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Effect of Bamboo Hand Sheet Types on Geometry and Mechanical Properties of the Bamboo Hand Sheet/Green Epoxy Composites Fabricated by Vacuum-Injection Technique

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Keyword: bamboo composite, biodegradable material, composite fabrication, bamboo hand sheet, bamboo fiber, mechanical properties

Abstract

In order to fabricate bamboo hand sheet/Green Epoxy composites (BHGECs), the individual bamboo fibers are extracted by using chemical solutions. The bamboo fibers are then used to make bamboo hand sheet before being combined with Green Epoxy. The compatibility of fiber and matrix is directly affected by the extracted bamboo fiber shape. The objective of this research is to investigate the suitable chemical solution for extracting and forming bamboo fiber as bamboo hand sheet for reinforcing BHGECs. The bamboo strips were cooked with the different chemical solutions (acid 85%, NaOH 1%, NaOH 6%, and NaOH 30%) in the reactor at 120°C for 2 hours. After washing and drying, the cooked bamboo fibers were then formed as the bamboo hand sheet by L'HOMARGY machine. These bamboo hand sheets were then combined with the Infu Green810 (Green Epoxy) by vacuum-injection technique which was developed in this research. The resulting composite materials were tested to derive tensile and bending strength according to ASTM D638 and ASTM D790 respectively. The best mechanical properties are obtained for 6% NaOH-BHGECs since the 6% NaOH bamboo hand sheets correspond to the most homogeneous, the straightest, and the longest bamboo fiber compared to other types of bamboo hand sheets.

Introduction

Composite materials are widely used because of their various mechanical properties [1, 2]. The biodegradability of materials is a factor that must be taken into account, given global warming and the problem of waste management [3]. Therefore, biodegradable and bio sourced composites are currently a very active research topic. Bamboo fiber is one of the most popular natural fibers used for fabricating biodegradable composite because bamboo is one of the fastest-growing tree on the planet [4-8], and bamboo fibers exhibit very high tensile strength (300-500 MPa) [5, 9, 10]. Even though natural fibers are commonly used as reinforcement in composites, the matrix is usually non-natural, so the resulting composite is still a non-biodegradable one [11]. Therefore, in this research, the Infu Green810 (Green Epoxy) was used as a matrix for developing eco-friendly composites.

There is less research on the bamboo fiber/Green Epoxy composites since the Green Epoxy has been developed quite recently [12, 13]. Moreover, the bamboo fibers cannot be directly fabricated with the Green Epoxy since the fibers will be flowed out of mold under the suction of vacuum. Therefore, the bamboo hand sheet is used in this research. The different types of bamboo hand sheet (acid 85%, NaOH 1%, NaOH 6%, and NaOH 30%) are fabricated with the Green Epoxy as composite for investigating the highest mechanical properties of bamboo hand sheet/Green Epoxy composite (BHGECS). Not only mechanical properties of bamboo hand sheet and Green Epoxy determine the mechanical properties of BHGECS, but also the adhesive interfacial bonding between bamboo hand sheet and Green Epoxy [14]. Actually, the best way to know the adhesive interfacial bonding between fiber and matrix is performing pull-out tests [15-17] but the extracted bamboo fiber is really small (20 micro-width and 2 millimeter-length [18]), so it appears to it seems difficult to carry out these tests. Therefore, only composites will be tested for evaluating the tensile strength and the bending strength of BHGECS. A morphological analysis is also conducted to investigate the bamboo fiber shape and the composite structure [11, 19, 20].

The aim of this study is to investigate different bamboo hand sheet types for fabricating BHGECS. The bamboo hand sheet forming, and the composite fabrication will be described in the composite preparation and testing section. The bamboo fiber shape analysis and the

mechanical properties of the different BHGECs will be presented before concluding the work in the last section.

Composite Preparation and Testing

In order to prepare composite, we choose to work with bamboo hand sheet instead of individual fibers because this last option could lead to non-homogeneous repartition of fibers in the final composite, due to the very small size of the fibers [18] and of the free flow of fibers during the injection of . The bamboo hand sheet is suitable for composite fabrication because this type of reinforced material is easy to made and is flexible to applied in the different composite fabrication methods [21].

Bamboo hand sheet forming

In order to make different bamboo hand sheets, the bamboo strips and the chemical solutions were prepared separately before cooking in the reactor. The chemical solutions used in this research (acid 85%, NaOH 1%, NaOH 6%, and NaOH 30%) are mixtures from the chemical substances listed in table 1. The acid 85% solution is the mixture of the formic acid and the acetic acid by the 70:30 ratio with 85% concentration by weight [22]. The NaOH solutions are used because the NaOH solution is the most commonly used chemical solution for extracting the natural fibers [23-25], but the optimum concentration for treating the bamboo fibers is not well-defined. NaOH 6% is used because this treatments provides high tensile strength on the bamboo hand sheets [21]. NaOH 1% solution is the lowest concentration of NaOH used to extract the bamboo fibers and the highest concentration of NaOH used for extracting the natural fibers is 30% [21].

Table 1. The chemical solution substance.

Name	Weight (g)			
	Formic acid	Acetic acid	NaOH	Distilled Water
Acid 85%	525	225	-	250
NaOH 1%	-	-	10	990
NaOH 6%	-	-	60	940
NaOH 30%	-	-	300	700

Rough Giant Bamboo, which growth in Chiang Mai, Thailand, was used in this research. The main components of bamboo wood are cellulose, hemi-cellulose, and lignin which occupy about 40-60%, 22% and 25%, respectively [26]. The bamboo wood was cut into bamboo strips, dried in the oven at 105°C over one night [21] before cooking as shown in figure 1a. A quantity of 100g of bamboo strips was mixed with the chemical solution/bamboo ratio at a weight ratio of 12:1 [21]. The cooking equipment was then closed and boiled in glycerol tank while the inside temperature was kept to 120°C for 2 hours. The equipment was smoothly shaken. After that, the heater was stopped, and the equipment was naturally cooled down until the inside temperature reached 40°C. The cooked bamboo strips were washed under distilled water until pH of wastewater reached 7 [21, 27]. Then, the washed cooked bamboo strips were filtered by 100-micron nylon fabrics, and they were dried over the night at the ambient temperature before being kept in plastic bags [27].

