Cotton-Bamboo Composite Material and Structure Applications

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Abstract. Green material and sustainable technologies have been becoming a heated topic recent years. This study tries to invent cotton-bamboo fiber reinforced composite material, a fully biodegrade green material, based on the preview study and explore the mechanical performance and its structure application. Two sets of experiments were carried out in this research, which are single-shear tensile loading test under ASTM standard and bending test of wind turbine blade. Results revealed that this biodegrade green material have good mechanical properties and can satisfy the requirement of some low-intensity industrial sectors. Further research is needed to apply this cotton-bamboo fiber material in broader market.

1. Introduction
Material is the foundation and precursor of the progress of human material civilization. The development of material civilization for thousands of years, especially the development of modern industry for more than 200 years, has made great achievements in the development of materials. Now more than 50,000 materials are available for human use, and new materials with high performance, multi-function and intellectualization are being developed one after another. With the deep integration of new materials and modern high technology, the extraction, synthesis, manufacture, modification and application of new materials have reached an unprecedented level, showing a very bright prospect for the future of mankind. On the other hand, all materials are exchanged for resources. There are only two kinds of global resources, one is non-renewable resources, the other is renewable resources. At present, the situation of global resources is that the non-renewable resources are exhausted day by day, and the renewable resources have not been fully exploited and utilized, which is the reason why green materials and materials have sprung up and become popular. Because the composite materials have the characteristics of multi-phase compounding and designable properties, the green development of the composite materials is more congenital advantages, and the prospect is very broad[1]. The so-called green materials and materials refer to the material from product design, raw material selection, processing and manufacturing, packaging and transportation, service use, recycling and reuse of the entire life cycle, the highest utilization rate of resources, the smallest impact on the environment[2].

Angel P M[3] and his partners has studied some properties about bamboo-polylactic acid(PLA) composite material before. In their study, the morphological study, the manufacture process and some mechanical tests have been researched. However, whether this material can be applied in industrial sectors remains a problem to solve.
This paper introduces a new natural fiber composite material, Cotton-bamboo fiber reinforced composite material, based on the bamboo-PLA material[3] and the structure application of this material.

2. Materials

2.1 Bamboo and matrix
Angel has found that the Guadua bamboo has better mechanical properties, with an average tensile strength of 202.7MPa (coefficient of variation COV=16.2%) and an average Young’s modulus of 25.52GPa (COV=6.4%). After his study, the Guadua species has been selected to manufacture the bamboo composite[3].

Ingeo PLA Biopolymer 4032D PLA as 0.025-mm-thick film sheets were selected by Angel for using in the selected manufacturing process of resin film infusion due to the properties of full-biodegradability, bio-based sourcing, commercial availability, and compatibility with the manufacturing process[3].

The preparation of the bamboo layer need bamboo pieces of the certain thickness width, and then the bamboo pieces are placed on the PLA layer without gaps, and after the laying is completed, another PLA is added on the other side. And using a hot air blower, blowing at 180 ° for 10-15 minutes, so that the PLA slightly sticks the bamboo piece. Back up. As shown in figure 1.

![Figure 1. Manufacture process of bamboo layer](image1)

2.2 Flex layer
The flex layer is made up by the cotton and a kind of natural transparent resin, shown in figure 2. The addition of the flex layer is aim to reduce the weight and increase flexibility and manipulability. The resin is made from potatoes and rice. So the flex layer is also fully biodegradable material.

The preparation of the flex layer is shown in figure 3. In outface of the self-made circular automatic roller, the mold cloth is first laid off firstly, and then a layer of cotton thread is evenly wound under the driving of the motor, and then two layers of resin are laid; 3 to 4 times, put into a 100 °C incubator for 15 to 20 minutes, until the resin layer is evenly melted in the flex layer. Take out and back up.

