A COMPARATIVE STUDY OF STRUCTURAL AND MODAL ANALYSIS ON SAVONIUS VAWT BLADE MADE OF STAINLESS STEEL AND GFRP MATERIALS USING ANSYS

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ABSTRACT

This paper studies savonius type Vertical Axis Wind Turbine(VAWT) systems with the goal of maximizing the efficiency and reducing the cost. The efficiency of the wind turbine depends on the material, angle and shape of the blade. So material plays an important role in the design of wind turbine. In this paper, Stainless Steel and GFRP materials are used to design savonius wind blades of 1 m height and 0.5 m chord length with 4 different arc radii.

For this purpose, Solid Works is used to model savonius wind blade and static structural and modal analysis of the Stainless Steel and GFRP blades are done by using ANSYS Workbench software.

Key Words: VAWT, Solid Works, Stainless Steel, GFRP,ANSYS.

DESIGN CALCULATION

The relationships between wind power, swept area, air density and wind speed are given by below equation.

$$P_w = \frac{1}{2} \rho A V^3$$

Where P_w = Power of the wind (W)

ρ = Air density = 1.23 kg/m^3

$A = D \times H = 1 \times 1 = 1\ m^2$

V = Wind speed in m/s

The output of a rotating body is obtained from the product of torque and angular speed.

$$P = M * \omega$$

P = Output in N-m/s (1 N.m/s = 1W)

M = Torque in N-m

ω = Angular speed / s = $2 \pi n / 60$

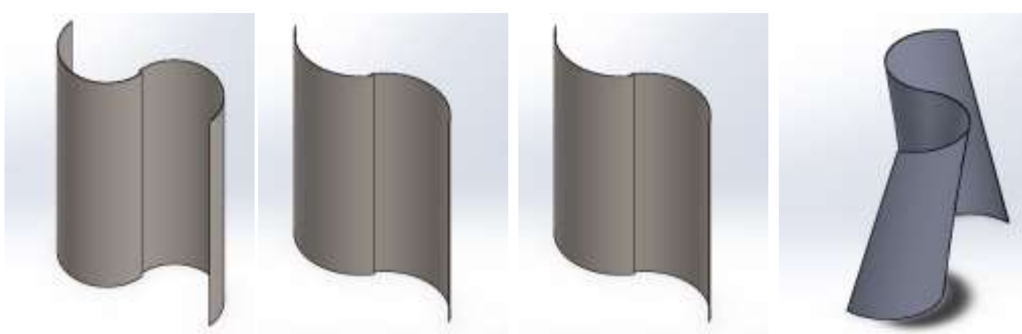
According to Betz's law, the maximum power that is possible to extract from a rotor is

$$P_{max} = 16/27 * 1/2 * \rho * A * v^3$$

Table 1 Power and Torque of the proposed wind turbine for various wind speeds

SL. NO	WIND SPEED (m/s)	ANGULAR SPEED (rad/sec)	ROTATIONAL SPEED (RPM)	P_{max} (Watts)	Torque (N-M)
1	5	10	96	45.36	4.54
2	6	12	115	78.38	6.53
3	7	14	134	124.46	8.89
4	8	16	153	185.78	11.61
5	9	18	172	264.52	14.70
6	10	20	191	362.85	18.14
7	11	22	210	482.95	21.95
8	12	24	229	627.00	26.13
9	13	26	248	797.18	30.66
10	14	28	267	995.66	35.56
11	15	30	287	1224.62	40.82

DESIGN OF SAVONIUS BLADE WITH FOUR DIFFERENT SHAPES



R250 mm R300mm R350 mm Twisted blade

Fig.1 : Different shapes of Wind blades

Dimension : Height : 1000 mm, Rotor Diameter : 1000 mm, Thickness : 3 mm

Each Blade has same chord length of 500 mm with different arc radius.

STATIC STRUCTURAL ANALYSIS OF WIND BLADE

All the four different shapes of stainless steel blades and GFRP blades are analyzed with different loads of 500N, 1000N, 1500N and 2000N. The results are tabulated and the comparisons of the results are plotted.

