Penerbit Akademia Baru

Malaysian Journal on Composites Science and Manufacturing

Journal homepage:
https://akademiabaru.com/submit/index.php/mjcsm
ISSN: 2716-6945

Mechanical Strength and Degree of Polymerization of Oil-paper Non-wood Kenaf Bast Fiber as New Transformer Insulation Presspaper

Nurul 'Izzati binti Hashim[1,2,*], Mohd Taufiq Ishak[2], Mohd Taufik Jusoh Tajudin[2], Ja'afar Adnan[2], Anis Shahida Niza Mokhtar[2], Nur Sabrina Suhaimi[3], Nadira Johari Halim Shah Ayob[4]

[1] Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan, Sarawak, Malaysia
[2] Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Sungai Besi, Malaysia
[3] Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, Malaysia
[4] Department of Electrical and Electronic Engineering, University of Manchester, Manchester, United Kingdom

ARTICLE INFO

Article history:
Received 16 October 2024
Received in revised form 23 December 2024
Accepted 16 January 2024
Available online 30 March 2025

Keywords:
Transformer insulation; Kenaf; tensile strength; aging behavior; DP

ABSTRACT

Growing populations and the lack of wood fiber have led to exploring non-wood fibers as alternatives for presspaper manufacturing, aiming to supplement the limited wood fiber resources. The Kenaf plant is one of the potential alternatives for these purposes. The aim of this study is to investigate the ageing characteristics of non-wood Kenaf fiber to assess its suitability for use as a new presspaper insulation in transformer. Kenaf presspaper was produced through soda pulping and laboratory handsheet process. Tensile strength (TS) and degree of polymerization (DP) assessments were conducted in according to TAPPI T494 and IEC60450 standard to measure the changes of degradation characteristic on Kenaf presspaper. The accelerated aging process at 90 °C up to 720 hours was done to simulate extended real operation of transformer. The results indicated a reduction in both the TS and DP of Kenaf presspaper (KP) with increased aging time. The relationship between DP and TS revealed consistent decreases over aging time due to the formation of cross-links between polymer chains during ageing, contributing to the overall deterioration of the fiber's mechanical integrity.

1. Introduction

Transformer plays a vital component in electrical power systems, that enable electricity to be distributed and transmitted efficiently. This device works on the basis concept of electromagnetic induction, changing voltage levels to allow for a continuous supply of power across the grid. For many years, a combination of insulating oil, presspaper, and pressboard has served as essential insulating materials in transformer [1]. Presspaper serves a vital role in a transformer by providing electrical insulation between different components, including winding layers and the transformer core. This

* *Corresponding author.*
E-mail address: hnizzati@unimas.my

https://doi.org/10.37934/mjcsm.16.1.235244

insulation is crucial to prevent electrical breakdown and ensure the safe and efficient operation of the transformer. Additionally, presspaper helps in managing heat generated within the transformer.

Traditionally, the main source of insulation materials for transformer, was specifically presspaper used to be made from softwood fiber. Softwood fiber has been used as a transformer insulation presspaper due to pure cellulose (42 % cellulose and 28 % lignin), having outstanding electrical properties and high mechanical strength [2]. The advantages of cellulose such as being a good insulator and polar, with a dielectric constant significantly higher than one makes them dominant in transformer insulation paper application. As applications become more demanding, the quality of the paper needs to be higher, leading to a bigger challenge due to the lack availability of softwood fiber. With a decrease in softwood resources, researchers have embarked on a pursuit for sustainable alternatives, prompting them to investigate non-wood fibers for potential use in transformer insulation applications. Non-wood fiber resources provide certain advantages over wood fiber resources due to their abundance, short cycle, fast generation, and low cost [3].

Kenaf plant (*Hibiscus cannabinus L.*) is a fast-growing non-wood fiber sources belongs to the Malvaceae family. Kenaf initiative in Malaysia was initiated in 1999 by the National Economic Advisory Council (NEAC). The research on Kenaf in Malaysia has commenced by evaluating the adaptability of Kenaf, identifying the suitable cultivars for industrial and agricultural use, managing agronomic practises and inputs, developing end products, and assessing cost development [4], [5]. Kenaf is an herbaceous plant that can be harvested after four to five months of planting, allowing two harvest cycle per year. Figure 1 shows the parts of Kenaf stalk.

