Natural Fibre - Reinforced Polymer Hybrid Plastic Fabrication and Investigating its Effect on Wind Turbine Blade

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Abstract:

Wishes of the world for the renewable power resources and its utilization is extending day by day due to fast depletion of traditional fuels. Along these lines, researchers in the domain of renewable power source resources also extended especially in the scope of wind turbines. By 2030 each huge country of the world wishes to utilize wind turbines by 35% for their electrical needs. Many sorts of troubles are stood up to in the improvement of wind energy generation units, for instance, topology, geography, material costs, building difficulties, etc. Remembering the true objective to finish the world vision for wind energy and to give access to wind energy at low cost, this project goes for building a cheap material, Natural Fibre – Reinforced Polymer Hybrid Plastic (NRPHP) which can be used as a building material for wind turbine blades. NRPHP is made and tested for both thermal and mechanical properties. These properties are used in the design of wind turbine blade. The wind turbine blade is designed in Autodesk Inventor Professional(AIP) and Computational Fluid Dynamics (CFD) analysis and Finite Element Analysis (FEA) on the wind turbine blade is carried out in Solidworks Flow Simulation and Solidworks Simulation packages for its sustainability in real operating conditions.

Keywords: **NRPHP, CFD, Design, FEA, Simulations, Wind Turbine Blade, AIP, Renewable Energy, Analysis.**

I. INTRODUCTION

These days around the world there arises a need for the improvement of new sustainable energy technologies because of the depletion of the existing non-sustainable energy resources such as hydrocarbon fuels which obtain from foil reserves. So, every county is trying to develop various new sustainable energy technologies in their own manner according to their commitments.

Researchers are mainly focusing on the non-sustainable energy technologies which utilize fluid energy and convert it to electricity by using generators because of the drawbacks of usage of other renewable technologies such as their efficiencies. They are mainly focusing on the wind turbine technologies as they interact and work on a compressible fluid, air which enables engineers to design and manufacture the power generation unit using various types of plastics, alloys, and metals.

Twenty-first-century materials such as fibre reinforced composites became the main material for manufacturing the wind turbine blades with larger span due to their good mechanical properties, lightness, high strength to weight ratio, and the simplicity in fabrication techniques. Currently, carbon fiber reinforced plastics are utilized in the fabrication of wind turbine blades. The carbon fiber reinforced plastic is a good material for the fabrication of wind turbine blade but its cost is high.

The improvement in the fibre reinforcements results in cost reduction. So, the examinations and improvement for the better reinforcement material should be done for a cheap cost and better wind turbine blades assume there will be an increase in the performance and efficiency of the wind turbine.

This paper aims at describing the procedure for modeling of the wind turbine blade using NACA 4424 airfoil in its design and analyzes it with the materials; ABS PC, GFRP and Nylon 6 10. A new composite material is made and its mechanical properties are evaluated using experimental and numerical approaches. The Cotton Fibre Reinforced Plastic (CFRP) and Cotton

- Jute Fibre Reinforced Plastic (CJFRP) are the two natural, friendly composite plastics whose test pieces are made by using the open casting method and evaluated experimentally by using UTM. Then these properties are incorporated into the design and analysis process.

Autodesk Inventors Professional (AIP) is used to design the wind turbine blade. The CFD and FEM analysis are carried out in Solidworks Flow Simulation and Solidworks Simulation packages. The evaluated properties of the wind turbine blade using the above materials are benchmarked and the best is suggested.

II. GOVERNING EQUATIONS

CFD: Computational Fluid Dynamics (CFD) is governed by the formulations of momentum, energy and mass equations which are given in Navier-Stokes equations.

A. Mass Conservation Equation (Equation of continuity):

Mass conservation equation is given as:

$$\frac{\partial \rho}{\partial t} + \nabla.[\,\rho\vec{v}\,] = 0 \qquad (1)$$

Where ρ = density and $\nu =$ velocity of the fluid.

B. Momentum Conservation Equation:

Momentum conservation equation is given as:

$$\rho\left[\frac{\partial \vec{v}}{\partial t} + (\vec{v}.\nabla)\vec{v}\right] = f \qquad (2)$$

Where f = external force/ unit volume and f acts on the material volume.

C. Energy Conservation Equation:

Energy conservation equation is given as:

$$\frac{\partial}{\partial t}(\rho e) + \nabla.[\,\rho\vec{v}e\,] = -\nabla.\left(\sum_j h_i J_j\right) + S_h \qquad (3)$$

*FEA:*The analysis was done using the finite element methods (FEM) and simulations are known as finite element analysis (FEA). FEA is used as a part of simulations to the wind turbine blade sustainability at real operating conditions using the previously discussed composite materials.

A.Pre-processing: In this stage, the FE mesh for the modeled design is done and boundary conditions, properties of materials, and loads are applied to the composed model.

B. Solution: In this stage, the answers to the obtained problems for the stated loads and boundary conditions. The outcomes, for example, Von Mises stress, displacements, strain, thermal impacts, and so on will obtain at this stage.

C. Post-processing: In this stage, the pictographically results known as contours, graphs,and deformed shapes are obtained. This progression helps in the investigating, confirmation and approval of results.

