Material Selection Of Wind Turbine Blade Using Finite Element Method

Diaaeldin M. Elsherif, Ayman A. Abd El-Wahab, Ramadan Badawy Mohamed Elgamsy, Mohamed Hazem Abdellatif

Abstract: In this paper the selection of material for a horizontal axis wind turbine blade is done using ANSYS Fluid-Structure Interaction simulation which is composed of two main parts. The first part is a computational fluid dynamic simulation of the fluid flow around the blade geometry to get the pressure load acting on the blade due to wind. The second part is a finite element analysis of the blade to get the deformation and stress distribution due to pressure load and its rotation. A study of several materials is made in this paper to select material based on total deformation, stress distribution and maximum equivalent stress (von-Mises).

Methodology

A fluid-structure interaction computer simulation is made using ANSYS Software for a horizontal axis wind turbine blade of length 43.2 m using different materials from ANSYS Materials Library according to the methodology in references [3] and [4] then results are obtained but for several different materials for the same blade in references [3] and [4]. The wind speed is 12 m/s and the rated rotational speed is 2.22 rad/s. The composite materials simulated are shown in the following table. Each material is represented by its properties as mere numerical values of density, Young's modulus, Poisson's ratio, and shear modulus. The idea behind this is that numerical simulation deals with materials numerically and we can insert any custom material to the simulation by inserting the numerical values of its properties to the program. In this paper the standard materials available in the ANSYS Computer Software library is used.

Table 1: *Materials Simulated*

Material Number	Material Name	Blade Mass [kg]
1	Epoxy E-Glass UD	289.98
2	Epoxy E-Glass Wet	268.23
3	Epoxy Carbon UD (230 GPa) Prepreg	216.03
4	Epoxy Carbon UD (230 GPa) Wet	220.09
5	Epoxy Carbon Woven (230 GPa) Prepreg	205.89
6	Epoxy Carbon Woven (230 GPa) Wet	210.38

In Table 1 the total mass of the blade is calculated based on the density property of the material by multiplying the density of the material by the volume of the blade which is calculated by the computer software not by hand computation. The idea of the paper is to have a computer aided design or simulation which is part of the field Computational Mechanics. In Table 2 the material properties of Materials 1 to 6 are shown. Each material was given a designation in this paper as in Table 1. The generated Computational Fluid Dynamics mesh is shown in Figure 1 while the generated Finite Element Method mesh is shown in Figure 2.

- *Diaaeldin M. Elsherif, Ayman A. Abd El-Wahab, Ramadan Badawy Mohamed Elgamsy, Mohamed Hazem Abdellatif*
- *Ain Shams University, Faculty of Engineering, Mechanical Design and Production Engineering*
- *M.Sc. Student, and Assistant Professors by the Department, Professor by the Department*

