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ENHANCED MECHANICAL PROPERTIES OF NATURAL FIBER BAMBOO/ PINEAPPLE LEAF/ COCONUT HUSK REINFORCED COMPOSITES FOR APPLICATION IN BIO-BOARD

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ABSTRACT: In this work, an experimental study of the behaviour of bamboo fiber/pineapple leaves/coconut fiber reinforced with epoxy resin is presented. The properties of the material were tested using a universal testing machine and crack surface structure through scanning optical and electron microscopy with the material combined with epoxy resin to become a hybrid composite material to determine the best characteristics of the tensile test properties treated with 6%. NaOH on every fiber. The results showed that the fiber mixture between bamboo/pineapple leaves and coconut fiber showed an increased tensile strength of 304.7 MPa compared to bamboo/pineapple leaves and 293.6 MPa compared to pineapple/coconut fiber leaves 268.2 MPa and the lowest Polyester was 109 MPa. The morphological appearance of each combined fiber brings diffusion of the polymer matrix to the porous fiber surface where the polymer matrix is compacted in a strong bond, causing the presence of bamboo fibers that have a high cellulose content which can replace apple failure. Pine leaves and coconut fiber and make hybrid composites not only as a strong material but also biodegradable.

Keywords: Flexural Strength; Hybrid Composite; Natural Fiber; Scanning Electron Microscope; Tensile Strength

1. INTRODUCTION

Recent research shows that composites added with natural fibers are more environmentally friendly compared to the addition of other synthetic fibers because they cause environmental pollution [1]. Composites from natural fibers are now considered the most promising materials in society because of their unique mechanical properties, abundant raw material availability can be biodegradable [2,3] and reduce the drastic effects of global warming [4]. Previous studies have shown that there is increasing interest in developing biodegradable reinforced polymer fiber reinforced composites (BFRP) as a substitute for conventional materials, especially in the automotive, marine, packaging, furniture and building construction industries [5-7]. The production of natural fibers from composite materials is very attractive and can be widely applied, due to the problem of global warming and reduced availability of petroleum. Natural fibers play an important role in developing biodegradable composites to solve ecological and environmental problems [8-10]. Lignocellulose (plant fiber) is also known as fiber that comes from every part of the plant such as bark [11], wood [12,13], leaves [14-16], seeds [17,18], fruit [19], vegetables [20], straw [21,22], bagasse [23], roots [24], and so on [25].

There are many natural fibers such as bamboo, hemp, sisal, pineapple, abaca and coir which have been considered as reinforcement and fillers in composites. Therefore, the facility uses bamboo as a filler because the plant can grow quickly, thus potentially becoming an abundant source of fiber that belongs to the Bambusae family, under the genus Gramineae [26]. Today many products use bamboo as a common material such as food containers, skewers, chopsticks, handicrafts, toys, furniture, floors, pulp and paper, ships, charcoal, musical instruments, weapons, bicycles, air balloons, windmills, scales, anchoring walls, ropes and cables [27-29], another source of cellulose is pineapple leaf fiber (pineapple leaf fiber), which is relatively inexpensive and widely available which has the potential to strengthen polymer composites [30]. Coconut coir is one of the outer parts surrounding the coconut shell and the coarse coconut coir contains dienriched with lignocellulose [31]. This fiber is widely used to make various kinds of flooring, furniture, yarn, rope and others [32]. Therefore, further research and development of these materials to produce the latest polymer sources include the use of coir as an amplifier in polymer composites.

Many materials are used as composite reinforcement and among them, the natural fibrous deserves attention. Indeed, due to its low thickness,

2. EXPERIMENTAL

2.1 Materials

In this study bamboo fibers, pineapple leaves and coconut fiber are used to make composite specimens. Bamboo fiber, pineapple leaves and coconut fiber are obtained from North Aceh. Isofalatine polyester resin and methyl ethyl ketone peroxide (MEKP) catalyst obtained from Sigma Aldrich. The accelerator used for the investigation is Cobalt Naphthenate and added 1% to the resin and catalyst.

