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Plithogenic Fuzzy Decision-making on Carbon-based Nanomaterials in Electrical Industries

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Abstract

Nanomaterials are occupying a significant status in almost all the industries and electrical industries are not an exception to it. The penetration of nanomaterials in the production of electrical components has been high in recent years because of the versatility nature of these nanomaterials. Carbon-based nanomaterials (CBM) are the embodiment of carbon particles and are widely used in electrical industries. The materials are highly competent as they possess the properties of high electrical conductivity, flexibility, elasticity, tensile strength, thermal conductivity but at the same time the number of CBM are many which constraints the decision-makers on choosing the optimal CBM. This decision-making problem on optimal CBM is presented in this paper and this research work aims in finding the optimal ranking using the integrated methods of plithogenic neutrosophic AHP (Analytical Hierarchy Process) and fuzzy RAPS (Ranking Alternatives by Perimeter Similarity). To examine the consistency of the ranking outcomes of the alternatives, the results are contrasted with various scenarios of identical criterion weights and differing criterion weights based on experts. The ranking approach discussed in this paper shall be applied to other types of nanomaterials as an extension of this work.

Keywords

Carbon-based nanomaterials, Plithogenic, Ranking alternatives by perimeter similarity, Analytical hierarchy process, Electrical industries

Introduction

The fourth industrial revolution is Internet of Things based, and it has brought tectonic shifts in the production management of electrical industries. At recent times the smart production elements (SPE) are incorporated by these industrial sectors to make their overall production more robust. SPE comprises of various aspects but in general it encompasses compatible input materials, technology-based production phases with sustainable products as end resultants. The objectives of industrial sectors with SPE are optimization of environment and economic sustainability. These two objectives shall be achieved together by the suitable choice of input materials which decide the qualitative attributes of the resultant products. Many industries are employing nanomaterials of different forms to optimize sustainability. The size of the nanomaterials is scaled down to 10^{-9} m and the dimension of the materials vary between 1 and 100 nm. The nanomaterials are classified based on the dimensions into zero dimension, one-dimension, two-dimension, and three-dimension. The nanomaterials are also classified into four types based on the composition of the materials as carbon-based materials, metal-based materials, dendrimers, and composites.

CBM comprises of carbon content which spindles well with other elements. The structural properties and characteristics of carbon-based materials have made them highly viable and feasible. CBM is extensively applied in electrical industries because of the potential attributes of adsorption competency, higher surface area, good electrical conductivity, mechanical properties, resistance, and transfer of electrical energies. In addition to these properties, few other significant physical properties enable these materials to be more adaptive to the storage and transfer of energy. There are many carbon-based materials available in nature and many are engineered using nanotechnological processes. Due to the large number of carbon-based materials available, choosing the right ones to employ in the electrical industries presents a challenge to decision-makers. The optimal decisions on CBM shall be obtained using MCDM (multi-criteria decision making) methods.

MCDM methods are widely applied in material selection. A decision-making scenario is characterized by feasible alternatives and criteria. Every decision-making process consists of two main steps: computing the criterion weights and ranking the options using the relevant MCDM techniques. In general, the criterion weights shall be assumed as equal, but in many cases distinct criterion weights are computed using different MCDM methods.

The method of AHP is used in many decision-making instances of calculating the weights of the criteria used in material selection. AHP developed by Saaty is based on pairwise comparison is used in various aspects of crisp, fuzzy, intuitionistic, neutrosophic, and plithogenic. This method is also integrated with other ranking methods for material selection. From the applications of AHP MCDM in material selection it is found that this method is not applied in the selection of carbon-based materials. A new combination of the plithogenic neutrosophic AHP and Fuzzy RAPAS is developed in this paper with three different sets of input. The results obtained using plithogenic aggregated input are more promising in comparison with separate input values.

The applications of AHP with special reference to material selection is presented under various decision-making conditions of crisp, fuzzy, intuitionistic, neutrosophic, and plithogenic. A deterministic decision-making environment is characterized as crisp, but in general the existence of uncertainty in a decision-making scenario creates space for the interference of fuzzy representations introduced by Zadeh [1] to resolve the issues of uncertainty and impreciseness. The extension of fuzzy sets to intuitionistic sets developed by Atanssov and Stoeva [2] and neutrosophic by Smarandache [3] solve the hurdles of indeterminacy. Plithogenic sets introduced by Smarandache [4] are the generalized form of all the above representations. The method of AHP is widely used in material selection under different environments. To mention a few, Vaidya and Kumar [5], Dweiri and Al-Oqla [6], Rao [7], Anojkumar et al. [8], Li et al. [9], Xu and Liao [10], and Abdel-Basset et al. [11]. Other than AHP method, several other methods are also used to determine optimal solution in material selection problem.