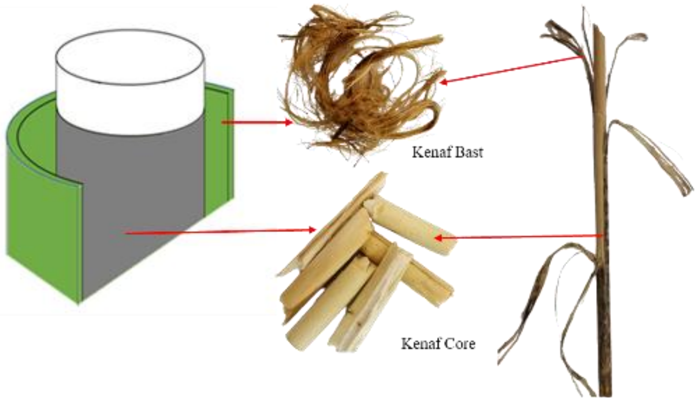

Fig. 1. Parts in Kenaf stalk

The bast fibers obtained from the outer layer of the Kenaf stalk which has a promising alternative for enhancing the performance of insulating presspaper. The height of Kenaf stalk varies between 3.7 m to 5.5 m, but its fibers normally range from 2.39 mm to 2.82 mm in length [6], which contributes to enhance the mechanical strength. The Kenaf bast typically contains 45 % to 57 % of cellulose and 8 % to 10 % lignin content, which aligns with the standard set by the Pulp and Paper Industry in Malaysia [2].

Recently, researchers have proved that Kenaf can be an alternative raw material in its broad range of applications across various automotive components, construction materials, medical, cosmetic, and grounding systems. A study in [7] highlights that the Kenaf fibers are increasingly being used as reinforcements in composite materials in the automotive sector, leading to the production of lightweight and environmentally friendly components. Pasilo *et al.,* in [8] presents the roofing tiles products manufactured from agricultural sources such as Kenaf fiber, corn cob fiber and water hyacinth fiber. It is found that that all agricultural sources are beneficial to the construction sector since its fibers improve the mechanical and physical properties of roofing tiles products.

A different study by Shahar *et al.,* [9] explores the potential of Kenaf composite as an alternative material for fabricating Ankle-Foot Ortho,sis (AFO) due its strength to weight ratio, cost effectiveness and biocompatibility. It is suggested that future research could lead to further advancement in the medical field. The author of another study [10] found that the performance of grounding systems can be enhanced by using mixtures of bentonite and Kenaf as both materials can absorb and maintain moisture from the surrounding soil. A recent study conducted by Nik Kechik *et al.,* [11] examined the influence of agricultural-based materials on heat transfer rates, concluding that Kenaf fiber reinforced with resin exhibited the highest thermal conductivity.

The increasing demand for sustainability in the power industry necessitates a thorough comprehension of the relationship between the mechanical properties, specifically Tensile Strength (TS), and the chemical characteristics, particularly Degree of Polymerization (DP), of insulation materials. Understanding the TS of presspaper is crucial because it signifies the material's durability to tearing or rupturing under mechanical stress. Higher TS implies better resistance to mechanical forces, contributing to the reliability and longevity of the insulation in transformer applications. While for DP is a main factor in determining the molecular weight and structural integrity of the insulating materials. Conducting a study that establishes a correlation between the mechanical and chemical properties of insulation materials contributes significantly to gaining an understanding of their overall performance and appropriateness for transformers applications.

2. Related Works

Katun *et al.,* [12] examine the impact of fibers and reinforced nanoparticles on the tensile strength of transformer oil-impregnated paper. The successful synthesis and characterization of rutile-TiO_2 nanoparticles were accomplished, and these nanoparticles were utilized as a reinforcing agent in the study. An increase in tensile strength was achieved by introducing surface-modified rutile-TiO_2 nanoparticles into the cellulose fibers. Multiple analytical methods, including X-ray diffraction (XRD), Raman spectroscopy and Fourier-transform infrared spectroscopy (FTIR), were used to examine the materials and confirm the presence of nanoparticles in the paper. This article also included scanning electron microscope (SEM) photos to visually demonstrate nanofillers' existence.

