REST Journal on Emerging trends in Modeling and Manufacturing
Vol: 9(4), December 2023
REST Publisher; ISSN: 2455-4537 (Online)
Website: https://restpublisher.com/journals/jemm/
DOI: https://doi.org/10.46632/jemm/9/4/4

Evaluating the Suitable Material Used in Small Wind Turbine Blades Using the GRA Method

*** Chinnasami Sivaji, Krishnan Chinnasamy, M. Ramachandran, Ramya sharma**

REST Labs, Kaveripattinam, Krishnagiri, Tamil Nadu, India.
*Corresponding Author Email: *krishnan7337@gmail.com*

Abstract*: The components used in "small wind turbine blades" have seen rapid growth in recent decades has resulted in improvements in manufacturing techniques. The choice of suitable materials is required since the aerodynamic loads rise as blade length increases. As it must satisfy numerous selection requirements, choosing the optimal material from among the many potential metals for "small wind turbine blades" is a crucial task. "A multi-criterion decision-making (MCDM)" situation is one in which one must choose the best materials for small wind turbine blades from all available options. The resources that have been identified are the proper ratios of "metal, plastic, natural, and synthetic/natural-synthetic hybrid materials". This study applies an approach that is based on "the Grey Relational Analysis (GRA) method" to assist in choosing the best materials for small wind turbine blades from all available options. The rank for Wood is 9, Aluminium is 10, CFRP$_{EP}$ is 1, GFRP$_{EP}$ is 2, GFRP$_{PP}$ is 5, CGFRP$_{EP}$ is 3, CGFRP$_{PP}$ is 4, FGFRP$_{EP}$ is 7, SGFRP$_{EP}$ is 6 and Plastic is 8. The ranking order is "CFRP$_{EP}$> GFRP$_{EP}$> CGFRP$_{EP}$> CGFRP$_{PP}$> GFRP$_{PP}$> SGFRP$_{EP}$> FGFRP$_{EP}$> Plastic > Wood > Aluminium". In this paper, the GRA analysis shows that "Epoxy-based Carbon Fiber Reinforced Plastic" is observed as an evolving best-compromised material for small wind turbine blades.*

Keywords: *Natural fibres, Tensile Strength, Flexural Strength, Composite materials, MCDM, Corrosion resistance, turbine blade.*

1. INTRODUCTION

The configuration of the blades has a significant influence on the amount of energy that is harvested from wind power, which is one of the most potentially sustainable energy resources. Variations in air pressure are what create the wind. Worldwide variations in "terrain, aquatic bodies, and flora" all have an impact on the velocity and direction of wind movement [1]."Wind turbines" are now used to produce energy. A propeller is moved by the angular momentum of the air, which rotates a generator's rotor and produces electrical energy. " The geometry and flow Reynolds number of wind turbines" are connected to their aerodynamics. " The horizontal-axis wind turbine" is the one that is most frequently utilised in commercial uses (HAWT). The rated produced power is used to categorise windmills. For instance, the term "small wind turbines" describes wind turbines with nominal powers under 50 kW [2].Small wind turbines are used to generate electricity for buildings, some of which may or may not be linked to the power system. According to "the World Wind Energy Association", the amount of installed wind power worldwide has "increased by 52.552 GW, bringing the total amount of power produced to 539.291 GW". This sizeable amount provides for 5% of the world's electricity needs, with Denmark setting a new record with wind generators providing 43% of its energy needs [3].According to "the World Wind Energy Association's research", the market for tiny wind turbines is anticipated to expand significantly over the next several years. One of the main components of a "small wind turbine (SWT)" is the blade, which many scientists have concentrated on in order to improve aerodynamics while few have focused on structural application [4].The majority of research studies on SWT blades are focused on the development of low Reynolds number airfoils and the use of observational and theoretical methods to assess the rotor's performance. The strength design, which includes substance choice, is a crucial step in the SWT blade design phase following "the aerodynamic design" [5].According to the "erratic nature of wind speed and direction", fatigue stresses are frequently applied to the revolving wind turbine rotors. Therefore, the blade should be strong enough to endure such circumstances for the duration of its intended life, which is made possible by adequate strength construction. The study on the strength layout and components for SWT blades has only been discussed by a small number of investigators [6]. The writers of the research studies that are now accessible have overlooked numerous important requirements for SWT blades in favour of focusing primarily on "high strength-to-weight ratios". Due to their "high strength to weight ratios, glass fibre reinforced plastic (GFRP) and carbon fibre reinforced plastic (CFRP)" are the materials most frequently utilised for SWT rotors [7]. By referencing their application in "the large wind turbine blades, GFRP and CFRP are used in SWT blades". Different materials that might not be appropriate for "large wind turbine blades" could be used for "SWT blades". As a result, a few scientists have considered these possibilities and suggested a few other materials that are especially appropriate for "SWT blades" [8]. Experts have also realised that green resources are needed in renewable energy devices due to the growing environmental and sustainable growth concerns over the past 20 years. A few scientists have also proposed and investigated blades made of "wood and aluminium" [9]. For "SWT blades", some investigators have suggested using natural fibres or a mix of natural and glass fibres. Although new resources for SWT blades have been offered by researchers, it is crucial to evaluate these elements using organised mathematical techniques to select the optimal one [10]. Choosing the right material for an SWT blade is a difficult undertaking because it must satisfy several requirements. A thorough assessment and the use of relevant "multi-criteria decision-making" approaches are required for the selection of relevant material amongst numerous options and criteria [11]. This study applies an approach that is based on "the Grey Relational Analysis (GRA) method" to assist in choosing the best materials for small wind turbine blades from all available options.