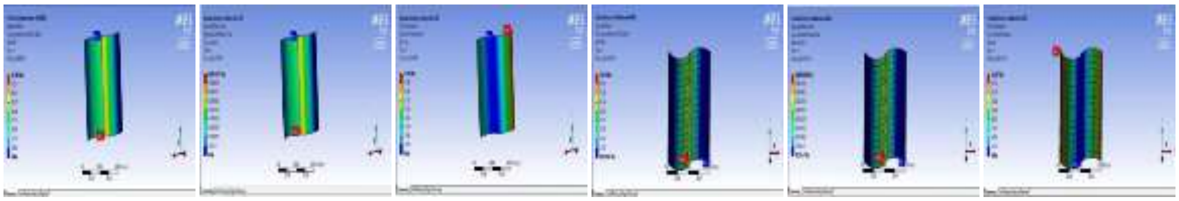


Fig.2 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 500N for Steel

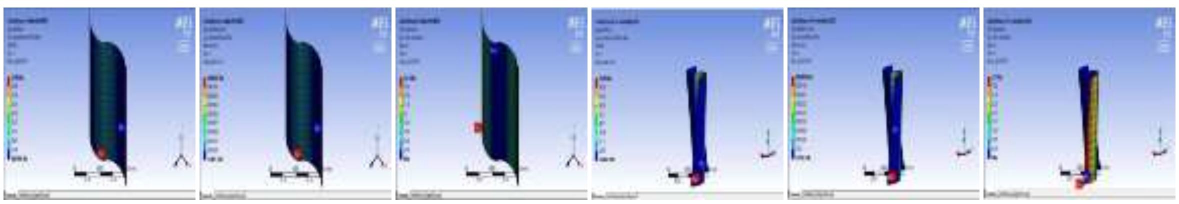


Fig.3: Stress, Strain & Deformation for R350mm & Twisted with R250mm in 500N for Steel

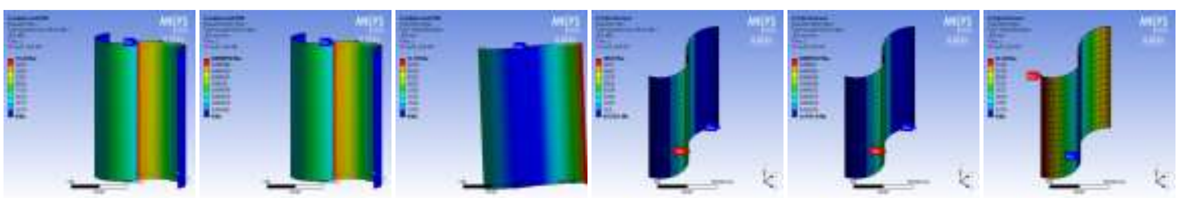


Fig.4 :Stress, Strain and Deformation for R250 mm and R300 mm in 1000N loads for Steel

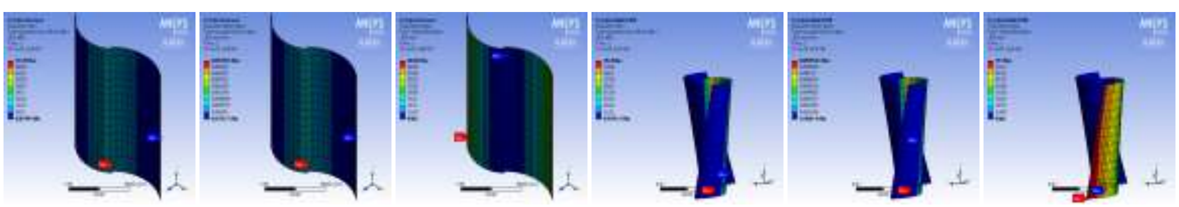


Fig.5 :Stress, Strain & Deformation for R350 mm & Twisted with R250 mm in 1000N for Steel

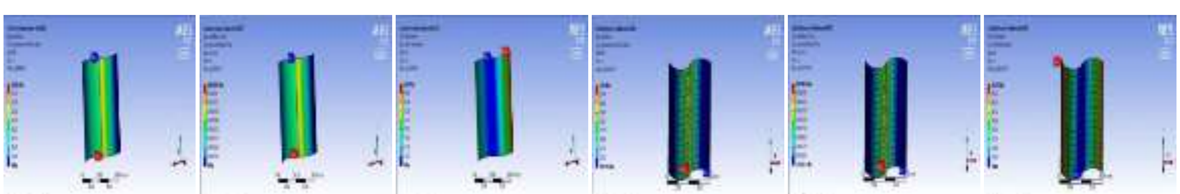


Fig.6 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 1500N loads for Steel

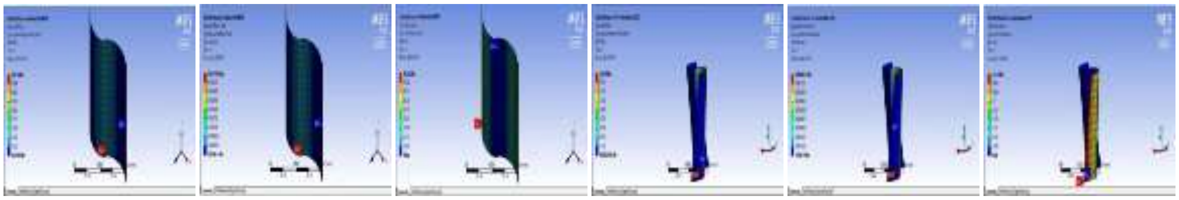


Fig.7: Stress, Strain &Total Deformation for R350mm & Twisted with R250 mm in 1500N for Steel

