

Research Article

Mechanical Characteristics of Green Composites of Short Kenaf Bast Fiber Reinforced in Cardanol

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In this experiment, thermoset cardanol resin was reinforced with short kenaf bast fibers to produce 100% green composites. Different fiber loadings based on weight ratios (0%, 30%, 40%, 50%, and 60%) were fabricated by the hand layup method followed by compression molding. The results indicated that 50UTK (untreated kenaf fibers) displays the highest mechanical properties (91.9% and 43.4% increment for tensile strength and impact strength, respectively) compared with the brittle cardanol polymer and other combinations of composite. This indicates a great load transfer mechanism by kenaf fiber reinforcement due to good fiber/matrix interface shown in scanning electron microscope (SEM) analyses. On the contrary, short kenaf fiber insertion creates a stress concentration spot at the fiber's end causing slightly lower flexural properties. Besides, high processing temperature has caused damage to the fibers and made further reduction of flexural strength. Therefore, a better load transfer mechanism has been compensated by negative influences of kenaf fiber insertion. In conclusion, 50 wt% of kenaf fiber insertion is found to be the optimum loading for cardanol matrix.

1. Introduction

Natural fibers are potential replacement of synthetic fibers due to their biodegradability, renewability, and cheaper price. However, in terms of mechanical properties, synthetic fibers demonstrated higher mechanical properties, causing limited application for natural fiber-reinforced composites [1–13]. Kenaf is one of the natural fibers that shows reasonably good mechanical properties with different types of resin [14]. The hydrophilic nature of kenaf fiber is the main factor that causes deterioration of mechanical properties. Higher water absorption of composites was found when kenaf fibers were used in the work of Lee et al. The drying of swelled kenaf fibers left the composite in macrovoids and failed to transfer the load applied effectively [15].

Besides, other factors that affect the mechanical properties are fiber weight fraction and fiber's length. The increment

in tensile strength with increasing fiber weight fraction was previously demonstrated for kenaf/poly(lactic acid) (PLA)/thymol composites [16]. However, flexural strength deteriorated, while the impact test showed reasonably reliable results, implying that kenaf fiber is a potential replacement of synthetic fibers in the composite industry [17]. On the contrary, Sharifah and Martin found long kenaf fibers reinforced in cashew nut shell liquid resin gave superior flexural strength and provided fiber orientation parallel to the direction of load applied [18]. Besides, long fiber provides better impact strength values. Moreover, the tensile strength increment with increasing kenaf fiber content depends on the type of the resin. Kenaf/poly(vinyl chloride)/thermoplastic polyurethane composites showed that increasing the fiber contents have led to poor tensile strength and strain. The SEM study of the tensile rupture surface indicates that the bonding between kenaf fiber and the resin is very poor [19].

The cashew nut produced from cashew trees is widely found in Brazil. Cardanol is a novolac phenolic resin derived with a linear unsaturated hydrocarbon side chain from cashew nut shell liquid (CNSL). Cardanol resins are well known in the synthesis of thermosetting matrices for composites, due to low cost. The cardanol matrices were found compatible with polyester, epoxy, or vinylester resins [20].

There is no previous research on short kenaf fiber reinforced in cardanol matrix. This composite can be used in many industries, such as aviation, car, and building construction industry. In this paper, the mechanical properties of the composites of short kenaf bast fiber reinforced in cardanol are studied on effect of fibers' insertion. Besides, the SEM has been used to investigate fiber/matrix interfacial conditions.

2. Materials and Methodology

2.1. Materials. Kenaf fibers were provided from the laboratory of biocomposites, Institute of Tropical Forestry and Forest Products (INTROP), University Putra Malaysia (UPM), in a bundle form which was required to be cleaned and combed properly before use as shown in Figure 1.

Cardanol resin was purchased from Chemovate Company in India, which is a byproduct of the cashew nut industry and a waste material extracted from cashew nut shell liquid (CNSL). It is a novolac phenolic resin that requires a cross-link agent to cure. The cross-link agent is usually hexamethylenetetramine which is known as hexa, hexamine, or HTMA as well. The cardanol was mixed with 11% weight ratio of hexa in Chemovate Co.

