Effect of Fiber Orientation on the Tensile Properties of Kenaf Fiber Reinforced Polyester Composite

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ABSTRACT

The increasing awareness on the relevant of protecting the environment and the demand for sustainable structures have motivated researchers to develop new bio-based composites that can minimize the harmful effect to the environment. Thus, this study highlights the effects of fiber orientation on the tensile properties of unsaturated polyester resin (UPR) reinforced with unidirectional (UD) continuous kenaf fiber. To this end, the kenaf fiber reinforced polyester composite was fabricated in a unidirectional orientation with fiber volume fraction of 40%. Consequently, the kenaf fiber reinforced polyester composite was subjected to tensile tests in the longitudinal (0°) fiber orientation, transverse (90°) fiber orientation and diagonal (45°) fiber orientation. Also, the plain polyester matrix tensile test was considered and used as reference point. The result of tests showed that the tensile stiffness for 0º and 90º fiber orientation is 21257.80 MPa and 2864.45 MPa, while the tensile strength are 179.30 MPa and 11.84 MPa respectively. Also, the 45° tensile stiffness and 45° tensile strength are 1736.83 MPa and 10.77 MPa respectively. The results demonstrated that the composites with 0º fiber orientation had the best mechanical performance, followed by those with 90º and 45º fiber orientations respectively. Hence, this current improvement in performance of UD KFRP composite at 0º fiber orientation may potentially replace conventional synthetic fibers, especially for structural applications.

Keywords: Natural fibers, Kenaf fiber, polymeric composites, tensile properties, mercerization.

1. INTRODUCTION

The increasing need for structures to have properties such as low self-weight, high strength and stiffness, and durability has made composite materials more attractive in a wide range of engineering applications (Ramesh *et al.*, 2017; Nor *et al.*, 2022). Synthetic fiber such as glass, carbon or aramid have played a dominant role for a long time as fiber reinforcement in composites production for variety of structural applications. However, in recent years, growing environmental issues coupled with the uncertainty about petroleum resources and high energy consumption during processing have triggered much interest in developing composite materials from bio-fibers. Also, the widespread usage and disposal of conventional composite materials presents a significant challenge. Natural fiber such as kenaf fiber on the other hand, have been gaining considerable attention for their potential contribution to addressing environmental issues, such as carbon dioxide neutrality, availability in fibrous form, low cost of extraction from plants and the saving of fossil resources (Pickering *et al.*, 2016; Masannan *et al.*, 2024). Kenaf fiber has been around for about 4,000 years, according to Vision (2003), and its origins can be traced back in Africa. Kenaf plant (Hibiscus cannabinus L.) is a member of the hibiscus family, which includes cotton, jute, and okra, and is grown in Malaysia, India, Indonesia, Vietnam, Bangladesh, Thailand, the United States of America, South Africa and a few other African countries, for example in Nigeria, an official estimate of 1,460 tonnes of total kenaf fiber output was produced in 2020, making it 4th in Africa and 13th globally. Kenaf fiber is as well produced in various regions of south-east Europe (Anuar & Zuraida, 2011; Sravya & Kumar, 2015; Busuguma *et al.*, 2021). According to Akil *et al.* (2011), bast and core fibers are the two main components of the kenaf stalk. Bast fibers make up roughly 30-40% of the dried plant's weight and form the stalk's outer layer. Bast fiber is made up of cellulose, hemicellulose, and lignin, having weight percentages of (56-60%), (21-35%), and (8-15%), respectively (Davoodi *et al.,* 2010; Mazuki *et al.,* 2011). Bast fibers, which have a high strength to low density ratio, are the main attraction of the kenaf plant. Pectin, which is a natural binder present in the plant, is responsible for keeping the fibers together. Despite their lower strength than bast fibers, the core fibers give crucial bending rigidity to the stalk. In a related line, Ashori *et al.* (2006) conducted studies on both the bast and the core fibers, concluding that the bast of kenaf fibers were slimmer and lengthier, while the core fibers were significantly broader and briefer. Kenaf was determined to be significantly more abundant and competitively priced in the appropriate form when compared to other types of natural fiber materials (Jusoh *et al.,* 2016). Jush *et al.* (2016) also reported that kenaf was designated as commercial kenaf because of its potential as a raw material for a wide range of goods in the manufacturing and industrial sectors. Above all, kenaf, like most other bio-fibers, has excellent mechanical properties, it could be recyclable easily, has a low price and low density (Nashino *et al.,* 2003; Mitchelle, 1986; Uzoma *et al.;* 2023).

