© Universiti Tun Hussein Onn Malaysia Publisher's Office

PAAT

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/paat
e-ISSN: 2821-2924

Progress in Aerospace and Aviation Technology

Application of Bamboo Composite for Unmanned Aerial Vehicle Rod Structure

Najwa Muslim[1], Latifah Md Ariffin[2], Mohammad Zulafif Rahim[3*]

[1,2,3]Faculty of Mechanical and Manufacturing Engineering,
University Tun Hussein Onn Malaysia, Parit Raja, 86400, MALAYSIA

DOI: https://doi.org/10.30880/paat.2023.03.02.007
Received 7 August 2023; Accepted 6 December 2023; Available online 14 December 2023

Abstract: Researchers are exploring the use of natural fibers, such as bamboo fibers, as a replacement for synthetic fibers in composite materials due to environmental concerns and rising costs. Bamboo fibers have several benefits, including low cost, biodegradability, light weight, and good mechanical qualities. This study focused on the mechanical and physical characteristics of bamboo fiber composites for drone structures. Tensile tests were conducted, revealing a relatively low tensile strength ranging from 22026.99 to 5474.92 N/m^3 compared to carbon fibre composites. The tensile strength was influenced by the composition and ratio of bamboo fibre and epoxy. The density of the bamboo fibre composite ranged from 0.9720 to 0.7790 g/cm^3, which is lower than carbon fibre composites. Increasing the bamboo fibre content resulted in a decrease in density.

Keywords: Natural fibers, bamboo fibers, composite, epoxy resin, unmanned aerial vehicles, rod structure

1. Introduction

Composite materials are widely utilized across industries like aerospace, architecture, automotive, and energy due to their superior properties. Composites consist of fibers as reinforcement and a matrix as glue, providing enhanced characteristics [4]. They are favored for their weight-saving advantages and are gradually replacing metallic components [29]. The main types of composites include polymer-matrix, metal-matrix, and ceramic-matrix composites [55]. Fiber reinforced polymers (FRP) are particularly popular due to their lightweight nature, high mechanical qualities, and corrosion resistance [39]. However, cost, and environmental concerns exist, leading researchers to explore natural composites made of biodegradable fibers. Natural fibers, such as bamboo, have gained traction for their positive economic and environmental attributes. Bamboo, with its diverse properties, is being investigated as a potential material source for rod structures in unmanned aerial vehicles (UAVs), traditionally made with carbon matrix composites. This exploration aligns with the aim of reducing costs and utilizing sustainable materials.

The use of unmanned aerial vehicles (UAVs) is increasing, and composite materials play a crucial role in their development. Current high-performance UAVs utilize composite materials due to their lightweight and high strength properties. While metals like aluminum are commonly used, carbon fiber composites are prevalent despite being expensive to manufacture. However, natural fiber composites, such as those made from plant fibers like bamboo, offer significant advantages over synthetic fibers. Natural fibers are abundant, lightweight, cost-effective, biodegradable, and require fewer chemicals during manufacturing. Although bamboo is mainly used in the textile and furniture industries, its potential as a natural fiber composite for UAV rod structures is promising.

2. Tensile Test

Tensile testing is performed to assess the mechanical properties of materials and is used in material selection, quality assurance, and the comparison of different materials and processes. Tensile test results provide information on ultimate

*Corresponding author: zulafif@uthm.edu.my

tensile strength, breaking strength, maximum elongation, and loss of area. These data can be used to calculate parameters such as Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Tensile strength is the maximum stress a material can bear before breaking, while yield strength is the point at which it begins to deform plastically. Ductility refers to a material's ability to undergo plastic deformation before breaking. Tensile testing involves subjecting a sample to a progressively increasing tensile force until it breaks, and the sample's dimensions and behavior are measured during the process.

3. Methodology

3.1. Material Preparation

The bamboo fiber obtained from the *G. scortechinii* type of bamboo plant, which was already extracted by the manufacturer. It will be easier to determine the thickness of each layer by weighing and setting a knot of bamboo fiber to be 4 grams each (this is done to make sure the distribution of the fiber is uniform). After weighing the fiber, it will be tied with a raffia string to make sure it does not bend. If the fiber is bent, the layering process will be difficult because it will not cover the layer properly. An epoxy resin will be mixed with hardener by following the recommended ratio by the manufacturer of 3:1, respectively. The mixture process was done in a plastic cup to make sure the epoxy resin did not stick to the container.

