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Material Selection of Face Sheet of Sandwich Plate Used in Blade of Wind Turbine Using MCDM Method

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Abstract: The design and materials of wind turbine blades are crucial in terms of performance and durability. They are an essential part of the energy sector. In this article, we use the Multi-Criteria Decision Making (MCDM) method to suggest a material selection method for the face sheet for a sandwich shell/web for wind turbine blades. To determine the best material out of all the options, the MCDM method allows the evaluation of multiple criteria. The suggested method takes into account a number of things, including weight, price, mechanical qualities, and environmental impact. Aluminium, Carbon Fibre Reinforced Polymer, and Glass Fibre Reinforced Polymer were the materials assessed in this study. According to the MCDM results, CFRP is the best material for a wind turbine sandwich shell or web's face sheet when taking the chosen criteria into account. The suggested strategy offers a method for selecting materials that is systematic and all-inclusive and can be used in other fields and applications.
Keywords: Sandwich plate, wind turbine rotor blade, MCDM methods, AHP, TOPSIS.

I. INTRODUCTION

Wind turbines are an essential part of wind energy conversion systems, and wind energy has been acknowledged as a significant alternative energy source. When it comes to harnessing wind energy and transforming it into mechanical energy, wind turbine blades are essential. Due to their excellent fatigue resistance and high stiffness-to-weight ratio, sandwich structures are frequently used in wind turbine blades. However, the performance and cost of sandwich structures are significantly influenced by the material selection.

A sandwich structure's face sheet, which carries the majority of the mechanical load, is a crucial component. The performance of the wind turbine blade as a whole depends on the choice of an appropriate face sheet material. However, because there are so many materials available and there are so many different criteria to consider, choosing the right material for the face sheet can be a difficult and complicated process.

The use of Multi-Criteria Decision Making (MCDM) techniques to choose the best material for a given application has grown in popularity in recent years. Multiple criteria are taken into account, and they are then prioritised based to their level of relative importance, offering a methodical and impartial approach to decision-making. To choose the best material for the face sheet in sandwich structures for wind turbine blades in this situation, MCDM methods can be used.

In order to demonstrate the use of MCDM methods for material selection, this paper aims to review the different kinds of materials employed in the face sheet of sandwich structures in wind turbine blades. The paper will give a thorough analysis of the MCDM techniques that are currently in use and how well suited they are for choosing materials for sandwich wind turbine blade structures. The study's findings will help designers and engineers choose the best material for wind turbine blade face sheets and offer useful insights into the material selection process.

II. LITERATURE REVIEW

The various research methods can be categorized into six main categories after reading papers on material used for wind turbine rotor blade mainly composite sandwich plate design, namely: 1) Paper on material selection 2) Experimental Paper 3) Design consideration 4) FEM modeling 5) Optimization Paper 6) weight and cost.

Babu [1] The main goal of this topic is to discuss the various materials that could be used to make turbine blades and to choose the best material by using a MADM (Multiple Attribute Decision Making) method with fuzzy linguistic variables.

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Following the selection of the material, the turbine blades are built using modelling software (CATIA V5R9), and analysis can be carried out using FEM.

Maskepatil [3] In this paper, a straightforward analytical hierarchy process for choosing the material for a small wind turbine blade is presented. One of the most straightforward and economical methods for making decisions is AHP. AHP is successfully used in this work to choose the material for small wind turbine blades.

Theotokoglou[4], A methodology for selecting materials has first been suggested. In order to represent the load-carrying box girder of the blade with a given airfoil shape, size, and type of interior load-bearing longitudinal beams-shear webs, a very thorough computational analysis based on finite element modes is developed. Both plane and shell elements are used with linear and nonlinear analyses to produce results for displacements and stresses.

Ganesh [7], For better strength, low weight, and corrosion resistance, the nacelle and wind turbine blades are typically made of glass and carbon fibers, along with the hub, gear box, nacelle, and tower. The goal of the study is to replace these materials with natural fibers because the main drawbacks of these materials are limited availability, inability to degradation, health risks, and high cost of production. In this study, promising future directions for their development are discussed along with the application of natural fiber reinforced polymer composites in wind turbines, requirements for the composites, their properties, constituents, manufacturing processes, and defects.

Thomsen [8], The article provides a general overview of the design principles and material technology used today over wind turbine blades, as well as highlights the constraints and significant design issues that must be resolved for upscaling wind turbine blades from their current maximum length of over 61 m to blade lengths close to 90 m as stated for future very large wind turbines. The article specifically discusses the potential benefits and difficulties of using sandwich type construction more widely than it is currently used for the load-carrying components of wind turbine blades.

[9] Bassyouni, this study involved the selection of materials for the production of wind turbine blades. Following this procedure, picked composite materials (GFRP and CFRP) went through chemical surface treatment. Materials may be chosen incorrectly if the process is based on studying each individual property. The selection of high-performance materials is influenced by the conversion of goals and restrictions to material indices. Utilizing the Cambridge Engineering Selector (CES) programme, materials indices, rankings, and screening were conducted. For wind turbine blades, CFRP and GFRP were determined to be the top contenders. The final mechanical properties of polymer composites are significantly influenced by the loading of the fibers and the surface treatment. Silane A1100 surface chemical treatment of the fibers improved the GFRP's mechanical characteristics.

[10] Zangenberg, the task of designing a composite preform for a wind turbine rotor blade is complicated and difficult, as shown in the survey above. The design entails numerous iterative steps that are connected in an illogical way. Experience and knowledge, such as those related to failure modes, manufacturing technology, and processing, can be used to pre-design a fabric. However, a lot of different stakeholders must be involved in the manufacturing, testing, certification, and implementation of a new fabric. The final performance is a balance of many different factors, but the stakeholders all have different approaches and interests.

[11] The thermoset composite technologies currently used in the wind turbine industry are being replaced with new materials and materials systems. The selection of materials has become essential because turbine blades are the main component of wind turbines and the size of the blade is growing in today's wind design. Important considerations include less weight, less price, higher performance, longer life, ease of processing, and recycling ability. The current article offers a critical examination of potential material contenders for advancements in wind turbine blade technology. The materials taken into consideration in this study include a variety of fibre reinforcements, thermoset composites, thermoplastic composites, natural fibre composites, and hybrid composites. The benefits and drawbacks of various materials are discussed, along with their limitations, which can be useful information when choosing materials for both large and small turbine blades.

[16] Samir, Companies now concentrate on rotor blades with a length of up to 80 metres as our desire for renewable energy from wind turbines grows. The blade material is now being designed to withstand environmental effects like ultraviolet surface degradation, dust accumulation at sandy locations, ice accretion on blades in cold countries, insect collision on blades, and moisture ingress in addition to large aerodynamic, inertial, and fatigue loads. To ensure that the blades live up to their intended lifespan, all of this is taken into account. Additionally, the manufacturing of composite blades is growing exponentially, producing a sizable amount of waste materials. The use of wind blade materials, their ability to address the aforementioned issues, and their ability to maintain structural integrity are all put to the test by these issues. In order to meet this challenge, this paper optimises based on the characteristics, advantages, disadvantages, and price of various potential rival materials. The material is then simulated using finite element analysis in accordance with standards like IEC-61400-1 to determine its structural integrity.

This study elaborates on the potential impact of nanotechnology on the development of the wind blade, illuminating the direction in which research will go in the future.

[17] In this study, three different sandwich structures with various core materials—Balsa wood, Tycor, and Polyethylene Terephthalate (PET)—were produced. Using digital image correlation (DIC), glass-fiber reinforced polymer (GFRP) skins were employed to analyse the effects of various core materials on the flexural behaviour for sandwich composites for four-point bending (4PB) conditions. DIC is one of the best methods for determining any structurally problematic areas by analysing the mechanical behaviour of the structure during the test. Strain maps of the structures were used to observe the structures' failure mechanisms. According to the findings, the sandwich structure with Balsa wood as the core material has the highest stiffness; unfortunately, catastrophic failure first appeared during the test. Under load, the sandwich structure made of PET and Tycor behaved very similarly.