2.2 Treatment of Fiber

The chemical treatment used has the aim of activating several hydroxyl groups wherein the fiber structure there are cellulose and lignin and may be involved in hydrogen bonding. With this procedure, the weakening of hydrogen bonds occurs in the molecular structure of cellulose, which presents itself as a net, which leads to an increase in the amount of amorphous cellulose. Because this chemical treatment occurs in the presence of water, the cellulose structure modifies its crystalline structure from monoclinic to polymorphic and hence swells. In addition, the mercerisation process promotes the dissolution of hemicellulose (dissolved in very low alkaline concentrations) and lignin (basic hydrolysis), two constituents of lignocellulosic fibers. This process increases the surface roughness of the fiber and improves mechanical retention [36].

Bamboo fiber is extracted by cutting it into small pieces with a shredder to get bamboo powder. Wash bamboo powder using water then immersed in a sodium hydroxide (NaOH) at a concentration of 6% volume of water for 3 hours at room temperature. Then the fiber is washed twice with water. The fibers are dried at room temperature for 8 hours. Fibers are stored in plastic bags to avoid atmospheric moisture contamination before the formation of composites.

Pineapple leaves are put into the decertification machine to get the fiber and then the fiber is cut into small pieces. The fiber is then soaked in a 5% NaOH solution for 1 hour at room temperature. The last fiber is rinsed several times, then dried at room temperature for 48 hours.

Coconut fiber is washed with water and dried. Then the fiber is cut short. The powdered fiber is soaked in 5% NaOH solution for 2 hours. The fiber is then washed with water to remove the excess NaOH attached to the fiber. Coir fibers are dried at room temperature for 3 hours for the formation of composites.

Based on the origin of natural fibers composed of plant, animal, or mineral fibers. According to some studies, among the most popular natural fibers are plant fibers that are used as reinforcement in fibre-reinforced composites. Plant fibers such as bamboo, sisal, kenaf, cotton, hemp, coir, pineapple, banana, etc., [37] are ideally widely used as reinforcement for NFRP composites because of the physical and chemical properties of natural fibers that can biodegrade. Table 1 shows the physical and chemical properties of bamboo fibers, pineapple leaves and coir.

Table 1. The physical and chemical properties of bamboo fiber, pineapple leaves and coconut husk [38,39].

Fiber	Bamboo	Pineapple leaf	Coconut husk
Cellulosa (wt.%)	48.2-73.8	71.6	32-43
Lignin (wt.%)	30	5-12.7	0.15-0.25
Hemicellulosa (wt.%)	21-31	4.58	40-45
Microfibril angle (^{0})	2-10	14	30-49
Density (g/cm^3)	1.23	1.3	1.2
Tensile strenght (MPa)	500-575	150-1627	170-230

2.3 Preparation of Composite Specimen

Polyester composite materials are produced by hand lay-up and heat compression moulding methods. The process begins with combined raw materials including bamboo, pineapple leaves and coconut fiber as fillers in polyester resin according to the volume fraction and 1% of the methyl ethyl ketone peroxide (MEKP) catalyst of the total weight of the matrix. mixed rules such as pineapple-coir leaves and bamboo-pineapple fiber, each type of fiber consists of 30% composite weight, whereas for type 3-fibre each type of fiber consists of 20%.

2.4. Preparation of Composite Specimen

To evaluate the morphology of the microstructure presented by untreated and observed fibers and to observe the effect of surface modification provided by the treatment, several observations were made using a Scanning Electron Microscope (SEM) Type JEOL-T20, where electron scanning analysis was carried out at 5-20 voltages KV, as shown in Figure 1 (a). Next to test the tensile properties for hybrid composite materials according to the ASTM D 638 standard. Tensile strength is measured using a universal testing machine (UTM) EXCEED Model E43. The dimensions, measuring length, and crosshead speed are selected according to ASTM D-638 standard.