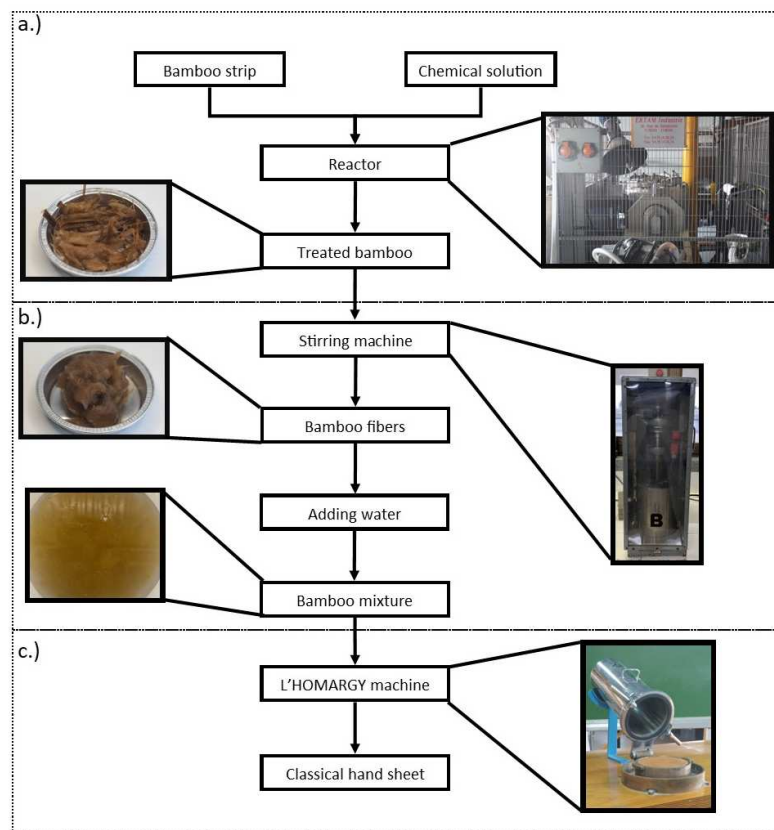


Figure 1. Overall bamboo hand sheet forming a.) bamboo strips cooking process, b.) bamboo fiber extraction, c.) bamboo hand sheet forming

The three samples of cooked bamboo strips were collected for determining the moisture content and the yield value of cooking. The samples were weighed, and they were put in the oven at 105°C over the night [28]. The samples were weighed again for defining the dry mass of sample [29, 30]. The moisture content and the yield value of cooking were calculated according to equation 1 and equation 2, respectively. The moisture content value and yield value of cooking in each case are shown in table 2.

$$\% \text{ Moisture Content} = \left(\frac{M_{wet} - M_{dry}}{M_{dry}} \right) \times 100 \quad (1)$$

$$\% \text{ Yield} = \left(\frac{M_{total \text{ dry final}}}{M_{total \text{ dry begin}}} \right) \times 100 \quad (2)$$

where M_{wet} is the weight of the wet sample, M_{dry} is the weight of the sample after being in the oven over one night, $M_{total \text{ dry final}}$ is the weight of dry bamboo after cooking, $M_{total \text{ dry begin}}$ is the weight of dry bamboo before cooking.

Table 2. The value of moisture contents and yields of cooking in each case.

Treatment	Acid 85%	NaOH 1%	NaOH 6%	NaOH 30%
Moisture Content	72.00%	77.91%	82.82%	86.01%
Yield	83.72%	71.02%	71.45%	67.59%

In order to make bamboo hand sheets, ten grams (dry weight) of the cooked bamboo strips were mixed with water until the total volume was 2 liters. Then, the mixtures were poured into the stirring machine operating at 300 rpm for 10 minutes as shown in figure 1b. After that, the bamboo fibers and the water were mixed until the total bamboo mixture weight was 10 kilograms in order to ensure a good distribution of the fibers in the bamboo hand sheets. Then, L'HOMARGY machine was used to form the hand sheets as shown in figure 1c. The cylinder was opened for installing the 100-micrometer wires as in figure 2a [21]. After that, the cylinder was closed, and the water and the bamboo mixture with the 1:2 ratio was added. For the good distribution of bamboo fibers in the bamboo hand sheets, the water and the bamboo mixture must be added in the following sequence: (1) about 1 liter of water is added from the bottom, (2) 1 liter of bamboo mixture is added from the top of cylinder (3) another 1 liter of water is added

from the bottom as shown in figure 2b. This bamboo mixture was stirred again by a special rod as shown in figure 2c. After that, the mixture was drained through the 100-micrometer wire as shown in figure 2d. The cylinder was opened and the hand sheet which lays on the wire was carefully removed without any pressing as shown in figure 2e. Finally, the hand sheets were dried in the fumes hood over the night [28]. The fiber arrangement in the obtained bamboo hand sheets is anisotropic.

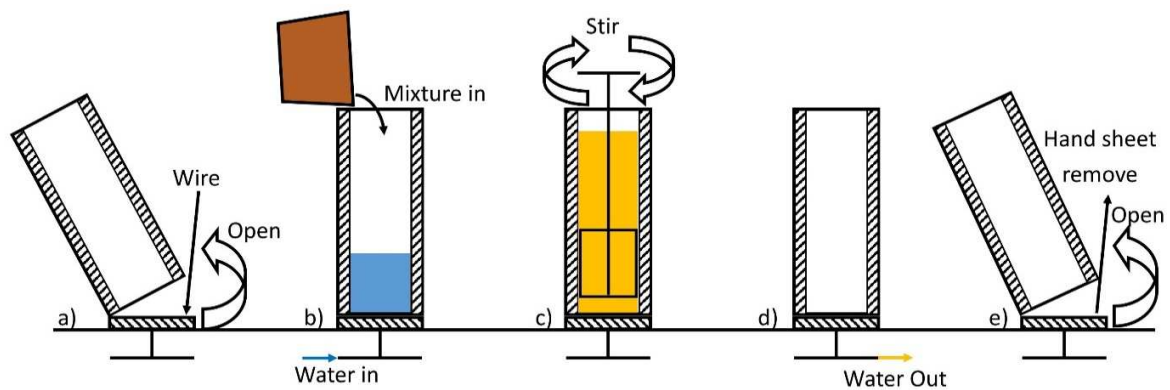


Figure 2. Hand sheet making process by using L'HOMARGY [21].

BHGECs fabrication

In this experiment, the BHGECs are fabricated by the so-called vacuum-injection technique. Note that the vacuum-injection is derived from the Seeman composites resin infusion molding process [1]. The normal vacuum-injection method is not operable directly in this experiment due to the heterogeneity of bamboo hand sheet, which affect to the Green Epoxy flow [27]. Moreover, the fiber arrangement in bamboo hand sheets is anisotropic, some fibers which arranged in perpendicular direction of Green Epoxy flow could block the resin flow, and gaps could occur behind the fibers. Therefore, the funnel-tap technique, developed by the laboratory, is used for injecting Green Epoxy through the bamboo hand sheets.

