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Structural Test and Evaluation of Composite Blade for Wind Turbine System

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Abstract : In this work, a structural design on horizontal axis wind turbine blade using natural flax fiber composite is performed. The structural design results of flax/epoxy composite blade are compared with the design results of glass/epoxy composite blade. In order to evaluate the structural design of the composite blade, the structural analysis was performed by the finite element method. Through the structural analyses, it is confirmed that the designed blade using natural composite is acceptable for structural safety, blade tip deflection, structural stability, resonance possibility, and weight. Finally, structural test of manufactured blade was performed. Through the structural test, it is confirmed that the designed blade is acceptable.

Key Words : Composite blade, Flax, Structural design, Finite element analysis, Structural test

1. Introduction

Throughout the world composites are used for a variety of purposes, structurally and decoratively. Their ability to perform the same tasks as metallic counterparts but with a lower weight enables their use in high-performance applications such as the aerospace and automotive sectors. Typically, composites used in these applications are derived from petrochemicals, which are toxic, energy intensive to manufacture and difficult to dispose of once a product reaches the end of its life cycle. In recent years there has been a growing interest in the use of naturally sourced fibres for use in composites design and manufacture. Natural fibres offer several benefits over petrochemical derived fibres, such as their relatively low cost, high abundance and sustainability, and their ability to be recycled [1-2].

Among the previous studies, P. J Herrera-Franco et al. studied investigation on mechanical properties of henequen natural fibre. In this work, the mechanical behavior high density polyethylene (HDPE) reinforced with continuous henequen fibres was studied[3]. M. Zampaloni et al. performed the study on kenaf natural fiber reinforced polypropylene composites. This study focused on the fabrication of kenaf fiber reinforced polypropylene sheets that could be thermoformed for a wide variety of applications with properties that are comparable to existing synthetic composites[4]. Vincent Placet studied investigation on mechanical properties of hemp fibre.

In recent years, considerable experimental studies have been performed to investigate the property of natural fibre. However, little research work has been carried out to apply natural composite for structural

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design. In this work, a structural design on 1kW class horizontal axis wind turbine blade using natural flax fibre composite is performed. A specific proper airfoil at low wind speed was selected, and the optimal aerodynamic design was derived through the parametric study on linear chord distribution and blade angle design with maximum lift-drag ratios. In structural design, the blade uses flax/epoxy composite and urethane foam materials, and its structure adapts the skin-spar-foam sandwich style. Moreover, the structural design results of flax/epoxy composite blade are compared with the glass/epoxy blade[5-6].

In order to evaluate the structural design results of the composite blade, the structural analysis was performed by the finite element method using MSC. Nastran. In this analysis, linear static stress analysis, eigenvalue analysis and buckling analysis were carried out. Finally, the structural safety was confirmed through the analysis results.

2. Aerodynamic Design and Analysis

The aerodynamic design is firstly performed according to design requirements, and its results are evaluated through performance analysis. For electric power generation, the direct drive AFPM (axial flux permanent magnet) generator is used for simplicity.

In this study, the airfoil of NACA 632-615, which has relatively high stall angle of attack, maximum lift coefficient and maximum lift-drag ratio was selected for the design purpose. There are several methods to design aerodynamically the blade such as chord length and twist angle. In this study, two methods, which are the most general method to find the optimum inclination angle with maximum lift-drag ratio and the method to get the linear chord length distribution, were investigated.

An in-house aerodynamic design program based on the theoretical equation above is newly coded. If the wind speed and design parameters are given as an input data, the program can calculate the tip speed ratio, power coefficient and power considering Reynold's number. Here the look-up table of the local Reynold's number of each airfoil is obtained by the CFD analysis. The final aerodynamic configuration is shown in Fig. 1.

Fig. 1 Designed aerodynamic configuration of blade

3. Structural Design and Analysis

In the structural design of the wind turbine blade, the strength of blades must be generally proved by a proper strength analysis. Components in compression must be investigated for stability failures such as buckling at the extreme load. Both the structural design and the strength analysis have to be carried out at the adequate number of cross-sections of the rotor blade.

