Examination of Savonius VAWT Blade Made of Stainless Steel and Aluminum using Ansys

M. Saravanan

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

Modeling software Solid Works is used to model savonius wind blade and static structural and modal analysis of the Stainless Steel and Aluminum blades are done by using ANSYS Workbench software.

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

I. INTRODUCTION

Savonius wind turbine is one type of vertical axis wind turbine used for converting the wind force into torque on a rotating shaft and electric power. The turbine consists of a number of blades vertically mounted on a rotating shaft. It is low cost and reliable, but efficiency is poor. This turbine is self starting and no pointing mechanism is required to allow for shifting wind direction. Sigurd Johannes Savonius invented this wind turbine in 1922. It was not widely used for many years. Its popularity is increasing recently due to increase of urbanized areas, which have specific demands. The Savonius rotor blade seems to satisfy these particular needs.

II. DESIGN CALCULATION

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

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

The angular velocity of a rotor is given by

$$\omega = \lambda \cdot V / R$$

Where λ = Dimensionless factor called the tip speed ratio.

λ is a characteristic of each specific wind mill and for a savonius rotor λ is typically around unity

R = Radius of the rotor

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

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

III. METHODOLOGY

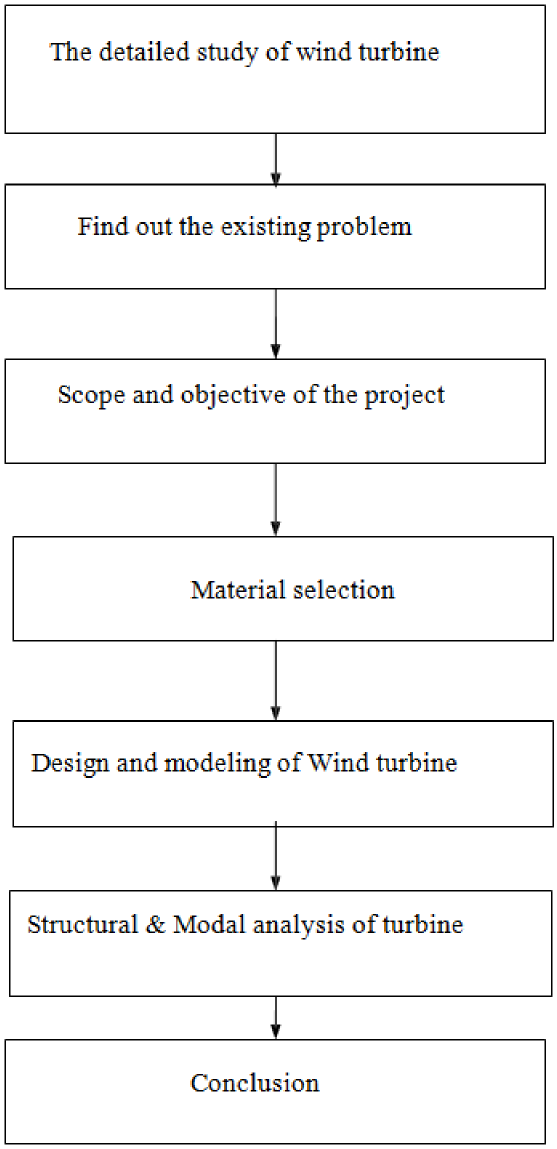

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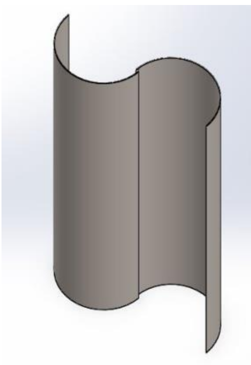
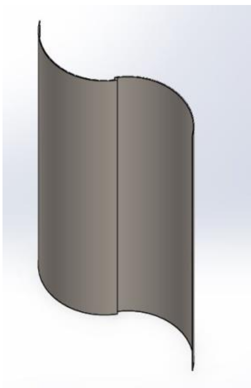
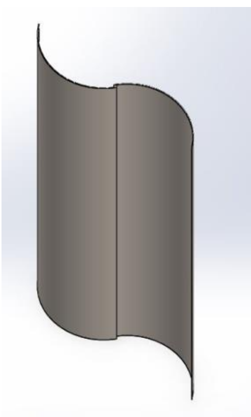
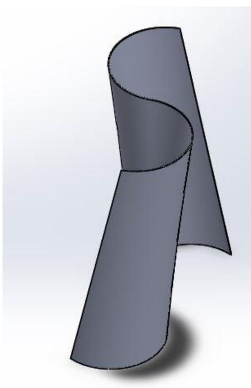
Table 1 Power and Torque of the proposed wind turbine for various wind speeds