The surface property of bio-fibers is important as it influences the interfacial adhesion amid the resin and the fibers' surface, which affects the properties of the natural fiber composite. Because of their molecular and chemical structure, all vegetable plant-derived cellulose fibers, such as kenaf fiber, are polar in nature (Ashori *et al.,* 2006). The non-cellulosic components of natural fibers include hemicelluloses, lignin, and pectin, the latter of which is hydrophilic. Hemicelluloses and pectin both include hydroxyl and carboxylic functional groups that are susceptible to water absorption. Because very little water may accumulate within the exceedingly organized and fully crystalline microfibrils, the cellulose component also has reasonable hydroxyl groups (Wambua *et al.,* 2003). Natural fiber pre-treatment, on the contrary, chemically cleans the surface, prevents moisture absorption, and raises the roughness of the fiber surface (Summerscales et al., 2010). Cao *et al.* (2007) demonstrated the effect of alkaline solution on the mechanical behavior of kenaf fibers. The sodium hydroxide was varied from 5wt%, 10wt%, and 15wt%. The researchers concluded that the 5wt% of alkaline treatment delivered the best result.

Fiber orientation is a crucial element influencing the composite characteristics of long fiber. Continuous and well aligned fiber composite present highly anisotropic mechanical properties. The mechanical properties of UD aligned fiber are known to be much higher than those of randomly oriented fibers, depending on the load applied to the composite sample (Tharazi, *et, al.* 2023). Similarly, Cardin, Bechtold & Pham (2018), carried out a research and stated that unidirectional (UD) long fiber could retain greater mechanical strength as compared to short fibers, nevertheless, while using a long UD fiber, insightful research on fiber orientation is needed as it may either improve or deteriorate the whole strength of structure. During in-service applications, transverse loads may also be present. Therefore, factors that may influence the transverse strength, which includes properties of fiber-matrix, fiber-matrix bond strength and void, should be further studied. Improving the factors that affect strength properties may potentially widen the usage of long fiber in many structural applications (Patel, Yadav & Winczek, 2023)

2. MATERIALS AND METHODS

2.1 Materials

The kenaf fibers used in this research was sourced from the National Kenaf and Tobacco Board (NKTB), Malaysia, in a curled continuous form as shown in Figure 1. The fibers supplied was extracted through the bacteria retting process and were in maximum length of about 1.5m. An appropriate washing of the kenaf fiber was carried out so as to expel dirt's from the fiber surfaces and it was then dried. Kenaf fiber is typically composed of cellulose, hemicellulose, lignin and pectin with roughly percentage of (32-57%), (21-23%), (4.79-19%) and (2.0%) by weight respectively. In addition, the hemicellulose and pectin contain predominantly functional groups of hydroxyl and carboxylic structures that are sensitive to water absorption. Hence, there is a need for modification of the kenaf fiber surface. To achieve this, mercerization which utilizes sodium hydroxide reagent was employed for the treatment. The sodium hydroxide was supplied by Merck Sdn. Bhd. in Johor Bahru, Malaysia. Unsaturated polyester resin (UPR) with a brand name polyester 2597APT waxed supplied by Wee Tee Tong Chemical Pte. Ltd. from Singapore was employed in the manufacturing of the kenaf fiber-polyester composite. In this study, the catalyst used was under the brand name Esterox MEKP and was also supplied by Wee Tee Tong Chemical Pte. Ltd. from Singapore. UPR is one of the most versatile synthetic co-polymers found suitable in a number of engineering applications.

Figure 1: Curled continuous kenaf fiber from water retting process

2.1.1 Kenaf fiber surface treatment

The kenaf bundle was separated and reduced to smaller bundles and cut to reasonable length. Then, one of the ends of the bunch is tied with plastic clip to make it ready and handy for the chemical treatment process.

2.1.2 Alkaline treatment

The dried kenaf fiber was exposed to mercerization (alkaline treatment) in order to enhance the absorption characteristics of the vegetable fiber. This was carried out to promote the hydroxyl group ionization to the alkoxide (Agrawal *et al.,* 2000). According to literature, researchers have employed different percentage of concentration of sodium hydroxide (NaOH) solutions (3%, 5%, 6%, 7%, 9%, 10%, 15%) and immersion times (1hour, 3 hours, and 24 hours) for the treatment of kenaf fibers (Mahjoub *et al.,* 2014; Meon *et al.,* 2012; Razak *et al.,* 2014; Razavi, 2016). However, the percentage of sodium hydroxide used in this research was limited to 5% concentration and immersion time of 3 hours.

2.1.3 Preparation of kenaf fiber reinforced polyester (KFRP) composites

Before fabricating the KFRP panel, the treated kenaf fiber bundles were combed with an iron comb and cut into length of 295 mm. Then the quantity be utilized was calculated and weighed based on the density and volume fraction of kenaf fiber and polyester resin. A mild steel mold of dimension 295 mm long x 210 mm wide x 6 mm thick was used, a transparent plastic veil was laid into the cavity and the mold was polished with a releasing agent. Mold releasing agent was used inside the mold for easy removal of the final product. Polyester resin was mixed with the catalyst Methyl Ethyl Ketone Peroxide (MEKP) in a ratio 100:1 as specified by the manufacturer with the aid of a mechanical mixer. The cut and combed fibers were laid, aligned layers by layers in the mold. Then mixture of polyester resin and catalyst was gently poured on the fiber while ensuring evenly distribution with the aid of a roller for ease and good penetration of the resin. Consequently, a mild steel lid cover weighing 22 kg was gently laid on the mold and clamped to the work bench that the mold was rested on. The specimen was left to cure for 24 hours at room temperature. The specimen panel was demolded after the curing period, cleaned and stored until the time of usage. Finally, the panels were machined to conform to any specimen size or shape as specified by ASTM using a bench saw and a hand grinding machine.

