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Effect of layering sequence on mechanical properties of hybrid oil palm empty fruit bunch/kenaf fibre reinforced epoxy composites

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KEYWORDS

Hybrid composites
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Mechanical properties

ABSTRACT

This paper presents the characterization on mechanical properties of hybrid oil palm empty fruit bunch (OPEFB)/kenaf reinforced epoxy composites at varying fibre layering sequence. OPEFB and kenaf in the form of short fibre (designated as OPs and Ks) and woven kenaf (Km) were used to form the final hybrid composites. All samples were characterized in accordance with ASTM D3039-14 for tensile test, ASTM D790-10 for flexural test and ASTM D256-10 for impact test. Results obtained revealed that the hybrid composites maximum tensile strength (26.876 MPa), tensile modulus (2.974 GPa), flexural strength (77.911 MPa), impact toughness (1.672 kJ/m^2) and impact energy (1.24 J) value was obtained for Km/OPs/Km layering sequence, while the minimum value for all mechanical properties was obtained for OPs/Ks/OPs layering sequence. Moreover, highest value for flexural modulus (3.470 GPa) was obtained for Ks/OPs/Ks layering sequence. In conclusion, layering sequence with more woven kenaf layers improved the final hybrid composites mechanical properties compared to short fibre kenaf due to longer fibre length and fibre orientation. The final hybrid composites mechanical strength is also greatly influenced by the strength of the extreme outer layer fibres within the laminates, as well as the fibre orientation (either woven or randomly oriented).

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1.0 INTRODUCTION

Nowadays, the use of natural fibre composites (NFC) as green and sustainable materials has been wide spreading. NFC offers notable advantage in term of better environmental performance thanks to its renewable and recyclable natural based reinforcement element (the fibre). Furthermore, NFC also inherent high specific strength, low fibre material cost and low fibre density when compared to synthetic fibres which provide the advantage of lightweight performance to the end product (Mansor et al., 2019; Pickering et al., 2016). Many major industrial sectors are harnessing the advantages of using similar NFC materials for their component fabrication especially those involved in building and construction, automotive and consumer good applications (Technavio, 2020; Gholampour and Ozbakkaloglu, 2020). In the automotive field, NFC was also used for tribological applications such as brake and other sliding components (Palai & Sarangi, 2021; Abdollah et al., 2020; Mustafa et al., 2017).

Based on the aforementioned advantages, many natural fibres especially plant based fibre are being applied for NFC formulation, which originated from either being cultivated as commodity plants such as kenaf fibre (Radzuan et al., 20202; Krishna and Kanny, 2016) or from agriculture waste such as oil palm empty fruit bunch (OPEFB) fibre (Nordin et al., 2020; Bujang and Nordin, 2020; Akindoyo et al., 2019), pineapple leaf fibre (Fadzullah and Mustafa, 2016; Agrebi et al., 2020; Fadzullah et al., 2016; Siakeng et al., 2020; Fadzullah et al., 2020) and banana pseudo-stem (Hassan et al., 2020; Zulkafli et al., 2019). In the same time, many studies have been conducted to further improved the properties of NFC such as through hybridization method, by combining two type of natural fibre within a single matrix. Most often, the NFC hybridization method is applied to strike balance between cost and performance for the two combine reinforcement materials forming the final NFC. The hybridization solution is highly beneficial especially in promoting higher content of low-cost natural fibre from waste which inherent low structural properties, by combining them with far structurally superior but more expensive natural fibre or synthetic fibres to form the high-performance composites (Gohal et al., 2020; Feng et al., 2020; Sanjay et al., 2019; Maslinda et al., 2017).