3.2. Sample Preparation

Table 3.1 shows the quantities of material required to make the final sample of bamboo fiber rod structure. There are several units made for each sample. The outer diameter of the sample must be less than or equal to 1 cm. Thus, the first sample will require four grams of bamboo fiber per layer, which results in five layers in total with 150 and 50 grams of epoxy resin and hardener, respectively. The second and third samples required 16 and 32 grams of bamboo fiber per layer, respectively, which resulted in two and one layers in total with 60 and 30 grams of epoxy resin and 20 and 10 grams of hardener, respectively. Table 3.1 also explains the parameters that need to be discussed after the experiment is done. The total value of bamboo fiber used for S2 and S3 is the same to investigate the difference in total epoxy used, which may affect the microstructure of the sample produced.

Table 3.1 - Quantities required for bamboo fiber (g), epoxy (g) and hardener (g) for final sample preparation

Sample	Total of Bamboo Fiber Used (g)	Hardener per Layer (g)	Epoxy Resin per Layer (g)	Total layer of Bamboo Fiber (g)
S1	20	10	30	5
S2	32	10	30	2
S3	32	10	30	1

3.3. Procedure

The metal rod will be covered with lubricant (petroleum gel) and wrapped in plastic to make sure the sample can be removed easily after it is finished. Then, the first layer of bamboo fiber will be wrapped around the metal rod. The fiber will be wrapped in a circular motion to cover the surface of the metal rod. A fiber mesh is used to wrap the fiber to secure its position before spreading the epoxy resin by using a brush. The procedure is repeated until it reaches the required layer of bamboo fiber following Table 3.1. After that, the sample will be inserted into a shrink tube and heated using a gun heater before being left to cure for 24 hours. During the heating process, the rod will be rotated to make sure the epoxy resin is spread evenly. After the curing process, the bamboo fiber rod will be removed from the metal rod base. Then, it will undergo a finishing step where the tip of the rod will be removed by using a metal saw to get a nice edge. Then, a lathe machine will be used to reduce the diameter of the produced samples to 1 cm each.

3.4. Tensile Strength Test

The bamboo fiber rod structure will be tested to evaluate its tensile strength. As a result, a tensile test will be performed on the sample to assess the bamboo fiber composite's strength under pulling force as well as the material's behavior when subjected to an applied tensile force. The specimen has a cylinder dimension of 120 mm and 1 mm of length and diameter, respectively. For tensile strength testing, universal testing machine in the solid mechanic laboratory was used. The rate of speed was set at 2 mm/min, as stated in ASTM D3039, with a gauge length of 10 mm. The specimens will be fixed between the grips of the Universal Testing Machine and tightened to make sure they stay intact during the testing. The machine is set to run, and the sample is pulled in opposing directions until it breaks, and it stops automatically when it breaks completely.

3.5. Density

Density is a convenient means of obtaining the mass of a body from its volume. The density test was performed to determine the density of the sample produced by using Balance XS64 Mettler Toledo density kits, which are available at ceramic laboratory. The sample will be put on the pan to measure the weight in air and then put under the basket since the sample is floating to measure the weight in liquid. The value of density for the specimen will be automatically calculated by the machine, and the result will be printed out. Based on the value of density, ρ, the weight of a material, W can be determined by using the following Equation (1) and Equation (2):

$$V = \pi r^2 l \tag{1}$$

$$W = V \times \rho \tag{2}$$

where r, l and V represent the radius, length, and volume of the specimen.

