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Modelling and Analysis of Domestic Windmill Turbine Blade

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Abstract: **Blade is the key component to capture wind energy. It plays a vital role in the whole wind turbine. The optimum twist of a windmill turbine blade is analyzed on the basis of elementary blade- element theory. Maximum efficiency of power is achieved when the blade is twisted consistently with a program that depends on variation of sectional lift and drag coefficients with angle of attack. For a typical airfoil cross-section, optimum angle of attack decreases from maximum lift coefficient angle of attack at the blade root to greater than 80 percent of this value at the blade tip**

The modelling is done in SolidWorks and the static and dynamic analysis is carried out by using ANSYS software. The materials used are stainless steel, e-glass epoxy and grey cast iron. The blade is subjected to FEA studies to demonstrate its ability to withstand the extreme loading conditions as defined in the international offshore wind standards. The results will have acceptable performance with regard to total deformation, directional deformation, equivalent stress, normal and shear stress.

Index Terms: **Windmill, efficiency, epoxy resin**

I. INTRODUCTION

A turbine is a device that converts the wind’s Kinetic Energy into electricity. They are an increasingly important source of intermittent renewable energy and are utilized in many countries to lower energy costs and reduce reliance on fossil fuels. Wind has the lowest relative greenhouse emission, smallest amount water consumption demands and therefore the most favorable social impacts in comparison to photovoltaic, hydro, geothermal, coal and gas [1] [3]. Smaller wind turbines are used for applications like battery charging for auxiliary power for boats or caravans, and to power traffic warning signs. While larger turbines can contribute towards domestic power supply while selling unused power back to the utility supplier via the electrical grid [6].

Wind turbines are manufactured during a wide selection of sizes, with horizontal or vertical axes. It is estimated that thousands of huge turbines, in installations referred to as wind farms, generate over 650 gigawatts of power, with 60 GW added annually. Wind turbines are classified by the wind speed. They are designed for, from class I to class III, with A to C pertaining to the turbulence intensity of the wind [5]. There are two basic sorts of wind turbines: Horizontal-axis turbines and Vertical-axis turbines. There are also sub types of vertical axis wind turbines namely Darrieus wind turbine, Giromill turbines and Savinous turbines [2] [4].

The size of wind turbines varies widely. The length of the blades determines the quantity of electricity a turbine can generate. Small wind turbines which will power one home may have an electricity generating capacity of 10 kilowatts (kW). The largest wind turbines have electricity generating capacities of up to kilowatts (10 megawatts), and bigger turbines are in development [8] [9]. Large turbines are often grouped together to make wind generation plants, or wind farms, that provide power to electricity grids.

II. WIND TURBINES AND BLADES

A. Wind turbine working:

According to Betz's law, maximum achievable extraction of wind power by a wind turbine as 16/27 (59.3%) times the rate at which the kinetic energy of the air arrives at the turbine [7].

Small wind turbines or Domestic wind turbines could also be used for spread of applications including on- grid or off-grid residences, telecom towers, rural schools and clinics, remote monitoring, offshore platforms and other purposes that need energy where there's no electric grid, or where the grid is unstable. Small wind turbines could also be as small as a fifty-watt generator for boat or caravan use [10]. Hybrid solar and wind powered units are increasingly getting used for traffic signage, particularly in rural locations, as they avoid the necessity to get long cables from the closest mains connection point [6].

A turbine turns wind energy into electricity using the force from the rotor blades, which works like an airplane wing or helicopter rotary wing as shown in figure 1. When wind flows across the blade, the atmospheric pressure on one side of the blade decreases. The difference in atmospheric pressure across the two sides of the blade creates both lift and drag. If the force of the lift is stronger than the drag, it causes the rotor to spin. The rotor is connected to the generator, either directly (if it’s an immediate drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for accommodating smaller generator as in figure 1. This translation of force to rotation of a generator creates electricity.

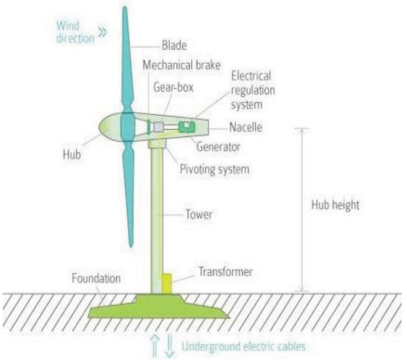

Figure 1. Working of the turbine

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B. Windmill Turbine Blades:

Most wind turbines designed for the production of electricity consists of a two or three bladed propeller rotating around a horizontal axis. These propeller like turbine blade designs convert the energy of the wind into usable shaft power called torque. This is achieved by extracting the energy from the wind by slowing it down or decelerating the wind as it passes over the blades. The forces which decelerate the wind are equal and opposite to the thrust type lifting forces which rotates the blades [4].