OPEFB is one of the plant fibres from palm oil agriculture waste that has high potential to be more extensively applied for NFC. OPEFB source is highly abundance and extremely low cost compared to other plant fibres. However, OPEFB inherit low mechanical properties which is not suitable for medium to high load bearing structural applications. Owing to the untapped potential, many studies have been carried out to address the issue especially through hybridization solution. Karim et al. (2020) performed the hybridization of short fibre OPEFB with rice husk at varying OPEFB to risk husk fibre contents. The hybrid OPEFB/rice husk reinforced urea formaldehyde composites were aimed as an alternative raw material to replace wood in a several types of industries. The hybrid OPEFB/rice husk were characterized in term of its tensile strength and morphological properties. Their study showed that the addition of rice husk successfully improved the tensile strength of OPEFB composites, up to 13.7 wt% of rice fibre loading. Saba et al. (2016) formulated hybrid OPEFB/kenaf reinforced epoxy composites with the addition of nanofiller which are Montmorillonite (MMT) and organically modified montmorillonite (OMMT) nanoclay. The OPEFB and kenaf fibre were cut into short fibre size, then mixed with the nanofiller at varying filler contents and later hand-lay up to form the final composites. The performance of the hybrid OPEFB/kenaf reinforced epoxy composites with added nanofillers were characterized in term of their storage modulus (E′), loss modulus (E″), Tan delta (δ) and glass transition temperature (Tg). Results from their study revealed that the addition of all nanofillers considerably increased the hybrid composites dynamic mechanical properties. Saba et al. (2019)

also investigated the flame-retardant properties of similar hybrid OPEFB/kenaf reinforced epoxy composites with added nanofillers.

In another report, Ramlee et al. (2019) developed hybrid OPEFB/sugarcane bagasse reinforced phenolic composites at varying OPEFB to sugarcane bagasse fibre contents. The hybrid composites were aimed to be the solution in addressing agriculture residue which can be applied in wall as a thermal insulation and heat retention for buildings and construction sector. The hybrid OPEFB/sugarcane bagasse reinforced phenolic composites performance were characterized in term of their tensile properties, as well as the thickness swelling and water absorption. Elsewhere, Fang et al. (2017) developed hybrid OPEFB/seaweed composites. The authors utilized the benefits of combining agricultural waste to turn them into valuable solution for soil erosion protection application. The hybrid OPEFB/seaweed composites were tested to determine their properties based on thickness swelling and water absorption.

Motivated by similar advantages of OPEFB as mentioned before, hybrid NFC utilizing oil palm empty fruit bunch (OPEFB) and kenaf (K) fibre reinforced epoxy composites were developed in this study. The purpose was to evaluate the tensile, flexural and impact properties of hybrid OPEFB/ kenaf reinforced epoxy composites developed using varying fibre layering sequence. OPEFB and kenaf in the form of short fibre (designated as OPs and Ks) and woven kenaf (Km) were used to form the final hybrid composites. The composites laminated were fixed at three (3) layers for all layering sequence and were characterized in accordance with ASTM D3039-14 for tensile test, ASTM D790-10 for flexural test and ASTM D256-10 for impact test.

2.0 METHODOLOGY

2.1 Materials

Three (3) types of fibre were used to formulate the hybrid NFC in this study, which are oil palm empty fruit bunch (OPEFB) and kenaf fibre in short fibre form, as well as woven type kenaf fibre (at 0/90 fiber orientation). The OPEFB fibre with density of 1.55 g/cm^3 was received from Kilang Kelapa Sawit Kempas, Melaka, Malaysia, while the kenaf fibre with density of 1.45g/cm^3 was obtained from Lembaga Kenaf dan Tembakau Negara (LKTN), Melaka, Malaysia. All fibres were dried to remove moisture using laboratory oven for 6 hours at temperature of 60 °C. The OPEFB and kenaf were cut to short fibre form with average size between 2-5 mm through crushing process. All samples were prepared using epoxy matrix, with amine hardener added as the curing agent at 2:1 ratio of epoxy to hardener. The woven kenaf mat was supplied by Malaysian Lembaga Kenaf dan Tembakau Negara (LKTN), Melaka, Malaysia having thickness of 3.5 mm and in the 1x1 plain weave form. The fibres used were designated as OPs (for short fibre OPEFB), Ks (for short fibre kenaf) and Km (for woven kenaf) as shown in Figure 1.

(a) (b) (c)

Figure 1: (a) short fibre OPEFB (OPs), (b) short fibre kenaf (Ks), (c) woven kenaf (Km).

2.2 Sample Preparation

Four (4) different variations of fibre layering sequence for the hybrid composites were formulated in this study. The matrix loading was fixed at 62.34 wt% for all samples. Hand lay-up method followed by static load compression was used to produce composite laminates in a window frame mould (200 mm × 200 mm x 3mm). Four (4) types of composite laminates were fabricated labelled as OPs/Km/OPs, OPs/Ks/OPs, Km/OPs/Km and Ks/OPs/Ks. Figure 2 shows the fibre layering sequence of the hybrid composites prepared in this study.