A study in [13] presents experimental data on the mechanical properties of two commonly used types of paper in transformer (plain Kraft and crepe paper), under different ageing states. This data not only serves as valuable information on the performance of these materials but also establishes benchmark values for comparison with manufacturers' data obtained in the factory setting. However, there are some limitations in this research where its scope is confined to just two types of paper, omitting information on alternative materials employed for transformer insulation. Furthermore, the study solely examines the mechanical characteristics of the insulation paper, neglecting an exploration of other variables that might potentially impact the effectiveness and durability of power transformers.

The main finding for article [14] is that the aging process affects the mechanical and dielectric properties of transformer grade Kraft paper. The study employed dielectric spectroscopic measurements to examine the relative permittivity, dielectric loss, and water absorption of paper samples that were conditioned in the ambient environment. The findings indicated that the paper's mechanical and dielectric characteristics experienced a decline as it aged. The study's shortcomings encompass the exclusive analysis of a single paper type, without accounting for the potential influence of other variables, such as temperature and humidity, on paper aging. In addition, the study did not explore strategies for preventing or alleviating the impact of aging on the paper.

Author [15] examines the degradation of wood pulp-cotton presspaper when exposed to different biodegradable oils. The study revealed that the impregnating fluid significantly affected the dielectric response of the presspaper. Natural esters exhibited higher tan δ values at low frequencies, while mineral oil exhibited higher tan δ values at low frequencies as well, but with less noticeable variations between the lowest and highest frequencies. The cellulose's polymerization degree was also assessed, revealing a decrease in DP as the cellulose degraded, reaching a value of 134 at the final point of exposure to mineral oil. The main constraint of the study lies in the challenge of establishing definitive results regarding the deterioration of the presspaper, owing to the intricate interplay between the oils and the presspaper.

Siddique *et al.,* [16] highlights the development of an innovative insulating oil for transformers by adding graphene oxide into natural ester. The study illustrates that introducing graphene oxide into the natural ester-based oil enhances its dielectric and thermal characteristics, which are crucial for insulating high voltage equipment. Nevertheless, the study's limitation is that it focuses only on the performance of the insulating oil. Additional investigation is required to assess its durability and suitability with current transformer systems over an extended period of time.

3. Experimental Method

Kenaf plant, known for its versatility and wide range of uses, undergoes comprehensive and systematic processing methods to extract its valuable fibers, utilized in the production of several end products. Figure 2 shows the process from harvesting of the Kenaf stalk to obtaining the Kenaf presspaper (KP). Firstly, the process of harvesting Kenaf stalks is carried out, which is a crucial phase that can be done either by hand or with machines, depending on the size of the production and the resources available. After the crops are harvested, the retting process begins, which involves soaking the stalks to remove non-fibrous substances using methods such as immersing them in water or applying chemicals.

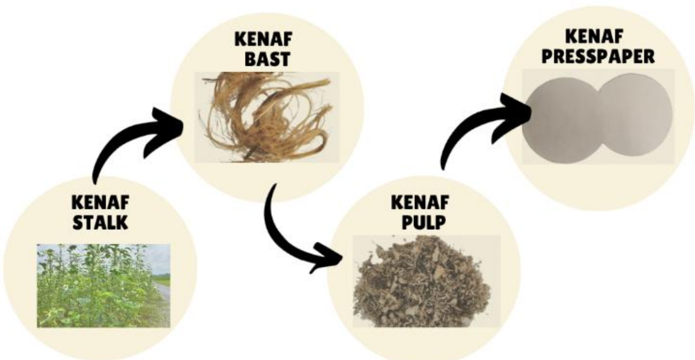

Fig. 2. Process from Kenaf stalks to Kenaf presspaper (KP)

Afterwards, the bast fibers, which are well-known for their strength in the Kenaf stalk, are obtained from the woody core using a specific machine called a decorticator. After being removed, the fibers are subjected to a comprehensive washing process. Subsequently, the bast fibers undergo the pulping process, where diverse techniques such as mechanical, chemical, or semi-chemical pulping are used to disintegrate the fibers into smaller entities, resulting in pulp suitable for paper. The pulping process for this study was soda pulping process.

