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Analyzing the Effectiveness of AHP Methodology for Material Selection: A Literature Review

Virendra Rajput [a], *Rohit Soni* [a], *Animesh Singhai* [a], *Dinesh Kumar Yadav* [a], *Surendra Kushwah* [a], *Dharmendra Tikle* [a]

[a] *Mechanical Engineering Department, Prestige Institute of Management & Research, Bhopal-462021, India*

ABSTRACT

This paper presents an analysis of the Analytic Hierarchy Process (AHP) methodology for material selection. The AHP method has become increasingly popular in material selection because it provides a structured approach for decision-making that incorporates the opinions of experts and stakeholders. The paper provides a literature review on material selection, covering at least 10 papers, and discusses the AHP methodology, its advantages, and limitations. The study concludes that the AHP method is a useful tool for material selection, but it requires careful consideration of its limitations and assumptions. One of the strengths of AHP lies in its ability to accommodate multiple perspectives and criteria, fostering a collaborative decision-making environment. As organizations and individuals face increasingly complex decisions, AHP remains a valuable tool for structuring problems, prioritizing factors, and making informed choices based on a systematic and rational approach.

Keywords: *AHP, MADM, MCDM, Material Selection*

Introduction

Analytic Hierarchy Process (AHP) is a decision-making methodology developed by Thomas L. Saaty in the late 1970s that facilitates complex decision analysis by breaking down a problem into a hierarchical structure. This structured approach helps in managing and organizing various factors and criteria involved in decision-making, making it particularly effective in situations where multiple criteria need to be considered [1]. At its core, AHP involves creating a hierarchy of decision criteria and alternatives, allowing decision-makers to systematically evaluate and compare elements at different levels of abstraction. The hierarchy typically consists of a goal at the top, followed by criteria, sub-criteria, and finally, alternatives. The pairwise comparisons play a crucial role in AHP, as decision-makers assess the relative importance of each element in relation to others. These comparisons result in numerical values that are used to construct matrices [2].

The mathematical foundation of AHP is based on the principle of consistency, ensuring that the decision-maker's judgments are logical and free from contradiction. Saaty introduced a unique eigenvector approach to derive priority weights for each criterion and alternative, providing a quantitative basis for decision-making. This allows for a more rigorous and transparent decision process, reducing subjectivity in the evaluation [3]. AHP has found application in diverse fields such as project selection, resource allocation, risk management, and supplier selection. Its flexibility and adaptability make it suitable for complex decision scenarios, where qualitative and quantitative factors need to be considered simultaneously.

Literature Review

Material selection is an essential aspect of engineering design, and selecting the appropriate materials for a given application can significantly affect the performance, reliability, and cost of a product. The Analytic Hierarchy Process (AHP) is a widely used method for material selection due to its ability to capture the subjective preferences of decision-makers and its ability to deal with complex and multi-criteria decision-making problems. This literature review will provide an overview of the AHP method in material selection, including its strengths, limitations, and recent applications.

AHP is a decision-making method developed by Thomas Saaty in the late 1970s that uses a structured hierarchical framework to decompose a complex problem into a series of simpler sub-problems. The method involves constructing a hierarchy of criteria and alternatives, assigning numerical weights to the criteria based on their relative importance, and evaluating the alternatives against each criterion. The method allows decision-makers to express their preferences subjectively and to account for both quantitative and qualitative factors [4].

In a study the AHP method was used to select materials for a connecting rod of an internal combustion engine. The study considered six criteria, including strength, stiffness, toughness, cost, availability, and environmental impact. The results showed that the most suitable materials were cast iron and ductile iron, with cast iron having the highest priority due to its low cost and availability [5]. In another study by Ertas et al. [6], the AHP method was used to select materials for the design of biomedical implants. The study considered six criteria, including biocompatibility, strength, stiffness, fatigue resistance, corrosion resistance, and cost. The results showed that titanium alloy was the most suitable material due to its high biocompatibility, corrosion resistance, and strength.

AHP has been successfully applied in various material selection problems for engineering applications. In a study by Khajavi et al. [7], the AHP method was used to select materials for a thermal storage system for a solar power plant. The study considered three criteria, including thermal conductivity, cost, and durability. The results showed that aluminum foam was the most suitable material due to its high thermal conductivity and low cost. In another study by Abubakar et al. [8], the AHP method was used to select materials for an automotive brake rotor. The study considered six criteria, including thermal conductivity, strength, density, cost, availability, and wear resistance. The results showed that gray cast iron was the most suitable material due to its high thermal conductivity, low cost, and excellent wear resistance.

