Material selection for onshore wind turbine blade using Analytical hierarchy process

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***Abstract*-** *Over the world, energy has continuously supplied by carbon neutral clean energy technology. Wind energy is generated by using wind turbine .Wind turbine blade manufacturing cost is about 15-20% of production cost of wind turbine. Wind energy production is not more the following criterion to be considered when installing the new range of megawatt (MW) turbine. . The wind turbine efficiency depends upon the material of blade, structure of blade and angle of blade.[1] The very important design parameter of turbine blade like material as high stiffness, mass, cost effectiveness, long fatigue life and low density. The main objective of our topic is to study the different material property candidates for wind turbine blade and choices the best material for wind turbine blade for onshore application.[2] Using one of the best MADM (Multiple attribute decision making).*

***Keywords*-** Wind turbine, MADM, MCDM, AHP

I. INTRODUCTION

The material selection of the wind turbine blades plays an important role in the wind turbine designs. An ever-increasing variety of materials is available today, with each having its own characteristics, applications, advantages, and limitation .Dane poul la cour ,who later discovered that fast rotating wind turbine with few rotor blades are more efficient for electricity production than slow moving turbines. When selecting materials for engineering designs, we must have a clear understanding of the functional requirements for each individual component. [3] In selecting materials for an application, economic aspects of material selection, such as availability, cost of raw materials, and cost of manufacturing, are equally important. The material selection process motivates us to develop a multi criteria decision-making method using AHP set theory. The materials taken into our study are listed below.

Table. 1 Material indices relative values with relate glass fiber reinforced epoxy [4]

Material	Mass	Cost	Carbon footprint	Embodied energy
PEEK/IM carbon fiber	0.259	1.17	0.821	0.696
Epoxy/HS carbon fiber	0.3	0.626	0.659	0.728
Epoxy/Aramid carbon fiber	0.359	1.09	0.872	0.759

Wind turbine material selection process as green and recyclable composite , sandwich material are increasing in the market and their per unit cost is decreasing due to advanced manufacturing process.[4]

II. MATERIAL SELECTION FOR WIND TURBINE BLADE

Much number of factors are affecting for the material selection. They are properties of materials, performance requirement material reliability, safety, physical attributes availability, disposal and recyclability economical factor. They are High material stiffness is needed to maintain optimal shape of performance. Low density is needed to reduce gravity forces; Long-fatigue life is needed to reduce material degradation. . Modern materials such as glass fibre reinforced plastic (GFRP), carbon fibre reinforced plastic (CFRP).[5] multi objective material selection study is pursued in this article on both blade on four conflicting objectives, viz., minimization of mass, carbon footprint, material cost and embodied energy.[6]

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III. ANALYTIC HIERARCHY PROCESS

The analytic hierarchy process (AHP) was developed by Thomas L. Saaty. The AHP is designed to solve complex problems involving multiple criteria. The Information is decomposed into a hierarchy of alternatives and criteria. Determine relative ranking alternatives. Both qualitative and quantitative information can be compared using informed judgments to derive weights and priorities. To develop a graphical representation of the problem in terms of the overall goal, the criteria, and the decision alternatives. (i.e., the hierarchy of the problem). The information on relative importance and preferences, a mathematical process is used to synthesize the information (including consistency checking) and provide a priority ranking of all alternatives in terms of their overall preference. The priority for each decision alternative in terms of how it in terms contributes to each criterion.

The AHP employs an underlying scale with values from 1 to 9 to rate the relative preferences for two items. [9]

Verbal judgment of preferences	Numerical Rating
Extremely preferred	9
Very strongly to extremely preferred	8
Very Strongly preferred	7
Strongly to Very strongly preferred	6
Strongly preferred	5
Moderately to strongly preferred	4
Moderate preferred	3
Equal to moderately preferred	2
Equally preferred	1

M 1- PEEK/MI Carbon fiber, **M 2-** Epoxy/HS Carbon fiber, **M 3-** Epoxy/Aramide carbon fiber.

IV. CONSISTENCY CHECHIING

The AHP provides a measure of the consistency of pairwise comparison judgments by computing a consistency ratio. The ratio is designed in such a way that values of the ratio exceeding 0.10 are indicative of inconsistent judgments. Multiply each value in the first column of the pairwise comparison matrix by the relative priority of the first item considered. Divide the elements of the vector of weighted sums by the corresponding priority value **1** Prepare pairwise comparison matrix. Divide each element of the matrix by its column total.