4. Result and Discussion

4.1. Tensile Strength

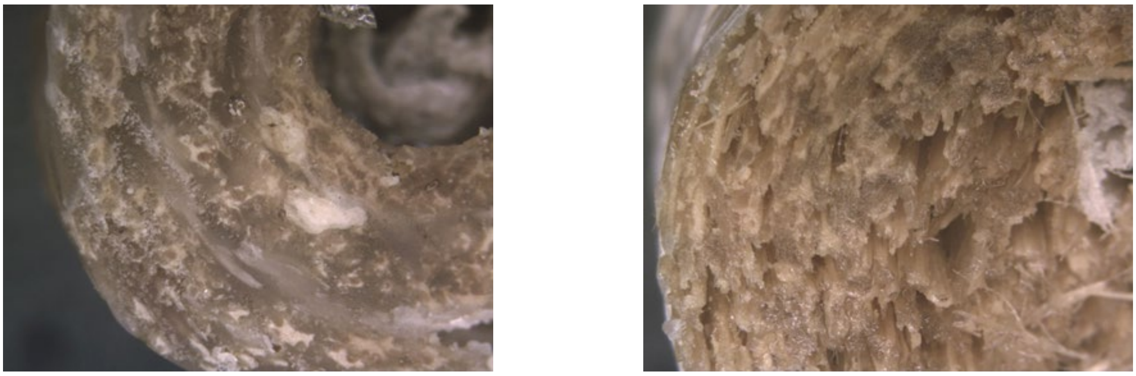
Tensile strength is defined as the capacity to endure tensile loads without breaking. Furthermore, it demonstrates the robustness of the materials to be utilized as goods. The tensile strength for each sample is presented in Table 4.1. The results of the study show that as the percentage of bamboo fiber increases in the composite, the tensile strength decreases. The highest tensile strength recorded was 22026.99 N/m^2 for sample S1, which had a lower bamboo fiber content. However, as the bamboo fiber content increased in samples S2 and beyond, the tensile strength decreased to 11586.45 N/m^2 and further dropped to 5474.92 N/m^2. The findings indicate that the total amount of epoxy resin and hardener used in the composite plays a crucial role in determining its strength. To achieve proper bonding of the fibers and to reduce the presence of pores between them, increasing the bamboo fiber content must be followed by a proportionate increase in the total weight of epoxy resin. Compared to previous studies on bamboo fiber reinforced epoxy composites and carbon fiber composites, the tensile strength of the bamboo fiber composite in this study is relatively high. However, it is still significantly lower than the tensile strength values reported for carbon fiber composites in previous research [22, 53].

Table 4.1 - Tensile strength of the samples

Sample	Maximum Load (N)	Area (m^2)	Tensile Strength (s) (N/m^2)
S1	1730	0.07854	22026.99
S2	910	0.07854	11586.45
S3	430	0.07854	5474.92

4.2. Effect of Bamboo Weight Per Layer on The Rod Microstructure

The weight per layer of bamboo fiber in the rod structure affects its microstructure. The density of the bamboo fiber cannot be accurately determined due to the extraction process by the manufacturer. Increasing the weight of bamboo fiber per layer theoretically increases the layer thickness. However, with a fixed volume of epoxy resin, the resin may not fully cover the increased weight of fiber, resulting in increased porosity of the rod structure. This porosity can potentially impact the mechanical properties of the rod structure. Figure 4.1 (a) shows the layers of epoxy with bamboo fiber at x700 magnification, where the bamboo fiber is fully covered with epoxy resin. However, in Figure 4.1 (b), the fiber is not fully covered with epoxy resin, particularly on the inner diameter of the specimen. This results in a visible porosity in the sample. The increased weight of bamboo fiber per layer makes it difficult for the resin to penetrate through the fiber layer, leading to incomplete coverage and increased porosity.



(a) (b)

Fig. 4.1 - (a) First sample; (b) Third sample

Figure 4.2 at x700 magnification shows the layers of epoxy with bamboo fiber. The void area in the second sample, which contains 16 grams of bamboo fiber and epoxy resin, is slightly more than the first sample but less than the third sample. This suggests that as the weight of bamboo fiber increases, the volume of epoxy resin also needs to increase to ensure a sturdy bamboo fiber rod with minimal voids. The presence of voids can affect the structure of the rod sample. This was evident during the production process when the third sample broke down while reducing the diameter using a lathe machine. The void area on the inner diameter of the sample prevented the epoxy resin from fully gripping the bamboo fiber, resulting in failure.

Fig. 4.2 - Second sample

4.3. Density of Bamboo Fiber Composite

The study used a Balance XS64 Mettler Toledo density kit available at a ceramic laboratory to calculate the density of the samples. Density is the mass per unit volume and determines whether an object will float or sink in water. If the density is greater than 1 gm/cm^3, the object sinks, while objects with a density less than 1 g/cm^3 float. Table 4.2 presents the density data obtained for the samples in the study. According to the data in Table 4.2, the average density of the samples decreases as the bamboo fiber content increases. Sample S1 has a density of 0.9720 g/cm^3, which is higher than the densities of samples S2 (0.8440 g/cm^3) and S3 (0.7790 g/cm^3). However, all the sample densities are lower than that of distilled water, which has a density of 0.9975 g/cm^3. Therefore, the samples would not sink when in contact with distilled water. The decrease in density with higher bamboo fibre content can be attributed to the presence of more pores within the sample, resulting in less compact particles in the composite. Sample S3, with a lower epoxy resin content, exhibits more pores, contributing to its lower density compared to S1 and S2. Comparing the density values to the density of *G. scortechinii* bamboo (0.641 g/cm^3), it can be observed that the S3 sample's density approximates that value [41]. The addition of epoxy resin improves the density of the bamboo fiber, but the resulting composite remains relatively light, as it still floats on distilled water. In comparison to previous research on carbon fiber epoxy composites, which typically have densities ranging from 1.4 to 1.8 g/cm^3, the bamboo fiber composite in this study has a lower density, closer to that of water (0.997 g/cm^3) [46].