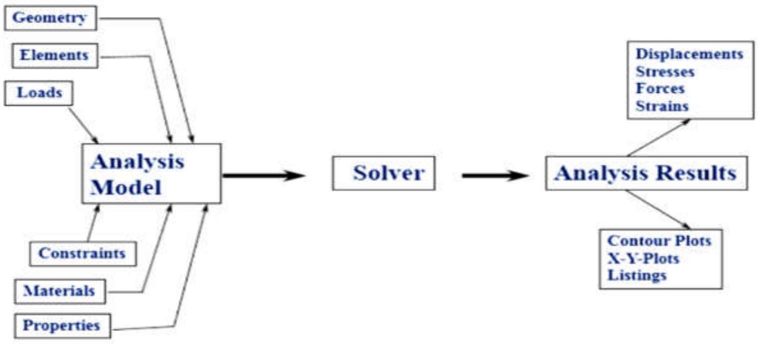

Fig. 1: FEA process chart

III. MATERIAL, AIRFOIL AND SPECIMEN CHARACTERISTICS

A. Material Characteristics:

The material properties of the materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP as shown in Table I.

Table I
Material Properties

Material	Yield strength (N/m^2)	Tensile strength (N/m^2)	Elastic modulus (N/m^2)	Mass Density (kg/m^3)
ABS PC	2.9e+07	4e+07	2.41e+09	1070
GFRP	2.875e+09	2.05e+09	8.5e+10	2580
Nylon 6 10	1.391e+08	1.4255e+08	8.3e+09	1400
CFRP	1.83e+06	1.89e+06	1.89e+07	1230
CJFRP	2.01e+06	2.07e+06	2.25e+07	1227

B. Airfoil Characteristics:

The characteristics and performance details of the NACA 4424 airfoil are listed in Table II.

Table II
NACA 4424 Details

Details	NACA 4424
Thickness	24.01%
Camber	4.01%
Trailing edge angle	27.01°
Lower flatness	3.21%
Leading edge radius	5.61%
Efficiency	36.11
Max C_L	2.2551
Max C_L angle	15.01
Max L/D	95.6281
Max L/D angle	-0.51
Max L/D C_L	0.5211
Stall angle	-0.51
Zero-lift angle	-5.01

C. Specimen Characteristics:

The properties of the specimens tested on the UTM are shown in Table III.

Table III
Specimen Properties

Properties	CFRP	CJFRP
Elastic modulus	18.9 N/mm^2	22.5 N/mm^2
Poisons Ratio	0.3	0.3
Yield strength	1.83 N/mm^2	2.02 N/mm^2
Ultimate TensileStrength	1.89 N/mm^2	2.07 N/mm^2
Mass Density	1230	1227
Thermal Conductivity	0.22 W/m.K	0.22 W/m.K
Elongation Percentage	10%	9.21%

IV. DESIGN AND ANALYSIS

A. Design of Wind Turbine Blade:

The wind turbine blade geometry is modeled in AIP. The dimensions of the wind turbine blade are shown in Figure 2.

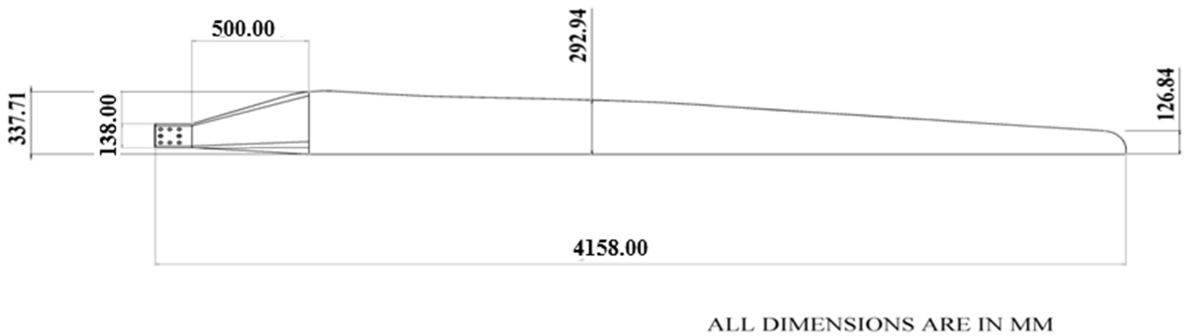

Fig. 2: Wind Turbine Blade

Volumetric properties of the wind turbine blade models are represented in Table IV.

Table IV
Volumetric Properties

Model With Material	Mass (kg)	Volume (m^3)	Density (kg/m^3)	Weight (N)
ABS PC	45.044	0.042091	1070.1	441.43
GFRP	108.61	0.042091	2580.3	1064.3
Nylon 6 10	58.936	0.042091	1400.2	577.57
CFRP	51.779	0.042091	1230.1	507.44
CJFRP	51.653	0.042091	1227.1	506.20

B. Analysis of Wind Turbine Blade:

The CFD and FEA analysis are carried out on wind turbine blade at real ambient conditions.