2.2. Methodology of Fabrication. The fabrication process includes mixing the untreated kenaf (UTK) fibers with cardanol based on the weight ratio with a mechanical mixer. Then it was put in the mold and in the hot press at 160°C and 1 bar for 20 min and after that in the oven with the temperature of 160°C for 1 hr. The specimen was ready for testing after cooling down. Figure 2 shows the fabrication process. Table 1 shows the specimen abbreviation with regard to their fiber/resin ratio in which CL represents cardanol and UTK is an abbreviation for untreated kenaf fiber.

2.3. Mechanical Testing

2.3.1. Tensile Test. To conduct the tensile test, the ASTM D 3039 [21] standard was followed. According to the standard, the specimens were cut to the size of 150 × 20 × 3 mm³. The test was performed by using a 30 kN Bluehill INSTRON Universal Testing machine with 2 mm/min cross head speed. Seven replications for each type of specimen were taken, and the tensile strength of the specimens was determined to study the effect of fiber weight fraction.

Mean values are determined, and standard deviation of the results is shown as the error bar in all the graphs.

2.3.2. Flexural Test. Flexural strength of the specimens were determined by the flexural test which was conducted by following the ASTM D790 [22] standard. According to the

standard, the specimens were cut to the size of 120 × 12 × 3 mm³. The 30 kN Bluehill INSTRON Universal Testing machine with 2 mm/min cross head speed was used for the flexural testing of all specimens with seven replications.

2.3.3. Impact Test. Impact strength determines the toughness of the specimen, that is, the ability of absorbent impact energy before breaking. The ASTM D256 [23] standard was followed for the impact test. The size of the specimens was required to be 60 × 12 × 3 mm³. An INSTRON CEAST9050 impact testing machine with a 0.5 J of hammer was used to perform the impact test. The angle of the hammer was set at 150°. Seven replications for each type of specimen were conducted to measure the average load at the first deformation under impact loadings.

2.3.4. Morphology Study. Morphology of the specimen was studied by using SEM for the tensile fracture surface. The specimens were gold-coated before being put into the HITACHI S-3400 instrument for SEM analysis. The test was performed with an emission current of 60 μA and 5.0 kV of voltage.

3. Results and Discussion

3.1. Morphology Study of the Composites. The morphology of the specimens was studied by using SEM of the tensile-fractured surface of the specimen, and its images are presented in Figure 3. Fiber pulled-out, microcracks, and broken fibers are the factors that caused poor interfacial bonding between fibers and matrix resulting in low mechanical properties.

The SEM analysis of 100CL (Figure 3(a)) demonstrated the cured cardanol in a layer form that is a sign of its brittleness property. For the 30UTK sample in Figure 3(b), good fiber matrix interface was found, and this has predicted good strength properties. However, low volume of fiber contents was proved by clear, smooth zone of cured cardanol polymer. Besides, 40UTK and 50UTK samples, fiber pulled-out, and broken fiber were the cause of fracture (Figure 3(c) and 3(d)). Yet, the 50UTK sample has better fiber/resin interface which leads to the good load transfer mechanism [24]. On the opposite, for the 60UTK sample (Figure 3(e)), the excess amount of fiber compared with the amount of cardanol leads to poor interfacial bonding, due to lack of resin.

3.2. Tensile Strength of the Biocomposites. Figure 4 and Table 2 show tensile strength of kenaf fibers reinforced cardanol composites and tensile strength detail values, respectively. It is found that increasing fiber loading has enhanced the tensile strength of composites up to 50 wt% fibers reinforcement. The tensile strength of 50UTK has observed an increment of tensile strength compared with pure cardanol (26.99 MPa). Öztürk determined that the tensile strength increased with the increment of fiber weight fraction up to 42 wt%, indicating the effectiveness of incorporation of kenaf with the resin [25]. Besides, Ramesh concluded the linear relationship between