3.1 Pulping Process

Kenaf bast fiber was initially cut into 10 cm length. Subsequently, a rotary digester was used to cook short Kenaf bast fiber with a combination of highly alkaline solution, called white liquor. Next, the softened Kenaf pulp was washed with water using a hydro pulper to remove the remaining black liquor. PTI Summerville Fractionators with a slot size of 0.05 mm screened the Kenaf pulp to remove the remaining oversized pulp. Next, the pulp was dried out using the spin-dried machine and dispersed by the Hobart mixer machine.

3.2 Handsheet Process

After the drying process, the pulp is processed into the stock for papermaking based on TAPPI T205 [17]. A 24 g oven dried (OD) pulp was diluted with 2000 ml of distilled water was disintegrated at 3000 rpm to scatter the pulp. Next, 8 litres of water were added to the stock, and stir the stock well in the stock divider to ensure proper mixing. Finally, 400 ml of stock with the half fill water was transferred to a sheet machine to make handsheet of KP.

3.3 Pre-processing of Oil Presspaper

The transformer used in this study was Nynas Nytro Libra. Firstly, the Mineral Oil (MO) was filtered using a Nylon membrane filter with pore size of 0.2 μm for three times. The size of tested KP were 50 mm X 50 mm pieces. The filtered MO and KP were dried at 90 ℃ for 24 h to remove the moisture. After the drying process, the KP are impregnated with MO for 24 h with the ratio oil and paper set to 20:1 prior to ageing process, a critical procedure that replicates the conditions of actual transformers. The process of impregnation serves to improve the dielectric properties of the presspaper, while also introducing a significant variable that influences the degree of polymerization over a period.

3.4 Accelerated Aging Process

The impregnated KP samples are then placed within an accelerated aging oven at 90 ℃ up to 720 hours. The sample was taken out every 240 hours, allowed to cool at room temperature before testing. The selection of the accelerated ageing conditions was selected as it falls within the range of normal ageing conditions described in standards like IEC 60076-7, where ageing occurs without reaching thermal failure temperatures typically below 150°C [18]. The 720-hour duration was chosen to provide sufficient time for observable ageing effects while balancing practical experimental timelines. This study was conducted as a preliminary investigation to assess material performance under controlled accelerated ageing conditions, aligning with standard industry practices.

3.5 Tensile Strength (TS)

Tensile tests were performed on a BUCHEL horizontal tensile test according to the TAPPI T494 standard [19]. A paper strip of 15 mm width and 100 mm length was clamped at each end between the two jaws. For each kind of presspaper, ten samples were tested. The tests were carried out with a condition of 23 ℃ and 50 % relative humidity.

3.6 Degree of Polymerization (DP)

The average viscometric DP based on IEC 60450 standard [20] were measured on KP. All the aging Kenaf presspaper were degreased before DP determination. 0.1 mg of sample presspaper and 20 ml of distilled water are added into a flask followed by the addition of 20 ml of cupric ethylenediamine (CUEN) solution of 1 mol/L. Three assessment were performed on each sample and DP was calculated from viscometric data.

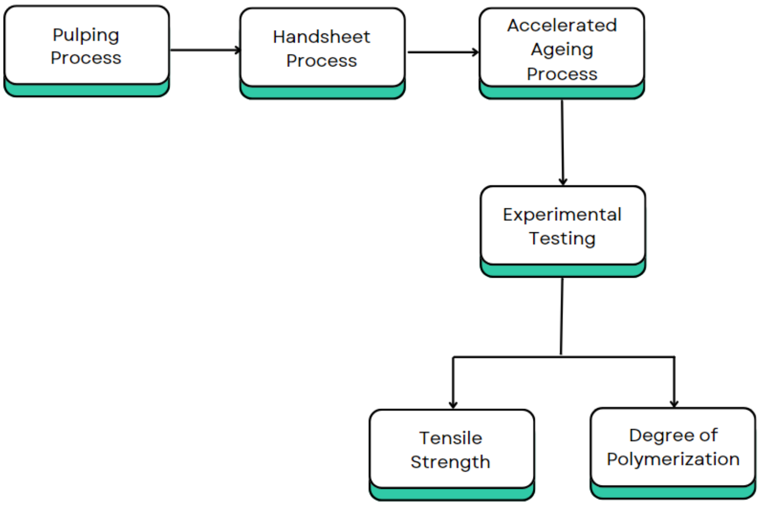

Fig. 3. General process

4. Results and Discussion

Table 1 shows the thickness and apparent density of produced KP. Table 2 provides the properties of the MO in which the insulation paper was impregnated for the ageing process.