2. MATERIALS & METHODS

A "multiple attribute decision-making" (MADM) issues is one where a decision must be made from a small set of alternatives that have been assessed on a variety of criteria, both quantitative and subjective. Recently, MADM has received a lot of attention from academics across a range of disciplines [12]."The grey system concept" is one method for investigating ambiguity that excels at mathematically evaluating systems with shaky knowledge. According to the grey system concept, a white system has all the information available, whereas a black system has all the information uncertain [13]."A grey system" is one that only has the least part of recognised details. " Grey relational analysis (GRA), grey decision, grey programming, and grey control" are the five main components of the grey systems approach. GRA is part of the grey systems approach, which helps tackle challenges with intricate interconnections between various components and quantities [14]. Therefore, the GRA technique has been extensively employed to address uncertainty issues arising from discontinuous data and partial knowledge. Additionally, the GRA approach is one of the most widely used techniques for examining numerous associations between discrete data collections and for making conclusions when dealing with several attributes. The main benefits of the GRA technique are that it is some of the best ways to make judgments in a corporate context, the computations are easy to understand, and the conclusions are dependent on the raw data [15]. Widespread use of "Deng's (1982) grey systems approach" in a variety of domains. It has been demonstrated to be practical for coping with inaccurate, insufficient, and ambiguous info. " Grey relational analysis (GRA)" is a branch of the grey systems approach, which can be used to solve issues involving complex interactions between several different elements and elements [16].Numerous MADM issues, including "hiring decisions (Olson & Wu, 2006), restoration planning for power distribution systems (Chen, 2005), an inspection of integrated-circuit marking processes (Jiang, Tasi, & Wang, 2002), modelling of quality function deployment (Wu, 2002), defect detection in silicon wafer slicing (Lin et al., 2006)", etc., have been effectively addressed by the use of GRA [17].By incorporating all of the achievement similarity measures taken into account for each option into a fixed value, GRA can help address MADM troubles. As a result, the original issue is reduced to a judgement issue involving a single attribute. As a result, following the GRA procedure, solutions with numerous characteristics can be simply evaluated [18]. Furthermore, a comparison sequence is created by converting the behaviour of each possibility into the primary step of GRA. The term "grey relational generating" refers to this phase. Based on those sequences, "a standard sequence (ideal target sequence)" is defined. Finally, the grey relational correlation between all similarity variants and the benchmark pattern is determined [19]."The grey relational grade" between each comparable pattern and the benchmark pattern is then generated based on those "grey relational coefficients". The optimal variant will be the one whose converted comparable sequence has the greatest grey relational grade among "the reference sequence and itself" [20].