From the literature it is evident that many methods are applied in optimal ranking of the input materials based on their feasibility. Some of the noteworthy research gaps observed in the literature are: (1) The MCDM methods used in material selection are not of recent developments. (2) The AHP method neither in any of the representations of crisp, fuzz, intuitionistic, neutrosophic, or plithogenic is applied in criterion weight calculation of the decision-making problem on CBM selection.

This is what inspired the authors of this study to apply the fuzzy RAPS integrated with plithogenic neutrosophic AHP approach to the CBM selection problem. One of the newest MCDMs is called RAPS, has been applied to the mining industry and in evaluating the performance of the departments in university [12]. The method of RAPS is not applied in any of the material selection problem either in crisp or fuzzy sense. The method of fuzzy RAPAS is not explored and also the integrated method of plithogenic neutrosophic AHP and fuzzy RAPS is not applied to any of the decision-making problem to the best of our knowledge. In the future, this newly created hybrid technique will be used to rank CBMs in the best possible way. In this method the individual expert's opinion and the plithogenic combination of the expert's opinion of the criteria are considered separately and subjected to decision making.

The remaining of the article is arranged as follows: Section 2 provides the methodology of the suggested integrated MCDM method, Section 3 applies the suggested method to the selection of CBMs, Section 4 discusses the findings, and Section 5 concludes the paper with a few key points and conclusions.

Methodology

This section presents the steps involved in the integrated method of plithogenic neutrosophic AHP and RAPS. The overall workflow is presented in figure 1.

Steps involved in AHP

Step I

The neutrosophic numbers, which are defined by the P NAHP method and used to compare various characteristics, correlate to the 1 to 9 Saaty scale.

Step II

Formulation of pairwise comparison matrix based on decision makers.

Step III

By comparing each criterion and sub-criterion pairwise, one can determine the neutrosophic preference.

Step IV

The consistency index (CI) is calculated as:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}$$

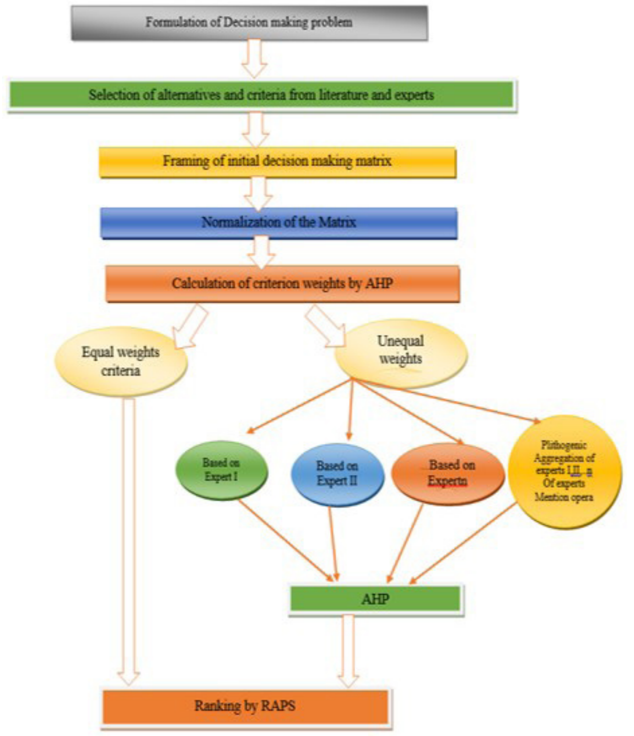

Figure 1: Flowchart of the proposed method.

Where, λ_{max} is the decision matrix's highest eigen value.

Step V

Calculate the consistency rate (CR).

$$CR = \frac{CI}{RI}$$

Step VI

Changes to the comparison matrix are necessary, and a new matrix must be requested, if CR = 0.1 is not an acceptable scope.

Step VII

Finding the weights using plithogenic neutrosophic AHP.