Table 1
Properties of the Kenaf presspaper insulation

Properties	Kenaf presspaper
Thickness (mm)	0.12
Apparent density (g/cm^3)	0.80

Table 2
Main properties of the mineral oil

Properties	Nytro Libra
Appearance	Clear and bright
Kinetic viscosity at 40 °C	9.6 mm2/s
Density at 20 °C	0.875 kg/dm3
Dielectric dissipation factor at 90 °C	0.001
Pour point	- 51 °C
Water content	< 20 mg/kg
Acidity	0.01 mgKOH/g
Flashpoint	152 °C

The ageing performance of KP can be observed through the DP and TS measurement. Figure 4 shows that the line graph of DP versus aging time. The graph shows that the DP decreases with increasing aging time. According to [1], value for DP for a new transformer presspaper insulation is between 1000 – 1200. In the initial state of aging from 0 hours to 240 hours, the DP decrease rapidly. During this phase, oxygen will contribute to the oxidation reaction which will weaken the glyosidic bond in the fiber. However, the DP does not decrease linearly with the ageing time due to many factors such as structure of the cellulose, the ageing condition, and the presence of inhibitors.

The graph in Figure 5 depicts the TS of KP before and after accelerated thermal aging. TS is a crucial characteristic that measure a material capability to withstand the test under the influence of tensile forced. According to the graph, the overall trend indicates a consistent decline in tensile strength as aging time increases. The rate of reduction appears more significant between 240 and 480 hours. The increasing error bars imply potential instability or greater measurement fluctuations as the material ages further. This data suggests that prolonged aging negatively affects the material's tensile strength, which could be a sign of material degradation over time. This occurs due to the process of ageing, which leads to chain scission, a phenomenon characterised by the breakage of polymer chains. Chain scission leads to a reduction in the material's strength, resulting in decreased resistance to tensile stresses. Nevertheless, after a certain limit, the rate of decline in tensile strength decelerates. This is due to the material having already undergone significant chain scission, resulting in a reduced number of chains that are capable of further breakage. This finding of this study consistent with other studies [21–23].

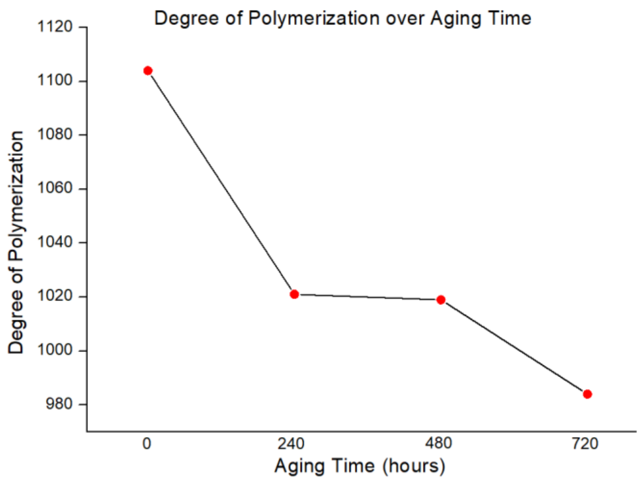

Fig. 4. Degree of polymerization with increasing aging hours

The relationship between the DP of KP and its TS after ageing for different time periods as indicated in Figure 6. The TS of the fiber decreases with increasing ageing time. This is because ageing causes the polymer chains in the fiber to break down, which reduces the fiber's overall strength. The DP of the fiber also decreases with increasing ageing time, which is consistent with the decrease in tensile strength.

