Finite Element Analysis of Horizontal Axis Wind Turbine Blades Using NACA 4412 Series

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Abstract**—** *Wind turbine technology is one of the rapid growth sectors of renewable energy all over the world. The ultimate objective of the project work is to increase the output power under specified atmospheric conditions. From the technical point of view, the output power depends on the shape of the blade. The blade plays a pivotal role, because it is the most important part of the energy absorption system. Finite element analysis was conducted by different materials used for blade fabrication namely glass fiber with epoxy resin, Aluminum and teak wood. The research work focuses on NACA4412. Also, the performance of a wind turbine blade is highly dependent on the structure Total deformation, Stress and Strain of the blade is critical to the wind turbine system service life. So, the wind turbine blades are analyzed taking these parameters into account.*

Keywords— Horizontal axis Wind turbine, NACA 4412, Finite element analysis, deformation.

I. INTRODUCTION

The modern blade can be divided into three main areas classified by aerodynamic and structural function. a). The blade root: The transition between the circular mount and the first aerofoil profile this section carries the highest loads. Its low relative wind velocity is due to the relatively small rotor radius. The low wind velocity leads to reduced aerodynamic lift leading to large chord lengths. Therefore the blade profile becomes excessively large at the rotor hub. The problem of low lift is compounded by the need to use excessively thick aerofoil sections to improve structural integrity at this load intensive region. Therefore the root region of the blade will typically consist of thick aerofoil profiles with low aerodynamic efficiency.

b). The mid span: Aerodynamically significant—the lift to drag ratio will be maximized. Therefore utilizing the thinnest possible aerofoil section that structural considerations will allow.

c). The tip: Aerodynamically critical—the lift to drag ratio will be maximized. Therefore using slender aerofoil's and specially designed tip geometries to reduce noise and losses. Such tip geometries are as yet unproven in the field in any case they are still used by some manufacturers.

AERODYNAMICS OF HAWT: Wind turbine blades are shaped to generate the maximum power from the wind at the minimum cost. Primarily the design is driven by the aerodynamic requirements, but economics mean that the blade shape is a compromise to keep the cost of construction reasonable. In particular, the blade tends to be thicker than the aerodynamic optimum close to the root, where the stresses due to bending are greatest.The blade design process starts with a "best guess" compromise between aerodynamic and structural efficiency. The choice of materials and manufacturing process will also have an influence on how thin (hence aerodynamically ideal) the blade can be built. The chosen aerodynamic shape gives rise to loads, which are fed into the structural design. Problems identified at this stage can then be used to modify the shape if necessary and recalculate the aerodynamic performance.

BLADE SECTION SHAPE

Apart from the twist, wind turbine blades have similar requirements to airplane wings, so their cross-sections are usually based on a similar family of shapes. In general the best lift/drag characteristics are obtained by an aerofoil that is fairly thin: its thickness might be only 10-15% of its "chord" length (the length across the blade, in the direction of the wind flow).If there were no structural requirements, this is how a wind turbine blade would be proportioned, but of course the blade needs to support the lift, drag and gravitational forces acting on it. These structural requirements generally mean the aerofoil needs to be thicker than the aerodynamic optimum, especially at locations towards the root (where the blade attaches to the hub) where the bending forces are greatest. Fortunately that is also where the apparent wind is moving more slowly and the blade has the least leverage over the hub, so some aerodynamic inefficiency at that point is less serious than it would be closer to the tip. Having said this, the section can't get too thick for its chord length or the air flow will "separate" from the back of the blade – similar to what happens when it stalls – and the drag will increase dramatically.To increase thickness near the root without creating a very short, fat, aerofoil section, some designs use a “flatback” section. This is either a standard section thickened up to a square trailing (back) edge, or a longer aerofoil shape that has been truncated. This reduces the drag compared to a rounder section, but can generate more noise so its suitability depends on the wind farm site.There is a trade-off to be made between aerodynamic efficiency and structural efficiency: even if a thin blade can be made strong and stiff enough by using lots of reinforcement inside, it might still be better to make the blade a bit thicker (hence less aerodynamically efficient) if it saves so much cost of material that the overall cost of electricity is reduced. The wind is free after all; it’s only the machine that we have to pay for. So there is inevitably some iteration in the design process to find the optimum thickness for the blade.