3.0 MECHANICAL TESTING

It is appropriate to carry out some sample tests in order to get the KFRP composites tensile properties. The tensile tests considered here are 0° longitudinal unidirectional (UD) fiber orientation, 90° perpendicular (UD) orientation, 45° diagonal (UD) fiber orientation and pure polyester matrix tensile test.

3.1 Tensile test of polyester polymer

Four samples were prepared based on ASTM D638-14 (ASTM, 2014b). In the preparation process, the required quantity of polyester resin and catalyst (MEKP) was calculated and a ratio of 100:1 as specified by the manufacturer was used. The resin and catalyst were mixed thoroughly and poured into a mild steel mold with dimension of 295 mm x 25 mm x 6 mm. The mixture was left to cure for 24 hours at room temperature 25^{o}C. Then, panel was demolded and fashioned to the required dog bone shape as specified by the Type II specimen dimension as shown in Figure 2. The thickness of each specimen is 6 mm and two strain gauges were placed on each of the specimen at the longitudinal and transverse direction to measure the strain as shown in Figure 2. Finally, the coupons were mounted into the instron 5570 universal testing machine with an in stored capacity of 30kN. The specimens were tested at a constant 1 mm/min head speed. The stress-strain data was obtained using the data acquisition system of the universal testing machine. In addition, the Poisson's ratio of the polyester resin was calculated.

Figure 2: Prepared polyester polymer tensile test samples with strain gauges attached

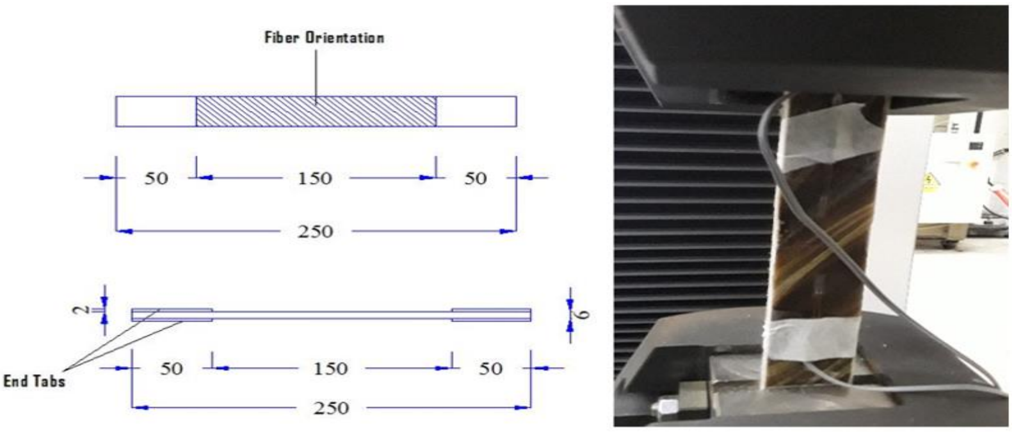
3.2 Tensile test of kenaf fiber polyester composite

The KFRP tensile test was conducted in two main groups. Five samples were fashioned out from the cured panel in the longitudinal (UD) direction, and four was cut in the perpendicular (UD) direction. The tensile tests were carried out in compliance with ASTM D3039/D3039-14 (ASTM, 2014c). The standard recommended a dimension of 250 mm long by 25 mm wide for the longitudinal (UD) direction and 175 mm long by 25 mm wide for the perpendicular (UD) direction. The standard geometry of the tensile samples is presented in Figure 3a and Figure 3b respectively.

(b) (a)

Figure 3: (a) Longitudinal tensile test setup, (b) perpendicular tensile test setup

The diagonal (45°) fiber orientation tensile test was performed on the KFRP in compliance with ASTM D3518/D3518M-13 (ASTM, 2013). This test was carried out in order to establish the shear properties of KFRP. The KFRP unidirectional fabricated panel used in tension was cut at angle 45 degrees. Therefore, the samples were cut in the diagonal direction of the panel of dimensions 250 mm x 25 mm x 6 mm as depicted in the diagram in Figure 4(a). A total of four samples were used for the test. Procedure employed for the in-plane shear test set-up were similar to that of KFRP tensile test. Two strain gauges were placed to each of the coupon in the opposite direction to measure the longitudinal strain as shown in Figure 4(b). The test was conducted using a universal testing machine (Shimadzu) with load cell capacity of 250 kN at a 1mm/min constant head speed.