3. RESULT AND DISCUSSION

Various kinds of fibers consist of cells (basic units in structure) and tissues. The fiber consists of parenchyma cells, distributed in vascular bundles and inserted into the basic tissue. They are composed for lignin and hemicellulose which connects cellulose microfibrils. Lignin is formed by aliphatic and aromatic polymer constituents, and hemicellulose consists of polysaccharides associated with cellulose [40]. The relationship between cellulose and lignin/hemicellulose, as well as the spiral angle of microfibrils, varies from one fiber to another, determining its properties. They have different physiological, morphological and structural functions [41,42].

Tensile testing of natural fiber reinforced polyester composite materials was analyzed using the Universal Testing Machine (UTM) Model E43 with a sample specimen used by ASTM D-638 shown in Figure 1 (b). Tensile strength and flexural composite hybrid polyester composite results are shown in Table 2 and Figure 2.

Table 2. Mechanical properties of different composite sample

Sample	Young's modulus (GPa)	StD (GPa)	Tensile strength (MPa)	StD (MPa)	Failure strain (%)	StD (%)
PLC[a]	10.14	2.89	268.2	84.9	3.19	0.21
BPL[b]	15.45	3.91	293.6	121.4	7.18	0.24
BPLC[c]	20.67	5.65	304.7	157.1	8.78	0.21
PE[d]	9.8	1.01	109	98.4	5.76	0.09

*PLC (Pineapple leaf-coconut husk)
*BPL (Bamboo-pineapple leaf)
*BPLC (Bamboo-pineapple leaf-coconut husk)
*PE (Polyester)

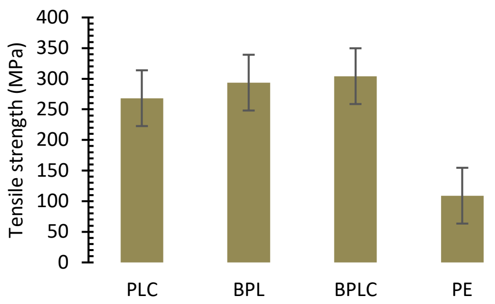


Figure 2. Influence of the treatments performed on composites on tensile strength

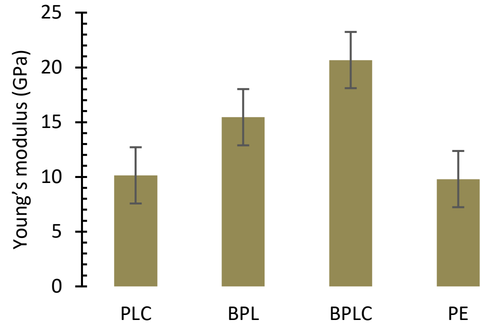


Figure 3. Influence of the treatments performed on composite on Young's modulus

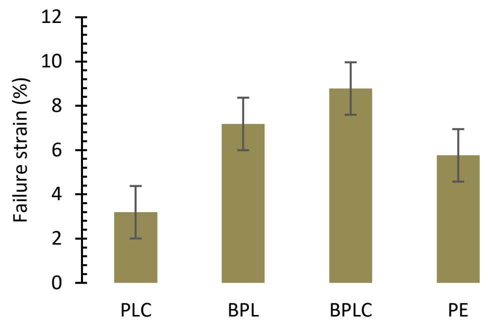


Figure.4. Influence of the treatments performed on composite on failure strain

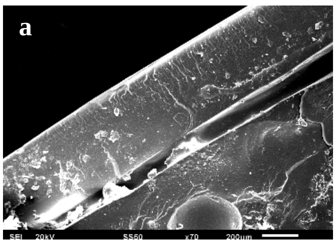
The nominal strain is determined by the change in ratio length (L) to the initial length (L0 = 40 mm) after the initial nonlinear correction observed in a particular stress-strain curve, using the LVDT transducer from the testing machine [43]. The maximum tensile strength of a fiber is determined as the maximum stress before breaking, and the associated strain is called the failure strain. Young's modulus is determined in the elastic linear phase of the stress-strain curve. Table 2 and summarize the main results of the tensile strength (Figure 2), both Young's modulus (Figure 3) and failure strain (Figure 4) are enhanced by the addition of various types of fibers, which are the best in the combination of bamboo fiber, coconut fiber and pineapple leaf fiber compared to polyester matrix.