[18] Bortolotti, the development of an optimisation methodology for the the composite components used in wind turbine blades is the focus of this work. The approach aims to provide recommendations to composite manufacturers on the best choices among mechanical properties and material costs while assisting designers in choosing the various materials for the blade. A multidisciplinary wind turbine optimisation procedure is used to implement the method, which uses a parametric material model and its free parameters as design variables. The theoretical 10 MW wind turbine blade's spar caps and shell skin laminates are optimised as part of the proposed method's structural redesign test. The process identifies a blade that is most suitable for a new spar cap laminate that is more expensive and has a higher longitudinal Young's modulus than the original laminate, but which also results in mass and cost savings for the blade. Adoption of a laminate with properties halfway between a bi-axial and a tri-axial results in slight structural improvements for shell skin.

[20] A. Rashedia, On the basis of innate structural constraints and potential design goals, the study initially aims to establish blade and tower material selection indices. Next, it discusses the entire process of choosing the material for the blades and towers of both small and large horizontal axis wind turbines that can be installed on land as well as offshore. Finally, it distinguishes advanced blade and tower materials in accordance with a design optimisation process based on multiple constraints and compound objectives. The study's findings can be used to create turbines that are structurally more promising, economically more viable, and environmentally more sustainable.

[21] Sjølund, this study applies discrete material and thickness optimisation (DMTO) to sandwich composite structures that are subject to linear and displacement buckling constraints. It is possible to size both the core and face sheet plies at the same time using a new thickness formulation where density design variables scale ply thicknesses rather than constitutive properties. This enables the core and face sheet layers as well as the covering of ply-drops to have various ply thicknesses. Additionally, by separating the core and face sheets, a symmetric lay-up can be enforced, which is beneficial for preventing warping during the curing process. Three numerical examples, each getting more complex, are used to illustrate the method.

[34] Mengal, this paper reviews the potential use of basalt fiber as a cheaper and high-performance alternative to traditional materials for wind turbine blades. By combining it with carbon fiber, it has the potential to reduce the weight and cost of the blades while maintaining or improving their performance. The review highlights the superior mechanical properties of basalt fiber compared to other composites and suggests that it represents a promising area for future research and development in the wind energy industry.

[37] Okokpujie , this study used AHP and TOPSIS methods to select the best material for a horizontal wind turbine blade in Nigeria, considering low wind speed variations. Aluminum alloy was found to be the best material, followed by glass fiber. The AHP method provided a workable consistency index and ratio, while TOPSIS provided performance scores for the alternatives. The decision-makers recommend using aluminum alloy to develop the wind turbine blade for sustainable energy generation in Nigeria.

In order to determine the contributions that each paper made to the topic at hand, the authors of the document carefully analysed the contents of several papers. They categorised the papers based on the results of this analysis and listed their conclusions in Table 2.1. This made it possible to present each paper's various contributions in a clear and succinct manner, which made it simpler for readers to comprehend the overall state of the field's research.

III. TABLE 1 - LITERATURE REVIEW

Author and Paper no.	Materials Selection	Experimental Paper	Design Consideration	FEM Modelling	Optimization Papers	Weight And Cost
[1] Babu, K	√					√
[2] Berggreen				√		√

[3] Maskepatil	√				√	√
[4] Theotokoglou	√			√		√
[5] Mishnaevsky	√	√				√
[6] Brøndsted	√					√
[7] Ganesh R Kalagi		√				√
[8] Thomsen	√					√
[9] Bassyouni	√	√	√			
[10] J. Zangenberg	√		√			√
[11] Raghavalu	√					√
[12] Mishnaevsky Jr	√					√
[13] Schubel, Peter J.		√				√
[14] Tarfaoui	√	√		√	√	√
[15] Scherer Roger	√		√			√
[16] Samir Ahmad	√			√	√	
[17] Kaboglu	√	√				√
[18] P Bortolotti1	√	√			√	√
[19] Grujicic	√		√		√	
[20] A. Rashedia	√	√				√
[37] Okokpujie	√					

IV. TABLE 2- NOTES AND REMARKS

Author Name	Material Properties	Methodology Used	Material used	O/P	Remark
[1] Babu, K	High stiffness, Low density, long fatigue life	TOPSIS method with fuzzy linguistic variables	Composite using carbon fibers	Best material	TOPSIS with Fuzzy and simulations in Catia V5 and ANSYS revealed carbon fiber composite material as favorable.
[2] Berggreen	Low density (Weight reduction), High stiffness, Increased bucking capacity.	FEA	Sandwich composite- fiber reinforced plastic (FRP) structures	Best structure for load carrying flange	The introduction of a load-carrying flange sandwich structure clearly demonstrates substantial weight reduction and improved buckling capacity.
Maskepatil [3]	Strength, density, cost, Corrosion resistance (durability) and availability	AHP	Wood, Glass fiber, carbon fiber,Steel Aluminum	Best Material	Carbon fiber is given the highest priority value of 0.2507, indicating that it should be our top priority material.
[4] Theotokoglou	high material stiffness, low density, long fatigue life	FEA	Sandwich composite- Face sheet-Tri-axial fiberglass composite laminate, core- balsa wood core, Adhesive-Epoxy based.	Best structure	This analysis is the initial step towards understanding the stress state in the box girder of the WTB made of monolithic and sandwich composites.

[5] Mishnaevsky Jr	Lightweight, highly durable, Fatigue resistant, Stiffness cost	Review Paper	Fiber reinforcement polymers, Carbon fiber, E-glass fiber, High strength glass- -basalt, -aramid and -natural fiber	-	In addition to the traditional composites (glass fibers/epoxy matrix composites) used for wind turbine blades, natural composites, hybrid composites, and nanoengineered composites are also covered.
[6] Povl Brøndsted	high material stiffness, low density, long-fatigue life.	-	Fibers, Matrix Materials, Composite Materials		-
[7] Kalagi	Disposal (biodegradable)	-	Natural fibers reinforced polymers composite.	Best material	One class of materials that not only has superior mechanical properties but is also naturally biodegradable is natural fibre reinforced composites.
[8] Thomsen	high bending stiffness, high strength, and high buckling resistance.	Review paper (journal)	Sandwich composite material	-	Using sandwich composite laminates for the main spar flanges, particularly on the suction side of the aerofoil, is advantageous as it provides additional buckling capacity and/or a lighter design with similar buckling capacity compared to monolithic composite laminates.
[9] Bassyouni	-	Wind turbine blade material selection was done with the CES program.	CFRP and GFRP.	Best material	CFRP and GFRP are the top choices for wind turbine blades. The mechanical properties of polymer composites are greatly affected by fiber loading and surface treatment. Surface chemical treatment with Silane A1100 improved the mechanical properties of GFRP.
[10] Zangenberg	Density, Stiffness, Tensile strength, Compression strength, Fatigue resistance, Cost, Energy consumption, Renewability, Recyclability, Accessibility, Distribution, Disposal.	-	Natural fibres, Glass fibres, Carbon fibres	Best material	Prior knowledge on failure modes, manufacturing technology, and processing can aid in fabric pre-design. However, multiple stakeholders are required for fabric production, testing, certification, and implementation.

