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Development And Examination of a Composite Material Reinforced with Natural Bamboo Fiber

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Abstract

This work provides a novel replacement for fiber-reinforced polymers (FRP) by integrating bamboo fibers into an epoxy matrix. Numerous studies are being conducted in this area to reach the intended standard. This composite exhibits a strong resemblance to synthetic fiber-based composites. This is mainly because to the benefits, which include low cost, biodegradable qualities, easy availability, non-toxicity, non-abrasiveness, and light weight. The representation used for the BFRP was a single cell model made up of 2 pair of fibers twisted integrally in a matrix of fibers. Tensile test was performed to analyze the Periodic constraints were applied to make the outcomes simpler. On artificial BFRP samples, tensile tests were conducted, and the results were contrasted with modeling results. For the simulation, we would build a failure case and run multiple tests with different model parameters to see how each affected the material quality. The energy cost of producing BFRP was calculated and compared to the energy cost of producing FRP. The energy cost of manufacturing CFRP was calculated to be between 380 and 420 MJ/kg, whereas the energy cost of creating BFRP was 72 MJ/kg. This endeavor is mostly motivated by this actual quantity, which is far lower.

Keywords: Natural fibre bamboo, composite material, durability properties, material properties, Energy cost, parameters

INTRODUCTION

Lightweight, extremely strong carbon fiber reinforced plastic & GFRP alloy are seeing increasing utilized in high-performance products such as obsessive items, sports gear, and aircraft. However, the production of carbon fibers requires a lot of energy and is reliant on the feedstock of fossil fuels. These environmental concerns, along with the rising social interest in generating recyclable and sustainable commodities, have raised the possibility of using organic bamboo fibers in polymer-fiber mixtures in place of carbon and glass fibers. High-quality BFRP can replace CFPRs or GFRPs in some current applications as a more ecologically friendly option [1].

The production of bamboo fibers raises a number of interesting issues in materials science and economics. Because bamboo is a natural material, the methods needed to produce its fibers differ from those needed to produce the fibers utilized in composites, like carbon fiber or fiberglass. One special kind of industrial process is fiber separation needed for natural fibers like bamboo. In contrast to carbon or glass fiber, bamboo fibers are a composite which is naturally formed of many fibers and a lignin substrate; hence, the majority of the plant must be removed to expose the fibers [2].

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By submerging the bamboo in liquid or undergoing additional treatments, lignin can be broken down into tiny pieces and the natural bamboo fibers can be extracted. Additional soaking phases can be carried out during the fiber separation process to enable broken bamboo that is dry and brittle that can be dragged out into fibers before breaking. Every one of these processes helps to optimize the overall structure and properties of the item as well as the materials in the future. Without these fibers, bamboo tends to crumble in any quantity of water, so additional treatment attention is required. In order to avoid water entry, the layout must ensure that each weave is appropriately enclosed in a matrix [2].

Scientists have specifically extracted fibers from hardwood and softwood sources to be utilized as augmentation in polymers. Research has concentrated on studying bamboo fiber polymers as a sustainable alternative to materials derived from petroleum-based chemicals. [1-3]. We examined a number of research topics related to the design objective, such as the evolution of different bamboo fiber composites and the mechanical characteristics of bamboo. Fortunately, no study has improved the process of weaving design as well as weaved bamboo fibers. Prior research has looked at how bamboo is treated and how to harvest its fiber, including how to weave carbon fiber into shapes that mimic bamboo [4-6].

Bamboo fibers are extremely hydrophilic because of chemical constituents like lignin, which might decrease adherence towards hydro-phobic matrix materials. Chemical treatment techniques have been used by several researchers, including as coupling agents, graft copolymerization, and alkalization, to remove fibers from bamboo. Conversely, alternative designs depend on finding a natural, eco-friendly solution.

The method used by Kushwaha et al. [7] entailed changing the surface of the bamboo fiber with distilled water. This process was safe and eco-friendly because no chemicals were employed. The task assigned to this group was to soak bamboo in distilled water for one, three, or six months before boiling it for six hours. The results demonstrated that the bamboo with the best mechanical and water resistance was that which was thoroughly soaked for 3 months.