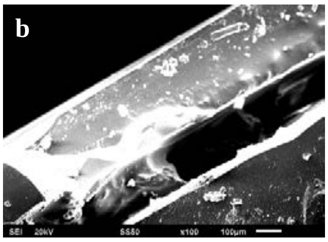
The results show that the mixture of bamboo fiber, pineapple-coconut husk leaves has a higher tensile strength compared to other materials. due to the good mechanical properties of bamboo fibers related to the composition of natural fibers as shown in Table 1 [38,39]. Thereby making pineapple-coconut bamboo-coconut hybrid polyester composite can produce a value of 304.17 MPa which results obtained are in accordance with ASTM D-638 standards. Polyester hybrid composites have a higher tensile strength than 229.54 MPa studies and which report the results of their investigation of Banana-Flax-Glass fiber composites which obtained the highest tensile strength of 39.5 MPa. As for pure polyester, it produces 109 MPa where there is no fiber mixture which causes no lignin phase in the matrix so that it brittle / breaks quickly [44]. Whereas the composite of the three fibers showed treatment of dissolving impurities, resins, hemicellulose and lignin portions. With the withdrawal of these compounds, the concentration in the volume of the lignin phase increases. Because the lignin phase is a stronger fiber compound, its properties are more exhibited. Values higher than the standard deviation can be explained by morphological changes, the strength of chemical bonds and variations in cellulose, hemicellulose and lignin content.

Despite the variability and irregularity, it was observed that pieces of natural fibers affected mechanical properties-inverse correlation between tensile strength and diameter. Other authors have also observed the same trend [45,46]. Other parameters also affect the results, such as the length of the fiber being tested - as the length increases, the number of defects, and the lignin content increase, leading to a decrease in tensile strength and strain failure. The rate of displacement absorbed in the tensile test also affects this parameter due to the viscoelastic behaviour of lignocellulose fibers. They behave like elastic material when subjected to mechanical loading at high displacement rates, making the crystal region experience most of the applied pressure and, in this way, produce an increase in Young's modulus and tensile strength [47,48].

3.1 Scanning Electron Microscopy

The morphology of the hybrid composite shown in Figure 5 (a), (b) and (c) observed at 1000x magnifications indicates increased adhesion of fibers and matrices distributed evenly throughout the composite section so as to show the optimal interface attachment between the fibers and Matrix





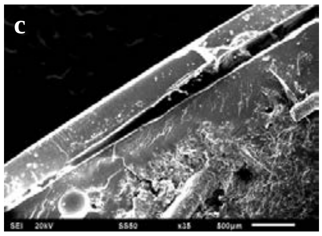


Figure 5. (a) pineapple leaf - coconut husk, (b) bamboo - pineapple leaf and (c) bamboo-pineapple leaf-coconut husk

Figure 5 (a) shows a picture of the dentation fracture of the specimen/fracture in a rough specimen showing adhesion formation. Figure 5 (b) poor bonding interactions at the substance interface occur due to the nature of natural fibers such as hydrophilic and hydrophobic [26]. Figure 5 (c) shows the presence of the boning mechanism that occurs between the fiber and the fiber matrix reinforced by interlocking fibers. So from the SEM analysis results obtained that the addition of three fibers in the manufacture of bio-board is better than the merging of the two previous fibers because of the interrelated properties of bamboo-pineapple-coconut fiber involving the diffusion of polymer matrix to the surface of the porous fiber. The polymer matrix will pass through the surface of the porous fiber and the embedded polymer and be compacted to form a strong bond between the fiber and the matrix as shown by the optimal value as reported in the results of the previous flexural test.