Step 1. sign of decision matrix and weight matrix

For an MCDM problem consisting of m alternatives and n criteria, let $D = x_{ij}$ be a decision matrix, where $x_{ij} \in R$

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \qquad 1$$

Step 2. Normalization of decision matrix

The normalization of two types of data i.e., better when the higher type or better when lower is evaluated using equations 2 or 3 respectively. After normalization, the data ranges from 0 to 1.

$$M_{ij} = \frac{N_{ij} - \min(N_{ij})}{\max(N_{ij}) - \min(N_{ij})} \qquad 2$$

$$M_{ij} = \frac{\max(N_{ij}) - N_{ij}}{\max(N_{ij}) - \min(N_{ij})} \qquad 3$$

Where $i, j = 1,2,3, \cdots, n$

Step 3. $Deviation = the \max value\ after\ normalization - value\ of\ the\ current\ row$ 4

Step 4. Calculation of Gray relation coefficient

$$C_{ij} = \frac{\Delta_{min} - \xi\Delta_{max}}{Current\ value - \xi\Delta_{max}}, where\ zeta\ (\xi)\ is\ distinguishing\ coefficient \qquad 5$$

Step 5. Calculation of Gray relation grade

It represents the Gray Relation Coefficient on averages. After that, options are ordered using the "Gray Relation Coefficient's average" [21, 22].we consider ten materials “Wood, Aluminium, $CFRP_{EP}$, $GFRP_{EP}$, $GFRP_{PP}$, $CGFRP_{EP}$, $CGFRP_{PP}$, $FGFRP_{EP}$, $SGFRP_{EP}$ and Plastic” as alternate. After consideration, “Tensile Strength (MPa), Flexural Strength (MPa), Corrosion resistance, Density (kg/m3), Blade Cost (Rupee) and Setup Cost (Rupee)” are to be used as evaluation parameters for SWT blade material selection. Here “Tensile Strength (MPa), Flexural Strength (MPa) and Corrosion resistance” are beneficial criteria. “Density (kg/m3), Blade Cost (Rupee) and Setup Cost (Rupee)” are taken as non-beneficial criteria.

3. RESULTS AND DISCUSSION

TABLE 1. Quantitative data for alternative materials for SWT

Material	Tensile Strength (MPa)	Flexural Strength (MPa)	Corrosion resistance	Density (kg/m3)	Blade Cost (Rupee)	Setup Cost (Rupee)
Wood	70	147	3	625	7407.9	576170
Aluminium	229	299	7	2700	12346.5	1975440
$CFRP_{EP}$	440	286	9	1400	13169.6	246930
$GFRP_{EP}$	190	252	9	1700	2469.3	246930
$GFRP_{PP}$	150	199	7	1350	2140.06	246930
$CGFRP_{EP}$	165	218	8	1300	1810.82	246930
$CGFRP_{PP}$	135	179	7	1200	1646.2	246930
$FGFRP_{EP}$	88	122	5	1320	2469.3	246930
$SGFRP_{EP}$	80	113	5	1340	1975.44	246930
Plastic	40	75	8	1250	823.1	1481580

Table 1 shows the initial decision matrix for Quantitative data for alternative materials for SWT. Here we consider ten materials “Wood, Aluminium, $CFRP_{EP}$, $GFRP_{EP}$, $GFRP_{PP}$, $CGFRP_{EP}$, $CGFRP_{PP}$, $FGFRP_{EP}$, $SGFRP_{EP}$ and Plastic” as alternate. After consideration, “TensileStrength (MPa), FlexuralStrength (MPa), Corrosionresistance, Density (kg/m3), BladeCost (Rupee) and SetupCost (Rupee)” are to be used as evaluation parameters for SWT blade material selection. Here “Tensile Strength (MPa), Flexural Strength (MPa) and Corrosion resistance” are beneficial criteria.“Density (kg/m3), Blade Cost (Rupee) and Setup Cost (Rupee)” are taken as non-beneficial criteria.