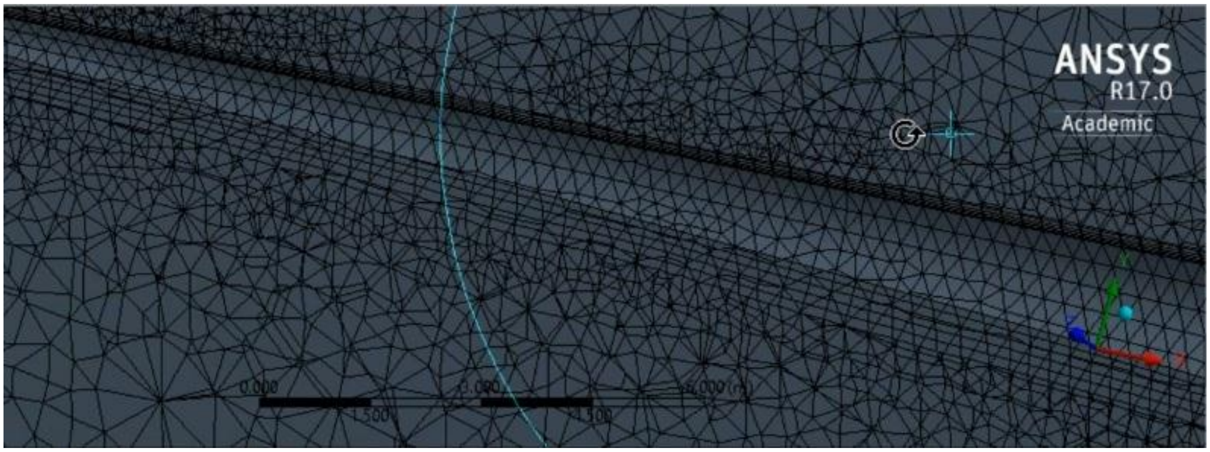

Figure 1: *The Computational Fluid Dynamics mesh generated by ANSYS*

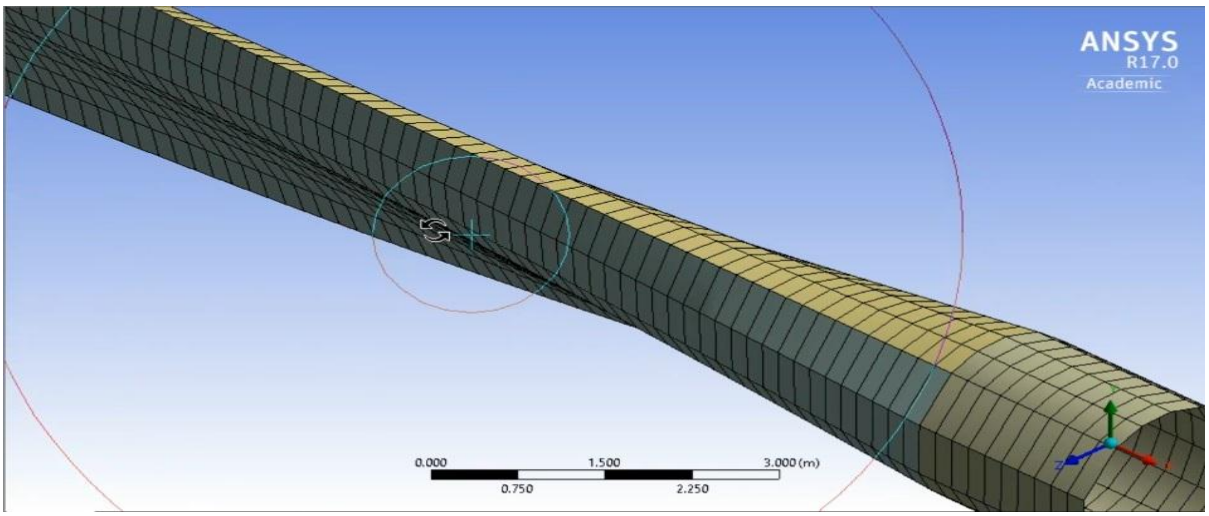

Figure 2: *The Finite Element Method mesh generated by ANSYS*

Table 2: *Materials 1 to 6 properties*

Property	Material 1	Material 2	Material 3	Material 4	Material 5	Material 6	Unit
Density	2E-09	1.85E-09	1.49E-09	1.51E-09	1.42E-09	1.451E-09	mm^-3 t
Young's Modulus X direction	45000	35000	121000	123340	61340	59160	MPa
Young's Modulus Y direction	10000	9000	8600	7780	61340	59160	MPa
Young's Modulus Z direction	10000	9000	8600	7780	6900	7500	MPa
Poisson's Ratio XY	0.3	0.28	0.27	0.27	0.04	0.04	
Poisson's Ratio YZ	0.4	0.4	0.4	0.42	0.3	0.3	
Poisson's Ratio XZ	0.3	0.28	0.27	0.27	0.3	0.3	
Shear Modulus XY	5000	4700	4700	5000	19500	17500	MPa
Shear Modulus YZ	3846.2	3500	3100	3080	2700	2700	MPa
Shear Modulus XZ	5000	4700	4700	5000	2700	2700	MPa
Stress Limits:							
Tensile X direction	1100	780	2231	1632	805	513	MPa
Tensile Y direction	35	31	29	34	805	513	MPa
Tensile Z direction	35	31	29	34	50	50	MPa
Shear XY	80	60	60	80	125	120	MPa
Shear YZ	46.1538	35	32	55	65	55	MPa
Shear XZ	80	60	60	80	65	55	MPa
Strain Limits:							
Tensile X direction	0.0244	0.0244	0.0167	0.0143	0.0126	0.0092	
Tensile Y direction	0.0035	0.0038	0.0032	0.0026	0.0126	0.0092	
Tensile Z direction	0.0035	0.0038	0.0032	0.0026	0.008	0.0078	
Shear XY	0.016	0.015	0.012	0.016	0.022	0.02	
Shear YZ	0.012	0.012	0.011	0.012	0.019	0.015	
Shear XZ	0.016	0.015	0.012	0.016	0.019	0.015	

Results

In this section the results from the simulation done using ANSYS Software is presented. For each material there are two results. The first one is the distribution of the deformation along the wind turbine blade. The second result is the equivalent (von-Mises) stress distribution along the blade. By looking at the legend for each deformation distribution figure we can see that the red colour represents the largest total deformation and the blue colour represents 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 colour 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.

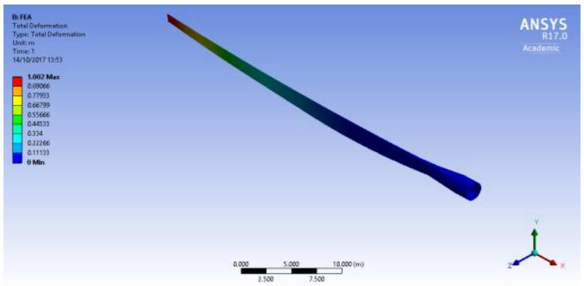

Figure 3: *Deformation distribution along the blade for Material 1*

In Figure 3 the deformation distribution for Material 1 – Epoxy E-Glass UD is depicted, showing a maximum total deformation of 1.002 m at the tip of the wind turbine blade

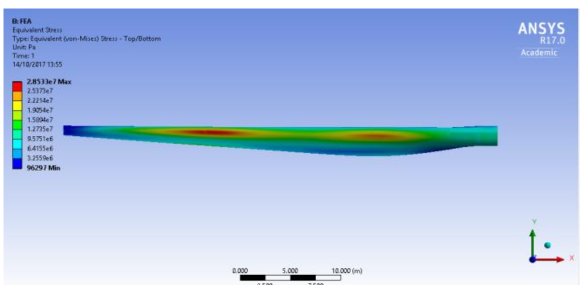

Figure 4: *Equivalent (von-Mises) stress distribution along the blade for Material 1*

In Figure 4 the equivalent (von-Mises) Stress for Material 1 – Epoxy E-Glass UD is presented, showing a maximum stress of 28.533 MPa

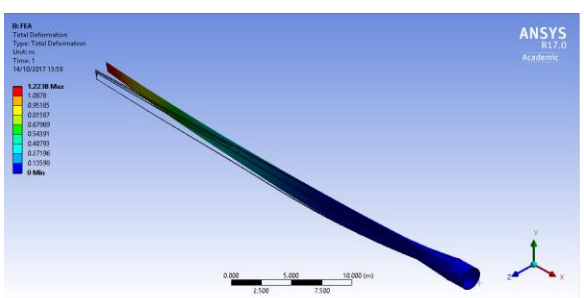

Figure 5: *Deformation distribution along the blade for Material 2*

Figure 5 shows a maximum total deformation of 1.2238 m at the tip of the wind turbine blade for Material 2 – Epoxy E-Glass Wet