The bamboo hand sheets were weighted, and their thickness was measured before calculating the grammage of bamboo hand sheets. The total grammage of each hand sheet's group must be around 150 g/m². Then, six groups of bamboo hand sheets were put on a Teflon plate as shown

in figure 3a. A spiral tube, used to produce the vacuum, was stuck around a Teflon area. The bamboo hand sheets were set in a hexagonal shape, as shown in figure 3a. To ensure an homogeneous flowing of Green Epoxy, a hexagonal mesh was installed over the bamboo hand sheets. An orange plug was put in the center of the mesh for injection of the Green Epoxy. Then a plastic wrap covered all over the equipment for generating the vacuum. A vacuum pump was then connected to the equipment by a yellow plug. Note that the system was accurately controlled for avoiding air-leak. A funnel was then put to an orange plug while a tap was closed. The Green Epoxy (Infu Green810) was mixed homogeneously with the hardener (SD8824) by using the ratio 100:22 w/w. Then, the resin mixture without air bubbles was poured into a funnel. After that, a funnel tap was opened carefully to prevent the splashing of resin. The resin mixture was then flowed through the mash and was absorbed through the bamboo hand sheets as shown in figure 3b. After the resin mixture absorbed through all the bamboo hand sheet, all taps and the vacuum pump were closed. The system was then left over two days for hardening. After that, the plastic wrap was removed. The bamboo composites, as shown in figure 3c, were peeled off, weighed, and their thickness measured. The density of each composite type was then calculated and is given in table 3. It can be observed that the density of all BHGECs is quite similar because the grammage of the bamboo hand sheet in each case was already averaged for preventing the influence of the fiber-resin ratio, since the fiber-resin ratio cannot be monitored in the vacuum-injection technique . Note that, the Green Epoxy was flown over the bamboo hand sheet by the vacuum suction power. The excess of resin was sucked out of the bamboo hand sheet. Therefore, the BHGECs fabricated by vacuum-injection technique have a similar fiber-resin ratio.

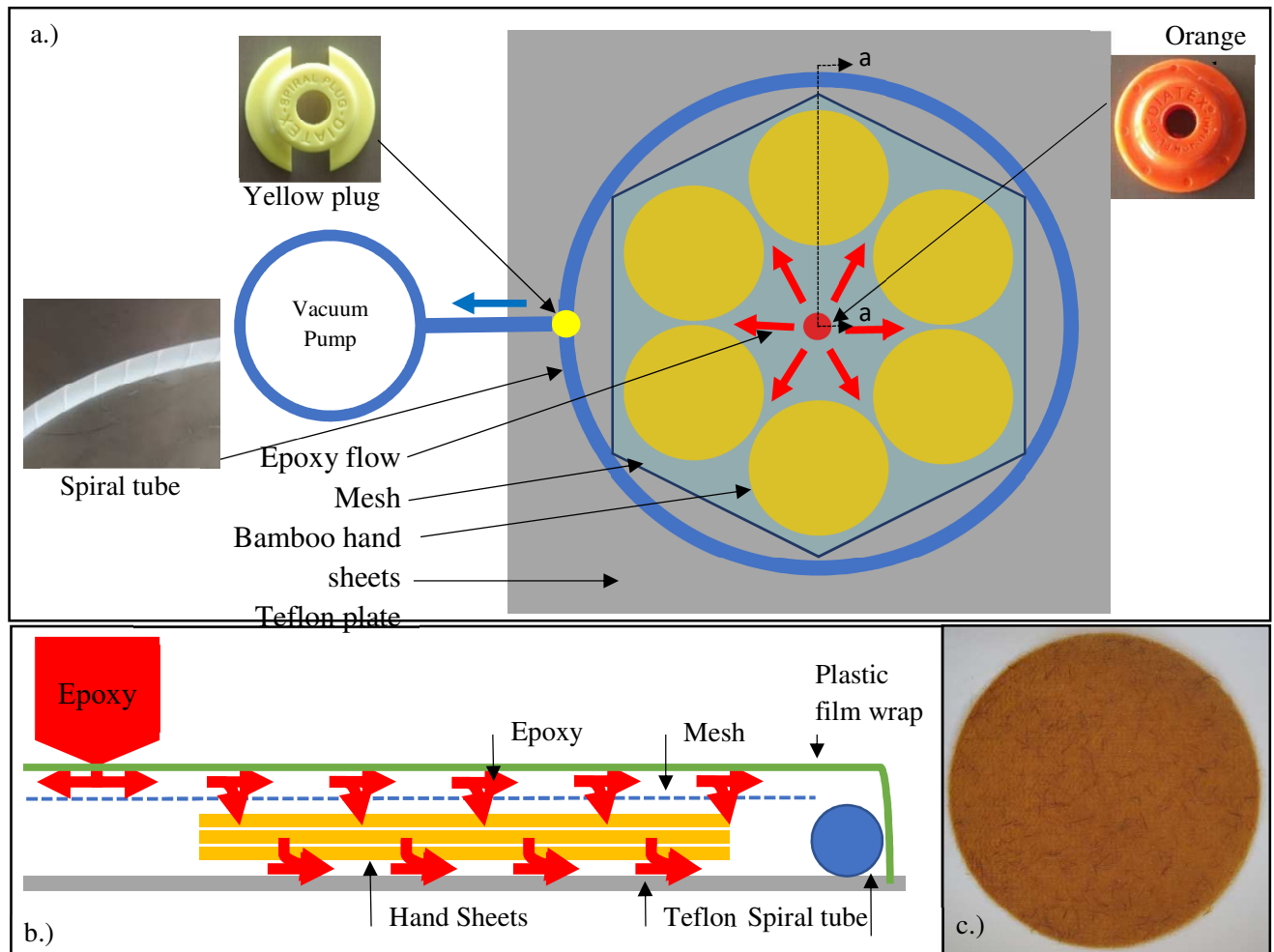


Figure 3. a.) Equipment setup for a fabrication of random BHGECs, b.) Resin flow diagram on one piece of composite cross-section (section a-a), c.) Sample of random-BHGECs fabricated by an injection technic

Table 3. An average density of BHGECs with different treatment processes of the bamboo fiber.

Composite types	Acid 85%	NaOH 1%	NaOH 6%	NaOH 30%
Density (kg/m ³)	1056.13 ± 54.42	1083.15 ± 52.96	1103.79 ± 19.52	1074.80 ± 33.09

The BHGECs were then cut in two different shapes by a Roland MDX-40A milling machine [31] to provide samples for tensile and bending test. For the tensile test, the size of the sample is determined by ASTM D638 as shown in figure 4 [32-35]. For the bending test, the samples

shape is rectangular, as shown in figure 5, [33, 36, 37] and according to ASTM D790. The tensile and bending results of each type of BHGECs were averaged from at least 5 samples.