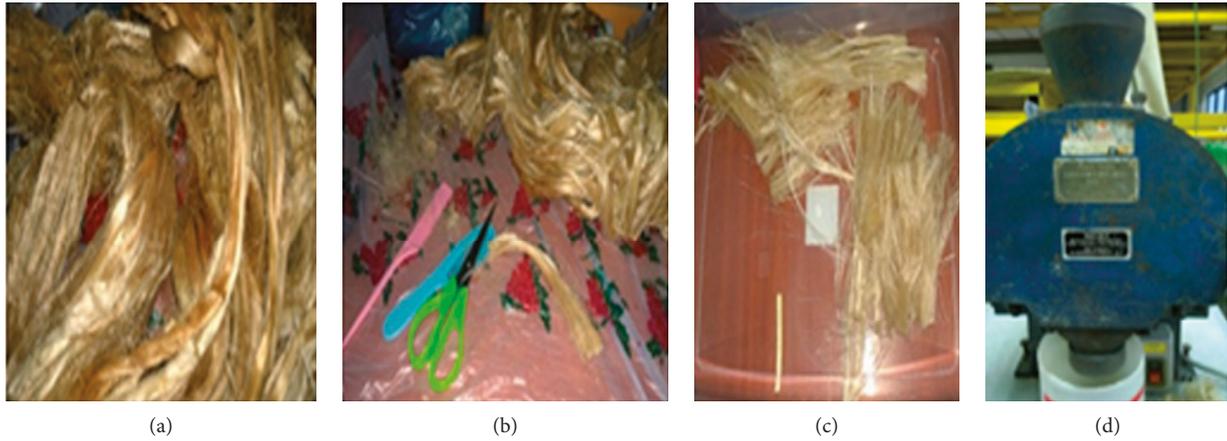


FIGURE 1: Kenaf fibers preparation. (a) Bundle of dirty kenaf. (b) Cleaning fibers. (c) Clean and tidy fibers. (d) Grinding machine.



FIGURE 2: Fabrication procedure.

TABLE 1: Biocomposites composition.

Sample	Cardanol matrix (wt %)	Kenaf fibers (wt %)
100CL	100	0
30UTK	70	30
40UTK	60	40
50UTK	50	50
60UTK	40	60

tensile strength and fiber weight fraction in which the tensile strength of the composites increased up to 50 wt% [26]. Higher fiber loadings laterally increased maximum loading barrier of composites. However, for 60UTK, lack of the resin has caused weak interfacial bonding due to low fiber wetting, making the fiber's load transfer mechanism fail before it received the highest load [27].

It is understood that pure cardanol has the lowest tensile strength (26.95 MPa) due to the brittleness property of the thermoset resins cardanol [28]. Better kenaf/cardanol bonding leads to easier load transfer from the matrix to the fiber, and therefore, the fracture under tensile strength gets delayed. Therefore, kenaf fiber improves the tensile strength of the cardanol as well.

3.3. Flexural Strength of the Biocomposites. Flexural strength results of the kenaf/cardanol composites and detail values for flexural strength are shown in Figure 5 and Table 3, respectively. Insertion of 30 wt% kenaf fiber had reduced the flexural strength due to short kenaf fibers creating a stress concentration spot at fiber's end, leading to the strength reduction [29]. Besides, high processing temperature shall cause damage to the fibers, further reducing flexural strength [17]. However, the flexural strength (10.44%) had increased with increment of fiber loading from 81.89 MPa for 30UTK to 90.44 MPa for 60UTK as reported similar previously by Saba et al. and Joseph et al. [30, 31]. The better load transfer mechanism found at higher kenaf fiber contents has compensated the negative influences of kenaf fibers insertion.

The three-point bending flexural test will cause shear and bending failure. The failure of the specimen occurred when the bending of the specimen was equal to the corresponding critical value [31]. Flexural strength shows how much load the composite can bear before bending. However, the general result agreed with the tensile strength, as both indicated that the increment of fiber weight fraction could increase the strength for both tensile and flexural strength, which was higher for the treated fiber for flexural strength.