4. CONCLUSION

This research presents the results of the addition of three bamboo fibers from pineapple and coconut fiber fibers which are reinforced with a polyester matrix so that it becomes an environmentally friendly particle. The mechanical properties of the tensile test results showed the highest value, namely the addition of three types of fiber 304.7 MPa, Young 20.67 GPa modulus and 8.78% failure strain. Morphological appearance shows the structure of flat composites and interconnected the interface of the filler with the matrix thus affecting the mechanical properties of the composite as well as the cellulose content in the fiber playing an important role in the tensile characteristics of composites and compounds. So that the combination of the three fiber materials results in a hybrid green composite so as to increase high tensile strength and good flexibility for a particle board for furniture products.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Silva, G., Kim, S., Aguilar, R., & Nakamatsu, J. (2020a). Natural fibers as reinforcement additives for geopolymers – A review of potential eco-friendly applications to the construction industry. *Sustainable Materials and Technologies*, *23*, e00132. https://doi.org/10.1016/j.susmat.2019.e00132.

[2] Patel, N., & Jain, P. (2020). An investigation on mechanical properties in randomly oriented short natural fiber reinforced composites. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.05.452.

[3] Günay, E. (n.d.). *Introductory Chapter: Natural Fiber Plastic Composites - A Brief Review*. https://doi.org/10.5772/intechopen.71477.

[4] Revuelta-Aramburu, M., Verdú-Vázquez, A., Gil-López, T., & Morales-Polo, C. (2020). Environmental analysis of the use of plant fiber blocks in building construction. *Science of The Total Environment*, *725*, 138495. https://doi.org/10.1016/j.scitotenv.2020.138495.

[5] Saindane, U. V., Soni, S., & Menghani, J. V. (2020). Recent research status on synthesis and characterization of natural fibers reinforced polymer composites and modern friction materials – An overview. *Materials Today: Proceedings*, *26*, 1616–1620. https://doi.org/10.1016/j.matpr.2020.02.334.

[6] Karthi, N., Kumaresan, K., Sathish, S., Gokulkumar, S., Prabhu, L., & Vigneshkumar, N. (2020). An overview: Natural fiber reinforced hybrid composites, chemical treatments and application areas. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.01.011.

[7] Suryani, S., Rihayat, T., Nurhanifa, N., & Riskina, S. (n.d.). Modification of Poly Lactid Acid (PLA)/Chitosan with cinnamon essential oil for antibacterial applications. IOP Conf. Ser.: Mater. Sci. Eng., 830, 042017. https://doi.org/10.1088/1757-899x/830/4/042017.

[8] (2014). *A View On Eco- Friendly Natural Fibers For Packaging*. 99–114. https://doi.org/10.1201/b17388-8 167.

[9] Lalhmangaihzuali, P. C., Latha, B. D., More, N., Choppadandi, M., & Kapusetti, G. (2019). Natural fiber reinforced biodegradable staples: Novel approach for efficient wound closure. *Medical Hypotheses*, *126*, 60–65. https://doi.org/10.1016/j.mehy.2019.03.021.

[10] Kaisangsri, N., Kerdchoechuen, O., & Laohakunjit, N. (2012). Biodegradable foam tray from cassava starch blended with natural fiber and chitosan. *Industrial Crops and Products*, *37*(1), 542–546. https://doi.org/10.1016/j.indcrop.2011.07.034.

[11] Kathirselvam, M., Kumaravel, A., Arthanarieswaran, V. P., & Saravanakumar, S. S. (2019). Characterization of cellulose fibers in Thespesia populnea barks: Influence of alkali treatment. *Carbohydrate Polymers*, *217*, 178–189. https://doi.org/10.1016/j.carbpol.2019.04.063.

[12] Xu, R., He, T., Da, Y., Liu, Y., Li, J., & Chen, C. (2019). Utilizing wood fiber produced with wood waste to reinforce autoclaved aerated concrete. *Construction and Building Materials*, *208*, 242–249. https://doi.org/10.1016/j.conbuildmat.2019.03.030.

[13] Wei, J., Rao, F., Zhang, Y., Yu, W., Hse, C., & Shupe, T. (2019). Laminating wood fiber mats into a densified material with high performance. *Materials Letters*, *253*, 358–361. https://doi.org/10.1016/j.matlet.2019.06.097.