(a) (b)

Figure 4. (a) Schematic diagram of diagonal (45°) orientation tensile test sample, (b) Diagonal (45°) tensile test setup

3. RESULTS AND DISCUSSION

3.1 Pure polyester tensile response

Figure 5. depicts the tensile stress-strain curves of the pure polyester 2597APT waxed used in the study. Because the polymer is brittle, it is extremely sensitive to even minor flaws, which explains the slight discrepancy in the strain-to-stress curves. The average tensile strength is 37.64 MPa. The average tensile modulus EM, computed from the slope of the stress-stain curves is 2079.35 MPa. Meanwhile, the average Poisson's ratio is 0.34. Figure 9a shows the typical failure mode experienced under tension load for the pure polyester composite.

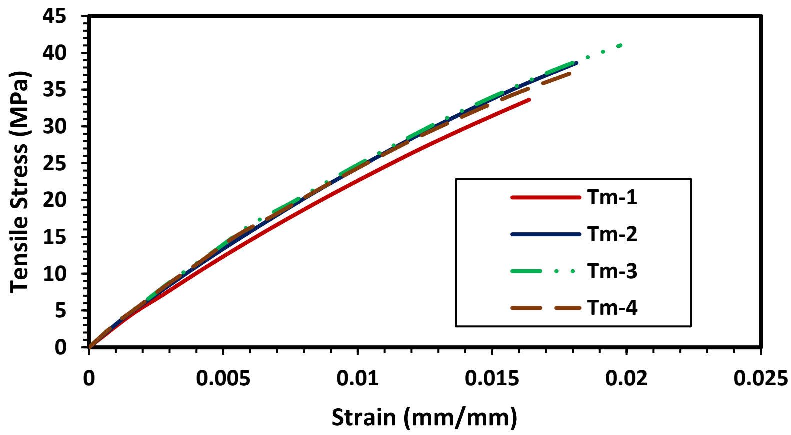


Figure 5: Pure polyester (matrix) tensile stress-strain curves

3.2 Tensile response of KFRP

Figure 6. shows the stress versus strain plot responses for the five longitudinal (UD) KFRP tensile specimens tested in the longitudinal direction. All the specimens from T0-1 to T0-5 exhibited a good match and similar behavior. In addition, it can be deduced that that the stress-strain plot for all the five specimens show predominantly linear behavior until failure. The average longitudinal tensile, X_t, and longitudinal modulus E_1, are 179.3 MPa and 21257.8MPa respectively. The average maximum tensile strain is 0.008352 mm/mm and the average Poison's ratio is 0.32 respectively. Figure 9b shows the typical failure mode in the inter-fiber ruptured or fracture close to the middle of the gauge length but there was no evidence of fiber pull out from the matrix. Five specimens. It observed that all longitudinal (UD) KFRP tensile specimens failed due to inter-fiber upture or fracture close to middle of the gauge length but there was no evidence of fiber pull out from the matrix.

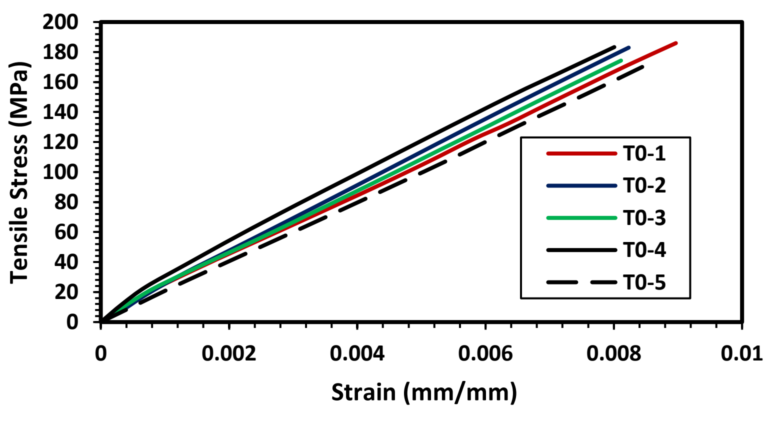


Figure 6: Longitudinal (0°) UD fiber orientation tensile stress-strain curves

Also, the perpendicular directional tensile stress-strain plots are presented in Figure 7. The stress-strain response of the specimens is predominantly linear, increasing till the maximum stress. The average transverse tensile strength, *Yt*, and modulus, E_2 are found to be 11.84 MPa and 2864.45 MPa, while the strain is 0.0041 mm/mm respectively. All observed failure modes of perpendicular tension specimens were inter- fiber rupture, away from the gripping region as shown in Figure 9c. The average diagonal tensile strength was found to be 10.78 MPa and the average diagonal tensile modulus, was computed from the slope of the curves to be 1736.83 MPa, from Figure 8. Figure 9d shows the diagonal fracture cracking failure mode at the gauge region experienced by the specimens. All the specimens failed at 45° shear mode due to fibers and matrix breakage between -45° and +45° ply orientations. This failure mode is known as an off-axial failure mode.