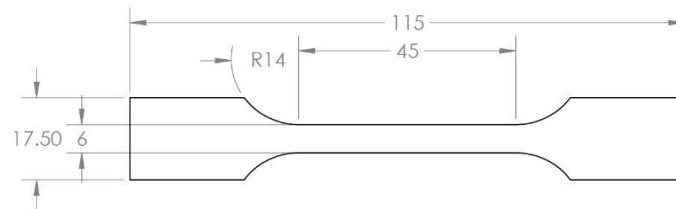


Figure 4. Dimensions of BHGECs sample for the tensile test.

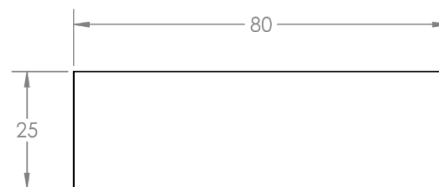


Figure 5. Dimensions of BHGECs sample for the bending test.

Results and Discussion

The chemical treatment used in the cooking process directly affects the shape of bamboo fiber which impacts the tensile strength of fibers and the compatibility between fiber and matrix. Therefore, this topic will be separated into two sections which deal with bamboo fiber shape and mechanical properties of BHGECs.

Bamboo fiber shape

The bamboo fiber shapes were analyzed by the MorFi analyzer, which is developed by LGP2 laboratory, Grenoble, France [38]. Four interesting parameters are derived from this analysis which are the number of fine contents, the fiber width, the fiber length, and the percentage of kinked fibers [39, 40]. All the morphology analysis results are shown in table 4. First, the number of fine contents is the quantity of the 200-micrometer diameter fiber in one gram of pulp. This number directly affects the quantity of the fibers contained in the hand sheets. The numbers of fine contents from the different cooking treatments are almost the same and about 4 million

fibers/1 gram of pulp. The second factor is the width of individual fibers. The result shows that bamboo fibers have similar width around 20 micrometers although they were cooked using different treatments. The third factor is the fiber length. Greater length of fiber can provide a higher ultimate tensile strength value of the BHGECs. The result shows that good cooking treatments correspond to the low concentrations of NaOH (1%, and 6%). The bamboo fiber length values are around 1500-micrometers even if they were cooked in different low concentrations of NaOH. On the other hand, the bamboo fiber length was approximately 1300 micrometers and 1200-micrometers for the acid 85% solution and NaOH 30% solution, respectively. The other important factor is the kinked fibers content that shows the percentage of kinked fibers in overall mixture. The large number of this value means that bamboo fibers in the mixture are kinked, and the tensile strength of the bamboo hand sheet is less. The results show that cooking bamboo strips in acid solution, and low concentration of NaOH (1%, and 6%) produces similar kinked fibers content value which are less than 10%. On the other hand, cooking bamboo in 30% NaOH produces more than 30% kinked fibers content value. Moreover, the acid solution not only eliminated the weakness part of fiber (the wax, the hemicellulose, the lignin, etc.) but also destroys the cellulose (as shown in figure 6) which is the main part to resist a tensile force.

Table 4. Morphology analysis result.

Treatment	Acid 85%	NaOH 1%	NaOH 6%	NaOH 30%
Fine Content (millions/g of pulp)	3.8 ± 0.2	4.3 ± 0.1	4.6 ± 0.0	4.1 ± 0.0
Width (µm)	20.5 ± 0.1	21.6 ± 0.1	20.5 ± 0.1	20.8 ± 0.0
Length (µm)	1362 ± 17	1471 ± 25	1509 ± 19	1261 ± 26
Kinked Fibers Content (%)	5.4 ± 0.2	7.4 ± 0.2	9.2 ± 0.5	31.8 ± 0.0

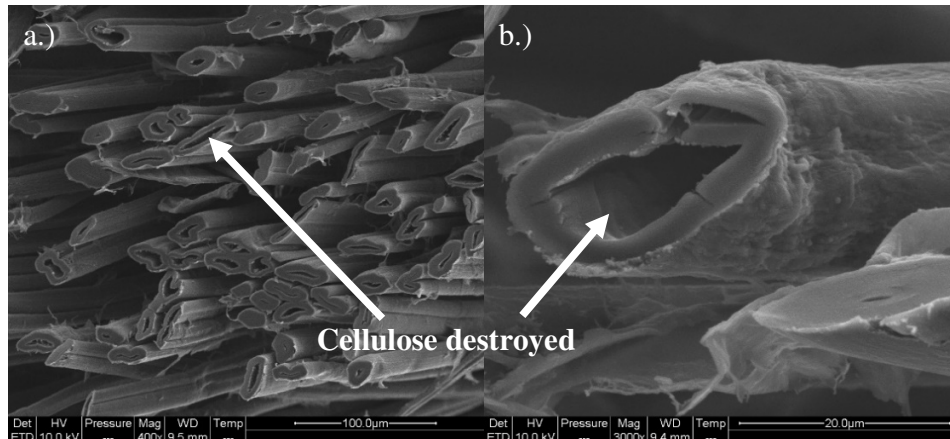


Figure 6. SEM cross-section photo of acid 85% bamboo hand sheet a.) at 400X, b.) at 3000X

Mechanical Properties of BHGECs

All the BHGECs were tested to derive tensile strength and bending strength according to ASTM D638 and ASTM D790 respectively. The composites were constantly stretched until they were broken, which is consistent with other research works [32, 41, 42]. The configuration of all damaged composites are similar as shown in figure 7a and 7b. All the BHGECs mechanical properties are compared with the pure Green Epoxy's mechanical properties values as shows in figure 7c. The tensile strength, the bending strength, the Young's modulus obtained from tensile test, and the Young's modulus obtained from bending test have the same tendency. The mechanical properties are close to the pure Green Epoxy's values in case of the acid-BHGECs, and the 30% NaOH-BHGECs. On the other hand, the values are greater for the 1% NaOH-BHGECs. The best mechanical properties are provided by 6% NaOH-BHGECs.