CFD Analysis:

The CFD analysis is done in Solidworks Flow Simulation package. Finite volume methods (FVM) are used for CFD analysis. Tetrahedron shaped cells and Cartesian immersed body type of meshing is used in the grid generation. The count of cells is shown in Table V.

Table V
Cells Count

Model	Fluid cells	Solid cells	Partial cells	Total cells
Wind Turbine Blade	516089	18587	11561	546237

Simulation parameters:

The flow parameters, initial and boundary conditions at which the wind turbine blade is analyzed are shown in Table VI.

Table VI
Boundary Conditions

Parameters	Wind Turbine Blade
Solver	FFEplus
Turbulence model	$k - \varepsilon$
Velocity (m/s)	8.6
Initial pressure (Pa)	101336
Initial temperature(K)	300
Boundary type	Real wall
Humidity	69%

FE Analysis:

The FEA is carried out on the wind turbine blade using Solidworks Simulation package. Finite element methods are used to discretize the model in FEA. Mesh type, type of element used for meshing, Jacobian points and solver type used in the FE analysis of wind turbine blade in Solidworks Simulation software are shown in Table VII.

Table VII
Analysis

Mesh	**Solid mesh**
Mesh Element	Tetrahedron
Jacobian points	4
Solver	FFEPlus

Figure 3 shows the meshes wind turbine blade.

Figure 3: Wind Turbine Blade Meshing

Detailed Meshing Information:

The detailed meshing information of wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are shown in Table VIII.

Table VIII
Meshing Information

Mesh Details	FEA
Mesh type	Solid mesh
Mesh Element Type	Tetrahedron
Jacobian points	4
Element Size	17.3994 mm
Tolerance	0.869969 mm
Total Nodes	90438
Total Elements	55938
Maximum Aspect Ratio	20.402
Percent of elements with Aspect Ratio < 3	97.2
Percent of elements with Aspect Ratio > 10	0.467
Percent of distorted elements(Jacobian)	0

The mesh details for the model of a wind turbine using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are same.

V. RESULTS AND DISCUSSIONS

CFD Results:

The CFD analysis performed on the wind turbine blade results in the plots for drag force, maximum velocity, maximum shear force and tables of minimum and maximum values for different parameters of CFD results are Shown below:

