Manufacturing of a prototype blade for small wind turbines

Pongtorn Prombut

Department of Mechanical Engineering, Faculty of Engineering, Kasetsart University
50 Phaholyothin road, Chatuchak, Bangkok, 10900, Thailand
E-mail: pongtorn.p@ku.ac.th, Tel: +66(0) 2942-8555 ext. 1809, Fax: +66(0) 2579-4576

Abstract

Most of the wind turbines installed in Thailand are designed and manufactured abroad, usually with optimum operation at wind speeds higher than the wind in Thailand. Attempts have been made to develop wind turbine blades locally to make them aerodynamically more suitable for actual wind conditions. It is then necessary to produce supporting structure capable of withstanding the operating loads of these blades. This paper presents the manufacturing of a prototype blade for small wind turbines. The objective is to implement simple manufacturing processes suitable for fabricating small blades yet capable of extending to the construction of larger blades.

The prototype blade was made in-house from a glass/polyester composite using hand lay-up process with an emphasis on materials and equipment that are readily available from local suppliers. An existing 1.2-meter blade was used to create the mould. The new blade made from this mould weighs 2.15 kg, only 0.1 kg or 5% heavier than the original “commercial” blade. Flapwise bending tests were performed on both blades in cantilever beam configuration. The new blade boasts 7% higher stiffness than the original one when load versus tip deflection results are compared. No significant twisting deformation was observed during the tests. The materials and processes used in this work can thus produce blades comparable in weight and stiffness to some that have reached commercial stage of development.

***Keywords**:* Wind turbine, blade, manufacturing, composite material

1. Introduction

Thai ministry of energy aims to promote wind power generation in the country to 115 MW by the year 2011 [1]. Incentives accompanying this plan have attracted private sector to investing in wind farm business. However, most of the wind turbines installed so far are designed and manufactured abroad. They are usually designed for optimum operation at wind speed around 10 m/s or even more. As a result, these wind turbines cannot generate electricity at their rated capacity in Thailand where the average wind speed can be as low as 4-6 m/s.

Attempts have been made to develop wind turbine blades locally to make them aerodynamically more suitable for actual wind conditions. It is then necessary to produce supporting structure capable of withstanding the operating loads of these blades. As wind turbine blades continue to grow in size, the accompanying weight and cost also continue to increase. New design concepts such as bend-twist coupling deformation or new material technologies such as carbon-fiberglass fabrics have been incorporated in blade design and manufacturing [2]. Substantial insight on the behavior and performance of these innovative blade types has been obtained through various analyses and tests [3] [4].

This work is part of a project to improve aerodynamic performance of an existing wind turbine rotor. Simple construction processes [5] are chosen due to the rotor blade's small size.

The paper presents the manufacturing of a prototype blade for small wind turbines. The objective is to implement simple manufacturing processes suitable for fabricating small blades yet capable of extending to the construction of larger blades. An efficient blade structural layout is chosen from an existing study [6].

2. Prototype blade construction

A prototype blade was made in-house from a glass/polyester composite using hand lay-up process. All materials and equipment are readily available from local suppliers. An existing 1.2-meter blade was chosen to be the original blade for this work. It served as a plug for mould manufacturing process (Figure 1).

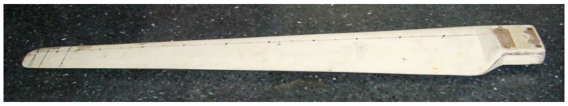

Figure 1. Existing blade for use as a plug.

2.1 Mould

The mould was made in two halves along the leading edge and trailing edge of the original blade. A plastic board was attached to the edges to support the flange of the first mould half. Voids are filled with modeling clay that does not react with the resin. After that, the original blade surface was cleaned and coated with mould release wax. Two layers of gelcoat were then applied on the original blade to provide durability and high-quality finish to the mould surface. The gelcoat was prepared with 1 kg of gelcoat resin (GC 920), 2 cm^3 of hardener (Butanox M-60), 2 cm^3 of accelerator (Cobalt), and some black pigment paste. The mould body is built upon the gelcoat with twelve layers of glass/polyester composite. The material composed of a chopped strand mat (CSM) grade 300 $gram/m^2$ (gsm) and a polyester resin (955P) mixed with the hardener and accelerator at the same proportion as the gelcoat.