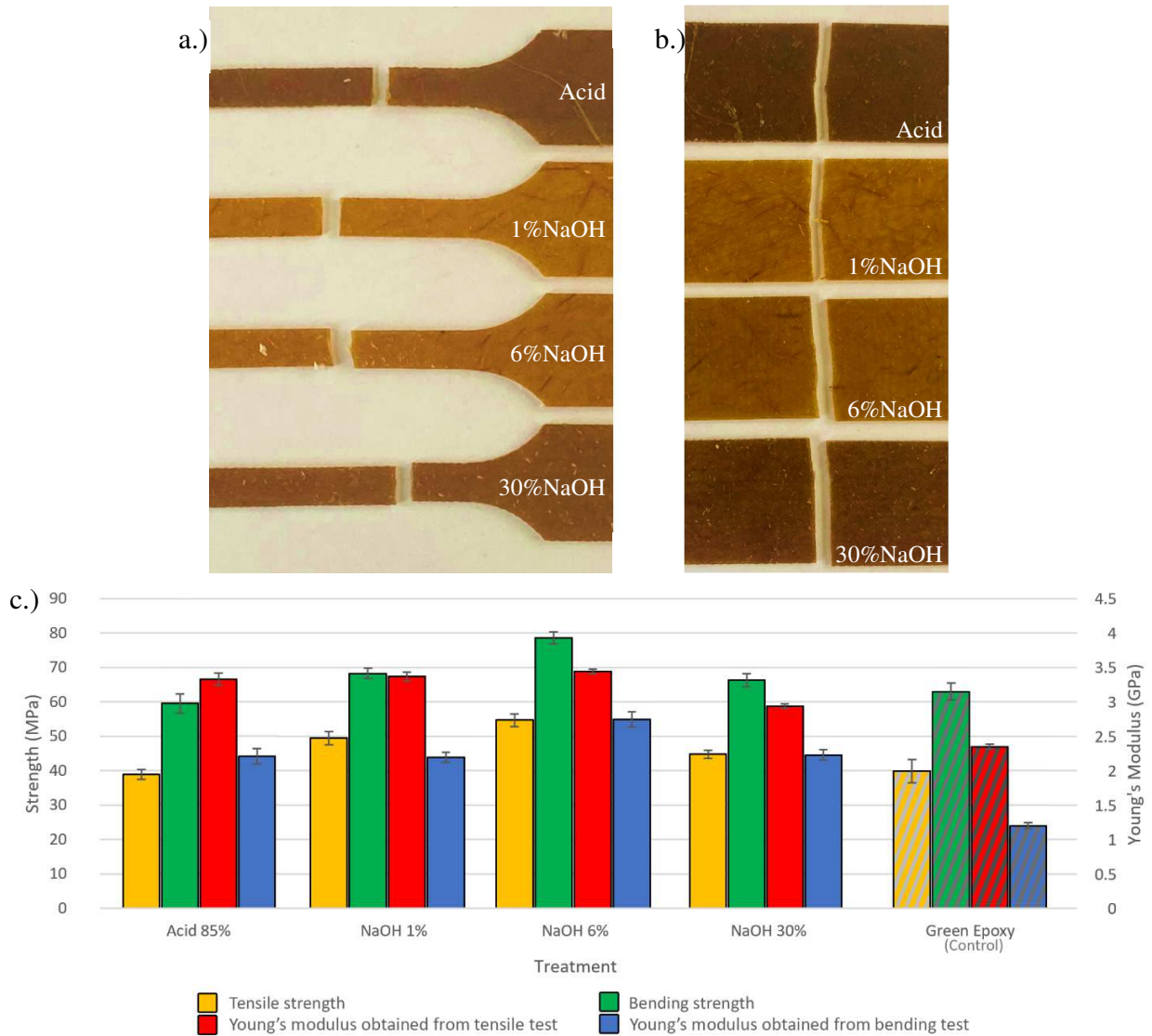


Figure 7. a.) Tensile breaking section of BHGECs b.) Bending breaking section of BHGECs
c.) Effect of chemical treatment processes of fibers on mechanical properties of BHGECs.

Focusing on the ultimate tensile strength, the acid-BHGECs have lower ultimate tensile strength than the pure Green Epoxy result. This phenomenon infers that hand sheet obtained from the acid bamboo fiber is not proper to be reinforcement in the composite material. The reason is the acid hand sheet was compounded with multi variant size of bamboo fiber as shown in figure 8a which affects the compatibility between fiber and matrix. Moreover, in the bamboo fiber contained in acid-BHGECs the cellulose was eliminated by acid [43] as shown in figure 6. On the other hand, the NaOH-BHGECs present a similar result of the ultimate tensile strength which is greater than

the ultimate tensile strength of the pure Green Epoxy. It can infer that the NaOH hand sheets are capable to reinforce the BHGECs. The reason is the NaOH-bamboo hand sheets are more homogeneous than the acid one, so the NaOH-BHGECs were more homogenized as shows in figure 8b-c. Moreover, in the bamboo fibers contained in NaOH-bamboo hand sheets the cellulose has not been destroyed. However, the ultimate tensile strength of the 30% NaOH-BHGECs is lower than the others (NaOH 1%, and NaOH 6% bamboo hand sheets) because bamboo fiber in NaOH 30% bamboo hand sheet is too short and kink as shows in figure 8d. For 1% NaOH-BHGECs, the weak parts of bamboo components (hemicellulose, wax, etc.) were not completely eliminated, and those components limit the reinforcement between fiber and matrix.

