

Fabrication and Evaluation of a Natural Bamboo Fiber Reinforced Composite Material

Vishnu Vardhan Mukkoti¹, Ananth Subramani¹, Deepak Kolar¹, Dhanraj Buragalla¹, Ramadevi Dungavath¹, Harshtih Basipangu¹ and Milan Sanathara²

¹Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad, Telangana, India

²Department of Mechanical Engineering, RK University, Rajkot, Gujarat, India

*Correspondence to:

Vishnu Vardhan Mukkoti
Department of Mechanical Engineering,
Vardhaman College of Engineering,
Hyderabad, Telangana, India.
E-mail: mukkotivishnu@gmail.com

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Abstract

This work presents a new alternative to fiber reinforced polymers (FRP) by modelling and fabricating a bamboo fiber reinforced polymer (BFRP) utilizing a standard weave of bamboo fibers incorporated within an epoxy matrix. The BFRP was represented by a unit cell model made up of a pair of parallel fibers braided perpendicularly in a matrix. A simulation of the tensile test was used for analysis. In order to make the results simpler, periodic boundaries was used. Tensile tests were performed on fabricated BFRP samples, and the findings were compared to those from simulations. The price of energy of manufacturing BFRP was computed and contrasted with the energy price of manufacturing FRP. This actual amount is far lower, and it serves as the primary inspiration for this effort.

Keywords

Natural fiber bamboo, Composite material, Durability properties, Material properties, Energy cost

Introduction

In applications that require high performance such as aerospace, obsession products, and sports equipment, lightweight, highly strong carbon fiber reinforced plastic and GFRP alloy are being utilized more and more. Nevertheless, the manufacturing of carbon fibers is energy intensive and dependent on fossil fuels feedstock. The potential use of organic bamboo fibers as a replacement to carbon and fibers made of glass in polymer-fiber mixtures is a result of these environmental issues and the growing social interest for producing reusable and sustainable goods. In some present uses, high-quality BFRP could takes place of CFPRs or GFRPs as an environmentally beneficial substitute [1].

There are numerous intriguing economic and materials science problems that arise from the manufacturing of bamboo fibers. Bamboo was a natural substance, thus the techniques required to manufacture fibers are distinct from those for producing fibers that are commonly utilized in composites, like carbon fiber or fiberglass. Natural fibers such as bamboo require a special manufacturing technique called fiber separation. Compared with carbon or glass fiber, bamboo fibers need to be removed from the bulk of the plant because they are a composite that is naturally made from multiple fibers and lignin substrate [2].

Lignin could be broken into smaller pieces and natural bamboo fibers separated by immersing the bamboo with liquid or other treatments. So that dry, fragile fragmented bamboo may be drawn out into fibers without breaking, further soaking phase can be performed throughout the fiber separation process. Each of these procedures contributes to the later optimisation of the materials' and the item's overall structure and attributes. Since bamboo tends to disintegrate

in any amount of water, lacking these fibers, further treatment consideration is necessary. By making sure that the weave is adequately encased in a matrix in order to avoid water intrusion, the layout must overcome this challenge.

In order to minimize the initial deterioration of bamboo fibers, any massive manufacturing would additionally have to take into account moisture along with other methods of how water might be incorporated through the bamboo while preparation. Understanding the underlying chemicals and how they could affect the qualities of the finished product is necessary to optimise each of these processes [3].

In particular, fibers derived from softwood and hardwood resources have been isolated by scientists for use as reinforcement in polymers. Studies have focused on bamboo fiber polymers as renewable substitute for substances made of petroleum-based chemicals [1-3].

We looked at several research areas that would be pertinent based on the design goal, together with examinations of the development of different bamboo fiber composites including the various properties of bamboo. Prior study has looked at bamboo treatment techniques, bamboo fiber extraction methods, and carbon fiber weaving techniques that resemble the designs it is utilised for; fortunately, no research has optimized a weaving design or weaved bamboo fibers [4-6].

Due to chemical components like lignin, which can reduce adhesion towards hydrophobic matrix resources, bamboo fibers are highly hydrophilic. To delignify the bamboo, a lot of researchers comprise used chemical-treatment techniques like alkalinization, etc. On the other hand, different designs rely on locating a natural, environmentally friendly answer.

Kushwaha et al. [7] technique involved using distilled water to alter the bamboo fiber's surface. Since no chemicals were used, this procedure was safe and environmentally friendly. This group's work entailed boiling bamboo for six hours after soaking it in water that was distilled for one month, three months, or six months. The findings showed that the bamboo that had been soaked for three months had the best mechanical along with water resistance capabilities.