Just like an aero plane wing, turbine blades work by generating lift through their curve. The side with the foremost curve generates low atmospheric pressure while high air beneath pushes on the opposite side of the blade shaped aerofoil.

This results in a lifting force perpendicular to the direction of flow of the air over the turbines blade. The rotary wing is designed to create the proper amount of rotary wing lift and thrust producing optimum deceleration of the air and therefore better blade efficiency.

If the turbines propeller blades rotate too slowly, it allows an excessive amount of wind to undergo undisturbed, and thus doesn't extract the maximum amount energy because it potentially could. On the opposite hand, if the propeller blade rotates too quickly, it appears to the wind as an outsized flat rotating disc, which creates an outsized amount of drag.

Generally, turbine blades are shaped to get the utmost power from the wind at the minimum construction cost. But turbine blade manufacturers are always looking to develop a more efficient blade design [8]. Constant improvements within the design of wind blades have produced new turbine designs which are more compact, quieter and are capable of generating more power from less wind. It is believed that by slightly curving the turbine blade, they are ready to capture 5 to 10 percent more wind energy and operate more efficiently in areas that have typically lower wind speeds.

Wind turbine blades are of following types as in Fig 2:

1. Flat blades
2. Curved blades
3. Aerofoil blades and
4. Twisted blades

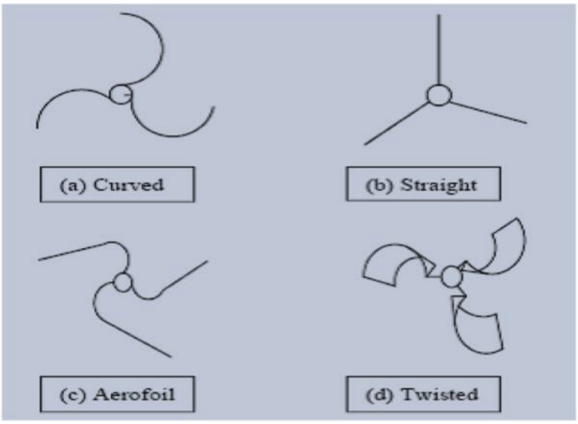

Figure 2. Types of the turbine blade

Flat or straight blade designs offer significant benefits compared to other wind blade designs. Flat rotor blades are easy and cheap to trim from sheets of plywood or metal ensuring that the blades have a uniform shape and size [1] [4]. They are also the simplest turbines that require less design and construction skills, but their efficiency and therefore the generating electric power is extremely low. Hence the blades of the turbine are designed as straight or flat as shown in figure 3.

III. DESIGN CONSIDERATIONS

A. Modelling of turbine blade

The modelling of turbine blade is done in SOLIDWORKS 2020 SP5 in SLDDRW drawing file and is saved in IGES format. Structural and transient dynamic analysis is carried out in ANSYS 14.5. Fig 3 is the front view; Fig 4 is the side view and Fig 5 is the top view shows the model draft of turbine blades.

