

APPLICATION OF FUZZY AHP-MOORA METHOD FOR POLYMERIC NANO-COMPOSITE MATERIAL SELECTION

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Abstract. Material selection is a crucial aspect of engineering processes and plays a decisive role in the success of final products. Improper material selection often leads to high costs and premature product failure. Therefore, a competent methodology for material selection is required to assist manufacturing organizations in choosing the best material for a specific application. Scientists have developed various selection techniques to address these issues. Multi-Criteria Decision Making (MCDM), which is also applied for material selection, has the potential to improve decision-making across all engineering areas. Another MCDM technique is the Multi-Objective Optimization based on Ratio Analysis (MOORA), introduced by Brauers and Zavadskas in 2006. As an extension of the AHP method, Fuzzy AHP plays a significant role, especially in cases of uncertainty. This article aims to select a polymeric nano-composite material for car bumper beams in the automotive industry based on the criteria of tensile strength, impact strength, comparative cost, and production difficulty using the integrated Fuzzy AHP-MOORA method. All material property indicators are classified as beneficial or non-beneficial.

Keywords: MOORA, Fuzzy-AHP, material selection, automotive industry.

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1. Introduction

Material selection represents one of the most critical stages in engineering design, directly influencing product performance, durability, cost, and manufacturability. In recent decades, the development of new materials, particularly polymeric nano-composites, has introduced both opportunities and complexities to the selection process. These materials offer enhanced mechanical properties, such as improved tensile and impact strength, while potentially reducing weight and cost. However, selecting the optimal material from a growing array of alternatives requires systematic and reliable decision-making tools [1, pp. 1–32].

Multi-Criteria Decision Making (MCDM) methods have emerged as powerful tools to address such complex selection problems [2]. Unlike single-criterion approaches, MCDM allows decision-makers to consider multiple, often conflicting, criteria simultaneously. Within the broad family of MCDM techniques, the Analytic Hierarchy Process (AHP) and its fuzzy extension, Fuzzy AHP, are widely recognized for determining the relative importance (weights) of criteria, especially when human judgment involves uncertainty [3]. On the other hand, the Multi-Objective Optimization based on Ratio Analysis (MOORA) method provides a robust and computationally efficient framework for ranking alternatives based on these weighted criteria [4].

The automotive industry, with its stringent requirements for safety, performance, and cost-efficiency, presents a pertinent case for applying such integrated methodologies. Components like bumper beams demand materials that offer excellent impact resistance, adequate tensile strength, reasonable cost, and feasible production characteristics. This study focuses on applying the integrated Fuzzy AHP-MOORA method to select the most suitable polymeric nano-composite material for car bumper beams, thereby demonstrating a structured approach to a real-world engineering challenge [5].

2. Research Objective and Problem Statement

The primary objective of this research is to implement and evaluate a hybrid decision-making model combining Fuzzy AHP and MOORA for the optimal selection of polymeric nano-composite materials. The specific problem addressed is the selection of the best material for an automotive bumper beam from six candidate alternatives (Alt-1 to Alt-6). The selection is based on four critical criteria: tensile strength (beneficial, to be maximized), impact strength (beneficial, to be maximized),

comparative cost (non-beneficial, to be minimized), and production difficulty (non-beneficial, to be minimized). This work aims to provide a transparent, reproducible framework that can handle the inherent uncertainty in expert judgments and deliver a clear ranking of material alternatives.

3. Methodology

The methodology of this research is divided into two main phases: (1) determining the weights of the selection criteria using Fuzzy AHP to account for judgmental uncertainty, and (2) ranking the material alternatives using the MOORA method based on the obtained weights.

3.1. Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

The classical AHP method, developed by Saaty, uses a crisp pairwise comparison scale (1-9) to derive priority weights. However, human preferences are often vague and imprecise. Fuzzy AHP extends this by utilizing triangular fuzzy numbers (TFNs) to capture the uncertainty in decision-makers' judgments [3].

A TFN is denoted as (l, m, u), where l, m, and u represent the lower, most likely, and upper values, respectively. The steps for Fuzzy AHP are as follows [3, 7]:

Step 1: Construct a fuzzy pairwise comparison matrix. Experts compare the criteria in pairs using linguistic terms (e.g., equally important, moderately more important), which are then converted into TFNs.

Step 2: Calculate the fuzzy geometric mean for each criterion. For criterion i, the fuzzy geometric mean \tilde{r}_i is calculated as:

$$\tilde{r}_i = (\prod_{j=1}^n \tilde{a}_{ij})^{1/n} \quad (1)$$

where \tilde{a}_{ij} is the TFN comparing criterion i to j, and n is the number of criteria.

Step 3: Compute the fuzzy weights. The fuzzy weight \tilde{w}_i for criterion i is:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1} \quad (2)$$

where \otimes and \oplus denote fuzzy multiplication and addition, respectively.

Step 4: Defuzzify the fuzzy weights. The Center of Area (COA) method is used to convert the fuzzy weight $\tilde{w}_i = (lw_i, mw_i, uw_i)$ into a crisp value w_i :

$$w_i = \frac{lw_i + mw_i + uw_i}{3} \quad (3)$$

Step 5: Normalize the crisp weights. The final normalized weight W_i for criterion i is obtained by:

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (4)$$

3.2. MOORA Method

The MOORA method, developed by Brauers and Zavadskas, is applied for the final ranking [4, 6, 8]. The steps are:

Step 1: Construct the decision matrix. A matrix $X = [x_{ij}]_{m \times n}$ is formed, where m is the number of alternatives (6) and n is the number of criteria (4), and x_{ij} is the performance of alternative i on criterion j.

