

Ranking of Epoxy/Kota Stone Dust/Fly Ash Composite Using Integrated AHP-TOPSIS Approach

Virendra Rajput^{1*}, Rohit Soni², Dinesh Singh Yadav³, Animesh Singhai⁴, Dharmendra Tikle⁵, Surendra Kushwah⁶, Alok Agrawal⁷

Abstract

The generation of industrial waste is a significant contributor to environmental pollution. The stone industry is no exception to this, and it is known to produce a significant amount of waste. The Kota Stone Industry in India is one such industry that generates waste. This research article focuses on composite material selection for mechanical and structural applications by fabricating epoxy composites reinforced with Kota stone dust and fly ash using manual hand layup process. The article employs Multi-Criteria Decision Making (MCDM) approaches such as Analytic Hierarchy Process (AHP) and TOPSIS to rank the composites based on their physical and mechanical properties. The Analytic Hierarchy Process (AHP), introduced by T. L. Saaty, has become one of the most widely used decision-making tools. The AHP method evaluates the weightage of each criterion, while the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method ranks the composites. The article highlights the use of these hybrid MCDM techniques for the first time in such a material and filler combination. Based on the analysis, the hybrid composite material that consists of EPO + 20KSD + FA was identified as the most optimal alternative. This composite shows the highest relative closeness value of 0.640, indicating that it is the most suitable material for the given application.

Keywords: AHP, MOORA, MCDM, epoxy, kota stone dust, mechanical properties

INTRODUCTION

*Author for Correspondence

Virendra Rajput
E-mail: virendra.rajput89@gmail.com

¹Associate Professor, Mechanical Engineering Department, Prestige Institute of Management & Research, Bhopal, India

²Assistant Professor, Mechanical Engineering Department, Prestige Institute of Management & Research, Bhopal, India

³Assistant Professor, Mechanical Engineering Department, Prestige Institute of Management & Research, Bhopal, India

⁴Assistant Professor, Mechanical Engineering Department, Prestige Institute of Management & Research, Bhopal, India

⁵Assistant Professor, Mechanical Engineering Department, Prestige Institute of Management & Research, Bhopal, India

⁶Assistant Professor, Mechanical Engineering Department, Prestige Institute of Management & Research, Bhopal, India

⁷Associate Professor, Mechanical Engineering Department, Sagar Institute of Research & Technology, Bhopal, India

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Polymers offer several benefits over other materials because of their unique combination of hydrogen and carbon atoms. They are highly resistant to microbial activity and have a longer lifespan compared to other materials. In various applications, petroleum-based plastics have been extensively used, especially in cases where strength is not a critical factor. In today's world, recycling is a crucial aspect that is emphasized in every sector [1]. The generation of industrial waste is a significant contributor to environmental pollution. Kota stone is a type of fine-grained limestone that is found in the Kota region of Rajasthan, India. Due to its widespread use in various civil construction projects such as exteriors, roadways, corridors, driveways, balconies, etc., the powder or dust of Kota stone is readily available in the stone industry [2]. The direct disposal of waste materials in open spaces can have detrimental effects

On the environment. However, utilizing such waste as filler in polymer matrix composites not

only helps in preserving the environment but also leads to a reduction in the overall cost of the final product [3]. This article discusses the critical advancements in polymer materials, specifically focusing on the synthesis, properties, and applications of biodegradable polymers. The authors emphasize the environmental impact of traditional plastics and propose biodegradable alternatives as a sustainable solution [4].

In this research article, the authors investigate the use of eco-friendly materials for enhancing the thermal properties of composite materials. The study reports on the incorporation of natural fibers and nanomaterials into polymer matrices, focusing on their influence on thermal conductivity and stability [5]. This paper presents an overview of the latest trends in nanocomposite materials, particularly in the context of their mechanical and thermal enhancements. The authors provide a comprehensive review of the different types of nanofillers used, including carbon nanotubes and graphene, and their respective effects on the properties of various polymer matrices [6]. The authors analyze various fiber types, including natural, synthetic, and hybrid fibers, and their influence on the tensile and compressive strength of composites. The research indicates that fiber orientation and volume fraction play crucial roles in determining the mechanical properties of the composites [7]. In this paper, the authors investigate the potential of biopolymers derived from renewable resources as alternatives to conventional petroleum-based plastics. The review highlights the various types of biopolymers, including polysaccharides, proteins, and polyesters, and discusses their properties, processing methods, and applications [8].