II. METHODOLOGY

The planform shape is chosen to give the blade an approximately constant slowing effect on the wind over the whole rotor disc (i.e. the tip slows the wind to the same degree as the centre or root of the blade). This ensures that none of the air leaves the turbine too slowly (causing turbulence), yet none is allowed to pass through too fast (which would represent wasted energy). Remembering Betz’s limit discussed above, this results in the maximum power extraction.Because the tip of the blade is moving faster than the root, it passes through more volume of air, hence must generate a greater lift force to slow that air down enough. Fortunately, lift increases with the square of speed so its greater speed more than allows for that. In reality the blade can be narrower close to the tip than near the root and still generate enough lift. The optimum tapering of the blade planform as it goes outboard can be calculated; roughly speaking the chord should be inverse to the radius. So if the chord was 2m at 10m radius, it should be 10m at 1m radius. This relationship breaks down close to the root and tip, where the optimum shape changes to account for tip losses. In reality a fairly linear taper is sufficiently close to the optimum for most designs, structurally superior and easier to build than the optimum shape.

MATERIAL PROPERTIES

Table 1: GLASS FIBER WITH EPOXY RESIN

Sl.no.	Property	Values	Units
1	Density	2520	Kgm^-3
2	Orthotropic Elasticity	-	-
3	Young’s Modulus in X direction	4.0085E+10	Pa
4	Young’s Modulus in Y direction	8.9138E+09	Pa
5	Young’s Modulus in Z direction	8.9138E+09	Pa
6	Poisson’s Ratio XY	0.284	
7	Poisson’s Ratio YZ	0.0602	
8	Poisson’s Ratio XZ	0.284	
9	Shear Modulus XY	3.4446E+09	Pa
10	Shear Modulus YZ	3.4446E+09	Pa
11	Shear Modulus XZ	3.4446E+09	Pa

Table 2: ALUMINIUM

Sl.no.	Property	Values	Units
1	Density	2770	Kgm^-3
2	Isotropic Elasticity	-	-
3	Derive from	Youngs modulus & poission ratio	
4	Young’s Modulus	7.1E+10	Pa
5	Poisson’s Ratio	0.33	
6	Bulk modulus	6.9608E+10	Pa
7	Shear modulus	2.6692E+10	Pa

Table 3: TEAK WOOD

Sl.no.	Property	Values	Units
1	Density	630	Kgm^-3
2	Isotropic Elasticity	-	-
3	Derive from	Youngs modulus & poission ratio	
4	Young’s Modulus	1.228E+10	Pa
5	Poisson’s Ratio	0.21	
6	Bulk modulus	7.0575E+09	Pa
7	Shear modulus	5.0744E+09	Pa

III. PRIOR APPROACH

M. Grujicic, G. Arakere, E. Subramanian, V. Sellappan, A. Vallejo, and M. Ozen [1], in this paper discussed about the problem of mechanical design, performance prediction, and material selection for a horizontal-axis wind turbine (HAWT) blade is investigated using various computer-aided engineering tools. A fully parameterized computer program has been developed for automated generation of the geometrical and finite-element meshed models of the HAWT-blades. The program enables the specification of the basic blade geometrical and structural parameters.

N.Manikandan, B.Stalin [2] The ultimate objective of the work is to increase the reliability of wind turbine blades through the development of the airfoil structure and also to reduce the noise produced during the running period of the wind turbine blades. The wind turbine blade is modeled and several sections are created from root to tip with the variation from the standard design for improving the efficiency. The blade has to be designed carefully to enable to absorb energy with its greatest efficiency. Generic model developed could take different shapes and sizes with the help associated parameters and could be used in the pre-design stage of winglets.

T.Vishnuvardhan, Dr.B.Durga Prasad, [3] The electricity produced by wind power is cost effective when compared with remaining green energy sources. Small wind turbine systems can be easily installed near the site where the power is required thus the investment on power transmission lines can be reduced. Finite element analysis was conducted by varying the composition of materials used for blade fabrication. All the blades are capable to bear maximum loading value when applied at the root section and the blades will fail at lower magnitude of loading, when the load is applied at tip of the blade. It is observed that all the blades when subjected to loading irrespective of the location at which the load is applied, the failure crack is observed near the root of the blade.

