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Material Selection Of Horizontal axis Wind Turbine Blade

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Abstract

In this paper the selection of material for a horizontal axis wind turbine blade is done using CFD and ANSYS. The first part is a computational fluid dynamic calculation of the fluid flow over the blade geometry to found the pressure load acting on the blade due to impact of wind. The second part is a finite element analysis in ANSYS of the blade to get the deformation in blade and stress distribution in blade due to pressure load and its rotation of blade. A study of different materials is made in this paper to select material based on von-mises stress (equivalent stress), stress distribution and deformation criteria.

Keyword: Material selection, Computational Fluid Dynamics, Finite Element Analysis, Blade Geometry.

Methodology

A fluid-structure interaction computer simulation and calculation are made using ANSYS Software for a horizontal axis wind turbine blade. Length of the blade 10.7m using different materials of epoxy carbon from ANSYS Materials. Results obtained on different type of composition of epoxy carbon material. Input wind speed is 12m/s and angular rotation 2.2rad/sec. The different composite materials are shown in the following table. Following values for different types of epoxy carbon and parameters considered as follows young's modulus, density, shear modulus, Poisson's ratio. In this research the various materials located in the ANSYS Computer Software library is used for study of composite material of blade.

NUMBER OF MATERIALS	MATERIAL NAMES
1	Epoxy E-Glass Unidirectional
2	Epoxy E-Glass Wet
3	Epoxy Carbon Unidirectional (Prepreg)
4	Epoxy Carbon Unidirectional (Wet)
5	Epoxy Carbon Woven (Prepreg)

Table no. 1

In Table 1 the total mass of the blade is calculated based on the properties of the material given by computer software. Design of the blade is done in CATIA V5 which is mandatory to find pressure and ANSYS inputs in CFD. Every mentioned material has different kind of properties and designation mentioned in table no.1

Solid works 3D cad model.

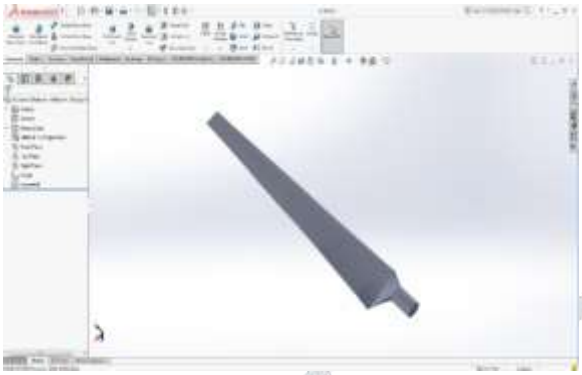

Figure 1

Inputs of air inlet and outlet or CFD is shown in figure.

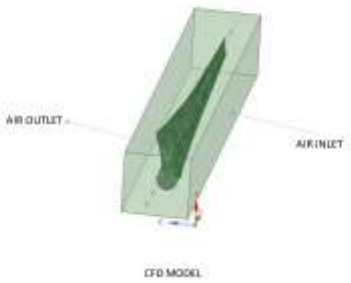

Figure 2

Boundary conditions of blade is mentioned table No.2

Boundary Condition	Value	unit
Air Inlet velocity	12	m/s
Blade rotating velocity	2.22	Rad/s
Outlet Pressure	0	Pa

Meshing done in CFD for HAWT blade.

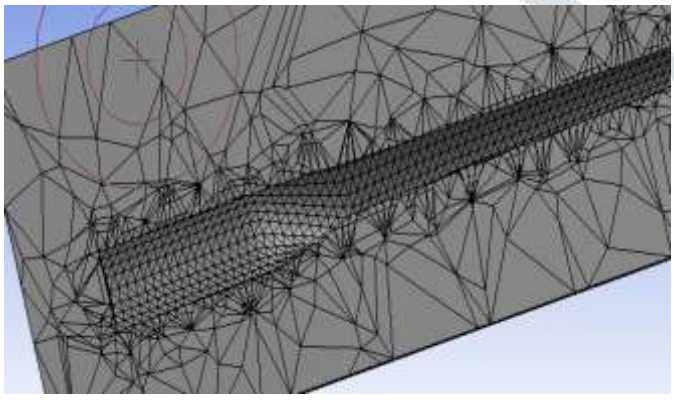

Figure 3 - The Computational Fluid Dynamics mesh generated by ANSYS

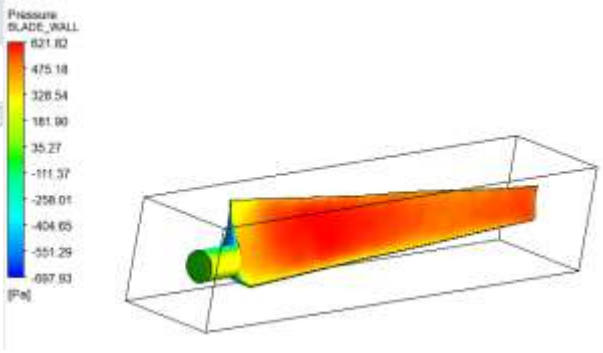

Figure 4 - Pressure Contour front side wall

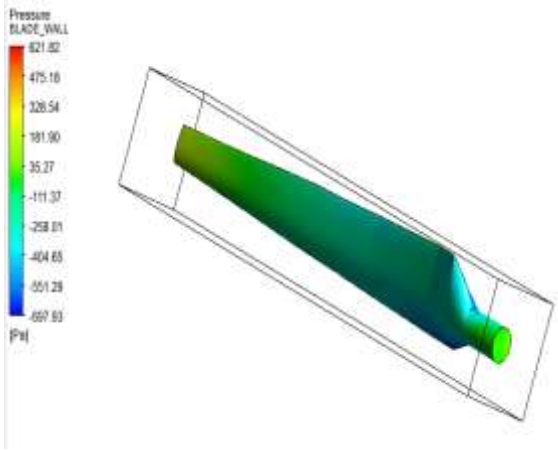

Figure 5 -Pressure Contour backside wall

The above figure shows that pressure around the backside of the blade. Which is less in comparing with front side

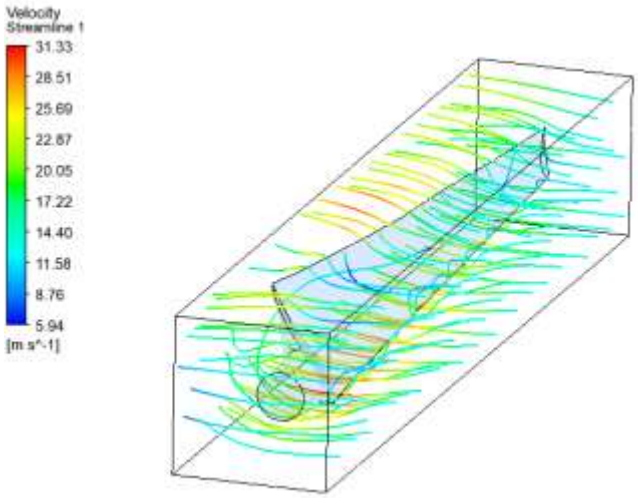

Figure 6 - Streamline over the blade.

