MALAYSIAN JOURNAL OF MICROSCOPY

Journal homepage: https://malaysianjournalofmicroscopy.org

RESEARCH ARTICLE

MORPHOLOGICAL, CHEMICAL, AND THERMO-MECHANICAL PROPERTIES OF TREATED UNTWISTED KENAF YARN

Syukrina Harun[1], Nor Dalila Nor Affandi[1,*], Wan Mohd Nazri Wan Abd Rahman[2], Jamaluddin Mahmud[3], Muhammad Hussain Ismail[3], Mohd Rozi Ahmad[1], Mohd Iqbal Misnon[1], Noor Najmi Bonnia[1,4]

[1]Textile Research Group, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam 40450, Selangor, Malaysia.
[2]Faculty of Applied Sciences, Universiti Teknologi MARA Cawangan Pahang, 26400 Bandar Tun Abdul Razak Jengka, Pahang, Malaysia.
[3]Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam 40450, Selangor, Malaysia.
[4]Materials Science and Technology, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam 40450, Selangor, Malaysia.

Abstract. Kenaf (*Hibiscus cannabinus L.*) is widely recognised for its high cellulose content, strength-to-weight ratio, and abundant availability. However, studies on the fundamental effects of water and thermal treatment on untwisted kenaf yarns remain limited. Hence, this study aims to investigate the behaviour of untwisted kenaf yarns under moisture and heat exposure by analysing their morphological, chemical, and thermo-mechanical properties. The control kenaf fibres and untwisted kenaf yarns subjected to water and heat treatments were characterised using scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), and tensile testing. SEM observations showed that water treated kenaf yarn exhibited more aligned, compact, and smoother fibre bundles than the loosely packed control kenaf fibres. The fibre diameter of the treated kenaf yarn was 12.46 % smaller than that of the control kenaf fibres. FTIR analysis showed an increase in the O-H stretching intensity (3330–3400 cm^{-1}) and a prominent C=O peak at 1730 cm^{-1}, indicating partial modification of hemicellulose and a rearrangement of hydrogen bonds within the treated kenaf yarn fibres. TGA results showed two degradation stages at around 240 °C and 311 °C, with the treated yarn exhibiting a higher total weight loss than the control fibres. Tensile testing revealed that the treated kenaf yarn exhibited a higher tensile stress of 101.73 ± 51.46 mN/Tex compared to the control kenaf fibres at 98.66 ± 22.35 mN/Tex, accompanied by a slight reduction in tensile strain from 1.028% to 1.025 %. Overall, the combined water and heat treatment improved fibre alignment, compactness, and tensile stress while slightly reducing ductility. These enhancements demonstrate the potential of this eco-friendly processing method to produce untwisted kenaf yarns.

Keywords: Kenaf fibre, untwisted kenaf yarn, FTIR, TGA, tensile properties.

Article Info

Received 22 October 2025
Accepted 13 April 2026
Published 8 June 2026

***Corresponding author: dalila@uitm.edu.my**

ISSN: 1823-7010, eISSN: 2600-7444

1. INTRODUCTION

Natural fibres have gained increasing attention in recent years as sustainable alternatives to synthetic reinforcements in polymer composites. Their attractiveness arises from inherent advantages such as low density, biodegradability, renewability, and cost-effectiveness [1,2]. Among the various natural fibres available, kenaf (*Hibiscus cannabinus L.)* has been widely studied because of its high cellulose content, excellent strength-to-weight ratio, and abundant availability in tropical and subtropical regions [3]. These attributes make kenaf a valuable raw material for developing lightweight, eco-friendly composites with improved structural performance.

In composite manufacturing, kenaf fibres are typically spun into yarns to facilitate handling, weaving, and preform formation. However, conventional twisted yarns often disrupt fibre alignment, which restricts efficient stress transfer along the fibre axis and reduces the overall mechanical performance of the composite [4,5]. This behaviour is consistent with previous studies on natural fibres, where the transition from fibre to yarn and fabric structures significantly influences mechanical performance, and improved fibre alignment results in more efficient stress transfer and enhanced tensile properties across different structural scales [6]. However, the helical structure formed by the yarn twist causes uneven stress distribution within the composite matrix, potentially leading to matrix delamination.

To overcome these limitations, this study proposes the use of untwisted kenaf yarn combined with a hydrothermal treatment approach. Although surface treatment of natural fibres has been reported in a previous study [7], the novelty of this work lies in the application of hydrothermal surface treatment to preserve a more unidirectional fibre arrangement in the untwisted kenaf yarn, thereby improving inter-fibre cohesion and stress transfer efficiency along the main load-bearing direction. The absence of twist allows for more effective stress transfer between fibres and the surrounding polymer matrix. However, it also reduces inter-fibre cohesion, which requires additional processing to stabilise the fibre bundle during handling, weaving, and composite lay-up processes. Therefore, additional treatments are necessary to enhance the inter-fibre bonding and stabilize the yarn structure without affecting the fibre alignment.