Peter J. Schubel and Richard J. Crossley [4] A detailed review of the current state-of-art for wind turbine blade design is presented, including theoretical maximum efficiency, propulsion, practical efficiency, HAWT blade design, and blade loads. The aerodynamic design principles for a modern wind turbine blade are detailed, including blade plan shape/quantity, aerofoil selection and optimal attack angles. A comprehensive look at blade design has shown that an efficient blade shape is defined by aerodynamic calculations based on chosen parameters and the performance of the selected aerofoils. The optimum efficient shape is complex consisting of aerofoil sections of increasing width, thickness and twist angle towards the hub. This general shape is constrained by physical laws and is unlikely to change. However, aerofoil lift and drag performance will determine exact angles of twist and chord lengths for optimum aerodynamic performance.

Arvind Singh Rathore, Siraj Ahmed [5] An aerodynamic analysis tool for analysis of horizontal axis wind turbine blades is developed by using both Blade Element Momentum (BEM) Theory and Computer Program. The method is used to optimize blade geometry to give the maximum power for a given wind speed, a constant rotational speed, a number of blades and a blade radius. The airfoil profiles and their aerodynamic data are taken from an existing airfoil database for which experimental lift and drag coefficient data are available. In this paper a computer program is used for analysis of aerodynamics of different airfoil. We take the 11 airfoils data for 21m length of blade out of which NACA-2415 airfoil has generated maximum power at nominal wind velocity. This program can be used for any number of airfoils.

IV. OUR APPROACH

STATIC ANALYSIS

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.

You will configure your static structural analysis in the Mechanical application, which uses the ANSYS depending on which system you selected, to compute the solution.

STEPS FOR STATIC ANALYSIS

1. Add a static structural analysis template by dragging the template from the Toolbox into the Project Schematic or by double-clicking the template in the Toolbox.
2. Load the geometry by right-clicking on the Geometry cell and choosing Import Geometry. Import the geometry in IGES format.
3. View the geometry by right-clicking on the Model cell and choosing Edit, or double-clicking the Model cell. Alternatively, you can right click the Setup cell and select Edit. This step will launch the Mechanical application.
4. In the Mechanical application window, click on geometry and select the material.
5. Now click on Mesh and select generate mesh.
6. Click on Analysis setting and then select fixed support. Fixed the end part of the blade.
7. Click on loads and select pressure and then apply on the faces of geometry.
8. Now click on solution and select Total deformation, Equivalent stress, and Equivalent strain and click on solve all results.
9. Now save all the images and solution information in word document.