Streamline of air showing striking air over the blade which is diverted because of Aerodynamical shape of the blade.

Finite element analysis

This is one of the way to find out stresses, strain, and deformation

Meshing – this is done for dividing blade into lakhs of part to find out accurate and precise results.

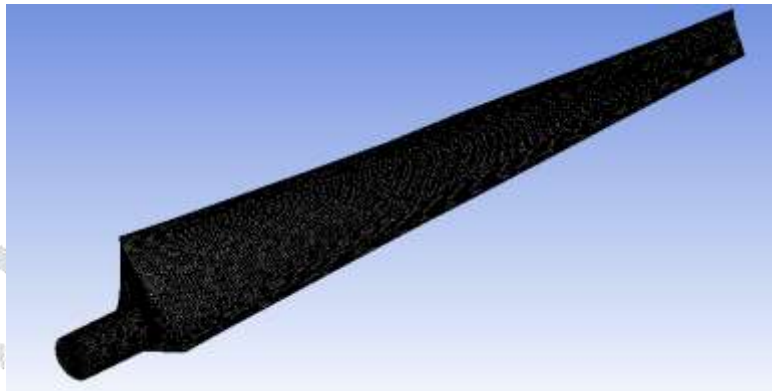

Figure 7 – Finite element analysis meshing

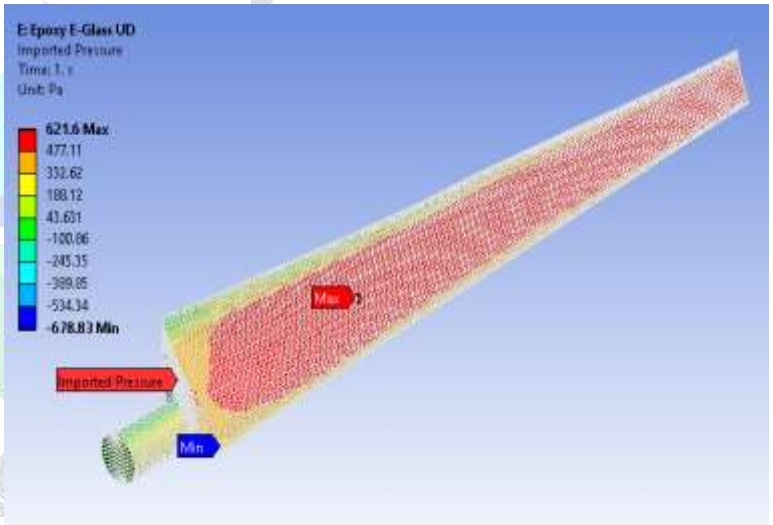

Figure 8 - Pressure input for FEA analysis

Collected pressure point after meshing and used all the values to find up stresses , strain and deformation.

Property	Material 1	Material 2	Material 3	Material 4	Material 5
Density (mm^-3 t)	2E-09	1.85E-09	1.49E-09	1.51E-09	1.42E-09
Young's Modulus X direction (MPa)	45000	35000	121000	123340	61340
Young's Modulus Y direction (MPa)	10000	9000	8600	7780	61340
Young's Modulus Z direction (MPa)	10000	9000	8600	7780	6900
Poisson's Ratio XY	0.3	0.28	0.27	0.27	0.04
Poisson's Ratio YZ	0.4	0.4	0.4	0.42	0.3
Poisson's Ratio XZ	0.3	0.28	0.27	0.27	0.3
Shear Modulus XY (MPa)	5000	4700	4700	5000	19500
Shear Modulus YZ (MPa)	3846.2	3500	3100	3080	2700
Shear Modulus XZ (MPa)	5000	4700	4700	5000	2700
Stress Limits:					
Tensile X direction (MPa)	1100	780	2231	1632	805
Tensile Y direction (MPa)	35	31	29	34	805
Tensile Z direction (MPa)	35	31	29	34	50
Shear XY (MPa)	80	60	60	80	125
Shear YZ (MPa)	46.1538	35	32	55	65
Shear XZ (MPa)	80	60	60	80	65
Strain Limits:					
Tensile X direction	0.0244	0.0244	0.0167	0.0143	0.0126
Tensile Y direction	0.0035	0.0038	0.0032	0.0026	0.0126
Tensile Z direction	0.0035	0.0038	0.0032	0.0026	0.008
Shear XY	0.016	0.015	0.012	0.016	0.022
Shear YZ	0.012	0.012	0.011	0.012	0.019
Shear XZ	0.016	0.015	0.012	0.016	0.019

Table No.2 – material properties generated in ANSYS

Results and Output.

These results are calculated and simulated by Ansys software and Computational fluid dynamics and finite element analysis. For every material calculated three results. The first result is the distribution of total deformation over the wind turbine blade. The second result is the equivalent (von-Mises) stress distribution over the blade. The third result is equivalent strain. By looking at the perspective for each deformation distribution figure which is in the red color representing the largest total deformation and the blue color representing the smallest total deformation. We can then read the value calculated by the simulation for the maximum total deformation which is the value next to the red color in the legend for a specific material. The deformation distribution and the equivalent stress distribution along the blade are shown for each blade material in the following figures.

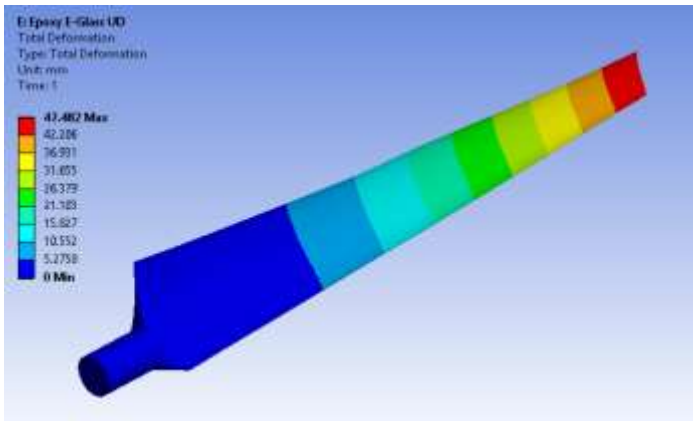

Figure 9: Deformation distribution along the blade for Epoxy E-Glass UD

In Figure 9 the deformation distribution OF Epoxy E-Glass UD material. maximum total deformation on tip of the wind turbine blade is 0.047 m.

