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Numerical simulation analysis as a tool to identify areas of weakness in a turbine wind-blade and solutions for their reinforcement

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ABSTRACT

Offshore wind energy is one of the main sources of renewable energy that can benefit from new generation materials that exhibit good oxidation resistance and mechanical reliability. Composite materials are the best consideration for harsh environment and deep sea wind turbine manufacturing. In this study, a numerical simulation was implemented to predict the stress distribution over a wind turbine-blade and to determine areas with high stress concentration. Finite Element Analysis (FEA) was used to find optimal material and bonding techniques to construct the blade. By using Abaqus commercial software, a finite element model of wind turbine blade was analyzed under bending-torsion coupled with a static-load condition in flap-wise direction. Structural damage in critical zones varies according to ply orientation and stack thickness as a result of composite orthotropic nature. This study leads existing scenarios and techniques which would provide a new and better solutions for wind turbine blade designers. The root section and trailing edge were found to be critical zones in the wind turbine blade. The root section failure can be reduced by (1) adjusting the thickness of the structure or increasing the number of plies in the composites laminate stacking and by (2) adjusting the bonding technique to prevent trailing-edge failure. Transverse-stitch method and the carbon cord tying methods are most effective for trailing edge reinforcement. Both solutions are proposed to reduce failures in wind turbine blades and proven by step-by-step numerical study. The goal of this study is to deliver a good reference for wind turbine blade designers and to improve the accuracy during design phase as well as to avoid failure.

1. Introduction

Offshore wind power is defined as generating electricity from wind by the installation of seaward located wind farms. Land-based wind power will remain dominant in the immediate future but installations at sea will become more and more important. Compared to onshore, offshore wind power stations are more complex and costly to install and maintain, but have also a number of key advantages. Winds are typically stronger and more stable at sea than on land, resulting in significantly higher production per unit installed. The recent fast growth in wind energy production motivates the industry to design large scale wind-turbines, in order to reduce the cost of energy. According to the world wind energy association (WWEA), the modern wind turbines are 10 times bigger than the traditional ones [10]. As the result, the wind energy industry should adapt to advanced materials to withstand high wind forces reacting on rotor blades. Composite materials with high strength-to-weight ratio and associated stiffness are used for the production of wind turbine components.

The up-scaling of blades requires design optimization to increase strength, reduce weight as well as cost of energy. Therefore strengthening the composite material is essential for new generation blades. Our blade model, mesh, load, material and boundary conditions should be adaptable to the large scale blade. Present reviews discuss most recent developments in wind turbine blade

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Table 1
Mechanical properties of composite materials.

Materials	E_1	E_2	ν_{12}	G_{12}	G_{23}
Plain weave fabrics – Glass	23.37 GPa	23.50 GPa	0.28	5.22 GPa	4.74 GPa
Plain weave fabrics – Carbon	63 GPa	62.73 GPa	0.05	4.37 GPa	2.91 GPa
Unidirectional – Glass	47.10 GPa	13.098 GPa	0.28	4.749 GPa	3.134 Gpa
Unidirectional – Carbon	103.3 GPa	9 GPa	0.05	5.32 GPa	3.51 GPa

Material	Young's modulus	Density
Adhesive material	275 MPa	1420 Kg/m^3
Foam	220 MPa	153 Kg/m^3

numerical simulation and explore similar studies to identify relevant circumstance. Cox [21] studied structural design for large-scale wind turbine blades. This article detailed a blade model with respect to industry standard failure criteria under load under extreme wind condition. Bonnet [9] studied the method of designing a blade by python scripts for Abaqus commercial software. This procedure of blade designing eases modeling process, even though the blade dimensions are variable and complicated. It is necessary to verify that the numerical results are providing appropriate information for experimental and real time structures; otherwise the numerical study has no significance for blade manufacturers. Li [42] investigated the effect of lay-up on wind turbine blade properties. A blade model was designed by shell elements and compared experimental results with numerical calculations to study the strength and mass distribution along the blade span. The significant method of meshing with shell element and load application was identified to approach the experimental condition. Ashwill [5] from Sandia Laboratory and some others [3,23] studied the coupling of bending and torsion forces acting on blades made of composites. Flap-wise direction of this load induces high magnitude force on blades. Bending and torsion loads could be sustained by optimal ply orientation and lay-up arrangement. Mechanical behavior of composite materials varies depending on the fiber stiffening directions. In light of this, the fiber direction should be selected to enhance the strength in the directions which need a high stiffness. The effect of thickness and lay-up orientation used in wind turbine blades was studied by Ref. [11]. This method helps to reduce the weight and gravitational force of wind turbine blades, also provide basic knowledge about composite material optimization. An optimization specialist in Altair [33] have investigated the ply stack sequence based on stiffness and laminate lay-up theory. He explained about free element sizing and super-ply stacking to strengthen the structure. In addition, he proposed that the 0° orientation plies should be in maximum number in the direction of blade length and the 90° orientation plies should be fewer for blade optimization. Ganz [15] investigated the advantage of composite materials over isotropic material. He has also studied the failure of these materials based on the Tsai-Wu criterion. The Tsai-

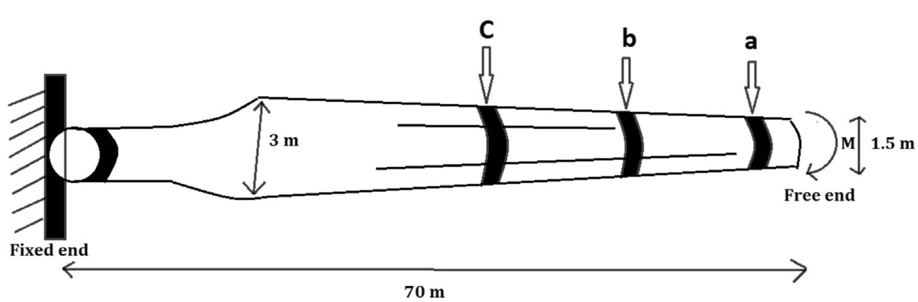

Fig. 1. Wind turbine blade's dimensions and load applied points.

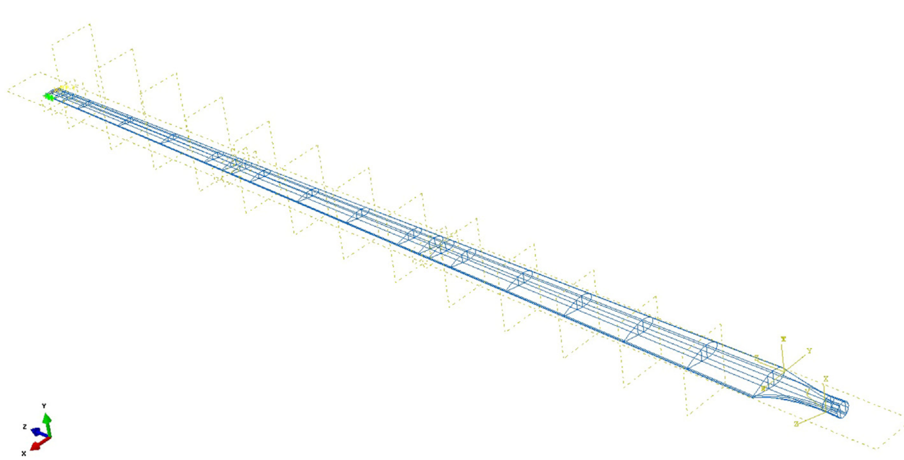

Fig. 2. Blade designed by several planes to maintain the airfoil profile and twist angle.