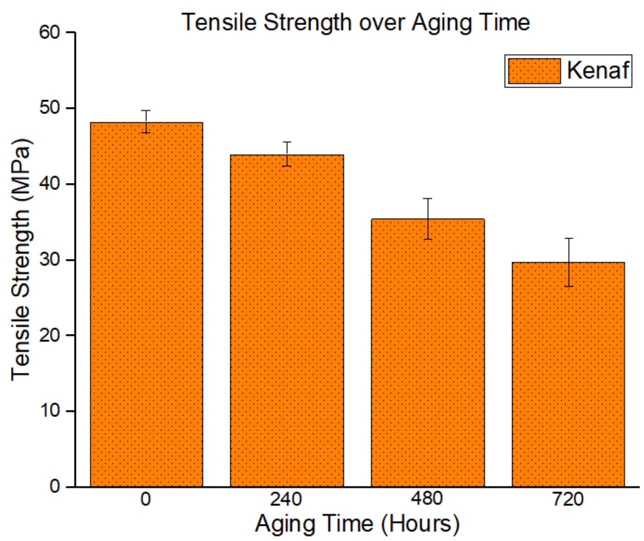

Fig. 5. Tensile strength with increasing aging hours

It is important to emphasize that the rate of decrease in TS surpasses the rate of decrease in DP. This implies that the deterioration of the mechanical properties of the fiber as it ages may be attributed to additional processes, potentially including the formation of cross-links between the polymer chains. These cross-links, formed during aging, may contribute significantly to the overall deterioration of the fiber's mechanical integrity. Therefore, understanding the intricate relationship between aging, TS, and DP becomes pivotal in unraveling the multifaceted degradation mechanisms at play in the fiber over time.

It is important to note that a DP value of 200 serves as an indication of the end of life of presspaper, as it becomes brittle and experiences a decline in mechanical strength. The result obtained agreed with previous studies [21,24].

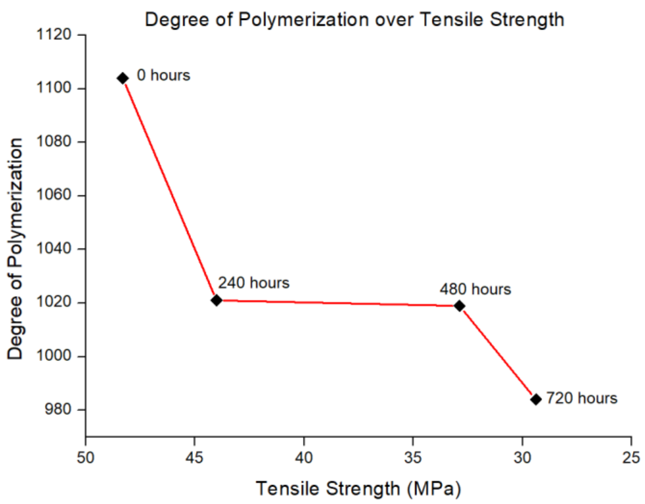

Fig. 6. Tensile strength and degree of polymerization with increasing aging hours

5. Conclusion

This study focused on examining the TS and DP of oil-impregnated non-wood Kenaf bast fiber as potential transformer insulation presspaper, using TAPPI and IEC standards as guidelines. The investigation found that the TS and DP of KP decrease with increased aging time. In summary, the correlation between aging time with TS and DP can be explained as follow:

i. The DP analysis indicate that the deterioration of KP decreases as the ageing time increases due to the oxidation process, which weakens the glycosidic link in the fiber. This leads to a significant decrease during the initial aging phase (0 to 240 hours), and the decrease in DP with aging time is non-linear, indicating the influence of multiple variables such as inhibitor availability, aging circumstances, and cellulose structure.
ii. The significant decrease in TS with increasing ageing time is attributed to chain scission, a process in which polymer chains fracture, leading to a reduction in the material's strength and ability to withstand tensile stresses. In addition, the rate of decrease in TS slows down after it reaches a certain limit, indicating that the chain scission processes have reached their maximum capacity.
iii. The correlation between DP and TS over different ageing periods demonstrates a continuous pattern of declining fiber strength and polymerization as aging time increases. Notably, the rate at which the tensile strength decreases is higher than that of DP, indicating the presence of other mechanisms that may be involved in the development of cross-links between polymer chains. It is important to highlight that a DP value of 200 is a critical threshold that signifies the end of life for presspaper. This is marked by its brittleness and a significant decrease in mechanical strength.