Table 4.2 - Density of samples

Sample	S1		S2		S3	
Diameter (cm)	2.0	2.0	2.0	2.0	2.0	2.0
Height (cm)	1.0	1.0	1.0	1.0	1.0	1.0
Weight in air (g)	3.8054	3.5790	4.0309	4.4976	2.5872	2.3569
Weight in liquid (g)	-0.0460	-0.1478	-0.6748	-0.8896	-0.7804	-0.6181
Density AL (g/cm^3)	0.9975	0.9975	0.9975	0.9975	0.9975	0.9975
Density composite (g/cm^3)	0.9860	0.9580	0.8550	0.8330	0.7670	0.7910
Average Density (g/cm^3)	0.9720		0.8440		0.7790	

In terms of application in drones, choosing a lightweight material is preferable to enhance maneuverability and increase flight time. To compare the weight of two materials, their densities are utilized. The average weight of the bamboo fiber rod structure, with dimensions of 25 cm in length and 1 cm in diameter, is measured at 67.9369 g. By using Equation (1) and Equation (2), the weight of a carbon fiber composite with the same dimensions can be determined. The average density of carbon fiber is found to be 1.4667 g/cm^3 [46]. Using the given dimensions, the volume (V) of the rod structure is calculated as 78.5398 cm^3. Multiplying the volume by the density of carbon fiber gives a weight (W) of 115.1943 g. Comparing the calculations, the weight of the carbon fiber composite is significantly heavier than that of the bamboo fibre composite studied in this project.

5. Conclusion

The aim of this research was to produce a rod structure for unmanned aerial vehicles (UAV) using bamboo fiber as reinforcement and epoxy resin as the matrix. The study also aims to evaluate the mechanical properties of the bamboo fiber composite rod. The bamboo fiber content was varied while keeping the epoxy resin to hardener ratio constant. Tensile and density tests were conducted to assess the strength and physical characteristics of the samples. The results showed a decrease in both tensile strength and density as the bamboo fiber content increased, while the amount of epoxy resin remained constant. The tensile strength of the bamboo fiber composite ranged from 22026.99 to 5474.92 N/m^3, which was found to be lower than the results reported in other studies. The density of the composite decreased as the percentage of bamboo fibre increased. This decrease in density was attributed to the presence of more pores within the sample, resulting in less compact particles in the composite. The densities of the bamboo fibre composites tested ranged from 0.9720 to 0.7790 g/cm^3, which was significantly lower than the density of carbon fiber composites that are usually utilized as the material for UAV structures. The low density of the bamboo fibre composite is advantageous for UAV applications as it improves manoeuvrability and potentially increases flight time. However, it should be noted that the tensile strength of the bamboo fibre composite is lower compared to carbon fibre composites, which may be a disadvantage in certain applications.

References

[1] Aakif Mairaj, B. A. (2019). Application specific drone simulators: Recent advances and challenges. Simulation Modelling Practice and Theory, 100-117.

[2] Abdelkefi, M. H. (2017). Classifications, applications, and design challenges of drones: A review. Progress in Aerospace Sciences, 99-131.

[3] Abdul Khalil H. P. S., e. a. (2014). Biofiber reinforcements in composite materials. Woodhead Publishing.

[4] Abramovich, H. (2017). Introduction to composite materials. Stability and vibrations of thin-walled composite structures, 1-47.

[5] Adamu Muhammad, M. R. (2019). Recent developments in bamboo fiber-based composites: Polymer Bulletin, 2655-2682.

[6] Aiman, H. M. (2022). Mechanical properties of bamboo fiber reinforced concrete. Johor: PTTA digital archive.

[7] Ali Akbarpour, M. M. (2021). Mechanical Behavior and Permeability of Plastic Concrete Containing Natural Zeolite under Triaxial and Uniaxial Compression. Journal of Materials in Civil Engineering.

[8] Ambigai, B. M. (2022). Bamboo fiber composite eco-icebox (BFCEI) for food storage container. Johor: PTTA Digital archive.