Water treatment and thermal pressing have been recognized as simple yet effective green processing techniques to improve fibre bonding, yarn compactness, and structural integrity. Water treatment promotes fibre-to-fibre cohesion by softening the natural pectin and waxy substances that coat the fibre surface, thereby increasing the contact area between adjacent fibres [8,9]. Following this, thermal pressing consolidates the fibre bundle by partially softening lignocellulosic components such as lignin and hemicellulose which, upon cooling, act as natural binders that lock the fibres together. This dual treatment approach enhances dimensional stability, smoothness, and overall uniformity, making it particularly advantageous for producing untwisted kenaf yarns where fibre cohesion depends mainly on thermal fusion rather than mechanical twist [3].

Despite these potential benefits, studies on the fundamental effects of water and thermal treatment on untwisted kenaf yarns remain limited. Previous research has predominantly examined individual kenaf fibres or conventionally twisted yarns, leaving a knowledge gap in understanding how untwisted configurations behave under moisture and heat exposure with respect to their morphological, chemical, and thermo-mechanical properties.

Hence, the present study aims to comprehensively investigate the effects of water treatment and thermal pressing on the structural, chemical, thermal, and mechanical properties of untwisted kenaf yarn. The research emphasizes on analysing the microscopic morphology, chemical composition, thermal properties, and tensile performance to develop a deeper understanding of how water–heat-based processing techniques influence yarn behaviour. The findings are expected to provide valuable research findings into optimizing processing parameters for developing high-performance, unidirectional kenaf yarns suitable for advanced composite applications.

2. MATERIALS AND METHODS

2.1 Materials

Kenaf fibres supplied by the Lembaga Kenaf dan Tembakau Negara (LKTN) were used as the main material in this study. The fibres were provided as premium-grade material that had undergone a controlled bio-retting process, followed by drying and cutting to achieve improved cleanliness, fibre separation, and uniformity prior to subsequent processing.

2.2 Preparation of Kenaf Fibres and Formation of Untwisted Kenaf Yarn

The kenaf fibres were brushed manually to form aligned fibres and to ensure uniform orientation. To form the untwisted kenaf yarn, the aligned fibres were cut and weighed to obtain a target yarn size of approximately 300 Tex. The fibres were then arranged longitudinally and lightly moistened using distilled water to improve cohesion between the fibres. The moisture was applied by spraying approximately 0.05–0.15 ml per spray onto the fibre assembly, and the fibres were allowed to absorb the moisture for a short duration, approximately 1-2 minutes before pressing. The fibre assembly was then compressed using a heat press at a temperature of 150 °C for 2 minutes under an applied pressure of approximately 30–50 psi to produce continuous untwisted kenaf yarn. Lower temperatures (<150 °C) at the same duration may result in fibre slippage and poor inter-fibre cohesion, whereas higher temperatures (>150 °C) may cause fibre thermal degradation. Therefore, the study is limited to a processing condition of 150 °C for 2 minutes to balance fibre integrity and inter-fibre cohesion. This condition is also industrially relevant, as it falls within practical heat-pressing parameters commonly used in scalable natural fibre processing and composite manufacturing. The untreated kenaf fibre served as a control sample, while the water-treated kenaf yarn served as treated sample. Both samples were evaluated for morphological structure, chemical composition, thermal, and mechanical properties.

2.3 Characterisation of Control Kenaf Fibres and Untwisted Kenaf Yarn

Both control kenaf fibres and water treated untwisted kenaf yarns were subjected to a series of characterisation techniques to examine their chemical, thermal, mechanical, and morphological properties. The surface morphology of the control and treated samples was observed using SEM (Hitachi TM 3000, Japan) following standard sample preparation procedures, which included sputter-coating with a thin layer of copper to prevent charging during observation. Micrographs were captured at magnifications ranging from 50x to 1000x to examine fibre surface features and fibre-to-fibre cohesion characteristics. The fibre diameters were measured from the SEM images using ImageJ software to ensure quantitative analysis. For accuracy and representativeness, ten measurements were randomly taken at different regions along the fibre surfaces.

The chemical structure of the samples was analysed using FTIR (PerkinElmer Spectrum 400, USA) equipped with an Attenuated Total Reflectance (ATR) probe in the range of 4000–400 cm^{-1} to identify the functional groups and evaluate changes in chemical bonding resulting from water treatment.

The thermal stability of the samples was determined using TGA (Q500, TA Instruments, USA), conducted under a controlled atmosphere at a heating rate of 10 °C/min from 30 °C to 315 °C. This analysis was performed to identify the decomposition stages and quantify the corresponding weight loss of the samples.