This study investigation not only enhances the comprehension of the degradation mechanisms in KP, but also offers valuable insights for optimising transformer insulation materials. This contributes to the wider range of sustainable and efficient solutions in power industry applications. Future work will aim to explore more extensive material characterization during the ageing intervals for a broader understanding of the ageing behavior.

Acknowledgement
The authors express their gratitude to the Center for Research & Innovation Management (CRIM), National Defence University of Malaysia (NDUM), for providing funding to this project through research grants UPNM/2023/GPJP/TK/5. The authors would also like to express their appreciation to Universiti Malaysia Sarawak (UNIMAS) for their assistance in managing the project and Pulp and Paper Laboratory, Forest Research Institute Malaysia (FRIM) for providing research equipment and support during production of Kenaf Presspaper.

References

[1] Prevost, Thomas A., and T. V. Oommen. "Cellulose insulation in oil-filled power transformers: Part I-history and development." *IEEE electrical insulation magazine* 22, no. 1 (2006): 28-35. https://doi.org/10.1109/MEI.2006.1618969
[2] Khalil, HPS Abdul, AF Ireana Yusra, A. H. Bhat, and M. Jawaid. "Cell wall ultrastructure, anatomy, lignin distribution, and chemical composition of Malaysian cultivated kenaf fiber." *Industrial Crops and Products* 31, no. 1 (2010): 113-121. https://doi.org/10.1016/j.indcrop.2009.09.008
[3] Junejo, Nasima, Arifin Abdu, Hazandy Abdul Hamid, Khalil Ahmed, and Mohd Hadi Akber. "Journey of kenaf in Malaysia: A Review." *Scientific Research and Essays* 9 (2014): 458-470. https://doi.org/10.5897/SRE12.471
[4] Wong, Choi Chee, MD Mat Daham, AM Abdul Aziz, and O. Abdullah. "Kenaf germplasm introductions and assessment of their adaptability in Malaysia." (2008): 1-19.