Table 2. Pairwise comparison matrix

A1 Pairwise comparison matrix				A2 Priority vector
Mass	M 1	M 2	M3	
M 1	1	5	7	0.696
M 2	0.2	1	5	0.231
M 3	0.14	0.2	1	0.071

Table 3. Weighted sum matrix

A1×A2=A3	A3÷A2=A4 Vector of weighted sums
2.248	3.373
0.725	3.188
0.184	2.591

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.017 \qquad CR = \frac{CI}{RI} = 0.029 \leq 0.10$$

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	1.45	1.49

Where n is the number of item comparable. RI [9] depends on the number of elements being compared and takes on the following values.

Where CI is the consistency index and CR is consistency ratio. λ_{max} is the average of the A4 matrix.

The degree of consistency exhibited in the pairwise comparison matrix for mass is acceptable. i.e. 0.029.

V. DEVELOPMENT OF PRIORITY RANKING

The overall priority for each decision alternative is obtained by summing the product of the criterion priority. The priority (i.e. preference) of the decision alternative with respect to that criterion. Ranking these priority values, we will have AHP ranking of the decision alternatives.

Divide each element of the matrix by its column total. All columns in the normalized pair wise comparison matrix now have a sum of 1.

Table 4 Pairwise comparison matrix for relative mass preference

A1 Pairwise comparison matrix				A2 Priority vector
Mass	**M 1**	**M 2**	**M3**	
M 1	1	5	7	0.696
M 2	0.2	1	5	0.231
M 3	0.14	0.2	1	0.071

Table 5 Pairwise comparison matrix for relative cost preference

B1 Pairwise comparison matrix				B2 Priority vector
Cost	**M 1**	**M 2**	**M3**	
M 1	1	2	8	0.696
M 2	0.5	1	6	0.231
M 3	0.125	0.166	1	0.071

Table 6 Pairwise comparison matrix for carbon footprint preference

B3 Pairwise comparison matrix				B4 Priority vector
Carbon footprint	**M 1**	**M 2**	**M 3**	
M 1	1	0.33	0.25	0.122
M 2	3	1	0.5	0.322
M 3	4	2	1	0.557

Table 7 Pairwise comparison matrix for embodies energy preference

B5 Pairwise comparison matrix				B6 Priority vector
Embodies energy	**M 1**	**M 2**	**M 3**	
M 1	1	0.25	0.16	0.086
M 2	4	1	0.33	0.273
M 3	6	3	1	0.638

Table 8 Pairwise comparison matrix for criteria

B7 Pairwise comparison matrix					B8 Priority vector
Criteria	**Mass**	**Cost**	**Carbon Footprint**	**Embodies energy**	
Mass	1	3	2	2	0.398
Cost	0.33	1	0.25	0.25	0.085
Carbon Footprint	0.5	4	1	0.5	0.218
Embodies Energy	0.5	4	2	1	0.299

VI. PRIORITY RANKING

Sum the product of the criterion priority (with respect to the overall goal) times the priority of the decision alternative with respect to that criterion. Priority of all decision is multiply the criterion priority.

Table 9 Priority vector matrix for each criteria and ranking

A2	B2	B4	B6	B8	Overall Priority	Ranking
0.123	0.087	0.593	0.265	0.398	0.2648	3
0.320	0.274	0.341	0.655	0.085	**0.4206**	**1**
0.557	0.639	0.066	0.080	0.218	0.3143	2
				0.299		

Overall Material priority and rank the priority values.

M 2= 0.398×0.320+0.085×0.274+0.218×0.341+0.299×0.65= **0.4206**

Final onshore wind turbine blade material stands as PEEK/IM carbon and epoxy/HS carbon fiber composite, Epoxy/Aramide carbon fiber.Out of these material Epoxy/HS carbon fiber(**M 2)** is the suitable material of wind turbine blade. In the above order of the ideal solutions, Epoxy/HS carbon fiber is the best alternative. They have good compressive strength, good machineability, and good environmental stability, good temperature strength. That's why we selected the best alternative as Epoxy/HS carbon fiber material (**M2).**

VII. CONCLUSION

The AHP provides a convenient approach for solving complex MCDM problems in engineering. In many engineering applications the final decision depends on the evaluation of a set of alternatives in terms of a number of decision criteria. This may be a difficult task and the Analytic Hierarchy Process seems to provide an effective way for properly quantifying the pertinent data. The pertinent data are derived by using a set of pairwise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. Our study is limited to focus on the material selection for wind turbine blades using the AHP method. The material selection process is an integrated step in any design process, which is solved precisely using this methodology. The AHP method, which is unique in the way of determining the preference order, presented clearer results. From the analysis we observed that if the wind turbine blades are made out of composite materials using HS carbon fibers, then they possess the high stiffness, low density and long fatigue life.

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