[9] Amin Nourmohammadi, M. J. (2018). A Survey on Unmanned Aerial Vehicle Remote Control Using Brain–Computer Interface. IEEE transactions on human-machine system, 337-348.

[10] Anam Tahir, J. B.-H. (2019). Swarms of Unmanned Aerial Vehicles — A Survey. Journal of Industrial Information Integration.

[11] Anu Gupta, A. K. (2011). Effect of Different Parameters on Mechanical and Erosion Wear Behavior of Bamboo Fiber Reinforced Epoxy Composites. International Journal of Polymer Science.

[12] Apurba, D. K. (2022). Review on manufacturing and fundamental aspects of laminated bamboo products for structural applications. construction and building materials.

[13] Arafat Rehman and M. C, P. (2019). Monitoring condition of concrete structures through nondestructive testing. AIP conference proceedings. AIP publishing.

[14] Chung, D. D. (2012). Carbon fiber composite. Burlington: Elsevier Science.

[15] Constable G, L. D. (2015). Cotton breeding for fiber quality improvement. Industrial crops: Breeding for bioenergy and bioproducts, 191-232.

[16] DesRochers, M. B. (2011). Root connections can trigger physiological responses to defoliation in nondefoliated aspen suckers. Botany, 753-761.

[17] Dusane, S. S. (2016). Strength Improvement of Concrete by Using Chopped Carbon Fiber. International Conference on Recent Trends in Engineering, Science & Management, (pp. 421-429). Maharashtra.

[18] Fazal Noor, K. M.-Z.-D. (2020). A Review of the Communications Perspective of Flying Ad-Hoc Networks: Key Enabling Wireless Technologies, Applications, Challenges and Open Research Topics. Drones.

[19] Fernando Rusch, G. B. (2019). Morphology, density and dimensions of bamboo fibers: a bibliographical compilation. Tropical agricultural research, 1-9.

[20] Ghanem, S. Y. (2019). Mechanical Properties of Carbon-Fiber–Reinforced Concrete. Advance Civil Engineering Material.

[21] Gunarathna, J., & Munasinghe, R. (2018). Development of a quadrotor fixed-wing hybrid unmanned aerial vehicle. In Proceedings of the 2018 Moratuwa Engineering Research Conference, (pp. 72-77). Moratuwa, Sri Lanka.

[22] Haidar F. Al-Qrimli, F. A. (2015). Carbon/Epoxy Woven Composite Experimental and Numerical Simulation to Predict Tensile Performance. Advances in Materials Science and Applications, 33-41.

[23] Hamdan Lias, A. R. (2020). Technological Development of Bamboo for "Batik" Stamp in Malaysian Textile Industries. IOP Conference Series: Earth and Environmental Science. Seoul, South Korea: IOP Publisher.

[24] Ilyas, H. S. (2022). bamboo species and utilization in Malaysia: a mini review. Composite sciences and technology international conference.

[25] Kalaiyarasan. A, R. P. (2018). Study of Advanced Composite Materials in Aerospace. International Journal of Scientific Research in Mechanical and Materials Engineering, 8-10.

[26] Karunakar Pothuganti, P. K. (2017). A Review on Geo Mapping with Unmanned Aerial Vehicles. International Journal of Innovative Research in Computer and Communication Engineering.

[27] Kassapoglou, C. (2013). design and analysis of composite structures: with applications to aerospace structures. John Wiley & Sons.

[28] Ke Liu, H. T. (2012). Effect of physicochemical structure of natural fiber on transverse thermal conductivity of unidirectional abaca/bamboo fiber composites. Composites Part A: Applied Science and Manufacturing, 1234-1241.

[29] Kit Ling Chin, S. I. (2017). Bioenergy production from bamboo: potential source from Malaysia's perspective. Bioresources.

[30] Kohl, W. L. (2015). Bamboo: The Plant and Its Uses. Springer International Publishing.

[31] Lina Osorio, T. E. (2011). Morphological aspects and mechanical properties of single bamboo fibers and flexural characterization of bamboo/ epoxy composites. Journal of Reinforced Plastics and Composites.

[32] Lina Osorio, T. E. (2018). In-depth study of the microstructure of bamboo fibers and their relation to the mechanical properties. Journal of Reinforced Plastics and Composites.

[33] Marketandmarkets. (2023, July 5). Carbon fiber market by raw material type (pan, pitch), fiber type (virgin, recycled), modulus (standard, intermediate, high), product type (continuous, long, short), application (composite, non-composite), end-use industry, region- global forecast to 2023. Retrieved from Market research report: https://www.marketsandmarkets.com/MarketReports/carbon-fiber396.html#:~:text=The%20price%20for%20aerospace%2Dgrade,10%20to%2 0USD%2020%2Flb.