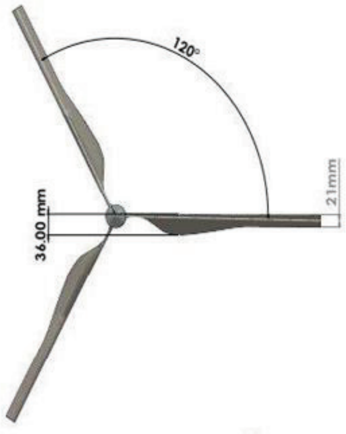

Figure 3. Front View of the turbine

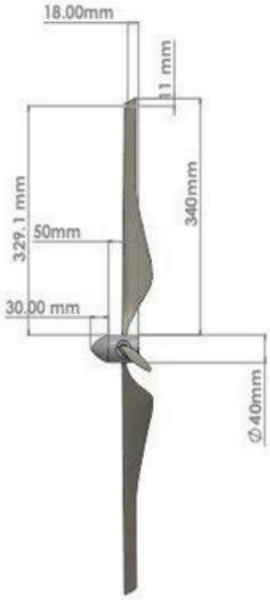

Figure 4. Side View of the turbine

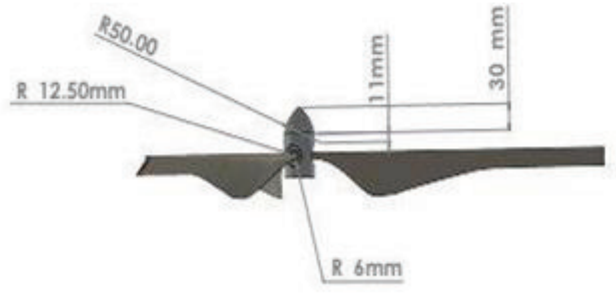

Figure 5. Top View of the turbine

B. Material Considerations

Materials like steel, irons or cast irons, aluminum, fibers, composites and plastics are most widely used in the manufacturing of turbine blades. Considering this stainless steel, grey cast iron and e glass epoxy are used for the design analysis of turbine blade.

Stainless Steel - Grade 304 (UNS S30400) is used for its good corrosion resistance, lower weight, good formability and weld ability. Table I shows properties of stainless steel.

TABLE I.
PROPERTIES OF STAINLESS STEEL

Density	7.85-8.06 mg/m3
Compressive strength	205-310 MPa
Ductility	0.3-0.57
Endurance limit	175-260 MPa
Hardness	1700-2100 MPa
Modulus of rupture	205-310 MPa
Shear modulus	74-81 GPa
Tensile strength	510-620 MPa
Young's modulus	190-203 GPa

JIS G5501 FC200 gray cast iron is used for its density and mechanical properties. Table II shows properties of gray cast iron.

TABLE II.
PROPERTIES OF GREY CAST IRON

Density	7.15 g/cm3
Compressive strength	115-205 MPa
Ductility	0.3-0.57
Endurance limit	175-260 MPa
Hardness	755 MPa
Modulus of rupture	205-310 MPa
Shear modulus	41 GPa
Tensile strength	115-205 MPa
Young's modulus	92.4 GPa

AW 106 Epoxy glass material is used for its toughness, resilience and resistance to dynamic loading. Table III shows properties of epoxy glass.

TABLE III.
PROPERTIES OF EPOXY GLASS

Density	2.6 Kg/Mm^3
Compressive Strength	450 MPa
Ductility	0.8-0.97
Endurance Limit	275 MPa
Hardness	920 MPa
Modulus Of Rupture	350-380 MPa
Shear Modulus	1.7-2.6 GPa
Tensile Strength	900 MPa
Young's Modulus	20 GPa

C. Structural Analysis

Structural analysis on blades is carried out in ANSYS at 750N, 1500N and 2000N for the total deformation, equivalent stress and strain at different loads.

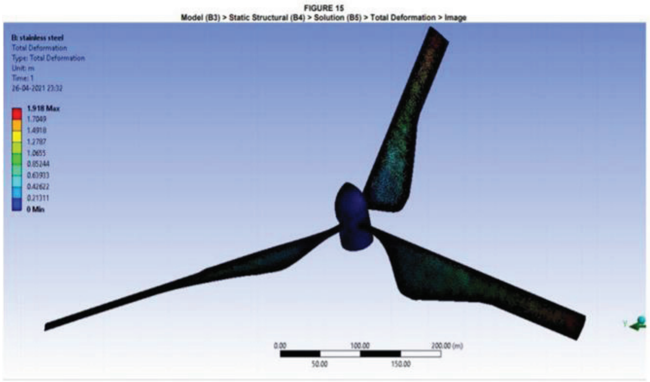

Figure 6. Total deformation of Stainless steel

Fig.6 shows the total deformation in stainless steel and it is observed that the maximum value is 1.198m.

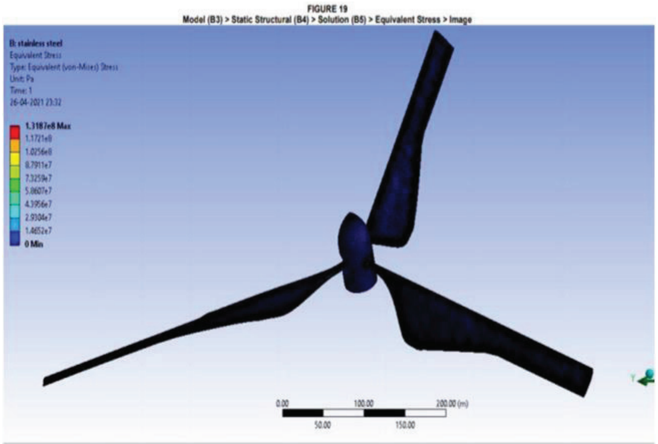

Figure 7. Equivalent Stress of Stainless Steel

Fig.7 shows the equivalent stress in stainless steel, and it is observed that the maximum value of stress is 1.318e8 Pa.