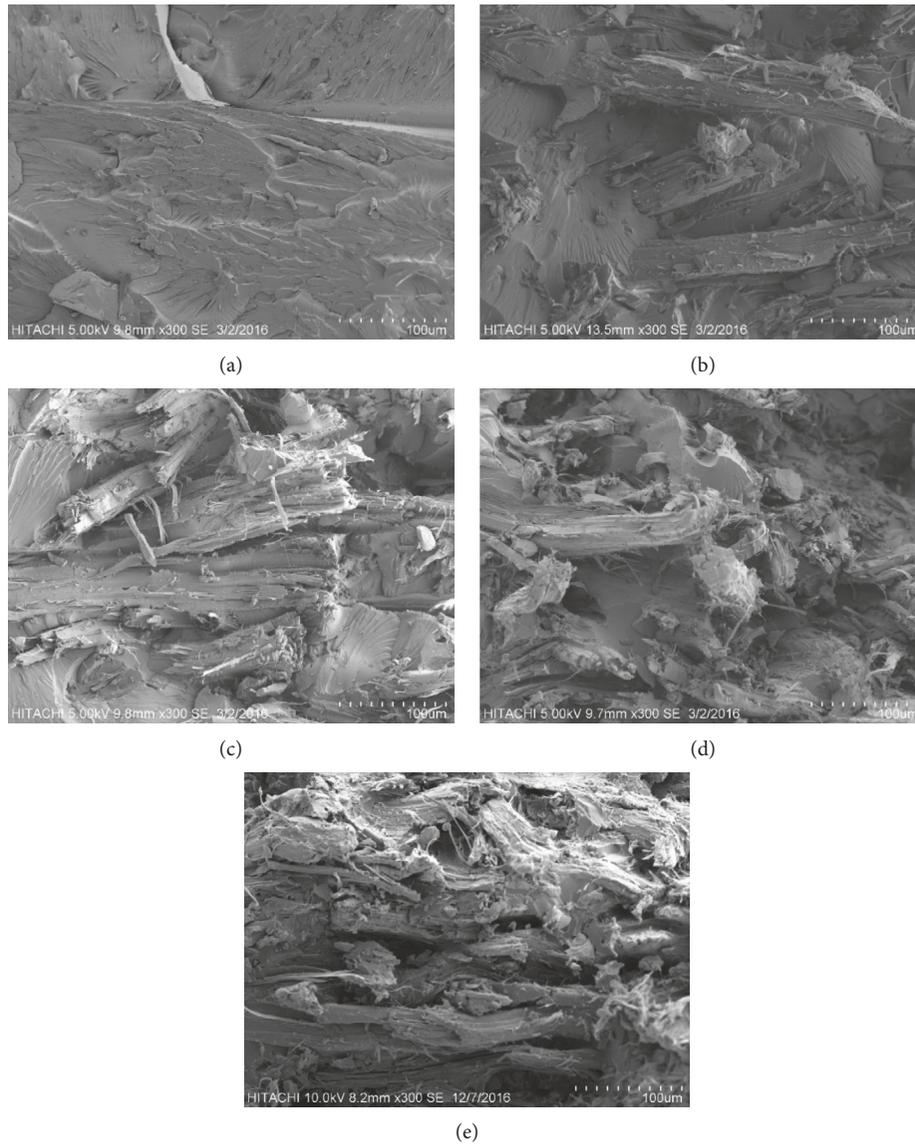


FIGURE 3: SEM image of the specimen tensile rupture surface. (a) 100CL. (b) 30UTK. (c) 40UTK. (d) 50UTK. (e) 60UTK.

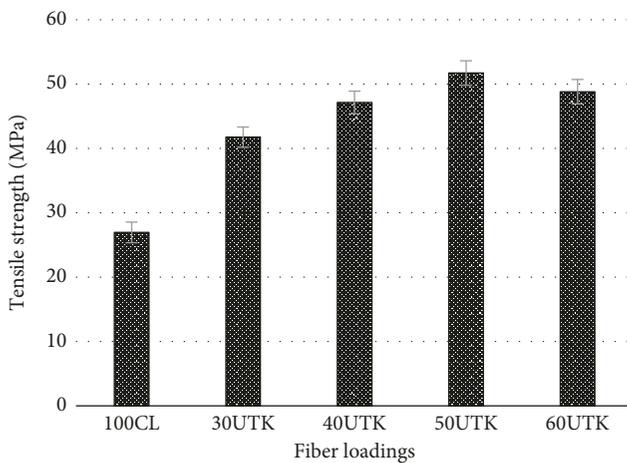


FIGURE 4: Tensile strength (MPa) vs. fiber content.

TABLE 2: Detail values for tensile strength.

Specimen	Tensile mean value (MPa)	Tensile standard deviation (MPa)	Percentage comparison (%)
100CL	26.95	1.6	100
30UTK	41.75	1.6	154.92
40UTK	47.14	1.8	174.92
50UTK	51.72	1.9	191.91
60UTK	48.81	1.9	181.11

The study showed that flexural strength of kenaf composites increased with the increment of fiber content up to 60% [26].