[11] Raghavalu	less weight, less price, higher performance, longer life, ease of processing, and capability of recycling	-	thermoplastics; thermosets; glass fibres; natural fibres; hybrid composites;	-	This article provides a critical review of potential materials for the development of future wind turbine blades.
[13] Schubel,	Blade design structure	Review Paper	-	Best Design	Thorough review of wind turbine blade design, covering factors such as theoretical maximum efficiency, propulsion, usable efficiency, HAWT blade design, and blade loads.
[14] Tarfaoui	Blade design	FEM	composite materials with glass fibre reinforcements using an epoxy resin	Structural strength	Wind turbine blade design review covering efficiency, propulsion, and loads.
[15] Scherer	Blade design Cost, lightweight, high lifecycle	Design Aspects	Epoxy resin/glass fibre, Polyester resin/glass fibre, Epoxy resin/wood, Epoxy resin/carbon-glass fibres	Aerodynamic Structural and structural design	Rotor blade design in wind turbine technology faces a challenging future to enable cost-effective, safe, lightweight, flexible structures with high lifecycle and resistance against static loads while maintaining maintenance-free production of wind energy.
[16] Ahmad	Fatigue resistance, Cost, weight.	FEM	Sandwich Composite- Face Sheet- Matrix – Polyester resin, vinyl ester resin, epoxies resin, thermoplastic resin. Fibres – E-glass, S-glass, Carbon and Aramid Core Material – PVC foam, Polystrene foam, Polyurethane foam	Best Material	After thorough examination of potential composite candidates for 30m wind blade manufacture, we conclude that carbon fiber with epoxy or thermoplastic resin is the best option considering its characteristics, benefits, drawbacks, and costs.
[17] Kaboglu	Stiffness	four-point bending (4PB) condition, using digital image correlation (DIC)	Composite sandwich structure- Face Sheet – Glass-Fibre Reinforced Polymer (GFRP) core materials: Balsa wood, Tycor and Polyethylene terephthalate	Best Material for core material	Balsa wood sandwich failed catastrophically, PET and Tycor behaved similarly under load.

[18] Bortolotti	Cost, Weight	Cp-Max is the design tool used in this study	(GFRP), (CFRP), epoxy resin, UD (E-GFRP), high modulus UD glass (H-GFRP), full carbon UD (F-CFRP), bi-axial GFRP(Bx-GFRP), tri-axial GFRP(Tx-GFRP)	Material selection methodology	Proposed method to optimize wind turbine blade design includes composite material selection as a factor.
[19] Grujicic	high material stiffness, low mass density, high-cycle fatigue strength, Durability	Computer aided material-selection methodology, finite-element analysis	Sandwich composite Face sheet – $(45^0/0^0/45^0)$ tri-axial fiber-glass composite-laminate Core – Basala Adhesive– Epoxy based	Best material, Structural response analysis, fatigue life prediction	Carbon-fibre reinforced composites outperformed E-glass fibre reinforced composites in terms of performance, and epoxy may not be the best matrix material for composites, as predicted by the study's findings.
[20] Rashedi	-	Ashby's apporoach	PEEK/IM carbon and epoxy/HS carbon fiber composite.	Best Material	The study found a compromise among candidate materials, each with advantages and disadvantages. To maintain competitiveness in all blade and tower categories, better synergy in composite material's properties and sequence is required.
[21] Sjølund	Mass	Discrete Material and Thickness Optimization (DMTO)	Sandwich Composite Face Sheet - –glass fiber reinforced plastic (GFRP) Core – Basla	Structural optimization.	Optimizing sandwich structures using DMTO involves choosing the best fibre angle and core thickness for each face sheet layer to minimize mass through gradient-based optimization.
[22] Ancona	Weight, Cost, life-cycle	Review paper on Materials and Manufacturing Fact Sheet	Materials used – Steel, Glass Reinforced Plastic, Wood Epoxy	-	Most rotor blades are made of glassfiber-reinforced plastic (GRP), but other materials such as steel, composites, and carbon-filament-reinforced plastic (CFRP) have been tested.
[34] Mengal	Weight, Cost.	Basalt Carbon Hybrid composite material for rotor blade	Material used- Basalt Carbon Hybrid.	-	This article discusses the use of basalt fiber in wind turbine blades, comparing it to glass and carbon fiber and emphasizing its exceptional mechanical properties and cost-effectiveness.

[37] Okokpujie	Price/cost, Lightweight, Corrosion resistance, Durability	Material selection using - AHP, TOPSIS.	aluminium alloy, stainless steel, glass fiber, and mild steel	Material selection	Aluminium alloy came out on top in the study's comparison of wind turbine blade materials using the AHP and TOPSIS methods, with glass fibre coming in second. It was advised to use aluminium alloy.

V. METHOD

This section contains the procedures used to find a sandwich face sheet for a turbine blade made of a suitable material. The face sheet's material was chosen using a quantitative research methodology in this study. The research involves the numerical analysis of data obtained from questionnaires and written sources, which serves to justify the quantitative research approach. The study used the AHP and TOPSIS techniques to create the pair-wise matrix and rank the four (4) options. The authors transform the views of design for industry engineers who are professionals in design and academic design experts. An evaluated the four options and evaluated their performance using the AHP and TOPSIS methods. The criteria were analysed by the authors in light of the market price and price/cost per kg at the time of the research. Moreover, the degree of durability, weight, and corrosion resistance rate. Using a scale of 1 to 5, where 5 represents excellent, 4 very good, 3 good, 2 satisfactory, and 1 poor. The authors translate their opinions into numerical data after receiving input from academic design experts as well as industrial engineers with professional design experience. To determine the ratings and performance evaluation of the four alternatives, an applied the AHP and TOPSIS methods. This section includes explanations of the data collection procedure, the AHP, TOPSIS framework, the goal, the criteria, the sub-criteria, alternatives, as well as the consistency study. The formulas from the AHP as well as TOPSIS method were applied by the authors using the Excel 2016 programme.

A. Expert Interview

In this study, the best material for a wind turbine rotor blade was determined using a knowledge-based system called Expert Interview. To choose the best material, the system involved interviewing experts from various industries. For the study, five experts were chosen, and during the interviews, the evaluation criteria were directly weighted. The materials were then ranked using the Analytic Hierarchy Process (AHP), which was done in accordance with Yunus'[43] methodology and based on professional judgement. Using this strategy, the researchers were able to select materials intelligently by drawing on the knowledge of experts in the field.

B. The analytical hierarchy process (AHP)

The pair-wise matrix is the first step in the analytical hierarchy process (AHP), and building the model involves contrasting each of the six criteria with each other. When two criteria are equally important, they will each receive a score of one (1). Using the scoring scale, the decision-makers assigned a score to the criterion which is more important than one high. The TOPSIS techniques were used to make the decision at the conclusion of the process based on ratings.

It decomposes the smart match relationship at a dimension into various square frameworks B = $[bij]_{nxn}$, starting at the top of the chain of command and working down. The study's four alternative criteria and six significant criteria led to the development of the matrix depicted in Eq. (1).

$$\begin{bmatrix} b_{11} & b_{12} & b_{13}\ldots & b_{1n} \\ b_{21} & b_{22} & b_{23}\ldots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & b_{n3}\ldots & b_{nn} \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13}\ldots & b_{1n} \\ \frac{1}{b_{12}} & b_{22} & b_{23}\ldots & b_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{b_{1n}} & \frac{1}{b_{1n}} & \frac{1}{b_{23}}\ldots & b_{nn} \end{bmatrix} \quad (1)$$

Eq. (2) demonstrated the reciprocal properties as a result.

$$b_{ji} = \frac{1}{b_{ij}} \tag{2}$$

The pair-wise matrix development decision should be made using a relative significance scale from 1 to 9, according to AHP. The vector weights, however, are calculated using Satty's eigenvector technique when designing all pair-wise comparison matrices (Saaty, 2008). is calculated using the eigenvector method developed by Satty (Saaty, 2008). There are two steps in the weight's calculation process. B = $[bij]_{nxn}$, the pair-wise comparison matrix, is first normalised by Eq. (3), and then the weights are calculated by Eq. (4).

$$\dot{b}_{ij} = \frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}} \tag{3}$$

The following weight calculation was made

$$\dot{\omega}_{ij} = \frac{\sum_{j=1}^{n} \dot{b}_{ij}}{n} \tag{4}$$

assuming that everything. i and j= 1, 2, 3….., n.
The relationship among the vector of weights, w, and the pair-wise comparison matrix, b exits, is given by equation (5).

$$B * \omega = \lambda_{max.} * \omega \tag{5}$$

The consistency ratio (CR) of the average vector is calculated using the max value, which is an important validating factor in AHP and is used as a situation index to screen information. Eq. (6) was used to find the CR and CI for every matrix of order n.

$$CI = \frac{\lambda_{max.} - n}{n - 1} \tag{6}$$

Therefore, by using Eq. (5) to determine the CR.

$$CR = \frac{CI}{RI} \tag{7}$$

where RI is the random consistency indices value obtained from a pair-wise evaluation matrix that was generated at random and then applied the RI matrix of the order of 1–10 shown Table 3 below. The comparisons are acceptable if CR is 0. However, if CR 0.1, the ratio values demonstrate that the matrix contains erroneous judgements.