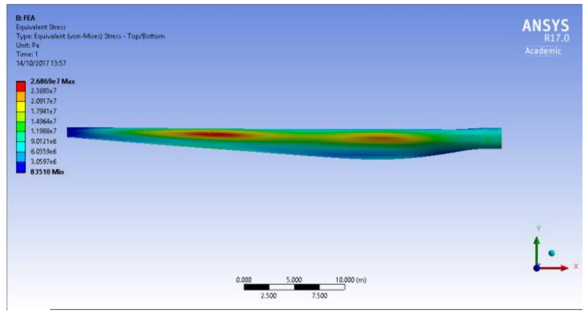

Figure 6: *Equivalent (von-Mises) stress distribution along the blade for Material 2*

Figure 6 for Material 2 – Epoxy E-Glass Wet shows a maximum stress of 26.869 MPa

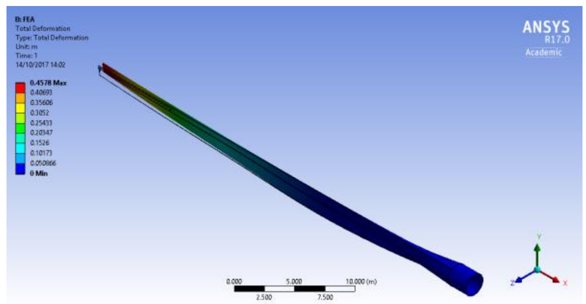

Figure 7: *Deformation distribution along the blade for Material 3*

Figure 7 for Material 3 – Epoxy Carbon UD (230 GPa) Prepreg shows a maximum total deformation of 0.4578 m at the tip of the wind turbine blade

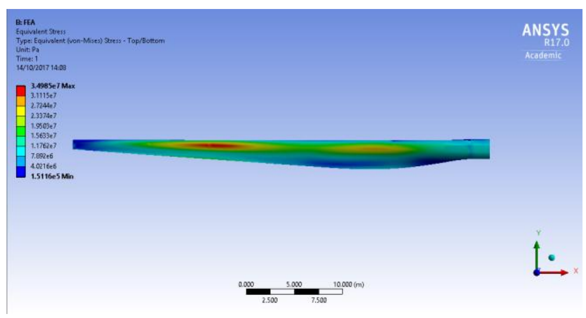

Figure 8: *Equivalent (von-Mises) stress distribution along the blade for Material 3*

In Figure 8 for Material 3 – Epoxy Carbon UD (230 GPa) Prepreg the von-Mises Stress distribution along the blade is depicted, showing a maximum stress of 34.985 MPa

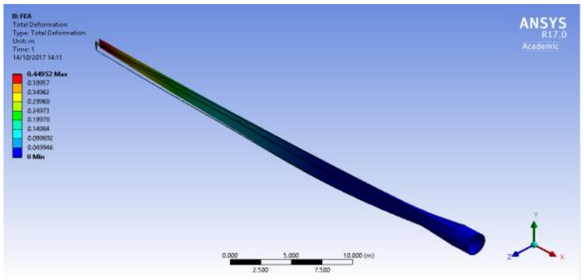

Figure 9: *Deformation distribution along the blade for Material 4*

Figure 9 for Material 4 – Epoxy Carbon UD (230 GPa) Wet shows a maximum total deformation of 0.44952 m at the tip of the wind turbine blade

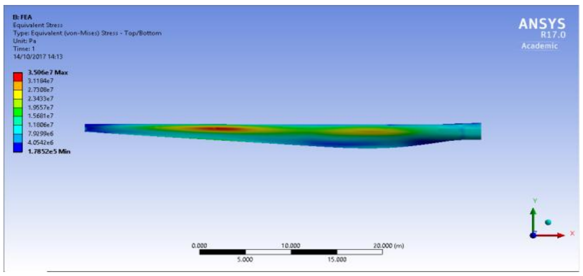

Figure 10: *Equivalent (von-Mises) stress distribution along the blade for Material 4*

Figure 10 for Material 4 – Epoxy Carbon UD (230 GPa) Wet shows a maximum stress of 35.06 MPa

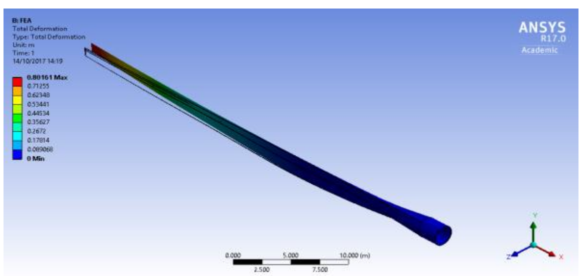

Figure 11: *Deformation distribution along the blade for Material 5*

In Figure 11 for Material 5 – Epoxy Carbon Woven (230 GPa) Prepreg the deformation distribution along the blade is depicted, showing a maximum total deformation of 0.80161 m at the tip of the wind turbine blade

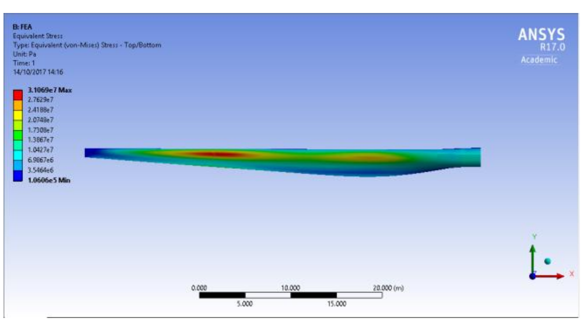

Figure 12: *Equivalent (von-Mises) stress distribution along the blade for Material 5*