S. 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

IV. 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.

V. STATIC STRUCTURAL ANALYSIS OF WIND BLADE

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

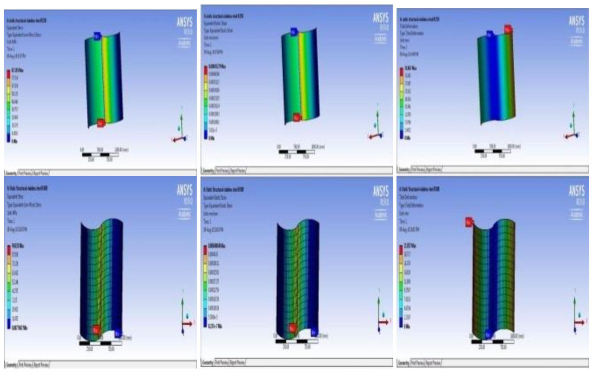


Fig.2 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 500N loads for Steel

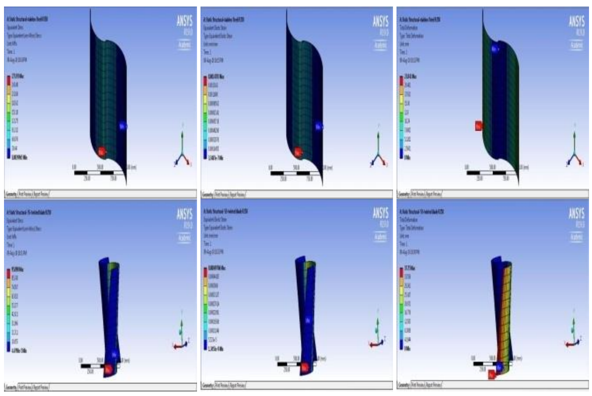


Fig.3 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 500N loads for Steel

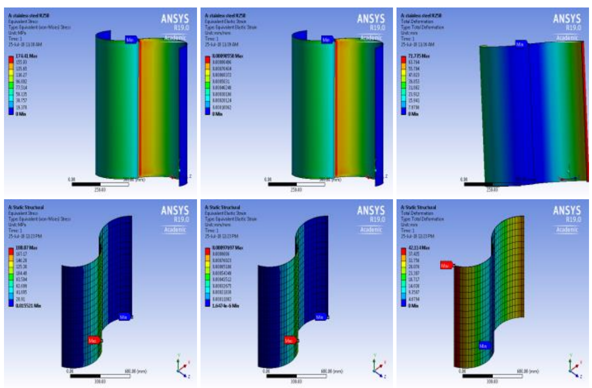


Fig.4 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 1000N loads for Steel

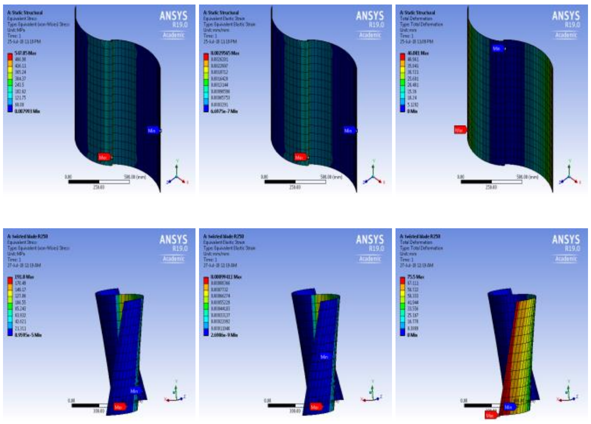


Fig.5 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 1000N loads for Steel