TABLE 3 -. RANDOM INCONSISTENCY INDICES(R.I.) FOR N = 10

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

TABLE 4 -. Saaty Rating scale

Intensity Of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Extreme importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
1/3, 1/5, 1/7, 1/9	Reciprocal for inverse comparison

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C. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)

The study employed the TOPSIS technique over the material's selection of the sandwich face sheet used in the blade. TOPSIS is a technique utilised by MCDM to effectively address global issues. The goal of TOPSIS is to identify the best option that is closest to the best ideal value and farthest to the worst ideal value. Minimising the cost criteria and maximising the profit criteria is the beneficial value or solution. The negative value, on the other hand, is the reverse of a positive value. The TOPSIS technique developed the vector-matrix, normalised matrix, and weighted normalised matrix using the specific scores for each alternative obtained from the criteria evaluation.

The TOPSIS decision-making process is as follows:

Step 1: The first step is to create a normalised decision matrix with definite and non-positive criteria for the sandwich face sheet of the wind turbine blade. Hence The normalised decision equation appears in equation (8).

$$\bar{b}_{ij} = \frac{b_{ij}}{\sqrt{\sum_{j=1}^{n} b_{ij}^2}} \quad (8)$$

where, $\bar{b}_{ij}$ and b_{ij} are the vectors that make up the and original normalised matrix, and j=1,2, 3…; i=1,2, 3, …...n.

In step 2, after creating a weighted model using Eq. (9), multiply the weights w_j of the evaluation criteria by the normalised decision matrix b_{ij} to create the weighted normalised decision matrix.

$$V_{ij} = \bar{b}_{ij} x \omega_j \quad (9)$$

Step 3: Determine the beneficial ideal value as well as the negative ideal value for each of the study's various materials. The authors calculate the ideal value using Eqs. (10) and (11) and the excel 2016 programme.

Where V_j^+ is the ideal, positive value that meets the criteria;

$$V_{ij} = \text{the maximum value} \quad (10)$$

$$V_j^- \ \text{the negative ideal value for the criteria.}\ V_{ij} = \text{the minimum value} \quad (11)$$

Step 4: Using the Excel programme to implement Eqs. (12) and (13) for the material selection process of face sheet of sandwich plate for the wind turbine blade, calculate the Euclidean distance between the ideal best (Ed+) and ideal worst (Ed-).

$$Ed^+ = \left[\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2\right]^{0.5} \quad (12)$$

$$Ed^- = \left[\sum_{i=1}^{n} \left(V_{ij} - V_j^-\right)^2\right]^{0.5} \quad (13)$$

Step 5: Determine the outcome score for the alternative selection process for each option. However, when choosing the material for the wind turbine blade, use Eq. (14) to test the option with the best performance score.

$$P_s = \frac{Ed_i^-}{Ed_i^+ + Ed_i^-} \quad (14)$$

Step 6: Ordering the options.

Ranking the options in accordance with the four options' respective maximum performance scores

D. Making the framework for system

The goal, the views of the decision-makers, the choice for alternatives, the assessment of sub-criteria, as well as the final output of the combination of choice with criteria are the five major sections that need to be determined in order to create a framework system for Multi-Criteria Decision Making (MCDM). Popularly used in MCDM for basic deductive reasoning, the Analytic Hierarchy Process (AHP) uses the following frameworks: disintegration, near decisions, as well as union of needs. The criteria over the assessment process must be carefully chosen, while this paper provides extensive literature on the subject. The five types of criteria that the paper focuses on are cost/price, weight, stiffness, Shape, Environment, and Corrosion resistance. In order to conduct the assessment, four alternative materials were chosen: GFRP, CFRP, Mild steel, Aluminum alloy. The AHP decision framework is depicted in Figure .1

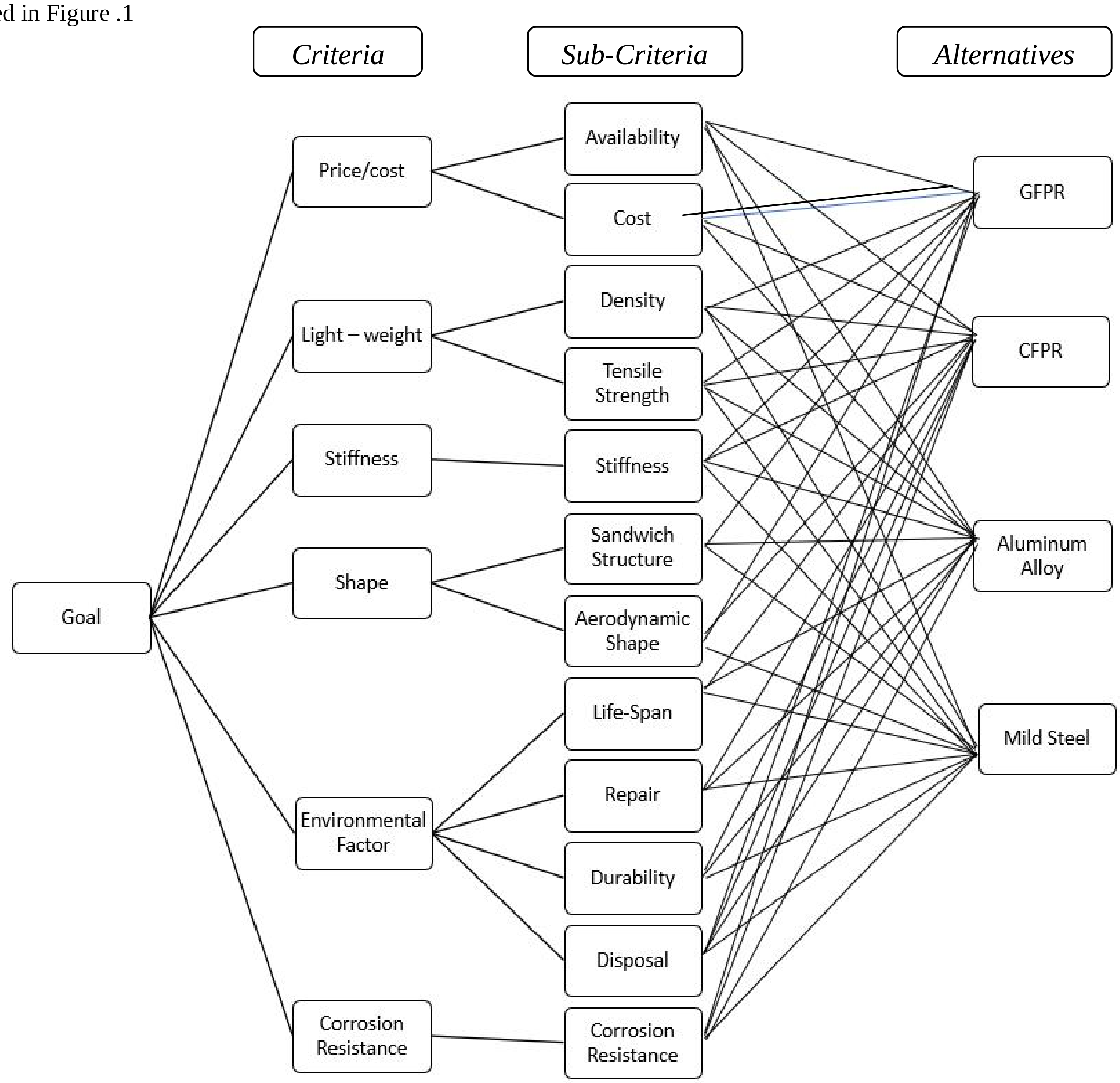

Fig. 1 AHP Decision Framework

E. Detail of Criteria, Sub-criteria, and Goal:

1) Goal: - Choosing the best material alternative for face sheet of sandwich plate for WTB rotor blade that can have low weight and high stiffness.
2) Criteria: - there are six major criteria while selecting the face sheet of material and they are as cost, light-weight, stiffness, shape, environmental factor and corrosion resistance.
3) Sub-Criteria: - Tables-5 shows the description all the sub-criteria and their importance.

