

Finite Element Analysis of Wind Turbine Blade

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Abstract: The wind turbine blade sustains wind loadings during the operation and parking states. Due to the increasing size of the turbine blade, it's important to utilize the composite materials during a sufficient thanks to reach the fabric strength. Most of the composite blades are made from glass fibers composites while carbon fibers also are employed in recent years. Composite materials have the benefits of high specific strength and stress. This study develops a GUI interface to construct the blade model for the strain analysis using ANSYS. With the help of visualization interface, the geometric model of the blade are often constructed by only a couple of data inputs. Supported the numerical stress analysis of the turbine blade, an easy iterative method was proposed to style the structure of the composite blade.

Index Terms: Wind turbine blade, stress analysis, structural design, and composite blade.

I. INTRODUCTION

Glass fiber or carbon fiber reinforced polymer composites are currently the foremost popular materials used for the turbine blade because of their light weight and superior mechanical properties. A turbine blade may sustain various loading during the operation and parking states. because of the increasing size of the composite turbine blade, it's a crucial issue to rearrange the composite materials during a sufficient thanks to reach the optimal utilization of the fabric strength. The fiber direction and thickness distribution of the composite are two important design parameters within the turbine blade structure.

The outer shape of a turbine blade is typically determined by the consideration of aerodynamic efficiency, and isn't subjected to vary generally. The structure of the composite blade consists of the composite skins bonded along side a spar or foam core. the planning problem thus becomes the determination of the fiber orientation and thickness distribution on the composite skin. There are many reports that address the planning of composite plate with simple geometry. However, limited studies are reported within the structural design of composite with the complex blade geometry. The blade divided into several sections and determined the stiffness of every section because the basis for material distribution and material might be used at the turbine blade to efficiently sustain the complex loading for increasing size of blade. Minimization of the blade weight was the planning goal in their study. it had been also reported that suitable design of the fiber directions and usage of unidirectional carbon fiber to exchange the optical fiber can reduce the entire weight of the turbine blade, while maintaining an equivalent strength and stiffness [1].

This study develops a the blade model for the stress analysis using ANSYS. With the help of visualization interface, the geometric model of the blade are often constructed by only a number of data inputs. supported the numerical stress analysis of the turbine blade, an easy iterative method was proposed to work out the thickness distribution of the composite skin of the blade structure. The thickness distribution of the composite skin is chosen supported the concept of uniform loading. In other words, with the applied wind loading during the parking state, the turbine blades are going to be designed to possess an equivalent factor of safety in each station by applying the failure criterion of the most principal stress.

II. MATERIAL SELECTION

One of the main objectives of project work is to find out suitable material for windmill blade. In this study Usually the blade used is fiber-reinforced material. Material selection process is done by two methods first decision making theorem and verify it with simulation results from FEA software. The material used for the current experiment are structural steel, Epoxy carbon, E-glass, S-glass, Aluminium alloy. In the material selection process TOPSIS for decision-making is used[2]. This is the only algorithm which define the result near the ideal result with considering all defined parameters[3].

Step 1: Select data and properties to be consider

A decision matrix generated for each materials with selected weight vector $W = [w_1, w_2, w_3, \dots, w_n]$

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}$$

Table 1 Data of Material Properties [4]

	<i>Stiffness</i>	<i>Tensile Strength</i>	<i>Density</i>	<i>Elongation at break</i>	<i>Max Temperature</i>
<i>Structural Steel</i>	200.00	550.00	7.50	15.00	550.00
<i>Aluminium Alloy</i>	120.12	324.00	2.70	12.00	400.00
<i>E-Glass</i>	80.00	2000.00	2.55	3.00	350.00
<i>Epoxy-Carbon</i>	123.34	2900.00	1.52	1.80	500.00
<i>S-Glass</i>	89.00	4750.00	2.49	11.00	250.00
	289.76295	5948.10693	8.86301	22.41071	947.36477

In this calculation weighted matrix $W = [1, 2, 2, 3, 4]$ is selected because of higher temperature is needed to sustain in hot areas. Higher wind flow also generated in hot areas because of low density of air.