In recent times, several Multi-Criteria Decision Making (MCDM) methods have gained popularity for selecting the best materials and composites. Material selection is a crucial step in the development of epoxy composites for various structural applications. Researchers evaluate different properties of the fabricated composites, and to rank them, they employ various MCDM and MADM techniques [9]. The AHP technique utilizes a combination of mathematical and psychological principles to solve complex decisions. In this research, the AHP method is utilized to calculate the weightage of criteria, which is then used in the TOPSIS method to obtain the final ranking of epoxy composites [10]. Kaleet al. [11] explore materials for small N wind turbine blades, focusing on optimizing performance and durability, essential for enhancing renewable energy infrastructure. Kumar et al. [12] utilize an AHP-TOPSIS technique to optimize design parameters for alumina nano-material particles and turbulence promoters in heat exchangers, aiming to improve thermal efficiency and operational effectiveness. Meanwhile, Kumar [13] applies a hybrid AHP-TOPSIS approach to analyze the braking performance of organic-ceramic fibrous reinforced friction composites, crucial for automotive safety and efficiency. Puspitasari and Febriani [14] integrate the AHP-TOPSIS method for material supplier selection, contributing to efficient procurement practices in industrial settings.

Ahmed and Kabir [15] present an integrated approach for failure analysis of natural gas transmission pipelines, emphasizing material reliability and structural integrity in critical infrastructure. Mahmoudkelaye et al. [16] adopt the Analytic Network Process (ANP) for sustainable material selection in building enclosures, promoting energy-efficient construction practices. In automotive engineering, Swapna et al. [17] employ AHP and TOPSIS methods to select optimal aluminum alloys for automobile panels, balancing lightweight design with mechanical strength. Comparative studies on automotive brake materials by multiple authors provide insights into the effectiveness of various MCDM techniques in selecting materials that meet performance and safety standards.

Shankar et al. [18] optimize the mechanical performance of natural fiber-based green composites using AHP-TOPSIS, while Bhadra et al. [19] conduct sensitivity analyses using integrated AHP-TOPSIS and CRITIC-TOPSIS methods to select natural fibers, enhancing the robustness of material selection processes. Avikalet al. [20] apply fuzzy-AHP and TOPSIS for selecting metal matrix composites, crucial for structural applications requiring high durability and performance. Sharma et al. [21] optimize waste fly ash powder filled glass fiber reinforced epoxy composites using a hybrid AHP-

TOPSIS approach, contributing to sustainable material solutions in construction. In biomedical engineering, Yadav and Lee [22] rank dental restorative composite materials using FAHP-FTOPSIS, enhancing material selection for dental applications based on performance criteria. Similarly, Singhet al. [23] apply fuzzy-AHP and M-TOPSIS for selecting composite materials in structural applications, optimizing material properties for enhanced performance and reliability. Finally, Raju et al. [24] rank Al-CSA composites using AHP- TOPSIS and MOORA methods, showcasing the versatility of MCDM techniques in evaluating material alternatives across different industrial contexts.

In conclusion, the AHP-TOPSIS method has been widely used for material selection in various applications, from wind turbine blades to automotive components. While it is not the only MCDM method available, its popularity is largely due to its ability to handle multiple criteria and preferences in the decision-making process.

Integrated AHP-Topsis Methodology

Here is a step-by-step guide to the AHP-TOPSIS methodology:

1. Identify the problem: Define the problem and the criteria for material selection. Identify the decision makers and stakeholders involved in the decision-making process.
2. Develop a hierarchical structure: Create a hierarchical structure that breaks down the criteria into sub-criteria and alternatives. This structure should reflect the goals and objectives of the decision makers [9].
3. Pairwise comparison using AHP: Use the AHP method to conduct pairwise comparisons of the criteria and sub-criteria. This involves comparing each criterion and sub-criterion against every other criterion and sub-criterion and assigning a score to reflect the relative importance of each criterion [24].
4. Calculate the weights: Use the scores from the pairwise comparison to calculate the weights of each criterion and sub-criterion. This is done by summing the scores for each row and normalizing the results.
5. Standardize the data: Standardize the performance data of each alternative with respect to each criterion using a common scale.
6. Calculate the performance score: Calculate the performances core for each alternative by multiplying the standardized score for each criterion by its corresponding weight and summing the results.
7. Determine the ideal and anti-ideal solutions: Identify the ideal and anti-ideal solutions based on the maximum and minimum values of the performance score for each criterion.
8. Calculate the distance: Calculate the distance of each alternative from the ideal and anti- ideal solutions using the Euclidean distance formula.
9. Calculate the relative closeness: Calculate the relative closeness of each alternative to the ideal solution using the TOPSIS method.
10. Rank the alternatives: Rank the alternatives in order of their relative closeness to the ideal solution, with the highest-ranked alternative being the most suitable material for the application.
11. Sensitivity analysis: Conduct sensitivity analysis to evaluate the robustness of the results by changing the weights and criteria.

Overall, the AHP-TOPSIS methodology provides a comprehensive framework for material selection by taking into account multiple criteria and preferences.

RESULTAND DISCUSSION

The AHP algorithm is used to calculate the relative weights or priority order of performance determining criteria. Table 1 tabulates the pairwise comparisons matrix between the criteria and Table 1 shows the normalized matrix and priority values of the criteria. Criteria selected in the present work are hardness, tensile strength, flexural strength, compressive strength, density and water absorption. In the normalized matrix shown in Table 2, the eighth column shows the priority values or relative weights. In the same way, the pairwise comparison matrix between the various alternatives can also be

formulated. From the eighth column of Table 2, the order of relative weights is Hardness > Flexural strength > Water absorption > Density > Tensile strength > Compressive strength. The Consistency Ratio (CR) is calculated as per methodology and the same is obtained as 0.084 which is less than 0.1. As per T. L. Satty, if the value of CR is less than 10% then the judgments made by us are acceptable.

Table 1. Pairwise comparison matrix among parameters.

Criteria	T.S.	C.S.	F.S.	Hardness	Density	Water absorption
T.S.	1	3	1/2	1/4	1/3	1/3
C.S.	1/3	1	1/2	1/3	1/2	1/4
F.S.	2	2	1	1/2	2	3
Hardness	4	3	2	1	3	3
Density	3	2	1/2	1/3	1	1
Water absorption	3	4	1/3	1/3	1	1

Table 2. Normalized matrix.

Criteria	T.S.	C.S.	F.S.	Hardness	Density	Water absorption	T.S.
T.S.	1	3	1/2	1/4	1/3	1/3	0.088
C.S.	1/3	1	1/2	1/3	1/2	1/4	0.065
F.S.	2	2	1	1/2	2	3	0.219
Hardness	4	3	2	1	3	3	0.336
Density	3	2	1/2	1/3	1	1	0.139
Water absorption	3	4	1/3	1/3	1	1	0.153
Consistency ratio(CR)=8.4%							

Table 3 shows the decision matrix for the fabricated composites. The table comprises the actual values obtained during the physical and mechanical characterization. Table 4 shows the normalized matrix. The values presented in the Table 4 are obtained as per methodology. Table 5 comprises the weighted normalized matrix. Table 6 shows the positive and negative ideal solutions for all the parameters under observation and the same is obtained from Table 5. The positive and negative ideal solutions for each criterion are found and the same is tabulated in Table 7. The next step is to calculate the relative closeness from an ideal solution from the positive and negative ideal solutions. The same is calculated and presented in the last column of Table 7. The best process parameters for the acquired closeness values were discovered using the higher-the-better characteristic.

Table 3. Decision matrix of fabricated composites.

Criteria	T.S.	C.S.	F.S.	Hardness	Density	Water absorption
EPO+10KSD+5FA	31.8	95.98	55.56	83	1.259	0.4702
EPO+20KSD+5FA	34.4	102.68	65.38	85	1.329	0.5451
EPO+30KSD+5FA	30.8	107.57	51.37	88	1.407	0.6659
EPO+40KSD+5FA	27.8	111.86	38.54	91	1.492	0.8885
EPO+10KSD+ 10FA	33.6	102.39	63.96	84	1.286	0.5100
EPO+20KSD+ 10FA	31.3	108.57	56.88	87	1.358	0.6297
EPO+30KSD+ 10FA	29.1	112.34	44.64	89	1.441	0.8476
EPO+40KSD+10FA	26.7	116.28	37.12	93	1.533	0.9586

Table 4. Normalized matrix.