Despite the bamboo that was subjected to water for a month, however, boosted the yield strength for the composite material by 36% when compared to untreated surfaces. The range of readings for flexural strength obtained from both chemical as well as non-chemical treatments was 120-145 MPa. Lignin may be effectively removed from fibers using both methods. To reduce the quantity of water which the fibers absorb, the bamboo has been dried after soaking. In the event that the water absorption levels are too high, the link between the bamboo fibers and the polymer matrix may be severely compromised. A single team warmed the bamboo at 120°C for two and half hours prior to processing the fibers.

Earlier research indicates that a range of cutting-edge techniques have been used to extract bamboo fibers from culms [8]. Among these techniques are the steam explosion, compression, roller mill methods, and sifter apparatus. Although fiber can be successfully extracted using each of these methods, the diameter and length of the fiber that can be obtained vary. Bamboo fibers have poor adhesion to an epoxy matrix as well as are more likely to experience surface fracture in the presence of voids, as per Okubo et al.'s research [9]. They also concluded that layering bamboo fibers next to one another increases the likelihood of these spaces developing.

The circumference with the smallest size was determined using the steam explosion technique. Using a vessel to forcefully boil water into steam, this extraction procedure breaks breaking the substance up into fibers and tiny fragments. The procedure obtained in fibers with a thickness of 10–30 micrometers and nearly completely eliminated lignin. Even if this method might produce perfect fibers, it's not usually simple to find or obtain this particular type of equipment.

Deshpande et al [10]. provided a description of the additional fiber extraction approaches that make use of compression techniques. In their investigation, they employed both the compression technique and the roll milling approach (RMT). The compression approach achieved an average diameter of the fiber of 149 micrometers, whereas the RMT generated an overall fibre diameter of 90 micrometers. To produce high-quality fibers, two factors need to be optimized: the length of the compression period and the thickness of the starting bed. After conducting several experiments, they found that a thickness of 1.25 - 2 cm, an extrusion period of ten seconds, and a normal load of 10 tons produced the best results for creating fiber.

This study aimed to develop a woven BFRP with properties superior to BFRPs with randomly organized fibers, so that it would resemble woven CFRPs. The main objective of this study is to reduce the amount of energy along with pollutants produced during the manufacture of composite materials by substituting natural fibers for synthetic fibers although preserving the properties natural fibres. Carbon fiber synthesis needs 380–420 MJ/kg of basic energy and produces 23.9–26.4 kg/kg of emissions of greenhouse gases. Burning extremely potent fossil fuels is necessary to manufacture carbon fiber, and this process generates a substantial amount of pollutants. By substituting bamboo fibers, it is possible to minimize this large energy use and pollution emission while preserving the mechanical integrity of the woven composite [11-12]. It was found that bamboo is a strong natural material, which is more resilient than certain types of wood, and has tensile and compressive strengths comparable to those of steel. Thus, when making woven composites, this helps to reduce the amount of energy used and pollutants produced.

MAKING OF COMPOSITES WITH REINFORCEMENT

In order to finish our design for a (BFRC), we created a technological strategy that involved modeling our composite, carrying out a FE analysis, and constructing a prototype. The design developed in FEA is utilized to simulate tensile loading scenarios. To ascertain the effect of each of the many model variables on the tensile strength as well as Young's modulus, several tensile tests are conducted while varying the model's parameters. In order to assist our research, demonstrate the concept, and allow us to compare our bamboo fiber composites with a carbon fiber composite, a prototype was made.

The epoxy was ready when the weaving was finished. With a 3:1 mixing ratio, the epoxy solution is a two-part epoxy. One component hardener and three components of epoxy resin was taken in total. Once the epoxy was well combined, any trapped air was released by placing it in a vacuum-sealed container. The bubbles vanished entirely after fifteen minutes or so, and the epoxy has been added into the mold until the chamber was completely filled. Before being removed from the mold, the epoxy was given a full day to cure.