2.4 Tensile properties of Control Kenaf Fibres and Untwisted Kenaf Yarn

The tensile properties of the yarns were evaluated in accordance with ASTM D2256, the standard test method for tensile properties of yarns. Testing was conducted using a tensile strength tester (Tenso Lab, Mesdan, Italy) at a crosshead speed of 10 mm/min, and the average values from ten replicates were recorded for analysis. The standard deviation was calculated to assess the variability of

the results, which is particularly important in the analysis of natural fibres. The tensile properties of the untwisted kenaf yarns and kenaf fibres were calculated using Equations (1) and (2),

$$\text{Tensile Stress} = \frac{\text{Force}}{\text{Yarn size}} \quad (1)$$

where maximum force to break yarn in millinewton (mN) and yarn size in Tex [10].

$$\text{Tensile Strain} = \frac{L_f - L_0}{L_0} \times 100 \quad (2)$$

where L_f is the final length of the yarn or fibre after tensile loading (cm), and L_0 is the initial length of the yarn or fibre before loading (cm) [10].

3. RESULTS AND DISCUSSION

3.1 Morphological Analysis of Kenaf Fibres and Untwisted Kenaf Yarn

At 50 x magnification, the control kenaf fibres exhibited loosely packed fibre bundles with noticeable misalignment among individual fibres (Figure 1(a)). In contrast, the yarn treated with water (Figure 1(b)) that underwent heat pressing at 150 °C showed more organized and parallel fibre bundles, indicating a structural improvement compared to the untreated sample.

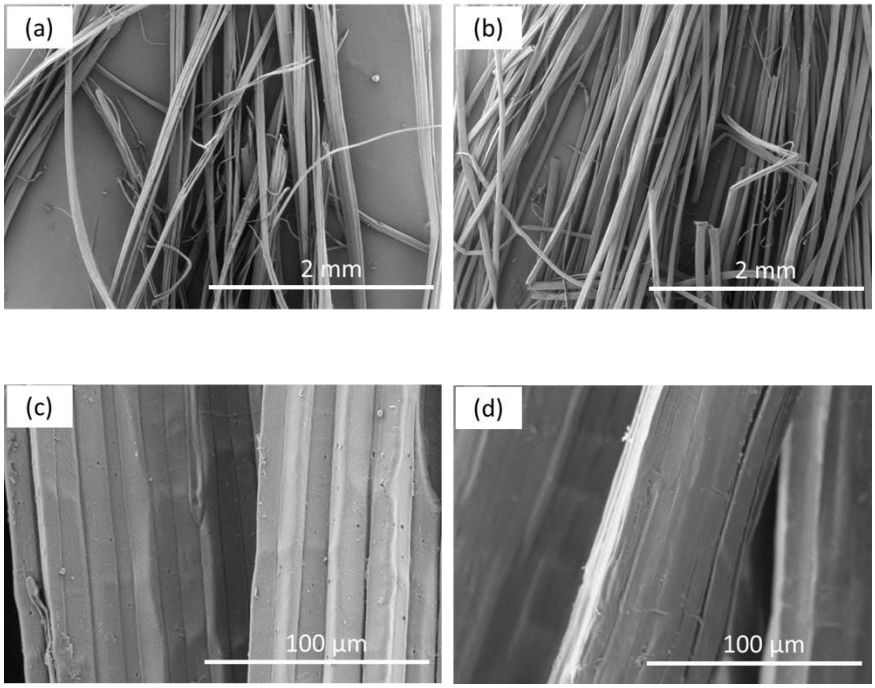

Figure 1: SEM micrographs of (a) control kenaf fibres at 50 x magnification, (b) water treated kenaf yarn at 50 x magnification, (c) control kenaf fibres at 1000 x magnification, and (d) water treated kenaf yarn at 1000 x magnification

When observed at a higher magnification of 1000 x, the control kenaf fibres (Figure 1 (c)) displayed a rough, uneven surface and a polygonal cross-sectional shape, which is commonly associated with untreated lignocellulosic fibres. In contrast, the fibres within the water treated yarn (Figure 1 (d)) appeared smoother and more uniform, with fibres tightly bonded to one another. This transformation suggests that the combination of water treatment and thermal pressing effectively enhanced fibre-to-fibre contact, promoting better fibre packing and alignment.

These improvements in fibre alignment and parallelization likely contributed to the enhanced mechanical strength observed during tensile testing, as discussed in Section 3.4. These findings align with previous research by Silva et al. [11], which reported similar structural and mechanical enhancements in thermally processed lignocellulosic fibres.