[14] Nashiruddin, N. I., Mansor, A. F., Rahman, R. A., Ilias, R. Md., & Yussof, H. W. (2020). Process parameter optimization of pretreated pineapple leaves fiber for enhancement of sugar recovery. *Industrial Crops and Products*, *152*, 112514. https://doi.org/10.1016/j.indcrop.2020.112514.

[15] Rihayat, Teuku, Suryani, Siregar, J. P., Satriananda, Yunus, M., Sariadi, Fitria, Riskina, S., Amalia, Z., & Syahputra, W. (n.d.). Synthesis and Characterization of North Aceh CEC Bentonite Determination with Methylene Blue Method and Increased D-Spacing after Addition of Surfactants CTAB-SDS. *IOP Conf. Ser.: Mater. Sci. Eng.*, *506*, 012054. https://doi.org/10.1088/1757-899x/506/1/012054.

[16] Madhu, P., Sanjay, M. R., Pradeep, S., Subrahmanya Bhat, K., Yogesha, B., & Siengchin, S. (2019). Characterization of cellulosic fibre from Phoenix pusilla leaves as potential reinforcement for polymeric composites. *Journal of Materials Research and Technology*, *8*(3), 2597–2604. https://doi.org/10.1016/j.jmrt.2019.03.006.

[17] Li, X., Su, X., Xiao, H., Chen, L., Li, S., & Tang, M. (2020). Continuous α-Al2O3 fibers grown by seeding with in-situ suspension. *Ceramics International*, *46*(10), 15638–15645. https://doi.org/10.1016/j.ceramint.2020.03.112.

[18] Rihayat, Teuku, Suryani, Satriananda, Riskina, S., Syahputra, W., Nurhanifa, & Mawaddah. (n.d.).

Formulation of Polyurethane with Bentonite-Chitosan as Filler Applied to Carbon Steel as an Antibacterial and Environmentally Friendly Paint. *IOP Conf. Ser.: Mater. Sci. Eng.*, *536*, 012093. https://doi.org/10.1088/1757-899x/536/1/012093.

[19] Narayanasamy, P., Balasundar, P., Senthil, S., Sanjay, M. R., Siengchin, S., Khan, A., & Asiri, A. M. (2020). Characterization of a novel natural cellulosic fiber from Calotropis gigantea fruit bunch for ecofriendly polymer composites. *International Journal of Biological Macromolecules*, *150*, 793–801. https://doi.org/10.1016/j.ijbiomac.2020.02.134.

[20] Azzouzi, D., Rabahi, W., Seddiri, F., & Hemis, M. (2020). Experimental study of the fibres content effect on the heat insulation capacity of new vegetable composite plaster-pea pod fibres. *Sustainable Materials and Technologies*, *23*, e00144. https://doi.org/10.1016/j.susmat.2019.e00144

[21] Sun, E., Liao, G., Zhang, Q., Qu, P., Wu, G., & Huang, H. (2019). Biodegradable copolymer-based composites made from straw fiber for biocomposite flowerpots application. *Composites Part B: Engineering*, *165*, 193–198. https://doi.org/10.1016/j.compositesb.2018.11.121.

[22] Barari, B., & Pillai, K. M. (2017). *Green composites made from cellulose nanofibers and bio-based epoxy*. 31–49. https://doi.org/10.1016/b978-0-08-100656-6.00003-0.

[23] Li, Z., Zhang, X., Fa, C., Zhang, Y., Xiong, J., & Chen, H. (2020). Investigation on characteristics and properties of bagasse fibers: Performances of asphalt mixtures with bagasse fibers. *Construction and Building Materials*, *248*, 118648. https://doi.org/10.1016/j.conbuildmat.2020.118648.

[24] Moshi, A. A. M., Ravindran, D., Bharathi, S. R. S., Indran, S., Saravanakumar, S. S., & Liu, Y. (2020). Characterization of a new cellulosic natural fiber extracted from the root of Ficus religiosa tree. *International Journal of Biological Macromolecules*, *142*, 212–221. https://doi.org/10.1016/j.ijbiomac.2019.09.094.