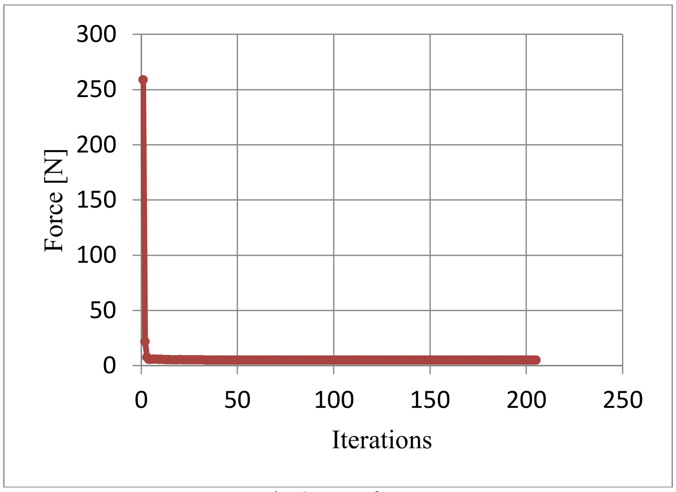

Fig. 3: Drag force

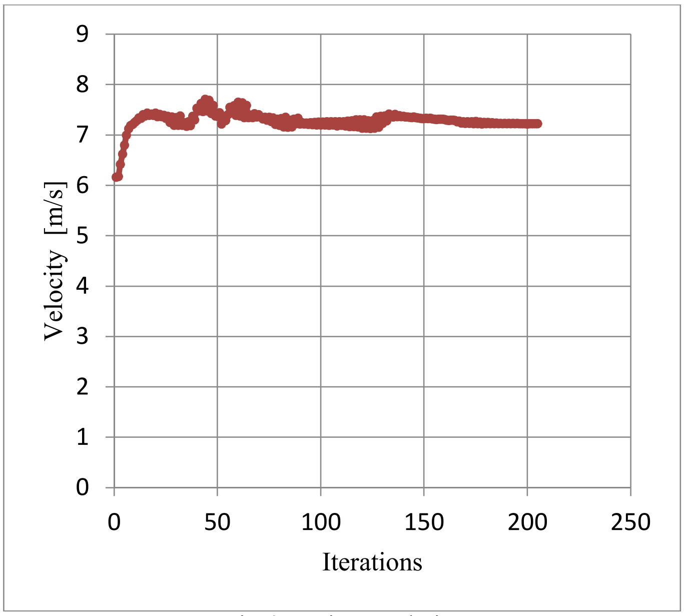

Fig. 4: Maximum Velocity

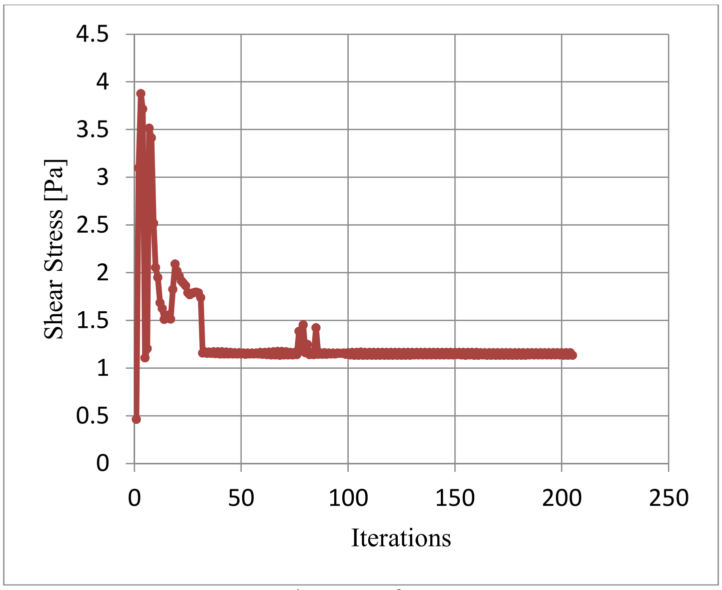

Fig. 5: Drag force

The maximum and minimum values are tabulated in Table IX for all iterations.

Table IX
Boundary Parameters

Parameter	Minimum	Maximum
Density (Fluid) [kg/m3]	1.17	1.17
Pressure [Pa]	101254.95	101398.26
Temperature [K]	299.96	300.04
Temperature (Fluid) [K]	299.96	300.04
Velocity [m/s]	0	11.613
Mach number	0	0.03
Shear Stress [Pa]	0	1.14

Velocity and pressure cut plots are as follows:

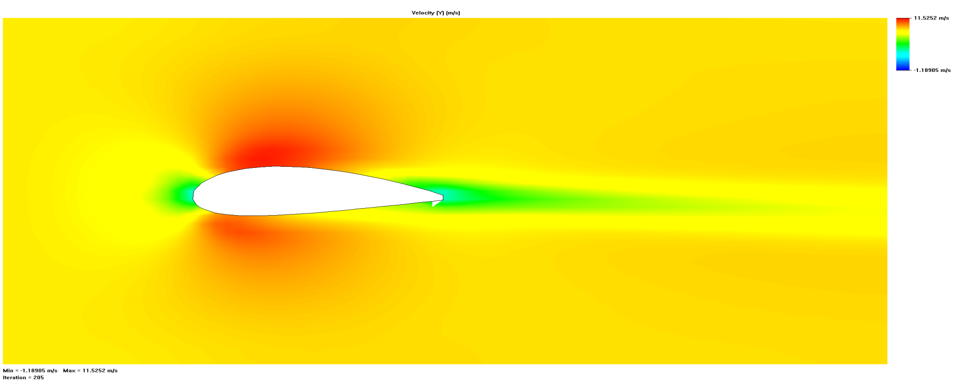

Fig. 6: Velocity cut plot

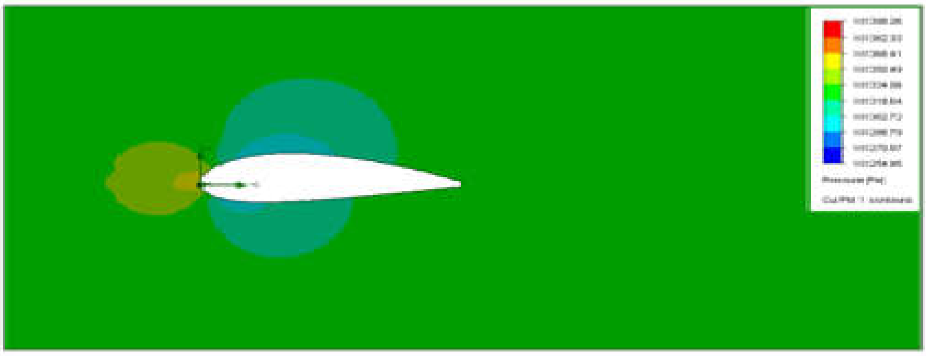

Fig. 7: Pressure cut plot

FE Analysis:

The FEA simulations on the wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP results in Von Mises stress, URES displacement, ESTRN strain and a factor of safety (FOS). The obtained results are shown below:

The failure criterion used is Von Mises stress failure criterion. The minimum and maximum value of Von Mises Stress on the wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are tabulated in Table X.

Table X
Von Mises stresses

Model With Material	Von Mises Stress (minimum) [N/m^2]	Von Mises Stress (maximum) [N/m^2]
ABS PC	4.449e+01 Node: 90419	1.028e+07 Node: 67848
GRFP	9.424e+01 Node: 90422	2.612e+07 Node: 67848
Nylon 6 10	5.356e+01 Node: 90419	1.403e+07 Node: 67848
CFRP	4.784e+01 Node: 90419	1.226e+07 Node: 67848
CJFRP	4.773e+01 Node: 90419	1.223e+07 Node: 67848

The minimum and maximum values of URES displacement of the wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are tabulated in Table XI.