TABLE 5 DEFINITION OF CRITERIA

Author	Criteria mentioned	Description
[1][2] [4][5][10] [12][17]	Stiffness	Stiffness is the tendency of a material to react with a small deformation when the material is stressed. It is measured with Young's Modulus, which is the angular coefficient, or slope, of the linear stress-strain curve. This property depends directly on the bond type between the atoms. The stronger the bond, the higher the modulus (or the stiffness) stiffness should be maximum
[1][2][3][4][5][6][7][8][10][11][12][14][18]	Density	Density is the mass per unit volume of a material, and materials with lower density can help reduce weight in weight-sensitive applications.
[3][7][8][10][12][17] [18]	Strength	Strength of a substance is the capacity of that substance to withstand great force or pressure without breakage or plastic deformation and should be maximum.
[1][4][5][6][7][10][12]	Fatigue resistance	Maximizing fatigue resistance is crucial for materials and structures, as it reflects their ability to withstand crack initiation under cyclic loading. This is typically evaluated by measuring the fatigue limit or strength at a limited life, with higher values indicating better resistance to fatigue.
[3][7]	Corrosion resistance	Corrosion resistance is defined as the inherent ability of a material (metallic or non-metallic) to withstand corrosion damage caused by either oxidation or other chemical reactions.it should be maximum.
[3][10]	Availability	The availability of raw material means that an existence of raw material in the place of manufacturing. Availability of material can be categorized namely availability of raw material and availability of material information.
[5][16]	Durability	Durability is defined as the ability of a material to remain serviceable in the surrounding environment during the useful life without damage or unexpected maintenance. It should be durable.
[2][8][10][18]	Mechanical properties	It consists of mechanical properties like Tensile strength, Compression strength, high buckling resistance, structural rigidity, etc.
[4][5][6][9][19]	Shape	Shape is the ability of a material to be shaped into the finished product. Whether the materials to be formed or shaped according to design requirement need to be considered.
[5][7][11][12][14][18] [19]	Weight	the weight of an object is the force acting on the object due to gravity. Select the material which enable to reduce weight of blade.
[10][11][16]	Recyclability	Recyclability is defined as the ability of a material to resist corrosion.
[10]	Disposal	Disposal is defined as the ability of a material to be disposed of in an environment way such as landfill and incineration.
[3][10][14][16][18] [20]	Cost	Cost plays a very significant role to determine the best material at the early stage of product development process. Material cost, manufacturing cost and repair cost are considered.

F. Material Alternative

Numerous material options are available for selecting the face sheets and core materials of sandwich structures used in WTBs. The optimal selection is dependent on various factors such as size, capacity, power output, environmental conditions, and structure. Through literature review, GFRP, CFRP, mild steel, and aluminum alloys are identified as potential face sheet materials, while medium density balsa, PVC Foam CoreCellTM T-foam [16], and Tycor W0.1(Polyurethane Foam) are recommended as core materials. These materials are considered as alternative options, from which the best-suited materials can be selected for constructing sandwich plates in WTBs. Here, in general, the properties of several materials are explained. Although there are thousands of materials available, this discussion will focus on four materials for the face sheet:

GFPR (Glass Fiber Reinforced Polymer), CFRP (Carbon Fiber Reinforced Polymer), mild steel, and aluminum alloy. Additionally, three materials will be discussed for the core: medium density balsa, PVC Foam [16], and Polyurethane Foam, based on literature sources.

1) *GFRP*: GFRP, or Glass Fiber Reinforced Polymer, is a popular material used in the manufacturing of wind turbine rotor blades. The material is composed of E-glass fibers and epoxy resin, which provide strength and stiffness, and act as the matrix to hold the fibers together. Continuous reinforcement is typically used in the manufacturing process, with the most common ply direction being unidirectional fiber orientation. The GFRP composites have a high stiffness-to-weight ratio, ranging from 20-38 GPa, and a density of 1.5 to 2.0 g/cm³ [6], which is lower than many traditional materials. The manufacturing process of GFRP wind turbine blades involves layering the fiber and resin materials precisely to create a strong and durable composite structure. The blades have a high tensile strength, ranging from 1000 to 1800 MPa [6], and excellent fatigue resistance, crucial for blades subjected to cyclic loading. GFRP blades are known for their durability, with good resistance to environmental factors like UV radiation, moisture, and temperature fluctuations. The material is inherently corrosion-resistant, making it suitable for harsh outdoor environments. The weight of GFRP wind turbine blades varies depending on size and design, typically ranging from 4 to 7 kg/m². The cost of GFRP varies based on factors like fiber and resin type, manufacturing process, and blade design, but generally, it is more expensive than traditional materials. The life span of GFRP blades can vary based on maintenance, environmental conditions, and design, but with proper maintenance, they can last for 20-25 years or more. If damaged, GFRP blades can be repaired using techniques like patching, bonding, and composite material reinforcement. GFRP materials are widely available in the market and have been scaled up to meet the demand from various industries, including wind energy.
2) *CFRP*: CFRP is another composite material used in wind turbine rotor blades. It is composed of carbon fibers and epoxy resin, which provides high strength and stiffness. The carbon fibers are usually in the form of continuous strands and are oriented in a particular direction, typically unidirectionally, to optimize the blade's properties. The stiffness of CFRP can range from 50 to 176 GPa, depending on the fiber orientation and resin type used. The density of CFRP is typically around 1.4 to 1.8 g/cm³ [6], making it lighter than traditional materials such as steel and aluminum. The manufacturing process for CFRP wind turbine blades involves various techniques, including autoclave curing, resin transfer molding, and filament winding. The weight of CFRP wind turbine blades varies based on their size and design, but on average, they weigh around 3 to 5 kg/m². The cost of CFRP is generally higher than traditional materials but can vary depending on factors such as fiber type, resin type, and manufacturing process. The tensile strength of CFRP wind turbine blades can range from 1500 to 2500 MPa, depending on the fiber orientation and resin type used. CFRP composites exhibit excellent fatigue resistance, making them suitable for wind turbine blades subjected to cyclic loading over their operational lifespan. With proper maintenance, CFRP blades can have a service life of 25 years or more. CFRP wind turbine blades are known for their durability and corrosion resistance, making them suitable for harsh outdoor environments. In case of damage, CFRP wind turbine blades can be repaired using techniques such as patching, bonding, and composite material reinforcement. CFRP materials are widely available in the market, and their production has been scaled up to meet the demand from various industries, including wind energy.
3) *Mild-Steel (low carbon steel):* Mild steel is a commonly used material for wind turbine rotor blades due to its availability, low cost, and good mechanical properties. Mild steel has a moderate strength-to-weight ratio, is easily machinable and weldable, making it a preferred choice for manufacturing large components like wind turbine blades. Compared to other materials like carbon fiber or GFRP, mild steel has moderate stiffness and density, but its durability and corrosion resistance are relatively low. Mild steel wind turbine blades are typically heavier than composite materials, with a weight ranging from 20 to 50 kg/m² [37]. The manufacturing process for mild steel wind turbine blades involves cutting and welding together steel plates of various thicknesses to form the desired blade shape, which is relatively simple and cost-effective compared to the complex layering and curing processes involved in composite blade manufacturing. The tensile strength of mild steel is typically around 400-500 MPa, which is lower than composite materials but still sufficient to withstand the mechanical stresses encountered during operation. The fatigue resistance of mild steel is relatively good, but its susceptibility to corrosion can limit its lifespan if not properly maintained. The cost of mild steel is significantly lower than composite materials, with an average cost of around 50-70 rupees/kg, making it a preferred choice for manufacturers looking to reduce costs while maintaining acceptable performance levels. Mild steel is widely available in the market, and its production has been scaled up to meet the demand from various industries, including wind energy. Repairs to mild steel wind turbine blades can be performed using welding or patching techniques, although the repair process can be more challenging compared to composites [37]. Overall, mild steel is a viable option for wind turbine rotor blades, especially for s

maller turbines or in regions where cost considerations outweigh performance requirements. However, due to its heavier weight and lower durability compared to composite materials, its use may be limited in larger turbines or harsh environmental conditions.