[25] Bourmaud, A., Shah, D. U., Beaugrand, J., & Dhakal, H. N. (2020a). Property changes in plant fibres during the processing of bio-based composites. *Industrial Crops and Products*, *154*, 112705. https://doi.org/10.1016/j.indcrop.2020.112705.

[26] Ullah, M. S., Gotoh, T., & Lim, U. T. (2014). Life history parameters of three phytophagous spider mites, Tetranychus piercei, T. truncatus and T. bambusae (Acari: Tetranychidae). *Journal of Asia-Pacific Entomology*, *17*(4), 767–773. https://doi.org/10.1016/j.aspen.2014.07.008.

[27] Jiang, S., Wei, Y., Hu, Z., Ge, S., Yang, H., & Peng, W. (2020). Potential application of bamboo powder in PBS bamboo plastic composites. *Journal of King Saud University - Science*, *32*(1), 1130–1134. https://doi.org/10.1016/j.jksus.2019.10.014.

[28] Jiao, J., & Tang, P. (2019). Application of bamboo in a design–build course: Lianhuadang Farm project. *Frontiers of Architectural Research*, *8*(4), 549–563. https://doi.org/10.1016/j.foar.2019.09.003.

[29] Ridwan, R., Rihayat, T., Suryani, S., Ismi, A. S., Nurhanifa, N., & Riskina, S. (n.d.). Combination of poly lactid acid zinc oxide nanocomposite for antimicrobial packaging application. *IOP Conf. Ser.: Mater. Sci. Eng.*, *830*, 042018. https://doi.org/10.1088/1757-899x/830/4/042018.

[30] Umanath, K., Prabhu, M. K., Yuvaraj, A., & Devika, D. (2020). Fabrication and analysis of Master leaf spring plate using carbon fibre and pineapple leaf fibre as natural composite materials. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.03.790.

[31] Widnyana, A., Rian, I. G., Surata, I. W., & Nindhia, T. G. T. (2020). Tensile Properties of coconut Coir single fiber with alkali treatment and reinforcement effect on unsaturated polyester polymer. *Materials Today: Proceedings*, *22*, 300–305. https://doi.org/10.1016/j.matpr.2019.08.155.

[32] Lertwattanaruk, P., & Suntijitto, A. (2015). Properties of natural fiber cement materials containing coconut coir and oil palm fibers for residential building applications. *Construction and Building Materials*, *94*, 664–669. https://doi.org/10.1016/j.conbuildmat.2015.07.154.

[33] Deng, Y., Li, W., Shao, J., Zhang, X., Kou, H., Geng, P., Zhang, X., Li, Y., & Ma, J. (2017). A novel theoretical model to predict the temperature-dependent fracture strength of ceramic materials. *Journal of the European Ceramic Society*, *37*(15), 5071–5077. https://doi.org/10.1016/j.jeurceramsoc.2017.06.044.

[34] Bourmaud, A., Shah, D. U., Beaugrand, J., & Dhakal, H. N. (2020b). Property changes in plant fibres during the processing of bio-based composites. *Industrial Crops and Products*, *154*, 112705. https://doi.org/10.1016/j.indcrop.2020.112705.

[35] Bousfield, G., Morin, S., Jacquet, N., & Richel, A. (2018). Extraction and refinement of agricultural plant fibers for composites manufacturing. *Comptes Rendus Chimie*, *21*(9), 897–906. https://doi.org/10.1016/j.crci.2018.07.001.

[36] Manral, A., & Bajpai, P. K. (2020). Analysis of properties on chemical treatment of kenaf fibers. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.03.266.

[37] Adesina, A. (2020). Performance of fibre reinforced alkali-activated composites – A review. *Materialia*, *12*, 100782. https://doi.org/10.1016/j.mtla.2020.100782.