Step 2: Create normalised decision matrix

This step transforms various attribute dimensions into non-dimensional attributes which allows comparisons across criteria. Because various criteria are usually measured in various units, the scores in the evaluation matrix X have to be transformed to a normalized scale. The normalization of values can be carried out by one of the several known standardized formulas. Some of the most frequently used methods of calculating the normalized value are the following:

Table 2 Normalised Decision Matrix

	<i>Stiffness</i>	<i>Tensile Strength</i>	<i>Density</i>	<i>Elongation at break</i>	<i>Max Temperature</i>
<i>Structural Steel</i>	0.69022	0.09247	0.84621	0.66932	0.58056
<i>Aluminium Alloy</i>	0.41455	0.05447	0.30464	0.53546	0.42222
<i>E-Glass</i>	0.27609	0.33624	0.28771	0.13386	0.36945
<i>Epoxy-Carbon</i>	0.42566	0.48755	0.17150	0.08032	0.52778
<i>S-Glass</i>	0.30715	0.79857	0.28094	0.49084	0.26389

Step 3: Calculate the separation measures from the positive ideal solution and the negative ideal solution.

This step transforms various attribute dimensions into non-dimensional attributes which allows comparisons across criteria. Because various criteria are usually measured in various units, the scores in the evaluation matrix X have to be transformed to a normalized scale. The normalization of values can be carried out by one of the several known standardized formulas. Some of the most frequently used methods of calculating the normalized value are the following:

Table 3 Distance from ideal solution

Ideal Best	0.69022	1.59715	0.34300	0.24096	2.32223
Ideal Worst	0.27609	0.10894	1.69243	0.24096	1.05556

Step 3: Calculate the relative closeness to the positive ideal solution.

This step calculate how close is the material from the ideal solution. where $0 \leq R_i \leq 1$, R_i $i = 1, 2, \dots, m$.

$$R_i = \frac{d_i^-}{d_i^- + d_i^+}$$

Table 3 Rank the preference order or select the alternative closest to 1

S_i^+	S_i^-	$S_i^+ + S_i^-$	$P_i = S_i^+ + S_i^-$		
2.63394	2.21451	4.84845	0.45675	5	<i>Structural Steel</i>
2.15108	1.85954	4.01061	0.46365	4	<i>Aluminium Alloy</i>
1.34886	1.33017	2.67903	0.49651	3	<i>E-Glass</i>
0.70817	1.92556	2.63372	0.73112	1	<i>Epoxy-Carbon</i>
1.82094	2.23843	4.05937	0.55142	2	<i>S-Glass</i>

III. CONSTRUCTION OF WIND TURBINE BLADE MODEL

Stress analysis of the turbine blade must be conducted so as to work out the strain field for the failure criterion. The geometric model of the blade is developed into CAD. The program will generate the geometry data which will be imported to the ANSYS for following finite element meshing and stress analysis. Figure 1(a) shows the graphical interface of the program. With the input of airfoil geometry, skin thickness, chord length, pitch angle, distance to the middle of every station, the blade geometry are often generated.

The mechanical properties of the material, including Young's modulus, Poisson ratio, fiber stacking layers and angles, also can be designated within the interface program. The geometric model are often output as a document and imported to ANSYS. the ultimate geometry of a sample turbine blade is as shown in Figure 1(b).

Table 2 Model Specification of Blade

Profile	NACA 2412
Root chord length	1651mm
Tip chord length	650mm
Length of blade	10700mm
Hub diameter	337.5mm
Hub length	1465mm
Hub to blade (neck)	1475mm

IV. STRUCTURAL LOADING

The turbine blade is subjected to complex loading induced by the incoming wind force and therefore the dynamic force. In some situations, the turbine blade may experience extreme wind speed caused by severe weather, like a hurricane or tornado. The system of the turbine is assumed to be ready to pitch the blades during a feathered position (the parking position). the planning of blade must be ready to withstand the acute wind speed without damage or failure at this position. This study follows the IEC 61400-1 turbine design/safety standard to possess an extreme wind speed of 59.2 m/s at the parking state as a design guide for the thickness distribution of the blade structure [5].