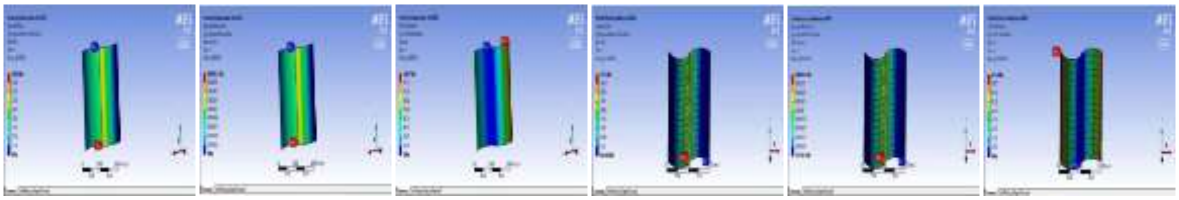


Fig.8 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 2000N loads for Steel

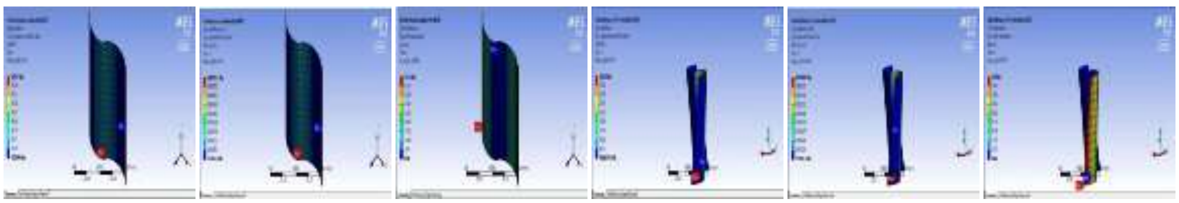


Fig.9: Stress, Strain & Deformation for R350mm & Twisted with R250mm in 2000N for Steel

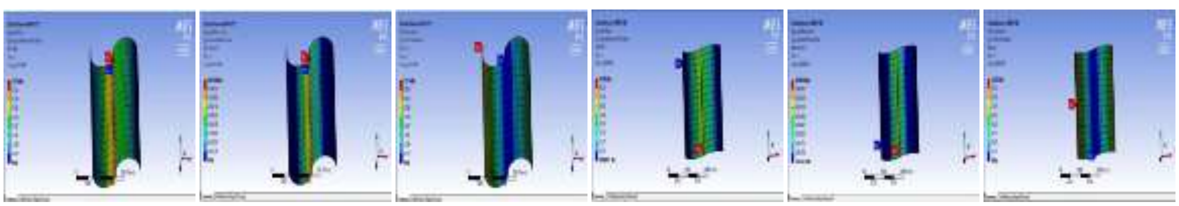


Fig.10 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 500N loads for GFRP

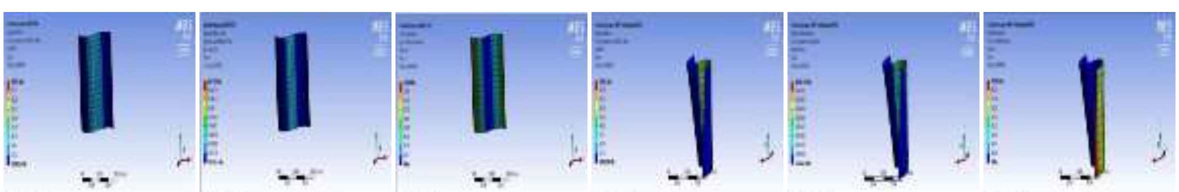


Fig.11 : Stress, Strain & Deformation for R350 mm & Twisted with R250 mm in 500N for GFRP

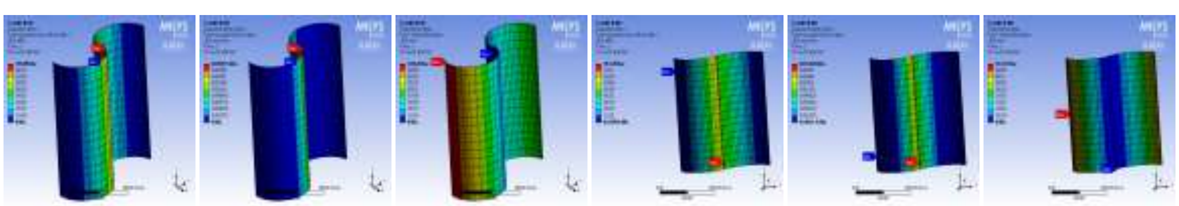


Fig.12 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 1000N loads for GFRP