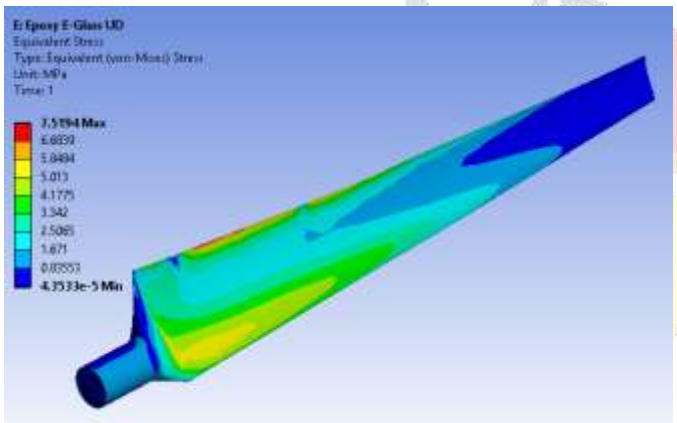

Figure 10: Equivalent (von-Mises) stress distribution along the blade for material Epoxy E-Glass UD

In Figure 10, the equivalent (von-Mises) Stress for Material Epoxy E-Glass UD is 7.519 MPa.

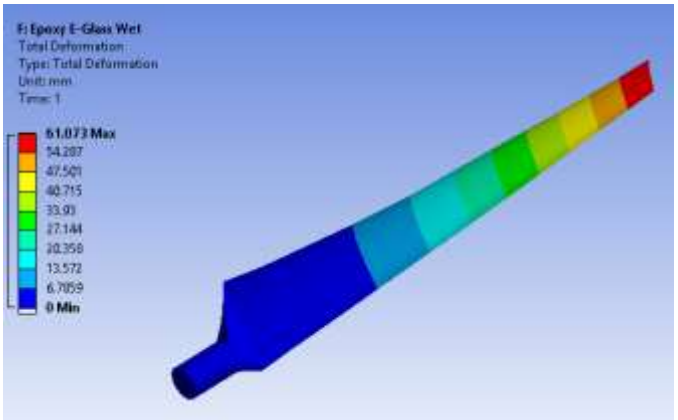

Figure 11: Deformation distribution along the blade for Epoxy E-Glass wet

In Figure 11 the deformation distribution of Epoxy E-Glass wet material. maximum total deformation of on tip of the wind turbine blade is 0.061 m.

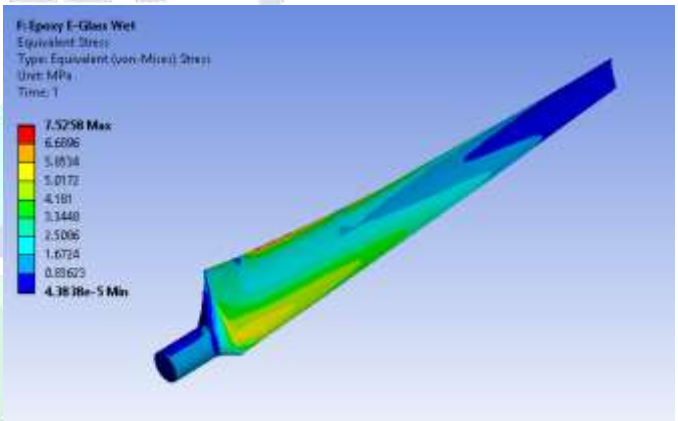

Figure 12: Equivalent (von-Mises) stress distribution along the blade for material Epoxy E-Glass wet

In Figure 11, the equivalent (von-Mises) Stress for Material Epoxy E-Glass UD is 7.5258 MPa.

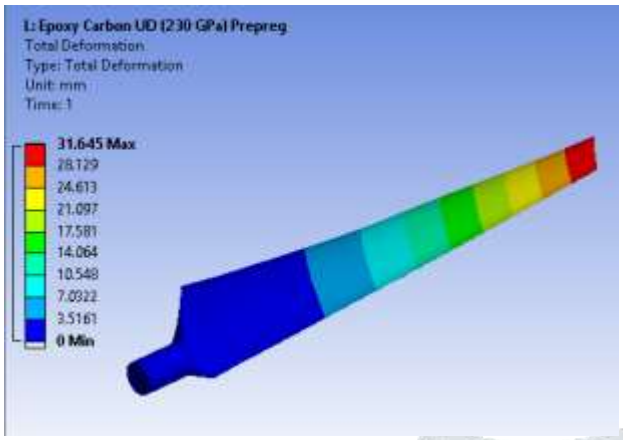

Figure 13: Deformation distribution along the blade for Epoxy carbon UD(230 GPa) Prepreg

In Figure 13 the deformation distribution of Epoxy E-Glass UD material. maximum total deformation on tip of the wind turbine blade is 0.0316 m.

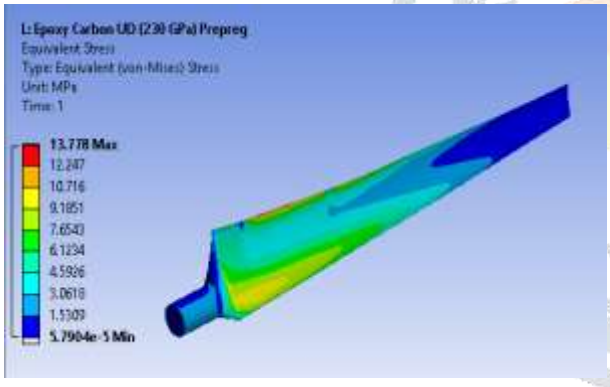

Figure 14: Equivalent (von-Mises) stress distribution along the blade for Epoxy carbon UD(230 GPa) Prepreg

In Figure 14 the equivalent (von-Mises) Stress for Material Epoxy E-Glass UD is 13.778 MPa.