Once the first mould half dried, the blade could be turned over and the flange support could be removed. The second half of the mould was made with the same procedure without removing the first mould half from the blade. Bolts were used to help positioning the two halves during new blade manufacturing (Figure 2).

Figure 2. Two mould halves with plug.

2.2 Blade

The blade consists of two composite shells and a box spar. The shells provide aerodynamics characteristics of the blade and support shear forces. Each blade half is made of to 4 full-length composite layers and 4 half-length layers. The stacking sequences from blade root to mid-length is $[0/45/45/0]_S$ and from mid-length to blade tip is $[0/45]_S$. The composite for blade construction is a combination of woven cloth (WC) glass fiber in plain weave format and the same resin mixture as in the mould body. Since a plain weave cloth has equal number of fibers in two mutually perpendicular directions, the 0-degree layers in the stacking sequences have fibers in 0° and 90°. Similarly, the 45-degree layers have fibers in +45° and -45°. Each layer is treated as an orthotropic material with $E_1 = E_2$. The composite layers were laid on the mould after two layers of gelcoat (Figure 3). The same gelcoat mixture as that of the mould surface was used, but this time with white pigment paste.

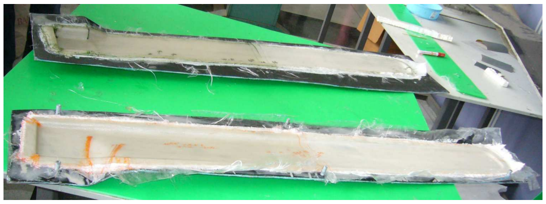

Figure 3. Blade shells in moulds.

The blade's resistance to flapwise deflection is essentially provided by the spar. An airfoil reinforced with different spar sections of constant section area has been evaluated. A box-section spar was found to possess the highest area moment of inertia [6]. It was then used for this prototype blade. Its width varies from 40 mm at the root to 20 mm at the tip in chordwise direction. The spar is centered along the quarter-chord distance measured from the leading edge of the blade. This location is a reasonable approximation of an aerodynamics force resultant on a typical airfoil of aircraft wings [7]. First, polyurethane (PU) foam was cast inside the two blade shells. The foam is then cut into dimensions described above (Figure 4). The thickness of this foam core was trimmed to accommodate two layers of unidirectional glass/epoxy composite that would be wrapped around it.

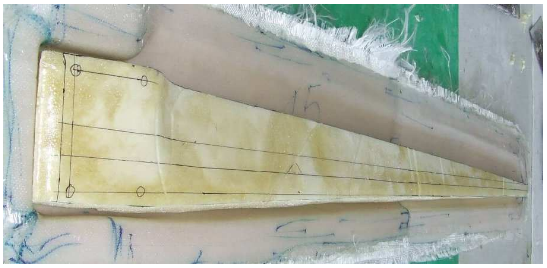

Figure 4. Spar core.

2.3 Assembly

The two halves of the blade were joined using a two-part epoxy adhesive. The contact lines were increased by casting small amount of epoxy resin along the edges. The spar was then fixed in position on one blade half. A wooden core was placed inside the blade root to accommodate the bolt holes and to provide compression resistance when the blade is bolted onto the rotor of the wind turbine. The other blade half was then placed to complete the assembly. The blade was put back in the mould to ensure the correct final shape. Contact pressure was maintained by c-clamps during the curing of the adhesive. The new blade weighs 2.15 kg while the original weighs 2.05 kg. Note that weight can probably be further reduced by using processes that can better control the resin amount such as vacuum infusion processing (VIP).