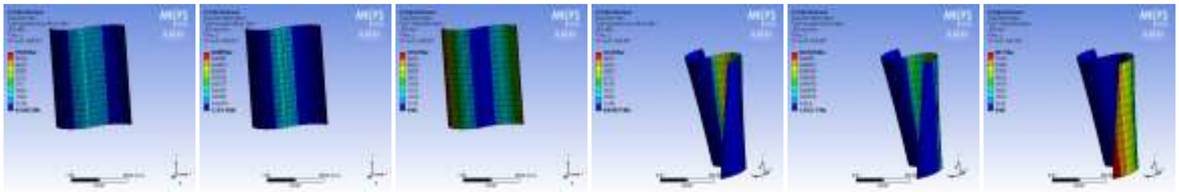


Fig.13: Stress, Strain & Deformation for R350 mm & Twisted with R250 mm in 1000N for GFRP

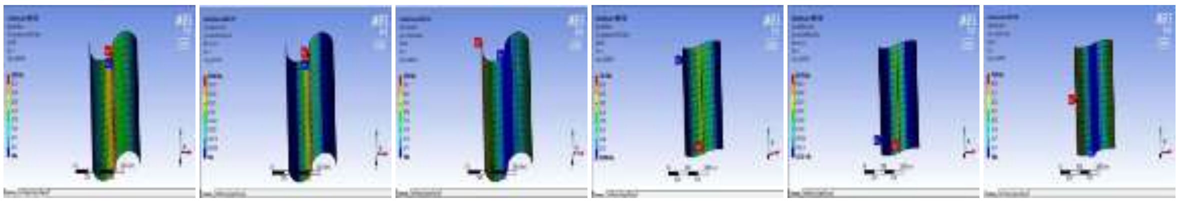


Fig.14 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 1500N loads for GFRP

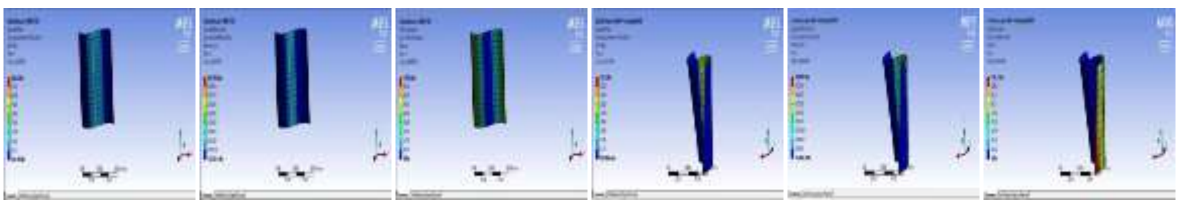


Fig.15: Stress, Strain & Deformation for R350mm & Twisted with R250mm in 1500N for GFRP

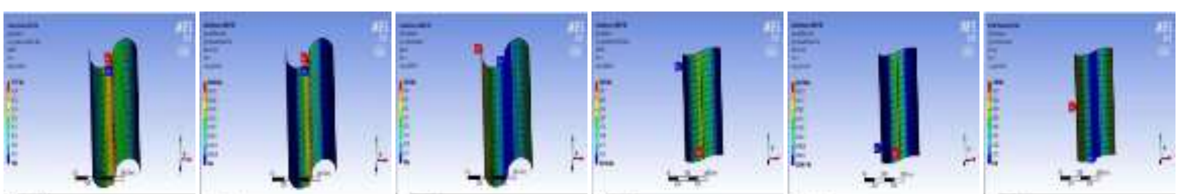


Fig.16 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 2000N loads for GFRP

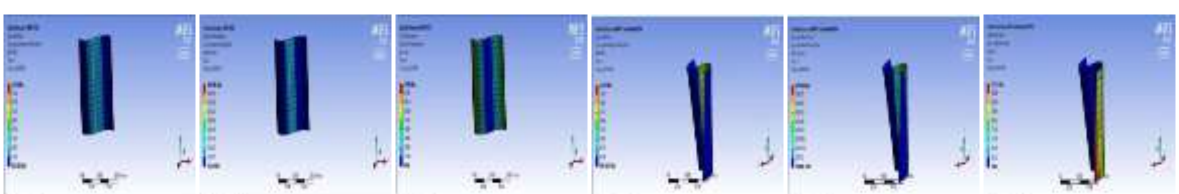


Fig.17: Stress, Strain & Deformation for R350 mm and Twisted with R250 mm in 2000N for GFRP