Table XI
URES Displacement

Model With Material	URES Displacement (minimum)[mm]	URES Displacement (maximum)[mm]
ABS PC	0.000e+00 Node: 3296	3.512e+01 Node: 90437
GRFP	0.000e+00 Node: 3296	2.399e+00 Node: 90437
Nylon 6 10	0.000e+00 Node: 3296	1.334e+01 Node: 90437
CFRP	0.000e+00 Node: 3296	5.150e+03 Node: 90437
CJFRP	0.000e+00 Node: 3296	4.315e+03 Node: 90437

The minimum and maximum values of ESTRN strain on the wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are tabulated in Table XII.

Table XII
ESTRN values

Model With Material	ESTRN Strain (minimum)	ESTRN Strain (maximum)
ABS PC	1.296e-08 Element: 23976	3.252e-03 Element: 15827
GRFP	7.110e-10 Element: 23976	2.034e-04 Element: 15827
Nylon 6 10	4.212e-09 Element: 23976	1.167e-03 Element: 15827
CFRP	1.668e-06 Element: 23976	4.559e-01 Element: 15827
CJFRP	1.397e-06 Element: 23976	3.820e-01 Element: 15827

The minimum and maximum values of factor of safety (FOS) on the wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are tabulated in Table XIII.

Table XIII
Factor of Safety Values

Model With Material	FOS (minimum)	FOS (maximum)
ABS PC	2.820e+00 Node: 67848	3.000e+00 Node: 1
GRFP	3.000e+00 Node: 1	3.000e+00 Node: 1
Nylon 6 10	3.000e+00 Node: 1	3.000e+00 Node: 1
CFRP	1.493e-01 Node: 67848	3.000e+00 Node: 1
CJFRP	1.643e-01 Node: 67848	3.000e+00 Node: 1

The Von Mises stress for the materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are shown from figure 6 to figure 10.