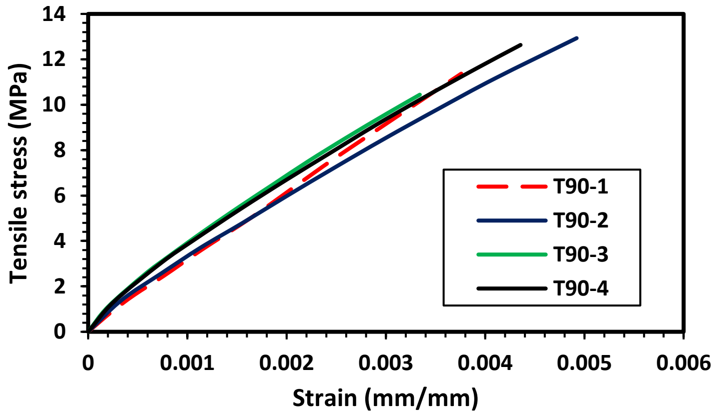


Figure 7: Perpendicular (90°) UD fiber orientation tensile stress-strain curves

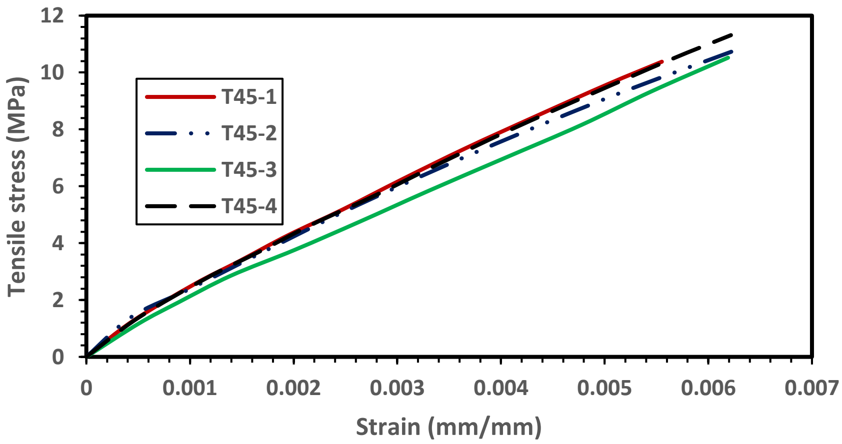
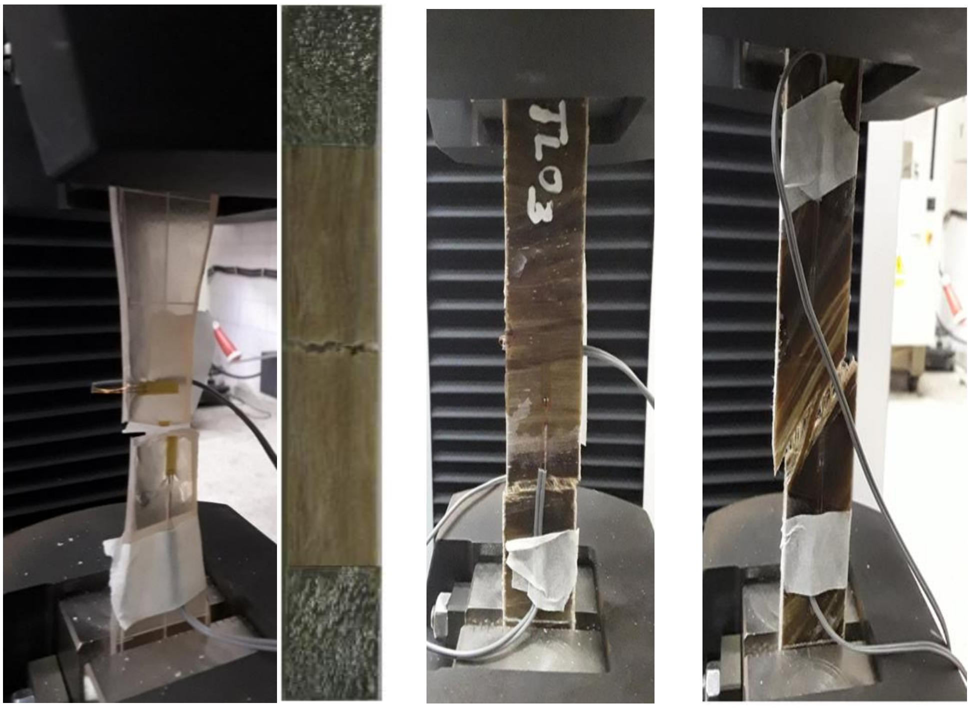