Steps involved in RAPS

Step I

The input data are normalized.

$$a_{ij} = \frac{y_{ij}}{\max y_{rj}} \text{ and } a_{ij} = \frac{\min y_{rj}}{y_{ij}} \tag{1}$$

Step II

Formation of IDM by using triangular fuzzy numbers, find the weighted normalization (V).

$$v_{ij} = w_{ij} * a_{ij} \tag{2}$$

Step III

Determine the optimal alternative by P = $\{P_1, P_2, \ldots\ldots, P_j\}$

Step IV

Find the ideal alternative's decomposition into its two components.

$$P = P^{\max} \cup P^{\min} \tag{3}$$

Step V

Calculate decomposition of the alternatives.

$$V_i = V_i^{\max} \cup V_i^{\min};\ i = 1, 2\ldots.m \tag{4}$$

Step VI

Determine magnitude of component.

$$P_k = \sqrt{p_1^2 + p_2^2 + \ldots + p_k^2};\quad P_h = \sqrt{p_1^2 + p_2^2 + \ldots + p_h^2}$$

$$V_{ik} = \sqrt{v_{i1}^2 + v_{i2}^2 + \ldots + v_{ik}^2};\quad V_{ih} = \sqrt{v_{i1}^2 + v_{i2}^2 + \ldots + v_{ih}^2};\quad i = 1, 2, \ldots, m \tag{5}$$

Step VII

The base and perpendicular sides of this triangle, P_k and P_h, respectively, $Q = P_k + P_h + \sqrt{p_k^2 + p_h^2}$; To determine the perimeter for each alternative:

$$Q_i = V_{ik} + V_{ih} + \sqrt{V_{ik}^2 + V_{ih}^2} \tag{6}$$

Step VIII

Comparison of each alternative's perimeter to that of the optimal alternative.

$$QS_i = \frac{Q_i}{Q};\ \forall i, i \in [1, 2\ldots m] \tag{7}$$

Alternatives are sorted and ranked according to their respective QS_i scores.

Results

Ranking of the CBMs

In this section a decision-making problem of ranking CBM alternatives is modeled. The different CBMs considered for ranking problem are presented in table 1. The criteria based on which the decision is made is presented in table 2. The initial decision-making matrix with linguistic values (Table 3) is represented in table 4. The quantified matrix using table 3 is presented in table 5. The normalized matrix using equation 2 is given in table 6.

Case (i) criterion weights are equal

In this case the criterion weights are assumed to be equal, and it is presented in table 7. The weighted normalized matrix is computed using equation 2 is in table 8. By using equation 6 and equation 7, the optimal ranking of the alternatives are calculated and it is presented in table 9.

Case (ii) criterion weights based on expert-I using crisp AHP

In this case the criterion weights are obtained based on the expertise of an Expert-I and it is presented in table 10. By using equation 6 and equation 7, the ranking results obtained

Table 1: Different carbon-based materials as alternatives.

Alternatives	Carbon-based materials	Description
CBM 1	Fullerenes	Allotropes of carbon, such as fullerene, have molecules made up of carbon atoms bound together by single and double bonds.
CBM 2	Graphene	A two-dimensional allotrope of carbon is called graphene. It is the fundamental component of the other carbon allotropes' structures.
CBM 3	Carbon nanotubes (CNT)	Chemical vapor deposition is the most popular technique for producing CNT
CBM 4	Carbon nanofiber (CNF)	Solid carbon fibers known as CNFs, also referred to as stacked cup CNTs, differ from CNTs in that they do not have a hollow chamber. CNFs are linear, non-continuous, sp2-based carbon fibers, as opposed to continuous, multi-micron-diameter carbon fibers.
CBM 5	Graphene oxide	One monomolecular layer of graphite with multiple oxygen-containing functions, including epoxide, carbonyl, carboxyl, and hydroxyl groups, makes up the unusual substance known as graphene oxide.
CBM 6	Graphite	Graphite has an opaque, grey to black tone with a metallic shine. Its Mohs hardness ranges from 1 to 2, making it a somewhat soft crystalline form of carbon. Graphite is stable and chemically inert at normal temperatures, but in the absence of air, it has an extremely high sublimation point.

Table 2: Criteria.