Figure 12 for Material 5 – Epoxy Carbon Woven (230 GPa) Prepreg shows a maximum stress of 31.069 MPa

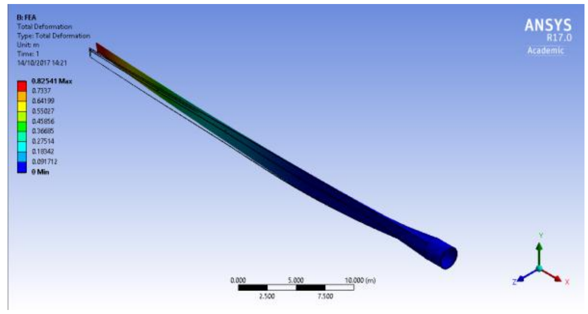

Figure 13: *Deformation distribution along the blade for Material 6*

Figure 13 for Material 6 – Epoxy Carbon Woven (230 GPa) Wet shows a maximum total deformation of 0.82541 m at the tip of the wind turbine blade

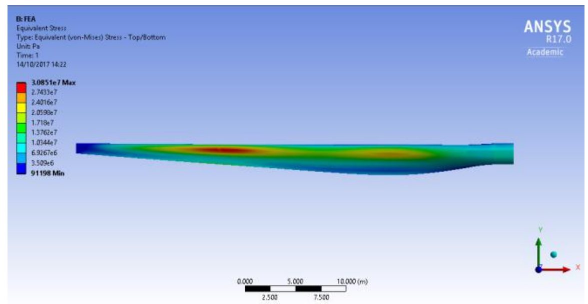

Figure 14: *Equivalent (von-Mises) stress distribution along the blade for Material 6*

Finally, Figure 14 for Material 6 – Epoxy Carbon Woven (230 GPa) Wet shows a maximum stress of 30.851 MPa

Discussion

The results of this work are analysed and presented in Figures 15 to 20.

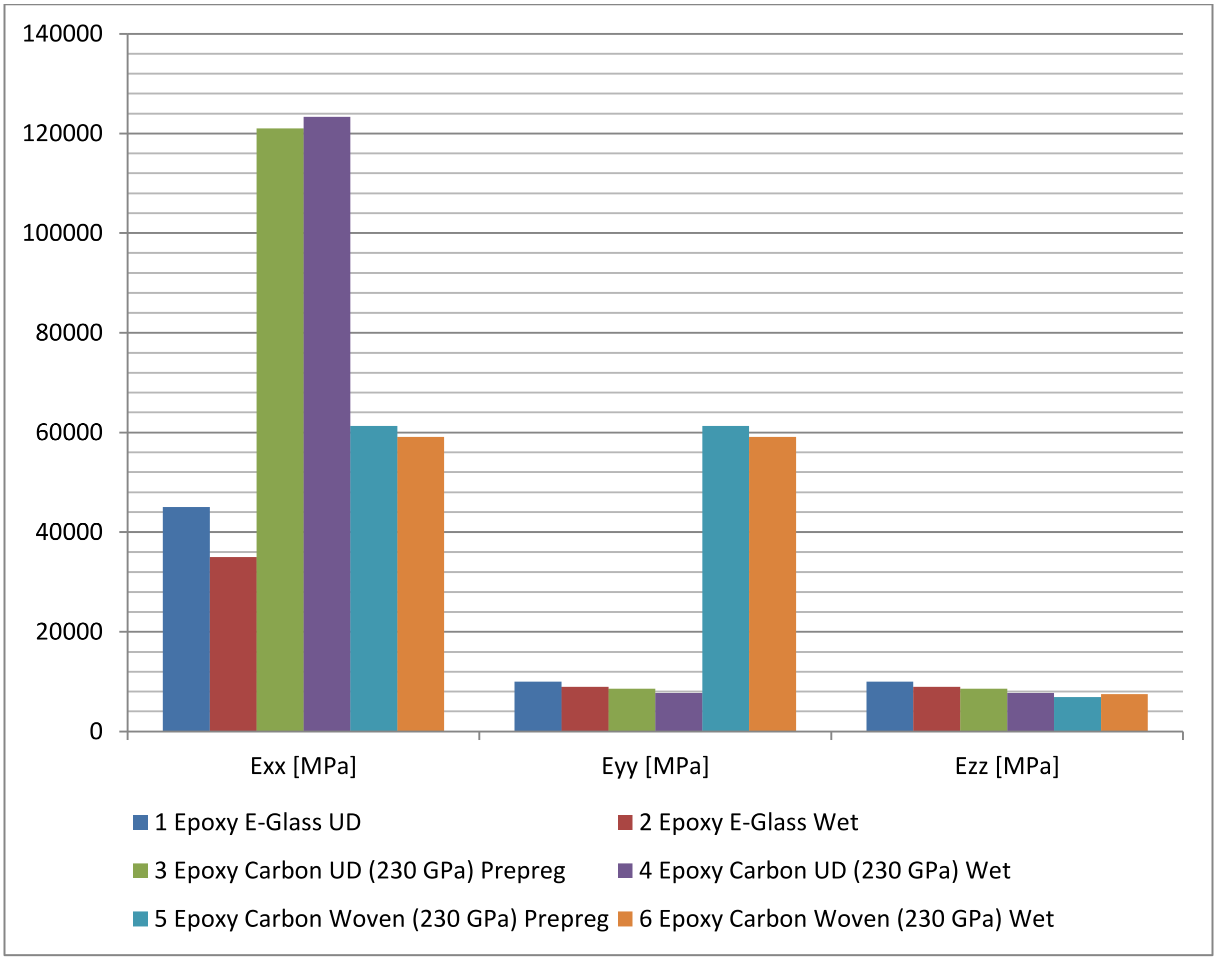

Figure 15: *Young's modulus in the x, y, and z directions for the simulated materials in the paper represented graphically*