3. Bending test

The blades were subjected to bending tests in flapwise direction to determine their stiffness in this critical loading mode. Possible twisting deformation was also monitored near the blade tip. The results were then compared between the new blade and the original one.

3.1 Test setup

The setup of the test is shown in Figure 5. The blade root is clamped onto the test stand by a hydraulic press. The blade's high pressure side is oriented upward and the load is applied downward by hanging different weights near the blade tip.

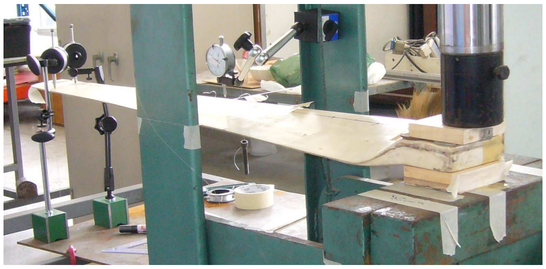

Figure 5. Blade fixed on test stand.

The load application line passes through the point which is located at 1,150 mm spanwise from the root end of the blade and a quarter of the distance chordwise from the leading edge to the trailing edge. Two dial gauges are used to measure the displacement of the quarter-chord line at 600 mm and 1,100 mm from the blade's root end. The third dial gauge is also placed at 1,100 mm from the root end but at 50 mm chordwise closer to the trailing edge to monitor twisting deformation (rotation) near the blade tip.

3.2 Test results

Two tests were performed on each blade to account for setup variability. After the first test, the blade and the gauges were removed from the test stand. Thus, the second test required a completely new installation. Average displacement values are used for data reduction. Blade tip deflection is measured on the quarter-chord line at 1,100 mm from the blade's root end. At the load of 71.4 N, equivalent to the root moment of 71.0 N-m, the load-deflection relation is still linear for both blades. Figure 6 shows that the new blade is about 7% stiffer than the original one. Note that the root moment is higher than the design flapwise bending moment of 45.6 N-m which has been estimated for the original blade. The design condition was the blade at rest against the wind speed of 118 km/hr normal to the chord direction [6].

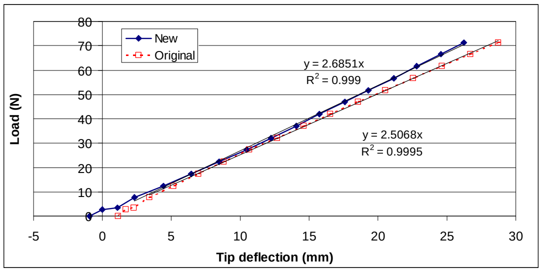

Figure 6. Blade tip deflection.

The mid-blade deflection is measured on the quarter-chord line at 600 mm from the root end. The new blade shows consistent results with the tip measurement by presenting higher stiffness than the original blade for about 2% (Figure 7).

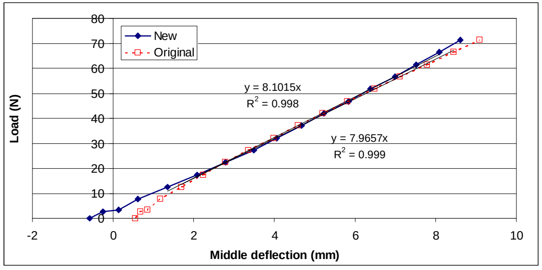

Figure 7. Mid-span deflection.

For both blades, the two dial gauges at 1,100 mm show average difference of displacement around only 1%. As a result, the twisting deformation or the blade tip rotation can be considered negligible.

4. Conclusions and Perspectives

A prototype blade of glass/polyester composite has been made in our laboratory. The chosen processes result in a new blade with the weight of 2.15 kg, or 5% heavier than the original blade. However, the new blade is also 7% stiffer under flapwise bending load. The materials and processes used in this work can thus produce blades comparable in weight and stiffness to some that have reached commercial stage of development.

Various structural analyses and tests [3] [4] should be performed to gain confidence on blade's behavior and performance.

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