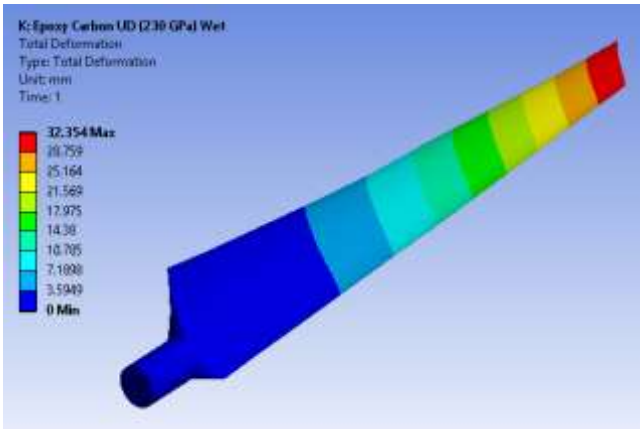

Figure 15: Deformation distribution along the blade for Epoxy carbon UD(230 GPa) Wet

In Figure 15 the deformation distribution for Material Epoxy E-Glass UD material. maximum total deformation on tip of the wind turbine blade is 0.0316 m

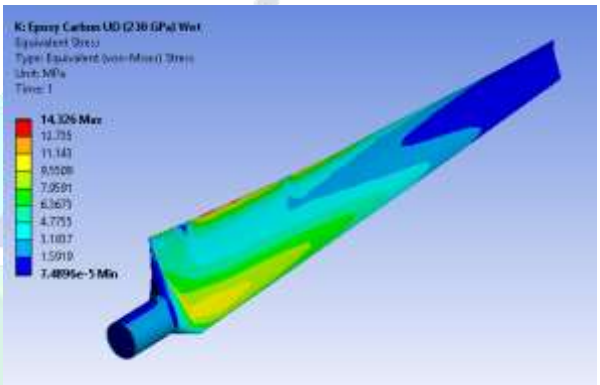

Figure 16: Equivalent (von-Mises) stress distribution along the blade for Epoxy carbon UD(230 GPa) Wet

In Figure 16 the equivalent (von-Mises) Stress for Material Epoxy E-Glass UD is 14.326 MPa.

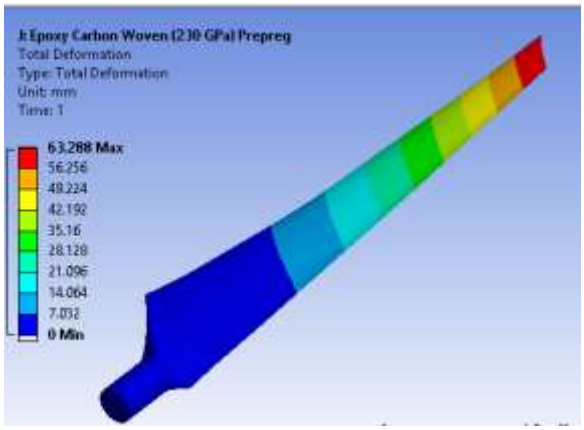

Figure 17: Deformation distribution along the blade for Epoxy carbon woven (230 GPa) Prepreg

In Figure 17 the deformation distribution of Epoxy E-Glass UD material showing a maximum total deformation of 0.0632 m at the tip of the wind turbine blade.

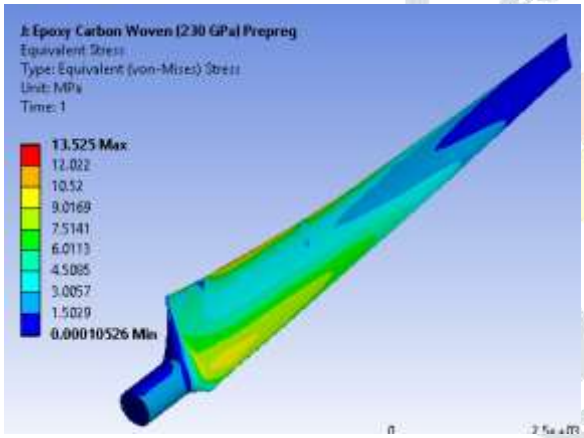

Figure 18: Equivalent (von-Mises) stress distribution along the blade for Epoxy carbon woven (230 GPa) Wet

In Figure 18 the equivalent (von-Mises) Stress for Material Epoxy E-Glass UD is 13.525 MPa.

Graph

The results of this work are analyzed and presented in Figures 9 to 18.

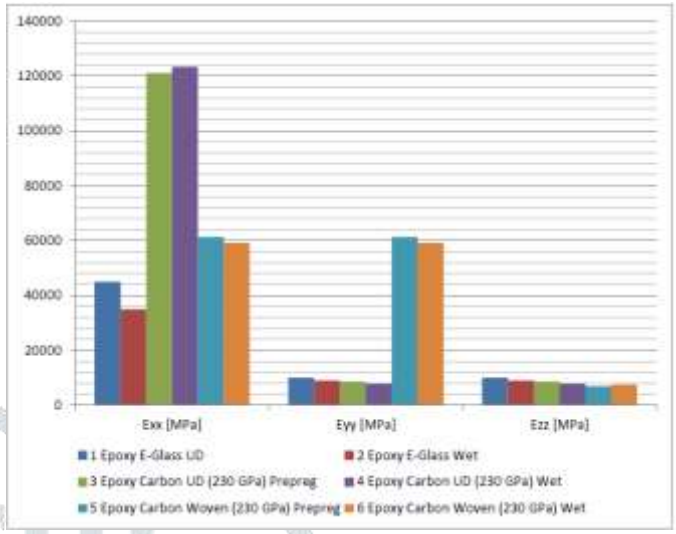

Figure 19: for comparison of Young's modulus in the x, y, and z directions of the materials represented graphically.

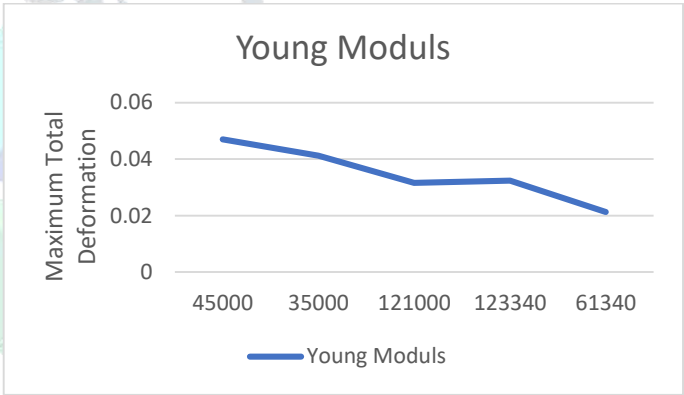

Figure 20: total deformation on TIP of the wind turbine blade decreasing with increase in young's modulus in the x direction. Each point on the plot represents a material.