However, compared to untreated surfaces, even the bamboo that had been exposed to water for a month increased the tensile strength for the composite by 36%. Flexural strength measurements from chemical and non-chemical treatments ranged between 120 and 145 MPa. Both processes have the capacity to successfully eliminate lignin from fibers.

The bamboo is dried after soaking in order to lessen the amount of water that the fibers absorb. If the amounts of water absorption become excessively high, the bond that exists among the polymer matrix along with bamboo fibers may suffer significantly. Before processing the fibers, one group dried the bamboo at a temperature of 120 °C for three hours.

According to earlier studies, bamboo fibers have been removed from culms using a variety of novel methods [8]. The steam exploding, roller mill methods, compression, and a sifter machinery are a few of these methods. While all of these

methods can successfully extract fiber, there are differences in the fiber diameter and length that can be obtained.

According to research by Okubo et al. [9], bamboo fibers have poor adherence to the epoxy matrix and are at greater risk of undergoing surface fracture when there are voids around them. They also came to the conclusion that these voids are more likely to appear when bamboo fibers are placed on top of one another. Optimal designs will shrink the diameter of the composite to lessen the number of voids.

The steam explosion technique was used to find the diameter with the smallest size. This extraction method violently boils water into steam in a vessel, splitting up the lumber into tiny fragments and fibers in the process. This process produced fibers with a diameter of 10 - 30 micrometres and lignin that was virtually entirely removed from their surface. Although this technique might result in ideal fibers, it's not always easy to get access to or locate this kind of equipment.

The other fiber extraction methods that utilise compression techniques were described by Deshpande et al. [10]. Both the roll mill approach, and the compression technique were used in their research. The compression approach produced an average fiber diameter of 149 micrometres, whereas the roll mill approach produced a fiber diameter of 90 micrometres on average. Compression duration and beginning bed thickness are the two variables that must be optimized to produce quality fibers. Following a number of tests, they discovered that an ideal fiber creation was achieved with an average load of 10 tons, an extrusion period of 10 sec, and a bed thickness of amid 1.25 - 2 cm.

Natural fibers have a significant role in the production of polymers that are highly valued in nanoform. New perspectives in the domains of science and engineering have been opened up by the production of nanofibers from polymers that are natural or synthetic, metallic substances, semiconductors, composite materials, and carbon-based materials. Nanofibers have also been the subject of extensive study [11].

The goal of this study was to create a woven BFRP that would mimic woven CFRPs and have better qualities than BFRPs having randomly arranged fibers. The major goal of this research is to replace synthetic fibers by natural fibers even as maintaining the characteristics by CFRPs or GFRPs in order to decrease the consumption of energy and pollutants generated during the fabrication of composite materials. The basic energy required to produce carbon fiber is 380 - 420 MJ/kg, and this fabrication generates 23.8 - 26.3 kg/kg of greenhouse gas emissions. The manufacture of carbon fiber necessitates the combustion of extremely powerful fossil fuels, which also produce significant amounts of pollutants. This significant energy consumption and pollutant output can be avoided while maintaining the woven composite's mechanical integrity by using bamboo fibers as a replacement. Bamboo was discovered to be a powerful natural material, with tensile along with compressive capabilities that are comparable to steel as well as being more durable than some forms of wood. This then contributes to the decrease in energy use and pollutant production when creating woven composites.

Experimentation

Preparation of reinforced composites

It is created a technological strategy that involved modelling our composite, doing the finite element analysis, and creating a product prototype because to finish the design of a BFRCC. It is simulated tensile loading situations using the model in a finite element analysis. In order to ascertain the impact of each of the different model variables effect the tensile strength and Young's modulus. This it is conducted many tensile tests while modifying the model's parameters. A prototype was created as evidence of concept, to support our study, and to provide a way to contrast our bamboo fiber composite with a carbon fiber composite.

The epoxy was prepared after the weave had been created. The epoxy has a 3:1 mixing ratio and is a two-part epoxy. Epoxy resin in three parts and hardener in one portion. The epoxy was properly mixed before being put within a chamber with a vacuum to remove trapped air. The epoxy has to put onto the mold, completely pouring into the cavity, after bubbles had been totally eliminated after around 15 min. Before it was removed from the mold, the epoxy was given 24 h to cure.