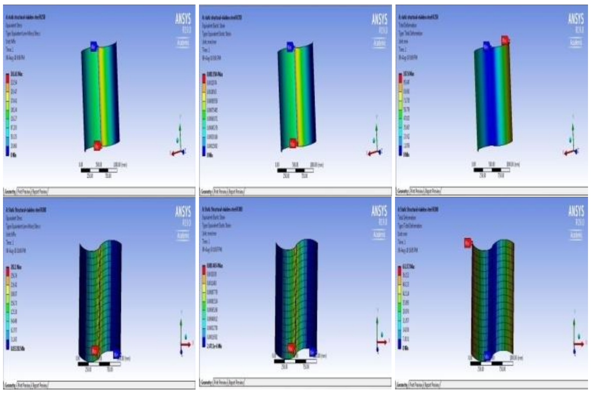


Fig.6 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 1500N loads for Steel

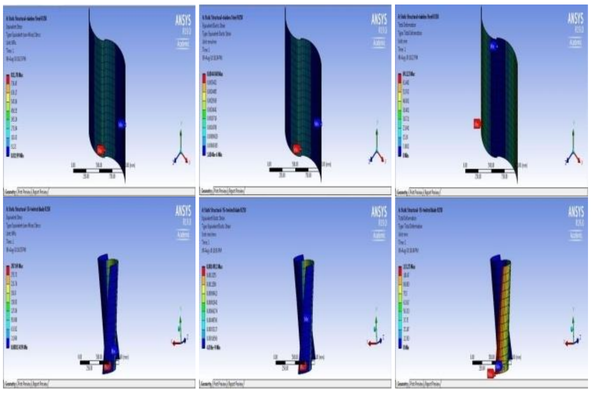


Fig.7 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 1500N loads for Steel

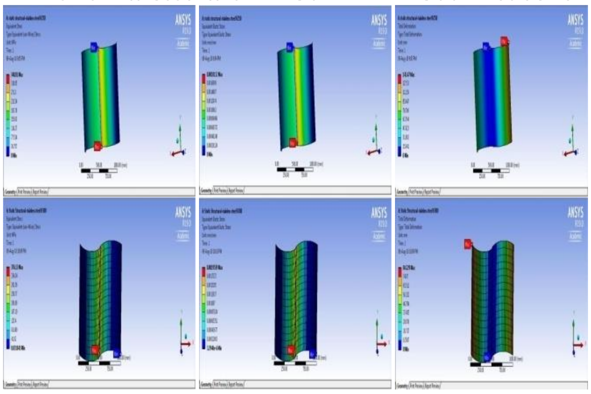


Fig.8 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 2000N loads for Steel

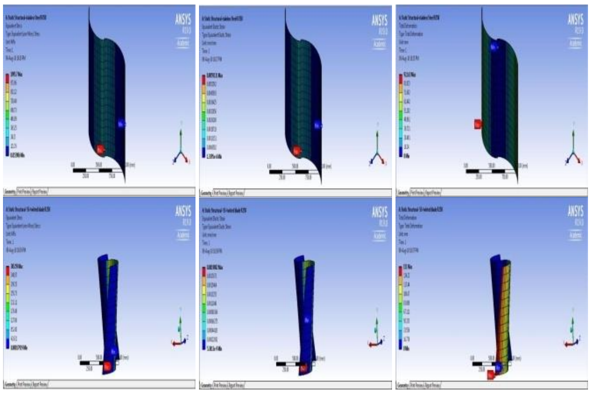


Fig.9 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 2000N loads for Steel

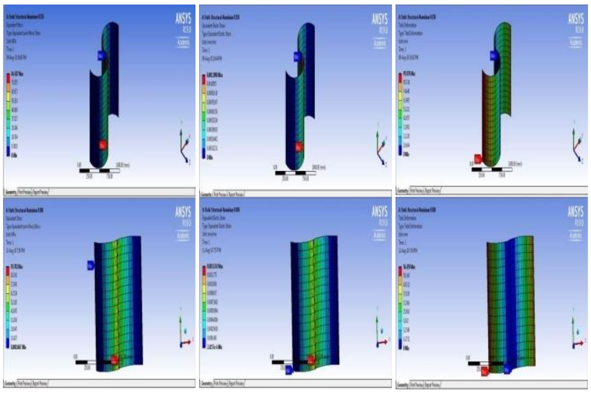


Fig.10 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 500N loads for Aluminum