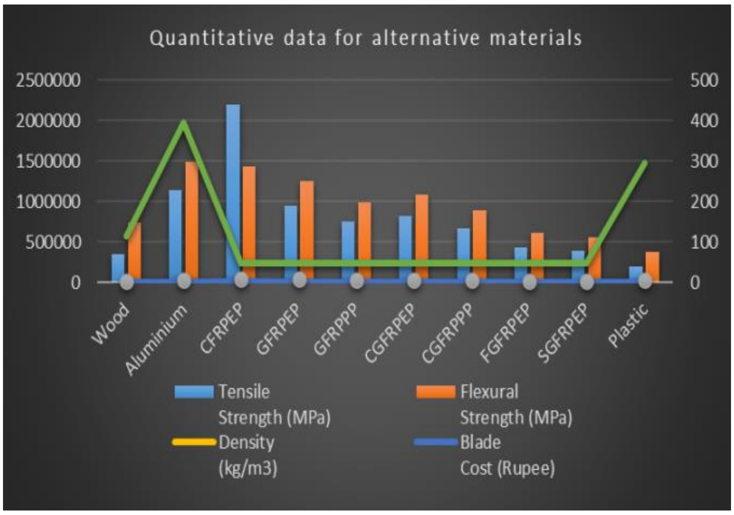

FIGURE 1. Quantitative data for alternative materials for SWT

Figure 1 illustratesthe initial decision matrix for Quantitative data for alternative materials for SWT. Here we consider ten materials “Wood, Aluminium, CFRP$_{EP}$, GFRP$_{EP}$, GFRP$_{PP}$, CGFRP$_{EP}$, CGFRP$_{PP}$, FGFRP$_{EP}$, SGFRP$_{EP}$ and Plastic” as alternate. After consideration, “Tensile Strength (MPa), Flexural Strength (MPa), Corrosion resistance, Density (kg/m3), Blade Cost (Rupee) and Setup Cost (Rupee)” are to be used as evaluation parameters for SWT blade material selection.

TABLE 2. Normalized matrix

0.0750	0.3214	0.0000	1.0000	0.4667	0.8095
0.4725	1.0000	0.6667	0.0000	0.0667	0.0000
1.0000	0.9420	1.0000	0.6265	0.0000	1.0000
0.3750	0.7902	1.0000	0.4819	0.8667	1.0000
0.2750	0.5536	0.6667	0.6506	0.8933	1.0000
0.3125	0.6384	0.8333	0.6747	0.9200	1.0000
0.2375	0.4643	0.6667	0.7229	0.9333	1.0000
0.1200	0.2098	0.3333	0.6651	0.8667	1.0000
0.1000	0.1696	0.3333	0.6554	0.9067	1.0000
0.0000	0.0000	0.8333	0.6988	1.0000	0.2857

Table 2 shows the normalized array for material propertiesof alternative materials for SWT. This is calculated using equation 2 for beneficial criteria (“Tensile Strength (MPa), Flexural Strength (MPa) and Corrosion resistance”) and equation 3 for non-beneficial criteria (“Density (kg/m3), Blade Cost (Rupee) and Setup Cost (Rupee)”).

TABLE 3. Deviation sequence

0.9250	0.6786	1.0000	0.0000	0.5333	0.1905
0.5275	0.0000	0.3333	1.0000	0.9333	1.0000
0.0000	0.0580	0.0000	0.3735	1.0000	0.0000
0.6250	0.2098	0.0000	0.5181	0.1333	0.0000
0.7250	0.4464	0.3333	0.3494	0.1067	0.0000
0.6875	0.3616	0.1667	0.3253	0.0800	0.0000
0.7625	0.5357	0.3333	0.2771	0.0667	0.0000
0.8800	0.7902	0.6667	0.3349	0.1333	0.0000
0.9000	0.8304	0.6667	0.3446	0.0933	0.0000
1.0000	1.0000	0.1667	0.3012	0.0000	0.7143

Table 3 shows the Deviation sequence matrix for material properties of alternative materials for SWT. This value is calculated using equation 4 that is Maximum value of the column of normalized value is subtracted from the current value of the normalized matrix.

TABLE 4. Grey Relation Coefficient

0.3509	0.4242	0.3333	1.0000	0.4839	0.7241
0.4866	1.0000	0.6000	0.3333	0.3488	0.3333
1.0000	0.8960	1.0000	0.5724	0.3333	1.0000
0.4444	0.7044	1.0000	0.4911	0.7895	1.0000
0.4082	0.5283	0.6000	0.5887	0.8242	1.0000
0.4211	0.5803	0.7500	0.6058	0.8621	1.0000
0.3960	0.4828	0.6000	0.6434	0.8824	1.0000
0.3623	0.3875	0.4286	0.5988	0.7895	1.0000
0.3571	0.3758	0.4286	0.5920	0.8427	1.0000
0.3333	0.3333	0.7500	0.6241	1.0000	0.4118

Table 4 shows the Grey Relation Coefficient matrix for material properties of alternative materials for SWT. This value is calculated using equation 5 and the zeta value is 0.5. Table 3 Deviation sequence matrix is for calculating Grey Relation Coefficient