![Figure 2. Flex layer](image2)

3. Single-shear tensile test
3.1 Geometric design
The single-shear type bolt connection method was chosen to test the properties. Therefore, the coupon geometry was designed on the basis of the ASTM Standard D5961 Procedure ‘C’. The Dimensions for the coupon geometry are in conformance with ASTM D5961 test method for the single shear one-piece specimen Procedure ‘C’, shown in figure 4. The geometric parameters are shown in table 1.

![Figure 4. Standard coupon geometry for procedure ‘C’](image)

| Parameter                | Value          |
|--------------------------|----------------|
| Bolt Diameter (d)        | 0.25 inch      |
| Coupon Hole diameter (D) | 0.250 inch     |
| Coupon Thickness range (h)| 0.08-0.208 inch|
| Coupon Length (L)        | 5.5 inch       |
| Width of the Coupon (w)  | 1.5 inch       |
| Distance from Hole Center to Edge (e) | 0.75 inch |

3.2 Lay up arrangement
Since natural fiber reinforced composites do not have molded prepregs like other composites, such as carbon fiber composites and glass fiber composites, laminates of resin and adhesive should be added between layers manually. The layup design should base on symmetry principle and the layup sequence is shown in table 2 below.

| N°       | Laying up Sequence |
|----------|--------------------|
| 1,25     | Resin*2            |
| 2,24     | +45°flex*1         |
| 3,23     | Resin*3            |
| 4,22     | -45°flex*1         |
| 5,21     | Resin*3            |
| 6,20     | 90°flex*1          |
| 7,19     | Resin*3            |
| 8,18     | 90°flex*1          |
| 9,17     | Resin*3            |
| 10,16    | +45°flex*1         |
| 11,15    | PLA*1              |
| 12,14    | 0°bamboo*1         |
| 13       | PLA*1              |

3.3 Coupon Preparation
Panel curing is carried out in a 180 ° incubator at atmospheric pressure for two hours after laying up and making the standard vacuum bag, shown in figure 5.

![Image](image1)

**Figure 5.** Under one atmosphere, placed in the incubator

Because the half laps of the joint are eccentric to each other, a packing piece (equal to the thickness of a half lap) is bonded to the end of each half lap remote from the joint. This ensures that the joint remains initially straight when it is clamped between the grips of the test machine. As the grips of the test machine move apart the joint is subjected to tension and bending with the latter being equal (initially) to the tensile load multiplied by the thickness of a half lap[4].

Some cheap materials was used to manufacture the packing block of same thicknesses as the composite laminates. Then the adhesive is used for bonding. It should be noted that the surface to which the backing plate and the test piece are bonded should be sanded in advance (as shown in figure 6).

![Image](image2)

**Figure 6.** Final assembly of the specimen

3.4 *Experimental results and discussion*

The experimental device is a servo hydraulic tensile testing machine, as shown in figure 7.

![Image](image3)

**Figure 7.** Servo hydraulic tensile testing machine

The thickness size of the specimen is 5.35mm. Three tests have been done. The maximize failure
stress is 130MPa, and the average failure stress is around 125MPa. It can be seen from the experimental phenomenon (shown in figure 8) and curves that the inherent damage mechanism is extremely complicated. Since natural fiber reinforced composite materials are still under study, many phenomena cannot be solved at present.

![Figure 8. Experimental phenomena of specimen](image)

Angel had pointed that many factors could influence the properties, especially the manufacturing process[3]. And the potential application of the developed material for aerospace are very restricted, but the present strength could fulfill the requirements of other industrial sectors, such as the wind turbine blades. In the next section, the application of the wind turbine blades will be introduced.

4. The application of the wind turbine blades
It is proved that small wind turbines have the characteristics of low cost, high power generation rate, flexible regional distribution and less land occupation. Small wind turbines can effectively fill the gap in the low wind energy market due to the low wind speed range requirements. And it is meaningful to environment that the green natural material was used in the wind turbine blades instead of the traditional material.