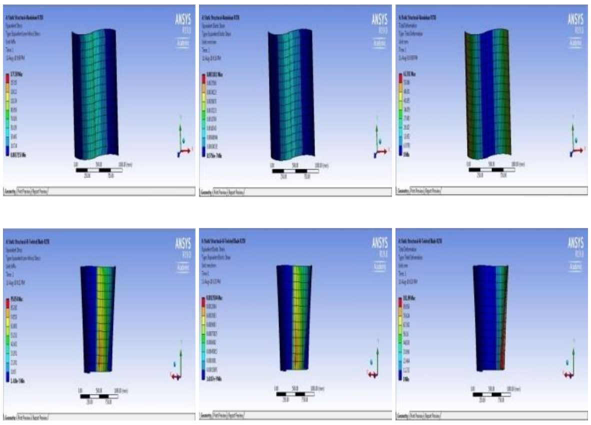
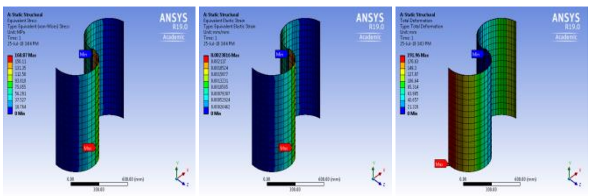


Fig.11 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 500N loads for Aluminum



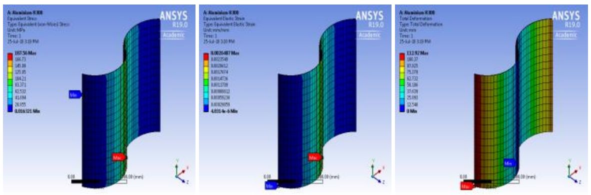


Fig.12 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 1000N loads for Aluminum

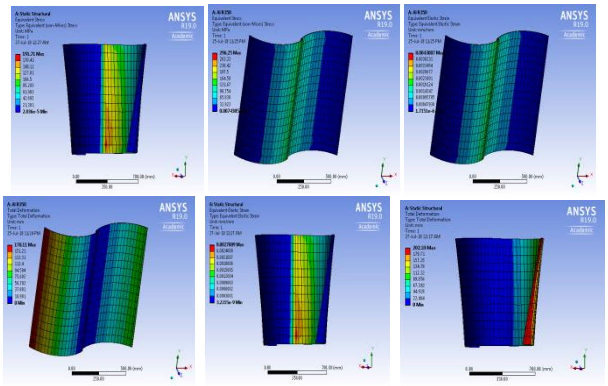


Fig.13 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 1000N loads for Aluminum

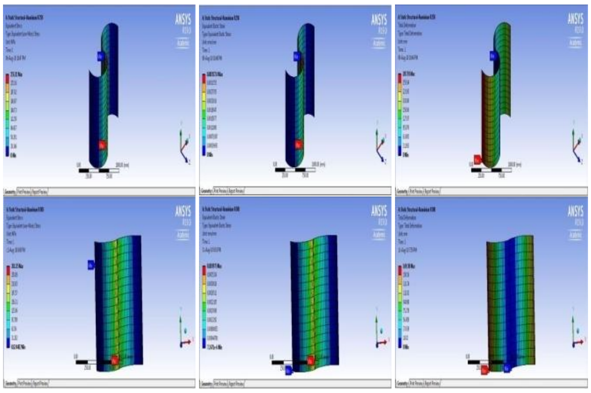


Fig.14 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 1500N loads for Aluminum

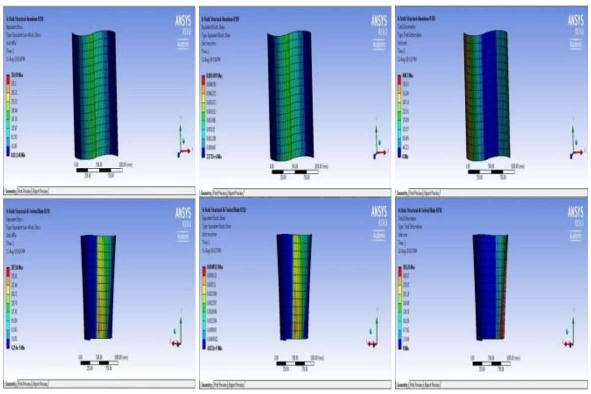


Fig.15 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 1500N loads for Aluminum