Criteria	T.S.	C.S.	F.S.	Hardness	Density	Water absorption
EPO+10KSD+5FA	0.365	0.316	0.373	0.335	0.320	0.233
EPO+20KSD+5FA	0.394	0.338	0.438	0.343	0.338	0.271
EPO+30KSD+5FA	0.353	0.354	0.344	0.355	0.358	0.331
EPO+40KSD +5FA	0.319	0.368	0.258	0.367	0.379	0.044
EPO+10KSD+ 10FA	0.385	0.337	0.429	0.339	0.327	0.253
EPO+20KSD+ 10FA	0.359	0.357	0.381	0.351	0.345	0.313
EPO+30KSD+ 10FA	0.334	0.370	0.299	0.359	0.366	0.421
EPO+40KSD+10FA	0.306	0.383	0.249	0.375	0.390	0.476

Table 5. Weighted normalized matrix.

Criteria	T.S.	C.S.	F.S.	Hardness	Density	Water absorption
EPO+10KSD+5FA	0.032	0.020	0.081	0.112	0.044	0.035
EPO+20KSD+5FA	0.034	0.021	0.095	0.115	0.046	0.041
EPO+30KSD+5FA	0.031	0.023	0.075	0.119	0.049	0.050
EPO+40KSD+5FA	0.028	0.024	0.056	0.123	0.052	0.006
EPO+10KSD+ 10FA	0.033	0.021	0.093	0.113	0.045	0.038
EPO+20KSD+ 10FA	0.031	0.023	0.083	0.117	0.047	0.047
EPO+30KSD+ 10FA	0.029	0.024	0.065	0.120	0.050	0.064
EPO+40KSD+10FA	0.026	0.025	0.054	0.126	0.054	0.072

Table 6 The positive and negative ideal solution matrix.

Criteria	T.S.	C.S.	F.S.	Hardness	Density	Water absorption
Positive ideal solution	0.034	0.025	0.095	0.126	0.044	0.006
Negative ideal solution	0.026	0.020	0.054	0.112	0.054	0.072

Table 7. Separation of each alternative from the ideal solution and its relative closeness to the ideal solution.

Criteria	Separation n from a positive ideal solution	Separation n from a negative ideal solution	Solution
			Relative closeness from an ideal solution
EPO+10KSD+5FA	0.0355	0.0472	0.57
EPO+20KSD+5FA	0.0369	0.0657	0.64
EPO+30KSD+5FA	0.0492	0.0321	0.394
EPO+40KSD+5FA	0.0403	0.0671	0.624
EPO+10KSD+ 10FA	0.0348	0.053	0.603
EPO+20KSD+ 10FA	0.0439	0.0396	0.474
EPO+30KSD+ 10FA	0.066	0.017	0.204
EPO+40KSD+10FA	0.0787	0.0148	0.158

CONCLUSION

The AHP-TOPSIS methodology was utilized to evaluate and select the optimal epoxy composite material that is filled with Kota stone dust. The AHP method was employed to determine the relative weights of the criteria, while the TOPSIS method was used to obtain the final ranking of the alternatives. The resulting rankings are as follows: Rank 1 (EPO + 20KSD + 5FA), Rank 2 (EPO + 40KSD + 5FA), Rank 3(EPO + 10KSD + 10FA), Rank 4, (EPO + 10KSD + 5FA), Rank 5 (EPO + 20KSD + 10FA),

Rank 6 (EPO + 30KSD + 5FA), Rank 7 (EPO + 30KSD + 10FA), Rank 8 (EPO + 40KSD + 10FA). Based on the analysis, the hybrid composite material that consists of EPO + 20KSD + FA was identified as the most optimal alternative. This composite exhibited the highest relative closeness value of 0.640, indicating that it is the most suitable material for the given application. The findings suggest that epoxy composites with 20% Kota stone dust are the most efficient composite for structural applications.

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