3.4. Impact Resilience of the Biocomposites. Impact strength of the kenaf/cardanol specimens and detail values for impact strength are shown in Figure 6 and Table 4, respectively. Due

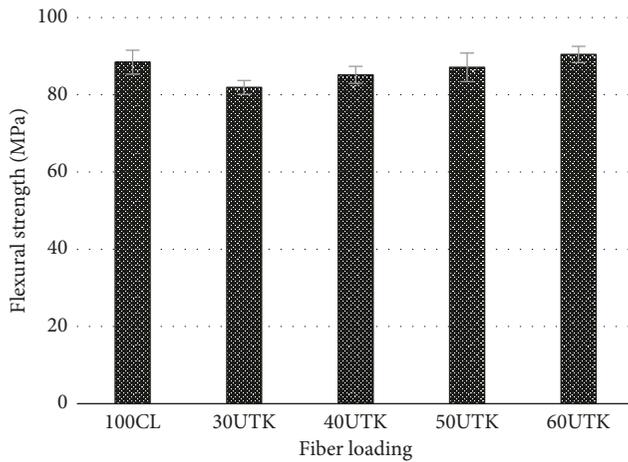


FIGURE 5: Flexural strength (MPa) vs. fiber content.

TABLE 3: Detail values for flexural strength.

Specimen	Flexural mean value (MPa)	Flexural standard deviation (MPa)	Percentage comparison (%)
100CL	88.43	3.1	100
30UTK	81.89	1.8	92.60
40UTK	85.16	2.2	96.30
50UTK	87.11	3.7	98.51
60UTK	90.44	2.1	102.27

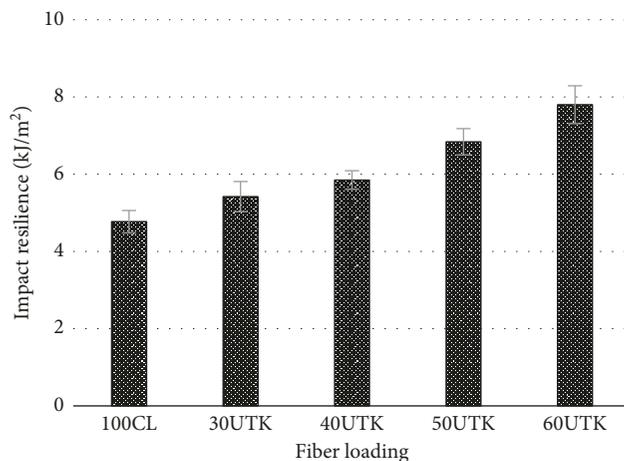
FIGURE 6: Impact resilience (kJ/m²) vs. fiber content.

TABLE 4: Detail values for impact strength.

Specimen	Impact mean value (MPa)	Impact standard deviation (MPa)	Percentage comparison (%)
100CL	4.77	0.29	100
30UTK	5.42	0.39	113.63
40UTK	5.85	0.24	122.64
50UTK	6.84	0.34	143.40
60UTK	7.8	0.49	163.52

to low toughness of the cardanol polymer, kenaf fiber enhanced the impact strength in the composite. The cardanol polymer shows lowest impact resilience with the value of 4.77 kJ/m². Increment of the fiber weight fraction enhanced

the impact resilience up to 7.8 kJ/m² for 60UTK. The enhancement of the impact resilience is due to the presence of crystalline cellulose in high crystalline kenaf fibers [32]. Reinforcement fiber absorbed the energy for debonding and pull-out, which helped to enhance the impact strength of composite. Therefore, a good interfacial bond between the fiber and the matrix is important, and it was evidenced in SEM analyses (Figures 3(c) and 3(d)) [15]. This result implies that kenaf fiber works as a successful reinforcement for cardanol composite.

4. Conclusions

Biocomposites of short kenaf bast fiber reinforced in cardanol with different fiber loadings were tested to investigate optimum weight fraction of kenaf fiber. The results found that 50UTK has increased tensile strength and impact strength of 91.9% and 43.4%, respectively. This indicates the better load transfer mechanism was done by kenaf fibers due to good fiber/matrix interfacial shown in SEM analyses (Figure 3). However, flexural properties of 50UTK were found to be slightly lower (1.49%) than those of cardanol polymer. Short kenaf fibers are responsible for flexural strength decrement by creating stress concentration spots at the fiber's end. Besides, high processing temperature has caused damage of the fibers, further reducing flexural strength. However, a better load transfer mechanism found at higher kenaf fiber content has compensated the negative influences of kenaf fiber insertion. In conclusion, 50 wt% of kenaf fibers reinforcement is the most optimum loading for the cardanol matrix.