Figure 2: Various hybrid OPEFB/kenaf reinforced epoxy composites layering sequence.

2.3 Mechanical Tests

All hybrid OPEFB/kenaf composites samples were subjected to tensile, flexural and impact mechanical tests. The tensile samples were cut to rectangular size of 100 mm length x 25 mm width according to American Standard Testing method (ASTM) D3039-14, while the flexural samples were cut to rectangular size of 100 mm length x 20 mm width according to ASTM D790-10 standard. For each layering sequence, five specimens were tested in both tensile and flexural tests followed by calculated average values. Three-point flexural test was performed with force applied at 2.2 mm/min. Meanwhile, the un-notched impact strength (in term of energy needed to break the samples and composites toughness) was measured using an Izod impact tester with accordance to ASTM D256-10 standard. The impact samples were prepared with dimensions of 80 mm of length x 10 mm of width with ten replications. All samples were cut using vertical band saw machine.

3.0 RESULTS AND DISCUSSION

Table 1 shows the summary of tensile, flexural and impact properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence obtained from the experiments conducted (noted the values in the parentheses refers to the standard deviation values). The results were later plotted in graphs with inclusion of the standard deviation values.

Figure 3 shows the graphical overview on the tensile strength and tensile modulus properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence. It can be observed that the maximum tensile strength and tensile modulus was obtained for layering sequence of Km/OPs/Km (tensile strength = 26.876 MPa and tensile modulus = 2.974 GPa), followed by Ks/OPs/Ks (tensile strength = 25.391 MPa and tensile modulus = 2.950 GPa), OPs/Km/Ops (tensile strength = 21.787 MPa and tensile modulus = 2.552 GPa) and the least for

OPs/Ks/Ops (tensile strength = 16.331 MPa and tensile modulus = 2.352 GPa). The combination of woven kenaf to the OPEFB laminate has greatly improved the overall tensile properties, as compared to short kenaf fibre. Similar findings were reported by Atiqah et al. (2014), in which the woven fibre orientation or arrangements of hybrid kenaf-glass mats also assist the composite to withstand higher force compared to randomly oriented fibre arrangement. This may be contributed due to uniform distribution of stress transfer with the application of tensile load in both the longitudinal and transverse directions for woven fibres. Furthermore, the use higher kenaf fibre layer also improved the overall hybrid OPEFB composites tensile properties, due to the presence of higher kenaf fibre loading which is stronger and stiffer compared to OPEFB fibre. The OPs/Ks/OPs laminate showed the lowest tensile properties among the other layering sequence due to high fibre loading of OPEFB involved and the short fibre length. OPEFB fibre has low mechanical properties compared to kenaf fibre.

Table 1: Summary of tensile, flexural and impact properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence.

Layering Sequence	**OPs/Ks/OPs**	**OPs/Km/OPs**	**Ks/OPs/Ks**	**Km/OPs/Km**
Tensile Strength, MPa	16.331 (0.817)	21.787 (1.501)	25.391 (3.073)	26.876 (1.269)
Tensile Modulus, GPa	2.352 (0.146)	2.552 (0.138)	2.950 (0.171)	2.974 (0.223)
Flexural Strength, GPa	55.790 (3.106)	54.552 (6.274)	59.444 (6.795)	77.911 (6.306)
Flexural Modulus, GPa	3.155 (0.173)	3.258 (0.145)	3.874 (0.532)	3.470 (0.475)
Impact Toughness,	1.353 (0.032)	1.502 (0.054)	1.556 (0.067)	1.672 (0.045)
Impact Energy, J	0.3 (0.110)	0.92 (0.075)	1.1 (0.089)	1.24 (0.037)