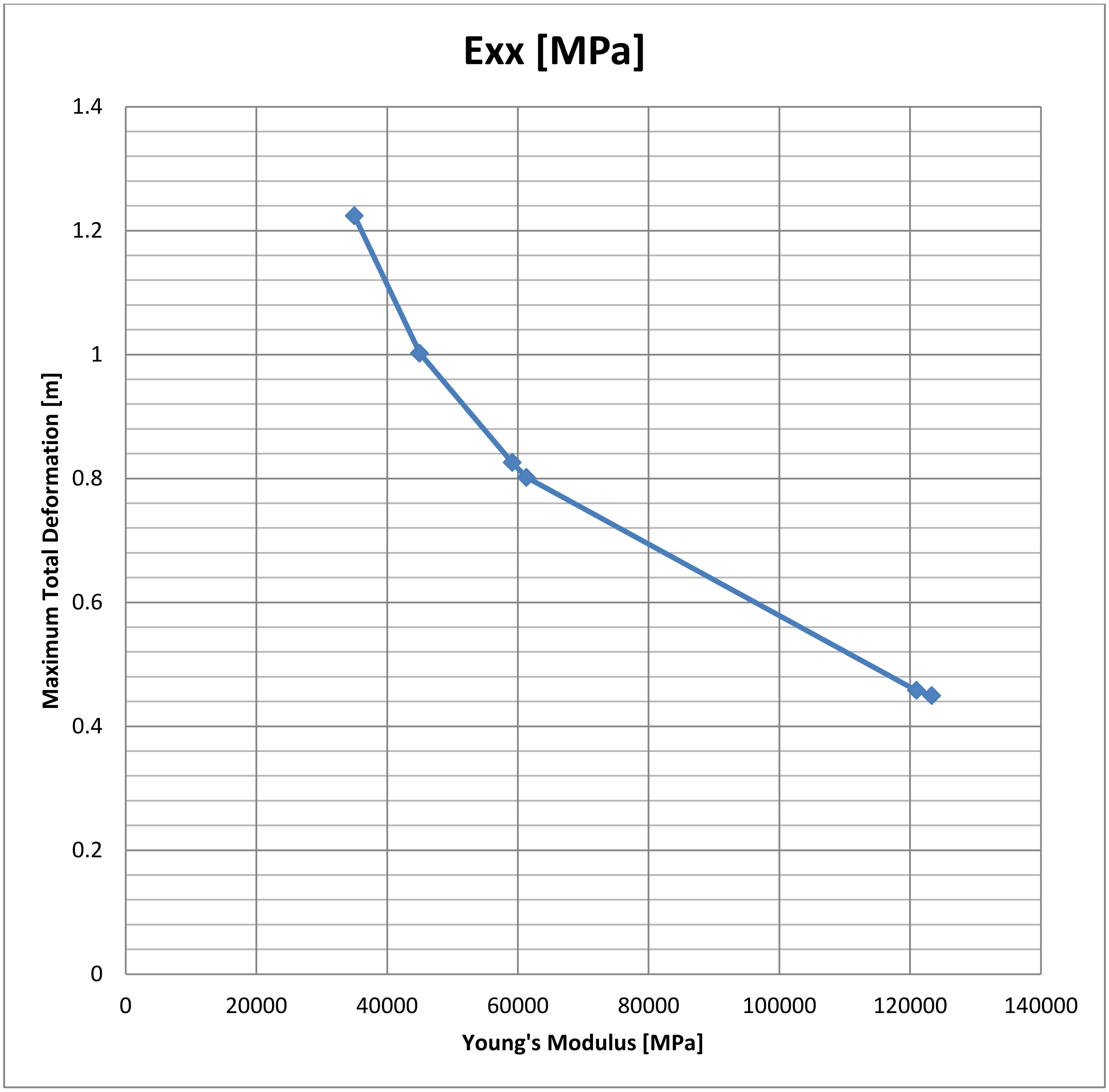

Figure 16: *Tip total deformation of the wind turbine blade decreasing with the increase in Young's modulus in the x direction. Each point on the plot represents a material.*

In Figure 15, Young's modulus in the x, y, and z directions for the simulated materials in the paper is represented graphically to facilitate comparing values and have an overview of the simulated materials. In Figure 16, each of the six materials is represented by one point using Exx values from Table 2 or from Figure 15. For example, material 1 is having Exx equals to 45000 MPa so from Figure 16, it is shown that it gives maximum tip total deformation of 1 m. It is also clear that the higher the Exx, the lower the maximum tip total deformation which is an expected result. According to this criteria, one could select the material with the lowest maximum total deformation (i.e. Materials 3 and 4) 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.