Figure 8: Diagonal (45°) UD fiber orientation tensile stress-strain curves



(a) (b) (c) (d)

Figure 9: (a) Failure mode experienced by polyester 2597APT waxed, (b) Typical failure mode of KFRP longitudinal (UD) fiber orientation tensile specimen, (c) The KFRP perpendicular (UD) fiber orientation tensile specimen failure mode, (d) The KFRP diagonal (UD) fiber orientation failure mode

3.3 Effect of fiber orientation on the tensile strength of KFRP composites

The effect of fiber orientation on the tensile strength of KFRP is shown in Figure 10. The fiber orientation considered here are the longitudinal (0°) fiber orientation, transverse (90°) and the diagonal (45°) fiber orientation. Also, the tensile strength of polyester polymer is tested and used as reference point. Among the samples obtained, composites bearing fibers oriented at 0^o showed the highest tensile strength (179.30MPa). The results reveal that incorporating long kenaf fibers effectively improves the strength of KFRP composites under a tensile load. The strength of KFRP composites with fibers oriented at 45^o and 90^o were (71.37% and 68.53%) lower than that of pure polyester composite. This decrease in strength was even more evident in KFRP composites at 45^o and 90^o (Figure 11). Such results indicate that fibers oriented at 0^o can better resist applied stress and transfer the same to other fibers in the matrix compared with fibers oriented at 45^o and 90^o. KFRP composites with fibers aligned diagonal or perpendicularly (i.e. 45^o and 90^o) to the applied force easily split along their longitudinal axis. Thus, fibers with these orientations fail as reinforcing agent because load transfer between the fiber and polyester matrix is restricted (Patel *et al.,* 2023).

3.4 Effect of fiber orientation on the tensile modulus of KFRP composites

Figure 11 shows the effect of fiber orientation on the tensile modulus of KFRP composites. Various tensile moduli values were exhibited at different fiber orientation. The KFRP composites with a fiber orientation 0^o tensile modulus is about 10 times higher than the pure polyester composite, while the KFRP composites with fibers oriented at 90^o demonstrated approximately 37.78% higher young modulus than the pure polyester composite as shown in Figure 11. These findings indicate that KFRP composites with 0^o and 90^o fibers orientation have greater stiffness compared with the pure polyester composite, while 45^o oriented fiber KFRP composite is lower in stiffness when compared with the pure polyester composite. A better stiffness may be explained by the structure property relationship, which is influenced by cellulose contents and interfacial actions between fiber and polyester polymer that allows the transmission of load throughout the matrix (Muthalagu *et al.*, 2021).

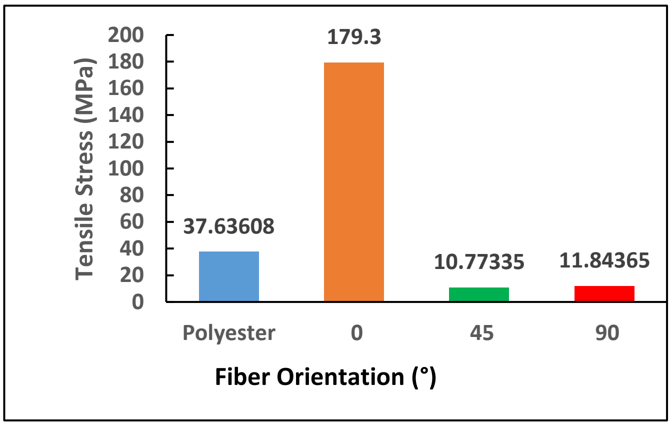


Figure 10: Effect of fiber orientation on the tensile strength of KFRP composites

