ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

IARJSET

International Advanced Research Journal in Science, Engineering and Technology
National Conference on Emerging Trends in Engineering and Technology (NCETET'16)
Lourdes Matha College of Science & Technology, Thiruvananthapuram
Vol. 3, Special Issue 3, August 2016

Linear Static Analysis and Computational Validation of a Composite Wind Turbine Blade

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Abstract: Wind power energy is getting more shares in the total energy production every year, with wind turbines growing bigger and bigger at the rhythm of technology. Wind turbines can be classified (in a first) approximation according to its rotor axis orientation and the type of aerodynamic forces used to take energy from wind. The blade is the most important component in a wind turbine which nowadays is designed according to a refined aerodynamic science in order to capture the maximum energy from the wind. Blades of horizontal axis are now completely made of composite materials. Composite materials satisfy complex design constraints such as lower weight and proper stiffness, while providing good resistance to the static and fatigue loading. An experiment conducted by Xiao Chen **(**Institute of Engineering Thermo physics, Chinese Academy of Sciences**)** and others on similar profile and tried to determine various fracture modes in it. Material used by them was a combination of epoxy glass resin and PVC. Using the guidelines set by the experiment, the blade was modelled using SOLIDWORKS and analyzed using Solid works FEA solver- Composite Material Module for superior materials like windstrand. The dynamic response of the system too was studied.

Keywords: Wind energy; blade geometry; Composite; Static Analysis; Dynamic Response; FEA.

1. INTRODUCTION

For validating the strength of the wind turbine blade, static analysis is always a powerful tool. The study presented here is regarding the ability of the blade to sustain suitable concentrated loads without yielding. The span of the blade (52.3 m) makes the analysis more complicated. Further, the composition of epoxy-PVC composite was regarded classified. For effective Mathematical Modelling, the blade could be considered as a cantilever beam with point loads applied at equidistance. Initially the analysis was carried out using the blade material: epoxy resin-PVC composite and then a new material with a better properties was suggested

With the expansion of wind energy in recent years, the sizes of wind turbine blades have become increasingly large in order to capture more power from wind and further reduce the cost of energy. When blades are small, tip deflection is a major driver in structural design and blade failure is of less concern. However, as blade sizes grow, the types of failure change and three-dimensional stresses become important.

Although several failure incidents of 50+ m blades have been reported in recent years, no experimental study focused on the failure of blades with lengths longer than 40 m has been publically. It is considered that larger blades may exhibit more complex failure behavior which has neither been observed from the existing studies nor been paid enough attention to in current blade design.

Therefore, there is an urgent need of experimental studies on large blades to gain more understanding on their failure behavior.

Various investigations were carried out on the failure behavior of large blades installed on multi-megawatt (MW) wind turbines by leading researchers. A few notable ones are the failure test on a 25 m blade under flap-wise bending emphasizing the geometrical nonlinearity at large deflections by Jorgensen, et al. [1].

Similarly Yang et al. [2] studied the structural collapse of a 40 m blade under flap-wise bending and found that debonding of aerodynamic shells from adhesive joints was the prime reason of collapse. This article is regarding the static and dynamic analysis of a carefully modelled wind turbine blade with longer span (53.3m) [3].

2. Design Premises

The blade was designed for 2.5 MW wind turbines and had a total length of 52.3 m. The original material [3] was made of glass fabrics and vacuum infused with epoxy resin. The cross section of the blade is shown in Figure 2.1.

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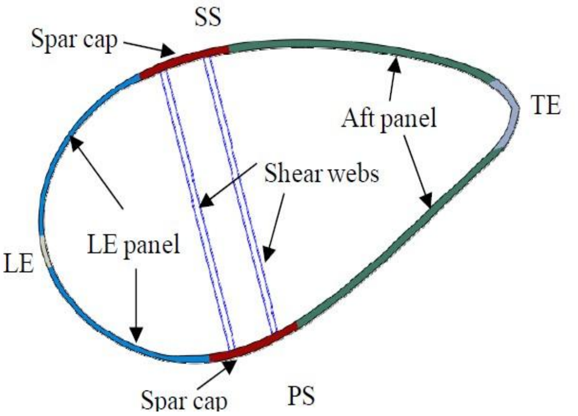


Figure 2.1: Cross section

Spar caps were made of composite laminates, which is designed for bending moments. The leading edge panel and aft panel were made of sandwich constructions with PVC foam cores. Designed to provide an aerodynamic airfoil shape. Shear webs were also sandwich constructions and designed to support two spar caps and transfer shear forces. In order to optimize the strength of the blade, we have remodeled the blade using windstrand and results were compared with the epoxy make.

The wind turbine blade is fixed at the root and hence it is modelled as a cantilever beam. The equivalent point loads are calculated from the maximum deflection obtained at the tip. The so obtained load is applied at three equidistant points.

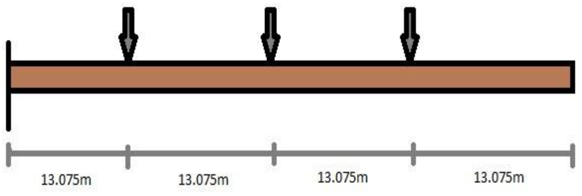


Figure 2.2: Loading pattern

While modelling the blade, a sandwich structure is assumed. Each ply is applied as layers, making an angle of 45° with each other. The root is made of cast iron, but it may not be considered for static analysis.