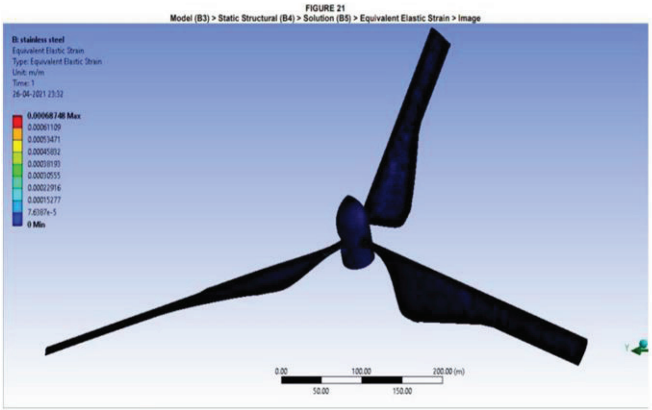

Figure 8. Equivalent Strain of Stainless Steel

Fig.8 shows the equivalent strain in stainless steel and it is observed that the maximum value is 0.000305.

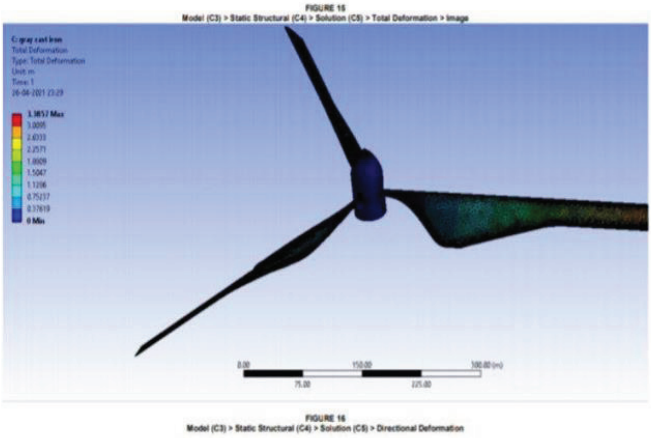

Figure 9. Total deformation of Gray Cast Iron

Fig.9 shows the total deformation in gray cast iron and it is observed that the maximum value is 0.75m.

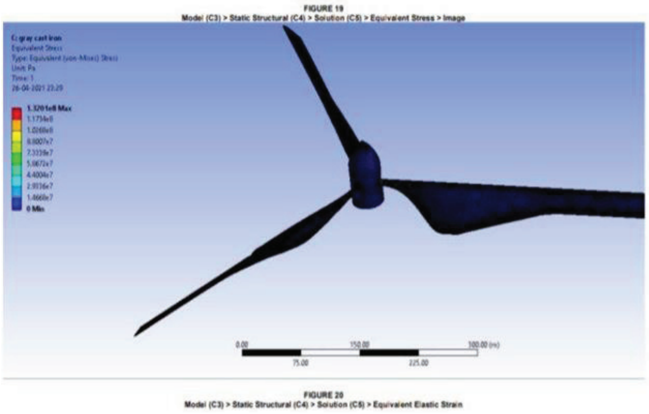

Figure 10. Equivalent Stress of Gray Cast Iron

Fig.10 shows the equivalent stress distribution in gray cast iron, and it is observed that the maximum value is 1.06e8 Pa.

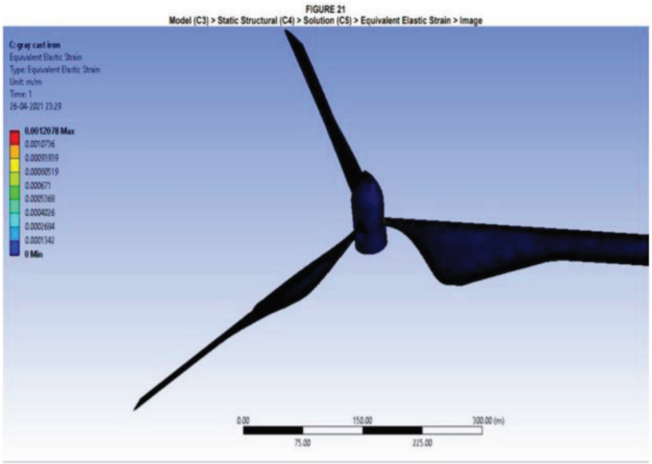

Figure 11. Equivalent Strain of Gray Cast Iron

Fig.11 shows the equivalent strain in gray cast iron and it is observed that the maximum value is 0.005368.