STATIC ANALYSIS OF NACA 4412

A). GLASS FIBER WITH EPOXY RESIN BLADE

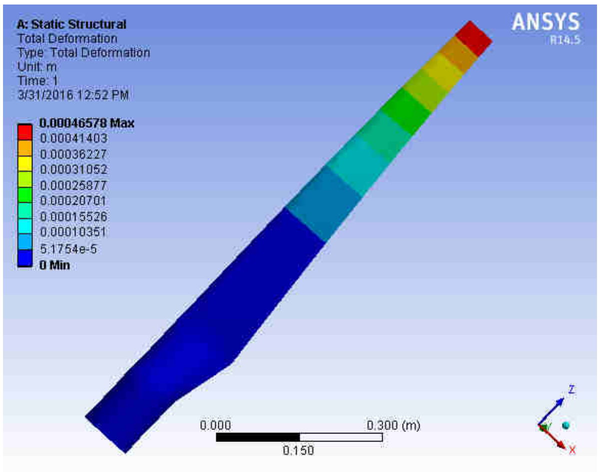


Fig.1 : TOTAL DEFORMATION

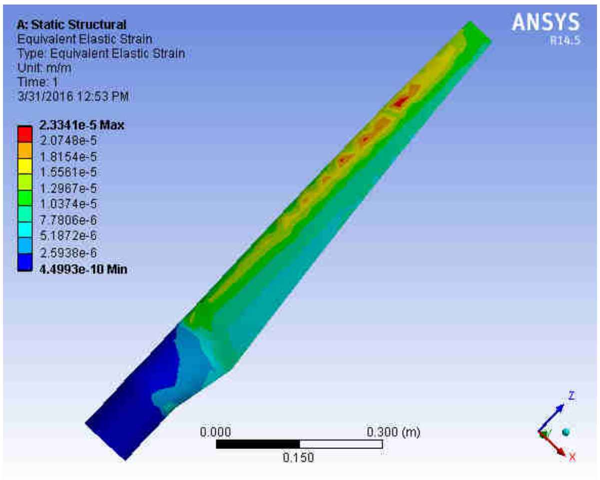


Fig.2 : EQUIVALENT ELASTIC STRAIN

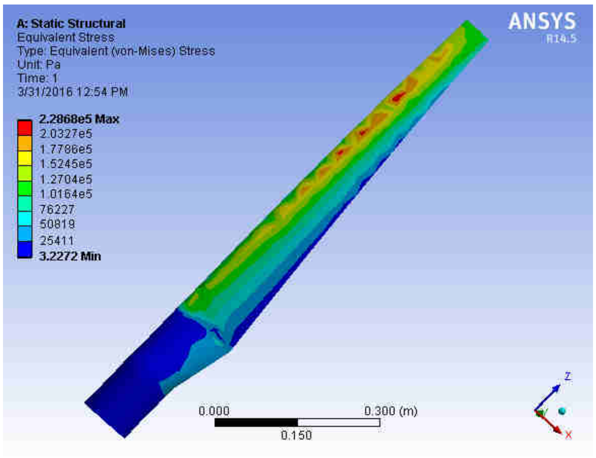


Fig.3 : EQUIVALENT STRESS

B). ALUMINIUM BLADE for NACA4412

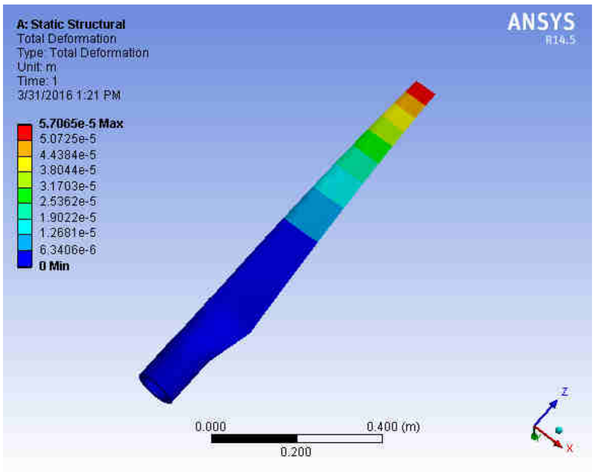


Fig.4 : TOTAL DEFORMATION