Table 2 Mechanical properties of Materials

Properties	Structural Steel	E - Glass	S - Glass	Epox - carbon	Aluminum alloy
Density(Kg/m ³)	7.85	2.6	2.495	1.518	2.7
Young's modulus (GPa)	80	85	93	123.34	7.73
Poisson's Ratio	0.29	0.23	0.23	0.27	0.33
Shear modulus	31.008	36	39	3080	26.0
Tensile stress (MPa)	450	2050	4800	1632	324

V. RESULTS

Table 2 Comparison of Results

Material	Stress (MPa)	Deformation	Mass (Kg)
Structural Steel	168.63	26.448	705.18
Epoxy-Carbon	189.42	65.601	132.95
E-Glass	183.93	221.3	179.66
S-Glass	177.66	220.17	179.65
Aluminium Alloy	169.04	73.923	248.83

VI. CONCLUSION

A wind turbine blade geometry constructing interface is developed in the study to facilitate the stress analysis using ANSYS. Two different methods are employed to estimate highly considered material for the wind load at the extreme wind speed while the blade is in the parking position. The TOPSIS is shown to be an efficient material selection method in calculations of the benefits for certain material specific property in blade design. Based on the maximum principal stress failure criterion, mass of materials and deformation of blade under high load, the composite blade can be determined under a specified safety factor. A uniform stress loading on the blade can be derived with this design methodology.

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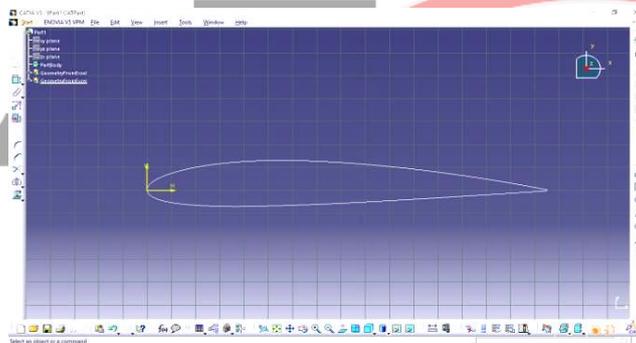


Figure 1(a) 2D view of NACA 2412 Aero foil Design.

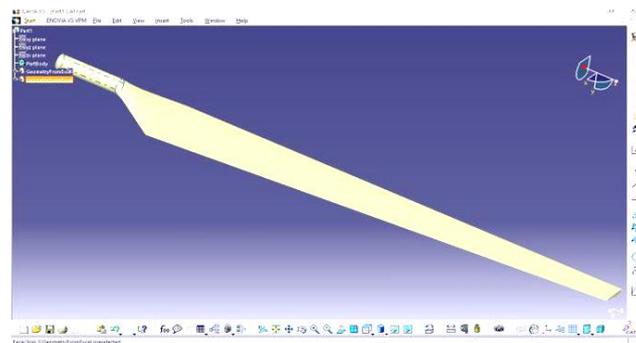


Figure 1(b) Isometric view of NACA 2412 Aero foil Design.

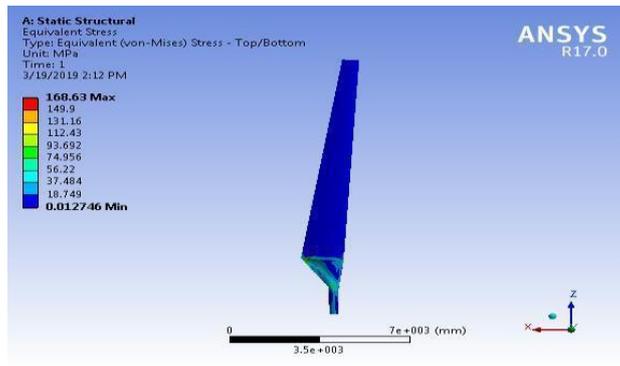


Figure 2(a) Von-Mises Stress Distribution of Structural Steel.

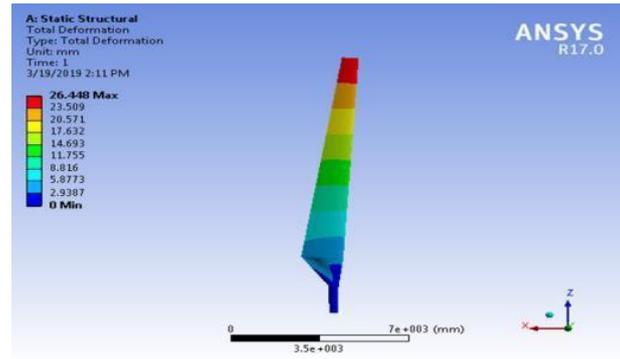


Figure 2(b) Total deformation of Structural steel.