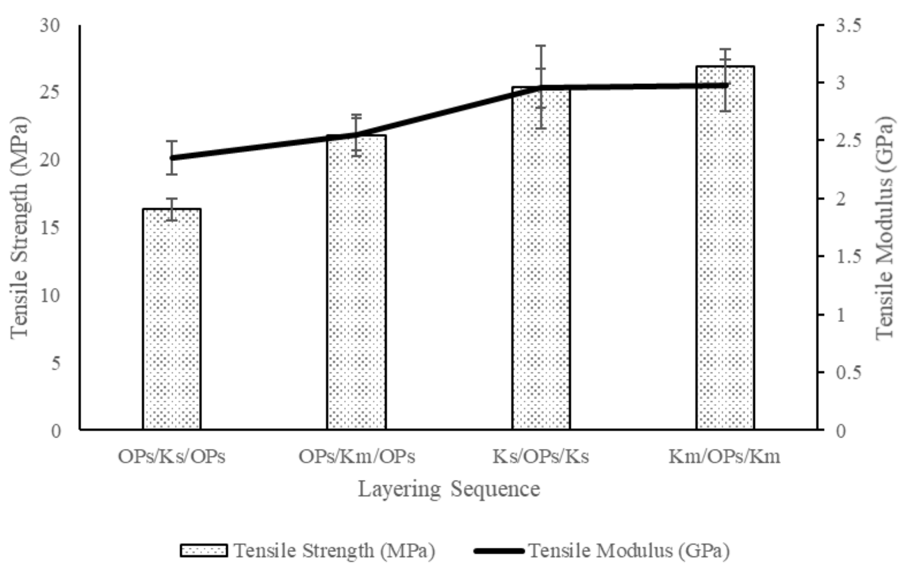

Figure 3: Tensile properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence.

Figure 4 meanwhile shows the plotted graph on the flexural properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence. It can be concluded that the maximum flexural strength of the hybrid composites was obtained for layering sequence of Km/OPs/Km, followed by Ks/OPs/Ks, OPs/Ks/OPs and the least for OPs/Km/OPs. In the other hand, the highest flexural modulus was found for hybrid OPEFB/kenaf composites using Ks/OPs/Ks layering sequence, followed by Km/OPs/Km, OPs/Km/OPs and the least for OPs/Ks/OPs layering sequence. This showed that final hybrid composites flexural properties can be improved by using higher kenaf fibre loadings (more layers of kenaf fibre) as compared to OPEFB layer. Similar finding was also reported by Jawaid et al. (2010) indicating that higher flexural strength of hybrid composite is due to the position of high strength fibre material in the outer layer on the overall laminate layering sequence. The use of long fibre kenaf mat (woven form) also contributes to higher flexural properties compared to short fibre. This is due to higher bending load bearing capability resulted from better effective stress transfer between the fibre and matrix (Amuthakkannan, 2013).

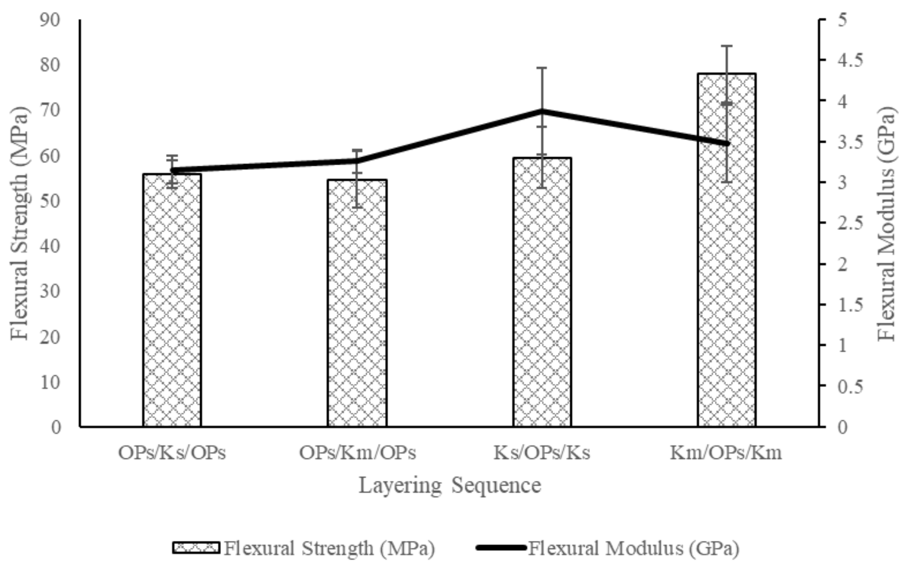

Figure 4: Flexural properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence.