In Figure 2, the control kenaf sample exhibits an average diameter of approximately 97.1 ± 0.03 µm, while the treated yarn showed a reduced average diameter of about 85 µm. The observed reduction can be attributed to the compression of fibres (Figure 1(d)) during heat treatment, which led to a decrease in fibre diameter. Furthermore, the relatively small standard deviation observed in this study is probably due to the quality of kenaf fibres supplied by LKTN, as discussed in Section 2.1. The kenaf fibres were adequately processed through bio-retting to produce more uniform fibres. The alignment process used in this study resulted in a more compact fibre bundle and improved fibre orientation, contributing to a denser and more uniform yarn structure.

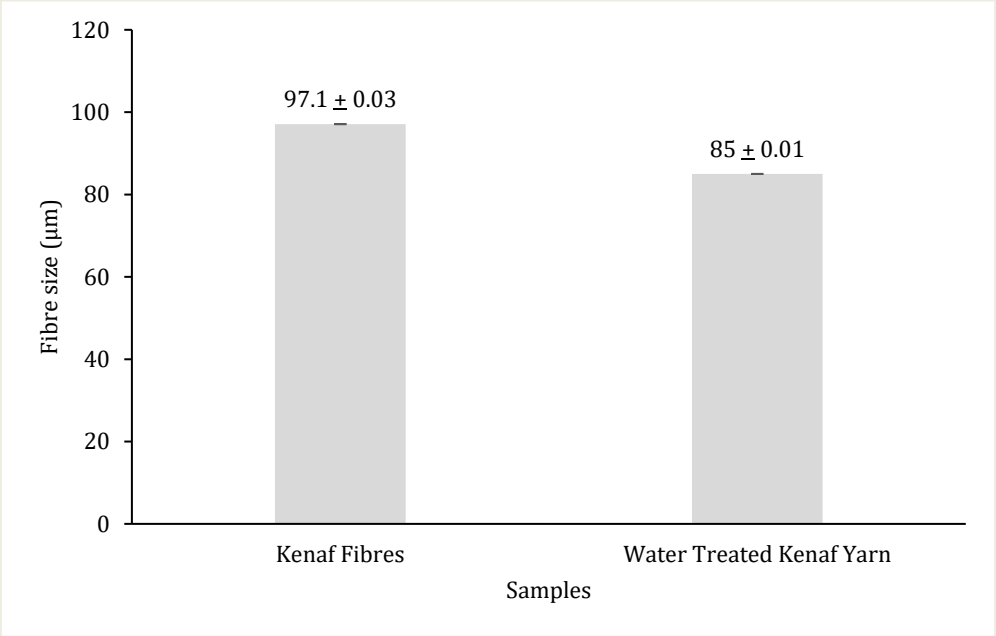

Figure 2: Fibre diameter measurements of control kenaf fibres, and water treated kenaf yarn

3.2 Chemical Compositions of Kenaf Fibres and Untwisted Kenaf Yarn

FTIR analysis was conducted to identify functional groups and observe possible chemical changes in control kenaf fibre and water treated untwisted kenaf yarn. Both samples exhibited characteristic absorption bands typical of lignocellulosic materials (Figure 3). The broad peak observed between 3330–3400 cm^{-1} corresponds to O–H stretching vibrations, indicating the presence of hydroxyl groups involved in intra- and intermolecular hydrogen bonding within cellulose and hemicellulose [12-14].

In the kenaf fibre, the O–H band appeared broader, suggesting a higher degree of hydrogen bonding and a relatively rigid cellulose structure. After water treatment and thermal pressing, a slight increase in the intensity of this band was observed, suggesting that heat partially disrupted the existing hydrogen bonds, while water facilitated the formation of new hydrogen bonds with the cellulose in kenaf.

The absorption band near 2900 cm^{-1}, attributed to C–H stretching of aliphatic groups, remained visible in both samples, reflecting the presence of cellulose and hemicellulose backbones. Peaks at approximately 1730 cm^{-1} and 1240 cm^{-1} correspond to C=O stretching and C–O–C vibrations,

respectively, associated with hemicellulose and lignin components. A noticeable increase in the 1730 cm^{-1} peak was observed in the water treated yarn, suggesting partial removal or alteration of hemicellulosic compounds during the combined water and heat treatment process. This observation aligns with the trends reported by Fiore et al. [7] for chemically treated kenaf fibres.