In graph of Young's modulus in the x, y and z direction of all materials are studied is represented graphically to comparing values and have an overview of materials. We take the five material compositions and represent by one factor using Exx value. For example, Epoxy carbon UD is having Exx equals to 45000 MPa so from z, it is shown that it gives maximum tip total deformation of 0.047 m. It is also clear that the higher the Exx, the lower the maximum tip total deformation which is an expected result. Based upon these conditions, one could select the material with the lowest maximum total deformation but we will conclude that since these materials are uni-directional composite materials they will not fulfil the condition of equivalent von-Mises stress with the y-direction tensile stress limit.

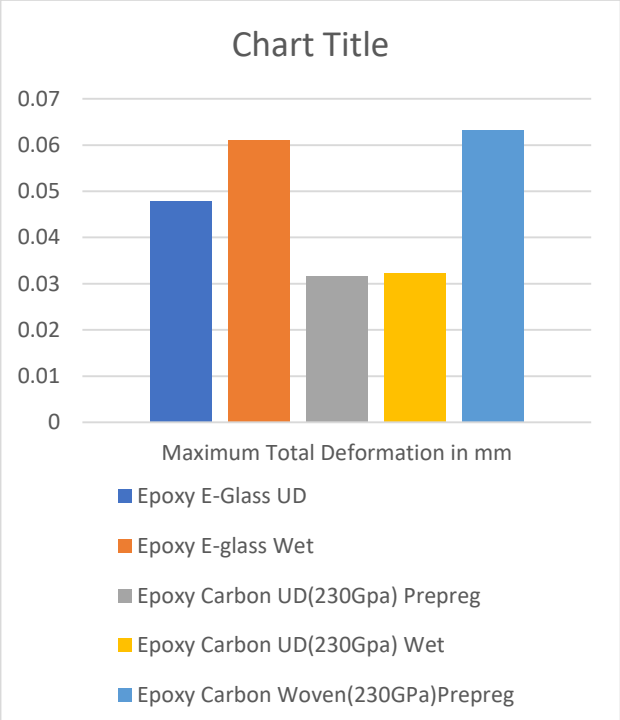

Figure 21: Tip maximum total deformation in meters

The above fig no. 21 shows that tip maximum total deformation in meters which is obtained from the ANSYS computer solver table for each of the materials simulated. From this above graph we get that the best materials are Epoxy Carbon UD(230GPa)Prepreg and Epoxy Carbon UD(230GPa)Wet but still Epoxy E-Glass UD is not to be excluded and stress limits must be examined for uni-directional materials in the directions y and z.

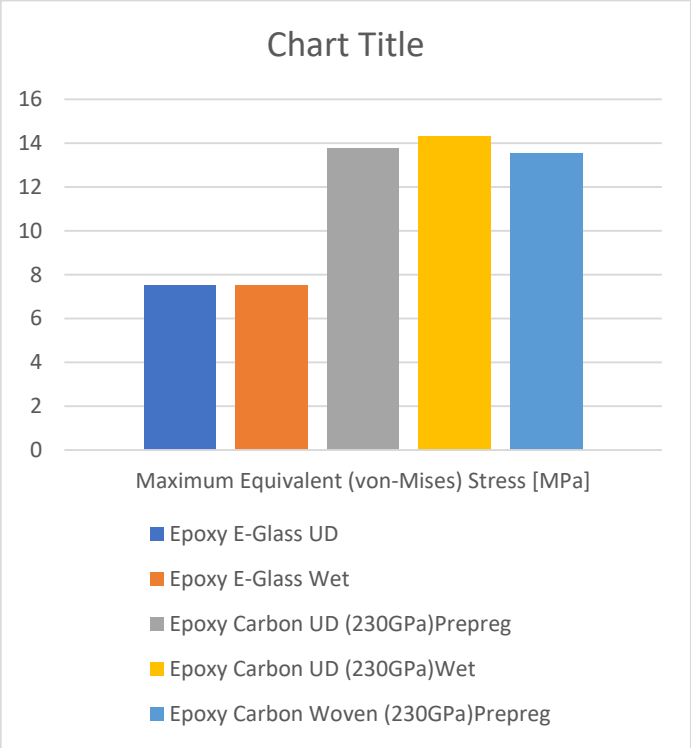

Figure 22: Maximum equivalent (von-Mises) stresses in MPa

The above fig. shows that Maximum equivalent (von-Mises) stress in MPa. Which is obtained from results obtained from the ANSYS computer simulation for each of the materials simulated. By comparing the results represented in Figure 22 with Exx values from Figure 19 we conclude that the all the materials are studied are very safe but since materials Epoxy E-Glass to Epoxy Carbon UD(230)Wet are uni-directional (UD) the stress limits in the y and z directions are crucial in material selection.

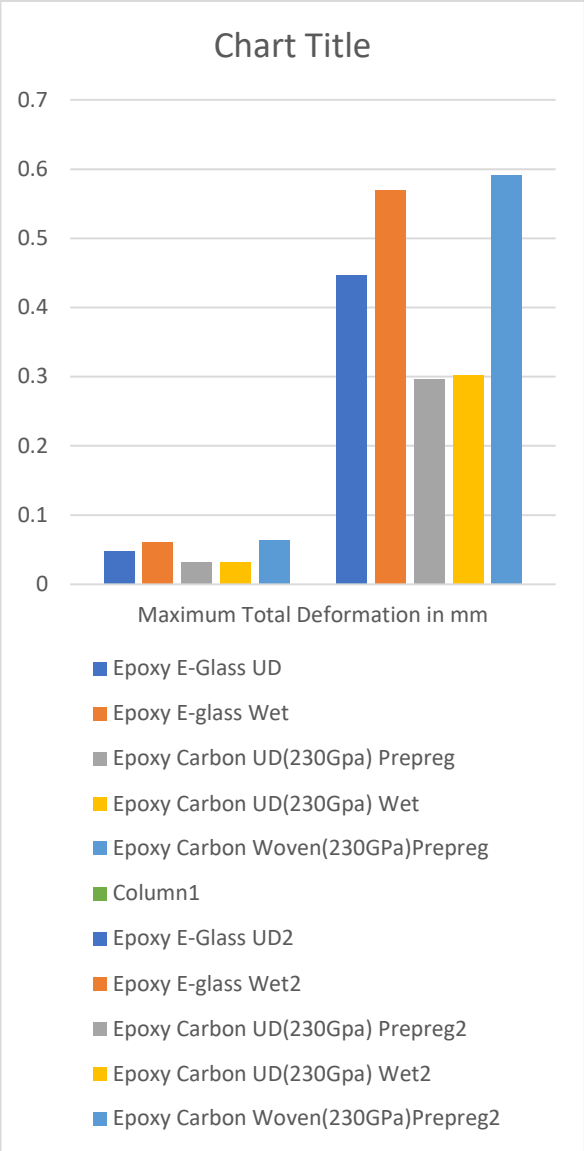

Figure 23: Tip maximum total deformation in meters and in percentage of the blade length results obtained from the ANSYS computer simulation for each of the materials simulated