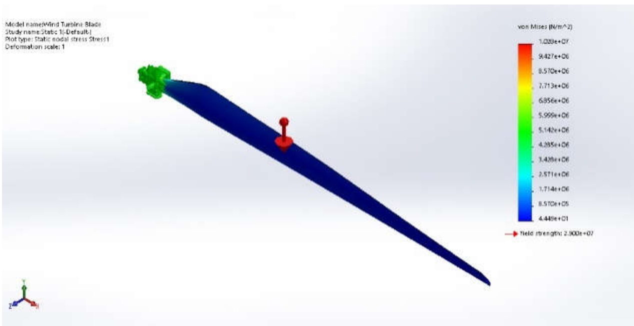

Fig. 6: ABS PC Von Mises stress

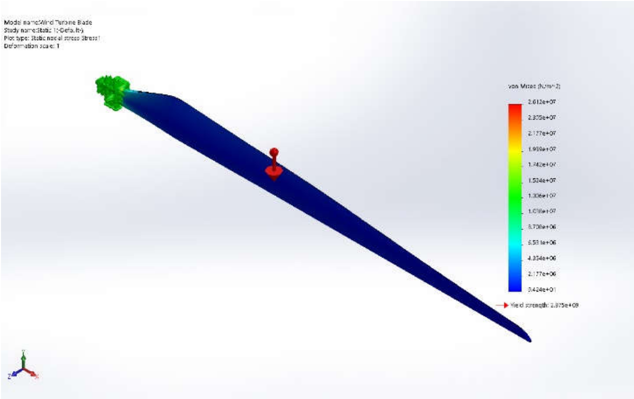

Fig. 7: GFRP Von Mises stress

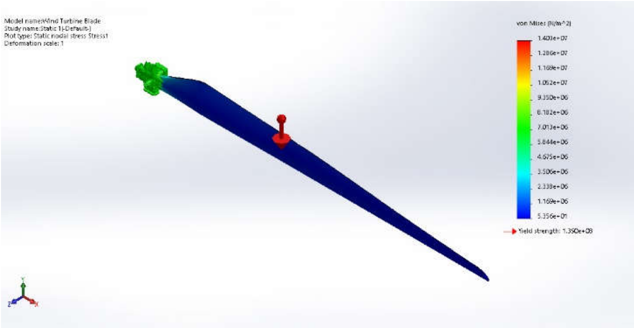

Fig. 8: Nylon 6 10 Von Mises stress

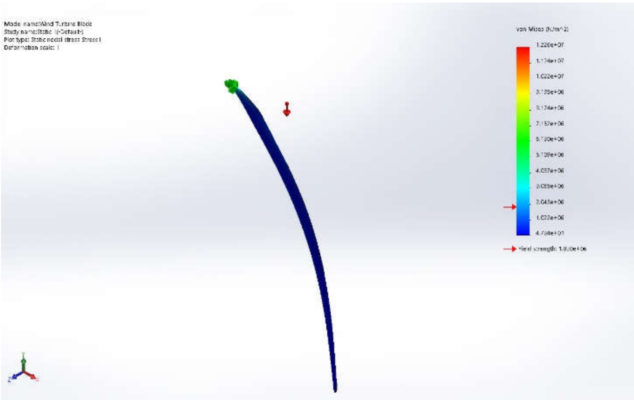

Fig. 9: CFRP Von Mises stress

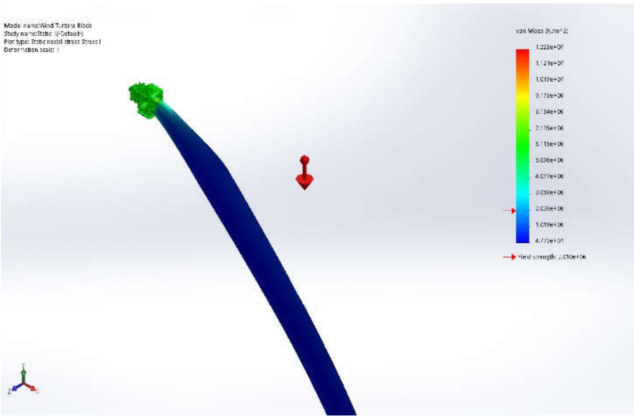

Fig. 10: CJFRP Von Mises stress

The FOS variation with respect to nodes models modeled with the materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are shown from figure 11 to figure 15.