In addition, Figure 5 shows the plotted graph on the impact properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence. Izod's impact test was conducted to analyse the effect of hybrid OPEFB/kenaf reinforced epoxy composites varying fibre layering sequence on the impact strength and energy absorption capabilities. The absorbed impact energy (J) is the total energy required to fracture the specimen whereby the toughness of composite or impact strength (kJ/m^2) was calculated by dividing the recorded absorbed impact energy with the cross-section area of the samples. Results obtained from the impact test evidently depicts that the sample that contain two layers of kenaf fibre (Km/OPs/Km and Ks/OPs/Ks) composites increases the impact strength and impact energy as compared with the sample with more OPFEB (OPs/Km/OPs and OPs/Ks/OPs). This was due to the higher impact strength of kenaf fibre compared to OPEFB fibre as report by Jawaid et al. (2010). Higher impact strength observed is contributed by the superior mechanical properties of the kenaf compared to OPEFB due to higher cellulose content and low lignin content. Mohammed et al. (2015) reported that kenaf fibre have higher cellulose contents (72 wt%) compared to oil palm fibre (65%). At the same time, kenaf fibre also has lower lignin contents (9 wt%) compared to oil palm (29 wt%). The crystalline cellulose structure contributes to higher load bearing performance compared to the amorphous lignin structure. Moreover, woven kenaf fibre showed better capability to improve the hybrid OPEFB impact properties compared to short kenaf fibre.

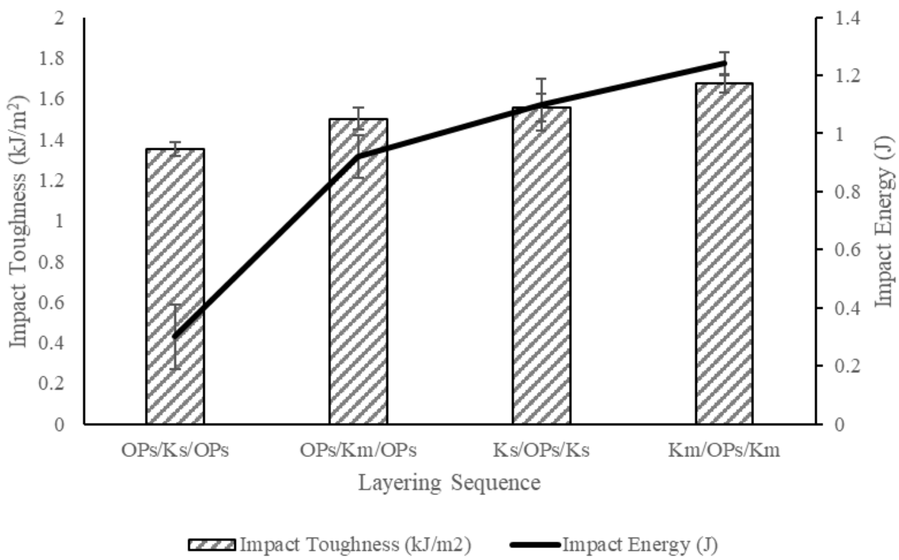

Figure 5: Izod impact strength properties of hybrid OPEFB/kenaf reinforced epoxy composites at varying layering sequence.

4.0 CONCLUSIONS

The effect of varying layering sequence for hybrid OPEFB/kenaf reinforced epoxy composites was investigated in this study. Results obtained revealed that the maximum tensile strength, tensile modulus, flexural strength, impact toughness and impact energy value was obtained for hybrid OPEFB/kenaf reinforced epoxy composites with Km/OPs/Km layering sequence, while the minimum value for tensile strength, tensile modulus, impact toughness and impact energy was obtained for OPs/Ks/OPs layering sequence. In the other hand, the highest value for hybrid OPFEB/kenaf reinforced epoxy composites flexural modulus was obtained for Ks/OPs/Ks layering sequence. It can be concluded that layering sequence with more woven kenaf layer was able to reinforce the mechanical properties of overall hybrid composites better compared to kenaf short fibre due to the longer fibre length and fibre orientation. Similarly, the use of higher kenaf fibre contents within the overall hybrid fibre loadings compared to OPEFB fibre also showed higher mechanical properties. From the study, it showed that the mechanical strength of the overall hybrid composites is greatly influenced by the strength of the extreme outer layer fibres within the laminates, as well as the fibre orientation (either woven or randomly oriented).