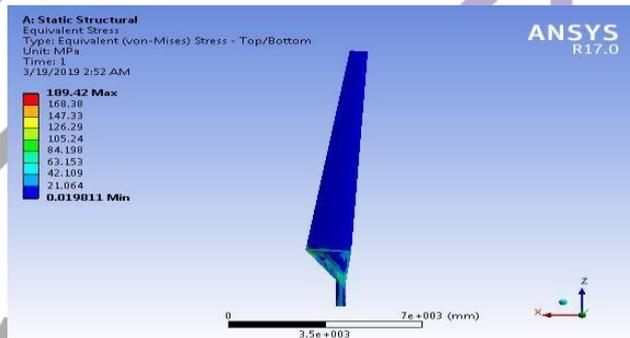


Figure 3(a) Von-Mises Stress Distribution of Epoxy Carbon.

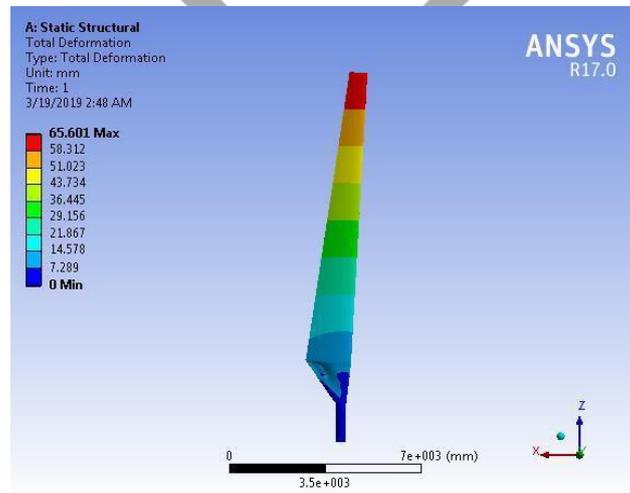


Figure 3(b) Total deformation of Epoxy Carbon.

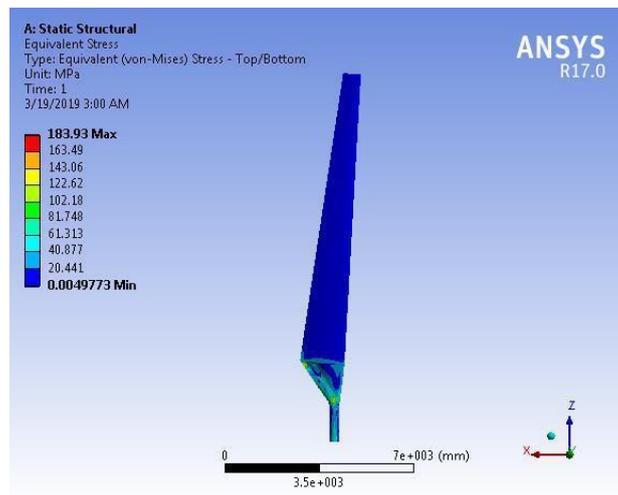


Figure 4(a) Von-Mises Stress Distribution of E - Glass

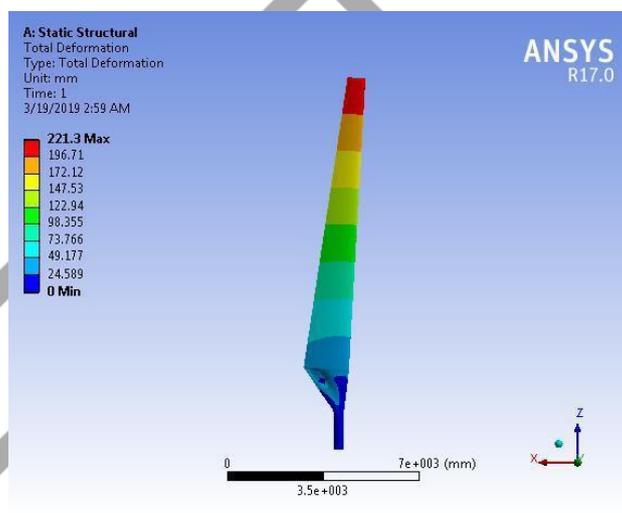


Figure 4(b) Total deformation of E - Glass.