Harvesting bamboo culms was the initial stage in the composite's prototype process. It was obtained through a local who had gathered bamboo. After the culms were acquired, they were cut into pieces by first slicing them before each node, and then they were cut into strips by using a rubber mallet to hit each section and allowing the bamboo to break naturally. Smashed to the proper width of about 1.5–2.5 cm, the strips ensured that the piece of bamboo was semi-flat but not curved. For the bamboo to span a roller mill, it needed to have a small curve. After gathering the strips, they were submerged in 0.1 M sodium hydroxide solutions for around 72 hours. This kind of solution was chosen for study since it was discovered that more lignin breakdown would result from a strong NaOH solution and an extended soaking period [10]. The scientists utilized a 0.1 M sodium hydroxide solution since its concentration yielded the optimal delignification outcomes while preserving the bamboo's mechanical qualities. After that bamboo has been completely submerged in water to eliminate any remaining NaoOH, it was torched within a temperature of approximately 120 degrees Celsius for two hours to dry it off [11].

PREPARATION OF COMPOSITE MATERIALS

Process

Bamboo fibers must first be inserted onto epoxy before being included into a composite in order to prototype it. The measurements were around 1 inch in diameter and 10 centimeters in length. Bamboo stems were chopped into six halves by trimming the extended ends on both ends of the nodes. The bamboo was divided into pieces and then submerged to get treatment within a 0.1 molar sodium hydroxide solution. This process helps the bamboo stick to the epoxy. The bamboo was immersed in water for three hours and then repeatedly rinsed to eliminate any leftover sodium hydroxide for a total of seventy-two hours. The bamboo was washed well and allowed to air dry for five days following its two-hour roasting at 120 degrees Celsius. The bamboo pieces were broken up into pieces using a roller mill. It was simpler for separating the bamboo fibers because to the bamboo splinters. Subsequently, the bamboo was immersed in water once more to increase the pliability of the fibers for the ultimate separation. It was challenging to remove the fibers from the broken bamboo without shattering it before soaking. The isolated fibers were gathered into bundles containing eight filaments. After that, the bundles were strung onto the loom, which was used to weave Figure 1. Then, an alternative over-under pattern was added in a straightforward plain weave design. Following that, the weaved fabric was positioned on the mold as seen in Figure 2.

Figure 1. Preparation of the mold.

Figure 2. Inserting a plain weave onto the opening.

Bamboo stalks were gathered at the first stage of the composite's development procedure. This was gathered by a local who harvested the bamboo stalks. Once the culms were acquired, they were chopped into sections by cutting them in front of each node. The sections were then smashed with a mallet made of rubber until the bamboo naturally snapped into strips. In order to prevent the bamboo's surface from curving, the strips were sliced until they measured between 1.5 and 2.5 cm in width. The bamboo needed to have little to no curvature in order to pass from a rolling mill. The strips which are obtained and then immersed in 0.1 M NaoH solutions for around 72 hours. Because the 0.1 M of sodium hydroxide produced the best delignification results which are preserving the physical qualities of the bamboo, it was chosen. As illustrated in Figure 3, the immersed bamboo was meticulously cleansed with water to remove all traces of NaOH before being dried for two hours at 120ºC.

Figure 3. Final product.

The next step in developing the prototype was to remove the fibers using a roller mill. Roll mills are used for extractions. In order to make the distance between the rollers slightly narrower compared to the size of the bamboo, it was adjusted. Twisted around each time, the bamboo chunks were sent over the roller repeatedly and precisely the same height.

After that, the segment was repeated with the right side facing up this time. Next, the gap's height is decreased. This process was continued until the height of the gap narrowed to the point where the strip split into broken pieces of bamboo. After being drenched with liquid to lessen their brittleness, the broken bamboo fibers has been manually severed to extract the fibers. To enable the use of the shorter fibers for longitudinal weaving and the larger ones for transverse weaving, the fibers were divided into different diameters. The fibers have diameters that vary between 171 to 300 micrometers. Table 1 below displays a typical diameter of the fiber for an instance of 100.

Table 1. Measurements of the split bamboo fibers.