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REFERENCES

Abdollah, M. F. B., Amiruddin, H., Nordin, M. J., Tokoroyama, T., & Umehara, N. (2020). Application of oil palm fiber in organic brake friction composite material. Proceedings of Mechanical Engineering Research Day, 2020, 22-23.

Agrebi, F., Hammami, H., Asim, M., Jawaid, M., & Kallel, A. (2020). Impact of silane treatment on the dielectric properties of pineapple leaf/kenaf fiber reinforced phenolic composites. Journal of Composite Materials, 54(7), 937-946.

Akindoyo, J. O., Beg, M. D., Ghazali, S., Heim, H. P., Feldmann, M., & Mariatti, M. (2019). Oxidative induction and performance of oil palm fiber reinforced polypropylene composites–Effects of coupling agent and UV stabilizer. Composites Part A: Applied Science and Manufacturing, 125, 105577.

Amuthakkannan, P., Manikandan, V., Jappes, J. W., & Uthayakumar, M. (2013). Effect of fibre length and fibre content on mechanical properties of short basalt fibre reinforced polymer matrix composites. Materials Physics and Mechanics, 16(2), 107-117.

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.

Bujang, A. M. B., & Nordin, N. I. A. B. A. Effect of Steam Treatment on the Characteristics of Oil Palm Empty Fruit Bunch and Its Biocomposite. Indonesian Journal of Chemistry, 20(2), 292-298.

Fadzullah, S. S. M., & Mustafa, Z. (2016). Fabrication and processing of pineapple leaf fiber reinforced composites. In Green Approaches to Biocomposite Materials Science and Engineering (pp. 125-147). Hershey: IGI Global.

Fadzullah, S. S. M., Ramli, S. N. N., Mustafa, Z., Razali, A. S., Sivakumar, D., & Ismail, I. (2020). Low velocity impact behaviour of pineapple leaf fibre reinforced polylactic acid biocomposites. Journal of Advanced Manufacturing Technology (JAMT), 14(1), 1-12.

Fang, T. W., Asyikin, N., Syasya, N. S., Shawkataly, A. K. H., Kassim, M. H. M., & Syakir, M. I. (2017). Water absorption and thickness swelling of oil palm empty fruit bunch (OPEFB) and seaweed composite for soil erosion mitigation. Journal of Physical Science, 28(2), 1-17.

Feng, N. L., Malingam, S. D., Ping, C. W., & Razali, N. (2020). Mechanical properties and water absorption of kenaf/pineapple leaf fiber-reinforced polypropylene hybrid composites. Polymer Composites, 41(4), 1255-1264.

Gholampour, A., & Ozbakkaloglu, T. (2020). A review of natural fiber composites: Properties, modification and processing techniques, characterization, applications. Journal of Materials Science, 1-64.

Gohal, H., Kumar, V., & Jena, H. (2020). Study of natural fibre composite material and its hybridization techniques. Materials Today: Proceedings Part 2, 26, 1368-1372.

Hassan, M. Z., Sapuan, S. M., Rasid, Z. A., Nor, A. F. M., Dolah, R., & Md Daud, M. Y. (2020). Impact damage resistance and post-impact tolerance of optimum banana-pseudo-stem-fiber-reinforced epoxy sandwich structures. Applied Sciences, 10(2), 684.