[5] Ashori, Alireza. "Pulp and paper from kenaf bast fibers." *Fibers and Polymers* 7 (2006): 26-29. https://doi.org/10.1007/BF02933598
[6] Ververis, C., K. Georghiou, N. Christodoulakis, P. Santas, and R. Santas. "Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production." *Industrial crops and products* 19, no. 3 (2004): 245-254. https://doi.org/10.1016/j.indcrop.2003.10.006
[7] Hassan, F., R. Zulkifli, M. J. Ghazali, and C. H. Azhari. "Kenaf fiber composite in automotive industry: an overview." *Int. J. Adv. Sci. Eng. Inf. Technol* 7, no. 1 (2017): 315-321. https://doi.org/10.18517/ijaseit.7.1.1180
[8] Pasilo, Arkom, and Umpaisak Teeboonma. "A Study of the Roofing Tiles Product Properties Manufactured from Agricultural Residues." In *2018 International Conference and Utility Exhibition on Green Energy for Sustainable Development (ICUE)*, pp. 1-4. IEEE, 2018. https://doi.org/10.23919/ICUE-GESD.2018.8635733
[9] Shahar, Farah Syazwani, Mohamed Thariq Hameed Sultan, Seng Hua Lee, Mohammad Jawaid, Ain Umaira Md Shah, Syafiqah Nur Azrie Safri, and Praveena Nair Sivasankaran. "A review on the orthotics and prosthetics and the potential of kenaf composites as alternative materials for ankle-foot orthosis." *Journal of the mechanical behavior of biomedical materials* 99 (2019): 169-185. https://doi.org/10.1016/j.jmbbm.2019.07.020
[10] Ahmad, WFH Wan, AH Abdul Rahman, J. Jasni, and M. Z. A. Ab-Kadir. "Performance of Bentonite and Peat Moss Mixtures as Grounding Enhancement Materials." In *2023 12th Asia-Pacific International Conference on Lightning (APL)*, pp. 1-6. IEEE, 2023. https://doi.org/10.1109/APL57308.2023.10181741
[11] Rahman, Nik Kechik Mujahidah Nik Abdul, Syamimi Saadon, Raja Eizzuddin Shah Raja, Muhammad Azhan Shah, Ezanee Gires Abd Rahim Abu Talib, Hanim Salleh, and Nasser Abdellatif. "Thermal Performance Study on Coconut Husk and Kenaf Fibre as Thermal Insulation Materials."
[12] Katun, Mohammed Mahmood, Ashley Smith, Rudo Kadzutu-Sithole, Chandima Gomes, Cuthbert Nynamupangedengu, and Nosipho Moloto. "Impact of fibres and reinforced nanoparticles on tensile strength of transformer oil-impregnated paper." In *2022 30th Southern African Universities Power Engineering Conference (SAUPEC)*, pp. 1-6. IEEE, 2022. https://doi.org/10.1109/SAUPEC55179.2022.9730720
[13] Oria, C., Carrascal, I., Ferreño, D., Fernández, I. and Ortiz, A., 2021. Experimental dataset on the tensile and compressive mechanical properties of plain Kraft and crepe papers used as insulation in power transformers after ageing in mineral oil. *Data in Brief*, *36*, p.107031. https://doi.org/10.1016/j.dib.2021.107031
[14] Hosier, Ian L., Paul L. Lewin, James Pilgrim, and Gordon Wilson. "Effects of aging on the mechanical and dielectric properties of transformer grade Kraft paper." In *2020 IEEE Electrical Insulation Conference (EIC)*, pp. 317-320. IEEE, 2020. https://doi.org/10.1109/EIC47619.2020.9158661
[15] Méndez Gutiérrez, Cristina, Jaime Sanz Asensio, Cristian Olmo Salas, Fernando Delgado San Román, Pedro José Quintanilla Cavia, Riccardo Maina, and Alfredo Ortiz Fernández. "Investigation of the degradation of a wood pulp-cotton presspaper in different biodegradable oils." (2022). https://doi.org/10.1109/ICDL49583.2022.9830979
[16] Siddique, Zaid B., Soumen Basu, and Prasenjit Basak. "Effect of graphene oxide dispersed natural ester based insulating oil on transformer solid insulation." *IEEE Transactions on Dielectrics and Electrical Insulation* 29, no. 2 (2022): 378-385. https://doi.org/10.1109/TDEI.2022.3157926
[17] Forming handsheets for physical tests of pulp. Technical Association of the Pulp and Paper Industry 205 (2000).
[18] Power transformers - Part 7: Loading guide for mineral-oil-immersed power transformers, IEC 60076-7 (2018).
[19] Paluskiewicz, Sarah A., and Christopher L. Muhlstein. "Mode I crack growth in paper exhibits three stages of strain evolution in reaching steady-state." *Theoretical and Applied Fracture Mechanics* 118 (2022): 103279. https://doi.org/10.1016/j.tafmec.2022.103279
[20] Han, Chan-Ho. "International electrotechnical commission." Electric Engineers Magazine (2007): 29-34.
[21] Sari, Yulia Erina, Fadhlurrachman Al-Ghifary, and Tjokorda IDK Dewi. "Chemical and physical performance of kraft paper immersed in natural ester from palm oil under accelerated thermal aging." *International Journal on Electrical Engineering and Informatics* 11, no. 2 (2019): 408-426. https://doi.org/10.15676/ijeei.2019.11.2.12
[22] Hill, D. J. T., T. T. Le, M. Darveniza, and T. Saha. "A study of degradation of cellulosic insulation materials in a power transformer. Part 2: tensile strength of cellulose insulation paper." *Polymer degradation and stability* 49, no. 3 (1995): 429-435. https://doi.org/10.1016/0141-3910(95)00100-Z
[23] Emsley, A. M., R. Jetal Heywood, M. Ali, and X. Xiao. "Degradation of cellulosic insulation in power transformers. Part 4: Effects of ageing on the tensile strength of paper." *IEE Proceedings-Science, Measurement and Technology* 147, no. 6 (2000): 285-290. https://doi.org/10.1049/ip-smt:20000644
[24] Munajad, Abi, Cahyo Subroto, and Suwarno. "Study on the effects of thermal aging on insulating paper for high voltage transformer composite with natural ester from palm oil using Fourier transform infrared spectroscopy (FTIR) and energy dispersive X-ray spectroscopy (EDS)." *Energies* 10, no. 11 (2017): 1857. https://doi.org/10.3390/en10111857