Data Availability

For currently, the data is not available for share, because it is part of on-going project.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

- [1] R. Mahjoub, J. M. Yatim, A. R. Mohd Sam, and M. Raftari, "Characteristics of continuous unidirectional kenaf fiber reinforced epoxy composites," *Materials and Design*, vol. 64, pp. 640–649, 2014.
- [2] I. S. M. A. Tawakkal, M. J. Cran, and S. W. Bigger, "Effect of kenaf fibre loading and thymol concentration on the mechanical and thermal properties of PLA/kenaf/thymol composites," *Industrial Crops and Products*, vol. 61, pp. 74–83, 2014.

- [3] R. Yahaya, S. M. Sapuan, M. Jawaid, Z. Leman, and E. S. Zainudin, "Effect of fibre orientations on the mechanical properties of kenaf-aramid hybrid composites for spall-liner application," *Defence Technology*, vol. 12, no. 1, pp. 52–58, 2016.
- [4] Y. A. El-Shekeil, S. M. Sapuan, M. Jawaid, and O. M. Al-Shuja'a, "Influence of fiber content on mechanical, morphological and thermal properties of kenaf fibers reinforced poly(vinyl chloride)/thermoplastic polyurethane poly-blend composites," *Materials and Design*, vol. 58, pp. 130–135, 2014.
- [5] C. H. Lee, S. M. Sapuan, and M. R. Hassan, "Thermal analysis of kenaf fiber reinforced floreon biocomposites with magnesium hydroxide flame retardant filler," *Polymer Composites*, vol. 39, no. 3, pp. 869–875, 2018.
- [6] M. Nashiatgozar, V. Daghigh, T. E. J. Lacy, H. Daghigh, K. Nikbin, and A. Simoneau, "Mechanical characterization of noval latania natural fiber reinforced PP/EPDM composites," *Polymer Testing*, vol. 56, pp. 321–328, 2016.
- [7] M. M. Davoodi, S. M. Sapuan, D. Ahmad, A. Aidy, A. Khalina, and M. Jonoobi, "Effect of polybutylene terephthalate (PBT) on impact property improvement of hybrid kenaf/glass epoxy composite," *Materials Letters*, vol. 67, no. 1, pp. 5–7, 2012.
- [8] D. Cho, J. M. Kim, and D. Kim, "Phenolic resin infiltration and carbonization of cellulose-based bamboo fibers," *Materials Letters*, vol. 104, pp. 24–27, 2013.
- [9] A. Nopparut and T. Amornsakchai, "Influence of pineapple leaf fiber and it's surface treatment on molecular orientation in, and mechanical properties of, injection molded nylon composites," *Polymer Testing*, vol. 52, pp. 141–149, 2016.
- [10] M. D. Stelescu, A. Airinei, E. Manaila, G. Cracium, N. Fifere, and C. Varganici, "Property correlations for composites based on ethylene propylene diene rubber reinforced with flax fibers," *Polymer Testing*, vol. 59, pp. 75–83, 2017.
- [11] H. Khosravi and R. Eslami-Farsani, "Enhanced mechanical properties of unidirectional basalt fiber/epoxy composites using silane-modified Na⁺-montmorillonite nanoclay," *Polymer Testing*, vol. 55, pp. 135–142, 2016.
- [12] A. Pozzi and R. Sepe, "Mechanical properties of woven natural fiber reinforced composites ECCM 2012-composites at Venice," in *Proceedings of the 15th European Conference on Composite Materials*, Venice, Italy, June 2012.
- [13] R. Sepe, F. Bollino, L. Boccarusso, and F. Caputo, "Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites," *Composites Part B: Engineering*, vol. 133, pp. 210–217, 2018.
- [14] A. M. Mohd Edeerozey, M. A. Hazizan, A. B. Azhar, and M. I. Z. Ariffin, "Chemical modification of kenaf fibers," *Materials Letters*, vol. 61, no. 10, pp. 2023–2025, 2007.
- [15] C. H. Lee, S. M. Sapuan, and M. R. Hassan, "Mechanical properties of kenaf fibre reinforced floreon biocomposites with magnesium hydroxide filler," *Journal of Mechanical Engineering and Sciences*, vol. 10, no. 3, pp. 2234–2248, 2016.