Jawaid, M., Khalil, H. A., & Bakar, A. A. (2010). Mechanical performance of oil palm empty fruit bunches/jute fibres reinforced epoxy hybrid composites. Materials Science and Engineering: A, 527(29-30), 7944-7949.
Karim, M. A., Shah, M. M., Jundam, M. F., & Abdullah, S. (2020, April). Investigation of tensile properties of the eco-board of hybrid composite that consist of oil palm empty fruit bunch (OPEFB) fiber added with rice husk. In IOP Conference Series: Materials Science and Engineering (Vol. 834, No. 1, p. 012012). IOP Publishing.
Krishna, K. V., & Kanny, K. (2016). The effect of treatment on kenaf fiber using green approach and their reinforced epoxy composites. Composites Part B: Engineering, 104, 111-117.
Mansor, M. R., Mastura, M. T., Sapuan, S. M., & Zainudin, A. Z. (2019). The environmental impact of natural fiber composites through life cycle assessment analysis. In Durability and Life Prediction in Biocomposites, Fibre-Reinforced Composites and Hybrid Composites (pp. 257-285). Woodhead Publishing.
Maslinda, A. B., Majid, M. A., Ridzuan, M. J. M., Afendi, M., & Gibson, A. G. (2017). Effect of water absorption on the mechanical properties of hybrid interwoven cellulosic-cellulosic fibre reinforced epoxy composites. Composite Structures, 167, 227-237.
Mohammed, A. R., Atiqah, M. N., Gopakumar, D. A., Fazita, M. R., Rizal, S., Hermawan, D., ... & Khalil, H. A. (2020). Influence of layering pattern of modified kenaf fiber on thermomechanical properties of epoxy composites. Progress in Rubber, Plastics and Recycling Technology, 36(1), 47-62.
Mohammed, L., Ansari, M. N., Pua, G., Jawaid, M., & Islam, M. S. (2015). A review on natural fiber reinforced polymer composite and its applications. International Journal of Polymer Science, 2015, ID 243947.
Mustafa, A., Abdollah, M.F.B., Amiruddin, H., Shuhimi, F.F. and Muhammad, N. (2017). Optimization of friction properties of kenaf polymer composite as an alternative friction material. Industrial Lubrication and Tribology, 69(2), 259-266.
Nordin, N. A., Rahman, N. M. M. A., & Hassan, A. (2020). Conditioning effect on the mechanical and thermal properties of heat-treated oil palm empty fruit bunch/high-density polyethylene composite. High Performance Polymers, 32(2), 158-167.
Palai, B. K., & Sarangi, S. K. (2021). Suitability evaluation of untreated and surface-modified Eichhornia crassipes fibers for brake pad applications. Journal of Natural Fibers, 1-14.
Pickering, K. L., Efendy, M. A., & Le, T. M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. Composites Part A: Applied Science and Manufacturing, 83, 98-112.
Radzuan, N. A. M., Tholibon, D., Sulong, A. B., Muhamad, N., & Haron, C. H. C. (2020). New processing technique for biodegradable kenaf composites: A simple alternative to commercial automotive parts. Composites Part B: Engineering, 184, 107644.
Ramlee, N. A., Jawaid, M., Zainudin, E. S., & Yamani, S. A. K. (2019). Tensile, physical and morphological properties of oil palm empty fruit bunch/sugarcane bagasse fibre reinforced phenolic hybrid composites. Journal of Materials Research and Technology, 8(4), 3466-3474.
Saba, N., Jawaid, M., Alrashed, M. M., & Alothman, O. Y. (2019). Oil palm waste based hybrid nanocomposites: Fire performance and structural analysis. Journal of Building Engineering, 25, 100829.
Saba, N., Paridah, M. T., Abdan, K., & Ibrahim, N. A. (2016). Dynamic mechanical properties of oil palm nano filler/kenaf/epoxy hybrid nanocomposites. Construction and Building Materials, 124, 133-138.

Sanjay, M. R., Arpitha, G. R., Senthamaraikannan, P., Kathiresan, M., Saibalaji, M. A., & Yogesha, B. (2018). The hybrid effect of Jute/Kenaf/E-glass woven fabric epoxy composites for medium load applications: impact, inter-laminar strength, and failure surface characterization. Journal of Natural Fibers, 16(4), 600-6012.
Sheikh Md Fadzullah, S. H., Mustafa, Z., Ramli, S. N. R., Yaacob, Q. A., & Mohamed Yusoff, A. F. (2016). Preliminary study on the mechanical properties of continuous long pineapple leaf fibre reinforced PLA biocomposites. Key Engineering Materials, 694, 18-22.
Siakeng, R., Jawaid, M., Asim, M., & Siengchin, S. (2020). Accelerated weathering and soil burial effect on biodegradability, colour and texture of coir/pineapple leaf fibres/PLA biocomposites. Polymers, 12(2), 458.
Technavio (2020). Natural fiber composites market by type, end-user, and geography - forecast and analysis 2020-2024. [Online]. Available: https://www.technavio.com/report/natural-fiber-composites-market-industry-analysis.
Zulkafli, N., Malingam, S. D., Fadzullah, S. H. S. M., Mustafa, Z., Zakaria, K. A., & Subramonian, S. (2019). Effect of water absorption on the mechanical properties of cross-ply hybrid pseudo-stem banana/glass fibre reinforced polypropylene composite. Materials Research Express, 6(9), 095326.