Table 2 Load and Stress (MPa)

LOAD(N)	SS R250	SS R300	SS R350	SS TWISTED	GFRP R250	GFRP R300	GFRP R350	GFRP TWISTED
500	87.203	94.033	273.93	95.898	79.441	97.088	285.41	105.51
1000	174.41	188.07	547.85	191.8	158.88	194.18	570.82	211.02
1500	261.61	282.1	821.78	287.69	238.32	291.26	856.22	316.52
2000	348.81	376.13	1095.7	383.59	317.77	388.35	1141.6	422.03

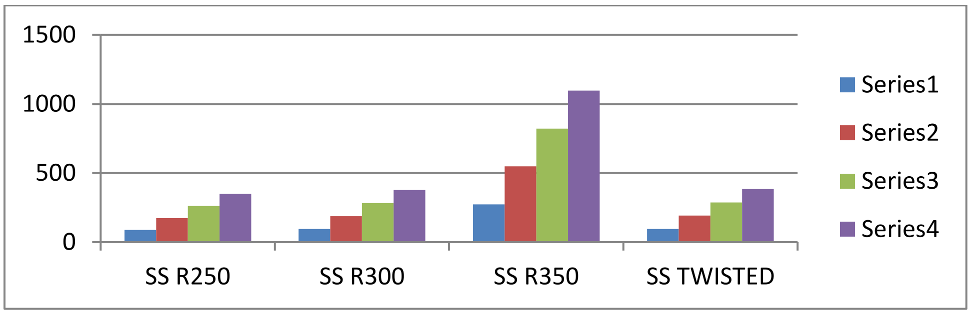


Fig.18 : Load Vs Stress for Steel

Fig.19 : Load Vs Stress for GFRP

Table 3 Load and Strain

LOAD (N)	SS R250	SS R300	SS R350	SS TWISTED	GFRP R250	GFRP R300	GFRP R350	GFRP TWISTED
500	0.00045	0.00048	0.00147	0.00049	0.01058	0.01058	0.02445	0.00611
1000	0.00090	0.00097	0.00295	0.00099	0.02031	0.02116	0.04891	0.01223
1500	0.00135	0.00146	0.00443	0.00149	0.03047	0.03175	0.07335	0.01835
2000	0.00181	0.00195	0.00591	0.00198	0.04063	0.04233	0.09780	0.02447

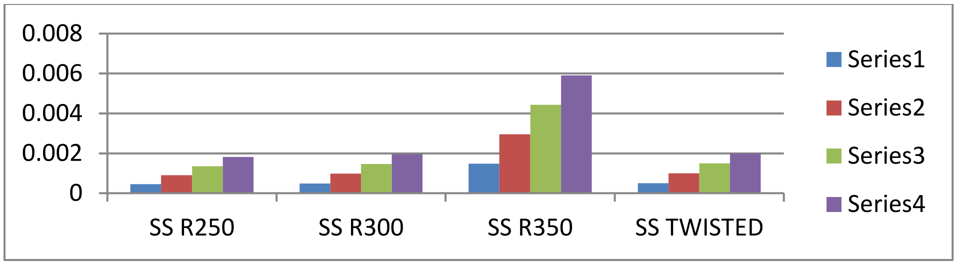


Fig.20 : Load Vs Strain for Steel

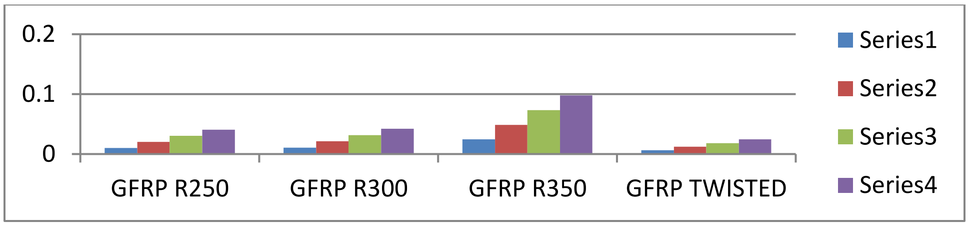


Fig.21 : Load Vs Strain for GFRP

Table 4 Load and Deformation (mm)

LOAD (N)	SS R250	SS R300	SS R350	SS TWISTED	GFRP R250	GFRP R300	GFRP R350	GFRP TWISTED
500	35.86	21.05	23.04	37.75	593.39	262.16	259.84	433.85
1000	71.735	42.11	46.08	75.50	1186.8	524.32	519.67	867.7
1500	107.60	63.17	69.12	113.25	1780.2	786.48	779.51	1301.5
2000	143.47	84.23	92.16	151.00	2373.6	1048.6	1039.3	1735.4