[34] Mirdehghan, S. A. (2021). Fibrous polymeric composites. Engineered Polymeric Fibrous Materials.

[35] Mohsan S.A.H, O. N. (2022). Unmanned aerial vehicles (UAVs): practical aspects, applications, open challenges, security issues and future trends. Intelligent service robotics.

[36] Muthukumarana T. V., A. M. (2023). A review on the variation of mechanical properties of carbon fiber-reinforced concrete. Construction and Building Materials, 1-12.

[37] Narayanan Venkateshwaran, E. A. (2012). Mechanical and Dynamic Mechanical Analysis of Woven Banana/Epoxy Composite. Journal of Polymers and the Environment, 565-572.

[38] Nasir, M. (2017). Natural fiber improvement by laccase; optimization, characterization, and application in medium density fiber board. J Nat Fibers, 379-389.

[39] Natesan Vijay, V. R. (2016). Assessment of Composite Waste Disposal in Aerospace Industries. Procedia environmental science.

[40] Nations, U. (2022, January 22). Sustainable development goals. Retrieved from United Nation: Department of economic and social affairs: https://sdgs.un.org/goals/goal9.
[41] Nordahlia Abdullah Siam, U. M. (2019). Anatomical, physical, and mechanical properties of thirteen Malaysian bamboo species. BioResources, 3925-3943.
[42] Patel Pratima A., M. A. (2013). Performance Evaluation of Bamboo as Reinforcement In Design. International Refereed Journal of Engineering and Science.
[43] Peng, Z. (2013). The draft genome of the fast-growing non-timber forest species moso bamboo (Phyllostachys Heterocycla). Nat Genet, 456-461.
[44] Piotr Kardasz, J. D. (2016). Drones and the Possibilities of Their Using. Journal of Civil & Environmental.
[45] Poostforush, M. A.-M. (2013). Investigation of Physical and Mechanical Properties of High-Density Polyethylene/Wood Flour Composite Foams. Res. J. engineering sci, 15-20.
[46] Prashanth S., S. K. (2017). Fiber Reinforced Composites - A Review. Journal of Material Sciences & Engineering.
[47] Ratna Prasad, A. a. (2011). Mechanical properties of natural fibre reinforced polyester composites: Jowar, sisal and bamboo. Materials & Design, 4658- 4663.
[48] Rovira-Sugranes. A, R. A. (2022). A Review of AI-enabled Routing Protocols for UAV Networks: Trends, Challenges, and Future Outlook. Ad hoc networks.
[49] Sadiku, N. A. (2016). Analysis of the calorific and fuel value index of bamboo as a renewable biomass feedstock for energy generation in Nigeria. Lignocellulose.
[50] Salit, A. O. (2017). Natural fiber composite. materials selection for natural fiber composites, 23-48.
[51] Siam, N. K. (2019). Properties of Bamboos. Bioresources. Bioresources.
[52] Srivastava, A. K. (2017). Preparation and Mechanical Properties of Jute Fiber Reinforced Epoxy. Industrial Engineering & Management.
[53] Subhankar Biswas, S. S. (2015). Physical, Mechanical and Thermal Properties of Jute and Bamboo Fiber Reinforced Unidirectional Epoxy Composites. Procedia Engineering, 933-939.
[54] Wen, S., Han, J., Lan, Y., Yin, X., & Lu, Y. (2018). Influence of wing tip vortex on drift of single rotor plant protection unmanned aerial vehicle. . Nongye Jixie Xuebao/Trans. Chin. Soc. Agric. Mach, 127-137.
[55] Xinzhang Song, C. P. (2016). Dynamic allocation and transfer of non-structural carbohydrates, a possible mechanism for the explosive growth of Moso bamboo (Phyllostachys heterocycla). Scientific Reports.
[56] Yang Fu, H. F. (2017). Study on the properties of the recombinant bamboo by finite element method. Composites Part B: Engineering, 151-159.
[57] Yongxiang Yang, R. B.-J. (2012). Recycling of composite materials. Chemical engineering and processing: process intensification, 53-68.
[58] Zakikhani, P. (2014). Extraction and preparation of bamboo fiber-reinforced composites. International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, 315-318.
[59] Ziaullah Khan, Y. B. (2017). Fracture behavior of bamboo fiber reinforced epoxy composites. Composites Part B: Engineering, 186-199.