Bamboo culms were harvested as the initial phase in the composite's prototyping process. It came from a local who harvested the bamboo. Once the culms were obtained, they were chopped into parts by slicing the culms prior to every node, then sliced into strips by striking each segment using rubber mallet as well as letting the bamboo naturally snap. To make that the bamboo was semi-flat and not bent, the strips was smashed till the appropriate distance across around roughly 1.5 - 2.5 cm was reached. The bamboo had to have a slight curvature to successfully pass across a roller mill. The strips were collected and then immersed using 0.1 M of sodium hydroxide (NaOH) treatments for roughly 72 h. This type of solution was selected for investigation since it was found that higher lignin breakdown will result from an extremely strong NaOH solution with a lengthy soaking period [10]. Because this concentration produced the best delignification outcomes while preserving the mechanical qualities of the bamboo, the authors utilised a 0.1 M NaOH solution. The bamboo is soaked, thoroughly mixed with water to erase all of the NaOH that was present, and then burned about 120 °C for 2 h in order to dry them [11].

Composite material preparation

To prototype it, it is required to insert bamboo fibers onto epoxy after which it is include those into a composite. The dimensions were about 10 cm in length and 1" of diameter. By cutting the long ends on each side of the nodes, the stem of bamboo was separated into six halves. After being chopped into parts and removed, the bamboo is submerged in a 0.1 M NaOH solution for being treated. This procedure aids in the adhesion of the bamboo with epoxy. The bamboo was soaked for 72 h, which included 3-hour soak with water and numerous rinses to take away any leftover NaOH. After being roasted in a 120 °C oven over 2 h, the bamboo was thoroughly cleaned and air dried for 5 days. Using a roller mill, the bamboo particles were crushed into fragmented bamboo. The

bamboo splinters made it easier to separate the bamboo fibers. After that, the bamboo was re-soaked in water to render the fibers more pliable during the final separation. Before soaking the broken bamboo, the fibers were hard to extract exclusive of breaking. The extracted fibers were collected in packages of 8 filaments. The bundles were then threaded into the loom, where figure 1 weave took place. Then, in a simplistic plain weave pattern, a different over-under pattern was applied. The woven cloth was then placed on the mold as shown in figure 2.

During the first step of the composite's prototyping process, bamboo stalks have been collected. This was collected by a native that harvested the stalks of bamboo. After getting the culms, it was separated into parts by removing the culms anterior to each node, then sliced onto strips by smashing the pieces by using a hammer and making the bamboo to snap naturally. To ensure the surface of the bamboo became semi-flat and not curved, the strips were broken until the desired breadth approximately 1.5 - 2.5 cm was attained. To properly travel through a roller mill, the bamboo required to have minimal or no curvature. After obtaining the strips, they were submerged in 0.1 M NaOH treatments for approximately 72 h. The solution of 0.1 M NaOH was used because it generated



Figure 1: Mold preparation.



Figure 2: Plain weave inserted into the cavity.

the most effective delignification outcomes while keeping the structural properties of the bamboo. The soaked bamboo was carefully cleaned by using water to eliminate every bit of NaOH prior drying for a two-hour period at 120 °C, as shown in figure 3.

The next stage of the prototype's development involved using the roller mill to get rid of the fibers. Extractions are carried out in a roll mill. The space width in the rollers is changed in such a way as it is somewhat less than the width of the bamboo. The bamboo chunks would run onto the roller two times on the exact altitude; however, the bamboo is twisted around each time.

The section was then run through once more, this time having the correct side facing up. The height of the gap is then lowered. This operation was repeated until the gap height grew so narrow that the strip broke into fragmented pieces of bamboo. To obtain the fibers, these fractured bamboo fibers were cut off by manually after being treated in water to soften their brittleness. The fibers were split into sizes in order that the shorter ones could be employed for longitudinal weaving and the longer ones for transverse weaving. The diameter of the fibers ranged from 170 to 300 micrometres. A typical fiber diameter for a sample of 100 is shown in table 1.

The longer fibers were tied onto the loom at evenly spaced places in clusters of eight fibers. This loom's operational mechanism employed wrap threading that was pushed from side to side by a shaft. Each wrap thread traverses the heddle onto a shaft. The heddles will be lifted in the same manner as the shaft, causing the cover (bamboo) threads to pass through the heddles. Depending on the design we choose, this loom will allow us to distribute the shafts evenly. The transverse fibers were coiled in bulk of eight and woven over the longitudinal fibers to form a basic weaving pattern. All

of those fibers had been immersed in water repeatedly before spinning to decrease brittleness and preserve fiber integrity. The finished mat measured 1" x 4". Three bamboo weaves were constructed in order to be made into a BFRP hybrid.