Criteria			Description
Cr1	Electrical conductivity	EC	EC is a measure of a material's ability to convey an electrical current. Its value varies depending on the substance and ranges from 10 - 18 to 107 $S.m^{-1}$ (Siemen per meter).
Cr2	Flexibility	F	The ability to bend or give way when pressure is applied, or something bumps into them makes flexibility crucial. This enables these components or instruments to carry out operations that call for a light touch.
Cr3	Elasticity	EC	When a material is elastic, it means that after the stress that created the deformation is removed, it will revert to its original shape.
Cr4	Specific surface area	SSA	A characteristic of solids known as SSA is the total amount of a material's surface per unit of mass (measured in m^2/kg or m^2/g) or solid or bulk volume (measured in m^2/m^3 or m).
Cr5	Tensile strength	TS	The largest force in weight per unit area tugging in the direction of length that a given substance can sustain without rupturing is how TS is described as the resistance to lengthwise stress.
Cr6	Thermal conductivity	TC	When a temperature gradient exits a region perpendicular to it, TC is the rate of heat transfer by conduction through the material's unit cross-section area.
Cr7	Synthesizing cost	SC	Electroplating, CVD, template techniques, and electrospinning are all used to create CNF. It is possible to manufacture CNTs efficiently using physical techniques like laser ablation and arc discharge as well as chemical techniques like CVD.
Cr8	Procurement Cost	PC	The expenses a business incurs to deliver the products or services your clients demand is referred to as PC.

Table 3: Quantification.

Linguistic variable	Triangular fuzzy number	Crisp value
Very high (VH)	(0.75,1,1)	0.92
High (H)	(0.5,0.75,1)	0.75
Moderate (M)	(0.25,0.75,0.75)	0.58
Low (L)	(0,0.25,0.25)	0.17

Table 4: Initial decision matrix.

Alternatives/ Criteria	EC	F	EC	SSA	TS	TC	SC	PC
CBM 1	L	H	H	H	H	L	L	VH
CBM 2	H	H	H	H	H	H	VL	M
CBM 3	H	VH	H	M	H	VH	L	VH
CBM 4	H	VH	M	M	VH	VH	L	VH
CBM 5	L	H	M	VH	M	VH	L	L
CBM 6	H	H	VL	L	M	H	VL	L

are presented in table 11.

Case (iii) criterion weights based on expert-II using crisp AHP

In this case the criterion weights are obtained based on the expertise of an Expert-II and it is presented in table 12. By using equation 6 and equation 7, the ranking results obtained are presented in table 13.

Table 5: Quantified matrix.

Alternatives/ Criteria	EC	F	EC	SSA	TS	TC	SC	PC
CBM 1	0.17	0.75	0.75	0.75	0.75	0.17	0.17	0.92
CBM 2	0.75	0.75	0.75	0.75	0.75	0.75	0.08	0.58
CBM 3	0.75	0.92	0.75	0.58	0.75	0.92	0.17	0.92
CBM 4	0.75	0.92	0.58	0.58	0.92	0.92	0.17	0.92
CBM 5	0.17	0.75	0.58	0.92	0.58	0.92	0.17	0.17
CBM 6	0.75	0.75	0.08	0.17	0.58	0.75	0.08	0.17

Case (iv) criterion weights based on plithogenic neutrosophic AHP

In this case, the criterion weights are obtained using plithogenic neutrosophic AHP using step 5, step 6, and step 7. Table 14 comprises of the combined criterion weights. Using these combined criterion weights, the optimal ranking results are obtained using plithogenic neutrosophic AHP using step 5, step 6, and step 7 and it is presented in table 15.

Discussion

Table 6: Normalized matrix.

Alternatives/Criteria	EC	F	EC	SSA	TS	TC	SC	PC
CBM 1	0.112	0.378	0.488	0.459	0.419	0.088	0.474	0.537
CBM 2	0.494	0.378	0.488	0.459	0.419	0.390	0.223	0.339
CBM 3	0.494	0.463	0.488	0.355	0.419	0.479	0.474	0.537
CBM 4	0.494	0.463	0.377	0.355	0.514	0.479	0.474	0.537
CBM 5	0.112	0.378	0.377	0.563	0.324	0.479	0.474	0.099
CBM 6	0.494	0.378	0.052	0.104	0.324	0.390	0.223	0.099

Table 7: Criterion weights.

Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

Table 8: Weighted normalized matrix.

Alternatives/ Criteria	EC	F	EC	SSA	TS	TC	SC	PC
CBM 1	0.01	0.05	0.06	0.06	0.05	0.01	0.06	0.07
CBM 2	0.06	0.05	0.06	0.06	0.05	0.05	0.03	0.04
CBM 3	0.06	0.06	0.06	0.04	0.05	0.06	0.06	0.07
CBM 4	0.06	0.06	0.05	0.04	0.06	0.06	0.06	0.07
CBM 5	0.01	0.05	0.05	0.07	0.04	0.06	0.06	0.01
CBM 6	0.06	0.05	0.01	0.01	0.04	0.05	0.03	0.01

Table 9: Optimal ranking of the alternatives.