4) *Aluminum Alloy:* Aluminum alloy is another commonly used material for wind turbine rotor blades due to its low density, good stiffness, and corrosion resistance. Its mechanical properties can vary depending on the specific alloy used, but overall, aluminum alloys offer a good strength-to-weight ratio and can be easily machined and welded, making them a preferred choice for manufacturing wind turbine blades. Compared to mild steel, aluminum alloys have a lower density and offer better corrosion resistance, which can improve their durability and lifespan in harsh environmental conditions. However, aluminum alloys can be more expensive than mild steel, with an average cost of around 100-200 rupees/kg. The manufacturing process for aluminum alloy wind turbine blades involves cutting and shaping the alloy sheets or extrusions to form the desired blade shape, followed by welding or bonding the sections together. This process can be more complex than mild steel blade manufacturing due to the need for precise welding or bonding techniques. The tensile strength of aluminum alloys typically ranges from 200-600 MPa [9], depending on the specific alloy used. While this is lower than some composite materials, it is still sufficient to withstand the mechanical stresses encountered during operation. The fatigue resistance of aluminum alloys is also relatively good, although it can be affected by factors such as surface treatments and operating conditions. In terms of availability, aluminum alloys are widely used in various industries, including aerospace and transportation, and are readily available in the market. Repairs to aluminum alloy wind turbine blades can be performed using welding or bonding techniques, but the repair process can be more challenging compared to composites [37]. Overall, aluminum alloys are a viable option for wind turbine rotor blades, particularly for larger turbines or in harsh environmental conditions where corrosion resistance is critical. However, their higher cost and more complex manufacturing process may limit their use in smaller turbines or regions where cost considerations outweigh performance requirements.

G. AHP-based consistency analysis

The C. R, C. I are calculated while using the R. I from Satty (1990) in the consistency study. The relative ranking scale and R. I. values used to create the pair-wise comparison matrix are displayed in Tables 3 and 4.

H. Conclusion and discussion

The author constructed a pair-wise comparison matrix and rated the criteria using a relative scale from extremely important to equally important in order to choose an appropriate material for the face sheet of the blade. As illustrated in Tables 6, 7, and 8, each interest is divided using the normalized pair-wise model, total pair-wise model, and the average weight of the pair-wise matrix is calculated using Eq. (4)

Using Eqs. (6), (7), and (8), identify the consistency analysis of the pair-wise comparison matrix. The six selection criteria's relative weights are shown in Table 9.

$$\lambda_{max.} = \frac{\sum_{j=1}^{n} \dot{\omega}_{ij}}{n} \qquad (15)$$

TABLE 6 Creating the Pair-Wise Comparison Matrix for The Six (6) Criteria Using the AHP Approach

Criteria	Price/Cost	Light-Weight	Corrosion Resistance	Stiffness	Shape	Environmental Factor
Price/Cost	1	0.25	1.35	0.28	0.74	0.49
Light-Weight	3.97	1	2.59	1.11	1.24	1.03
Corrosion Resistance	0.74	0.39	1	0.48	0.76	0.51
Stiffness	3.53	0.9	2.08	1	1.24	0.96
Shape	1.36	0.81	1.32	0.81	1	0.78
Environmental Factor	2.05	0.97	1.95	1.05	1.28	1

TABEL 7 Pair-Wise Comparison Matrix Total in Column.

Criteria	Price/Cost	Light-Weight	Corrosion Resistance	Stiffness	Shape	Environmental Factor
Price/Cost	1	0.25	1.35	0.28	0.74	0.49
Light-Weight	3.97	1	2.59	1.11	1.24	1.03
Corrosion Resistance	0.74	0.39	1	0.48	0.76	0.51
Stiffness	3.53	0.9	2.08	1	1.24	0.96
Shape	1.36	0.81	1.32	0.81	1	0.78
Environmental Factor	2.05	0.97	1.95	1.05	1.28	1
Total	12.65	4.32	10.29	4.73	6.26	4.77

TABLE 8 Normalization of The Pair-Wise Comparison Matrix

Criteria	Price/Cost	Light-Weight	Corrosion Resistance	Stiffness	Shape	Environmental Factor
Price/Cost	0.08	0.06	0.13	0.06	0.12	0.1
Light-Weight	0.31	0.23	0.25	0.24	0.2	0.22
Corrosion Resistance	0.06	0.09	0.1	0.1	0.12	0.11
Stiffness	0.28	0.21	0.2	0.21	0.2	0.2
Shape	0.11	0.19	0.13	0.17	0.16	0.16
Environmental Factor	0.16	0.22	0.19	0.22	0.2	0.21
Total	12.65	4.32	10.29	4.73	6.26	4.77

TABLE 9 The Pair Comparison Matrix's Comprehensive Consistency Analysis Result

Criteria	Price/Cost	Light-Weight	Corrosion Resistance	Stiffness	Shape	Environmental Factor	Criteria Weight (%)
Price/Cost	0.08	0.06	0.13	0.06	0.12	0.1	9.166667
Light-Weight	0.31	0.23	0.25	0.24	0.2	0.22	24.16667
Corrosion Resistance	0.06	0.09	0.1	0.1	0.12	0.11	9.666667
Stiffness	0.28	0.21	0.2	0.21	0.2	0.2	21.66667
Shape	0.11	0.19	0.13	0.17	0.16	0.16	15.33333
Environmental Factor	0.16	0.22	0.19	0.22	0.2	0.21	20
Total	1	1	1	1	1	1	100%
						Eigen Value(λ_{max})	6.136983333
						C.I.	0.027396667
						C.R.= C.I/R.I.	2.209408602 %

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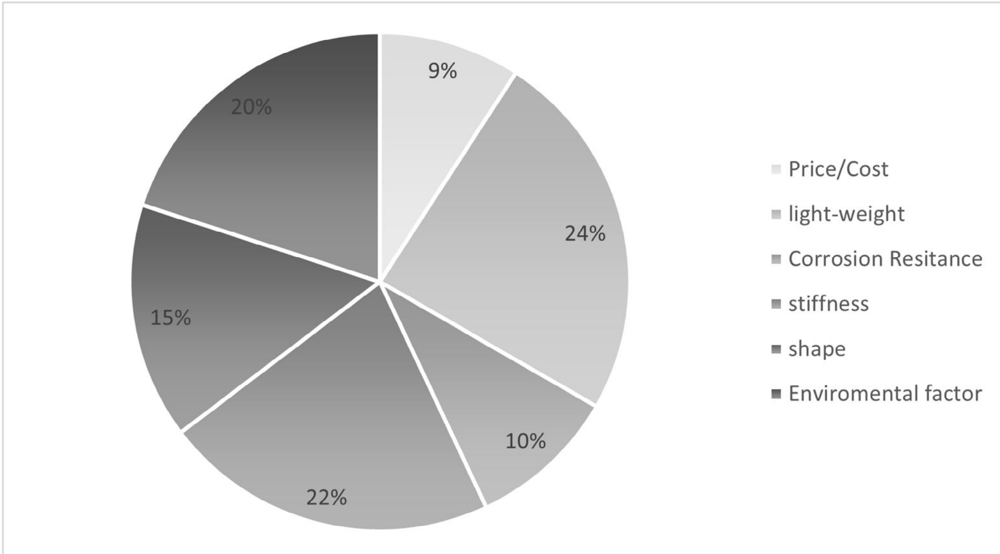

Fig 2. Pie-Chart for Criteria Weight Value for Selected Criteria

Since the consistency ratio's proportion of inconsistency is less than 0.1, the resulting pair-wise comparison matrix is therefore consistent for the four alternatives. The decision-maker used weight criteria in this study when making decisions. Figure 2 displays the weighted criteria value for the six criteria that were chosen for the decision-making process of the material for the sandwich structure's face sheet used in wind turbine blades.