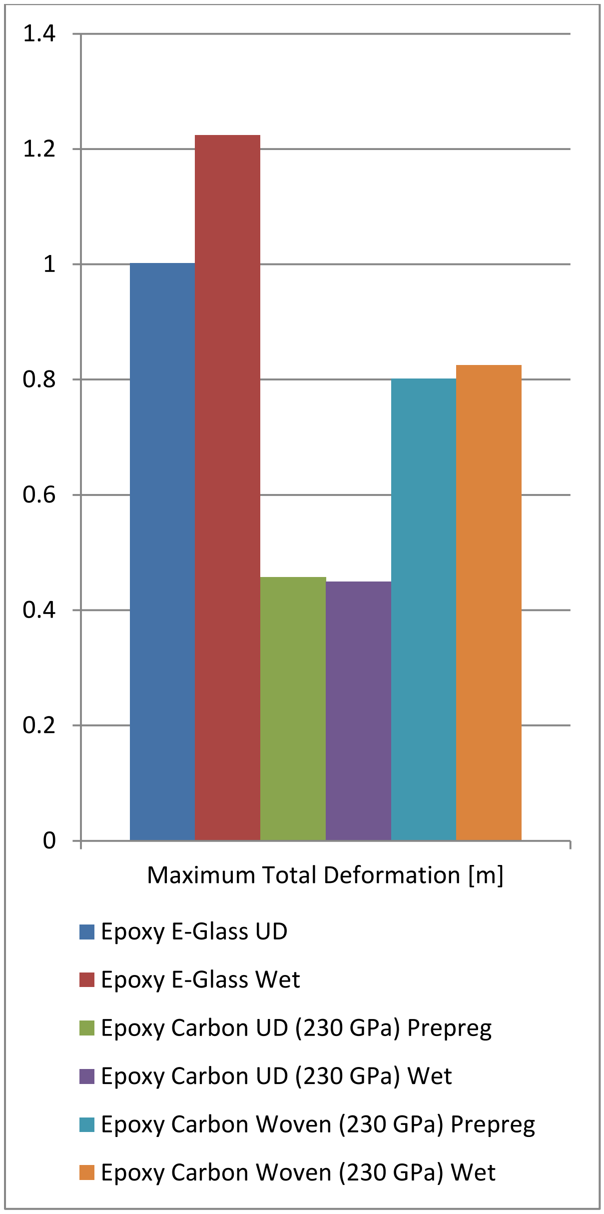

Figure 17: *Tip maximum total deformation in meters*

In Figure 17, tip maximum total deformation in meters are shown which is obtained from the ANSYS computer simulation for each of the materials simulated. From this figure one could conclude that the best materials are materials 3 and 4 but still material 1 is not to be excluded and stress limits must be examined for uni-directional materials in the directions y and z. This will be discussed in more details in the end of the discussion section and in the conclusion.

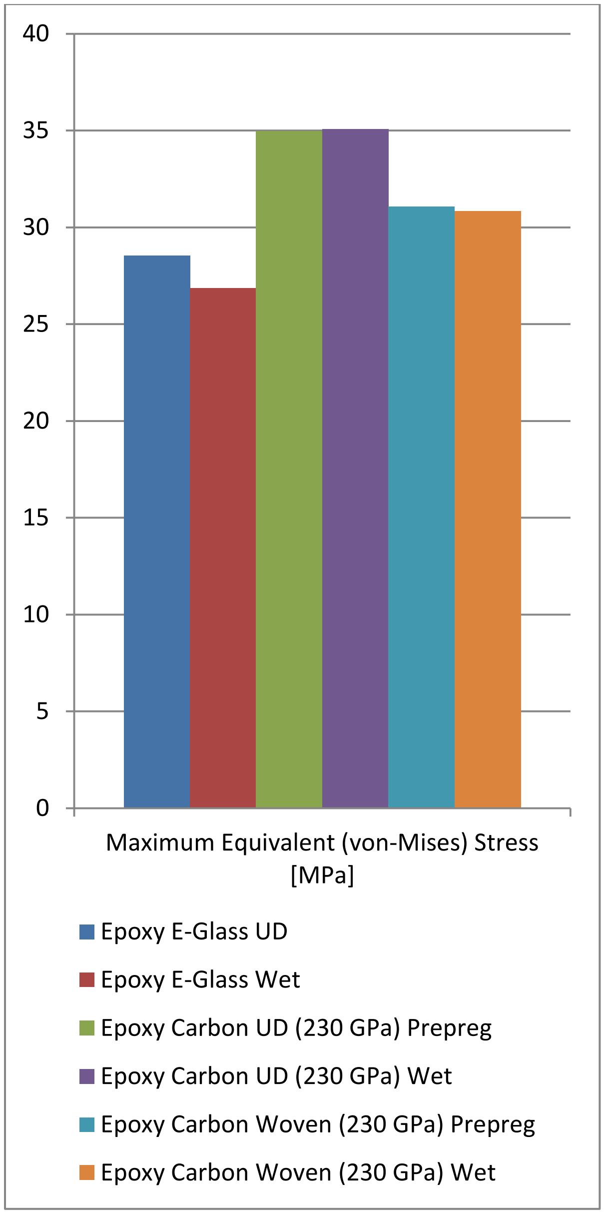

Figure 18: *Maximum equivalent (von-Mises) stresses in MPa*

In Figure 18, Maximum equivalent (von-Mises) stress in MPa are shown which is obtained from results obtained from the ANSYS computer simulation for each of the materials simulated. By comparing the results represented in Figure 18 with Exx values from Figure 15 we might think that the materials are very safe but since materials 1 to 4 are uni-directional (UD) the stress limits in the y and z directions are cruical in material selection.