Estimation of loads has been a major concern in wind turbine designs to date. The most approved method of load estimation should be to run steady-state or transient response cases on the system simulation, and then adapt the time-history output to obtain maximum, minimum, mean and cyclic loads that occur. Through the load analysis, various loads such as mean operating loads, limit loads, fatigue loads and blade internal and external pressure should be defined. Various load cases have been defined in international specification IEC61400-2 for small wind turbine. In order to meet the international standard, this study adapts some design specifications and standards for the small wind turbine blade as follows IEC 61400-2.

In this study, there are two design steps such as the preliminary design stage and the detail design stage. For the preliminary structural design of the blade, the number of cross-sections will be considered as 10 cross-sections. The structural type is adapted the skin-spar-foam sandwich style.

In this work, the natural fibre was adopted for structural design. The growth of use of natural composite is indicative of their wider application due to the favorable mechanical performance of natural fibres. Among them, flax, hemp, jute and sisal are most popular composite fibres in natural composites. The flax fibre has better mechanical properties compared to other natural fibres. Therefore, the flax/epoxy composite material was selected for the wind turbine blade design. Moreover, the structural design results of flax/epoxy composite blade are compared with the design results of glass/epoxy composite blade.

4. Material Properties

The blade performance analysis is performed for investigation whether the aerodynamic design of blade is acceptable for the design target performance.

In order to compare with the mechanical properties of natural and glass fibre, this study evaluates the mechanical properties of the flax /epoxy and glass/epoxy. Finally, the structural design results of flax/epoxy composite blade were compared with the glass/epoxy blade.

The mechanical properties of different types of specimen were evaluated under tension, compression, flexure, shear test. The structural design is performed based on the mechanical properties of materials selected. Each specimen tests were performed by ASTM regulation. Table 1 shows the comparison result of mechanical properties of glass/epoxy laminate and flax/epoxy laminate.

5. Structural Test

A prototype blade for the static strength test was tested, and used for comparison with the analyzed model. During the test until the maximum loading, there was no failure such as catastrophic failure, local failure, de-bonding, de-lamination, local buckling, etc. Prediction from the model is in good agreement with the measured values indicating that, at least, the structural construction of the blade was reasonably modeled. Fig. 2 shows static strength test loads simulated by three-point loading method.

Table 1 Aerodynamic design results of small wind turbine blade

Material Property	Glass/epoxy	Flax/epoxy
Elastic modulus [MPa]	10,500	9,648
Shear modulus [MPa]	1,450	3,842
Poisson's ratio	0.27	0.43
Tensile strength [MPa]	283	157
Compressive strength [MPa]	184	85
Shear strength [MPa]	15	26
Density [g/cm3]	1.87	1.43

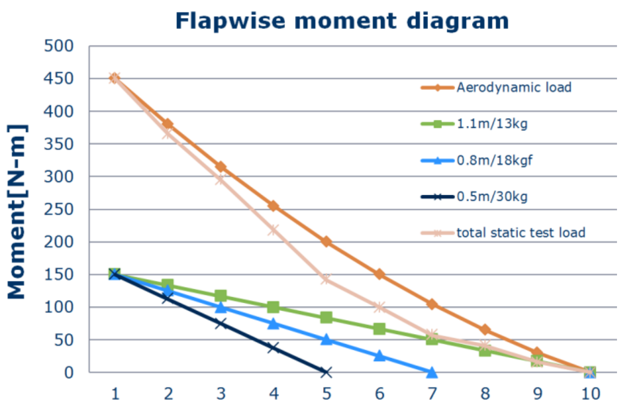

Fig. 2 Static strength test loads simulated by three-point loading method

6. Conclusions

This work carried out the study on composite blade design using flax natural fibre for small scale horizontal axis wind turbine system. The optimum aerodynamic configuration of the small wind turbine blade was proposed by parametric studies. From the aerodynamic design result, the designed blade has about 1kW power at the rated wind speed of 12 m/s. In structural design, a light composite structure, which can endure effectively various loads, was designed. In this study, the structural design results of flax/epoxy composite blade are compared with the design results of glass/epoxy composite blade. In order to evaluate the designed blade structure, the structural analysis was performed by the finite element method. Through the structural analyses, it is confirmed that the designed blade using natural flax composite is acceptable for structural safety and stability.

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