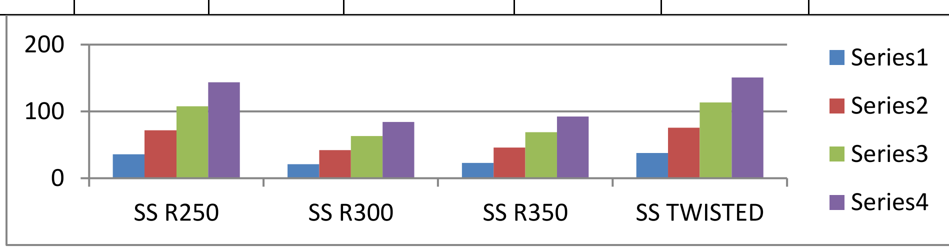


Fig.22 : Load Vs Deformation for Steel

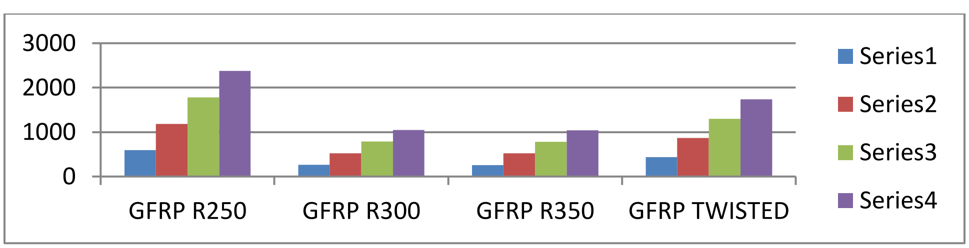


Fig.23 : Load Vs Deformation for GFRP

MODAL ANALYSIS OF STAINLESS STEEL AND ALUMINUM WIND BLADE

All the four different shapes of Stainless Steel(SS) and Glass Fiber Reinforced Polymer (GFRP) material blades are analyzed. The results are tabulated and compared with each other.