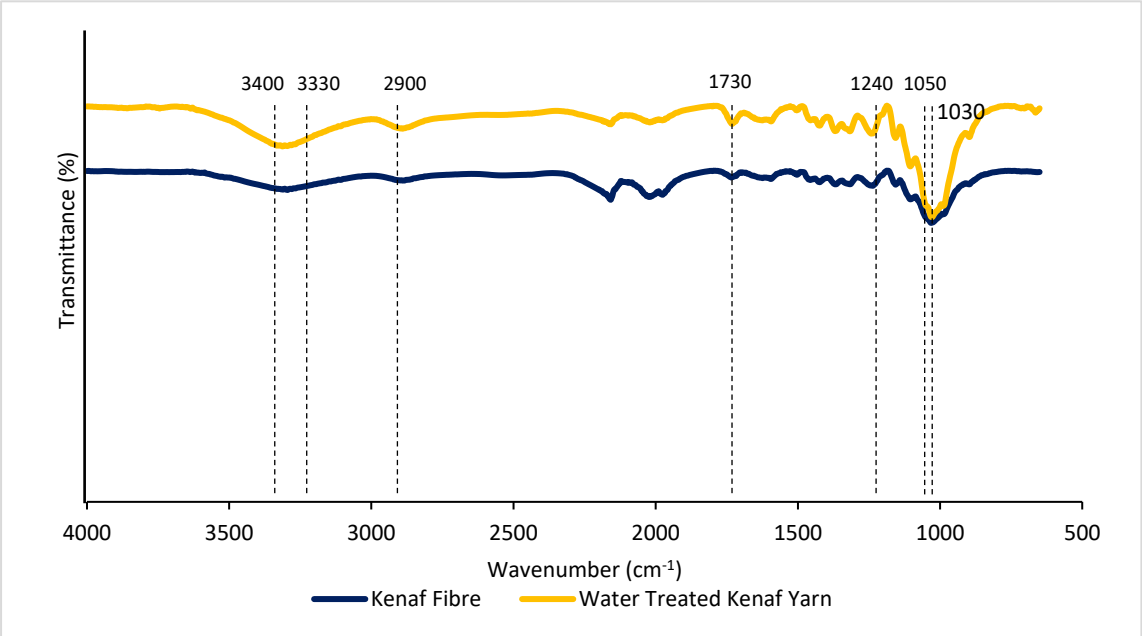

Figure 3: IR spectra of control kenaf fibres, and water treated kenaf yarn

Additionally, the band around 1030–1050 cm^{-1}, representing C–O–C stretching of polysaccharides, showed slight sharpening in the water treated sample, which may indicate a more ordered cellulose structure. These observations suggest that water treatment did not introduce new functional groups but induced minor structural rearrangements, particularly in hydrogen bonding, contributing to increased molecular organisation.

3.3 Thermal Behaviour of Kenaf Fibres and Untwisted Kenaf Yarn using Thermogravimetric Analysis (TGA)

The thermal behaviour of control kenaf fibre and water treated untwisted kenaf yarn was evaluated using thermogravimetric analysis (TGA). This analysis provides thermal degradation behaviour and stability of both samples [11]. Figure 4 shows TGA of control kenaf fibres, and water treated kenaf yarn. In Figure 4, the TGA curve of control kenaf fibre displayed two main degradation stages. The first degradation temperature occurred around 241 °C, corresponding to the decomposition of hemicellulose and amorphous non-cellulosic compounds. The second degradation stage was observed at approximately 309 °C, attributed to the breakdown of the cellulose backbone. This two-step degradation behaviour is consistent with typical lignocellulosic materials [11, 12]. The total weight loss of the control kenaf fibres was approximately 63.09 %.

Similarly, the water treated kenaf yarn exhibited two main stages of thermal degradation, occurring at 240 °C and 311 °C. The treated yarn demonstrated a higher total weight loss of 82.73 %, which was 23.74 % greater than that of the control kenaf fibres. This suggests that the water and heat treatment disrupted certain hydrogen bonds and altered the polymeric structure, making the cellulose more vulnerable to thermal scission [14, 15]. As a result, the treated kenaf yarn displayed lower thermal stability compared to the control fibres. The disruption of hydrogen bonding in the treated yarn was

further supported by the FTIR results, where a slight increase in band intensity was observed, indicating the rearrangement of hydrogen bonds within the kenaf structure following the water and heat treatments.