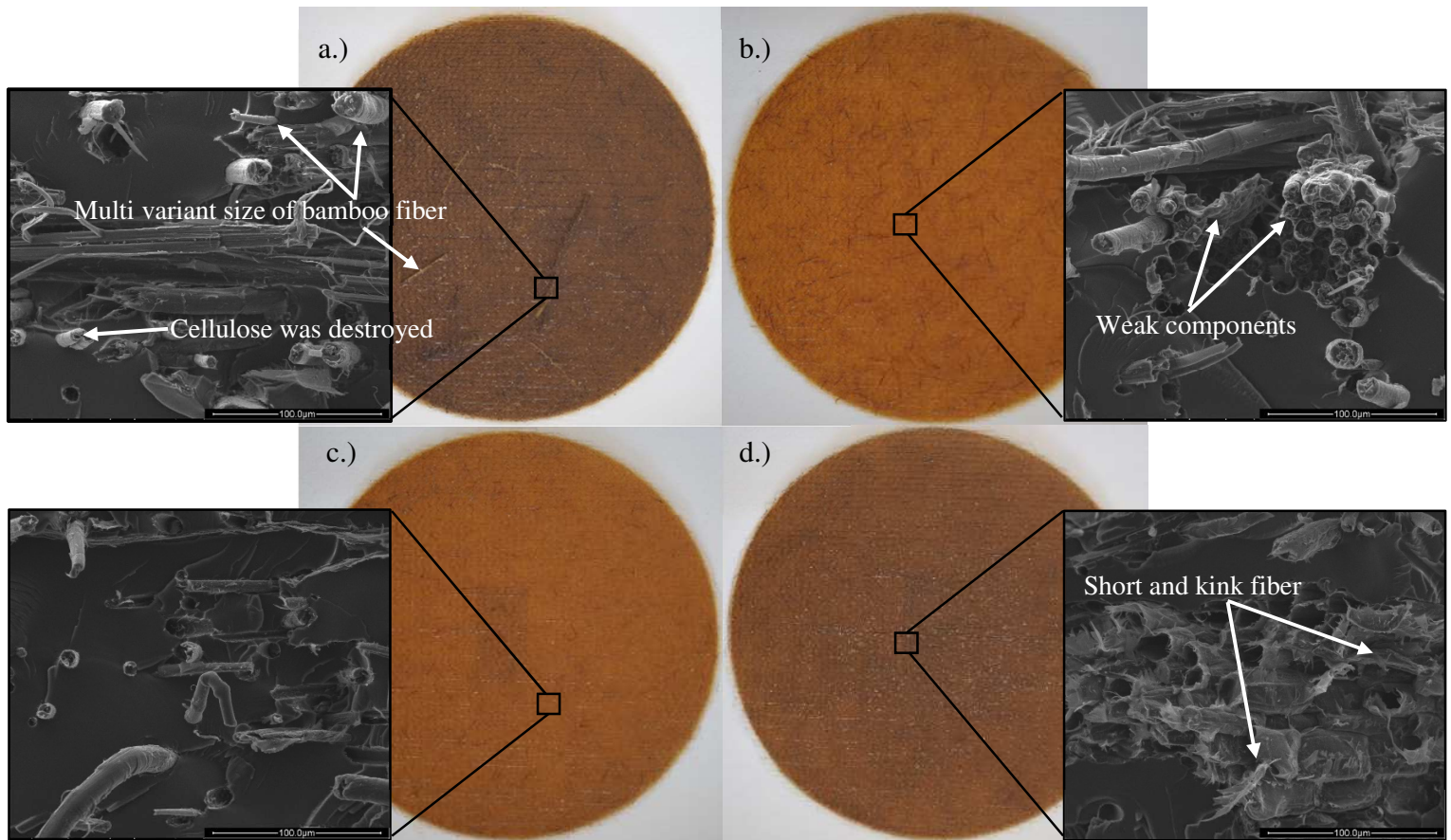


Figure 8. BHGECs fabricated with different bamboo hand sheets and their SEM at 600X. a.) Acid 85%, b.) NaOH 1%, c.) NaOH 6%, d.) NaOH 30%.

Concerning the bending tests, the Green Epoxy is coated all around the composite skin, so the bending strength of BHGECs is mostly determined by the bending strength of Green Epoxy [36, 44, 45]. Due to the fact that the first cracking point of the composite almost locates on the outside skin of composite, the proper hand sheet should have less kink fiber and regular fibers dispersion. The acid-BHGECs, and 30% NaOH BHGECs provide the same range of bending strength as the pure Green Epoxy. It means that those bamboo hand sheets are not reinforcing BHGECs. In addition, for acid-BHGECs, the fibers are not dispersed in the composite skin as shown in figure 9a. In the case of 30% NaOH-BHGECs the fibers are too short as shown in figure 8d and 9d. On the other hand, NaOH 1%, and NaOH 6% bamboo hand sheets produce a significant reinforcement in BHGECs thanks to the regularity of bamboo hand sheets. This affects the compatibility between fiber and matrix due to the higher increment of the contact area compared with acid-BHGECs and 30% NaOH-BHGECs. Moreover, the fibers contained in NaOH 1%, and NaOH 6% bamboo hand sheets are long enough for absorbing bending forces as show in figure 9b and 9c.

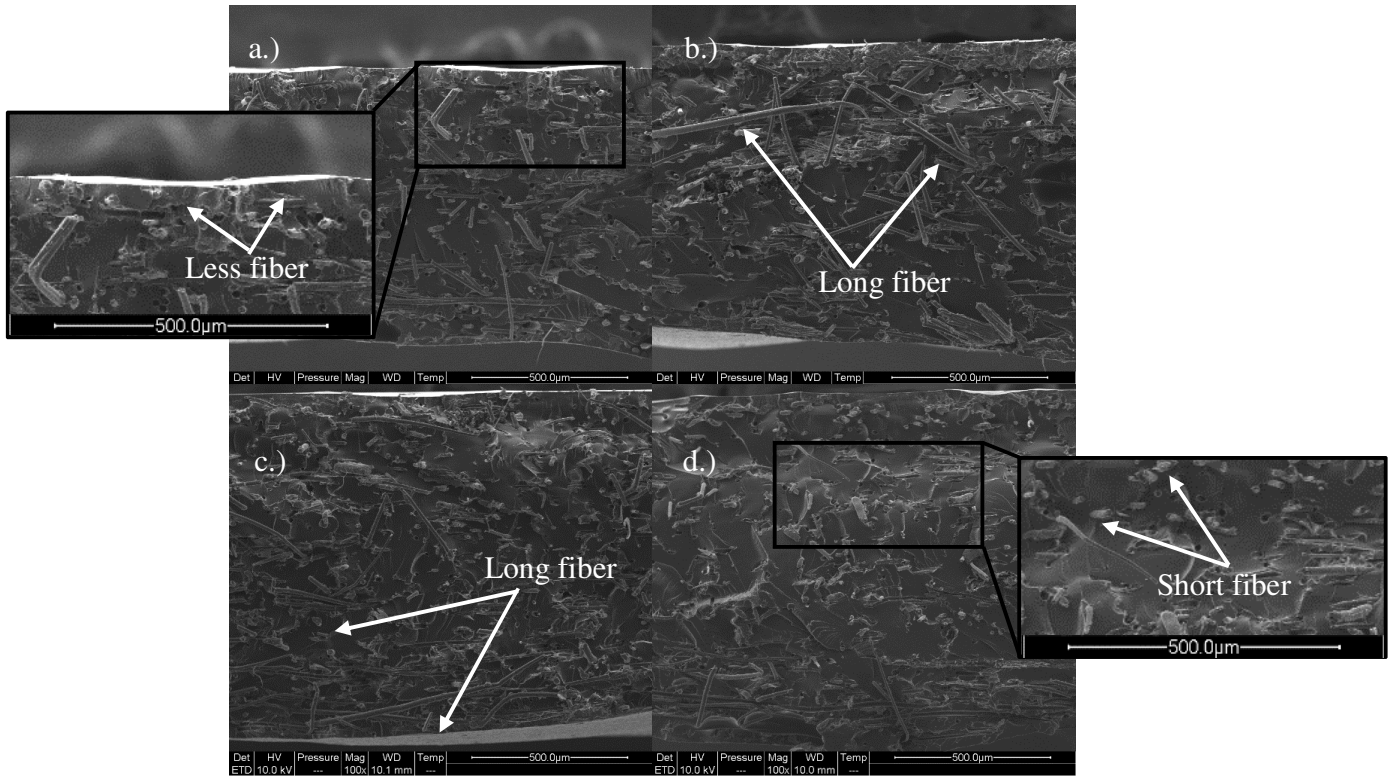


Figure 9. SEM photo of cross-sectional BHGECs at 100X.

a.) Acid 85%, b.) NaOH 1%, c.) NaOH 6%, d.) NaOH 30%

Focusing on Young's modulus obtained from tensile test, the Young's modulus of all BHGECs has higher values than pure Green Epoxy one, which shows that all BHGECs are reinforced by all types of bamboo hand sheets. The Young's modulus values of acid-BHGECs, 1% NaOH-BHGECs, and 6% NaOH-BHGECs are in the same range. On the other hand, Young's modulus obtained from tensile test of 30% NaOH-BHGECs is slightly reduced compared to other composites since there are too much short and kink fibers as shown in figure 9d.

