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A Study on Structural Design and Test of Micro Scale Composite Material Blade for Wind Turbine

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Abstract. The purpose of the present study is to design a micro scale composite wind turbine blade. The blade airfoil of FFA-W3-211 was selected to meet Korean weather condition. The skin-spar-foam sandwich type structure was adopted for improving buckling and vibration damping characteristics. The design loads were determined at wind speed of 25m/s, and the structural analysis was performed to confirm safety and stability from strength, buckling and natural frequency using the finite element analysis method. The prototype was manufactured using the hand-lay up method and it was experimentally tested using the three point concentrated loading method. In order to evaluate the design results, it was compared with experimental results. According to comparison results, the estimated results such as compressible stress, max tip deflection, natural frequency and buckling load factor were well agreed with the experimental results.

1 Introduction

This study carried out the design and analysis on the aerodynamics and structures of a composite blade for a 500W-class micro scale horizontal-axis wind turbine with low wind speed starting characteristics and airfoils of excellent aerodynamic performance so that it could be applied to the geography of Korea.

It was designed to be advantageous to the area of low wind speed by determining low wind speed as rated wind speed as much as possible within a range that the blade's diameter does not excessively become larger. The FAA-W3-211 airfoil which characteristics such as Reynolds number, maximum lift coefficient, stall angle of attack, maximum lift-drag ratio and maximum thickness are relatively good was used, and according to the strip theory that uses the momentum theory and blade element theory together, the basic shape was designed to determine its airfoil's chord length and wing's torsion angle distribution. Even if there was a little inconvenience in manufacturing, it was selected a method to design as optimum angle of attack which could get higher efficiency [1].

The structural design was based on a sandwich basic structure of skin-spar-foam and made its thickness thinner towards the blade's tip to focus on weight lightening [2]. For the used materials, the glass/epoxy, which was produced by a Korean company and its material property was proven, was used. For structural analysis, the finite element method was used to analyze stress and strain, and a local buckling problem by the bending load was considered. In addition, the stability in operation was considered by checking its natural frequency.

2 Design and Analysis

The specification of the blade which aerodynamics was designed to be suitable for Korea's weather condition in this study is as Table 1, and its 3-dimensional shape is as Fig. 1.

The load mainly considered in terms of structural design is aerodynamic load, and the load condition was considered as Table 2.

Table 1. Aerodynamic design results of 500W class wind turbine blade.

Rated power	500W
Cut-in wind speed	3.0 m/s
Rated wind speed	10.0 m/s
Cut-out wind speed	25 m/s
Design tip speed ratio	6.6
Rated rotational speed	400 rpm
Number of blade	3
Rotor diameter	2.52 m
Aerodynamic profile	FFA-W3-211
Blade root chord	158 mm
Blade tip chord	44mm
Blade total twist angle	7.2°

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As a result of the load analysis, it was verified that the load case II caused the greatest load on the blade, and the structural design was carried out on the basis of this load [3].

Table 2. Load case for structural design.

Load Case	Case I	Case II	Case III
Reference wind speed	10.0 m/s	25.0 m/s	55.0 m/s
Gust condition (±20 m/s, ±40°)	Without gust	With gust	Storm condition
Rotational speed	400 rpm	450 rpm	Stop

3 Structural Design Concept

For the basic structure for structural design of composite blade, the precedent study results and literature were referred to select the sandwich structure as Fig. 1 [4]. This structure was laminated in the direction of ±45°, mainly in the longitudinal direction of the skin, which is responsible primarily for the shearing load, and the blade, composed of a spar and flange structure being responsible mainly for the bending load, and designed as a sandwich structure shape that internally applies polyurethane foam having an excellent vibration damping effect as well as significantly improving buckling strength. Table 3 shows the structural design results for blades.

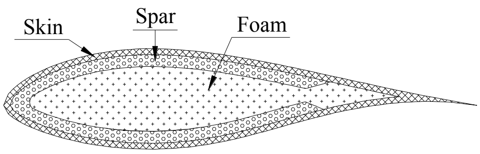

Figure 1. Skin-spar-form sandwich type structure.

Table 3. Structural design results of blade.