Minimum ø	**168 micrometers**
Maximum ø	305 micrometers
Average ø	210 micrometers
Standard Deviation	20.9 micrometers

Clusters of eight longer fibers have been attached across the loom at uniform intervals. The working mechanism of this loom used wrap threading which was shifted by a shaft from side to side. Every wrap thread passes through a shaft and a heddle. The cover (bamboo) threading flow through the heddles when the heddles are raised in the same way as the shaft. We will be able to disperse the shafts equally with this loom, subject to the design we select. To create a simple weaving design, the transverse fibers were coiled into pairs of 8 and weaved over the longitudinal fibers. Before spinning, each of those fibers had been submerged in water several times to reduce brittleness and maintain fiber integrity. The completed mat was 1" by 4". To create a BFRP hybrid, three different bamboo weaves were built.

RESULTS AND DISCUSSION

Three BFRP, CFRP, and plain epoxy prototypes were manufactured satisfactorily, and we then conducted a tensile test. The features of every material could be input into ANSYS using the results of the tensile test. We may immediately compare the experimental results with our simulations by providing the experimental mechanical properties. Nevertheless, because we were unable to fake our samples, the data we gathered was unreliable. It was found that the fiber wasn't well retained in the epoxy and that the volume % was too low. Eventually, the majority of the bending force is felt, whereas very little tension force is felt. The results of a 3-point bending test indicate the material's flexural characteristics. This is necessary to ascertain the extent to which our composite is capable of withstanding the bending pressures experienced by snowboarders. Moreover, this would allow us a deeper understanding of the mechanical properties of our materials.

We conducted some 3-point bend test as our adhesive's volume component was still excessively large. The weave is able to remain in the plane even when no force is applied to it because the stress transforms from the compression to tensile tension (on the upper face) at its center. The composite is around 0.25 inches thick with a thin bamboo weaving strand in the center measuring 0.1 inches. The resulting data would resemble an epoxy rather than a composite. To remain relevant, we may need to increase the volume percentage of bamboo in our BFRP. The fiber volume percentage for the composite and our fiber volume calculation are shown below.

The volume fraction in this composite was only 4.13%, compared to the typical fiber-based composite's capacity fraction of 50–60%. The volume percent was calculated under the supposition that every fiber was cylinder-shaped and the same size. We used 213 micrometers for the fiber diameter, which is the standard diameter of the workpiece with 100 fibers according to Table 1. As per the tensile strength data showed that our small quantity of fibers ultimately resulted in worse overall quality samples. For the creation of upcoming models, Vacuum bag molding technique would be employed, that is advancement over a manual lay-up process. In this method, excess glue and trapped air are removed with a hoover. Increased control over resin/fiber ratios, better layer adhesion, and higher concentrations of reinforcement are all made possible by this method. Figure 4 shows the sample preparation process.

An Instron Model 1123 was used for the tensile test, and a GS3U3-23S6M-C with a million images per second resolution was used to take digital pictures. A 25 KN load cell and a 2 mm/min pull speed were applied to each specimen. The setup used for a tensile test is shown in Figure 5.

