# Bamboo Laminated Composites for Wind Turbine Blade Material: a Review

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**Abstract**

This review aims at highlighting on an attempt for exploring the feasibility of utilizing bamboo-based composite for wind turbine blade material. Turbine blades, which play an important role in wind turbine operation, demand uniformity and low variability in the material properties used. However, the current materials of turbine blade which mainly based on glass fibre-reinforced composites (GFRP) have some disadvantages as they tend to be abrasive and are difficult to dispose of at the end of their lifetime. Bamboo has a high potential for wind turbine blade material as it easily grows and the fibre was known to have superior mechanical properties in term of strength and toughness. With the increased emphasises on the need to biodegradable material, it is interesting to develop a bamboo-based composite for use in wind energy at lower cost. This paper discusses the current effort and key research challenges in the development of bamboo laminated composite for use in wind turbine blade. It evaluates the key parameters in processing of bamboo laminated composite in satisfying the requirement for wind energy application. Considering the fact that mechanical performances of natural fibre-reinforced composite are greatly influenced by environment conditions, it is necessary to understand the change of mechanical properties during service life of wind turbine.

Keywords**:** wind turbine blade, composite, bamboo laminated, material properties

## 1. Introduction

The environmental awareness of the society has risen to the point in finding alternatives of carbon-based fuels for protection of natural resources and reduction of $CO_2$ emission. The scarcity of non-renewable resources such as petroleum, coal and natural gas has also becomes a great problem for the whole world. Wind power has been receiving attention as the new energy resource in addressing the ecological problems of burning fossil fuels. Wind turbine blades play an important role as part of the wind turbine which produces the wind energy. As the blades work by rotation during wind turbine operation, they demand uniformity and low variability in the material properties used. The material should have high strength and stiffness with a low density and high fatigue properties.

Currently, wind turbine blades are being manufactured using polymer matrix composite materials which mainly based on glass fibre-reinforced composites (GFRP). Glass fibres have many benefits, including low cost and relative ease of manufacture, as well as possessing moderate strength and stiffness to weight ratios (Al-Bahadly, 2013). However, they also have many disadvantages as tend to be abrasive, thus making them dangerous to work with, as well as increasing the wear on processing machinery. More importantly, glass fibers could present a health risk to those working with them. The biggest problem with glass and other synthetic fibers is that they are difficult to dispose of at the end of their lifetime.

Recently, a large number of researchers and manufacturers are shown their interests on natural fibre reinforced composites. Natural fibres like bamboo, sisal, banana, jute, oil palm and kenaf require very little energy to produce which easily available in relative lowercost. They also have better renewability and because possess high calorific values, they can be incinerated at the end of their lifetime for energy recovery. Natural fiber-reinforced thermoset composites are now finding extensive uses in various fields from household articles to automobiles. Besides low cost and biodegradability, other advantages of natural fibers over synthetic fibers are good thermal insulation properties, light weight, high

specific strength and low density (Porras and Maranon, 2012). Currently, the renewable-based material mostly used for turbine blade production is natural wood which considered pose other environment concerns related to forest cultivation.

A high potential and sustainable resource that has not been fully explored for wind turbine blade material is bamboo. Bamboo easily grows in most tropical countries including Indonesia, requires only 5 years to grow as a mature plant (Rassiaha et al., 2014). The bamboo fibre was known to have superior mechanical properties compared to wood in term of strength and toughness. Several reports on characterization of bamboo reinforced composites exist (Okubo et al., 2004, Hung et al., 2012, TANAKA et al., 2007, Corradi et al., 2009, Vermaa et al., 2014), mostly based on fibre extracted from the culm. With the increased emphasis on the need to use recyclable bio-based materials in wind energy, and a better understanding of the mechanical properties of bamboo, there are some attempts performed in developing bamboo-based composites for use in both small and large scale wind turbine blades (Holmes and P., 2009, Huang et al., 2015 ). In wind turbine blade application, it is necessary to understand not only the materials properties but also the potential route for degradation. Deterioration of material properties in natural fibre-based composites might be observed after prolonged exposure to the environment, especially high temperature and humidity (Widiastuti et al., 2013). Another point to be considered in the development of wind turbine blade is the price of material. Thus, it is beneficial to develop manufacturing approach of bamboo based composite for wind turbine applications at moderate cost for resulting energy to be competitive in price.