It is observed that all BHGECs provide a value for the Young's modulus in bending test which is twice as large as the pure Green Epoxy one. In detail, acid-BHGECs, 1% NaOH-BHGECs, and 30% NaOH-BHGECs provide the same range of Young's modulus obtained from bending test. On the other hand, the 6% NaOH bamboo hand sheet produces a better Young's modulus than the one obtained from bending strength because the fibers obtained in 6% NaOH bamboo hand sheets are more homogeneous, their shape is straight and longer compare with others bamboo hand sheet types.

Conclusion

The BHGECs were fabricated by a specific vacuum-injection technique developed in this research. Different types of bamboo hand sheet (acid, 1% NaOH, 6% NaOH, and 30% NaOH) were used as reinforcement part and Green Epoxy (Infu Green810) was used as matrix part. Funnel, taps, and spiral tube were used for equal flow of Green Epoxy. Tensile and bending tests according to ASTM D638 and ASTM D790 respectively were performed to determine the mechanical properties of BHGECs. Moreover, MorFi analyzer and SEM were used to investigate the bamboo fiber shape and geometry of the BHGECs. The best mechanical properties were found for 6% NaOH-BHGECs. The reasons are (1) the bamboo fiber shape obtained in 6% NaOH bamboo hand sheet is homogeneous, straight, and long leading to good mechanical properties of composite, (2) the bamboo fibers are evenly distributed in 6% NaOH-BHGECs.

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Reference

- [1] R. F. Gibson, *Principles of composite material mechanics*, Fourth edition. ed. (Mechanical engineering : a series of textbooks and reference books). Boca Raton: CRC Press, Taylor & Francis Group, 2016.
- [2] P. K. Mallick, *Fiber-reinforced composites : materials, manufacturing, and design*, 2nd ed., rev. and expanded. ed. (Mechanical engineering ; 83). New York: M. Dekker, 1993.
- [3] A. K. Mohanty, M. Misra, and G. Hinrichsen, "Biofibres, biodegradable polymers and biocomposites: An overview," *Macromolecular Materials and Engineering*, [https://doi.org/10.1002/\(SICI\)1439-2054\(20000301\)276:1<1::AID-MAME1>3.0.CO;2-W](https://doi.org/10.1002/(SICI)1439-2054(20000301)276:1<1::AID-MAME1>3.0.CO;2-W) vol. 276-277, no. 1, pp. 1-24, 2000/03/01 2000.
- [4] H. Zhang, J. Liu, Z. Wang, and X. Lu, "Mechanical and thermal properties of small diameter original bamboo reinforced extruded particleboard," *Materials Letters*, vol. 100, pp. 204-206, 2013.

- [5] K.-t. Lau, P.-y. Hung, M.-H. Zhu, and D. Hui, "Properties of natural fibre composites for structural engineering applications," *Composites Part B: Engineering*, vol. 136, pp. 222-233, 2018.
- [6] J. K. Kim and K. Pal, *Recent advances in the processing of wood-plastic composites*. Heidelberg: Springer, Berlin, Heidelberg, 2010, p. 176.
- [7] X. Wei, G. Wang, L. M. Smith, and H. Jiang, "The hygroscopicity of moso bamboo (*Phyllostachys edulis*) with a gradient fiber structure," *Journal of Materials Research and Technology*, vol. 15, pp. 4309-4316, 2021/11/01/ 2021.
- [8] Z. Lou *et al.*, "Nano-Fe₃O₄/bamboo bundles/phenolic resin oriented recombination ternary composite with enhanced multiple functions," *Composites Part B: Engineering*, vol. 226, p. 109335, 2021/12/01/ 2021.
- [9] J. Kaima, I. Preechawuttipong, P. Jongchansitto, and N. Charoenloe, "Effect of Chemical Solution on Tensile Strength of Bamboo Fiber," *IOP Conference Series: Materials Science and Engineering*, vol. 886, p. 012061, 07/28 2020.
- [10] Y. Wu, Y. Zheng, F. Yang, and L. Yang, "Preparation process and characterization of mechanical properties of twisted bamboo spun fiber bundles," *Journal of Materials Research and Technology*, vol. 14, pp. 2131-2139, 2021/09/01/ 2021.
- [11] Z. Lou *et al.*, "Fabrication of Crack-Free Flattened Bamboo and Its Macro-/Micro-Morphological and Mechanical Properties," *Journal of Renewable Materials*, vol. 9, no. 5, 2021.
- [12] S. Rwawiire, B. Tomkova, J. Militky, A. Jabbar, and B. M. Kale, "Development of a biocomposite based on green epoxy polymer and natural cellulose fabric (bark cloth) for automotive instrument panel applications," *Composites Part B: Engineering*, vol. 81, pp. 149-157, 2015.
- [13] M. D. M. Lopes *et al.*, "Natural based polyurethane matrix composites reinforced with bamboo fiber waste for use as oriented strand board," *Journal of Materials Research and Technology*, vol. 12, pp. 2317-2324, 2021/05/01/ 2021.
- [14] X. Gao, D. Zhu, S. Fan, M. Z. Rahman, S. Guo, and F. Chen, "Structural and mechanical properties of bamboo fiber bundle and fiber/bundle reinforced composites: a review," *Journal of Materials Research and Technology*, vol. 19, pp. 1162-1190, 2022/07/01/ 2022.
- [15] G. Desarmot and J.-P. Favre, "Advances in pull-out testing and data analysis," *Composites Science Technology*, vol. 42, no. 1-3, pp. 151-187, 1991.
- [16] A. Javadian, M. Wielopolski, I. F. C. Smith, and D. E. Hebel, "Bond-behavior study of newly developed bamboo-composite reinforcement in concrete," *Construction and Building Materials*, vol. 122, pp. 110-117, 2016/09/30/ 2016.