TABLE 5. Grey Relation Grade

Materials	**GRG**
Wood	0.55274
Aluminium	0.51702
CFRP$_{EP}$	0.80029
GFRP$_{EP}$	0.73824
GFRP$_{PP}$	0.65822
CGFRP$_{EP}$	0.70321
CGFRP$_{PP}$	0.66743
FGFRP$_{EP}$	0.59446
SGFRP$_{EP}$	0.59938
Plastic	0.57542

Table 5 shows the Grey Relation Grade value for alternate materials taken for this paper. Its average values of the Grey Relation Coefficient using table 4. Here Grey Relation Grade value for Wood is 0.55274, Aluminium is 0.51702, CFRP$_{EP}$ is 0.80029, GFRP$_{EP}$ is 0.73824, GFRP$_{PP}$ is 0.65821, CGFRP$_{EP}$ is 0.70321, CGFRP$_{PP}$ is 0.66742, FGFRP$_{EP}$ is 0.59445, SGFRP$_{EP}$ is 0.59937 and Plastic is 0.57541

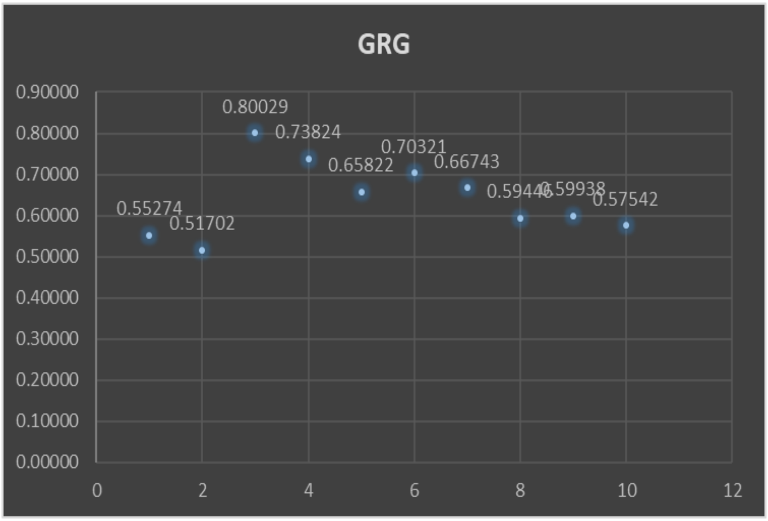

FIGURE 2. Grey Relation Grade

Figure 2 shows the graphical representation of the Grey Relation Grade value for alternate materials taken for this paper. Its average values of the Grey Relation Coefficient using table 4. Here Grey Relation Grade value for Wood is 0.55274, Aluminium is 0.51702, CFRP$_{EP}$ is 0.80029, GFRP$_{EP}$ is 0.73824, GFRP$_{PP}$ is 0.65821, CGFRP$_{EP}$ is 0.70321, CGFRP$_{PP}$ is 0.66742, FGFRP$_{EP}$ is 0.59445, SGFRP$_{EP}$ is 0.59937 and Plastic is 0.57541.

TABLE 6. The rank of BPM tools

Materials	**Rank**
Wood	9
Aluminium	10
CFRP_{EP}	1
GFRP_{EP}	2
GFRP_{PP}	5
CGFRP_{EP}	3
CGFRP_{PP}	4
FGFRP_{EP}	7
SGFRP_{EP}	6
Plastic	8

Table 5 shows the rank of the alternate materials taken for this paper by ranking Grey Relation Grade values using table 5. Here rank for Wood is 9, Aluminium is 10, CFRP_{EP} is 1, GFRP_{EP} is 2, GFRP_{PP} is 5, CGFRP_{EP} is 3, CGFRP_{PP} is 4, FGFRP_{EP} is 7, SGFRP_{EP} is 6 and Plastic is 8. The ranking order is “CFRP_{EP}> GFRP_{EP}> CGFRP_{EP}> CGFRP_{PP}> GFRP_{PP}> SGFRP_{EP}> FGFRP_{EP}> Plastic > Wood > Aluminium”.