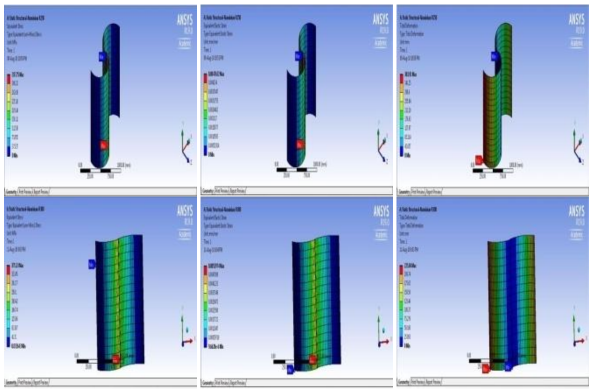


Fig.16 : Stress, Strain and Total Deformation for R250 mm and R300 mm in 2000N loads for Aluminum

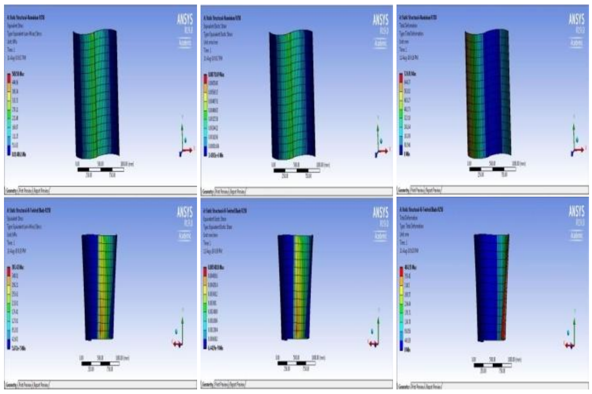


Fig.17 : Stress, Strain and Total Deformation for R350 mm and Twisted with R250 mm in 2000N loads for Aluminum

VI. MODAL ANALYSIS OF STAINLESS STEEL AND ALUMINUM WIND BLADE

All the four different shapes of Stainless Steel(SS) and Aluminum(Al) material blades are analyzed. The results are tabulated and the comparisons of the results are plotted.