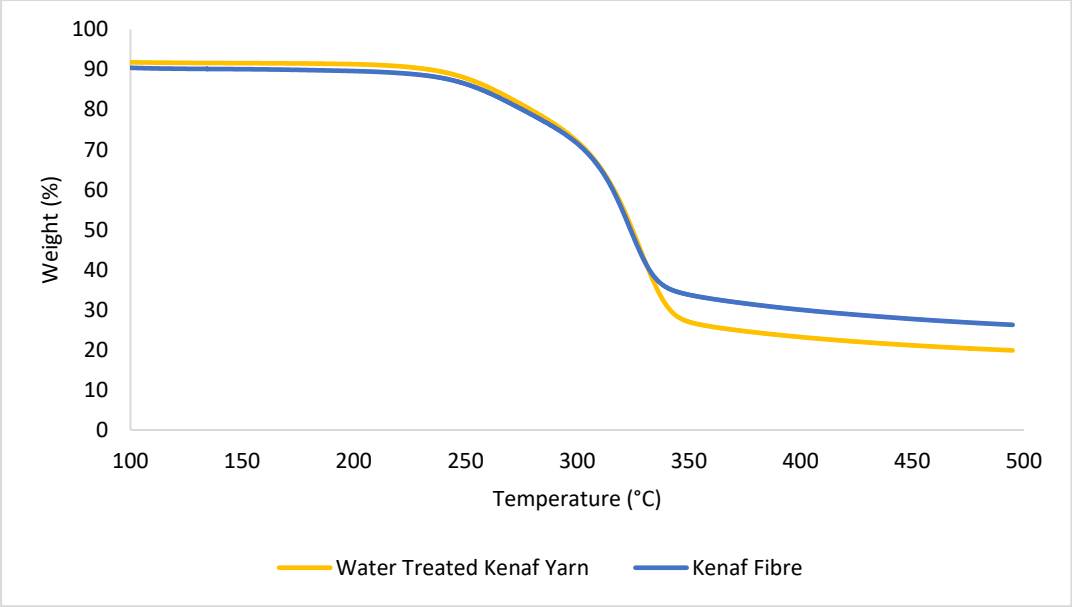

Figure 4: TGA of control kenaf fibres, and water treated kenaf yarn

Overall, the TGA results demonstrate that water and heat treatment modify the molecular interactions and structural arrangement of kenaf yarn, suggesting that the combined effects of these treatments reorganize its molecular structure and potentially enhance its performance as a reinforcement material in unidirectional fabric composites [16].

3.4 Mechanical Properties of Kenaf Fibres and Untwisted Kenaf Yarn

The selected temperature (150 °C) is considered sufficient to promote fibre consolidation through partial softening of lignocellulosic components, which enhances inter-fibre bonding without causing severe thermal degradation. This contributes to the observed improvement in tensile performance, consistent with previous studies [8, 17]. This observation is further supported by SEM images, which show improved fibre packing and reduced inter-fibre gaps after treatment.

Figure 5 illustrates the stress-strain curves of control kenaf fibres and water treated kenaf yarn. The water treated kenaf yarn recorded a higher average tensile stress (101.73 ± 51.46 mN/Tex) compared to control kenaf fibre (98.66 ± 22.35 mN/Tex), showing an improvement of approximately 3%. This enhancement is attributed to water and heat treatments of cellulose structure, which increases load-bearing capacity of fibres in the kenaf yarn. These improvements align with previous studies reporting that surface-treated kenaf fibres exhibit enhanced tensile strength and better interfacial bonding in composite systems [18]. However, this increase is relatively small (less than approximately 3 %), likely due to the mild nature of the treatment applied. In this study, only water and heat treatments were used, which do not significantly alter the internal chemical structure of cellulose, hemicellulose, or lignin. As a result, the enhancement in load-bearing capacity is limited compared to more aggressive chemical treatments, such as alkali modification, which have been reported by Kamarudin et al. to significantly enhance fibre–matrix interaction and mechanical performance [12].

In addition, the use of relatively high-quality (premium) kenaf fibres may have contributed to the minimal improvement observed, as the untreated fibres may already exhibit good inherent

mechanical properties, leaving limited room for further enhancement. Previous studies have shown that significant improvements in mechanical properties typically require chemical modification or optimized fibre alignment and processing conditions [8]. Therefore, further studies involving chemical treatments, hybrid treatments, or process optimization are recommended to achieve more substantial mechanical enhancement.