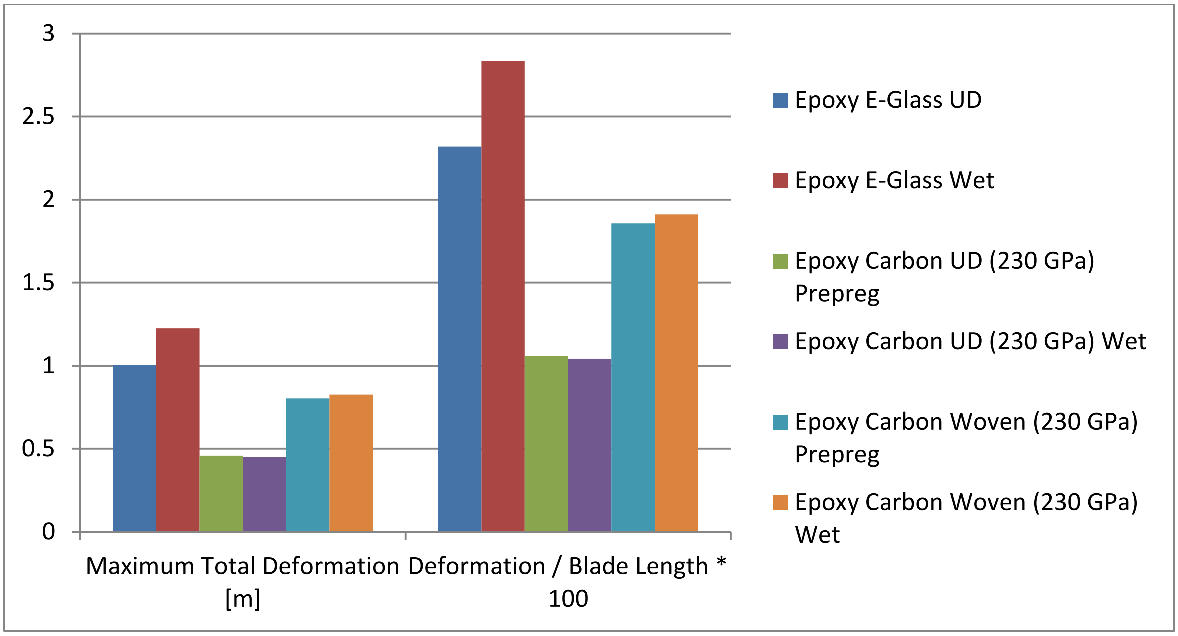

Figure 19: *Tip maximum total deformation in meters and in percentage of the blade length results obtained from the ANSYS computer simulation for each of the materials simulated*

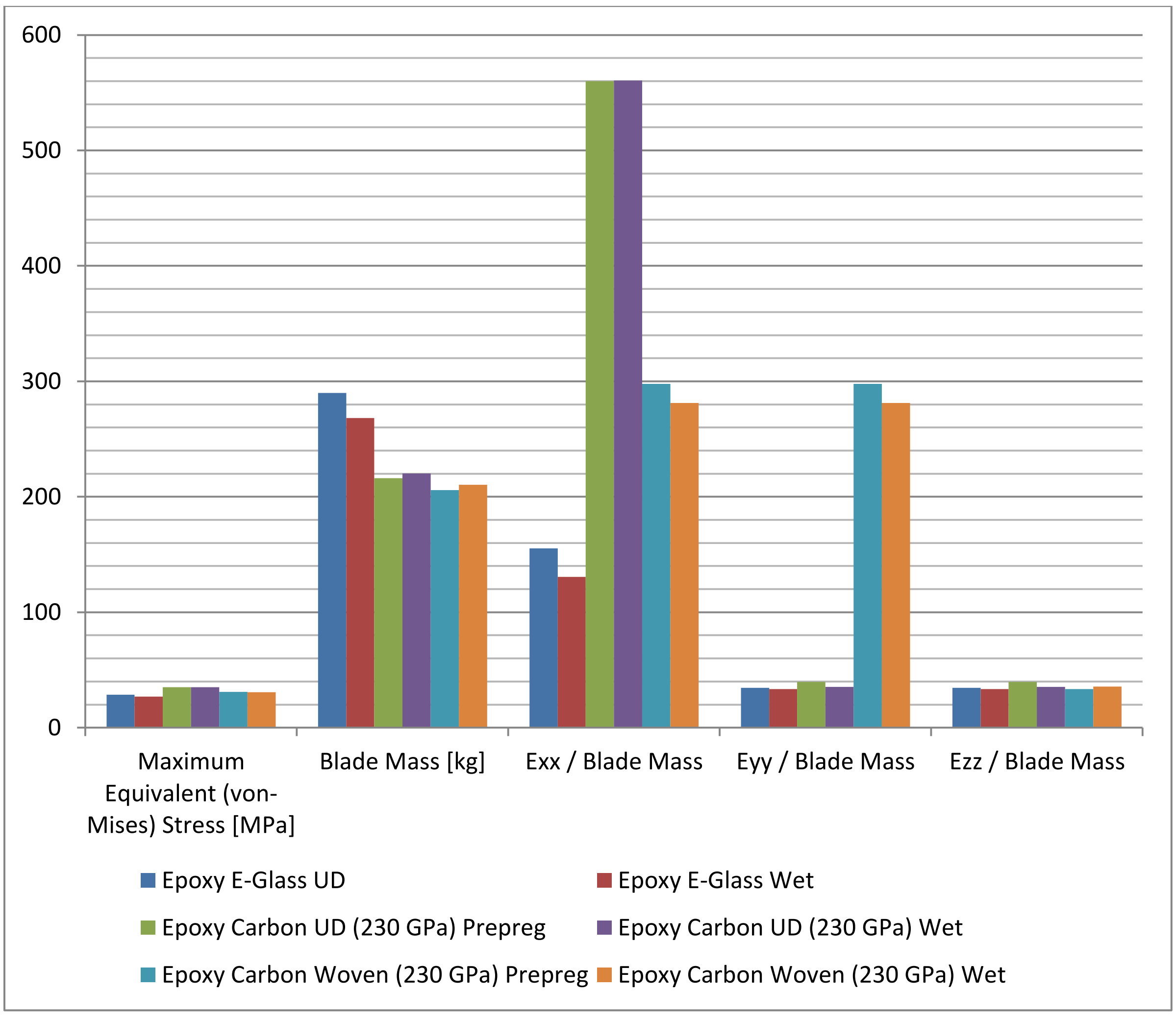

Figure 20: *Young's modulus per unit mass of the blade for the x, y, and z directions*

In Figure 19, 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 (43.2 m of length). Figure 20 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. From the discussions above, Epoxy E-Glass Unidirectional (Material 1), Epoxy Carbon UD (230 GPa) Prepreg (Material 3), and Epoxy Carbon UD (230 GPa) Wet (Material 4) were selected for conducting more analysis by determining their equivalent (von-Mises) strain distribution along the blade as given in Figure 21, 22, and 23.