[38] Yusoff, R. B., Takagi, H., & Nakagaito, A. N. (2016). Tensile and flexural properties of polylactic acid-based hybrid green composites reinforced by kenaf, bamboo and coir fibers. *Industrial Crops and Products*, *94*, 562–573. https://doi.org/10.1016/j.indcrop.2016.09.017.

[39] Akil, H. M., Omar, M. F., Mazuki, A. A. M., Safiee, S., Ishak, Z. A. M., & Abu Bakar, A. (2011). Kenaf fiber reinforced composites: A review. *Materials & Design*, *32*(8–9), 4107–4121. https://doi.org/10.1016/j.matdes.2011.04.008.

[40] Goulis, P., Kartsonakis, I. A., Mpalias, K., & Charitidis, C. (2018). Combined effects of multi-walled carbon nanotubes and lignin on polymer fiber-reinforced epoxy composites. *Materials Chemistry and Physics*, *218*, 18–27. https://doi.org/10.1016/j.matchemphys.2018.07.025

[41] Chen, W.-H., Wang, C.-W., Ong, H. C., Show, P. L., & Hsieh, T.-H. (2019). Torrefaction, pyrolysis and two-stage thermodegradation of hemicellulose, cellulose and lignin. *Fuel*, *258*, 116168. https://doi.org/10.1016/j.fuel.2019.116168.

[42] Dorez, G., Ferry, L., Sonnier, R., Taguet, A., & Lopez-Cuesta, J.-M. (2014). Effect of cellulose, hemicellulose and lignin contents on pyrolysis and combustion of natural fibers. *Journal of Analytical and Applied Pyrolysis*, *107*, 323–331. https://doi.org/10.1016/j.jaap.2014.03.017.

[43] Fedorov, A. Y., Kosheleva, N. A., Matveenko, V. P., & Serovaev, G. S. (2020). Strain measurement and stress analysis in the vicinity of a fiber Bragg grating sensor embedded in a composite material. *Composite Structures*, *239*, 111844. https://doi.org/10.1016/j.compstruct.2019.111844.

[44] Atiqah, A., Maleque, M. A., Jawaid, M., & Iqbal, M. (2014). Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications. *Composites Part B: Engineering*, *56*, 68–73. https://doi.org/10.1016/j.compositesb.2013.08.019.

[45] Rihayat, T, Suryani, S., Riskina, S., & Nurhanifa, N. (n.d.). Synthesis and characterization of chitosan-bentonite modified polyurethane with biomedical potential. *IOP Conf. Ser.: Mater. Sci. Eng.*, *830*, 042016. https://doi.org/10.1088/1757-899x/830/4/042016.

[46] Bazán, A. M., Cobo, A., & Montero, J. (2016). Study of mechanical properties of corroded steels embedded concrete with the modified surface length. *Construction and Building Materials*, *117*, 80–87. https://doi.org/10.1016/j.conbuildmat.2016.04.109.

[47] Rihayat, Teuku, Suryani, Zaimahwati, Salmyah, Sariadi, Fitria, Satriananda, Putra, A., Fona, Z., & Juanda. (n.d.). Composition on Essential Oil Extraction from Lemongrass Fragrant by Microwave Air Hydro Distillation Method to Perfume Dermatitis Production. *IOP Conf. Ser.: Mater. Sci. Eng.*, *506*, 012053. https://doi.org/10.1088/1757-899x/506/1/012053.

[48] Zhang, X., Li, W., Deng, Y., Li, Y., Zhang, X., Zheng, S., Dong, P., Wang, S., Zhang, X., & Shen, Z. (2019). Modeling the temperature dependent ultimate tensile strength for unidirectional ceramic-fiber reinforced ceramic composites considering the load carrying capacity of broken fibers. *Ceramics International*, *45*(18), 24309–24317. https://doi.org/10.1016/j.ceramint.2019.08.145.

[49] Djafar, Z., Renreng, I., & Jannah, M. (n.d.). Tensile and Bending Strength Analysis of Ramie Fiber and Woven Ramie Reinforced Epoxy Composite. *Journal of Natural Fibers*, 1–12. https://doi.org/10.1080/15440478.2020.1726242.