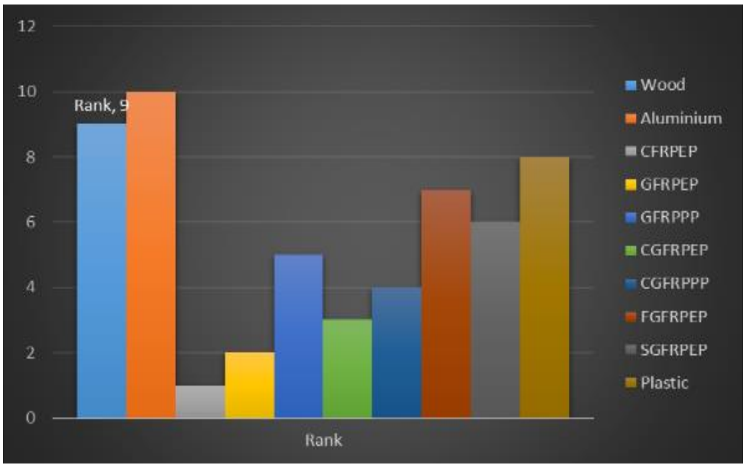

FIGURE 3. The rank of alternate materials

Figure 3 shows a graphical representation of the alternate materials taken for this paper by ranking Grey Relation Grade values using table 5. Here rank for Wood is 9, Aluminium is 10, CFRP_{EP} is 1, GFRP_{EP} is 2, GFRP_{PP} is 5, CGFRP_{EP} is 3, CGFRP_{PP} is 4, FGFRP_{EP} is 7, SGFRP_{EP} is 6 and Plastic is 8. The ranking order is “CFRP_{EP}> GFRP_{EP}> CGFRP_{EP}> CGFRP_{PP}> GFRP_{PP}> SGFRP_{EP}> FGFRP_{EP}> Plastic > Wood > Aluminium”.In this paper, the GRA analysis shows that “Epoxy-based Carbon Fiber Reinforced Plastic” is observed as an evolving best-compromised material for small wind turbine blades.

4. CONCLUSION

A key factor affecting the amount of energy harvested from wind farms is the blade configuration, which is among the most prospective renewable energy resources. The variations in air pressure are what truly causes the wind to blow. Around the world, there are differences in terrain, aquatic systems, and flora, which have an impact on "the speed and patterns of wind flow".Windmills are now used to produce energy. A propeller is moved by the potential energy of the air, which rotates an engine's rotor and produces electrical generation". The geometry and flow Reynolds number of wind turbines" are connected to their aerodynamics. The horizontal-axis wind turbine is the one that is most frequently utilised in commercial applications. The rated produced power is used to categorise wind turbines. Since the chosen material must satisfy several requirements, choosing the right material for an "SWT blade" is a difficult undertaking. The use of proper "multi-criteria decision-making approaches" and a thorough examination are required for the selection of relevant materials among numerous alternatives.This study applies an approach that is based on "the Grey Relational Analysis (GRA) method" to assist in choosing the best materials for small wind turbine blades from all available options.In this paper, the GRA analysis shows that “Epoxy-based Carbon Fiber Reinforced Plastic” is observed as the best-compromised material for small wind turbine blades.

PREFERENCES

[1]. Pourrajabian, Abolfazl, Maziar Dehghan, Adeel Javed, and David Wood. "Choosing an appropriate timber for a small wind turbine blade: A comparative study." *Renewable and Sustainable Energy Reviews* 100 (2019): 1-8.

[2]. Muhsen, Hani, Wael Al-Kouz, and Waqar Khan. "Small wind turbine blade design and optimization." *Symmetry* 12, no. 1 (2019): 18.

[3]. Madhusudhan Dasari sreeramulu, “Analysis of Wireless Security and Networks using COPRAS Method” REST Journal on Data Analytics and Artificial Intelligence 2(4), December 2023, 32-41.

[4]. Evans, Samuel, Scott Dana, Philip Clausen, and David Wood. "A simple method for modelling fatigue spectra of small wind turbine blades." *Wind Energy* 24, no. 6 (2021): 549-557.

[5]. Wang, Chen, and Yongqiang Gu. "Research on infrared nondestructive detection of small wind turbine blades." *Results in Engineering* 15 (2022): 100570.

[6]. Islam, Md Robiul, Labid Bin Bashar, and Nazmus Sowad Rafi. "Design and simulation of a small wind turbine blade with qblade and validation with MATLAB." In *2019 4th International Conference on Electrical Information and Communication Technology (EICT)*, pp. 1-6. IEEE, 2019.

[7]. Awadallah, Mohammed, and Ameen El-Sinawi. "Effect and detection of cracks on small wind turbine blade vibration using special Kriging analysis of spectral shifts." *Measurement* 151 (2020): 107076.

[8]. Kulak, Michal, Michal Lipian, and Karol Zawadzki. "Investigation of performance of small wind turbine blades with winglets." *International Journal of Numerical Methods for Heat & Fluid Flow* 31, no. 2 (2021): 629-640.