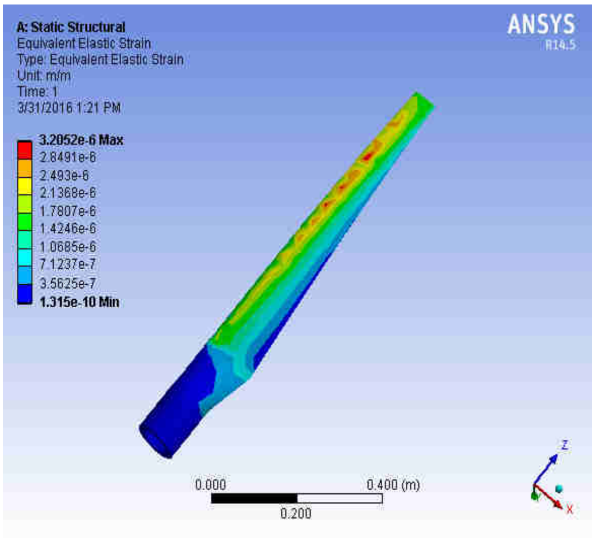


Fig.5 : EQUIVALENT ELASTIC STRAIN

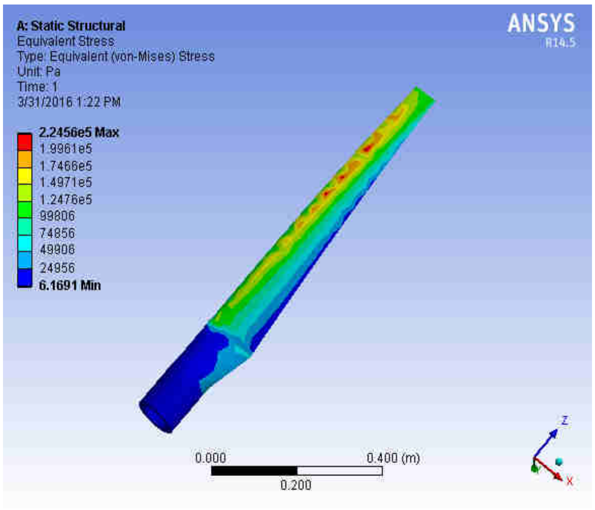


Fig.6 : EQUIVALENT STRESS

C). TEAK WOOD BLADE for NACA4412

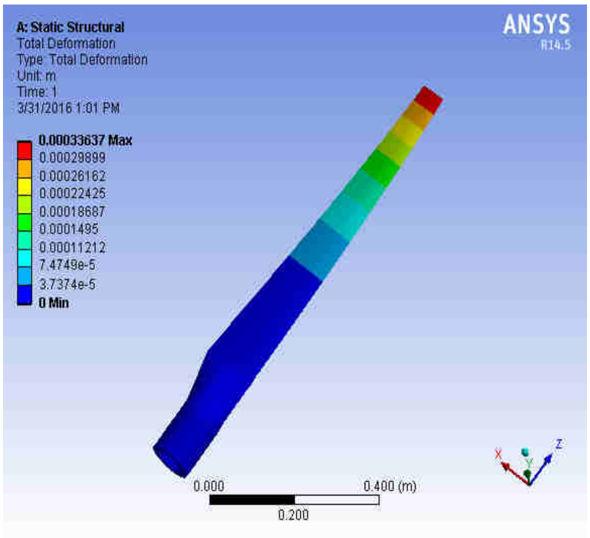


Fig.7 : TOTAL DEFORMATION

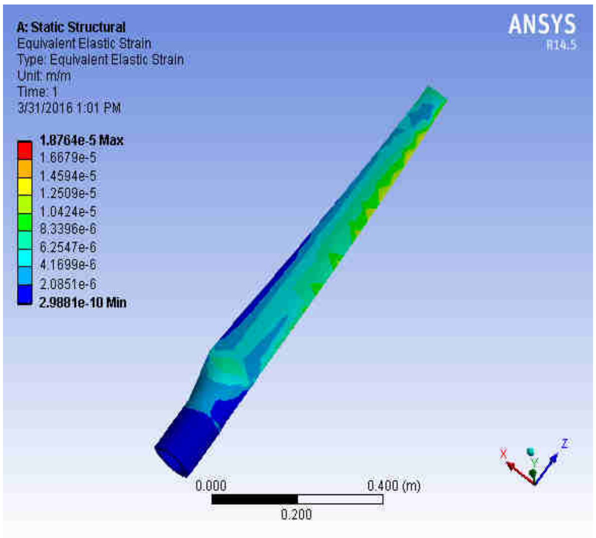


Fig.8 : EQUIVALENT ELASTIC STRAIN

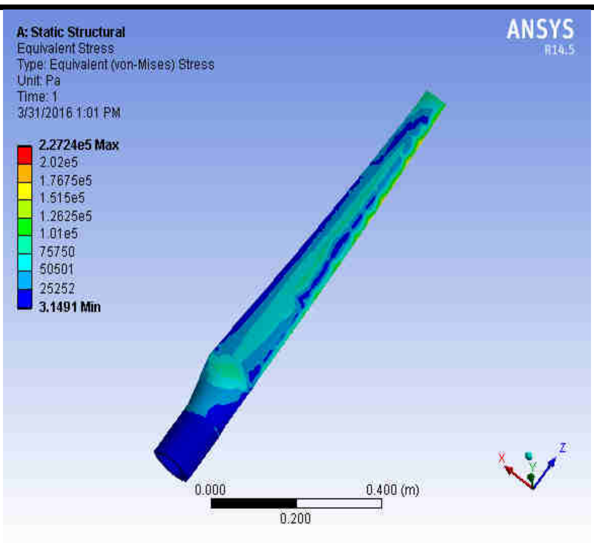
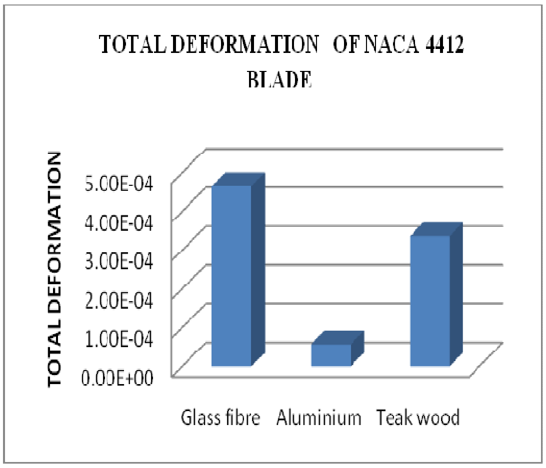