## 2. Wind Turbine Blade

The idea of harnessing energy from wind power and using it as a renewable energy source was first developed in the 1970's (Butler et al., 2013). World energy consumption is predicted to grow by 50% from 2005 to 2030. The transition to greater clean energy output has caused an increase in energy that is being produced by wind power. The standard wind turbines are either VAWT (Vertical Wind Air Turbine) or HAWT (Horizontal Air Wind Turbine). A typical upwind HAWT with three blades is shown in Figure 1. As the wind passes through the blades of the wind turbine, it causes the turbine to spin, generating electricity through the generator.

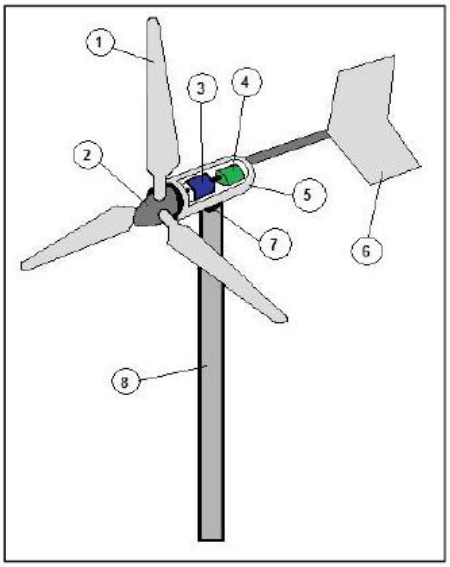


Figure 1. Typical components of a wind turbine system: 1) Blades, 2) Hub, 3) Gearbox/Drivetrain, 4) Generator, 5) Nacelle, 6) Tail Vane, 7) Yaw Bearing, 8) Tower (*adopted from Nosti (2009)*)

The current turbine blade are typically made from either a fibre reinforces plastic material or constructed using wooden laminates. Its design is mainly tends to a sandwich structure so that it could help rotor blade maximum avoid the external load from both wind and gravity. A sandwich structure wind turbine blade is consisted of 4 main typical parts; they are: Wing shells, Main spar, Spar cap and internal webs / stiffeners.

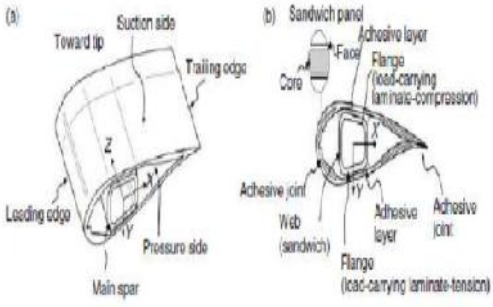


Figure 2 : A Specific Sandwich Design of Wind Turbine Blade

The external loads for rotor blades are most depend on the wind and gravity. So that the material used for making turbine blade requires several criteria such as:

- high stiffness to maintain optimal aerodynamic performance
- low weight (low density) to reduce gravity forces
- long fatigue life to reduce material degradation

## 3. Bamboo Reinforce Polymer Composite

Composite is composed of two main components: the fibre as reinforcement and the matrix (Debnath et al., 2013). The reinforcing element is able to support high tensile loads although the matrix imparts rigidity to the composite. The application of stress on the composite is results transfer of the loads from one fibre to another, via the matrix. The use of natural fibres composites matrices is highly beneficial because the strength and toughness of the resulting composites are greater than those of the un-reinforced matrix. Moreover, cellulose-based natural fibers are strong, light in weight, very cheap, abundant and renewable.

As a whole, matrix materials cover the range from polymers to metals to ceramics. The matrix is a substance that is capable of holding the reinforcing materials together by surface connection. Matrix can also be defined as material that gives body and holds the reinforcement of the composite together, and is generally of lower strength than the reinforcement. Matrices are generally be classified into two major types, which are thermoplastics and thermosets. The selection criteria of the matrices depend only on the composite end use requirements. For example, if chemical resistance together with elevated temperature resistance is needed for a composite material, then thermoset matrices are preferred rather than thermoplastics. In contrast, when a composite material with high damage tolerance and recyclables is needed, then thermoplastics are preferred. Thermoset resin is defined as a plastic material which is initially a liquid monomer or a pre-polymer, which is cured by either application of heat or catalyst to become an infusible and insoluble material. Among the most common thermosetting resins used in composite manufacturing are unsaturated polyesters, epoxies, vinyl-esters and phenolics.