[9]. Latoufis, Kostas, Vasilis Riziotis, Spyros Voutsinas, and Nikos Hatziargyriou. "Effects of leading-edge erosion on the power performance and acoustic noise emissions of locally manufactured small wind turbine blades." In *Journal of Physics: Conference Series*, vol. 1222, no. 1, p. 012010. IOP Publishing, 2019.

[10]. Chaudhary, Manoj Kumar, and S. Prakash. "Investigation of blade geometry and airfoil for small wind turbine blade." *Advanced Science, Engineering and Medicine* 11, no. 5 (2019): 448-452.

[11]. Stępień, Małgorzata, Michał Kulak, and Krzysztof Jóźwik. "“Fast Track” Analysis of Small Wind Turbine Blade Performance." *Energies* 13, no. 21 (2020): 5767.

[12]. Garmode, Ravindra K., Vivek R. Gaval, Sandip A. Kale, and Sanjay D. Nikhade. "Comprehensive evaluation of materials for small wind turbine blades using various MCDM techniques." *Inernational Journal of Renewable Energy Research* 12, no. 2 (2022): 981-992.

[13]. Madhusudhan Dasari sreeramulu, “Sensitive Analysis of Natural Language Processing Using for MOORA Method”, Computer Science, Engineering and Technology, 1(1), March 2023, 46-53.

[14]. Younas, Muhammad, Syed Husain Imran Jaffery, Mushtaq Khan, Muhammad Ali Khan, Riaz Ahmad, Aamir Mubashar, and Liaqat Ali. "Multi-objective optimization for sustainable turning Ti6Al4V alloy using grey relational analysis (GRA) based on analytic hierarchy process (AHP)." *The International Journal of Advanced Manufacturing Technology* 105 (2019): 1175-1188.

[15]. Sreenath Devineni, Bhargavi Gorantla, “Security and Privacy Issues in Internet of Things (IoT) Devices Using COPRAS Method” REST Journal on Data Analytics and Artificial Intelligence, 2(4), 2023, 15-22.

[16]. Inaganti Rambabu, Yalavarthy Sreekanth, “FUSING CYBERSECURITY, AI, AND EMERGING TECHNOLOGIES IN MEDICAL DEVICES FOR IMPROVED HEALTHCARE” INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS, 10(4), 2023, 74-81.

[17]. Olabanji, Olayinka Mohammed, and Khumbulani Mpofu. "Appraisal of conceptual designs: Coalescing fuzzy analytic hierarchy process (F-AHP) and fuzzy grey relational analysis (F-GRA)." *Results in Engineering* 9 (2021): 100194.

[18]. Sathiyaraj Chinnasamy, M. Ramachandran, Vimala Saravanan, Prabakaran Nanjundan, "Performance Analysis of Agricultural Waste Using Gray Relational Analysis (GRA) Method", uilding Materials and Engineering Structures, 1(4), December 2023, 22-28.

[19]. Rani, Pratibha, Arunodaya Raj Mishra, Mohd Dilshad Ansari, and Jabir Ali. "Assessment of performance of telecom service providers using intuitionistic fuzzy grey relational analysis framework (IF-GRA)." *Soft Computing* 25 (2021): 1983-1993.

[20]. Chandrasekar Raja, Chinnasami Sivaji, M. Ramachandran, Ramya Sharma, "An Overview of Qualitative Comparative Analysis Using GRA Methodology", Journal on Innovations in Teaching and Learning,2(4), December 2023,28-35.

[21]. Dhanabalan.R D. Kaviyarasan andSandeep Dubey SheelaTa, Seema.S, Madura.R, Uma DeviPongiya, “Cyanobacteria in Degradation of Sugar Mill Wastes” Bulletin of Environment, Pharmacology and Life Sciences, 5 (5), 2022, 620-628.

[22]. Murthy, Ashwin Narasimha, Souptik Sen, and Ramesh Krishnamaneni. "Enhanced image retrieval and classification frameworks for brain disease diagnosis using hybrid deep learning models." *International Journal of Computer Science and Information Technology Research* 3, no. 1 (2022): 37-47.