Station	Thickness (mm)	
	Upper surface	Lower surface
1	10t / Skin 1.25t / Spar 7.00t	
2	Skin 1.5t/Spar 6.25t	Skin 1.5t/Spar 6.25t
3	Skin 1.5t/Spar 6.25t	Skin 1.5t/Spar 6.25t
4	Skin 1.5t/Spar 6.25t	Skin 1.5t/Spar 6.25t
5	Skin 1.5t/Spar 5.00t	Skin 1.5t/Spar 5.00t
6	Skin 1.5t/Spar 5.00t	Skin 1.5t/Spar 5.00t
7	Skin 1.5t/Spar 5.00t	Skin 1.5t/Spar 5.00t
8	Skin 1.5t/Spar 2.75t	Skin 1.5t/Spar 2.75t
9	Skin 1.5t/Spar 2.75t	Skin 1.5t/Spar 2.75t
10	Skin 1.5t/Spar 2.75t	Skin 1.5t/Spar 2.75t

4 Structural Analysis

This study used the finite element analysis method to conduct the structural analysis [5, 6]. As a result of generating a mesh for analysing finite elements, it was composed of a total of 2,860 elements and 3,460 nodes. Table 4 is one that verified the result of the finite element linear static analysis according to the load case II and the structural stability for it, which was verified that it was structurally secure enough. Fig. 2 is the stress distribution for the design load (load case II) which is the maximum load.

Table 4. Structural analysis result.

Analysis result		Case II
Max. stress [Mpa]	Ten.	10.07
	Com.	10.06
Max. disp. [mm]		88.82
Max. stress failure criterion	Sxx/allow	0.054
	Syy/allow	0.013
	Sxy/allow	0.047

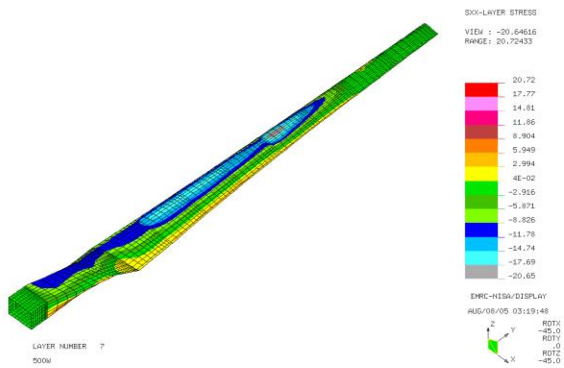

Figure 2. Stress analysis result of load case II.

For the natural frequency analysis, 1, 3 and 6 P.R.O are important because of the potential for resonance if it has three rotors [7]. Fig. 3 is one that draws the flap mode and shape. Examining the Campbell diagram of Fig. 4, it could be verified that the first flap mode's natural frequency did not cause resonance at 400 rpm which is the operational number of revolutions.

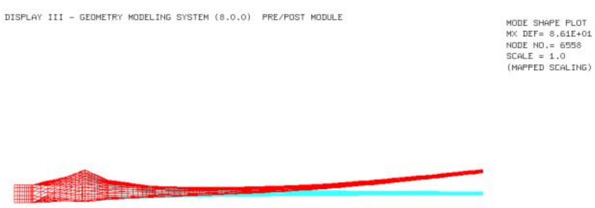

Figure 3. First flap mode shape and frequency.

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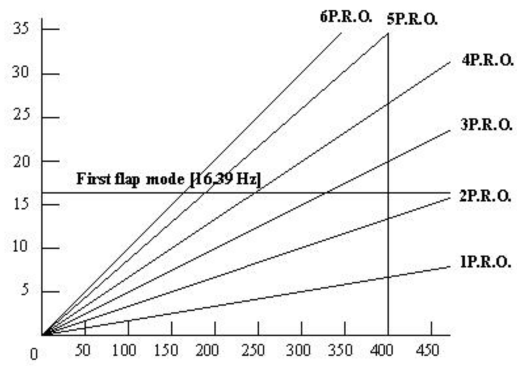

Figure 4. Campbell diagram.

Fig. 5 shows the result of buckling analysis for the load case II, which was verified that the minimum load factor was 15.36 and there was no buckling.

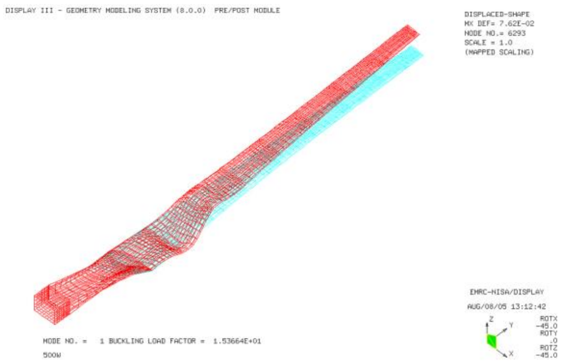

Figure 5. First buckling mode and load factor at load case II.

