistic fuzzy sets and neutrosophic sets.

CONCLUSION

Green material alternatives selection is the MCDM problem that is affected by several criteria. This paper proposed the integrated fuzzy MCDM model to solve the green material alternatives selection and evaluation problem. In the proposed approach, the ratings of alternatives and relative importance weights of criteria for are expressed in linguistic values which are represented by the triangular fuzzy numbers. An application was given to illustrate the applicability of the proposed approach. The results indicate that the proposed integrated fuzzy MCDM approach is practical and useful.

SIGNIFICANCE STATEMENTS

This study proposes the integrated fuzzy MCDM approach which combines the fuzzy TOPSIS and fuzzy AHP to select and evaluate the green material. The fuzzy AHP was used to determine the importance weights of selected criteria. The fuzzy TOPSIS was applied to rank the alternative materials. In this study, the economics, environmental and physical properties were simultaneously considered in the assessment process for green material alternatives. This study will help companies to select the most suitable green material alternatives in order to increase their productivity, profitability and reputation. The proposed method could be extended by applying the neutrosophic and intuitionistic fuzzy sets.

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