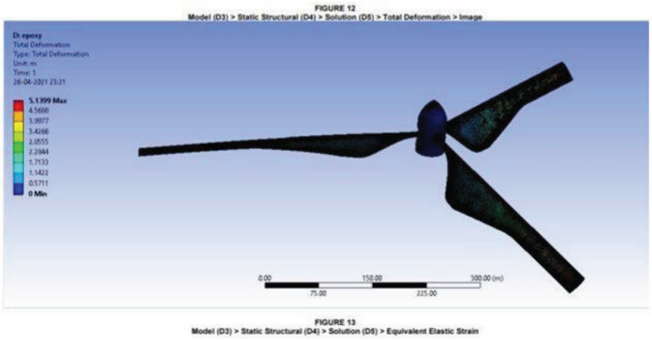

Figure 12. Total deformation of Epoxy Glass

Fig.12 shows the total deformation in epoxy glass and it is observed that the maximum value is 3.42m.

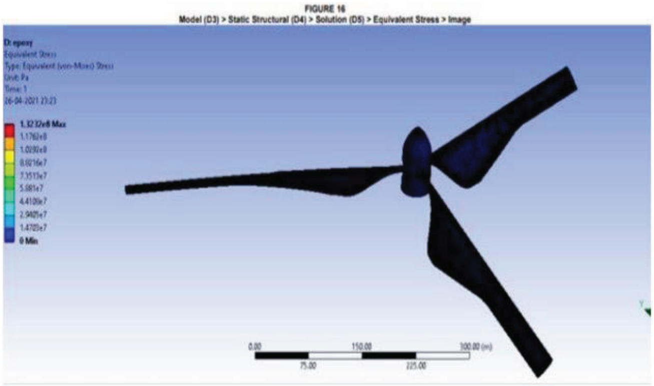

Figure 13. Equivalent Stress of Epoxy Glass

Fig.13 shows the distribution of equivalent stress in epoxy glass, and it is observed that the maximum value is 8.82e7 Pa.

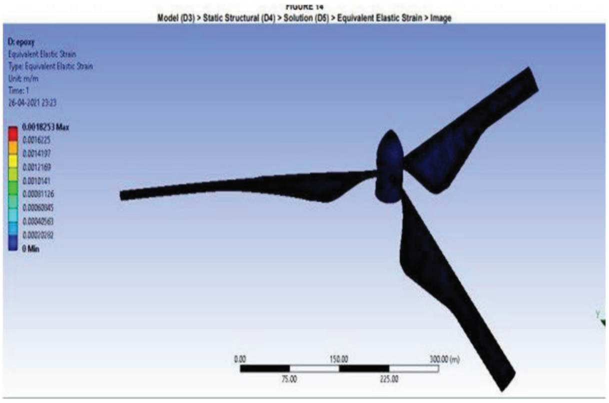

Figure 14. Equivalent Strain of Epoxy Glass

Fig.14 shows the total deformation in stainless steel and it is observed that the maximum value is 0.004256.

IV. RESULTS AND DISCUSSIONS

TABLE IV.
A) RESULTS OF ANALYSIS AT 750 N

Material	Total Deformation (m)	Equivalent Stress (Pa)	Equivalent Strain
Stainless Steel	0.92	6.03e7	0.000305
Gray Cast Iron	0.75	2.93e7	0.0002684
Epoxy Glass	1.14	2.912e7	0.004256

B) RESULTS OF ANALYSIS AT 1500 N

Material	Total Deformation (m)	Equivalent Stress (Pa)	Equivalent Strain
Stainless Steel	1.27	7.36e7	0.00045
Gray Cast Iron	1.12	5.86e7	0.0005368
Epoxy Glass	2.28	5.88e7	0.000603

C) RESULTS OF ANALYSIS AT 2000 N

Material	Total Deformation (m)	Equivalent Stress (Pa)	Equivalent Strain
Stainless Steel	1.918	1.318e8	0.000687
Gray Cast Iron	1.5	1.06e8	0.000805
Epoxy Glass	3.42	8.82e7	0.00121

The Table IV shows the total deformation, equivalent stress and strain for stainless steel, gray cast iron and epoxy glass at 750 N, 1500 N and 2000N. From the analysis results of turbine blade, it is observed that the material STAINLESS STEEL is the preferable material with desirable physical and mechanical properties for turbine blade. Also, it has less deformation under the given loads than the other two materials i.e., grey cast iron and epoxy glass. The analysis carried out on various materials above will make an impressing mark in the field of renewable energy.

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