5 Prototype Manufacturing and Test

To make a prototype, a template for the exterior shape was manufactured, which was used to divide into the upper and lower sides to make a mold. After applying a mold release agent and spreading gel coat on the mold manufactured like this, glass fiber epoxy was laminated by the hand lay-up method. At that time, to keep the laminated fiber close to the mold, urethane foam was applied in advance to cut with heat rays, and then inserted to bond them. Fig. 6 is the manufactured blade prototype.

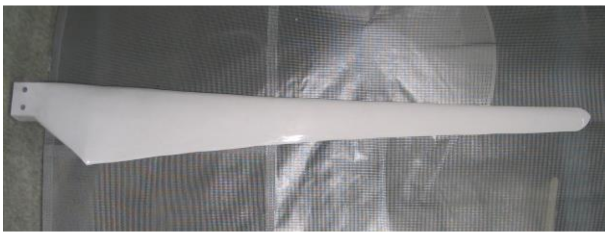

Figure 6. First blade prototype.

A structural test was carried out to evaluate the design result. First, to measure the natural frequency, a strain gauge was attached, and then an impact hammer was used to give impact. And the strain values varied at that time were collected through a data acquisition device (EDS400A, KYUWA). Fig. 7 is the collected data and the result of analysing them by FFT, the analysis and experiment results are 16.39Hz and 17.21Hz, respectively, and it could be known that they are almost the same.

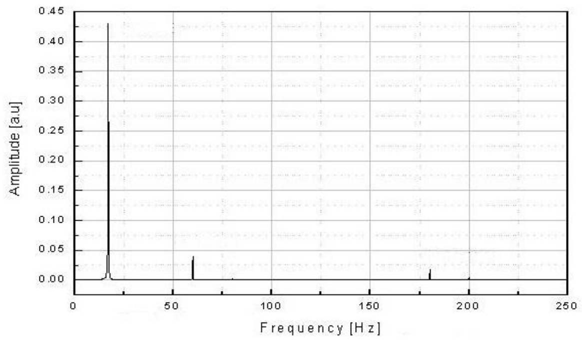

Figure 7. Eigenvalue test result.

For the static structure test, the design load was simulated as 4-point concentrated load as Fig. 8, and for the sandbag weights and load positions, 5, 11.5, 14 and 16 kg were used at 0.2, 0.5, 0.7 and 0.9 m, respectively. Table 5 is one that compares the structure test result with the finite element analysis result, which was verified that they are closely matched each other.

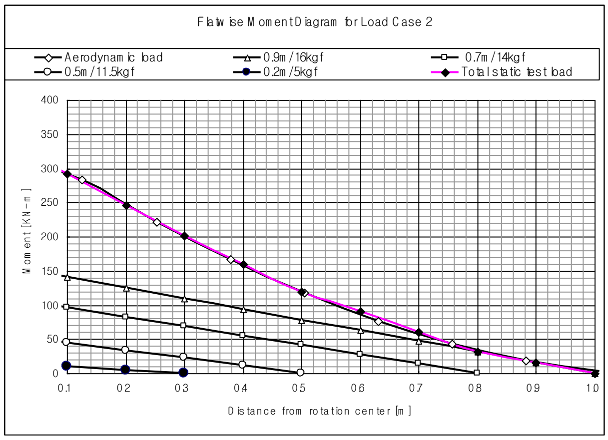

Figure 8. Simulated bending moment.

Table 5. Comparison between the static analysis results and the test results.

Item	Analysis results	Test results
Tip deflection	89 mm	98 mm
Upper and lower surface stresses at 0.2 r/R station	+10.07 Mpa -10.06 Mpa	+10.0 Mpa -10.4 Mpa

6 Conclusion

Through this study, the structure design and analysis of composite blades for a 500W-class micro scale wind power generation system applicable to the low wind

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speed geography like Korea was carried out, and the following conclusion was drawn.

As a result of the linear static analysis, it was verified that the blade, which structure design was finally confirmed, was a safe structure that secures 21.2 of safety coefficient even in the maximum load condition, and the blade's maximum displacement at that time was about 88.2 mm. As a result of drawing the Campbell diagram from the natural frequency analysis result to examine the potential for resonance, it was verified that there was no chance that resonance occurs during operation. As a result of the buckling analysis, the load factor for the primary buckling mode was 15.36, and it was verified that it was stable against the buckling. For the blade structure, it was selected the skin-spar foam sandwich structure type with excellent weight lightening, buckling and vibration damping characteristics. For the prototyping, it was selected the method that considers the ease of making to manufacture foam separately to bond. As a result of this study, it was examined that the blade design method performed in this study was reasonable.

Acknowledgements

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