Step 2: Normalize the decision matrix. The normalized value n_{ij} is calculated using the vector normalization method to make the criteria dimensionless:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (5)$$

Step 3: Construct the weighted normalized matrix. The weighted normalized value v_{ij} is computed by multiplying the normalized value by its corresponding criterion weight W_j obtained from Fuzzy AHP:

$$v_{ij} = W_j \times n_{ij} \tag{6}$$

Step 4: Calculate the overall assessment score. For each alternative i , the score y_i is calculated by summing the weighted normalized values for beneficial criteria and subtracting the sum for non-beneficial criteria:

$$y_i = \sum_{j=1}^g v_{ij} - \sum_{j=g+1}^n v_{ij} \tag{7}$$

where g is the number of beneficial criteria.

Step 5: Rank the alternatives. The alternatives are ranked in descending order of their y_i scores. The alternative with the highest score is the most preferred.

4. Data and Criteria Weights

The performance data for the six polymeric nano-composite alternatives across the four criteria are presented in Table 1. Tensile and impact strength data are in MPa, while comparative cost and production difficulty are assessed on a relative scale of 1 to 6, where a lower value is preferable for these non-beneficial criteria.

Table 1

Material property indicators of the six nano-composites

Alternatives	Tensile strength (MPa)	Impact strength (MPa)	Comparative cost	Production difficulty
Alt-1	25.00	113.70	4	1
Alt-2	37.55	103.54	5	2
Alt-3	34.79	96.51	6	3
Alt-4	35.38	224.58	1	4
Alt-5	41.71	154.06	2	5
Alt-6	41.92	133.53	3	6

Applying the Fuzzy AHP process as described in Section 3.1, based on expert evaluations of the relative importance of the four criteria, the final normalized weights were determined. The results highlight that impact strength is considered the most critical factor for a bumper beam, followed by tensile strength. Cost and production difficulty, while important, carry less relative weight in this specific engineering context. The calculated weights are:

- Impact Strength (W_1): 0.564
- Tensile Strength (W_2): 0.302
- Comparative Cost (W_3): 0.089
- Production Difficulty (W_4): 0.046

4.1. MOORA Ranking

Following the MOORA steps, the decision matrix from Table 1 was normalized using Equation (5). The weighted normalized matrix was then computed using Equation (6) and the weights from Fuzzy AHP. Finally, the overall assessment score y_i for each alternative was calculated using Equation (7), where tensile and impact strength were treated as beneficial criteria (summed), and cost and production difficulty as non-beneficial (subtracted). The results are summarized in Table 2.

Table 2

Ranking of alternatives using the Fuzzy AHP-MOORA method

Alternatives	Overall Assessment Score (S_{y_i})	Rank
Alt-4	0.3426	1
Alt-5	0.1999	2
Alt-6	0.1309	3
Alt-1	0.0739	4
Alt-2	0.0347	5
Alt-3	0.0157	6

4.2. Analysis of Results

The ranking clearly identifies **Alternative 4 (Alt-4)** as the optimal choice for the automotive bumper beam application. Despite having a tensile strength (35.38 MPa) that is not the highest among the candidates, Alt-4 possesses a vastly superior impact strength (224.58 MPa), which is the most heavily weighted criterion. Furthermore, it has the lowest possible comparative cost (1). Although its production difficulty rating (4) is not the best, its exceptional performance on the two most important criteria outweighs this drawback.

Alternative 5 (Alt-5) and Alternative 6 (Alt-6) secure the second and third ranks, respectively. They both offer high tensile strength and good impact resistance but are penalized by higher cost and production difficulty scores compared to Alt-4. The lower-ranked alternatives (Alt-1, Alt-2, Alt-3) are characterized by significantly lower impact strength values, which leads to their poor performance in the overall assessment [5,9].

5. Discussion and conclusion

The application of the integrated Fuzzy AHP-MOORA method proved to be highly effective for this material selection problem. The Fuzzy AHP component successfully quantified the subjective preferences of decision-makers regarding the criteria, transforming linguistic assessments into precise numerical weights while accounting for uncertainty. The subsequent MOORA analysis provided a clear, mathematically sound ranking that directly reflects these priorities.

The outcome is logically consistent with engineering intuition for a safety-critical component like a bumper beam: impact resistance is paramount. The model's strength lies in its ability to make this intuition explicit, quantifiable, and defensible. It systematically avoids the pitfalls of ad-hoc selection and ensures that all relevant factors are considered in a balanced manner.

This study's findings align with and extend the work of previous researchers who have applied MCDM techniques to material selection. The hybrid approach used here offers a practical framework that can be adapted to other material selection problems in various industries by simply modifying the set of criteria and alternatives.

This research demonstrated the successful application of an integrated Fuzzy AHP-MOORA model for selecting polymeric nano-composite materials for automotive bumper beams. The model effectively combined the strengths of both methods: Fuzzy AHP to handle the uncertainty in determining criterion importance, and MOORA to execute a straightforward and robust ranking of alternatives. The analysis identified Alt-4 with its exceptional impact strength and low cost, as the most suitable material among the six candidates considered.

The proposed methodology is transparent, systematic, and can be easily implemented by engineers and decision-makers. It provides a rational basis for material selection that can improve product quality, reduce costs, and shorten development time.

For future work, the model could be enhanced in several ways. Firstly, other fuzzy set representations (e.g., trapezoidal fuzzy numbers, intuitionistic fuzzy sets) could be explored within the AHP framework. Secondly, the MOORA method could be compared with or combined with other

ranking techniques like TOPSIS or VIKOR to assess result stability. Finally, the set of selection criteria could be expanded to include environmental factors (e.g., recyclability, carbon footprint) and other lifecycle considerations to support sustainable material selection.

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Accepted: 14.05.2026