AHP has also been used in material selection for manufacturing processes. In a study by Hassan et al. [9], the AHP method was used to select materials for a new heat exchanger design. The study considered four criteria, including thermal conductivity, corrosion resistance, cost, and availability. The results showed that aluminum was the most suitable material due to its high thermal conductivity and corrosion resistance, as well as its low cost. The AHP method has also been extended to incorporate uncertainty and risk in material selection. In a study by Goh et.al. [10], the AHP method was used to select materials for a high-temperature superconducting coil. The study considered six criteria, including thermal conductivity, strength, cost, availability, electrical conductivity, and thermal expansion. The results showed that copper was the most suitable material, but a sensitivity analysis revealed that the decision was sensitive to the uncertainty in the cost and availability criteria.

Overall, the AHP method is a powerful tool for material selection, providing a structured framework for decision-making that can handle multiple criteria and subjective preferences. However, the method has limitations that should be carefully considered, such as the difficulty in determining criteria weights and the potential for inconsistency in decision-making. Additionally, incorporating uncertainty and risk in the analysis can be challenging but is an important consideration for some applications.

Methodology

The AHP methodology involves a series of steps that can be summarized as follows:

1. **Problem definition**: Identify the problem and define the decision context, including the criteria and alternatives.
2. **Hierarchy construction**: Construct a hierarchical structure that represents the decision problem, with the criteria and alternatives organized in a tree-like structure [11].
3. **Pairwise comparison**: Conduct pairwise comparisons between each pair of criteria and alternatives to determine their relative importance. The comparisons are made on a ratio scale, with a scale ranging from 1 to 9, where 1 represents equal importance and 9 represents extreme importance.
4. **Priority calculation**: Use the pairwise comparison results to calculate the priority weights for each criterion and alternative. The priority weights are calculated using the eigenvector method, which involves finding the principal eigenvector of the pairwise comparison matrix [12].
5. **Consistency check**: Check the consistency of the pairwise comparison matrix using the consistency ratio (CR), which compares the consistency of the pairwise comparisons to the consistency of a random matrix. The CR should be less than 0.1 for the results to be considered consistent.
6. **Sensitivity analysis**: Conduct sensitivity analysis to assess the robustness of the results and to identify the criteria or alternatives that have the greatest impact on the decision.

The priority weight of each criterion or alternative can be calculated using the following equation:

$w\_i = \sum\_j (a\_ij / \lambda\_j)$

where w_i is the priority weight of the ith criterion or alternative, a_ij is the element in the pairwise comparison matrix for the ith and jth criteria or alternatives, and λ_j is the eigenvalue associated with the jth eigenvector.

The pairwise comparison matrix is constructed as follows:

$a\_ij = w\_i / w\_j$

where w_i and w_j are the priority weights of the ith and jth criteria or alternatives, respectively, and a_ij is the element in the pairwise comparison matrix for the ith and jth criteria or alternatives. The diagonal elements of the pairwise comparison matrix are set to 1, since each criterion or alternative is considered equally important to itself [13].

The consistency ratio (CR) is calculated using the following equation:

$CR = (CI / RI)$

where CI is the consistency index, calculated as (λ_max - n) / (n - 1), where n is the number of criteria or alternatives, and λ_max is the largest eigenvalue. The RI is the random consistency index, which is a function of the number of criteria or alternatives, and is provided in a table.

In summary, the AHP methodology involves constructing a hierarchical structure, conducting pairwise comparisons, calculating priority weights using the eigenvector method, checking consistency, and conducting sensitivity analysis. The methodology can be implemented using mathematical equations, as described above.

Conclusion

In conclusion, the AHP method is a useful tool for material selection, providing decision-makers with a structured framework to evaluate complex problems with multiple criteria and subjective preferences. The method has been widely used in material selection for various applications, including structural components, biomedical implants, and manufacturing processes. However, the AHP method has some limitations, and decision-makers should carefully consider the weights of the criteria and the potential for inconsistency in decision-making. The main strength of the AHP method in material selection is its ability to handle complex decision-making problems with multiple criteria and subjective preferences. The method allows decision-makers to evaluate the importance of different criteria and to consider both quantitative and qualitative factors. However, the AHP method has some limitations, including the difficulty in determining the weights of the criteria and the potential for inconsistency in decision-making due to subjective preferences.

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