VI. USING TOPSIS METHODOLOGIES, RANK THE OPTIONS

The study used the TOPSIS technique to rank the chosen alternatives after calculating the criteria weight with the AHP. As a result, the normalized vector matrix is displayed in Table 10 below.

Figures 3 display the performance evaluation of the four options based on the chosen parameters, such as cost, weight, corrosion resistance, stiffness, shape and environmental factor. The examples show the professional's ideals as they related to the alternative's functional capabilities in those areas.

Using the pair-wise matrix C. I and C. R developed using the AHP approach and the data gathered from the questionnaire, Eq. (8) converts the normalized decision matrix. The ideal best & the ideal worst from the four choices can also be found using Eq. (9). In order to analyses the performance score for the final ranking of the alternatives, Eq's. (12), (13), and (14) are used to calculate the Euclidean distance between the ideal best (Ed^{+}) and ideal worst (Ed^{-}). The results are presented in Tables 10, 11, 12, and 13, correspondingly.

TABLE 10 The Vector Normalization Matrix Utilizing the Six Criteria for The Four Alternatives.

	Criteria Weight (%)											
	Price/Cost 8.7%		Light/weight 19.5%		Stiffness 36.9%	Shape 13.8%		Environment factor 12.9%				Corrosion resistance 8.1%
Alternatives	Availability 4.35%	Cost 4.35% (/kg)	Density 9.75% (g/cm^3)	Tensile strength 9.75%	Stiffness 36.9%	Sandwich Structure 6.9%	Aerofoil Shape 6.9%	Life span 3.225% [11]	Repair 3.225%	Durability 3.225%	Disposal 3.225%	Corrosion resistance 8.1%
GFRP	4	450	1.87 [6]	1800 [6]	38 [6]	6	4	7	3	7	2	8
CFRP	3	710	1.49 [6]	2050 [6]	176 [6]	5	4	8	3	6	1	7

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Mild steel (Low carbon steel)	5	100	7.5 [37]	440 [51]	30 [1]	4	3	4	7	2	5	1 [37]
Aluminium alloy	5	435	2.7 [37]	550 [9]	10 [1]	4	4	6	6	4	4	5 [37]

TABLE 11 The Normalized Decision Matrix, Complete with Criteria and Options.

	Availability	Cost	Density	Tensile strength	Stiffness	Sandwich Structure	Aerofoil Shape	Life span	Repair	Durability	Disposal	Corrosion resistance
GFRP	0.46	0.47	0.22	0.64	0.21	0.62	0.53	0.54	0.30	0.68	0.29	0.68
CFRP	0.35	0.75	0.18	0.73	0.96	0.52	0.53	0.62	0.30	0.59	0.15	0.59
Mild steel	0.58	0.11	0.90	0.16	0.16	0.41	0.40	0.31	0.69	0.20	0.74	0.08
Aluminium Alloy	0.58	0.46	0.32	0.20	0.05	0.41	0.53	0.47	0.59	0.39	0.59	0.42

TABLE 13 The Weighted Normalized Decision Matrix with The Criteria and The Alternatives

	Availability	Cost	Density	Tensile strength	Stiffness	Sandwich Structure	Aerofoil Shape	Life span	Repair	Durability	Disposal	Corrosion resistance
GFRP	2.01	2.06	2.19	6.23	7.67	4.29	3.66	1.76	0.95	2.20	0.95	5.50
CFRP	1.51	3.25	1.75	7.09	35.53	3.58	3.66	2.01	0.95	1.89	0.48	4.81
Mild steel	2.51	0.46	8.79	1.52	6.06	2.86	2.74	1.00	2.22	0.63	2.38	0.69
Aluminium Alloy	2.51	1.99	3.16	1.90	2.02	2.86	3.66	1.51	1.91	1.26	1.90	3.44

TABLE 14 Computing the Optimal Ideal Best and Ideal Worst Values

Ed^{+}	2.51	0.46	1.75	7.09	35.53	4.29	3.66	2.01	2.22	2.20	2.38	5.50
Ed^{-}	1.51	3.25	8.79	1.52	2.02	2.86	2.74	1.00	0.95	0.63	0.48	0.69

TABLE 15 The Ranking Was Determined by Euclidean Distance (Ed^{+}) Ideal Best & (Ed^{-})Ideal Worst, And Performance Score

Alternative	Ed^{+}	Ed^{-}	P_{si}	Rank
GFRP	27.99	11.34	0.29	3
CFRP	34.99	37.23	0.52	1
Mild Steel	12.28	12.28	0.50	2
Aluminium Alloy	8.51	8.51	0.50	2