Results and Discussion

Tensile test was conducted after successfully manufacturing three BFRP, CFRP, and plain epoxy prototypes. The tensile test results might be used to input the properties of all the materials using ANSYS. By entering the experimental mechanical properties, we can compare the experimental results to our simulations directly. Yet, the information we collected was invalid due to the failure to fabricate our samples. Our volume percentage was discovered to be too short, and the fiber is not well enclosed in the epoxy. Finally, barely a minor quantity of tension force and the most of bending force are felt. A 3-point bending test indicates the material's flexural characteristics. This is necessary to assess whether our composite can endure the bending forces experienced by snowboards. Furthermore, this would provide us with a more thorough grasp of our materials' mechanical properties.

Because the volume portion of our adhesive remained too high, we performed a 3-point bend test. Because the stress goes from compression to tensile stress (on the upper face) while the weave is centered at the middle of it, that the weave is able to stay in the plane with no force exerted on it. The thickness of the composite is approximately 0.25 inches, and it had 0.1" thin fiber of bamboo weaving in the centre. The data that results would be more akin to an epoxy than a composite. In order to remain relevant, we would need to increase the volume proportion of bamboo in our BFRP. Our fiber volume computation and the fiber volume proportion for the composite are displayed below.

A normal fiber-based composite's volume fraction is roughly 50 - 60%, whereas in this, it was only 4.13%. When computing the volume fraction, the assumption that each fiber was cylindrical and of identical size. We utilised a fiber diameter of 213 micrometres, which corresponds to the typical diameter of a specimen of 100 fibers from table 1. As evidenced by the tensile test data, the low volume percentage of our fibers ultimately reduced the overall quality of resulting samples. We would employ a vacuum bag molding technology, which is a development of a manual lay-up procedure, to create future prototypes.

A Hoover is used in this approach to remove entrapped air and extra resin. The approach allows for larger reinforcement concentrations, improved layer adherence, and greater control across resin/fiber ratios. The sample preparation procedure is depicted in figure 4.

Digital images were taken with a GS3U3-23S6M-C camera that has an agreement of a million pictures per second during the tensile test on an Instron Model 1123. A 25 KN load cell and a 2 mm/min pull speed were used for each specimen. The setup of the experiment for a tensile test is shown in figure 5.



Figure 3: Final mat.

Table 1: Dimensions of separated bamboo fibers.

Minimum diameter	170 micrometers
Maximum diameters	300 micrometers
Average diameter	213 micrometers
Standard deviation	21.4 micrometers



Figure 4: Sample processing procedure.

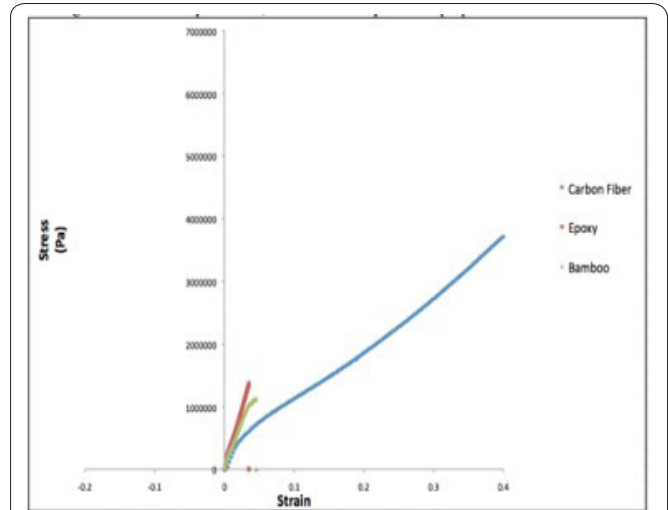


Figure 6: Stress-strain curves for the 3 non-failing samples.

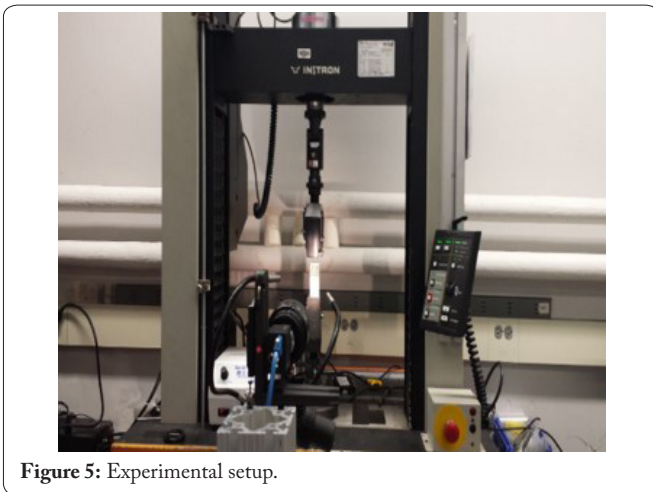


Figure 5: Experimental setup.