Fig.9 : EQUIVALENT STRESS

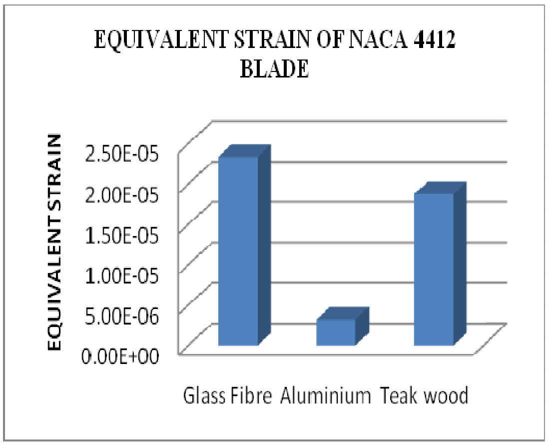
Table 4: STATIC ANAYSIS OF NACA 4412 AT ATMOSPHERIC PRESSURE

Sl. no	**Material**	**Total Deformation (m)**	**Equivalent Strain**	**Equivalent Stress (pa)**
1	Glass Fiber with epoxy resin	4.6578e-004	2.3341e-005	2.2868e+005
2	Aluminum	5.7065e-005	3.2052e-006	2.2456e+005
3	Teak Wood	3.3637e-004	1.8764e-005	2.2724e+005

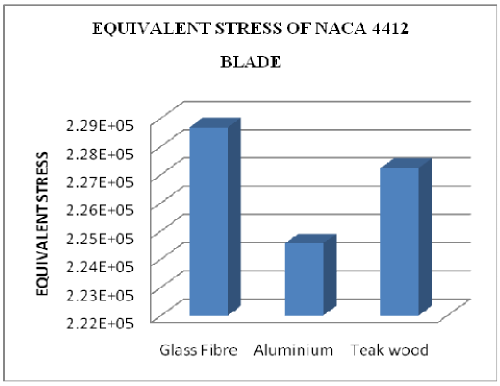
Table 4 from the above table we are comparing stress , strain and deformation values of Glass Fiber with Epoxy resin , Aluminium and Teak Wood



Graph 1 from the above column chart we come to know that deformation values of aluminium are less when compared to glass fiber with epoxy resin and teak wood at atmospheric pressure.



Graph 2 from the above column chart we come to know that equivalent strain values of aluminium are less when compared to glass fiber with epoxy resin and teak wood at atmospheric pressure.



Graph 3 from the above column chart we come to know that equivalent stress of aluminium are less when compared to glass fiber with epoxy resin and teak wood at atmospheric pressure.

V. CONCLUSION

A simple HAWT blade material selection procedure was developed which combines weighted contributions of the material indices pertaining to the blade performance and longevity. The performance of a wind turbine blade is highly dependent on the structure and is critical to the wind turbine system service life. The results revealed that, from the performance point of view, Aluminium is preferred over the teak wood and glass fiber with epoxy resin. . The total deformation, equivalent strain and equivalent stress values of NACA 4412 are 5.7065e-005m, 3.2052e-006, 2.2456e+005Pa. Thus, Aluminium is the best choice for the material.

A preliminary parameter variation study was conducted which revealed that further improvements in the HAWT blade performance are possible with targeted changing the series of NACA 4412.

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