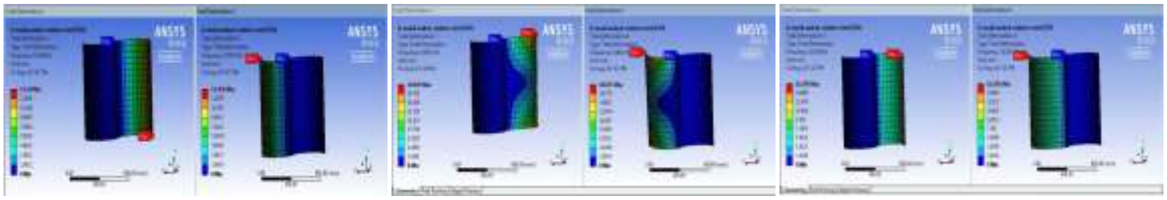


Fig.24 : Natural Frequency and Total Deformation for SS R250

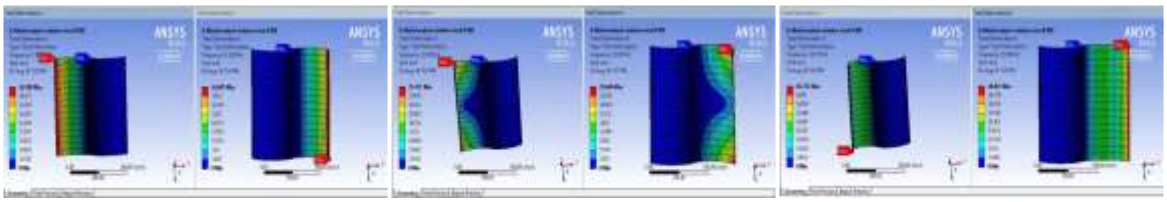


Fig.25 : Natural Frequency and Total Deformation for SS R300

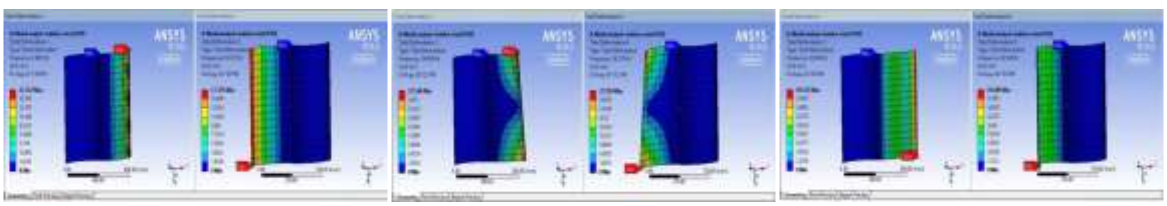


Fig.26 : Natural Frequency and Total Deformation for SS R350

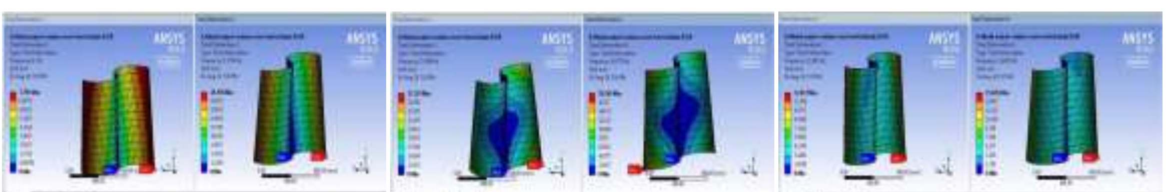


Fig.27 : Natural Frequency and Total Deformation for SS Twisted blade

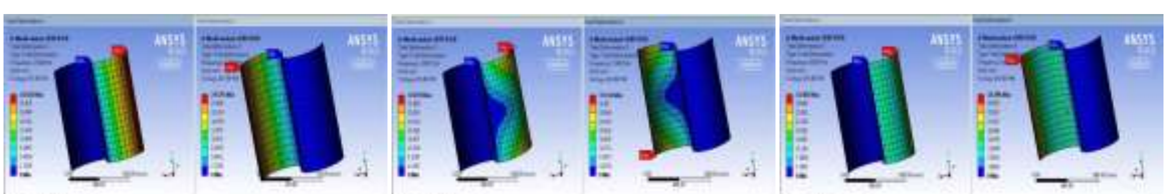


Fig.28 : Natural Frequency and Total Deformation for GFRP R250

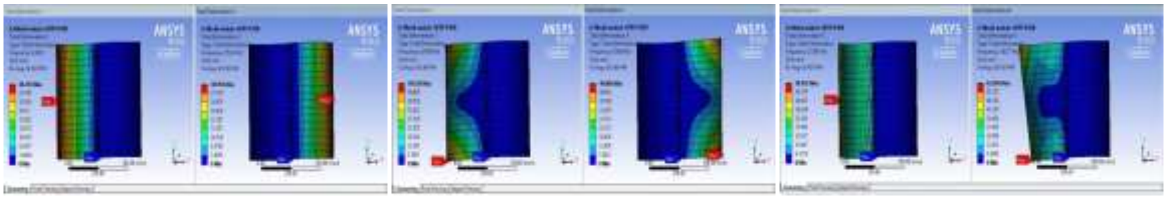


Fig.29 : Natural Frequency and Total Deformation for GFRP R300

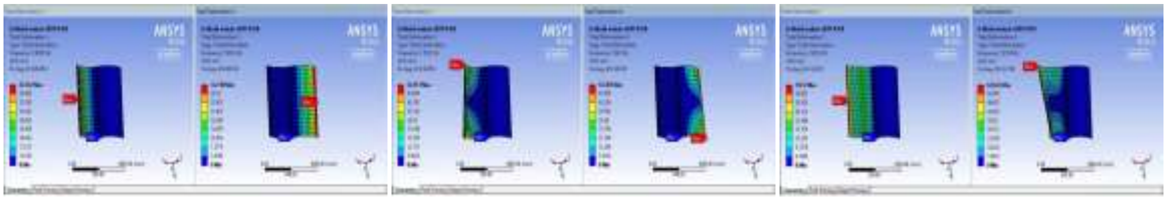


Fig.30 : Natural Frequency and Total Deformation for GFRP R350

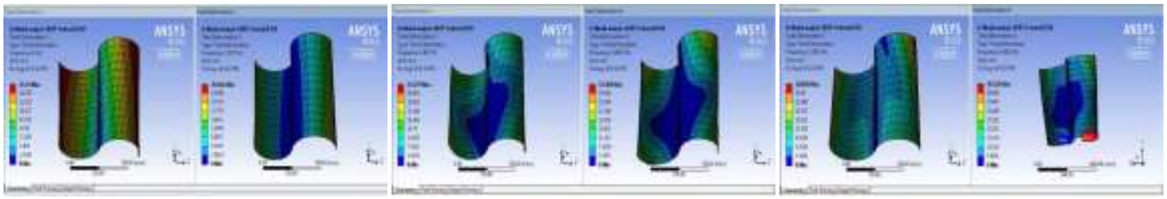


Fig.31 : Natural Frequency and Total Deformation for GFRP Twisted blade

Table 5 POWER AND FORCING FREQUENCY FOR VARIOUS WIND SPEEDS

SL. NO	WIND SPEED (m/s)	ANGULAR SPEED (rad/sec)	ROTATIONAL SPEED (RPM)	FORCING FREQUECY OF ROTOR(Hz)= (RPM/60)	P_{max} (Watts)	Torque (N-M)
1	1	2	19	0.32	0.36	0.18
2	2	4	38	0.64	2.90	0.73
3	3	6	57	0.96	9.80	1.63
4	4	8	76	1.27	23.22	2.90
5	5	10	96	1.59	45.36	4.54
6	6	12	115	1.91	78.38	6.53
7	7	14	134	2.23	124.46	8.89
8	8	16	153	2.55	185.78	11.61
9	9	18	172	2.87	264.52	14.70
10	10	20	191	3.18	362.85	18.14
11	11	22	210	3.50	482.95	21.95
12	12	24	229	3.82	627.00	26.13
13	13	26	248	4.14	797.18	30.66
14	14	28	267	4.46	995.66	35.56
15	15	30	287	4.78	1224.62	40.82

Table 6 NATURAL FREQUENCY AND DEFORMATION OF STAINLESS STEEL

MODE	SS R250		SS R300		SS R350		SS- TWISTED BLADE	
	FREQ.(Hz)	DEFOR(mm)	FREQ. (Hz)	DEFOR(mm)	FREQ. (Hz)	DEFOR (mm)	FREQ. (Hz)	DEFOR (mm)
1	5.0344	13.33	7.933	16.508	8.886	17.322	0.002	7.793
2	5.0536	13.352	8.1265	16.605	8.9772	17.375	5.1779	10.358
3	8.4563	18.847	12.88	25.471	14.064	27.146	7.8308	17.219
4	8.4812	18.877	13.067	25.668	14.178	27.254	8.8773	18.169
5	16.044	16.295	34.773	18.732	42.989	19.132	11.003	12.823
6	16.103	16.292	35.609	18.815	43.594	19.189	16.493	15.831

Table 7 NATURAL FREQUENCY AND DEFORMATION OF GFRP

MODE	GFRP R250		GFRP R300		GFRP R350		GFRP TWISTED BLADE	
	FREQ.	DEFOR	FREQ.	DEFOR	FREQ.	DEFOR	FREQ.	DEFOR