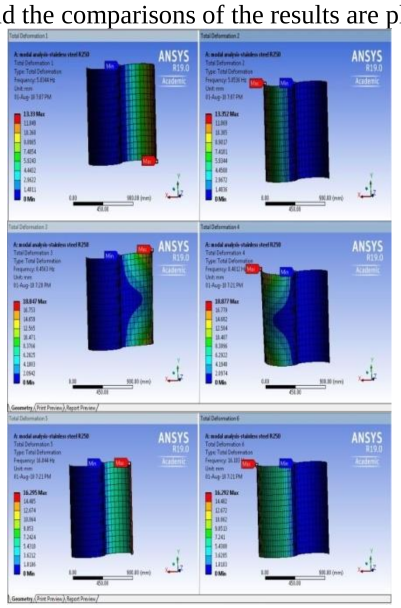


Fig.18 : Natural Frequency and Total Deformation for SS R250

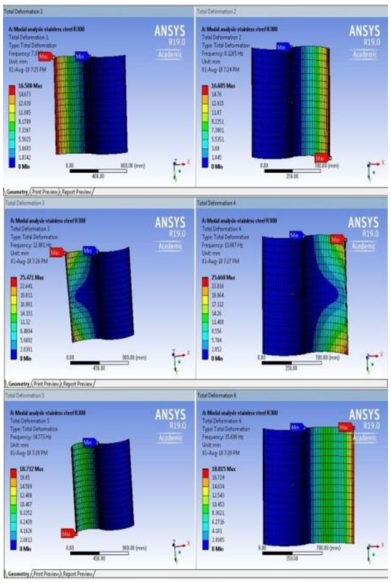


Fig.19 : Natural Frequency and Total Deformation for SS R300

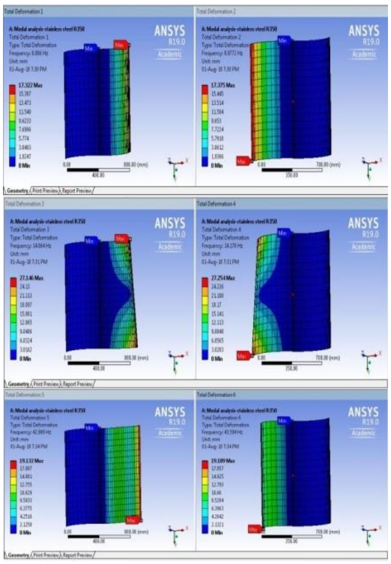


Fig.20 : Natural Frequency and Total Deformation for SS R350

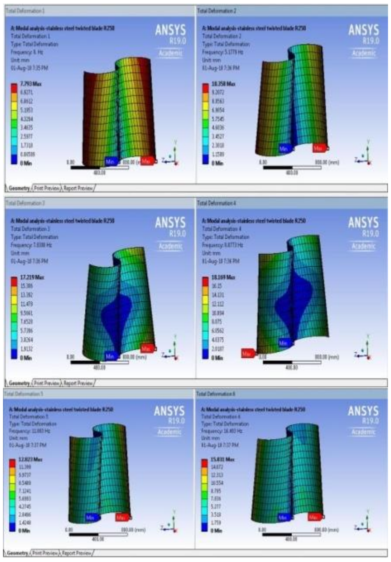


Fig.21 : Natural Frequency and Total Deformation for SS Twisted blade

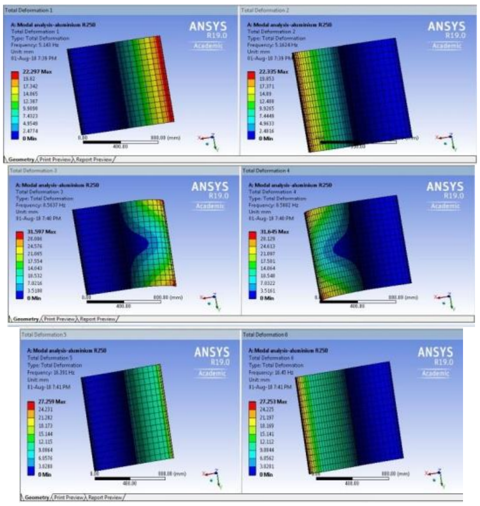


Fig.22 : Natural Frequency and Total Deformation for Al R250

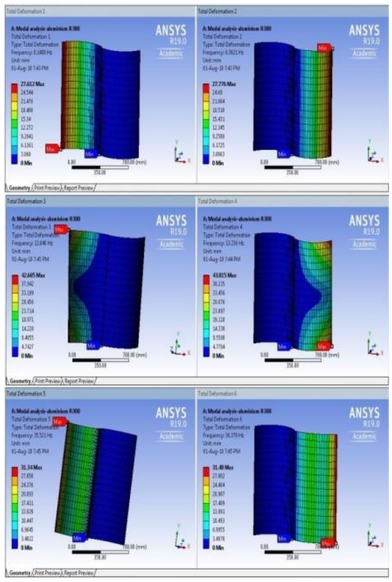


Fig.23 : Natural Frequency and Total Deformation for Al R300

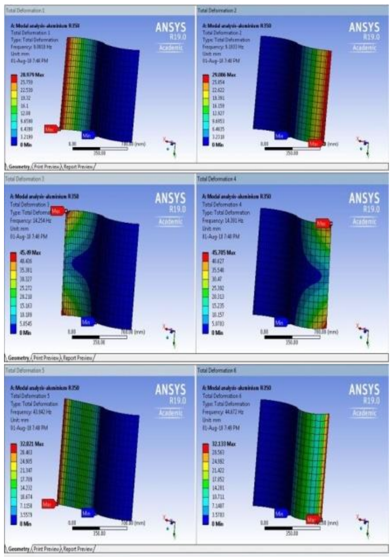
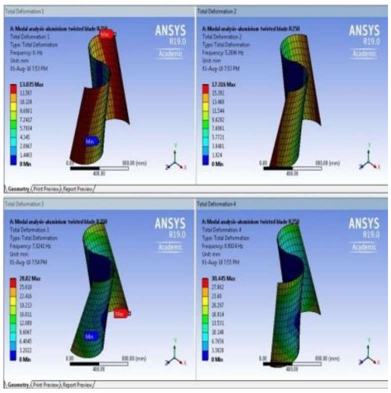


Fig.24 : Natural Frequency and Total Deformation for Al R350



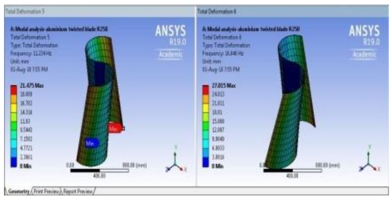


Fig.25: Natural Frequency and Total Deformation for Al Twisted blade

VII. RESULT AND DISCUSSION

Table 2 Load and Stress (MPa)