[23]. Neha Bharani, “Blockchain Technology and Its Role in the Bitcoin Ecosystem A Review” International Journal of Novel Research and Development, 2023

[24]. Wu, Lei, Jiao Liu, Jun Zhou, Qiuli Zhang, Yonghui Song, Shuai Du, and Wei Tian. "Evaluation of tar from the microwave co-pyrolysis of low-rank coal and corncob using orthogonal-test-based grey relational analysis (GRA)." *Journal of Cleaner Production* 337 (2022): 130362.

[25]. Verma, Pradeep. "Effective Execution of Mergers and Acquisitions for IT Supply Chain." *International Journal of Computer Trends and Technology* 70, no. 7 (2022): 8-10.

[26]. Logeshwaran, J., Venkata Ashok K. Gorantla, Venkataramaiah Gude, and Bhargavi Gorantla. "The Smart Performance Analysis of Cyber Security Issues in Crypto Currency Using Blockchain." In *2023 6th International Conference on Contemporary Computing and Informatics (IC3I)*, vol. 6, pp. 2235-2241. IEEE, 2023.

[27]. Sindhu, Dinesh, Lalit Thakur, and Pankaj Chandna. "Multi-objective optimization of rotary ultrasonic machining parameters for quartz glass using Taguchi-Grey relational analysis (GRA)." *Silicon* 11 (2019): 2033-2044.

[28]. Liang, Z. H. O. U., Tai-hua MU, Ruo-fang ZHANG, Qing-hua SUN, and Yan-wen XU. "Nutritional evaluation of different cultivars of potatoes (Solanum tuberosum L.) from China by grey relational analysis (GRA) and its application in potato steamed bread making." *Journal of integrative agriculture* 18, no. 1 (2019): 231-245.

[29]. Suvvari, Anandarao, and Phanindra Goyari. "Financial performance assessment using Grey relational analysis (GRA): An application to life insurance companies in India." *Grey Systems: Theory and Application* (2019).

[30]. Bhaumik, Munmun, and Kalipada Maity. "Multi-response optimization of EDM parameters using grey relational analysis (GRA) for Ti-5Al-2.5 Sn titanium alloy." *World Journal of Engineering* 18, no. 1 (2021): 50-57.

[31]. Wang, Lihong, Kedong Yin, Yun Cao, and Xuemei Li. "A new grey relational analysis model based on the characteristic of inscribed core (IC-GRA) and its application on seven-pilot carbon trading markets of China." *International journal of environmental research and public health* 16, no. 1 (2019): 99.

[32]. Verma, Pradeep. "Sales of Medical Devices–SAP Supply Chain." *International Journal of Computer Trends and Technology* 70, no. 9 (2022): 6-12.

[33]. Javed, Saad Ahmed, Angappa Gunasekaran, and Amin Mahmoudi. "DGRA: Multi-sourcing and supplier classification through Dynamic Grey Relational Analysis method." *Computers & Industrial Engineering* 173 (2022): 108674.

[34]. Bharani, Neha. *Complexity study of software engineering phases and software quality*. Book Rivers, 2022.

[35]. Murthy, Ashwin Narasimha, Souptik Sen, and Ramesh Krishnamaneni. "Enhanced image retrieval and classification frameworks for brain disease diagnosis using hybrid deep learning models." *International Journal of Computer Science and Information Technology Research* 3, no. 1 (2022): 37-47.

[36]. Inaganti Rambabu, Yalavarthy Sreekanth, “Innovative Solutions: AI-Enabled Medical Devices and Digital Twin Technology Shaping Future Healthcare”, INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS, 11(12), 2023, e497-e506.

[37]. Madhusudhan Dasari sreeramulu, “Optimizing Cloud Computing Networks in Information Security Controls using COPRAS Method”, Computer Science, Engineering and Technology 1(2), 2023, 42-54.

[38]. Li, Weichen, Xusheng Ren, Shimin Ding, and Lichun Dong. "A multi-criterion decision making for sustainability assessment of hydrogen production technologies based on objective grey relational analysis." *International Journal of Hydrogen Energy* 45, no. 59 (2020): 34385-34395.

[39]. Thangaraj, Sheela, Paul Olusegun Bankole, and Senthil Kumar Sadasivam. "Microbial degradation of azo dyes by textile effluent adapted, Enterobacter hormaechei under microaerophilic condition." *Microbiological Research* 250 (2021): 126805.

[40]. Sreenath Devineni, Bhargavi Gorantla, “Energy-Efficient Computing and Green Computing Techniques”, Computer Science, Engineering and Technology, 1(4), 2023, 37-45.