Table 2: Comparison of simulation results and experimental values.

Results	Ultimate tensile strength (MPa)
ANSYS results	1.259
Experimental result	1.123

Strength (1.13 MPa) than the regular epoxy sample. Although the bamboo composite had a lower maximum stress than the epoxy, the stress created inside a BFRP is significantly lower than that stress produced inside the epoxy if an identical strain was used.

Table 2 shows that the simulated with experimental results were within a reasonable range of acceptability. This demonstrates the common qualities of all the components in the composite, as well as the possibility for BFRP to be a less expensive, environmentally conscious substitute to CFRP.

The tensile test results show that the sample produced was a failure. Only one sample from every type: bamboo fiber, carbon fiber, and epoxy produced adequate results. The other samples had a variety of problems as a result of inadequate fabrication procedures (fiber-epoxy ratio). Except for one, all of the carbon fiber and epoxy specimens broke at the grasp, indicating the presence of voids and bubbles of air under the sample. This indicates that the vacuum and mold approach was ineffective. The bamboo fiber reinforced composite performed similarly poorly. One sample shattered at the Instron machine’s grips, whereas another fractured across the sample’s side, as seen in figure 6. The sample’s side fracture was probably brought on by an absence of adhesion between the epoxy and bamboo fibers. In the future, fabrication would be done using a vacuum-bagging, layer-up method to increase adhesion and the fiber-to-epoxy ratio.

Despite the fact that most of the collected specimens were unsuccessful, it is capable to execute an appropriate tensile test on one of them. These samples yielded stress-strain curves, which are depicted in figure 6.

The greatest tensile strength was clearly proven by the CFRP composite. The bamboo-fiber reinforced polymer composite performed poorly. It had a lower ultimate tensile

The inherent energy for raw bamboo, the inherent energy of NaOH utilised for fiber segregation, the energy consumed by the power source, the energy used to drive the roller mill used for separating the fibers, and the energy used by labourers to physically complete the task were all taken into account. When all procedures except physical effort are added together, the energy necessary to make fibers is just 32 MJ/kg, which is much lower than the inherent energies of carbon or glass fiber, ranging from 380 - 420 MJ/kg as well as 68.7 - 75.9 MJ/kg, respectively. When individual is factored in, the amount of energy embodied is 72 MJ/kg, which is similar to glass fibers but considerably lower than carbon fibers; yet our fibers remain environmentally friendly compared to glass fibers because human energy is sustainable, powered by the human’s food. Thus, when it comes to of power, our model fibers are more environmentally friendly than carbon or glass fibers since they use far less energy than CFRPs and are derived through a greater number of renewable sources than GFRPs.

Conclusion

Finally, the first goals were to optimize the weave parameters in order to make the strong BFRP feasible. We were able to design an RVE model, mesh it with user-defined parts, and

specify the interactions between our material's components. We could also execute this RVE in every direction to create an entire model of a composite. Furthermore, it was capable to set a tensile load to the design and calculate the material's maximum and minimum stresses. We would construct a failure condition for the simulation and run several tests that modify model parameters to assess the impact of all of them to the material qualities. In addition, we would conduct the identical analysis for a three-point setup.

In the context of prototype, it is successful in producing, treating, and weaving the bamboo fibers. Still, the proposed method for producing the blended materials (bamboo and carbon fiber) was incorrect since the trials were failed to take into consideration for the total fraction of fibers to epoxy. This was determined to be a contributing cause in the failure of the tensile test. Furthermore, we were unable to carry out a 3-point yield test since the quantity of epoxy was far too large. In the near future, we would employ a hoover bag strategy that incorporates a "bottom-up" approach. It will ensure good adhesion among the fibers and the epoxy, as well as a more exact volume fraction of fibers. Because of the aforementioned shortcomings in the prototype process, the majority of the samples failed. The tensile strengths of the failed carbon fiber and bamboo fiber composites were significantly lower than earlier literature results. Furthermore, this is due to our manufacturing procedures. If we have extra time for prototyping, then would have constructed the BFRP from the bottom up and also performed a 3-point bend check to evaluate the bamboo snowboard technology accurately.

The environmental outcomes exceeded the expectations. The cost of energy of producing BFRP was estimated to be 72 MJ/kg, while the cost of energy of producing CFRP approximated 380 - 420 MJ/kg. This number is considerably lower and is major motivator for this effort.

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None.

Conflict of Interest

None.

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