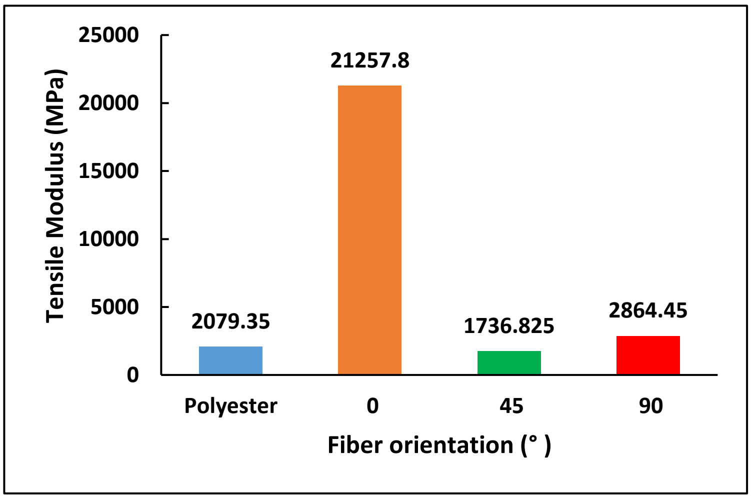


Figure 11: Effect of fiber orientation on the tensile modulus of KFRP composites

4. CONCLUSION

This study investigated the effect of different fiber configurations on the tensile properties of KFRP composites. The unidirectional longitudinal stress-strain curve, the unidirectional perpendicular stress-strain curves, and the unidirectional diagonal stress-strain curves, as well as the pure polyester polymer stress-strain curves. All samples behaved predominantly linear up to failure. The optimal tensile strength and tensile modulus were obtained at 0^o fiber orientation KFRP composite with 179.3MPa and 21257.8MPa respectively. With the fiber orientations at 45^o and 90^o, the failure of fiber reinforcement within the KFRP composites was due to the existence of voids and debonding of fibers during the mechanical testing. This has caused reinforcement-matrix load transmission failure that deteriorates the whole structure of the KFRP composites. Nevertheless, KFRP composites with 0^o fiber orientation have sufficiently good mechanical properties. Therefore, a KFRP composites with 0^o (UD) alignment is ideal for structural applications. Future studies may focus on the moisture absorption and weathering resistance of these composites to assess their potentials as alternative materials for exterior components of structures.

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REFERENCE

Agrawal, R., Saxena, N. S., Sharma, K. B., Thomas, S., & Sreekala, M. S. (2000). Activation energy and crystallization kinetics of untreated and treated oil palm fiber reinforced phenol formaldehyde composite. *Materials Science and Engineering :A*, *277*(1–2), 77–82.

Akil, H. M., Omar, M. F., Mazuki, A. A. M., & Safiee, S. (2011). Kenaf fiber reinforced composites: A review. *Material and Design*, *32*(8–9), 4107–4121
https://doi.org/https://doi.org/10.1016/j.matdes.2011.04.008

Anuar, H., & Zuraida, A. (2011). Improvement in mechanical properties of reinforced thermoplastic elastomer composite with kenaf bast fibre. *Composites Part B: Engineering*, *42*(3), 462–465. https://doi.org/10.1016/J.COMPOSITESB.2010.12.013

Ashori, A., Harun, J., Raverty, W. D., & Yusoff, M. N. D. (2006). Chemical and morphological characteristics of Malaysia cultivated kenaf (Hibiscus cannabinus L.) fibre. *Polymer Plastics Technology and Engineering*, *45*(1), 131–134.

ASTM. (2013). Standard Test method for in-plane shear response of polymer matrix composite materials by tensile test of a±45 laminate. *ASTM D 3518/D 3518. 94.*

ASTM. (2014b). Standard test method for tensile properties of plastics. *ASTM Intetional. Designation: D. 638, 1-*

ASTM. (2014c). Standard test method for tensile properties of polymer matrix composite materials. *ASTM D3039/D 3039M.*

Busuguma, U. A., Yakubu, M .K., kogo, A. A., Bukhari, M. M & Shuaibu, M. A. (2021). Determination of Phytochemicals and Elemental Composition of Kenaf Non-woven Fiber Using Proximate and X-ray Fluorescence. *Nigerian Research Journal of Chemical Sciences*. *9 (2)*, 240-251. (ISSN: 2682-6054)

Cao Y., Sakamoto, S., & Goda K. (2007). Effects of heat and alkali treatments on mechanical properties of kenaf fibres,. *16th International Conference on Composite Materials*.

Cordin, M., Bechtold, T. & Pham, T. (2018). Effect of fiber orientation on the mechanical properties of polypropylene-lyocell composites. *Cellulose. 25:* 7197-7210. http:// doi.org/10.1007/s10570-018-2079-6

Davoodi, M. M., Sapuan, S. M., Ahmad, D., Ali, A., Khalina, A., & Jonoobi, M. (2010). Mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam. *Materials & Design*, *31*(10), 4927–4932. https://doi.org/10.1016/J.MATDES.2010.05.021

Jusoh, A. H., Rejab, M. R. M., Sirgar, J. P., & Bactiar, D. (2016). Natural fibre reinforced composites: A review on potential for corrugated core of sandwich structures. *MATEC Web of Conference*, 1–5.

Kumar, S. B & Kumar, J. S. (2023). Characterization ofkenaf fiber reinforced compositr with and without alkali treatment. *International Journal of Scientific Research in Science, Engineering and Technology. 10(5)*, 118-126. http;//doi. org/ 10.32628

Lee, B. H., Kim, H. J., & Yui, W. R. (2009a). Fabrication of long and discontinuous natural fiber reinforced polypropylene bio-composites and their properties. *Fibers and Polymers*, *10*(1), 83–90.

Lee, B. H., Kim, H. J., & Yui, W. R. (2009b). Fabrication of long and discontinuous natural fibre reinforced polypropylene bio-composites and their properties. *Fibers and Polymers*, *10*(83–90).