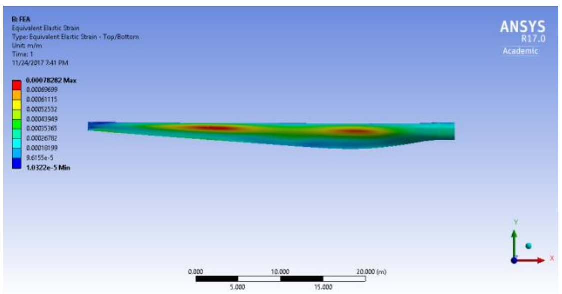

Figure 21: *von-Mises Strain distribution along the blade for Material 1*

Figure 21 *shows a maximum von-Mises strain of 0.000783 for Material 1 – Epoxy E-Glass UD*

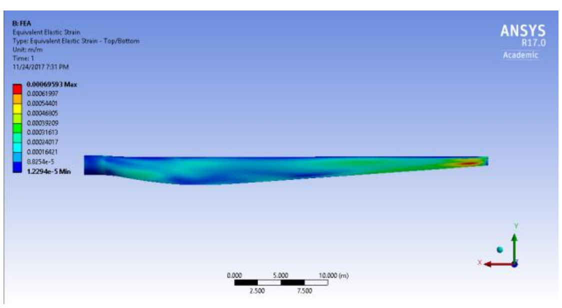

Figure 22: *von-Mises Strain distribution along the blade for Material 3*

Figure 22 *shows a maximum von-Mises strain of 0.000696 for Epoxy Carbon UD (230 GPa) Prepreg*

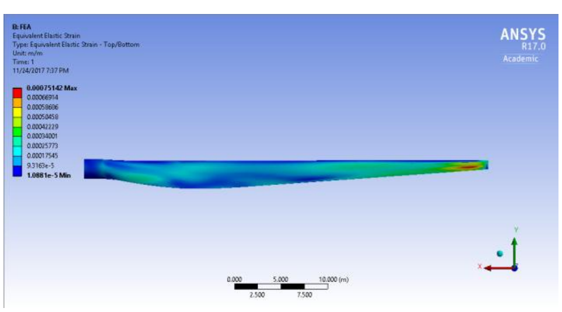

Figure 23: *von-Mises Strain distribution along the blade for Material 4*

Figure 23 *shows a maximum strain of 0.000751 for Epoxy Carbon UD (230 GPa) Wet*

Conclusion

The selected material for manufacturing wind turbine blade is Material 1 [Epoxy E-Glass UD], because it has maximum equivalent von-Mises Stress of 28.533 MPa which is lower than 31 MPa stress limit in the y and z direction. Also it has maximum von-Mises strain of 0.000783 as shown in Figure 21 which is below the strain limits 0.0244 in the x-direction and 0.0035 in the y and z directions of the composite material. Material 2 is excluded because the maximum total tip deformation of 1.224 m is higher than material 1 maximum total tip deformation of 1.002 m. Although Material 3 [Epoxy Carbon UD (230 GPa) Prepreg] and 4 [Epoxy Carbon UD (230 GPa) Wet] have the lowest tip maximum total deformation of 0.46 m, and 0.45 m respectively, since they are having the highest specific modulus (specific stiffness) of 560 MPa/Kg and the lowest maximum von-Mises strain of 0.000696, and 0.000751 respectively, as shown in Figure 22, and 23 respectively, which is below the strain limits 0.0032, 0.0026 of the composite materials (i.e. Materials 3 and 4). Yet, they were not because they have maximum equivalent von-Mises Stress of 34.985 MPa, and 35.06 MPa respectively which is higher than the safe tensile stress in the y or z direction of Material 3 and 4 (i.e. higher than 29 for Material 3 and 34 for Material 4). As for Materials 5 and 6 which are woven, they will be more expensive than the Unidirectional (UD) composite materials and there is no need for them according to the analysis since material 1 is sufficient. It is felt that because materials 5 and 6 are not selected since these materials are woven which will lead to higher manufacturing cost. Material 1 is considered the best material for the wind turbine blade.

References

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

[2]. ANSYS Academic R17.0 Computer Software Material Library

[3]. confluence.cornell.edu, Wind Turbine Blade FSI Part 1 from the internet website https://confluence.cornell.edu/pages/viewpage.action?pageId=262012971 of Confluence, Cornell University, USA

[4]. confluence.cornell.edu, Wind Turbine Blade FSI Part 2 from the internet website https://confluence.cornell.edu/pages/viewpage.action?pageId=262013005 of Confluence, Cornell University, USA

[5]. Finite Element Method course notes studied at the Technical University of Munich in the Computational Mechanics (COME) postgraduate program, Munich, Germany

[6]. Computational Fluid Dynamics course notes and lab studied at the Technical University of Munich in the Computational Mechanics (COME) postgraduate program, Munich, Germany

[7]. Materials and Numerical Methods courses notes studied at Ain Shams University in the Mechanical Design and Production MSc program, Cairo, Egypt

[8]. Kevin Cox and Andreas Echtermeyer "Structural Design and Analysis of a 10MW Wind Turbine Blade", Energy Procedia, Volume 24, 2012

[9]. F. W. Perkins and Duane E. Cromack "Wind Turbine Blade Stress Analysis And Natural Frequencies" Technical Report, University of Massachusetts, 1978

[10]. GE 1.5 MW Wind Turbine Brochure, http://geosci.uchicago.edu/~moyer/GEOS24705/Readings/GEA14954C15-MW-Broch.pdf

[11]. LearnEngineering internet website http://www.learnengineering.org/2012/12/what-is-von-mises-stress.html