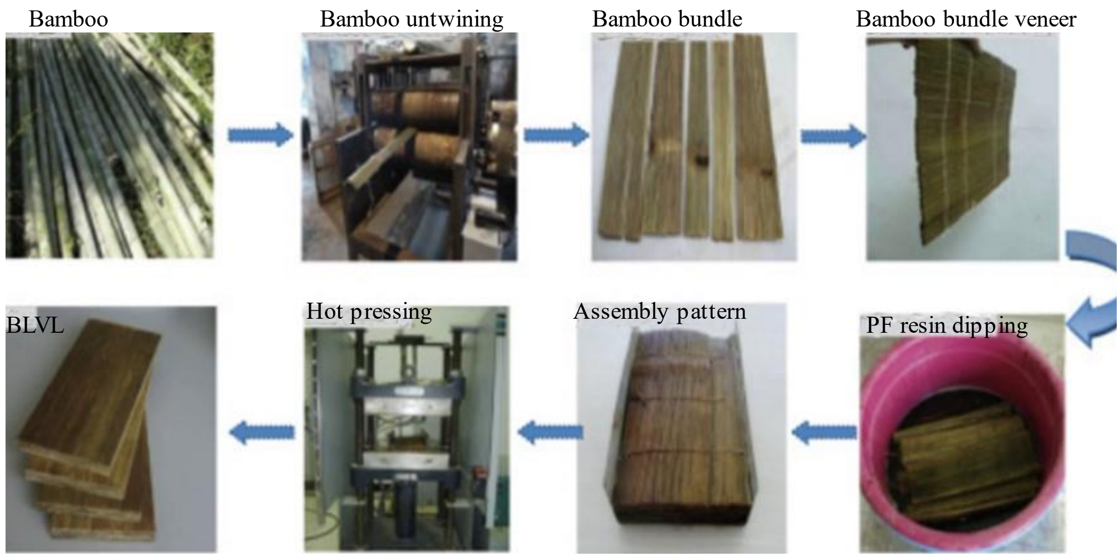

Figure 4. Procedure for dealing with samples.

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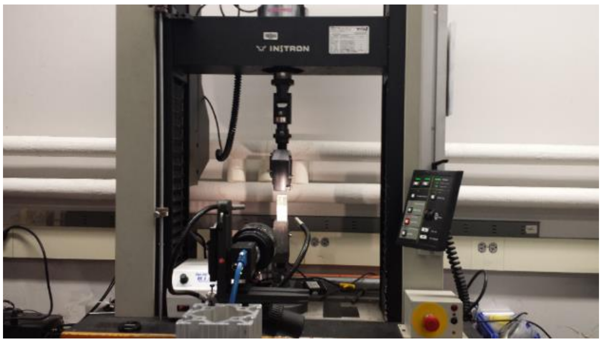

Figure 5. Setof of the equipment.

The results of the tensile test demonstrate that the generated sample was unsuccessful. For bamboo fiber, carbon fiber, and epoxy, only one sample of each type yielded sufficient results. The other samples' insufficient fabrication techniques (fiber-epoxy ratio) led to a number of issues. All carbon fiber and epoxy specimens, with the exception of one, broke at the grip, suggesting the presence of air bubbles and spaces beneath the sample. This suggests that the suction and mould method was not successful. The performance of the composite reinforced with bamboo fiber was also subpar. As seen in Figure 9, a single specimen cracked at the Instron machine's grips, whereas the second sample cracked along its side. The sample's side fracture is probably the consequence of the epoxy and bamboo strands not sticking to one another. As mentioned earlier, a vacuum-bagging, layer-up method would be used in subsequent fabrication to increase both the fiber-to-epoxy ratio and adhesion.

It is able to perform a suitable tensile test on each of the collected specimens, even though the most of them did not work. Stress-strain curves were obtained from these materials, and Figure 6 shows them.

The highest tensile strength was demonstrated by the CFRP composite. The polymer composite reinforced with bamboo fibers did not work well. Its maximum ultimate strength was less than that of the standard epoxy sample. Even though the epoxy had higher stress compared to the bamboo composite, if the same strain was applied, the stress generated within a BFRP is substantially less than the stress generated inside the epoxy.

Table 2 demonstrates that the simulated and experimental findings fell within a respectable acceptable range.

Table 2. Analyzing and contrasting experimental values with simulation results

Findings	**Ultimate tensile strength (MPa)**
ANSYS Values	1.189
Experimental Values	1.0978

This illustrates the shared characteristics of every component in the composite and raises the possibility that BFRP could replace CFRP in a more cost-effective and ecologically responsible manner.