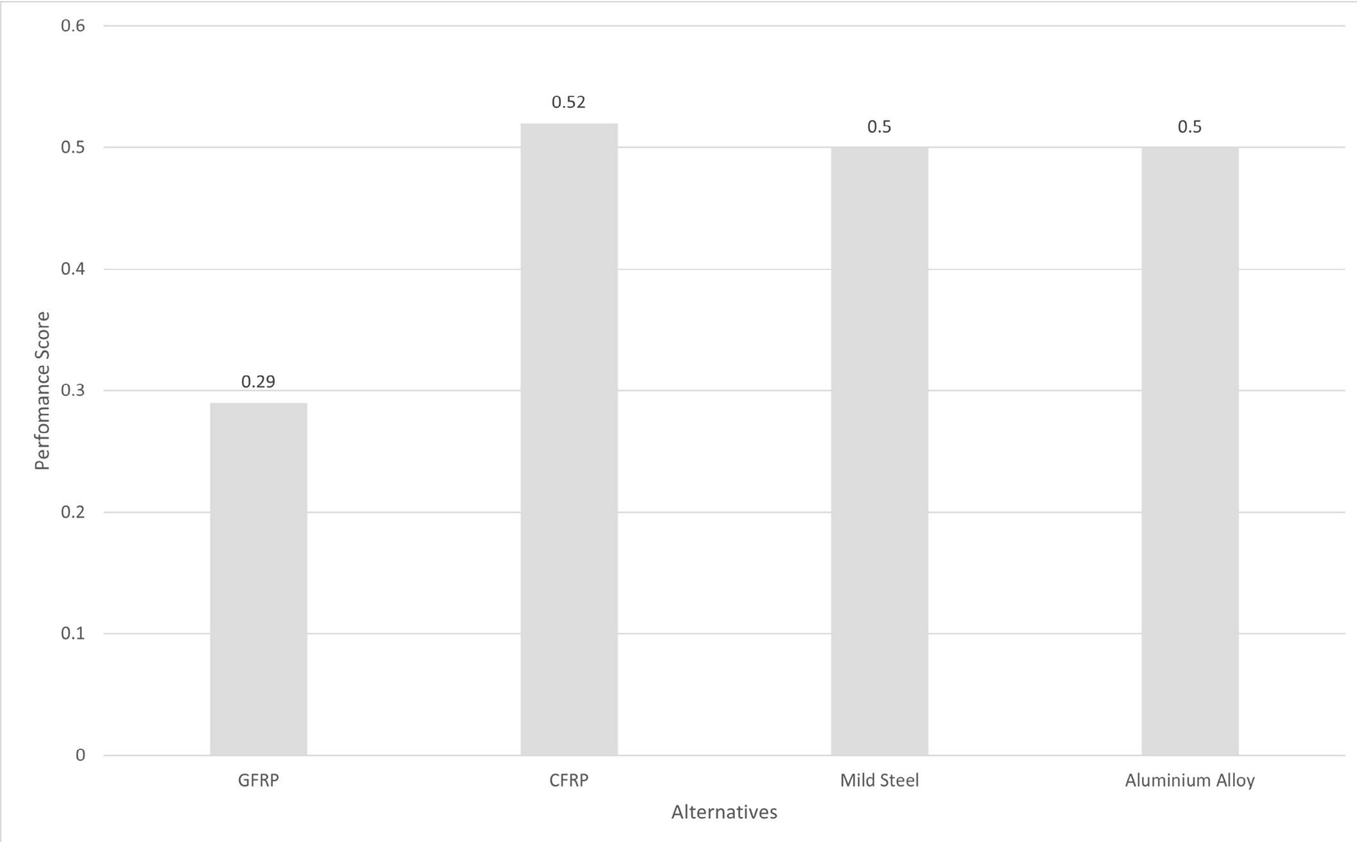

Fig.3 Alternative Materials' Performance Value Analysis.

Determine the effectiveness of the four alternative criteria by using the normalized decision matrix, CR, CI, RI, Euclidean distance, and ideal best analysis. Figure 9 displays the outcome of the MCDM in choosing a suitable material for the creation of the sandwich plate face sheet utilized in turbine blades. The best performance value is 0.52 for CFRP, followed by 0.50 for mild aluminum alloy and steel alloy and 0.29 for GFRP. Because of its high stiffness and low weight, CFRP is the ideal material for creating the face sheet of sandwich structures used in wind turbine blades, according to the results of the investigation. Although GFRP, Aluminum alloy, and mild steel are other viable options, CFRP material is the greatest suit for this study because of its low density and high stiffness value. Additionally, it is lighter than any of them, giving it an advantage over other options when it comes to the creation of sandwich plate faces for use in wind turbine blades. This outcome also goes against the findings of Babu et al. (2006) [1], who looked at pure aluminum, steel, carbon fibers, aramid fibers, and electrical glass in their study. The outcome of the analysis and the decision-makers' approval of carbon fiber as the best substitutes. The authors failed to take into account the fact that carbon fiber, when utilized for the production of wind turbine blades, is stiff and can fail with little to no warming during operation. The use of carbon fiber in the manufacture of wind turbine blades, according to the author [37], may result in rigidity and the possibility for failure during operation without warning. However, this issue was not taken into account by the study's authors. Author [37] advises using an alternative material, specifically the aluminum 6061-T9 alloy, to address this issue.

VII. CONCLUSIONS

The study in question used the AHP and TOPSIS in MCDM to carry out a material selection procedure for the face sheet of sandwich structure used in the development of wind turbine blades. The Multi-Criteria Decision Making (MCDM) approaches AHP and TOPSIS are both frequently used for assessing alternatives based on several criteria.

The study took into account four options for the material selection process: mild steel, aluminum alloy, carbon fibre reinforced polymer (CFRP), and glass fibre reinforced polymer (GFRP). Following the evaluation, the study discovered that mild steel and aluminum alloy both received scores of 50%, while CFRP received the maximum performance rating of 52%. GFRP, on the other hand, had the lowest rating of 0.29%.

These findings imply that CFRP is the best material for the sandwich face sheet utilized in the manufacturing of wind turbine blades because it outperformed all other materials according to the study's criteria. This might be a result of CFRP's special qualities, namely its high strength-to-weight ratio, which makes it a good material for use in wind turbines where little weight and great strength are essential. In order to make the best choice for a given application, it is crucial to evaluate materials using a variety of factors, according to the study's conclusion. Due to its poor performance in the study, it also implies that GFRP could not be a suitable material for the construction of wind turbine blades.

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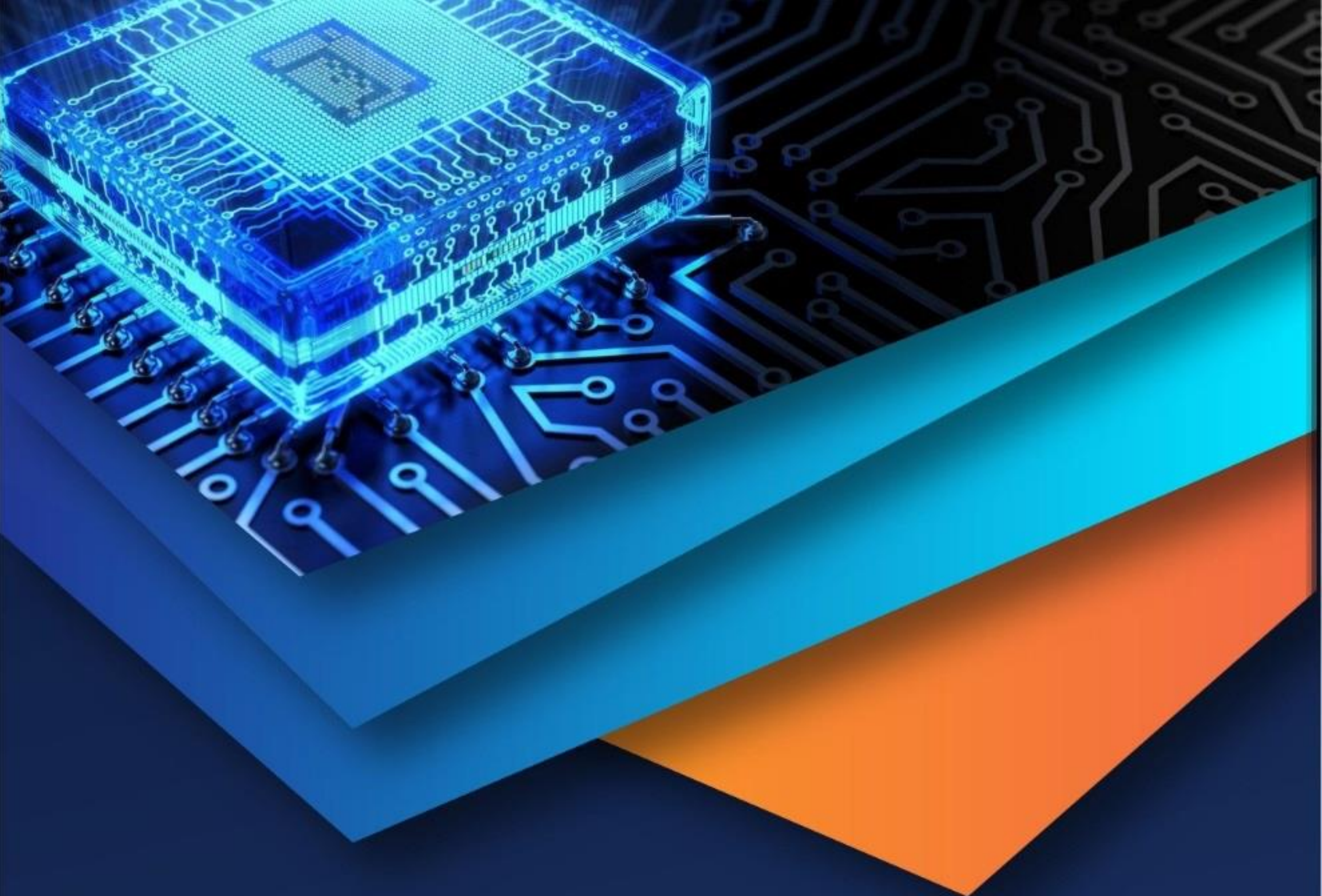

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