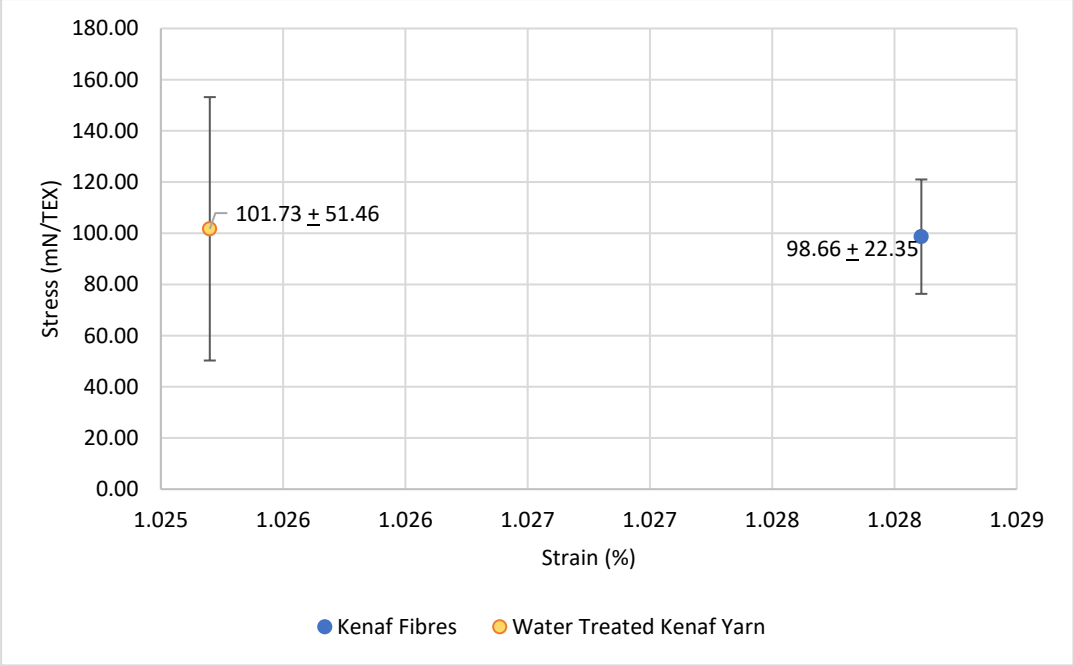

Figure 5: Stress-strain curves of control kenaf fibres, and water treated kenaf yarn

However, the increase in tensile stress was accompanied by a slight decrease in elongation. The water-treated kenaf yarn exhibited a tensile strain of 1.025 %, which was slightly lower than that of the control kenaf fibres (1.028 %), representing a reduction of approximately 0.29 %. This suggests that the yarn became slightly less flexible after thermal exposure. This trade-off between strength and extensibility is commonly reported in heat-treated lignocellulosic fibres, as elevated temperatures tend to reduce amorphous regions and restrict molecular mobility [19].

It is also important to note that the tensile results exhibit relatively high variability, as indicated by the large standard deviation (±51.46 mN/Tex) for the treated yarn. This variability is characteristic of natural fibres such as kenaf, which inherently demonstrates non-uniform properties due to differences in maturity, and extraction conditions. A previous study has highlighted that mechanical testing of lignocellulosic fibres often shows significant scatter due to these factors, as well as testing conditions [7]. Consequently, the high standard deviation observed in this study is consistent with the natural variability of plant-based fibres.

From the result, it shows that water and heat treatment enhance the structural integrity and tensile stress of untwisted kenaf yarn while slightly reducing its ductility. These improved characteristics may be advantageous for subsequent weaving and composite fabrication processes.

4. CONCLUSIONS

Based on the morphological, chemical, thermal, and mechanical analyses, it can be concluded that the combined water and heat treatment significantly influenced the structural and molecular properties of kenaf yarn. At magnifications of 50× and 1000×, the treated kenaf yarn exhibited improved

fibre alignment, smoother surfaces, and tighter fibre packing compared to the control fibres, indicating enhanced structural organisation. The observed reduction in fibre diameter in the treated yarn is attributed to improved fibre parallelisation and consolidation of the fibre bundle, rather than a change in the intrinsic fibre cell wall dimensions. This reflects a more compact and uniform yarn structure. FTIR analysis revealed an increase in the intensity of the O–H stretching band (3330–3400 cm^{-1}) and a noticeable increase in the C=O peak at 1730 cm^{-1}, suggesting partial modification of hemicellulose and rearrangement of hydrogen bonding within the fibre structure. TGA results showed two major degradation stages at approximately 240 °C and 311 °C, with the treated yarn exhibiting a higher total weight loss (82.73 %) compared to the control fibres (63.09 %), indicating alterations in polymeric composition and a slight reduction in thermal stability. From a mechanical perspective, the treated kenaf yarn demonstrated a marginal improvement in tensile strength, with an average tensile stress of 101.73 ± 51.46 mN/Tex compared to 98.66 ± 22.35 mN/Tex for the control fibres, representing an increase of approximately 3 %. However, this was accompanied by a slight reduction in tensile strain from 1.028 % to 1.025 %, indicating a minor decrease in ductility. Future work may incorporate more comprehensive statistical analyses to further validate the significance of the differences between treated and untreated samples. Overall, the combined water and heat treatment enhanced fibre alignment, structural integrity, and tensile performance, while slightly reducing ductility. These characteristics are advantageous for the weaving process and the formation of unidirectional fabric composites.

Acknowledgements

The research work was funded by the Lembaga Kenaf dan Tembakau Negara (LKTN) (Project File No.:100-TNCPI/GOV 16/6/2 (085/2024). The authors also gratefully acknowledge the Faculty of Applied Sciences and the Research Management Centre, Universiti Teknologi MARA, Malaysia, for their support of the research activities.

Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work does not require any ethical procedures.

References

[1] Bhambure, S. S., Rao, A. S. & Senthilkumar, T. (2022). Analysis of mechanical properties of kenaf and kapok fiber reinforced hybrid polyester composite. *Journal of Natural Fibers*, *20*(1), 1-10.

[2] Yong, C. K., Ching, Y. C., Chuah, C. H. & Liou, N. (2015). Effect of fiber orientation on mechanical properties of Kenaf-Reinforced polymer composite. *BioResources*, *10*(2), 2597-2608.