Load (N)	SS R250	SS R300	SS R350	SS Twisted	AL R250	AL R300	AL R350	AL Twisted
500	87.2	94.03	273.93	95.8	84.43	93.7	177.5	95.8
1000	174.4	188.07	547.85	191.8	168.8	187.5	296.2	191.7
1500	261.6	282.1	821.78	287.6	253.3	281.3	376.9	287.5
2000	348.8	376.13	1095.7	383.5	337.7	375.1	500.5	383.4

Table 3 Load and Strain

Load (N)	SS R250	SS R300	SS R350	SS Twisted	AL R250	AL R300	AL R350	AL Twisted
500	0.0004	0.0005	0.0014	0.0005	0.0012	0.0013	0.0031	0.00135
1000	0.0009	0.0009	0.0029	0.0009	0.0024	0.0026	0.0043	0.00270
1500	0.0013	0.0015	0.0044	0.0015	0.0036	0.0039	0.0054	0.00405
2000	0.0018	0.0019	0.0059	0.0019	0.00476	0.0053	0.0073	0.00540

Table 4 Load and Deformation (mm)

Load (N)	SS R250	SS R300	SS R350	SS Twisted	Al R250	Al R300	Al R350	Al Twisted
500	35.8	21.0	23.0	37.7	95.9	56.45	62.7	101.0
1000	71.7	42.1	46.0	75.5	191.9	112.9	170.1	202.1
1500	107.6	63.1	69.1	113.2	287.9	169.3	400.7	303.2
2000	143.4	84.2	92.1	151.0	383.9	225.8	724.9	404.3

Table 5 Power and Forcing Frequency for Various Wind Speeds

Sl. No	**Wind speed (m/s)**	**Angular speed (rad/sec)**	**Rotational speed (rpm)**	**Forcing Frequency 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	5.03	13.33	7.93	16.51	8.88	17.32	0.002	7.79
2	5.05	13.35	8.12	16.6	8.97	17.37	5.17	10.35
3	8.45	18.84	12.88	25.47	14.06	27.14	7.83	17.22
4	8.48	18.87	13.06	25.66	14.17	27.25	8.87	18.17
5	16.0	16.29	34.77	18.73	42.98	19.13	11.0	12.82
6	16.1	16.29	35.61	18.81	43.59	19.18	16.49	15.83

Table 7 Natural Frequency and Deformation of Aluminum

Mode	Aluminum R250		Aluminum R300		Aluminum R350		Aluminum Twisted Blade	
	Freq(Hz)	Defor (mm)	Freq. (Hz)	Defor (mm)	Freq. (Hz)	Defor (mm)	Freq (Hz)	Defor (mm)
1	5.14	22.29	8.14	27.61	9.08	28.98	0.01	13.03
2	5.16	22.33	8.36	27.77	9.19	29.1	5.28	17.31
3	8.56	31.59	13.04	42.68	14.25	45.49	7.92	28.82
4	8.58	31.64	13.23	43.01	14.39	45.7	8.99	30.44
5	16.4	27.25	35.52	31.34	43.94	32.02	11.2	21.47
6	16.6	27.25	36.37	31.48	44.13	32.13	16.8	27.01

The result of static structural analysis for Stainless Steel and Aluminum blades to evaluate deformation, stress and strain were compared. In stainless steel, the maximum stress of 1095.7 Mpa and strain of 0.00591 is found in SS R350 blades at 2000N loads. In aluminum, maximum stress of 500.58 Mpa and strain of 0.00732 is realized in Aluminum R350 blades at 2000N loads.

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

So both the materials are suitable for fabrication of wind blades of that dimensions. From table 6 and 7, it is found that more deformation occurs in aluminum material when compared with stainless steel for the same frequency.

But cost and weight of the aluminum blade is less compared with steel.

VIII. CONCLUSION

Though the result of static structural and modal analysis for Stainless steel is good, the cost and weight is more than that of aluminum. So aluminum can be chosen as suitable material for making wind blade. When comparing the four different shapes of the blades, the analysis result of R350mm is better and it is decided that Aluminum R350mm blade is optimum design.

It is suitable for houses in urban areas to produce green energy which can produce electric power of 363 Watts and 1225 Watts at wind speed of 10 m/s and 15 m/s respectively.

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