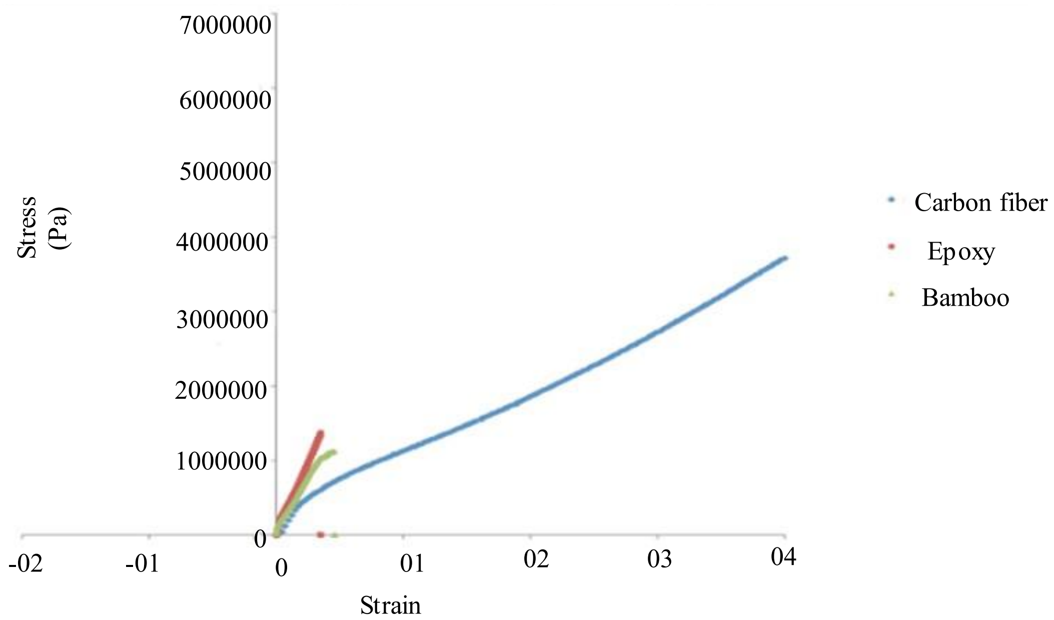

Figure 6. Stress-strain graphs for the three samples that did not fail.

The energy contained in raw bamboo, the energy contained in NaOH, which is used to separate the fibers, the energy used to heat the oven and dry the submerged bamboo, the energy used to run the roller mill, which divides the fibers, and the amount of energy expended by manual labors to finish the operation were also considered. When physical work is excluded, the total energy needed to make fibers is only 32 MJ/kg. This is considerably a smaller amount than the intrinsic values of carbon as well as glass fiber, that is ranging from 380 to 420 MJ/kg and 68.7 to 75.9 MJ/kg, approximately [12]. Individual considerations result in an energy embodied of 73 MJ/kg, which is considerably thinner than a carbon fiber but equivalent to glass fibers. Nevertheless, compared to glass fibers, our fibers are still environmentally beneficial due to human energy is renewable and derived from food. Because our model fibers are sourced from more renewable sources and need significantly less energy than CFRPs, they are therefore less harmful to the environment than carbon as well as glass fibers in terms of electricity.

CONCLUSIONS

With the goal to achieve strong BFRP possible, the primary objectives were to optimize the weave parameters. We were capable of to create such RVE approach, mix it using user-defined components, and outline how the different sections of our material would interact. In order to generate a complete composite model, we might alternatively do this RVE in all directions.

In addition, it could compute the highest and lowest stresses in the material and apply a tensile load on the design. For the simulation, we would build a failure case and run multiple tests with different model parameters to see how each affected the material quality. We would also perform the same analysis in the case of a three-point configuration.

It is successful in growing, processing, as well as weaving the bamboo fibers for the prototype. Nevertheless, the suggested process for generating the materials composites (carbon fiber & bamboo) is defective since the studies neglected to consider about the overall percentage of fibres in epoxy. It has shown to be one of the factors that contributed to the tensile test failing. Furthermore, because there was far too much epoxy, we were unable to do a 3-point yield test. Soon, we would employ a "bottom-up" approach using a hoover bag strategy.

It will guarantee a precise volume fraction of fibers and good adhesion between the fibers and the epoxy. Because of the previously noted shortcomings in the prototype process, the majority of the samples were not successful. The unsuccessful composites made of bamboo and carbon fiber had tensile strengths that were noticeably less than those reported in previous research. This is also a result of our manufacturing processes. More time to prototype would have allowed us to construct the BFRP using the bottom followed by a 3-point bend inspection to precisely assess the technology behind the bamboo snowboard.

The environmental results were better than anticipated. The energy cost of manufacturing CFRP was calculated to be between 380 and 420 MJ/kg, whereas the energy cost of creating BFRP was 72 MJ/kg. This figure is a key source of inspiration for this endeavor because it is much lower.

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