For the past several years, public attention has gone to natural fibres as a resource due to their fast growth. Natural fibres can be classified based on their origin into three categories: (i) plant fibres, (ii) animal fibres and (iii) mineral fibres (Debnath et al., 2013). The development of natural biodegradable materials becomes significant with the increasing awareness to avoid the depletion of limited fossil resources and increasing volume of non-biodegradable material waste. Over the time, variety of bio-composites has been developed with fairly good mechanical properties using different natural fibres. Cellulose is an important constituent of the natural fibres as it defines the mechanical properties of the fibres.

Despite its biodegradability advantage, the use of natural fibre reinforce composites has been restricted due to certain characteristics of the natural fibres such as moisture absorption tendency, poor adhesion with the synthetic counterparts and low thermal stability during processing. When a material is intended for a prolonged period of usage, its durability becomes a critical issue. The mechanical properties of natural fibre based composite deteriorate over a period of time as both the natural fibre and the polymer matrix is typically affected by time, temperature and humidity (Widiastuti et al., 2014, Debnath et al., 2013).

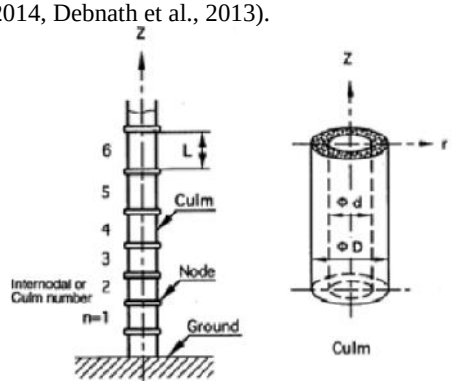


Figure 3. Basic Structure of a Bamboo Culm

Bamboo is an abundant natural resource in Asia and South America, because it takes only several months to grow up. Bamboo is a natural fibre-reinforced composite material, in which cellulosic fibres are embedded in a lignin matrix. Bamboo has traditionally been used for making furniture

and daily products such as beds, tables, benches, chairs, baskets, mats, chopsticks, spoons, fans, and umbrellas. A piece of bamboo consists of several culms in which the highest stiffness appears at node number 14 and 15. The outside area of a culm has better stiffness, strength and fracture toughness in the outside area compared to the inside. Therefore, the area above the red line in Figure 4 is the best part for producing wind turbine blade.

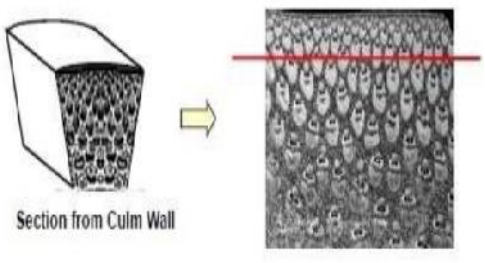


Figure 4. The high density of outside bamboo culm

Several papers have already been published on the study of bamboo fiber reinforced composites using thermosetting plastic (epoxy and polyester). The experimental works performed by Okuba et al (2004) showed that the bamboo fibres had a specific strength, equivalent to that of conventional glass fibres. Rassiah et.al (2014) showed the tensile, flexural and static strength of the composite reinforced by bamboo orthogonal strip mats and concluded that the material based on unsaturated polyesters yield excellent mechanical properties. Using epoxy resin as matrix material, Vermaa et.al (2014) developed a laminate bamboo composite which can be used as an alternative material to wood for structural purpose.

Few reports have discussed how the environment affecting their mechanical properties. The reduction of flexural properties on bamboo-based composites was found after moisture absorption, but chemical modification through acetylation was proven to enhance the durability and decay resistance of the composites (Hung et al., 2012). The application of bamboo polymer composites in wind energy application has been investigated (Holmes and P., 2009, Huang et al., 2015 ). However it is required further investigation in the dynamic mechanical behaviour and influence of environment exposure on it.

## 4. Conclusion

Bamboo fibre is one type of renewable materials which has been found to be an ideal candidate for wind turbine blade applications considering its good mechanical properties, ease of processing and biodegradable properties. A review into studies in the field of glass fibre-reinforced polymer (GFRP) composite has shown the requirement for improving the safety and degradability of this material. The development of bamboo laminated composites may resolve the weakness of GFRP composite for being an alternative of wind turbine blade material. For the future direction of bamboo based composites, the beneficial properties of these materials should be optimally taken advantage appropriate to the requirement of specified wind power application.

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