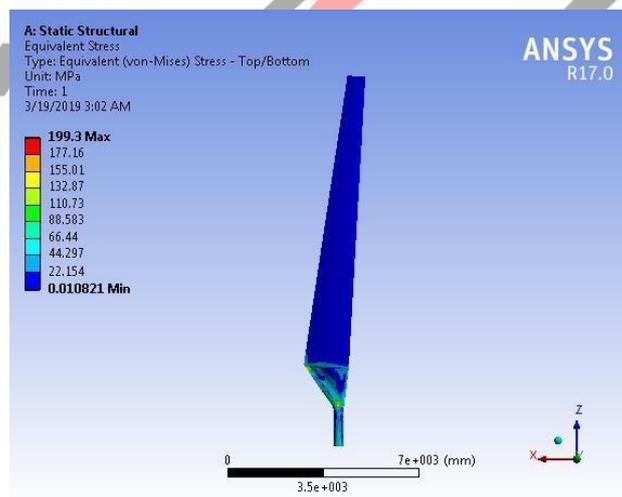


Figure 5(a) Von-Mises Stress Distribution of S - Glass.

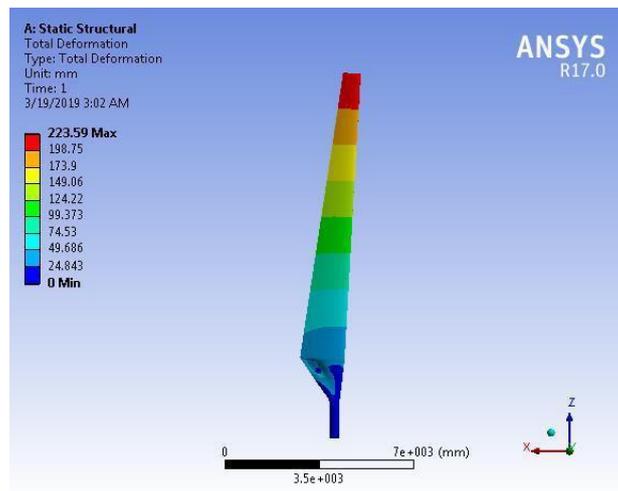


Figure 5(b) Total deformation of S - Glass.

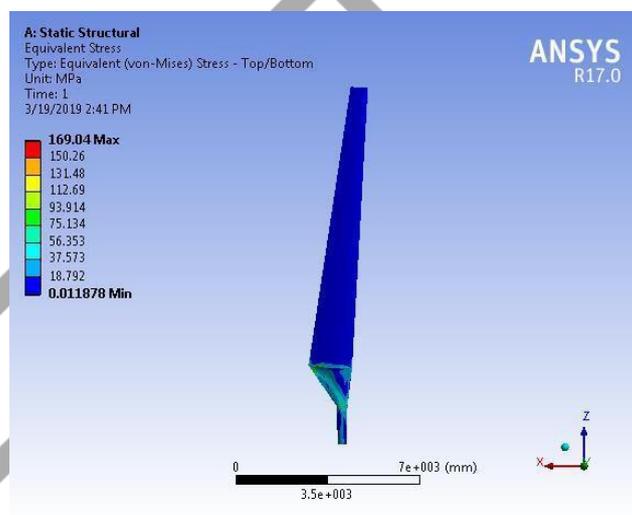


Figure 6(a) Von-Mises Stress Distribution of Aluminium Alloy.

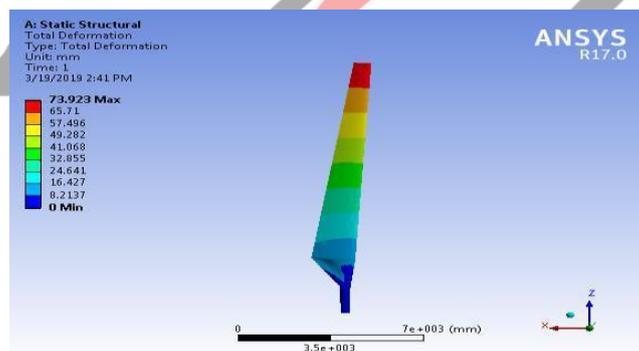


Figure 6(b) Total deformation of Aluminium Alloy.