Carbon-based materials	Optimal ranking
CBM 1	4
CBM 2	3
CBM 3	2
CBM 4	1
CBM 5	5
CBM 6	6

Table 10: Criterion weights based on expert-I.

Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8
0.366	0.2131	0.1018	0.1187	0.0952	0.04	0.0429	0.02

Table 11: Optimal ranking of the alternatives based on expert-I.

Carbon-based materials	Optimal ranking
CBM 1	3
CBM 2	4
CBM 3	2
CBM 4	1
CBM 5	5
CBM 6	6

Table 12: Criterion weights based on expert-II.

Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8
0.355	0.232	0.1105	0.1093	0.0861	0.05	0.0384	0.02

Table 13: Optimal ranking of the alternatives based on expert-II.

Carbon-based materials	Optimal ranking
CBM 1	4
CBM 2	3
CBM 3	2
CBM 4	1
CBM 5	5
CBM 6	6

Table 14: Combined criterion weights.

Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8
0.063	0.0797	0.1179	0.1087	0.12	0.16	0.1616	0.1918

Table 15: Optimal ranking of the alternatives based on combined criterion weights.

Carbon-based materials	Optimal ranking
CBM 1	4
CBM 2	3
CBM 3	2
CBM 4	1
CBM 5	5
CBM 6	6

Table 16: Ranking results obtained under different cases.

Alternatives	Case (i)	Case (ii)	Case (iii)	Case (iv)
CBM 1	4	3	4	4
CBM 2	3	4	3	3
CBM 3	2	2	2	2
CBM 4	1	1	1	1
CBM 5	5	5	5	5
CBM 6	6	6	6	6

The ranking results obtained under different cases are presented in table 16 and figure 2. The table clearly states the consistency of the ranking results using the integrated methods of AHP and RAPS under different cases. On considering equal criterion weights, the ranking results obtained using crisp AHP and fuzzy RAPS are presented in the case (i) column. But according to the literature and based on the experts, it is observed that the criterion weights cannot be assumed equal at all instances, suppose if the criterion weights are distinct, three cases arise. In case (ii), the criterion weights are obtained using expert I and using the method of AHP. The case (ii) column represents the ranking results of the alternatives based on expert-I and using the method of crisp AHP and fuzzy RAPS. The case (iii) column represents the ranking results of the alternatives based on expert-II and using the method of crisp AHP and fuzzy RAPS. On comparing the two columns of case (ii) and case (iii) the ranking results are not same. The

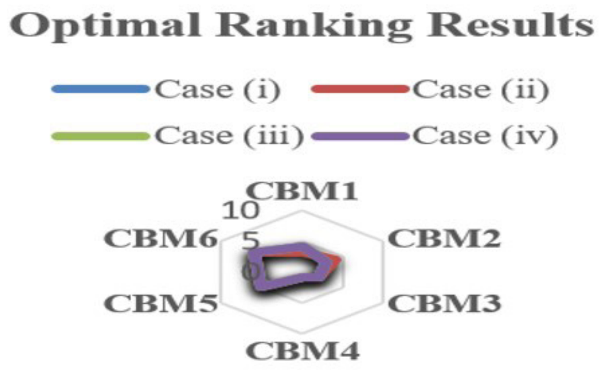

Figure 2: Optimal ranking results.

plithogenic neutrosophic AHP approach is now employed to get a consistent ranking with variable criterion weights, and the column example (iv) provides the same. It is observed that the ranking results appear to be consistent under three cases and the case (iv) seems to yield more consistent results in comparison with individual expert's opinion as discussed under case (ii) and case (iii).

Conclusion

This paper presents a novel combination of decision-making methods to make optimal material selection of CBMs. The proposed hybrid method or the integrated method effectively handles the uncertainty, impreciseness, and indeterminacy in a decision-making environment. The ranking results of the carbon-based materials are more promising, and the results obtained under several cases are reflecting the realistic situations. This decision-making method will be more beneficial to the decision makers of the electrical industries as the optimal ranking results are obtained after subjecting to the plithogenic operators, which are considered to be more comprehensive in nature.

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Conflict of Interest

None.

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