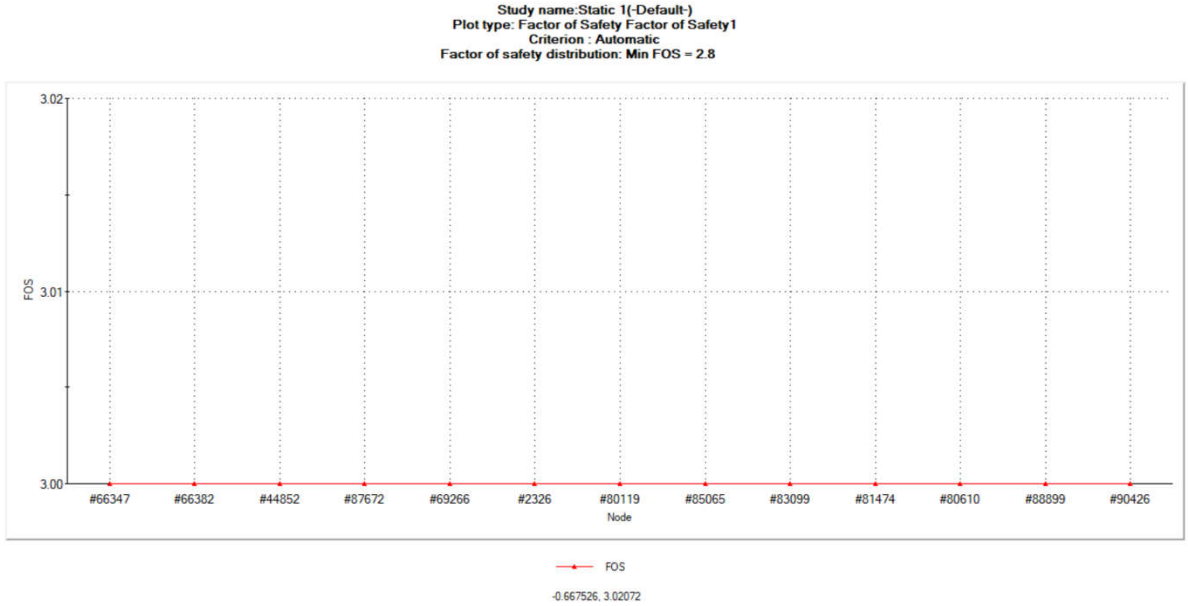

Fig. 11: ABS PC FOS

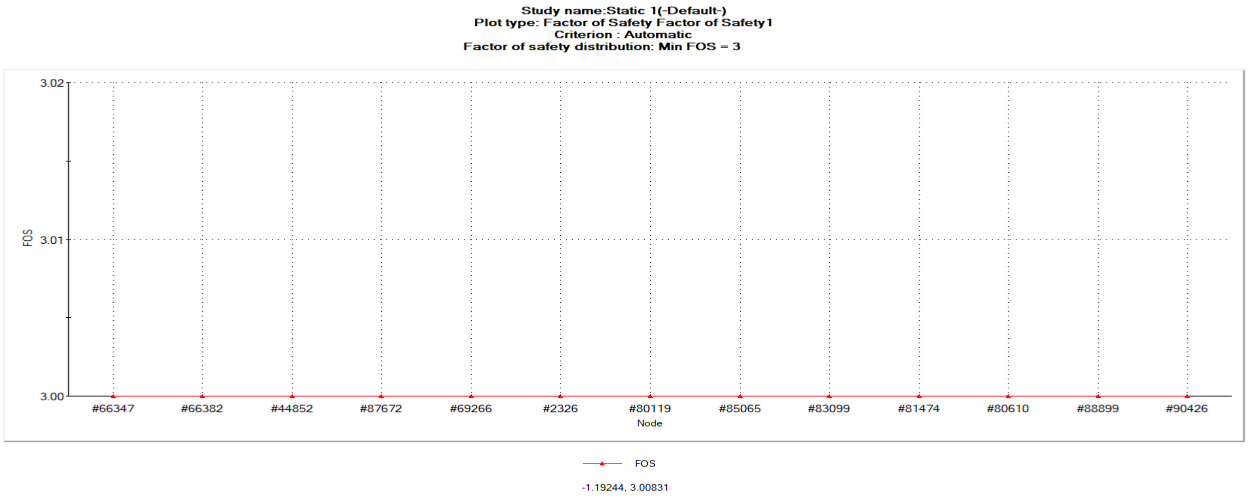

Fig. 12: GFRP FOS

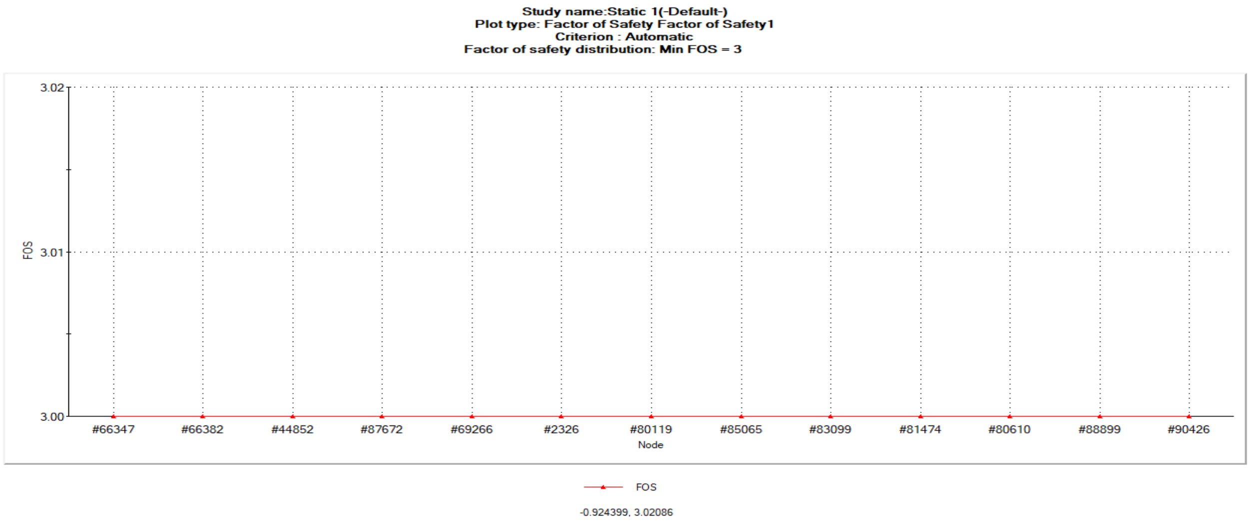

Fig. 13: Nylon 6 10 FOS

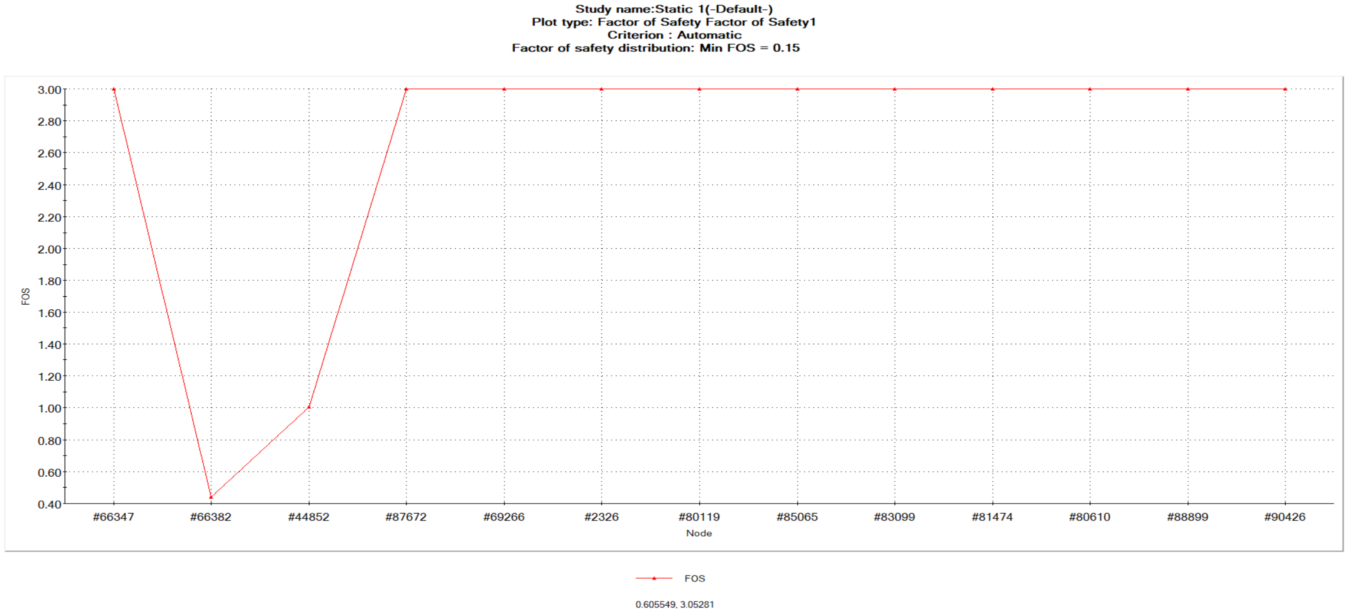

Fig.14: CFRP FOS

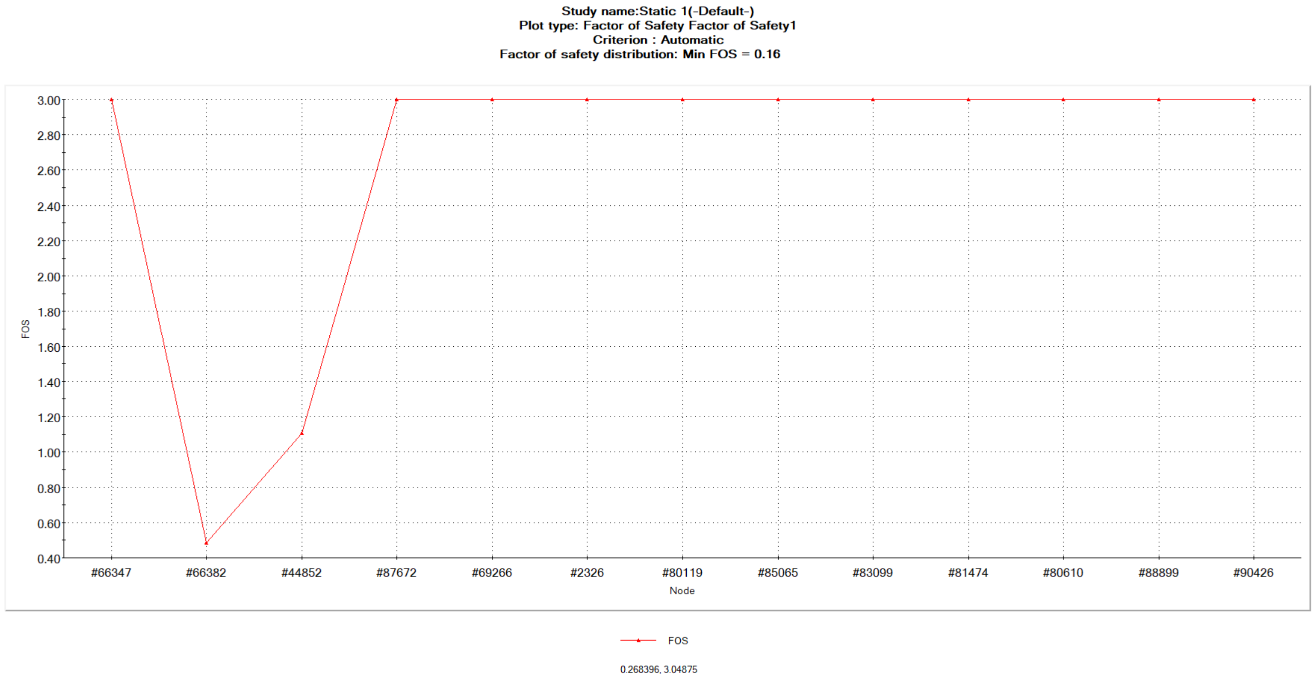

Fig. 15: CJFRP FOS

Results Interpretation:

From the CFD analysis, the forces exerting on the wind turbine blade due to air are computed which are utilized as the forces in the FE analysis. From the table 1 to table 10, we can see that GFRP exhibited the best sustainability. The sustainability order of materials ABS PC, GFRP, and Nylon 6 10 based on the Von Mises failure criterion are GFRP > Nylon 6 10 > ABS PC. CFRP and CJFRP showed less sustainability to the modeled blade since their Von Mises stress values are greater than the material yield strength.

VI. CONCLUSION

The wind turbine blade modeled using AIP is analyzed at real operating conditions using Solidworks Flow Simulation software considering air as working fluid to obtain various stress acting on the wind turbine blade results from the action of air on the blade. The observations made from FEA on the wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are as follows:

1) The minimum and maximum values of Von Mises stress of the modeled wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP,and CJFRP are ***4.449e+01N/m²***for ABS PC and ***2.612e+07N/m²***for GFRP.
2) The minimum and maximum values of URES displacement of the modeled wind turbine blade using materials ABS PC, GFRP, Nylon 6 10,CFRP and CJFRP are ***0.000e+00 mm*** for all the five materials and ***5.150e+03mm***for CFRP.
3) The minimum and maximum values of ESTRN stain of the modeled wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are ***7.110e-10***for GFRP and ***4.559e-01*** for CFRP.
4) The minimum and maximum values of FOS of the modeled wind turbine blade using materials ABS PC, GFRP, Nylon 6 10, CFRP and CJFRP are ***1.493e-01*** for CFRP and ***3.000e+00***for all the five materials.

The design of the wind turbine blade is successful since the FOS resulted in considering the materials ABS PC, GFRP, and Nylon 6 10 is above 2. But in the case of CFRP and CJFRP, the Von Mises stresses are above the yield strength of the respective materials. As a result, the blade started bending.

The newly fabricated materials exhibited some good mechanical properties but they cannot be used for the wind turbine blade modeled in this study at the considered operating conditions. However, the materials CFRP and CJFRP can be used for wind turbine blades with shorter span and where the atmospheric conditions are less than the considered characteristics of the working fluid used as a part of the study.

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