1	2.3844	24.542	4.4	30.765	5.4298	32.522	0.001	15.34
2	2.3943	24.575	4.5241	30.954	5.6016	32.749	3.1573	26.661
3	3.9803	37.073	6.4748	49.533	7.5122	52.973	4.067	33.279
4	3.9893	37.114	6.5964	49.884	7.683	53.387	5.0055	33.369
5	9.6076	33.302	23.993	38.451	31.818	39.32	5.3983	28.856
6	9.6309	33.296	24.177	62.693	32.074	63.611	8.4013	45.523

CONCLUSION

The results taken from static structural analysis for Stainless Steel and GFRP blade to evaluate displacement, stress and strain are good and it shows that GFRP is better choice to fabricate wind turbine blades when compared with Stainless Steel material. We can reduce 1/4th of weight and 50% of cost by GFRP material when compared to Steel. The maximum stress of 1095.7 MPa and strain of 0.00591 is realized in SS R350 blades at 2000N loads. On the other hand the maximum stress of 1142MPa and stain of 0.09 is realized in GFRP R350 blades at 2000N loads.

In modal analysis, the natural frequencies of four different wind blades made of stainless steel and GFRP at different wind speed are compared with forcing frequency of table 5 and no natural frequencies of Stainless Steel match with forcing frequencies. So failure of structure will not occur in Stainless Steel.

In GFRP material, the natural frequencies of GFRP R250 mm at mode 1, 2, 3 and 4 are same at wind speed from 7 m/s to 12 m/s. In GFRP R300 mm, the natural frequency at mode 1 and 2 are same at wind speed from 13 m/s to 15 m/s. In twisted blade, the natural frequency at mode 2 and 3 are same at wind speed from 10 m/s to 13 m/s. Hence there is a possibility for resonance. So failure of structure may occur in R250, R300 and twisted blades. But natural frequency of GFRP R350 mm at all modes differs from forcing frequency. In this case no natural frequencies match with forcing frequencies. So failure of structure will not occur. GFRP material weight and cost are less than steel. So GFRP R350 mm is suitable wind blades with less weight and low cost without affecting its performance.

It is suitable for small houses to produce green energy. It can produce electric power of 362 Watts and 1225 Watts at wind speed of 10 m/s and 15 m/s respectively.

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