Figure 2.3: Meshed view of blade

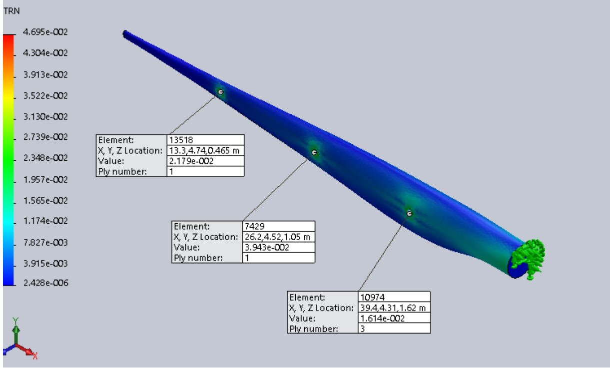


Figure 2.4: Position of loading points

Rather than applying a uniformly distributed load, point loads were preferred. First, 20% of the maximum load was applied, then 40% followed by 60%, 80% and finally 100% of the total load were applied. In the experiment conducted by Xiao Chen [3], cranes were employed for applying load. Loads were applied simultaneously and then held for ten seconds. Strain gauges and load cells were used to record the data.

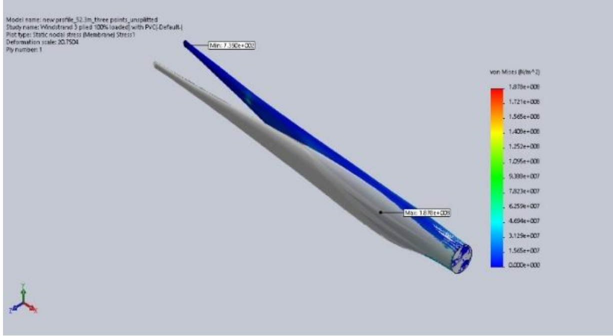


Figure 2.5: Von mises stress patten and displacement for 52.3m long Windstrand make blade for 100% of load

Deflections of the blade were measured at loading saddle locations and at blade tip using draw-wire displacement transducers. Longitudinal strains were recorded by strain gauges located along the middle axis of spar caps.

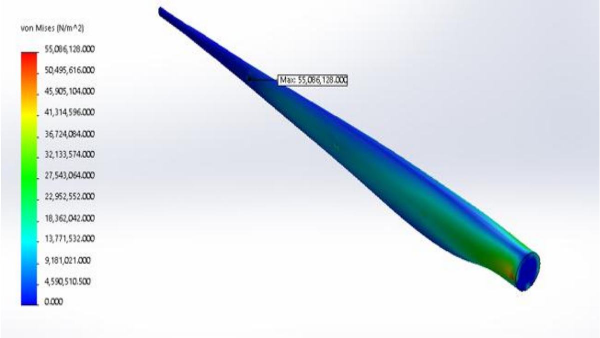
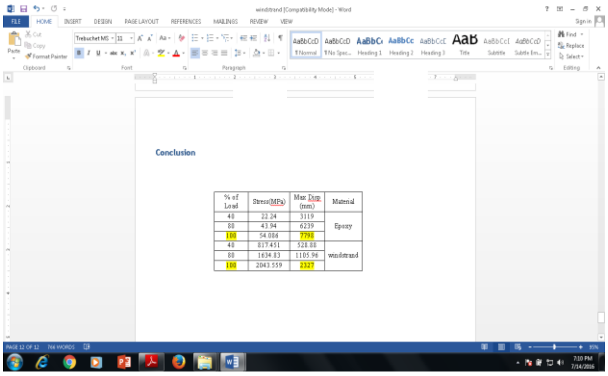


Figure 2.6: Von mises stress patten and displacement for 52.3m long Epoxy make blade for 100% of load

Behaviors of Materials such as Epoxy [4] composite, Windstrand were studied. For 100% loading (in the case of

Epoxy) the maximum stress induced was 54.086Mpa, which was well below its yield and the maximum displacement noticed was 7798mm. Dynamic response of material for the same load using K-Epsilon model too gave promising results.

For 100% loading (in the case of Windstrand) the maximum stress induced was 2043.559Mpa, which was well below its yield (2358MPa).Similarly for 100% loading (in the case of Windstrand) the maximum displacement noticed was 2327mm.


Conclusion

% of Load	Stress(MPa)	Max Disp (mm)	Material
40	22.24	3119	Epoxy
80	43.94	6239	
100	54.086	7798	
40	817.451	528.88	windstrand
80	1634.83	1105.96	
100	2043.559	2327	

Figure 2.7: Comparison between Epoxy and Winstrand blades

General studies suggest a maximum deflection of 10m before failure. It is interesting to notice that the deflection is only 2.3m (in the case of Windstrand) when compared to 7.79m (in the case of Epoxy) for maximum load. For superior materials like Windstrand, the deflection for the same load was reduced to 70.47%.This study emphasized the significance of through-thickness stresses on the failure [5] of large composite blades.

3. CONCLUSION

The global-local modeling approach could be employed, which is a proved and effective methodology to capture failure behavior of the blade while considerably reducing difficulties in modeling an entire blade. The loading history of the blade could also be numerically reproduced and the complex failure characteristics could be observed at the transition region using FE simulation.Our studies emphasise the importance of material selection for the same design. With advancement of technology, new and better material such as Winstrand and aramid are best proven for wind turbine blade due to least density and high yield strength.

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