- [17] A. Patrikis, M. Andrews, and R. Young, "Analysis of the single-fibre pull-out test by the use of Raman spectroscopy. Part I: pull-out of aramid fibres from an epoxy resin," *J Composites Part A: Applied Science*, vol. 52, no. 3, pp. 387-396, 1994.
- [18] H. Chen *et al.*, "Effect of alkali treatment on microstructure and mechanical properties of individual bamboo fibers," *Cellulose*, vol. 24, pp. 1-15, 01/01 2017.
- [19] R. Aguado, A. Moral, P. López, P. Mutjé, and A. Tijero, "Morphological analysis of pulps from orange tree trimmings and its relation to mechanical properties," *Measurement*, vol. 93, pp. 319-326, 2016/11/01/ 2016.
- [20] V. da Costa Correia, F. M. Siqueira, R. Donizetti Dias, and H. Savastano, "Macro, Micro and Nanoscale Bamboo Fiber as a Potential Reinforcement for Composites," *Key Engineering Materials*, vol. 668, pp. 11-16, 2016.
- [21] J. Kaima *et al.*, "Effect of NaOH concentration on tensile strength of bamboo hand sheet," (in English), *Materials Science Forum*, vol. 1067, pp. 113-118, 2022.
- [22] M. El Boustani, G. Lebrun, F. Brouillette, and A. Belfkira, "Effect of a solvent-free acetylation treatment on reinforcements permeability and tensile behaviour of flax/epoxy and flax/wood fibre/epoxy composites," *The Canadian Journal of Chemical Engineering*, vol. 95, no. 6, pp. 1082-1092, 2017.
- [23] D. Liu, J. Song, D. P. Anderson, P. R. Chang, and Y. Hua, "Bamboo fiber and its reinforced composites: structure and properties," *Cellulose*, vol. 19, no. 5, pp. 1449-1480, 2012.
- [24] O. Balogun, J. A. Omotoyinbo, K. Alaneme, and B. Babalola, "The Effect Of Chemical Treatment On Tensile Properties Of Soil Retted Entada Mannii Fibres," *American Journal of Engineering Research*, vol. 4, 09/01 2015.
- [25] Z. Lou *et al.*, "Bamboo flattening technique: a literature and patent review," *European Journal of Wood and Wood Products*, vol. 79, no. 5, pp. 1035-1048, 2021/09/01 2021.
- [26] H. Sun, X. Li, H. Li, D. Hui, M. Gaff, and R. Lorenzo, "Nanotechnology application on bamboo materials: A review," vol. 11, no. 1, pp. 1670-1695, 2022.
- [27] J. Kaima *et al.*, "Tensile Strength Enhancement of the Bamboo Fiber Hand Sheet by Fiber Arrangement," *Materials Science Forum*, vol. 1069, pp. 31-36, 2022.
- [28] A. Morais, P. Abreu, W. Wasielesky, and D. Krummenauer, "Morais et al. 2020," 02/17 2020.
- [29] K. Y. Park, D. Y. Kwon, K. W. Lee, and S. Park, *Korean Functional Foods: Composition, Processing and Health Benefits*. CRC Press, 2018.

- [30] Y. Pomeranz and C. E. Meloan, "Determination of Moisture," in *Food Analysis: Theory and Practice*, Y. Pomeranz and C. E. Meloan, Eds. Boston, MA: Springer US, 1994, pp. 575-601.
- [31] A. Makris and I. Ntintakis, "Toolpath generation and optimization of machining of pine wood surfaces," presented at the Innovation in Forestry Industry and Engineering Design, Sofia, 2019.
- [32] Y. Cao and Y.-q. Wu, "Evaluation of statistical strength of bamboo fiber and mechanical properties of fiber reinforced green composites," *Journal of Central South University of Technology*, vol. 15, no. 1, pp. 564-567, 2008/09/01 2008.
- [33] S. Jain, R. Kumar, and U. C. Jindal, "Mechanical behaviour of bamboo and bamboo composite," *Journal of Materials Science*, vol. 27, no. 17, pp. 4598-4604, 1992/09/01 1992.
- [34] W. Jordan and P. Chester, "Improving the Properties of Banana Fiber Reinforced Polymeric Composites by Treating the Fibers," *Procedia Engineering*, vol. 200, pp. 283-289, 2017/01/01/ 2017.
- [35] S. Ochi, "Tensile Properties of Bamboo Fiber Reinforced Biodegradable Plastics," *International Journal of Composite Materials*, vol. 2, no. 1, pp. 1-4, 2012.
- [36] F. Mujika, N. Carbajal, A. Arrese, and I. Mondragon, "Determination of tensile and compressive moduli by flexural tests," *Polymer Testing*, vol. 25, no. 6, pp. 766-771, 2006/09/01/ 2006.
- [37] Y. Yu, H. Wang, F. Lu, G. Tian, and J. Lin, "Bamboo fibers for composite applications: a mechanical and morphological investigation," *Journal of Materials Science*, vol. 49, no. 6, pp. 2559-2566, 2014/03/01 2014.
- [38] G. Tourtollet, F. Cottin, A. Cochaux, and M. Petit-Conil, "The use of MorFi analyser to characterise mechanical pulps," presented at the International Mechanical Pulping Conference, Québec City, Canada, June 2-5, 2003.
- [39] J. Li, J. Hu, S. Li, J. Li, and J. Liu, "The effect of guar gum and chitosan on fiber and fiber fine micromorphology in paper-process reconstituted tobacco pulp," *Carbohydrate Polymers*, vol. 196, 05/01 2018.
- [40] J. Kaima *et al.*, "Bio-based composites made from bamboo fibers with high lignin contents: a multiscale analysis," in *7th EPNOE-International Polysaccharide Conference*, 2021.
- [41] P. A. Bonnet-Masimbert, F. Gauvin, H. J. H. Brouwers, and S. Amziane, "Study of modifications on the chemical and mechanical compatibility between cement matrix and oil palm fibres," *Results in Engineering*, vol. 7, p. 100150, 2020/09/01/ 2020.

- [42] H. Ku, H. Wang, N. Pattarachaiyakoo, and M. Trada, "A review on the tensile properties of natural fiber reinforced polymer composites," *Composites Part B: Engineering*, vol. 42, no. 4, pp. 856-873, 2011.
- [43] R. M. Sheltami, I. Abdullah, I. Ahmad, A. Dufresne, and H. Kargarzadeh, "Extraction of cellulose nanocrystals from mengkuang leaves (*Pandanus tectorius*)," *Carbohydrate Polymers*, vol. 88, no. 2, pp. 772-779, 2012/04/02/ 2012.
- [44] S. Cao, G. Xue, and E. Yilmaz, "Flexural Behavior of Fiber Reinforced Cemented Tailings Backfill Under Three-Point Bending," *IEEE Access*, vol. 7, pp. 139317-139328, 2019.
- [45] Y. Kubojima, T. Okano, and M. Ohta, "Bending strength and toughness of heat-treated wood," *Journal of Wood Science*, vol. 46, no. 1, pp. 8-15, 2000/02/01 2000.