[3] Sulong, A. B., Ya, Z., Radzuan, N. A. M. & Tharazi, I. (2025). Mechanical properties of Kenaf fiber and nano-clay on Poly (Lactic) acid (PLA) composites: a review. *Jurnal Kejuruteraan*, *37*(2), 695–719.

[4] Thilagavathi, G., Muthukumar, N., Krishnanan, S. N. & Senthilram, T. (2019). Development and characterization of pineapple fibre nonwovens for thermal and sound insulation applications. *Journal of Natural Fibers*, *17*(10), 1391–1400.

[5] Lee, C. H., Khalina, A., Nurazzi, N. M., Norli, A., Harussani, M. M., Rafiqah, S. A., Aisyah, H. A. & Ramli, N. (2021). The challenges and future perspective of woven Kenaf reinforcement in thermoset polymer composites in Malaysia: a review. *Polymers*. *13*(9), 1390.

[6] Aldroubi, S., Kasal, B., Yan, L. & Bachtiar, E. V. (2023). Multi-scale investigation of morphological, physical and tensile properties of flax single fiber, yarn and unidirectional fabric. *Composites Part B: Engineering*. *259*, 110732.

[7] Fiore, V., Di Bella, G. & Valenza, A. (2014). The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites. *Composites Part B Engineering*, *68*, 14–21.

[8] Radzuan, N. A. M., Tholibon, D., Sulong, A. B., Muhamad, N. & Haron, C. H. C. (2020). Effects of high-temperature exposure on the mechanical properties of kenaf composites. *Polymers*, *12*(8), 1643.

[9] Prome, F. S., Hossain, M. F., Rana, M. S., Islam, M. M. & Ferdous, M. S. (2025). Different chemical treatments of natural fiber composites and their impact on water absorption behavior and mechanical strength. *Hybrid Advances*. *8*, 100379.

[10] Hearle, J. W. S. & Morton, W. E. (2008). *Physical Properties of Textile Fibres*. 4th edition (Woodhead Publishing.) pp. 274-319.

[11] Silva, T., Silveira, P., Ribeiro, M., Lemos, M., Da Silva, A., Monteiro, S. & Nascimento, L. (2021). Thermal and chemical characterization of kenaf fiber (Hibiscus cannabinus) reinforced epoxy matrix composites. *Polymers*. *13*(12), 2016.

[12] Kamarudin, S. H., Abdullah, L. C., Aung, M. M. & Ratnam, C. T. (2020). Thermal and structural analysis of epoxidized jatropha oil and alkaline treated Kenaf fiber reinforced Poly (Lactic Acid) biocomposites. *Polymers*. *12*(11), 2604.

[13] Ashadujjaman, M., Saifullah, A., Shah, D. U., Zhang, M., Akonda, M., Karim, N. & Sarker, F. (2021). Enhancing the mechanical properties of natural jute yarn suitable for structural applications. *Materials Research Express*, *8*(5), 055503.

[14] Qian, C., Wang, Y., Shi, C., Wang, H., Yang, H., Yang, J., Wang, D. & Shi, Z. (2023). Development of all-cellulose sustainable composites from directionally aligned bamboo fiber scaffold with high strength, toughness, and low thermal conductivity. *Chemical Engineering Journal*, *473*, 145437.

[15] Rafiqah, S. A., Abdullah, N., Abdan, K., Roslim, M. H. M. & Radzuan, M. N. (2025). Influence of alkali treatment on mechanical, physical, thermal and morphological properties of Kenaf Fiber/Polyamide 6 Composites. *Journal of Natural Fibers*, *22*(1), 2515468.

[16] Jayaramudu, J., Reddy, G. S. M., Varaprasad, K., Sadiku, E. R., Ray, S. S. & Rajulu, A. V. (2014). Mechanical properties of uniaxial natural fabric grewia tilifolia reinforced epoxy based composites: Effects of chemical treatment. *Fibers and Polymers*, *15*(7), 1462–1468.

[17] Tharazi, I., Azam, F., Muhamad, N., Hui, D., Sulong, A. & Gaff, M. (2023). Effect of fiber orientation and elevated temperature on the mechanical properties of unidirectional continuous kenaf reinforced PLA composites. *Reviews on Advanced Materials Science*, *62*, 1-12.

[18] Abdullah, A. H., Tharazi, I., Salleh, F. M., Halim, N. H. A., Solihin, Z. H., Marzuki, A. P. & Abdan, K. (2024). Tensile properties and dynamic mechanical analysis of kenaf/epoxy composites. *Journal Of Mechanical Engineering and Sciences*, *18*(1), 9835–9844.

[19] Csiszár, E., Herceg, I. & Fekete, E. (2023). Effect of heating and citric acid on the performance of cellulose nanocrystal thin films. *Polymers*. *15*(7), 1698.