Mahjoub, R., Yatim, J. M., Mohd Sam, A. R., & Hashemi, S. H. (2014). Tensile properties of kenaf fiber due to various conditions of chemical fiber surface modifications.
Construction and Building Materials, *55*, 103–113. https://doi.org/10.1016/J.CONBUILDMAT.2014.01.036

Malik, M., Choudhary, V., & Varma, I. K. (2000). Current status of unsaturated polyester resins. *Journal of Macromolecular Science, Part C: Polymer Reviews*, *40*(2–3), 139–165.

Masannan, V., Anbalagan, C., Lakshmaiya, L. & Kumar., P. (2024). Experimental investigation on the drilling characteristics of kenaf/PLA-based laminates. *Engineering proceeding MDPI. 16(9)*, 2-8. http://doi.org/10.3390

Mazuki, A. A. M., Akil, H. M., Safiee, S., Ishak, Z. A. M., & Bakar, A. A. (2011). Degradation of dynamic mechanical properties of pultruded kenaf fiber reinforced composites after immersion in various solutions. *Composites Part B: Engineering*, *42*(1), 71–76. https://doi.org/10.1016/J.COMPOSITESB.2010.08.004

Meon, M. S., Othman, M. F., Husain, H., Remeli, M. F., & Syawal, M. S. (2012). Improving tensile properties of kenaf fibers treated with sodium hydroxide. *Procedia Engineering*, *41*, 1587–1592.

Mitchelle, A. J. (1986). Composites of commercial wood pulp fibres and cement. *Appita*, *33*(6), 461–463.

Mohd Nor, M. A., Sapuan, S. M., Yusoff, M. Z. M. & Zainudin, E. S. (2023). Mechanical, thermal and morphological properties of woven kenaf fiber reinforced polylactic acid (PLA) composites. *Fibers and Polymers. 23 (10)*, 2875-2884. http:// doi. 10. 1007/s1. 2221-4370-2

Muthalagu, R., Srinivasan, V., Kumar, S. S. & Krishna, M. V. (2021). Extraction and effects of mechanical characterization and thermal attributes of jute, prosopsis juliflora bark and kenaf fibers reinforced bio-composites used for engineering applications. *Fibers and Polymers. 22 (7)*, 2018-2026

Nashino, T., Hireo, K., Kotera, M., Nakamae, K., & Inagaki, K. (2003). Kenaf reinforced biodegradable composite. *Composites Science and Technology*, *63*(9), 1281–1286.

Patel, R. V., Yadav, A. & Winczek, J. (2023). Physical, mechanical, and thermal properties of natural fiber-reinforced epoxy composites for construction and automotive applications. *Applied Sciences. 13*, 5126, 2-28. https://doi.org/103390/app

Pickering, K. L., M. G. Aruan, E., & Le, T. M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. *Composites: Part A*, *83*, 98–112.

Ramesh, M., Palanikumar, K., & Reddy, K. H. (2017). Plant Fiber Based Bio Composites: Sustainable and Renewable Green Materials. *Renewable and Sustainable Energy Reviews*, *79*, 558–584. https://doi.org/https://doi.org/10.1016/j.rser.2017.05.094

Razak, S. I. A., Abdul Rahman, W., Hashim, S., & Yahya, M. Y. (2014). Enhanced interfacial interaction and electronic properties of novel conducting kenaf/polyaniline bio-fibers. *Polymer Plastics Technology and Engineering*, *52*(1), 51–71.

Razavi, M. (2016). *Performance of kenaf fiber reinforced polymer composites in various environments*. PhD Thesis. Universiti Teknologi Malaysia. Malaysia.

Sravya, S., & Kumar, B. S. (2015). Evaluation on the Mechanical Properties of Hybrid Composites (kenaf, E-glass, Jute). *International Journal of Latest Trends in Engineering and Technology*, *5*, 164–170.

Summerscales, J., Dissanayake, N. P. J., Virk, A. S., & Hall, W. (2010). A review of bast fibres and their composites. Part 1 – Fibres as reinforcements. *Composites Part A: Applied*

Science and Manufacturing, *41*(10), 1329–1335. https://doi.org/10.1016/J.COMPOSITESA.2010.06.001

Thaazi, I., Azam, F. A. A., Muhamad, N., Hui, D., Sulong, A. & Gaff, M. (2023). Effect of fiber orientation and elevated temperature on the mechanical properties of unidrectional continuous kenaf reinforced PLA composites. *Reviews on Advanced Materialss Science. 62;* 20220275, 1-13

Uzoma, A. E., Nwaeche, C. F., Al-Amin, Md., Muniru, O. S., Olatunji, O. & Nzeh, S. O. (2023). Development of interior and exterior automative plastics parts using kenaf fiber reinforced polymer composite. *Eng. MDPI. 4,* 1698-1710

Vision paper. (2003). About the kenaf fiber plant. *Retrieved September 25, 2018, from Http://Www.Visionpaper. Com/Kenaf2.Html*.

Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics? *Composites Science and Technology*, *63*(9), 1259–1264. https://doi.org/10.1016/S0266-3538(03)00096-4