4.1 Selection of the airfoil
In this section, the main parameters concerned are the pressure distribution of airfoil surface, the lift coefficient and the lift-to-drag ratio. Therefore, these parameters were selected as the standard for the best airfoil with low Reynolds number.

Ronit K, Singh and his partners have pointed out that the airfoil AF300 was optimized from existing low Re airfoils through Xfoil code[5], the geometric shape of the AF300 airfoil is shown in figure 9.

![Figure 9. Geometric shape of the AF300 airfoil](image)

4.2 Structure analysis
The foam structure was selected for its excellent performance that it is more responsive to structural and strength requirements in complex stress conditions and it has a lower water absorption rate that can reduce maintenance costs for its closed cell structure[6][7].

The main role of foam in the blade is to ensure the stability of the blade while reducing the quality
of the blade, so that the blade increases the wind-capturing area while satisfying the stiffness. Focusing on cost factors, PU foam has a great advantage in cost.

4.3 Manufacturing process

As for the lay up arrangement, [−45° F, +45° F, B, 90° F, B, +45° F, −45° F] (F is flex layer, B is bamboo layer) sequence was firstly design. However, the two layers of bamboo had lead to the difficult to carry out the close operation because of the thickness. Therefore, the number of the bamboo layer was reduced. And the final layup arrangement of the wind turbine blade was [−45° F, +45° F, 90° F, B, 90° F, +45° F, −45° F]. In order to get enough resin to stick together and improve the performance, alternated layers of transparent resin and the PLA were applied. The detailed layup arrangement was shown in figure 10. It is important to note that the compaction is necessary during the laying up process.

![Figure 10. Wind turbine blade layup arrangement](image10.png)

The manufacture of the wind turbine blade is not easy for its geometric complexity. Getting the bamboo layer, laying up, making the vacuum bag and final cutting are the main difficult steps. Shown in figure 11-figure 13.

![Figure 11. Bamboo layer](image11.png)
The curing temperature of the adhesive was 120 °C, and the resin curing temperature was 180 °C. The adhesive is first cured so that each laminate can be bonded to the mold. When the temperature reaches 180 °C, the resin will melt into a liquid, but will not move the position of each layer, the detail temperature of curing process is shown in figure 14.

![Figure 12. Vacuum bag](image1)

![Figure 13. Blade](image2)

![Figure 14. Curing temperature](image3)

4.4 Bending test

Bending test was carried out to validate whether this blade made by the biodegrade material could fulfill the request of the related industrial sectors. Fixe the blade root, and gradually increases the weight in a little until the damage occurs, the experiment process and damage of the blade are shown in figure 15 and figure 16, respectively. To ensure that the blade roots were completely fixed during the test, 20 layers of carbon fiber prepreg were placed on the blade roots and secured to the brackets with pins, as shown. Due to the significant bearing capacity of the mechanical properties of the three materials, the minimum weight of the material used in the test was 1 kg. The blade deformation displacement was recorded each time a 1 kg weight was loaded. The results show that when the weight of the load is 5Kg, the natural fiber reinforcement blade is destroyed, and the damage is located at the root of the blade, and its deformation displacement is 16mm. This strength can withstand the torque load of low-speed wind turbine.

![Figure 15. Experiment process](image4)

![Figure 16. Blade damage](image5)
5. Conclusion
In this investigation, the aim is to explore the properties and structure application of the Cotton-bamboo fiber reinforced composites based on the sustainable technologies. And the present study has shown that this biodegradable composite material has good mechanical performance and could fulfill the request of low-speed wind turbine blade. In the future, we can try to explore more application in low-intensity industrial sectors. As well as it is totally green nature material and very friendly for the environment. Therefore, it is potential to get more development and widely application in the future.

As for the future work, firstly, wind tunnel test can be carried out based on the test described above to get a further performance validation; Secondly, more research and study need to be done to improve the mechanical performance. And because of the complexity of the manufacture process, the environment condition plays an important role and could be paid more attention in the later work; Thirdly, more application in industrial sectors could be explored based on the present study.

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