Blade Mass

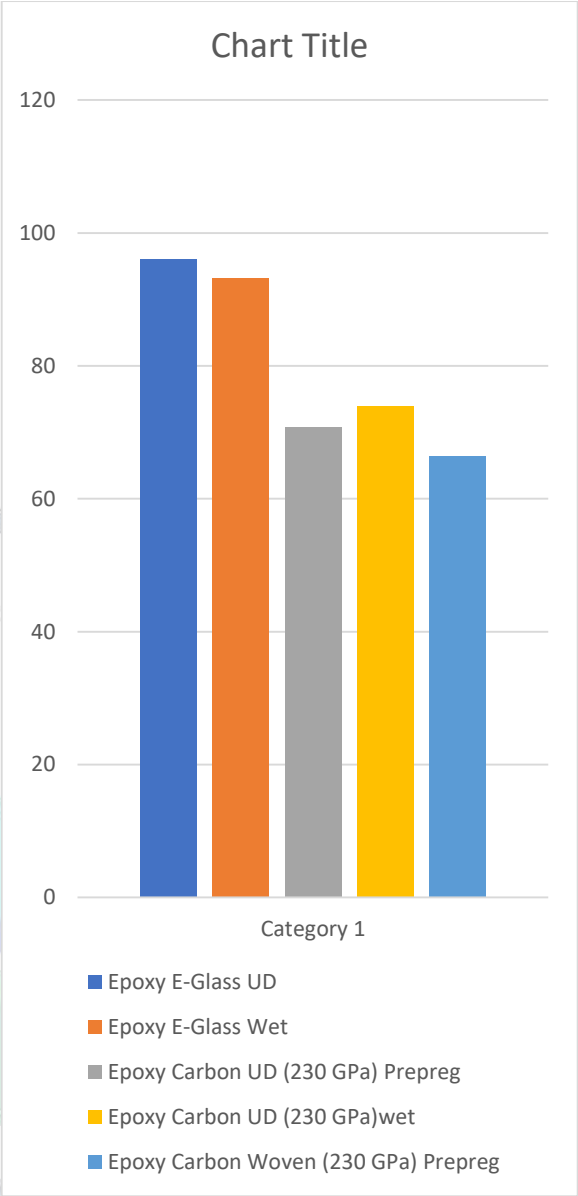

Figure 24: Blade Mass

Exx / Blade Mass

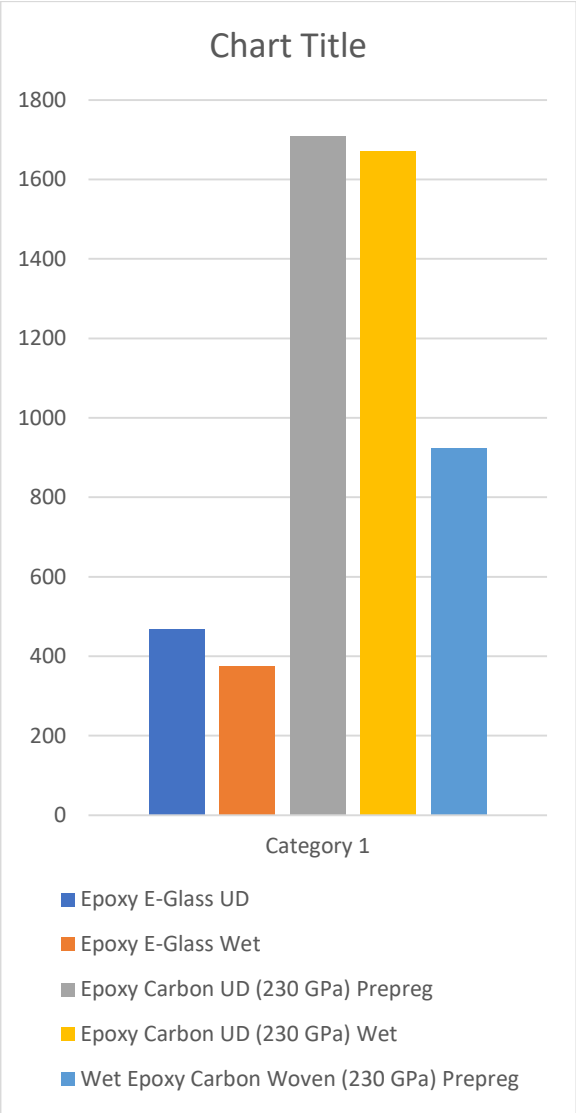

Figure 25: Young's modulus per unit mass of the blade for the x directions

Eyy / Blade Mass

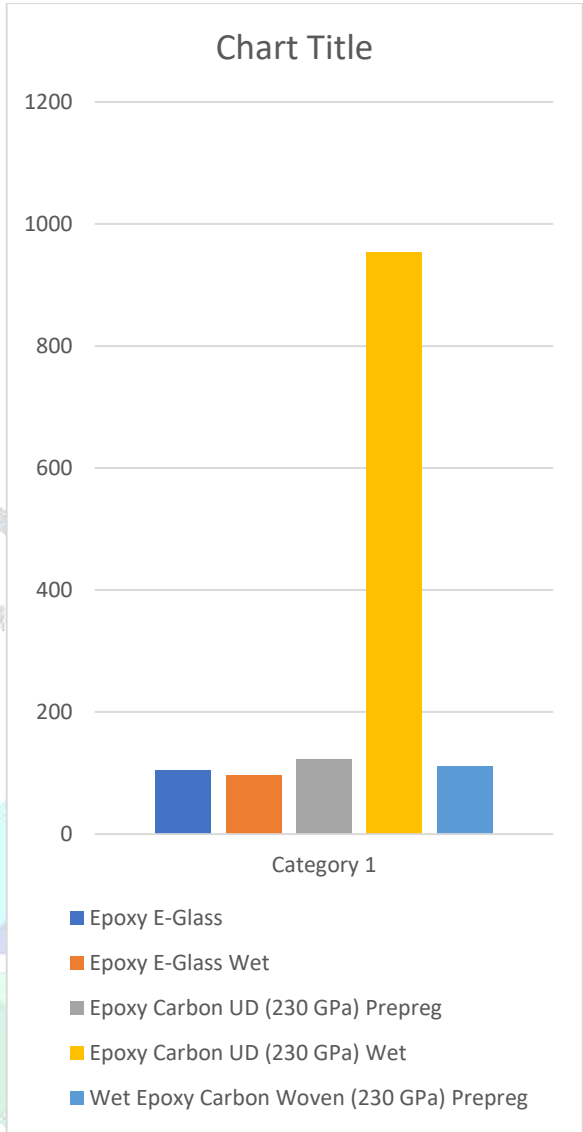

Figure 26: Young's modulus per unit mass of the blade for the y directions

Ezz / Blade Mass

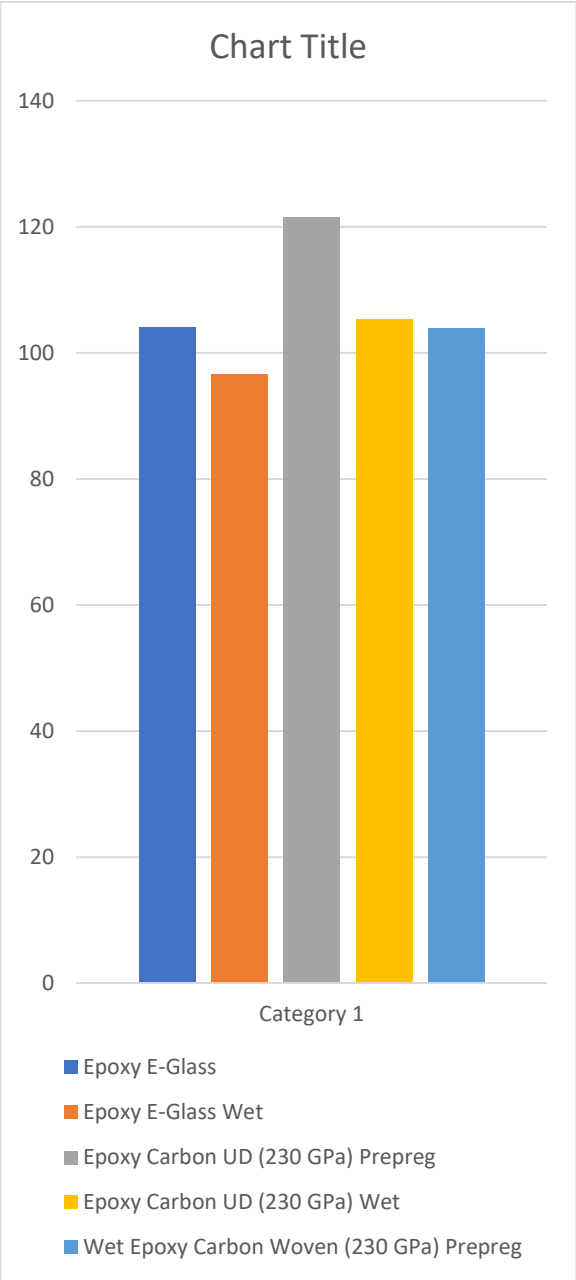

Figure 27: Young's modulus per unit mass of the blade for the z directions

Combining the above data Young's modulus per unit mass of the blade for the x, y, and z directions.

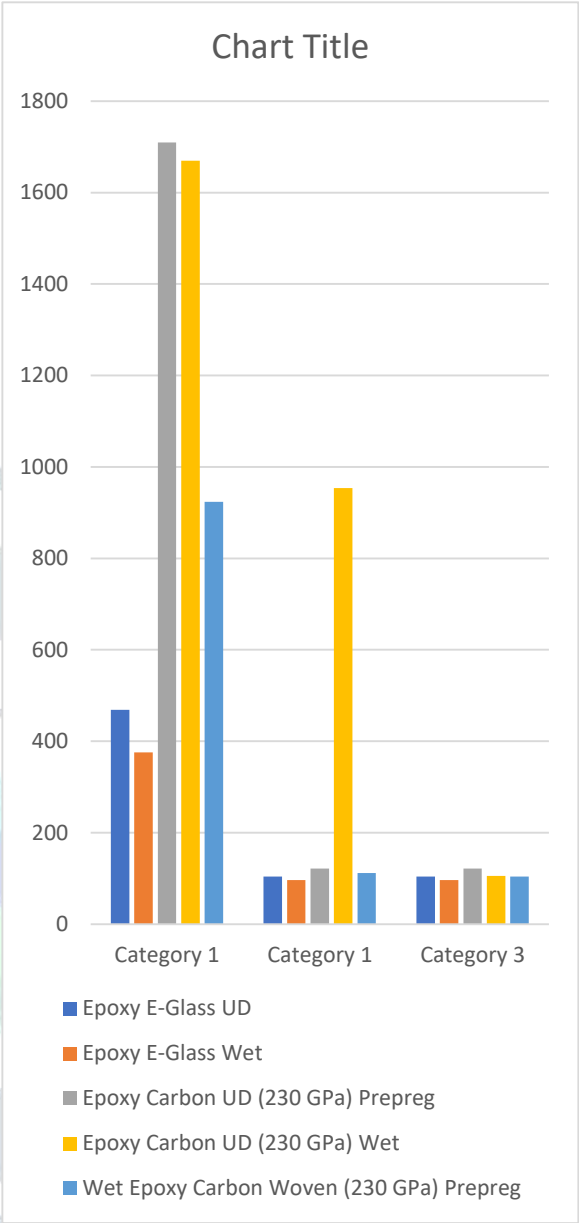

Figure 28: Young's modulus per unit mass of the blade for the x, y, and z directions

In Figure 28, tip maximum total deformation in meters and in percentage is depicted. This is to take the blade length into consideration and highlighting that the blade is long (10.7 m of length). The above chart shows young's modulus per unit mass of the blade for the x, y, and z directions for each of the materials simulated by ANSYS computer Fluid Structure Interface Simulation. The equivalent (von-Mises) strain distribution for material Epoxy E-Glass Unidirectional, Epoxy Carbon UD (230 GPa) Prepreg, and Epoxy Carbon UD (230 GPa) Wet are simulated and their results shows their equivalent strain distribution in below figures.