- [16] J. K. Sameni, S. H. Ahmad, and S. Zakaria, "Mechanical properties of kenaf thermoplastic natural rubber composites," *Polymer-Plastics Technology and Engineering*, vol. 42, no. 3, pp. 345–355, 2003.
- [17] B. V. Ramnath, S. J. Kokan, R. N. Raja et al., "Evaluation of mechanical properties of abaca-jute-glass fibre reinforced epoxy composites," *Materials and Design*, vol. 51, pp. 357–366, 2013.
- [18] H. A. Sharifah and P. A. Martin, "The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: part 2 cashew nut shell liquid matrix," *Composites Science and Technology*, vol. 64, no. 9, pp. 1231–1238, 2004.
- [19] A. Arsad, N. L. Suradi, A. R. Rahmat, and J. M. Danlami, "The influence of kenaf fiber as reinforcement on recycled polypropylene/recycled polyamide-6 composites," *International Journal of Plastics Technology*, vol. 17, no. 2, pp. 149–162, 2013.
- [20] A. Balaji, B. Karthikeyan, J. Swaminathan, and C. R. Sundar, "Thermal behavior of cardanol resin reinforced 20 mm long untreated bagasse fiber composites," *International Journal of Polymer Analysis and Characterization*, vol. 23, no. 1, pp. 70–77, 2017.
- [21] ASTM D 3039, *Standard Test Method for Tensile Properties of Polymer Matrix Composites*, ASTM, West Conshohocken, PA, USA, 2014.
- [22] ASTM D790, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, ASTM, West Conshohocken, PA, USA, 2016.
- [23] ASTM D256, *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics*, ASTM, West Conshohocken, PA, USA, 2015.
- [24] D. Bachtiar, J. B. Siregar, A. S. Sulaiman, and M. R. Mat Rejab, "Tensile properties of hybrid sugar palm kenaf fiber reinforced polypropylene composites," *Applied Mechanics and Materials*, vol. 695, pp. 155–158, 2014.
- [25] S. Özturk, "Effect of fiber loading on the mechanical properties of kenaf and fiberfrax fiber-reinforced phenol-formaldehyde composites," *Journal of Composite Materials*, vol. 44, no. 19, pp. 2265–2288, 2010.
- [26] M. Ramesh, "Kenaf fibre based bio-materials: a review on processing and properties," *Progress in Materials Science*, vol. 78–79, pp. 1–92, 2016.
- [27] N. I. Razak, N. A. Ibrahim, N. Zainuddin, M. Rayung, and W. Z. Saad, "The influence of chemical surface modification of kenaf fiber using hydrogen peroxide on the mechanical properties of biodegradable kenaf fiber/poly(lactic acid) composites," *Molecules*, vol. 19, no. 3, pp. 2957–2968, 2014.
- [28] Y. Zhang, F. Ferdosian, Z. Yuan, and C. C. Xu, "Sustainable glucose-based phenolic resin and its curing with a DGEBA epoxy resin," *Journal of the Taiwan Institute of Chemical Engineers*, vol. 71, pp. 381–387, 2017.
- [29] C. H. Lee, S. M. Sapuan, and M. R. Hassan, "Mechanical and thermal properties of kenaf fiber reinforced polypropylene/magnesium hydroxide composites," *Journal of Engineered Fibers and Fabrics*, vol. 12, no. 2, pp. 50–58, 2017.
- [30] N. Saba, M. T. Paridah, and M. Jawaid, "Mechanical properties of kenaf fibre reinforced polymer composite: a review," *Construction and Building Materials*, vol. 76, pp. 87–96, 2015.
- [31] S. Joseph, M. S. Sreekala, Z. Oommen, P. Koshy, and T. Sabu, "A comparison of the mechanical properties of phenol formaldehyde composites reinforced with banana fibres and glass fibres," *Composites Science and Technology*, vol. 62, no. 14, pp. 1857–1868, 2002.
- [32] I. S. Aji, E. S. Zainudin, K. Abdan, S. M. Sapuan, and M. D. Khairul, "Mechanical properties and water absorption behavior of hybridized kenaf/pineapple leaf fiber reinforced high density polyethylene composite," *Journal of Composite Materials*, vol. 47, no. 8, pp. 979–990, 2012.



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