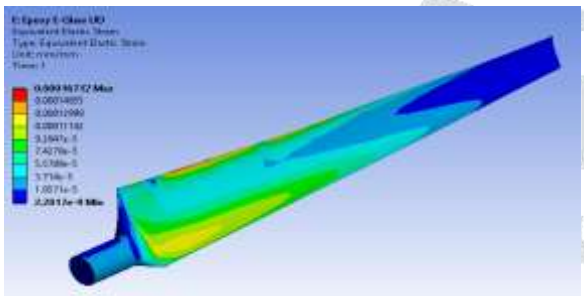

Figure 29: von-Mises Strain distribution over the blade of Epoxy E-Glass UD

It shows Epoxy E-Glass UD have maximum von-Mises strain of 0.0001671

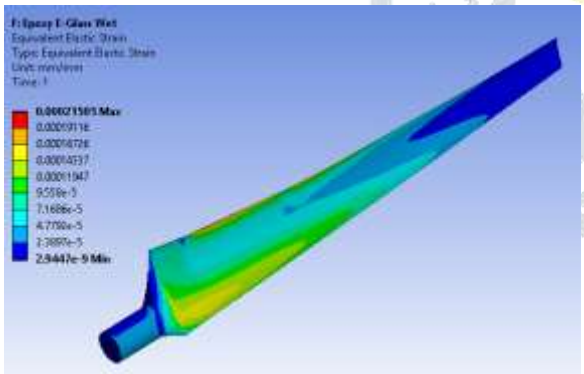

Figure 30: von-Mises Strain distribution over the blade of Epoxy E-Glass Wet

It shows Epoxy E-Glass Wet have maximum von-Mises strain of 0.0002150

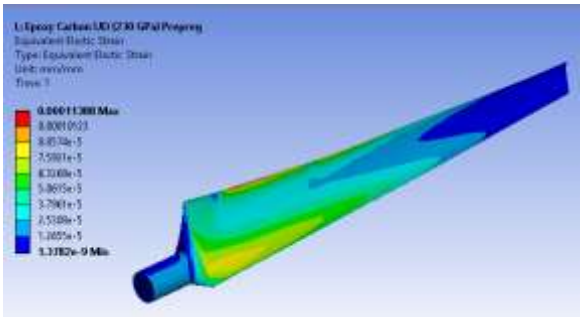

Figure 31: von-Mises Strain distribution over the blade for Epoxy Carbon UD (230GPa)Prepreg

It shows Epoxy Carbon UD (230GPa)Prepreg maximum von-Mises strain of 0.0001138

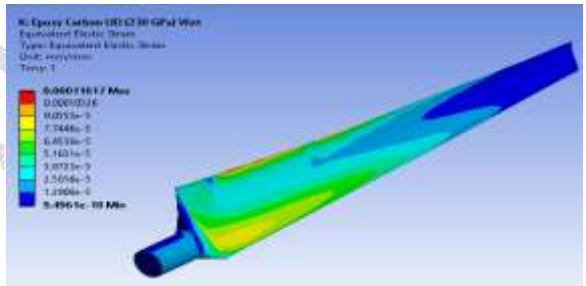

Figure 32: von-Mises Strain distribution over the blade of Epoxy Carbon UD(230GPa)Wet

It shows Epoxy Carbon UD(230GPa)Wet maximum von-Mises strain of 0.0001161

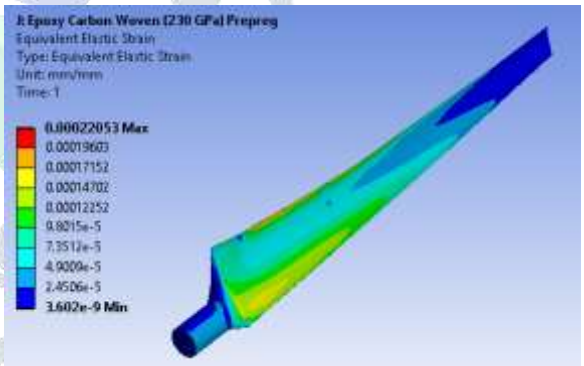

Figure 33: von-Mises Strain distribution over the blade of Epoxy Carbon UD(230GPa)Prepreg

Conclusion

Epoxy E-Glass UD is selected to manufacture blade of HAWT. because it has maximum equivalent (von-Mises) Stress of 7.51 MPa which is lower than 31 MPa stress limit in the y and z direction. Epoxy E-Glass UD has maximum (von-Mises) strain of 0. 0001671.which is less than strain limits 0.0244 in the x-direction and 0.0035 in the y and z directions of the composite material. Epoxy E-Glass wet is not selected because the maximum total tip deformation of 0.0610 m is bigger than Epoxy E-Glass UD maximum total tip deformation of 0.04748 m. Epoxy Carbon UD (230 GPa) Prepreg and Epoxy Carbon UD (230 GPa) Wet have the less tip maximum total deformation of 0.031 m, and 0.032 m respectively, but they are having the highest specific modulus (specific stiffness) of 560 MPa/Kg and the minimum maximum von-Mises strain of 0.0001161, and 0.0002205 respectively. Which is less the strain limits 0.0001138, 0.0001161 of the composite materials Epoxy Carbon UD (230GPa) Prepreg and Epoxy Carbon UD (230GPa) Wet. Yet, they were not because they have maximum equivalent von-Mises Stress of 13.78 MPa, and 14.32 MPa respectively which is bigger than the safe tensile stress in the y or z direction of Epoxy Carbon UD (230GPa) Prepreg and Epoxy Carbon UD (230GPa) i.e., higher than 29 for Material Epoxy Carbon UD (230GPa) Prepreg and 34 for Material Epoxy Carbon UD (230GPa) Wet. As for Materials Epoxy Carbon Woven(230GPa) Prepreg. which are woven, they will be more expensive and less market availability than the Unidirectional (UD) composite materials. It is considered that Epoxy Carbon Woven(230GPa) Prepreg are not selected because woven which will lead to higher manufacturing cost. Epoxy E-Glass UD is selected the best material for the wind turbine blade.

Reference

[1]. ANSYS R17.0 Computer Software Tool with Academic License

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